Mitigating Chondrichthyan Bycatch

Bibliography

Hope Shinn, Librarian, MPF-ZAI on assignment at NOAA Central Library

NCRL subject guide 2023-01
doi: 10.25923/gnra-pe54

November 2022

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
NOAA Central Library – Silver Spring, Maryland

Table of Contents

Background & Scope

The NOAA Central Library has compiled the following bibliography on articles that deal with the reduction of chondrichthyan bycatch in commercial fisheries, with a particular focus on Latin America.

The references have been divided into groups according to the type of fishery or bycatch reduction method covered by each article. There are 226 total articles, and many articles are in more than one group.

The groups are as follows:

1. **Fishery Types**
    1.1. Gillnets
    1.2. Hook and line
    1.3. Longlining
    1.4. Purse seine
    1.5. Trawling

2. **Bycatch Reduction Method**
    2.1. Fishing behavior modifications
    2.2. Gear modifications
    2.3. Policy or management modifications

Sources Reviewed

Along with a web search for relevant grey literature materials, the following databases were used to identify sources: ProQuest's Aquatic Science and Fisheries Abstracts and Earth-Atmospheric & Aquatic Science Database; Dimensions; Lens.org; Clarivate Analytics' Web of Science: Science Citation Index Expanded; Google Scholar; ScienceDirect; and JSTOR.

1. Fishery Types

1.1 Gillnet Fisheries

Bayse, S. M., & Grant, S. M. (2020). Effect of baiting gillnets in the Canadian Greenland halibut fishery. *Fisheries Management and Ecology,* 27(5), 523-530. https://doi.org/10.1111/fme.12434

Catch rates were compared between gillnets with and without bait in the Greenland halibut Reinhardtius hippoglossoides (Walbaum) fishery off Baffin Island, Canada. Two different types of baiting techniques were compared: bait bags where squid were placed into 2-mm mesh bags, and tied bait where squid were tied into meshes. Both types of baited gillnets significantly increased the capture of the target species, Greenland halibut, with increases of 253.8% and 149.7% for the bait bag and tied bait, respectively. Common bycatch species showed mixed effects, with roughhead grenadier Macrourus berglax Lacepede showing no increase in catch per unit effort (CPUE) for either bait type (p > 0.05), and porcupine crab Neolithodes grimaldii (Milne-Edwards and Bouvier) only had a higher CPUE with baited gillnets when bait bags were placed on the footrope. Less common bycatch species-but with threatened populations-showed an increase in CPUE, including Greenland shark Somniosus microcephalus (Bloch and Schneider) and Northern wolffish Anarhichas denticulatus Kroyer. Baiting gillnets affected the CPUE of gillnets in the Greenland halibut fishery, and management should consider how the increased CPUE of both target and bycatch species are affected by this new fishery trend.

Bettis, S. (2017). *Shark Bycatch in Commercial Fisheries: A Global Perspective.* (Master of Science), Nova Southeastern University, Retrieved from https://nsuworks.nova.edu/cnso_stucap/331/

Many shark species have global distributions and are caught incidentally in different types of fisheries. Over the last two decades, shark populations have declined tremendously, with one of the leading causes of this decline bycatch in primarily teleost fisheries. Bycatch occurs throughout the world's fisheries, but is not well documented in terms of species composition and numbers of each species captured. Information on shark bycatch is spread through the primary and grey literature, but has not been compiled in summary to date. The goal of my capstone is to present global shark bycatch data and provide a comparative review to determine fishery types that affect shark populations and identify shark species at risk as a result of bycatch. Longline fisheries caught a larger variety of shark species, and the post-release mortality was generally low. In contrast, trawl fisheries caught mostly the same few species, but post-release mortality was extremely high. Blue sharks (Prionace glauca), silky sharks (Carcharhinus falciformis), and spiny dogfish (Squalus acanthias) were caught most often in trawl fisheries, and in large numbers that likely adds to risk of overexploitation of their populations. This literature review revealed a severe lack of standardization in bycatch data reporting by different fishing nations, and in documents prepared by management agencies and scientists, including the definition of bycatch used and the way it was recorded. Establishing a universal definition of bycatch and standardizing its reporting would vastly improve ability to assess the scale and composition of shark bycatch and its impacts on shark populations. Systematic and standardized accounting of shark bycatch would provide information helpful for collaboration among regulatory agencies. Rather than simply document bycatch, a number of fishing gear alterations show promise for bycatch reduction and are worthy of integration into fisheries by managers. Additional important steps that can improve bycatch

assessment is increased observer coverage in fisheries, marine protected areas, and making bycatch data public.

Box, S. J., & Bonilla, R. S. (2009). *An Evaluation of Fishing Practices in the Small Scale Fisheries of the Golfo de Fonseca, Honduras. Recommendations for Management.* Retrieved from https://web.archive.org/web/20140712074615/http://www.utilaecology.org/assets/documents/Artes%20de%20Pesca%20en%20el%20Golfo%20de%20Fonseca%202009%20english_1.pdf

The artisanal and small scale fisheries within the Honduran Golfo de Fonseca underpin the local economy and are an essential livelihood within small coastal communities. As a mixed fishery, confined within the shallow waters and mangrove estuary of the Golfo de Fonseca, the fishermen exploit a range of demersal and bentho-pelagic fish species using gill nets, hook and lines and bottom set long lines. In addition to fish, shrimp are an important resource and are targeted with trammel and cast nets. In the absence of official statistics, anecdotal evidence suggests that all sectors of the fishery are in decline. This study aimed to assess whether unselective practices could be an important contributory factor to the purported decline and to identify management options that aim to increase the sustainability of the fishery. The study re-evaluated existing catch and length frequency data sets and collected new information during field work and through interviews with fishermen and other stakeholders. We found that fishing within the Golfo de Fonseca predominantly uses gears with broad selectivity. Over a third of the landed catch by weight is low grade, low value fish. There is currently no market incentive for selectivity with little price premium for fish size compared to total fish volume. Of extreme concern is that large proportions of fish of commercially valuable species were being landed at sizes below the size of maturity. Within the group of the commercially most important fin fish, the “Babosas” (Cynoscion spp) the percentage of individuals within the landed catch that were below the estimated size at maturity ranged from 22 % (Babosa; C. squamipinnis) to 81 % (Corvina; C. reticulates). The majority of the landings of low value species and small sized individuals are mainly from the ubiquitous use of trammel nets that target shrimp. For every one pound of shrimp being landed, over five pounds of fin fish are also being landed. The sustainability of fin fishing is likely directly inhibited by the shrimp fishing. Since it is the same fishermen who are reliant on both resources integrating shrimp management and fish management is recommended. Rather than specifying changes in gear types which are unlikely to occur due to limitations in enforcement, a more feasible option based on current management capacity is to identify and instigate a closed season for shrimp fishing that corresponds to peak abundance of small individuals of commercial fish species that use the area as a nursery ground. This would help to minimise the incidental catch of undersize fish by trammel nets which currently reduces the economic efficiency and ecological sustainability of the fishery. In addition the study found that the extensive use of bottom set long-lining was likely to threaten the most ecologically vulnerable species found in the Golfo de Fonseca including the commercially important catfish Bagre pinnimaculatus and large pelagic species including sharks. Based on the precautionary principle of sustainable fisheries management, long lining within the gulf should be prohibited until their effect on these vulnerable species can be investigated. The lack of fishing selectivity was identified to be a clear problem in the Golfo de Fonseca fishery, however it is considered to be symptomatic of wider problems in the ecosystem and with the socioeconomic structure of the fishery as a whole. Other serious threats exist that are evidently going to affect sustainability, including the loss of critical habitat, water pollution and disruption in trophic webs that support the fish. From the perspective of gear selectivity, the current market structure rewards volume over quality and provides no incentive for using more selective methods of fishing. Addressing this problem first is necessary before any regulation in fishing methods will likely be successful.

Broadhurst, M. K., & Cullis, B. R. (2020). Mitigating the discard mortality of non-target, threatened elasmobranchs in bather-protection gillnets. *Fisheries Research,* 222. https://doi.org/10.1016/j.fishres.2019.105435

Globally, many gillnet fisheries have excessive discards which can comprise charismatic megafauna threatened with extinction, including numerous elasmobranchs. Very few discarded elasmobranch species have been assessed for their, associated fates. Here we describe the immediate mortality of several threatened species discarded from gillnets deployed off eastern Australia to target key carcharhinids and white sharks, Carcharodon carcharias (within an objective of protecting bathers) and causal factors for abundant elasmobranchs. In total, 420 animals comprising at least 22 species were gillnetted with a total immediate mortality of 49 % and group-specific estimates of 100 % for dolphins (n = 8), 100 % for teleosts (n = 16), 86 % for sharks (n = 75), 45 % for turtles (n = 20) and 36 % for rays (n = 301). Among elasmobranchs, species that were obligate ram-ventilating (e.g. great hammerhead, Sphyrna mokarran and common blacktip shark, Carcharhinus limbatus) had greater mortality (> 95 %) than those species with spiracles, and likely capable of some stationary respiration (e.g. whitespotted guitar fish, Rhynchobatus australiae, whitespotted eagle ray, Aetobatus ocellatus, Australian cownose ray, Rhinoptera neglects and to a lesser extent, pygmy devilray, Mobula kuhlii cf. eregoodootenkee) (16-74 % mortality). Mortalities among Australian cownose rays increased across longer soaks. The effect of soak time was further assessed to determine an optimal to maintain gillnet efficiency for target sharks, but minimise the absolute mortality of abundant rays and was estimated at up to three or four fishing nights (72-96 h). Other potential operational modifications, including using light and better retroactive deterrents to reduce turtle and dolphin bycatches and mortality, warrant investigation.

Cosandey-Godin, A., & Morgan, A. (2011). *Fisheries bycatch of sharks: Options for mitigation.* Pew Environment Group, Washington, DC. Retrieved from https://www.sarri.org/storage/app/media/tools_pdfs/PewOSSsharkbycatchreviewpdf.pdf

Bycatch (see definition below) is one of the most significant issues in the management and conservation of global fisheries (Hall et al. 2000, Kelleher 2005, Lewison et al. 2004) and has been identified as one of the leading causes of shark population declines. Sharks are susceptible to high fishing mortality rates because of their life history characteristics, which include slow growth, late ages at maturity, and the production of a limited number of young over a lifetime (Cortes 2002, Heppell et al. 1999, Cortes 1999). In addition, research has shown that several species of sharks have very high rates of mortality associated with the fishing process (Morgan and Burgess 2007, Mandelman et al. 2008), and it has been estimated that species such as sandbar shark (Carcharhinus plumbeus) (Sminkey and Musick 1994, Cortes 1999) and dusky shark (Carcharhinus obscurus) (Simpfendorfer 1999) increase their population sizes so slowly that they are considered particularly vulnerable to mortality from fishing activities (Musick et al. 2000a). For example, Cortes et al. (2006) found that if fishing for dusky shark stopped for 30 years, their population in the Northwest Atlantic would still be depleted. Over the past two decades, serious population declines have been reported for a number of shark species in several regions around the world (Baum et al. 2003, Ferretti et al. 2008, Robbins et al. 2006, Ferretti et al. 2010, Clarke 2011) and are attributed to both targeted and incidental capture. According to the International Union for Conservation of Nature (IUCN) and other sources, bycatch is one of the primary threats facing sharks (Musick et al. 2000b, Lewison et al. 2004). Despite widespread recognition of shark bycatch issues (Food

and Agriculture Organization [FAO] 1999; FAO 2010), few mitigation actions have been established, and there are no clear guidelines about which mitigation actions would be most effective. In addition, there are very few management measures requiring actions to mitigate shark bycatch. However, it is clear that managers and fishermen must aim to reduce both bycatch rates and the harmful effects from bycatch (e.g., injuries from capture on fishing gear). Based on the best available information, this review provides a summary of the current knowledge and understanding of shark bycatch and discusses available management options and technical measures aimed at reducing both the rate at which sharks encounter fishing gear and the associated damaging effects.

Coulter, J. (2019). *Evaluating Current Knowledge and Future Directions of Visual Cues as Bycatch Reduction Technologies in Passive Net Fisheries.* (Master of Environmental Management), Duke University, Retrieved from https://hdl.handle.net/10161/18435

Fisheries bycatch is consistently identified as a leading cause of population decline for many species of sea turtles, seabirds, and marine mammals. Many of these species rely primarily, or in part, on visual cues to perceive their environment, and visual cues can affect behavior. Recent research suggests that utilizing visual cues on passive fishing gear, such as gillnets, can reduce incidental interactions and associated mortality. This review synthesizes studies on visual cue bycatch reduction technologies (BRTs), focusing on the use of colored nets and net illumination. It draws upon existing knowledge to discuss both potential benefits, including streamlining bycatch reduction of multiple species, and challenges, such as current cost and maintenance requirements, associated with visual cue BRT development and implementation. The success of visual cue BRTs in initial studies, primarily on gillnets, holds much promise for bycatch reduction of air-breathing megafauna in passive gear fisheries. However, this research is still in its early stages, and future studies must expand research to more passive gear types, identify and conduct local studies in applicable fisheries, consider their potential use with other stimuli as multi-sensory BRTs, and support the development of new light-emitting diode (LED) technologies that reduce cost and maintenance requirements. As a case study, I present the preliminary findings from the first year of a multi-year study on the use of green LEDs as a sea turtle BRT on pound nets in the North Carolina flounder fishery. We compared the catch per unit effort (CPUE) of experimental green LEDs and control inactive LEDs on three pound nets in Core Sound (near Harker's Island, NC). Preliminary analyses suggest that green LEDs reduced sea turtle and elasmobranch bycatch rates but also reduced the target catch rate of flounder and other fish species. However, these results do not account for the potential influence of environmental conditions, and variables, including wind speed, reveal trends that may indicate influence on catch rates. These effects will need to be further considered after additional data collection. This research demonstrates one example of current, continued efforts to expand visual cue BRT research to multiple passive gear fisheries to increase their applicability.

Garcia-Rodriguez, E., & Sosa-Nishizaki, O. (2020). Artisanal fishing activities and their documented interactions with juvenile white sharks inside a nursery area. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 30(5), 903-914. https://doi.org/10.1002/aqc.3300

Juvenile white sharks distribute in coastal nursery areas, which are essential for population growth. Bahia Sebastian Vizcaino (BSV), Mexico, is a white shark nursery area in the north-eastern Pacific.

Despite existing regulations forbidding the capture of white sharks, incidental catches still occur in some areas. Artisanal fisheries constitute one of the most important economic activities in BSV, yet no formal description of either these fisheries or the incidental catch of juvenile white sharks exists due to the poor data reporting system, thus preventing a clear understanding of the implications of these catches for the white shark population of the north-eastern Pacific. Artisanal fishing activities and their interactions with juvenile white sharks in BSV are described based on fishermen's knowledge. Artisanal fisheries in BSV are multi-specific, targeting mostly bottom-related species (e.g. white seabass and California halibut) that are also common prey for juvenile white sharks. These activities are the only source of income for the majority of fishermen in BSV and are conducted throughout the year, with gillnets being the main fishing gear. White sharks are incidentally caught in bottom gillnets mainly during the summer, although another peak in incidental catch was recorded during winter, possibly related to the presence of juvenile white sharks from California, USA. The most common size of juvenile white sharks incidentally caught was <2 m in the nearshore areas close to the mouth of the Ojo de Liebre Lagoon; larger juveniles (similar to 3 m) were caught in areas near Cedros, Natividad, and San Benito Islands. The multi-specific nature of BSV artisanal fisheries and their socio-economic value, and the high post-release survival of juvenile white sharks suggest that future regulatory actions should focus on the release of incidentally caught live juvenile white sharks and the involvement of the BSV fishing community to increase the effectiveness of management efforts.

Gilman, E., & Lundin, C. (2010). Minimising bycatch of sensitive species groups in marine capture fisheries: lessons from tuna fisheries. In *Handbook of Marine Fisheries Conservation and Management.* Q. Grafton, R. Hillborn, D. Squires, M. Tait, & M. Williams (Eds.), (pp. 23): Oxford University Press Retrieved from http://ecite.utas.edu.au/58808

Bycatch in marine capture fisheries is the retained catch of nontargeted but commercially viable species (referred to as “incidental catch”) plus all discards (Food and Agriculture Organization of the United Nations [FAO] 2005).1 It is an increasingly prominent international issue, raising ecological concerns, as some bycatch species of cetaceans (whales, dolphins, and porpoises), seabirds, sea turtles, elasmobranchs (sharks, skates, and rays), and other fi sh species are particularly vulnerable to overexploitation and slow to recover from large population declines (FAO 1999a, 1999b, in press; Fowler et al. 2005; Gales 1998; Gilman et al. 2005, 2006a, 2006c, 2008; Lutz and Musick 1997). Bycatch can alter biodiversity and ecosystem functions by removing top predators and prey species at unsustainable levels (Myers et al. 2007). It also alters foraging behavior of species that learn to take advantage of discards. Economic effects of bycatch on fi sheries include loss of bait, reduced availability of baited hooks when they are occupied with unwanted bycatch species, and concomitant reduced catch of marketable species; the imposition of a range of restrictions, closed areas, embargos, and possible closures; allocation among fi sheries, where bycatch in one fi shery reduces target catch in another, and bycatch of juvenile and undersized individuals of a commercial species can adversely affect future catch levels (Brothers et al. 1999; Hall et al. 2000). Discarded bycatch raises a social issue over waste: From 1992 to 2001 an average of 7.3 million metric tons of fi sh were annually discarded, representing 8 percent of the world catch (FAO 2005). Prominent bycatch issues include dolphins and porpoises in purse seine fi sheries and driftnets; fi sh discards in shrimp trawl fi sheries; and seabird, sea turtle, marine mammal, and shark bycatch in longline, purse seine, gillnet, and trawl fi sheries (FAO 1999a, 1999b, 2005, in press; Hall et al. 2000). In commercial tuna fi sheries, the incidental bycatch of sensitive species groups (seabirds, sea turtles, marine mammals, and sharks) and bycatch of juvenile and undersized tunas are allocation and conservation issues. In addition to problematic bycatch,

overexploitation and illegal, unreported, and unregulated (IUU) fi shing, which complicates bycatch management, are additional conservation issues facing the management of tuna fi sheries. This chapter employs examples of bycatch in commercial tuna fi sheries to describe (1) the range of options to reduce bycatch, (2) principles and approaches to successfully introduce effective bycatch reduction measures, and (3) initiatives taken by intergovernmental organizations, the fi shing industry, and retailers to address bycatch. Changes needed to improve the sustainability of tuna production are recommended.

Graf, A. J. (2013). Great White Shark Bycatch Reduction Problems in the California/Oregon Drift Gillnet Fishery. *Golden Gate University Environmental Law Journal,* 6(2), 347. Retrieved from https://digitalcommons.law.ggu.edu/gguelj/vol6/iss2/8/

Part I of this Comment explores the problems of great white shark bycatch by examining the white shark's susceptibility to bycatch and the Fishery responsible for a significant portion of white shark bycatch. Part II discusses the federal statutes and regulations applicable to bycatch and the Fishery. Part III provides recommendations for reducing white shark bycatch in the future by modifying current federal statutes, amending existing regulations, and increasing research efforts.

Graham, J., Kroetz, A. M., Poulakis, G. R., Scharer, R. M., Carlson, J. K., Lowerre-Barbieri, S. K., . . . Grubbs, R. D. (2022). Commercial fishery bycatch risk for large juvenile and adult smalltooth sawfish (Pristis pectinata) in Florida waters. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 32(3), 401-416. https://doi.org/10.1002/aqc.3777

Incidental catch of marine species can create ecological and economic issues, particularly for endangered species. The smalltooth sawfish (Pristis pectinata) is endemic to the Atlantic Ocean and listed as Endangered in the US Endangered Species Act. One of its major threats is bycatch mortality in commercial fisheries. Despite the protection afforded by the US Endangered Species Act, smalltooth sawfish are still captured as bycatch in commercial fisheries. Acoustic and satellite tag data collected on 59 sawfish between 2011 and 2019 were analysed to assess commercial fishery bycatch risk for large juveniles and adults off Florida. This study focused on shrimp trawl, south-east coastal gillnet, and shark bottom longline fisheries, as these were identified in the recovery plan as having the greatest potential threats to recovery. Bycatch risk associated with the shrimp trawl fishery was significantly higher than the other fisheries, indicating that this fishery currently poses the greatest threat to recovery. Bycatch risk was concentrated in all seasons in the Gulf of Mexico adjacent to the lower Florida Keys for the shrimp trawl fishery, off Cape Canaveral in the south-east coastal gillnet fishery, and in the Atlantic Ocean adjacent to the Florida Keys in the shark bottom longline fishery. Tagging location and sex were predictors of bycatch risk. Individuals tagged in Charlotte Harbor had the highest shrimp trawl bycatch risk. Females tagged in south Florida tended to reside in the deepest water, which is where shrimp trawl effort is highest. Therefore, females may be at more risk in these deeper waters. Results from this study indicate a year-round closure of waters off south-west Florida to the shrimp trawl fishery between Charlotte Harbor and the western Florida Keys would reduce sawfish bycatch, and thus mortality, which is in line with recovery plan goals.

Kroetz, A. M., Mathers, A. N., & Carlson, J. K. (2020). Evaluating protected species bycatch in the US Southeast Gillnet Fishery. *Fisheries Research,* 228. https://doi.org/10.1016/j.fishres.2020.105573

Incidental capture or 'bycatch' of non-targeted species is a global fisheries issue that threatens ocean ecosystems and the conservation and recovery of protected species. Many protected species are at a high risk of incidental capture and mortality in commercial fisheries, which could have an impact on already decreasing populations. From 1998 to 2017, U.S. federal fisheries observers aboard fishing vessels in the U.S. Southeast Gillnet Fishery collected data on captures of encountered protected species. Data collected by the observers were used to describe protected species incidental capture within this fishery. A generalized linear zero-inflated negative binomial two-part model (GLM-ZINB) was applied to determine which environmental and fishing characteristic factors influence the probability of incidental capture of protected species including leatherback, Dermochelys coriacea, and loggerhead, Caretta caretta, sea turtles, bottlenose dolphins, Tursiops truncates, and giant manta ray, Manta birostris. While a variety of factors were considered in our models, no one single factor was found to influence all protected species. Incidental capture of leatherback turtles was influenced by season, depth, and gillnet depth, while loggerhead turtles were influenced by season, sea surface temperature, and target species of the fishery. Bottlenose dolphin bycatch was most influenced by soak duration, gear type, and season, while giant manta ray captures were influenced by soak duration, gear type, and depth. Environmental factors and fishing characteristics associated with incidental capture of protected species can be used to help guide fishery managers as to what species-specific regulations could be implemented to help mitigate capture.

Poisson, F., Abascal Crespo, F., Ellis, J. R., Chavance, P., Pascal, B., Santos, M. N., . . . Murua, H. (2016). Technical mitigation measures for sharks and rays in fisheries for tuna and tuna-like species: turning possibility into reality. *Aquatic Living Resources,* 29(4). https://doi.org/10.1051/alr/2016030

Tuna fisheries have been identified as one of the major threats to populations of other marine vertebrates, including sea turtles, sharks, seabirds and marine mammals. The development of technical mitigation measures (MM) in fisheries is part of the code of conduct for responsible fisheries. An in-depth analysis of the available literature regarding bycatch mitigation in tuna fisheries with special reference to elasmobranchs was undertaken. Studies highlighting promising MMs were reviewed for four tuna fisheries (longline, purse seine, driftnets and gillnet, and rod and line - including recreational fisheries). The advantages and disadvantages of different MMs are discussed and assessed based on current scientific knowledge. Current management measures for sharks and rays in tuna Regional Fishery Management Organizations (t-RFMOs) are presented. A review of relevant studies examining at-vessel and postrelease mortality of elasmobranch bycatch is provided. This review aims to help fisheries managers identify pragmatic solutions to reduce mortality on pelagic elasmobranchs (and other higher vertebrates) whilst minimizing impacts on catches of target tuna species. Recent research efforts have identified several effective MMs that, if endorsed by t-RFMOs, could reduce elasmobranchs mortality rate in international tropical purse seine tuna fisheries. In the case of longline fisheries, the number of operational effective MMs is very limited. Fisheries deploying driftnets in pelagic ecosystems are suspected to have a high elasmobranchs bycatch and their discard survival is uncertain, but no effective MMs have been field validated for these fisheries. The precautionary bans of such gear by the EU and by

some t-RFMOs seem therefore appropriate. Recreational tuna fisheries should be accompanied by science-based support to reduce potential negative impacts on shark populations. Priorities for research and management are identified and discussed.

Ramirez-Amaro, S., & Galvan-Magana, F. (2019). Effect of gillnet selectivity on elasmobranchs off the northwestern coast of Mexico. *Ocean & Coastal Management,* 172, 105-116. https://doi.org/10.1016/j.ocecoaman.2019.02.001

The regulation of mesh size is important for the effective and sustainable management of fisheries using gillnets, which are the main fishing gear used in artisanal elasmobranch fisheries throughout northwestern Mexico. Gillnet selectivity studies focusing on elasmobranchs have generally evaluated the impact on target species, and information on bycatches remains scarce. This study assessed the impact of gillnet selectivity on both target elasmobranch species and bycatches, by varying the mesh size of gillnets. Sampling was performed from 2009 to 2015 in five artisanal fishing grounds located along the northwestern coast of Mexico. The species composition and ecological parameters of the elasmobranch communities that were caught, as well as the size structure and estimated selectivity models for the main species caught, were compared between four mesh sizes: 10.16, 15.24, 20.32 and 25.4 cm (stretched opening). Overall, 32 elasmobranch species were caught, nine of which were common to all mesh sizes. Our results indicate that the species composition of the catch varied with mesh size. While the small-sized sharks Mustelus californicus and M. henlei were the main species caught by gillnets with the smaller mesh sizes, the guitarfish Pseudobatos productus and Zapteryx exasperata, and the Pacific angel shark Squatina californica were the main species caught gillnets with the largest mesh sizes. Gillnet selectivity was estimated for these latter four species as well as for the horn shark Heterodontus francisci. Optimum length for these species varied widely, increasing proportionally to mesh size. These findings emphasize the difficulty of determining an optimal minimum mesh size for multi-species fishery in this area. Finally, recommendations for future directions according to the species' vulnerability to fishing are discussed, focusing on the development of effective strategies to initiate or strengthen the recovery of elasmobranchs of the northwestern coast of Mexico.

Roberson, L. A., & Wilcox, C. (2022). Bycatch rates in fisheries largely driven by variation in individual vessel behaviour. *Nature Sustainability*. https://doi.org/10.1038/s41893-022-00865-0

Fisheries bycatch continues to drive the decline of many threatened marine species such as seabirds, sharks, marine mammals and sea turtles. Management frameworks typically address incidental catch with fleet-level controls on fishing. Yet, individual operators differ in their fishing practices and efficiency at catching fish. If operators have differing abilities to target, they should also have differing abilities to avoid bycatch. We analysed variations in threatened species bycatch among individual operators from five industrial fisheries representing different geographic areas, gear types and target species. The individual vessel is a significant predictor of bycatch for 15 of the 16 cases, including species that represent high or low costs to fishers or have economic value as potentially targeted byproducts. Encouragingly, we found high-target and low-bycatch operators in all five sectors, including gears known for high bycatch mortality worldwide. These results show that there is untapped opportunity to reduce negative environmental impacts of fisheries with interventions targeting specific performance groups of individuals, supporting an alternative perspective towards managing global fisheries.

Sacchi, J. (2019). *Mitigation Measures for Protected Species.* Paper presented at the Seventh Meeting of the Parties to ACCOBAMS. Retrieved from https://accobams.org/wp-content/uploads/2019/04/MOP7.Doc30_Mitigation-measures-for-protected-species.pdf

Highly migratory for the most part, occupying a wide distribution across the oceans, the marine megafauna undergo all possible forms of human pressure. Among them, bycatch fishery has increased exponentially in recent years and is now considered the most serious threat to these highly vulnerable species. Minimizing bycatch, is therefore a key component of sustainable fisheries management to maintain marine biodiversity and consequently to reduce negative effects on the resources (see Hall, 1996; Hall et al., 2000). The aim of this document is to present various experimented approaches and strategies that could also serve as an example for fisheries facing the same problems. This review of the different mitigation measures draws on the analysis of the available literature, comprising scientific journal articles together with reports from international organisations and documents available on the internet. The presentation adopted here is guided by the principle that it is not species that should be managed but fishing activities (metiers)1 that should be the target of the technical or management measures that are required to reduce the negative impacts of interactions with fisheries. Consequently, for each of the main fishing gear groups (gill and trammel nets, longlines and lines, trawls, purse seines, trapnets and pots) the various solutions found in the documents consulted are classified by the four main groups of protected species (Cetaceans, Birds, Sharks and Sea turtles).

Senko, J. F., Peckham, S. H., Aguilar-Ramirez, D., & Wang, J. H. (2022). Net illumination reduces fisheries bycatch, maintains catch value, and increases operational efficiency. *Current Biology,* 32(4), 911-918 e912. https://doi.org/10.1016/j.cub.2021.12.050

Small-scale fisheries are vital for food security, nutrition, and livelihoods in coastal areas throughout the world's oceans.(1-9) As intricately linked social-ecological systems, small-scale fisheries require management approaches that help ensure both ecological and socioeconomic sustainability.(7,)(10-14) Given their ease of use and lucrative nature, coastal gillnet fisheries are globally ubiquitous.(10,15) However, these fisheries often result in high discarded capture of non-target organisms (bycatch) that can lead to significant cascading effects throughout trophic chains(16-18) and costly fisheries restrictions that result in important revenue losses in coastal communities with scarce economic alternatives.(19,)(20) Despite these challenges, few solutions have been developed and broadly adopted to decrease bycatch in coastal gillnet fisheries, particularly in developing nations.(5,21) Here we used controlled experiments along Mexico's Baja California peninsula to show that illuminating gillnets with green LED lights-an emerging technology originally developed to mitigate sea turtle bycatch-significantly reduced mean rates of total discarded bycatch biomass by 63%, which included significant decreases in elasmobranch (95%), Humboldt squid (81%), and unwanted finfish (48%). Moreover, illuminated nets significantly reduced the mean time required to retrieve and disentangle nets by 57%. In contrast, there were no significant differences in target fish catch or value. These findings advance our understanding of how artificial illumination affects operational efficiency and changes in catch rates in coastal gillnet fisheries, while illustrating the value of assessing broad-scale ecological and socioeconomic effects of species-specific conservation strategies.

Thorpe, T., & Frierson, D. (2009). Bycatch mitigation assessment for sharks caught in coastal anchored gillnets. *Fisheries Research,* 98(1-3), 102-112. https://doi.org/10.1016/j.fishres.2009.04.003

Fishing with modified gillnets was conducted to elucidate their potential for reducing shark bycatch. Experimental fishing focused on two commercial fisheries, Spanish mackerel (Scomberomorus maculatus) and spot (Leiostomus xanthurus). The modification took the form of increasing the gillnet tension using larger floats on the head-rope and increasing the lead-core lead-line weight. Gillnet mesh sizes were 7.2 cm (spot fishery) and 7.6 and 10.2 cm (Spanish mackerel fishery). Gillnet selectivity of the four most commonly encountered shark species were fitted to fork-length distribution data using the SELECT method. There was no significant difference in the catch rate of the target species between control and modified gillnets for all mesh sizes used. Catch rates of some shark species were significantly reduced in modified gillnets. Model deviance values indicated good fits to the data for blacknose (Carcharhinus acronotus), blacktip (Carcharhinus limbatus) and bonnethead (Sphyrna tiburo) sharks with lowest deviance values (i.e., best fit) generally associated with the normal scale (spread proportional to mesh size) form. The selectivity results demonstrated that all life stages of Atlantic sharpnose (Rhizoprionodon terraenovae) and blacknose sharks were available to the gillnets. The mesh selectivity of bonnethead sharks was largely uniform due to their exaggerated cepholaphoil that resulted in the majority being hammer-wrapped. Further, capture data indicated a dominance of large juveniles and adult bonnethead sharks resulting in poor model fits. The capture mortality rate for all shark species was high (78.6%) with higher mortality rates associated with heightened locomotor performance and wrapping as an entanglement mode. These results demonstrated that modified gillnets have the potential to reduce shark bycatch, particularly for those species for which wrapping was the primary entanglement mode.

Tixier, P., Lea, M. A., Hindell, M. A., Welsford, D., Mazé, C., Gourguet, S., & Arnould, J. P. Y. (2021). When large marine predators feed on fisheries catches: Global patterns of the depredation conflict and directions for coexistence. *Fish and Fisheries,* 22(1), 31-53. https://doi.org/10.1111/faf.12504

The sustainable mitigation of human–wildlife conflicts has become a major societal and environmental challenge globally. Among these conflicts, large marine predators feeding on fisheries catches, a behaviour termed “depredation,” has emerged concomitantly with the expansion of the world’s fisheries. Depredation poses threats to both the socio-economic viability of fisheries and species conservation, stressing the need for mitigation. This review synthesizes the extent and socio-ecological impacts of depredation by sharks and marine mammals across the world, and the various approaches used to minimize it. Depredation was reported in 214 fisheries between 1979 and 2019 (70% post-2000) and affected fleets from 44 countries, in all sectors (commercial, artisanal and recreational), and in all major fishing techniques (nets, traps and hook-and-lines). A total of 68 predator species were involved in depredation (20 odontocetes, 21 pinnipeds and 27 sharks), and most (73%) were subject to either by-catch and/or retaliatory killing from fishers when interacting with gear. Impacts on fishers were primarily associated with catch losses and gear damage but often lacked assessments. Deterrence was a major mitigation approach but also the least effective. Gear modifications or behavioural adaptation by fishers were more promising. This review highlights the need for improved monitoring, and interdisciplinary and integrated research to quantify the determinants and impacts of depredation in the socio-ecological dimension. More importantly, as the conflict is likely to escalate, efforts directed

towards changing perceptions and integrating knowledge through adaptive co-management are raised as key directions towards coexistence between fisheries and large marine predators.

White, J., Heupel, M. R., Simpfendorfer, C. A., & Tobin, A. J. (2013). Shark-like batoids in Pacific fisheries: prevalence and conservation concerns. *Endangered Species Research,* 19(3), 277-284. https://doi.org/10.3354/esr00473

Shark-like batoids are a group of elasmobranchs with a body form similar to that of sharks (i.e. elongate body, well developed caudal and dorsal fins, and head, gill and mouth morphology similar to that of skates and sting rays). Despite a poor understanding of their biology, ecology and resilience to fishing, shark-like batoids are known to have been heavily exploited throughout the Indo-Pacific. Between 2007 and 2009, we recorded the occurrence of shark-like batoid species in the inshore gillnet fishery of Queensland (Australia) across 2 habitat types. Glaucostegus typus and Anoxypristis cuspidata were most frequently caught in intertidal habitats, whereas Rhynchobatus spp. dominated the catch in inshore coastal habitats. Comparison of gillnet catches to research longline sampling showed that not all size classes of shark-like batoids are captured by the gillnet fishery. Given that home-range size and habitat use by elasmobanchs can change between ontogenetic stages and species, vulnerability to fisheries may vary depending on overlap of preferred habitats and fishing activity and whether each size class is susceptible to the gear. Gillnets are highly selective for certain sizes classes; therefore, knowledge of which sizes and thus which life-history stages are susceptible is necessary to effectively regulate the use of this type of fishing gear. Understanding the occurrence and availability of shark-like batoid species to fishing activities and their contribution as bycatch/by-products in fisheries is critical to management and conservation of these species.

Zollett, E. A., & Swimmer, Y. (2019). Safe handling practices to increase post-capture survival of cetaceans, sea turtles, seabirds, sharks, and billfish in tuna fisheries. *Endangered Species Research,* 38, 115-125. https://doi.org/10.3354/esr00940

Incidental capture of marine animals in fishing gear may cause immediate or delayed mortality due to injury. Increasing post-capture survival of these species is very important to reducing the widespread impacts of bycatch, particularly on protected and threatened populations. In this paper, we review recent literature on safe handling of sea turtles, cetaceans, seabirds, sharks, and billfish and summarize the most effective measures for improving survivability of these species after interactions with gillnet, pelagic longline, and purse seine gear. We also review the current tuna Regional Fishery Management Organization (tRFMO) measures on safe handling and release to identify gaps in implementation of safe handling practices. Strategies that increase post-capture survival of marine species can be grouped into 3 primary categories: reducing immediate mortality, minimizing injury that results in delayed mortality, and reducing stress that can lead to death. Routine training of fishermen on safe handling practices greatly improves the effectiveness of these measures. When bycatch does occur, the strategies to increase post-release survival become key for protecting vulnerable marine populations. This inventory highlights the great conservation value that can be provided by the tRFMOs by providing guidance and training on safe handling practices to increase post-release survival across taxa.

1.2 Hook and Line Fisheries

Bettis, S. (2017). *Shark Bycatch in Commercial Fisheries: A Global Perspective.* (Master of Science), Nova Southeastern University, Retrieved from https://nsuworks.nova.edu/cnso_stucap/331/

Many shark species have global distributions and are caught incidentally in different types of fisheries. Over the last two decades, shark populations have declined tremendously, with one of the leading causes of this decline bycatch in primarily teleost fisheries. Bycatch occurs throughout the world's fisheries, but is not well documented in terms of species composition and numbers of each species captured. Information on shark bycatch is spread through the primary and grey literature, but has not been compiled in summary to date. The goal of my capstone is to present global shark bycatch data and provide a comparative review to determine fishery types that affect shark populations and identify shark species at risk as a result of bycatch. Longline fisheries caught a larger variety of shark species, and the post-release mortality was generally low. In contrast, trawl fisheries caught mostly the same few species, but post-release mortality was extremely high. Blue sharks (Prionace glauca), silky sharks (Carcharhinus falciformis), and spiny dogfish (Squalus acanthias) were caught most often in trawl fisheries, and in large numbers that likely adds to risk of overexploitation of their populations. This literature review revealed a severe lack of standardization in bycatch data reporting by different fishing nations, and in documents prepared by management agencies and scientists, including the definition of bycatch used and the way it was recorded. Establishing a universal definition of bycatch and standardizing its reporting would vastly improve ability to assess the scale and composition of shark bycatch and its impacts on shark populations. Systematic and standardized accounting of shark bycatch would provide information helpful for collaboration among regulatory agencies. Rather than simply document bycatch, a number of fishing gear alterations show promise for bycatch reduction and are worthy of integration into fisheries by managers. Additional important steps that can improve bycatch assessment is increased observer coverage in fisheries, marine protected areas, and making bycatch data public.

Box, S. J., & Bonilla, R. S. (2009). *An Evaluation of Fishing Practices in the Small Scale Fisheries of the Golfo de Fonseca, Honduras. Recommendations for Management.* Retrieved from https://web.archive.org/web/20140712074615/http://www.utilaecology.org/assets/documents/Artes%20de%20Pesca%20en%20el%20Golfo%20de%20Fonseca%202009%20english_1.pdf

The artisanal and small scale fisheries within the Honduran Golfo de Fonseca underpin the local economy and are an essential livelihood within small coastal communities. As a mixed fishery, confined within the shallow waters and mangrove estuary of the Golfo de Fonseca, the fishermen exploit a range of demersal and bentho-pelagic fish species using gill nets, hook and lines and bottom set long lines. In addition to fish, shrimp are an important resource and are targeted with trammel and cast nets. In the absence of official statistics, anecdotal evidence suggests that all sectors of the fishery are in decline. This study aimed to assess whether unselective practices could be an important contributory factor to the purported decline and to identify management options that aim to increase the sustainability of the fishery. The study re-evaluated existing catch and length frequency data sets and collected new information during field work and through interviews with fishermen and other stakeholders. We found that fishing within the Golfo de Fonseca predominantly uses gears with broad selectivity. Over a third of the landed catch by weight is low grade, low value fish. There is currently no market incentive for

selectivity with little price premium for fish size compared to total fish volume. Of extreme concern is that large proportions of fish of commercially valuable species were being landed at sizes below the size of maturity. Within the group of the commercially most important fin fish, the "Babosas" (Cynoscion spp) the percentage of individuals within the landed catch that were below the estimated size at maturity ranged from 22 % (Babosa; C. squamipinnis) to 81 % (Corvina; C. reticulates). The majority of the landings of low value species and small sized individuals are mainly from the ubiquitous use of trammel nets that target shrimp. For every one pound of shrimp being landed, over five pounds of fin fish are also being landed. The sustainability of fin fishing is likely directly inhibited by the shrimp fishing. Since it is the same fishermen who are reliant on both resources integrating shrimp management and fish management is recommended. Rather than specifying changes in gear types which are unlikely to occur due to limitations in enforcement, a more feasible option based on current management capacity is to identify and instigate a closed season for shrimp fishing that corresponds to peak abundance of small individuals of commercial fish species that use the area as a nursery ground. This would help to minimise the incidental catch of undersize fish by trammel nets which currently reduces the economic efficiency and ecological sustainability of the fishery. In addition the study found that the extensive use of bottom set long-lining was likely to threaten the most ecologically vulnerable species found in the Golfo de Fonseca including the commercially important catfish Bagre pinnimaculatus and large pelagic species including sharks. Based on the precautionary principle of sustainable fisheries management, long lining within the gulf should be prohibited until their effect on these vulnerable species can be investigated. The lack of fishing selectivity was identified to be a clear problem in the Golfo de Fonseca fishery, however it is considered to be symptomatic of wider problems in the ecosystem and with the socioeconomic structure of the fishery as a whole. Other serious threats exist that are evidently going to affect sustainability, including the loss of critical habitat, water pollution and disruption in trophic webs that support the fish. From the perspective of gear selectivity, the current market structure rewards volume over quality and provides no incentive for using more selective methods of fishing. Addressing this problem first is necessary before any regulation in fishing methods will likely be successful.

Cosandey-Godin, A., & Morgan, A. (2011). *Fisheries bycatch of sharks: Options for mitigation.* Pew Environment Group, Washington, DC. Retrieved from https://www.sarri.org/storage/app/media/tools_pdfs/PewOSSsharkbycatchreviewpdf.pdf

Bycatch (see definition below) is one of the most significant issues in the management and conservation of global fisheries (Hall et al. 2000, Kelleher 2005, Lewison et al. 2004) and has been identified as one of the leading causes of shark population declines. Sharks are susceptible to high fishing mortality rates because of their life history characteristics, which include slow growth, late ages at maturity, and the production of a limited number of young over a lifetime (Cortes 2002, Heppell et al. 1999, Cortes 1999). In addition, research has shown that several species of sharks have very high rates of mortality associated with the fishing process (Morgan and Burgess 2007, Mandelman et al. 2008), and it has been estimated that species such as sandbar shark (Carcharhinus plumbeus) (Sminkey and Musick 1994, Cortes 1999) and dusky shark (Carcharhinus obscurus) (Simpfendorfer 1999) increase their population sizes so slowly that they are considered particularly vulnerable to mortality from fishing activities (Musick et al. 2000a). For example, Cortes et al. (2006) found that if fishing for dusky shark stopped for 30 years, their population in the Northwest Atlantic would still be depleted. Over the past two decades, serious population declines have been reported for a number of shark species in several regions around the world (Baum et al. 2003, Ferretti et al. 2008, Robbins et al. 2006, Ferretti et al. 2010, Clarke 2011) and are attributed to both targeted and incidental capture. According to the International Union for

Conservation of Nature (IUCN) and other sources, bycatch is one of the primary threats facing sharks (Musick et al. 2000b, Lewison et al. 2004). Despite widespread recognition of shark bycatch issues (Food and Agriculture Organization [FAO] 1999; FAO 2010), few mitigation actions have been established, and there are no clear guidelines about which mitigation actions would be most effective. In addition, there are very few management measures requiring actions to mitigate shark bycatch. However, it is clear that managers and fishermen must aim to reduce both bycatch rates and the harmful effects from bycatch (e.g., injuries from capture on fishing gear). Based on the best available information, this review provides a summary of the current knowledge and understanding of shark bycatch and discusses available management options and technical measures aimed at reducing both the rate at which sharks encounter fishing gear and the associated damaging effects.

Driggers, Campbell, M. D., Hannan, K. M., Hoffmayer, E. R., Jones, C. M., Jones, L. M., & Pollack, A. G. (2017). Influence of bait type on catch rates of predatory fish species on bottom longline gear in the northern Gulf of Mexico. *Fishery Bulletin,* 115(1), 50-59. https://doi.org/10.7755/fb.115.1.5

Identifying effective methods of reducing shark bycatch in hook-based fisheries has received little attention despite reports of declines in some shark populations. Previously proposed shark bycatch mitigation measures include gear modifications, time and area closures, avoidance of areas with high shark abundance, use of repellents, and use of specific bait types. Regardless of the method of shark bycatch reduction, knowledge of the effects of the chosen method on the catch rates of targeted fish species should be understood. To examine the effects of bait type on catch rates of sharks and teleosts on bottom longline gear, standardized gear was deployed with bait alternating between Atlantic mackerel (Scomber scombrus) and northern shortfin squid (Illex illecebrosus). For all shark species examined, except the scalloped hammerhead (Sphyrna lewini), a preference for hooks baited with Atlantic mackerel was observed. Commercially and recreationally important teleosts had no significant preference for a specific bait, with the exception of the red drum (Sciaenops ocellatus), which had a significant preference for hooks baited with northern shortfin squid. Bait preference decreased as total catch rate increased on individual longline sets. Our results point to the use of specific baits as a viable method to reduce shark catch rates without decreasing catches of targeted teleosts.

François, P., Sidonie, C., Caroline, C., & Jean-Marc, G. (2019). The effect of hook type and trailing gear on hook shedding and fate of pelagic stingray (Pteroplatytrygon violacea): New insights to develop effective mitigation approaches. *Marine Policy,* 107, 103594. https://doi.org/10.1016/j.marpol.2019.103594

The pelagic stingray (Pteroplatytrygon violacea) in the French Atlantic bluefin tuna makes up almost half of the catch in numbers, ranking first of the five major species caught. Given the high levels of catches, more attention was given to the impact of this fishery in order to avoid future conservation issues. The effects of the hook shape (circle versus J-type hooks) and trailing gear on hook retention has been investigated on 10 individuals kept in captivity during 125 days. Experiments showed that the J-type hook used commonly by fishers had a fast self-shedding rate which will allow for a quick resumption of feeding and minimal injury which means quicker wound healing and better chance for survival. J-type hooks were all expelled within 6 days while circle hook shedding rates were much longer, taking 44.5 ± 54.4 days (mean ± SD). The mechanism of expulsion of the hook has been clearly described and

the impact of the trailing line assessed. Appropriate handling practices maximizing the crew safety and the post-release survival were identified. Other effective mitigation approaches for the fishery are proposed and discussed.

Gilman, E., & Lundin, C. (2010). Minimising bycatch of sensitive species groups in marine capture fisheries: lessons from tuna fisheries. In *Handbook of Marine Fisheries Conservation and Management.* Q. Grafton, R. Hillborn, D. Squires, M. Tait, & M. Williams (Eds.), (pp. 23): Oxford University Press Retrieved from http://ecite.utas.edu.au/58808

Bycatch in marine capture fisheries is the retained catch of nontargeted but commercially viable species (referred to as "incidental catch") plus all discards (Food and Agriculture Organization of the United Nations [FAO] 2005).1 It is an increasingly prominent international issue, raising ecological concerns, as some bycatch species of cetaceans (whales, dolphins, and porpoises), seabirds, sea turtles, elasmobranchs (sharks, skates, and rays), and other fi sh species are particularly vulnerable to overexploitation and slow to recover from large population declines (FAO 1999a, 1999b, in press; Fowler et al. 2005; Gales 1998; Gilman et al. 2005, 2006a, 2006c, 2008; Lutz and Musick 1997). Bycatch can alter biodiversity and ecosystem functions by removing top predators and prey species at unsustainable levels (Myers et al. 2007). It also alters foraging behavior of species that learn to take advantage of discards. Economic effects of bycatch on fi sheries include loss of bait, reduced availability of baited hooks when they are occupied with unwanted bycatch species, and concomitant reduced catch of marketable species; the imposition of a range of restrictions, closed areas, embargos, and possible closures; allocation among fi sheries, where bycatch in one fi shery reduces target catch in another, and bycatch of juvenile and undersized individuals of a commercial species can adversely affect future catch levels (Brothers et al. 1999; Hall et al. 2000). Discarded bycatch raises a social issue over waste: From 1992 to 2001 an average of 7.3 million metric tons of fi sh were annually discarded, representing 8 percent of the world catch (FAO 2005). Prominent bycatch issues include dolphins and porpoises in purse seine fi sheries and driftnets; fi sh discards in shrimp trawl fi sheries; and seabird, sea turtle, marine mammal, and shark bycatch in longline, purse seine, gillnet, and trawl fi sheries (FAO 1999a, 1999b, 2005, in press; Hall et al. 2000). In commercial tuna fi sheries, the incidental bycatch of sensitive species groups (seabirds, sea turtles, marine mammals, and sharks) and bycatch of juvenile and undersized tunas are allocation and conservation issues. In addition to problematic bycatch, overexploitation and illegal, unreported, and unregulated (IUU) fi shing, which complicates bycatch management, are additional conservation issues facing the management of tuna fi sheries. This chapter employs examples of bycatch in commercial tuna fi sheries to describe (1) the range of options to reduce bycatch, (2) principles and approaches to successfully introduce effective bycatch reduction measures, and (3) initiatives taken by intergovernmental organizations, the fi shing industry, and retailers to address bycatch. Changes needed to improve the sustainability of tuna production are recommended.

Hyatt, M. W., Anderson, P. A., & O'Donnell, P. M. (2018). Influence of Temperature, Salinity, and Dissolved Oxygen on the Stress Response of Bull (Carcharhinus leucas) and Bonnethead (Sphyrna tiburo) Sharks after Capture and Handling. *Journal of Coastal Research,* 34(4), 818-827. https://doi.org/10.2112/jcoastres-d-17-00118.1

Capture and handling stress can induce acidosis in sharks. This response, endured during commercial bycatch and in catch-and-release recreational fisheries, could be exacerbated in certain environmental conditions. To assess environmental influence on stress response, changes in acid-base, blood gas, and metabolite analytes (pH, pCO(2), and lactate) measured with the i-STAT portable clinical analyzer were evaluated immediately after capture and removal from gillnets among wild bull (Carcharhinus leucas) and bonnethead (Sphyrna tiburo) sharks caught in waters of differing temperature (T), salinity (Sal), and dissolved oxygen (DO). Time from capture to blood collection (C-BD) was also recorded. Effects of T, Sal, DO, and C-BD on acid-base physiology were evaluated by modeling their ability to predict pH, pCO(2), and lactate concentrations using ordinal logistic regression (OLR). The OLR models suggest that C. leucas sharks experienced a mixed metabolic and respiratory acidosis in warmer waters and at the low end of their salinity tolerance, and that S. tiburo sharks experienced a metabolic acidosis in warmer waters with a potential for respiratory acidosis at the high end of their salinity tolerance. In S. tiburo, capture and handling time exacerbated acidosis. Based on these findings, it is recommended that commercial and catch-and-release fisheries conduct operations cautiously during times of the year when water temperatures are high and salinities are at either extreme, by decreasing soak times, using the strongest proper tackle gear to reduce fight times, and releasing sharks as soon as possible after capture and detection.

Miller, K. I., Nadheeh, I., Jauharee, A. R., Anderson, R. C., & Adam, M. S. (2017). Bycatch in the Maldivian pole-and-line tuna fishery. *Plos One,* 12(5), e0177391. https://doi.org/10.1371/journal.pone.0177391

Tropical tuna fisheries are among the largest worldwide, with some having significant bycatch issues. However, pole-and-line tuna fisheries are widely believed to have low bycatch rates, although these have rarely been quantified. The Maldives has an important pole-and-line fishery, targeting skipjack tuna (Katsuwonus pelamis). In the Maldives, 106 pole-and-line tuna fishing days were observed between August 2014 and November 2015. During 161 fishing events, tuna catches amounted to 147 t: 72% by weight was skipjack, 25% yellowfin tuna (Thunnus albacares) and 3% other tunas. Bycatch (all non-tuna species caught plus all tuna discards) amounted to 951 kg (0.65% of total tuna catch). Most of the bycatch (95%) was utilized, and some bycatch was released alive, so dead discards were particularly low (0.02% of total tuna catch, or 22 kg per 100 t). Rainbow runner (Elagatis bipinnulata) and dolphinfish (Coryphaena hippurus) together constituted 93% of the bycatch. Live releases included small numbers of silky sharks (Carcharhinus falciformis) and seabirds (noddies, Anous tenuirostris and A. stolidus). Pole-and-line tuna fishing was conducted on free schools and schools associated with various objects (Maldivian anchored fish aggregating devices [aFADs], drifting FADs from western Indian Ocean purse seine fisheries, other drifting objects and seamounts). Free school catches typically included a high proportion of large skipjack and significantly less bycatch. Associated schools produced more variable tuna catches and higher bycatch rates. Fishing trips in the south had significantly lower bycatch rates than those in the north. This study is the first to quantify bycatch rates in the Maldives pole-and-line tuna fishery and the influence of school association on catch composition. Ratio estimator methods suggest roughly 552.6 t of bycatch and 27.9 t of discards are caught annually in the fishery (based on

2015 national catch), much less than other Indian Ocean tuna fisheries, e.g. gillnet, purse-seine, and longline.

O'Connell, C. P., Abel, D. C., Stroud, E. M., & Rice, P. H. (2011). Analysis of permanent magnets as elasmobranch bycatch reduction devices in hook-and-line and longline trials. *Fishery Bulletin,* 109(4), 394-401. Retrieved from https://spo.nmfs.noaa.gov/content/analysis-permanent-magnets-elasmobranch-bycatch-reduction-devices-hook-and-line-and

Previous studies indicate that elasmobranch fishes (sharks, skates and rays) detect the Earth's geomagnetic field by indirect magnetoreception through electromagnetic induction, using their ampullae of Lorenzini. Applying this concept, we evaluated the capture of elasmobranchs in the presence of permanent magnets in hook-and-line and inshore longline fishing experiments. Hooks with neodymium-iron-boron magnets significantly reduced the capture of elasmobranchs overall in comparison with control and procedural control hooks in the hook-and-line experiment. Catches of Atlantic sharpnose shark (Rhizoprionodon terraenovae) and smooth dogfish (Mustelus canis) were significantly reduced with magnetic hook-and-line treatments, whereas catches of spiny dogfish (Squalus acanthias) and clearnose skate (Raja eglanteria) were not. Longline hooks with barium-ferrite magnets significantly reduced total elasmobranch capture when compared with control hooks. In the longline study, capture of blacktip sharks (Carcharhinus limbatus) and southern stingrays (Dasyatis americana) was reduced on magnetic hooks, whereas capture of sandbar shark (Carcharhinus plumbeus) was not affected. Teleosts, such as red drum (Sciaenops ocellatus), Atlantic croaker (Micropogonias undulatus), oyster toadfish (Opsanus tau), black sea bass (Centropristis striata), and the bluefish (Pomatomas saltatrix), showed no hook preference in either hook-and-line or longline studies. These results indicate that permanent magnets, although eliciting species-specific capture trends, warrant further investigation in commercial longline and recreational fisheries, where bycatch mortality is a leading contributor to declines in elasmobranch populations.

Pilcher, N. J., Nickson, A., McClellan, L., & Cartwright, I. (2006). Hook, line and bycatch workshop setting the agenda for mitigation of bycatch in longline fisheries. *Indian Ocean Turtle Newsletter,* 3, 32. Retrieved from https://www.iotn.org/wp-content/uploads/2015/11/03-8-ANNOUNCEMENT4.pdf

During the IUCN World Conservation Congress in 2004, we identified the need for a forum where bycatch issues could be considered at an ecological, multi-species level rather than on a case-by-case basis. We recognized that several bycatch reduction measures are already in place, but noted that there was insufficient communication and collaboration among the various species groups impacted by longline fisheries, and that opportunities might exist for cross-group information sharing and collaboration. The workshop was intended as a forum to: 1. Exchange knowledge on bycatch problems and mitigation techniques among four key species groups (turtles, seabirds, cetaceans, sharks); 2. Identify conflicts/mutual benefits of mitigation gears and fishing strategies; 3. Share knowledge on the spatial-temporal overlap of distributions of these species; 4. Identify needs, priorities and opportunities for collaborative mitigation research; and, 5. Define a priority global agenda to create a significant and measurable reduction in longline bycatch. The workshop brought together marine resource specialists composed of managers and policy makers, scientists, NGOs, IGOs, industry representatives and fishers,

from 14 countries and sharing a wealth of global experience, who worked to identify, develop, and recommend applicable and integrated solutions to reduce interactions of birds, mammals, turtles and sharks with pelagic longline fisheries. The technical report includes commonalities, synergies and conflicts between species groups and mitigation measures for target (and non-target) species, through the use of a comparative matrix, and identifies criteria for evaluating trade-offs in the application of bycatch mitigation methods. It highlights the potential for the use of risk-based methods for assessing i) bycatch reduction priorities and ii) multi-species effects of bycatch reduction methods and strategies, and suggests means of monitoring and evaluating mitigation efforts with respect to performance indicators and adaptive management approaches, including timing considerations. The outcomes highlight research priorities including filling data gaps, and promising new mitigation methods and strategies aimed at raising awareness of multi-species data needs, to encourage governments and industry to collect standardized multi-species data in all observer programs. The Technical Report is envisioned to form the basis of a 'roadmap' or plan of action with regard to multi-species bycatch mitigation. A second key outcome was a preliminary mathematical model based on existing mitigation measures and intended to assist fisheries managers in decision making. The model is a process through which decision-makers can determine the top priorities for mitigation, both in terms of the bycatch species and the mitigation options, and combinations thereof at a multi-species (ecological) level. The model requires an up front determination of the species being impacted by a given fishery, which are then assigned 'conservation values' or some form of risk assessment weighting based on existing criteria. Based on the groups of species being impacted, a list of all potential bycatch mitigation measures is then assembled, and a matrix drawn up of the potential positive or negative impact of any given measure on each species or species group. A mathematical modeling process then assigns weights to species value, factors these against mitigation measures, and prioritizes the top mitigation measures.

Poisson, F., Abascal Crespo, F., Ellis, J. R., Chavance, P., Pascal, B., Santos, M. N., . . . Murua, H. (2016). Technical mitigation measures for sharks and rays in fisheries for tuna and tuna-like species: turning possibility into reality. *Aquatic Living Resources,* 29(4). https://doi.org/10.1051/alr/2016030

Tuna fisheries have been identified as one of the major threats to populations of other marine vertebrates, including sea turtles, sharks, seabirds and marine mammals. The development of technical mitigation measures (MM) in fisheries is part of the code of conduct for responsible fisheries. An in-depth analysis of the available literature regarding bycatch mitigation in tuna fisheries with special reference to elasmobranchs was undertaken. Studies highlighting promising MMs were reviewed for four tuna fisheries (longline, purse seine, driftnets and gillnet, and rod and line - including recreational fisheries). The advantages and disadvantages of different MMs are discussed and assessed based on current scientific knowledge. Current management measures for sharks and rays in tuna Regional Fishery Management Organizations (t-RFMOs) are presented. A review of relevant studies examining at-vessel and postrelease mortality of elasmobranch bycatch is provided. This review aims to help fisheries managers identify pragmatic solutions to reduce mortality on pelagic elasmobranchs (and other higher vertebrates) whilst minimizing impacts on catches of target tuna species. Recent research efforts have identified several effective MMs that, if endorsed by t-RFMOs, could reduce elasmobranchs mortality rate in international tropical purse seine tuna fisheries. In the case of longline fisheries, the number of operational effective MMs is very limited. Fisheries deploying driftnets in pelagic ecosystems are suspected to have a high elasmobranchs bycatch and their discard survival is uncertain, but no effective MMs have been field validated for these fisheries. The precautionary bans of such gear by the EU and by

some t-RFMOs seem therefore appropriate. Recreational tuna fisheries should be accompanied by science-based support to reduce potential negative impacts on shark populations. Priorities for research and management are identified and discussed.

Sacchi, J. (2019). *Mitigation Measures for Protected Species.* Paper presented at the Seventh Meeting of the Parties to ACCOBAMS. Retrieved from https://accobams.org/wp-content/uploads/2019/04/MOP7.Doc30_Mitigation-measures-for-protected-species.pdf

Highly migratory for the most part, occupying a wide distribution across the oceans, the marine megafauna undergo all possible forms of human pressure. Among them, bycatch fishery has increased exponentially in recent years and is now considered the most serious threat to these highly vulnerable species. Minimizing bycatch, is therefore a key component of sustainable fisheries management to maintain marine biodiversity and consequently to reduce negative effects on the resources (see Hall, 1996; Hall et al., 2000). The aim of this document is to present various experimented approaches and strategies that could also serve as an example for fisheries facing the same problems. This review of the different mitigation measures draws on the analysis of the available literature, comprising scientific journal articles together with reports from international organisations and documents available on the internet. The presentation adopted here is guided by the principle that it is not species that should be managed but fishing activities (metiers)1 that should be the target of the technical or management measures that are required to reduce the negative impacts of interactions with fisheries. Consequently, for each of the main fishing gear groups (gill and trammel nets, longlines and lines, trawls, purse seines, trapnets and pots) the various solutions found in the documents consulted are classified by the four main groups of protected species (Cetaceans, Birds, Sharks and Sea turtles).

Smith, L. E., & O'Connell, C. P. (2014). The effects of neodymium-iron-boron permanent magnets on the behaviour of the small spotted catshark (Scyliorhinus canicula) and the thornback skate (Raja clavata). *Ocean & Coastal Management,* 97, 44-49. https://doi.org/10.1016/j.ocecoaman.2013.05.010

Elasmobranchs (sharks, skates, and rays) are frequently captured as bycatch on a wide variety of fishing gears, such as pelagic longlines and hook-and-line fisheries, and therefore many species have experienced severe population declines. To reduce elasmobranch bycatch, scientists have begun exploring the effectiveness and potential application of elasmobranch-specific repellents, such as permanent magnets and electropositive metals. For the present study, the behavioural responses of captive small spotted catsharks (Scyliorhinus canicula) and thornback skates (Raja clavata) were observed in response to neodymium-iron-boron (Nd2Fe14B) permanent magnets. Results demonstrate that both R. clavata and S. canicula; (1) significantly avoided the Nd2Fe14B magnets more often in comparison to the control and procedural control and (2) significantly fed from the control and procedural control more often in comparison to the Nd2Fe14B magnets. Data also suggests a relationship between water temperature and the avoidance distance by R. clavata, with closer approaches prior to avoidance occurring in association with water temperatures of <= 12 degrees C. Additionally, the tail beat frequency associated with the avoidance behaviour of S. canicula was significantly slower (<= 9 beats/10 s) in water temperatures of <= 12 degrees C. The findings from this study agree with previous electrosensory repellent studies, in that elasmobranchs detect and are

deterred by permanent magnets however, the present study also demonstrated that there is a correlation between avoidance speed and distance with water temperature. These findings suggest that water temperature may be correlated to magnetic repellent effectiveness and thus warrants further experimentation.

Tixier, P., Lea, M. A., Hindell, M. A., Welsford, D., Mazé, C., Gourguet, S., & Arnould, J. P. Y. (2021). When large marine predators feed on fisheries catches: Global patterns of the depredation conflict and directions for coexistence. *Fish and Fisheries,* 22(1), 31-53. https://doi.org/10.1111/faf.12504

The sustainable mitigation of human–wildlife conflicts has become a major societal and environmental challenge globally. Among these conflicts, large marine predators feeding on fisheries catches, a behaviour termed “depredation,” has emerged concomitantly with the expansion of the world’s fisheries. Depredation poses threats to both the socio-economic viability of fisheries and species conservation, stressing the need for mitigation. This review synthesizes the extent and socio-ecological impacts of depredation by sharks and marine mammals across the world, and the various approaches used to minimize it. Depredation was reported in 214 fisheries between 1979 and 2019 (70% post-2000) and affected fleets from 44 countries, in all sectors (commercial, artisanal and recreational), and in all major fishing techniques (nets, traps and hook-and-lines). A total of 68 predator species were involved in depredation (20 odontocetes, 21 pinnipeds and 27 sharks), and most (73%) were subject to either by-catch and/or retaliatory killing from fishers when interacting with gear. Impacts on fishers were primarily associated with catch losses and gear damage but often lacked assessments. Deterrence was a major mitigation approach but also the least effective. Gear modifications or behavioural adaptation by fishers were more promising. This review highlights the need for improved monitoring, and interdisciplinary and integrated research to quantify the determinants and impacts of depredation in the socio-ecological dimension. More importantly, as the conflict is likely to escalate, efforts directed towards changing perceptions and integrating knowledge through adaptive co-management are raised as key directions towards coexistence between fisheries and large marine predators.

1.3 Longline Fisheries

Afonso, A. S., Hazin, F. H. V., Carvalho, F., Pacheco, J. C., Hazin, H., Kerstetter, D. W., . . . Burgess, G. H. (2011). Fishing gear modifications to reduce elasmobranch mortality in pelagic and bottom longline fisheries off Northeast Brazil. *Fisheries Research,* 108(2-3), 336-343. https://doi.org/10.1016/j.fishres.2011.01.007

One of the biggest challenges of fisheries research is reducing the bycatch of unwanted species. The incidental fishing mortality of species with low reproductive rates, such as elasmobranchs (sharks, skates, and rays), is recognized as a key threat for their populations. In the present study, gear modifications related to the type of hook and position of the hook in the water column were tested to examine their effects on catch rates and mortality of elasmobranch species in both pelagic and coastal environments. Comparisons between circle (size 18/0,0 degrees offset) and J-style (size 9/0, 10 degrees offset) hooks demonstrated that the circle hooks have a greater efficiency in reducing the mortality of most species caught, both in pelagic and coastal longline fisheries. Internal lodging of the hook was significantly less frequent for the individuals caught with circle hooks, which likely contributed to their higher survival rate at haulback. Additionally, circle hooks also increased the CPUE of elasmobranchs caught in the pelagic longline fishery, which was particularly evident for Carcharhinus falciformis and Prionace glauca. The position of the hook in the water column exhibited a strong influence on the species caught in the coastal bottom longline fishery. Suspending hooks in the middle of the water column reduced the bycatch of common demersal species, such as Carcharhinus acronotus, Ginglymostoma cirratum, and Dasyatis americana, while increasing the CPUE of potentially aggressive species, such as Galeocerdo cuvier and Carcharhinus leucas. The interaction of the type of hook utilized with its position in the water column appears to be an essential factor in the optimization of longline selectivity and minimization of bycatch mortality.

Afonso, A. S., Mourato, B., Hazin, H., & Hazin, F. H. V. (2021). The effect of light attractor color in pelagic longline fisheries. *Fisheries Research,* 235. https://doi.org/10.1016/j.fishres.2020.105822

Improving the selectivity of the fishing gear is one of the most promising methods to mitigate deleterious impacts of longline fisheries upon bycatch species. Light lures have recently become widespread in epipelagic longline fisheries since they increase the catch rates of valuable target species such as swordfish and tunas. Yet, little is known about their effect upon the incidence of bycatch. Here, we compared the catchability of target and bycatch species in a pelagic longline fishery targeting swordfish and tunas equipped with light attractors with three different colors to ascertain if any of the light attractor colors would enhance the selectivity of the fishing gear. A total of 3488 individuals were caught across 57 fishing sets. The proportion of target species to bycatch species was high (58-65 %) in each color treatment. Overall, green attractors (peak wavelength at 525 nm) exhibited the highest catch rates of target species, but they were also responsible for the highest incidence of bycatch, rendering 73 % and 82 % of the blue shark and sea turtle catch, respectively. Blue (peak wavelength at 465 nm) and white attractors caught significantly less individuals of both target and bycatch species. Further, significant interactions between light attractor color and the intensity of lunar illumination were observed for most species analyzed. Differences in the catchability of bycatch such as blue sharks and white marlins across attractor color treatments were more conspicuous at high lunar illumination levels (i.e. full moon periods), when white attractors rendered the lowest catch of these taxa. In contrast, the catchability of target species such as swordfish, yellowfin tuna and albacore showed greater differences between treatments at low illumination levels (i.e. new moon periods). The observed differences in the

performance of the three light attractor colors across the lunar cycle might provide an opportunity to mitigate bycatch incidence in longline fisheries. Yet, further research is required to fully understand the combined effects of light lures and lunar illumination on the behavioral responses of pelagic species.

Afonso, A. S., Santiago, R., Hazin, H., & Hazin, F. H. V. (2012). Shark bycatch and mortality and hook bite-offs in pelagic longlines: Interactions between hook types and leader materials. *Fisheries Research,* 131, 9-14. https://doi.org/10.1016/j.fishres.2012.07.001

This study addressed the influence of hook type (circle vs J-hook) and leader material (nylon vs wire) on longline catch and mortality rates of target and bycatch species in a pelagic longline fishery targeting swordfish. Xiphias gladius, and tunas. A total of 603 individuals (53% classified as bycatch) were caught on 17,000 hooks. Sharks constituted 45% of the bycatch. Bite-offs (i.e. missing hooks) corresponded to similar to 33% of the shark catch and occurred mostly on nylon leaders (97%). Hook type had no significant effect on catchability or mortality of any species or groups. However, nylon leaders caught more bigeye tuna. Thunnus obesus and all target species combined, while wire leaders caught more blue shark. Prionace glauca and all sharks combined. If bite-offs were assumed to be undetected sharks, differences in shark catchability between leader types disappear. Moreover, significant differences in blue shark catch rate between leader types was found in J-hook treatments only. Higher proportions of live sharks were found on wire leaders. The catch and mortality rates of sharks in longline fisheries may be underestimated when monofilament leaders are used. This study highlights the need for understanding the role of every longline component in gear performance analysis.

Aguilar, C., González-Sansón, G., Hueter, R., Rojas, E., Cabrera, Y., Briones, A., . . . Baker, P. (2014). Captura de tiburones en la región noroccidental de Cuba. *Latin American Journal of Aquatic Research,* 42(3), 477-487. Retrieved from https://www.scielo.cl/scielo.php?script=sci_arttext&pid=S0718-560X2014000300008

Sharks have been important as seafood source and fisheries revenue in Cuba. Nevertheless, current information about this group of fishes in Cuba is scarce and in the last decades they have not been the focus of any organized research. From October 2009 to June 2011, fisheries and biological (229 sharks examined) data were collected at four landing sites in the northwest of Cuba. At present, there is no organized fishery specifically targeting only sharks along the northwest coast of Cuba, but they are caught as a component of multispecies fisheries on the insular shelf and as bycatch in longline fisheries targeting billfishes. We registered a total of 17 species, six in the commercial fishery, dominated by Carcharhinus perezii, Sphyrna mokarran, and Carcharhinus leucas, and 14 in the sport fishery (i.e., small-scale artisanal, not recreational properly), dominated by Isurus oxyrinchus, Isurus paucus, Carcharhinus longimanus, Carcharhinus falciformis, Galeocerdo cuvier and Prionace glauca. Mean CPUE by months in sport fishing varied from 0.43 to 4.44 number of sharks caught per ten fishing trips. Most oceanic sharks caught in the Cuban sport fisheries are highly migratory species and their populations show great ecological connectivity throughout the Gulf of Mexico and adjacent waters. This fact and the presence of a high proportion of individuals of C. longimanus and C. falciformis below maturity size are important results to be considered for regional conservation of sharks and planning rational use of shark fisheries.

Amorim, S., Santos, M. N., Coelho, R., & Fernandez-Carvalho, J. (2015). Effects of 17/0 circle hooks and bait on fish catches in a Southern Atlantic swordfish longline fishery. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 25(4), 518-533. https://doi.org/10.1002/aqc.2443

This paper reports the results of using different hook style and bait type combinations on the catches of targeted, bycatch and discarded fishes in the Portuguese commercial longline fishery targeting swordfish (Xiphias gladius) in the South Atlantic Ocean. In total, 310 longline experimental sets (446 400 hooks) were deployed between October 2008 and February 2012. Three different hook styles were tested; the traditional J-hook (9/0) 10(o) offset was compared with two 17/0 circle hooks (a non-offset and a 10(o) offset), and squid (Illex spp.) bait was compared with mackerel (Scomber spp.). Catch per unit effort (CPUE) was calculated for each fish species per fishing set and compared between the different hook style and bait type combinations. Results indicated that the effects of hook style and bait on the CPUEs were species-specific. For example, swordfish (target species, Xiphias gladius) CPUEs were higher with J-hooks baited with squid, while for the blue shark (most important bycatch species, Prionace glauca) the highest CPUEs were obtained with circle hooks baited with mackerel. For tuna (Thunnus spp.) and marlin (blue, Makaira nigricans and white, Kajikia albida) only the bait effect was significant, with higher catches with squid. For the discarded species, the proportions of alive vs dead specimens at the time of fishing gear retrieval were also species-specific. The total retained catch value per unit of effort (VPUE) did not changed between the different hook and bait combinations, but these VPUEs are highly dependent on market fluctuations.

Andraka, S., Mug, M., Hall, M., Pons, M., Pacheco, L., Parrales, M., . . . Vogel, N. (2013). Circle hooks: Developing better fishing practices in the artisanal longline fisheries of the Eastern Pacific Ocean. *Biological Conservation,* 160, 214-224. https://doi.org/10.1016/j.biocon.2013.01.019

Since 2004, governments and non-governmental organizations, together with the fishing communities from nine countries, from Mexico to Peru, have implemented joint efforts to reduce incidental mortality of sea turtles in artisanal longline fisheries of the Eastern Pacific Ocean (EPO). These countries are involved in a Regional Sea Turtle Bycatch Program to achieve this goal. Circle hooks have been proposed as a way to mitigate incidental mortality of sea turtles. Thus, we analyze the performance of circle hooks in relation to)style and tuna hooks on the hooking rates of target and non-target species in the artisanal surface longline fisheries of three of the participating countries with the largest sample sizes (Ecuador, Panama and Costa Rica). These fisheries target mahi-mahi, Coryphaena hippurus, or a combination of tunas, billfishes and sharks (TBS), and use different techniques and gear configurations to catch their targets. For the TBS fishery we presented the results of comparisons between tuna hooks and 16/0 circle hooks from Ecuador, Panama and Costa Rica, and between tuna hooks and 18/0 circle hooks in Costa Rica. For the mahi-mahi fishery, we analyzed the performance of 14/0 and 15/0 circle hooks in Ecuadorian vessels and 16/0 circle hooks in Costa Rican vessels vs. the traditional J-style hooks. A total of 730,362 hooks were observed in 3126 sets. Hooking rates for target and non-target species were not consistent for all fisheries and countries analyzed. However, circle hooks reduced sea turtle hooking rates in most of the comparisons.

Ariz, J., Delgado de Molina, A., Ramos, M., & Santana, J. (2006). *Check list and catch rate data by hook type and bait for Bycatch species caught by Spanish experimental longline cruises in the South-western Indian Ocean during 2005.* Western and Central Pacific Fisheries Commission, Retrieved from https://meetings.wcpfc.int/node/6339

In this paper, catch data are presented, in number of individuals and round weight (Kg), per a thousand hooks, from data obtained in the experimental cruises carried out by the Instituto Espanol de Oceanografia (IEO) in two surface Spanish longliners in international waters of South-western Indian Ocean between 25ºS - 35ºS and 30ºE - 50ºE. This pilot action, which was followed continuously by scientific observers, was carried out in 2005 and several types of hooks and baits were experimentally used. Although there is space-time stratification for sampling in the prospecting area, it has not been taken into consideration for this document. Joint analysis has been made of all the specimens sampled since activities began (539 sets with a total of 531916 hooks) for the entire area. Total catch raised 1162t, from which 30t are considered true bycatch. The related species included in this group were 2.6% of total tons caught. Sharks and Rays, and Other Fishes are species which inclusion in ship holds depends on the fleet and has varied according to the trade. Detailed information is presented about the catch of sea turtles, marine mammals and sea birds. This document presents, in the same way, the total catch, in number and weight, for all and each one of the species or groups captured in this Pilot Action, indicating if they were included as commercial catch or as bycatch.

Auger, L., Trombetta, T., Sabarros, P., Rabearisoa, N., Romanov, E., & Bach, P. (2015). *Optimal fishing time window: an approach to mitigate bycatch in longline fisheries.* IOTC–2015–WPEB11–15. Indian Ocean Tuna Commission, Retrieved from https://www.bmis-bycatch.org/system/files/zotero_attachments/library_1/9HQDDHIW%20-%20IOTC-2015-WPEB11-15_-_Optimal_time_window.pdf

One of the main concerns of the ecosystem approach to fisheries is the mitigation of bycatch, especially in pelagic longline fisheries. Bycatch represent unmarketable species and protected species for some of them. Various mitigation measures already exist to reduce bycatch in longline fisheries, notably concerning the equipment used and the strategy of fishing gear deployment. However, measures that concern the hours of gear deployment remain poorly studied. Using hook-timer data collected during scientific longline fishing campaigns between 2004 and 2014 in the South West Indian Ocean, we developed a method to identify optimal fishing practice that maximizes bycatch reduction and swordfish yield (in number). Here we found that hourly capture patterns of swordfish and bycatch (sharks, turtles) are different and allow to identify an optimal fishing practice that consists in fishing between 18pm and 9am. This methodology certainly provides a relevant bycatch mitigation approach that benefits to fishermen but also allow to mitigate the impact of longline fisheries on the ecosystem.

Bayse, S. M., & Kerstetter, D. W. (2010). Assessing Bycatch Reduction Potential Of Variable Strength Hooks For Pilot Whales In A Western North Atlantic Pelagic Longline Fishery. *Journal of the North Carolina Academy of Science,* 126(1), 6-14. Retrieved from http://www.jstor.org/stable/24336337

The pelagic longline fishery off Cape Hattaras in the western North Atlantic Ocean, which targets swordfish (Xiphias gladius, Linnaeus 1758) and tunas (Thunnus spp.), has a high frequency of interactions with marine mammals, particularly pilot whales (Globicephala spp.). The typical hooks used

in the this fishery are size 16/0 "strong" hooks that straighten at 250 lb of pull (113 kg); some fishermen use alternative "weak" hooks that straighten at 150 lb of pull (68 kg). Other commonly used hooks in this fishery are size 18/0 strong hooks that straighten at 350 lb (159 kg) of pull, and the weak equivalent hooks that straighten at 225 lb (102 kg). Taking advantage of the size difference between large bycatch animals and relatively smaller target species, weak hooks could be implemented to reduce bycatch. Twenty-one pelagic longline sets were made targeting yellowfin tuna (T. albacares, Bonnaterre 1788) and bigeye tuna (T. obesus, Lowe 1839) using alternating 16/0 strong and weak hooks. Nine additional sets targeted swordfish with size 18/0 hooks and the same alternating hook methodology. No significant reduction in total tuna catch (α < 0.05) or of any target species, although weak hooks exhibited higher catch per unit effort (CPUE) for tuna and swordfish. The only species with a significant difference in total catch between strong and weak 16/0 hooks was the pelagic stingray (Pteroplatytrygon violacea, Bonaparte, 1832), with more individuals caught by the strong hook. The sets with 18/0 hooks had similar catches for all species, except the target species swordfish. Swordfish CPUE was higher with the strong hooks, and had significantly higher total catches. Seven weak hooks were retrieved straightened, and one of these hooks was observed being straightened by a pilot whale. While not conclusive, such results suggest further research into weak hooks for the reduction of large animal bycatch in the pelagic longline fishery.

Bettis, S. (2017). *Shark Bycatch in Commercial Fisheries: A Global Perspective.* (Master of Science), Nova Southeastern University, Retrieved from https://nsuworks.nova.edu/cnso_stucap/331/

Many shark species have global distributions and are caught incidentally in different types of fisheries. Over the last two decades, shark populations have declined tremendously, with one of the leading causes of this decline bycatch in primarily teleost fisheries. Bycatch occurs throughout the world's fisheries, but is not well documented in terms of species composition and numbers of each species captured. Information on shark bycatch is spread through the primary and grey literature, but has not been compiled in summary to date. The goal of my capstone is to present global shark bycatch data and provide a comparative review to determine fishery types that affect shark populations and identify shark species at risk as a result of bycatch. Longline fisheries caught a larger variety of shark species, and the post-release mortality was generally low. In contrast, trawl fisheries caught mostly the same few species, but post-release mortality was extremely high. Blue sharks (Prionace glauca), silky sharks (Carcharhinus falciformis), and spiny dogfish (Squalus acanthias) were caught most often in trawl fisheries, and in large numbers that likely adds to risk of overexploitation of their populations. This literature review revealed a severe lack of standardization in bycatch data reporting by different fishing nations, and in documents prepared by management agencies and scientists, including the definition of bycatch used and the way it was recorded. Establishing a universal definition of bycatch and standardizing its reporting would vastly improve ability to assess the scale and composition of shark bycatch and its impacts on shark populations. Systematic and standardized accounting of shark bycatch would provide information helpful for collaboration among regulatory agencies. Rather than simply document bycatch, a number of fishing gear alterations show promise for bycatch reduction and are worthy of integration into fisheries by managers. Additional important steps that can improve bycatch assessment is increased observer coverage in fisheries, marine protected areas, and making bycatch data public.

Beverly, S., Curran, D., Musyl, M., & Molony, B. (2009). Effects of eliminating shallow hooks from tuna longline sets on target and non-target species in the Hawaii-based pelagic tuna fishery. *Fisheries Research,* 96(2-3), 281-288. https://doi.org/10.1016/j.fishres.2008.12.010

A longline experiment consisting of 45 paired sets (90 sets total) was carried out to evaluate a technique which maintains target catch rates while reducing non-target catch rates. Control sets were compared to experimental sets which eliminates the shallowest hooks (similar to less than 100 m depth). Researchers hypothesized that by eliminating shallow hooks, target catch of deeper dwelling species such as bigeye tuna (Thunnus obesus) would be maximized while incidental catch of many other non-target, but marketable epi-pelagic species (e.g, billfish), bycatch (discards) of other fishes and elasmobranchs, and protected sea turtles and marine mammals would be simultaneously reduced. To control for differences in fishing power, gear, and deployment techniques: a single vessel was contracted to perform all 90 paired longline sets (45 experimental sets using no-shallow-hooks and 45 control sets using standard methods). Control sets consisted of longlines that were suspended by floats on typical 30m long floatlines in catenary-type shapes that fished a range of depths. determined by temperature-depth recorders (TDRs) to be 44-211 m (27.5-11.2 C). By contrast, elimination of shallow hooks in the upper 100m of the water column (hereinafter referred to as experimental sets) was achieved by suspending the fishing portion of the mainline on 75-m long, 3 kg weighted vertical sections of mainline suspended by floats on 30 m floatlines. As determined by TDRs, this arrangement ensured that all hooks fished at depths >100 m (103-248 m: 24.8-11.3 C). Thirty percent of hooks in control sets fished at depths less than 100 in while all hooks on experimental gear fished greater than 100 m. Because many factors influence catchability, longline sets are by nature multivariate, and statistical comparisons were made between the two set types using canonical discriminant analysis (CDA). Except for the depth of shallow hooks, operational characteristics between experimental and control sets were the same. The catch rates of bigeye tuna were similar on the two sets types but the catch rate of sickle pomfret (Taractichthys steindachneri) was significantly higher ($p = 0.011$) in the experimental sets as compared to control sets. However, statistically fewer wahoo (Acanthocybium solandri, $p = 0.019$), dolphinfish (Coryphaena hippurus, $p = 0.008$), blue marlin (Makaira nigricans, $p = 0.001$), striped marlin (Kajikia audax, $p = 0.018$) and shortbill spearfish (Tetrapturus angustirostris, $p = 0.006$) were captured on the experimental sets; thus longline interactions and impacts on these species were reduced with the experimental gear. The reason for the differences in catch rates between gear types is likely due to the vertical habitat preferences of the species involved; interactions with epi-pelagic species with shallow distributions in the uniform mixed layer were reduced by deploying hooks greater than 100 m. By logical extension, the experimental gear will also likely reduce interactions with sea turtles. Except for additional lead weights, floats, and floatlines, only slight modification of existing longline fishing gear and methods were required to deploy the experimental gear. The main drawback of this method was the increase in time to both deploy (approximate to 0.5 h) and retrieve (approximate to 2 h) the gear. Knowledge of species vertical distribution patterns can play an important role in modifying fishing gear to reduce bycatch and can also assist managers in regulating fishing practices with a higher degree of likelihood of predicting catch rates and species captured in different gea types.

Booth, H., Powell, G., Yulianto, I., Simeon, B., Muhsin, Adrianto, L., & Milner-Gulland, E. J. (2022). Exploring cost-effective management measures for reducing risks to threatened sharks in a problematic longline fishery. *Ocean & Coastal Management,* 225, 106197. https://doi.org/10.1016/j.ocecoaman.2022.106197

Many shark and ray species (Class Chondrichthyes, herein 'sharks') are threatened by overfishing. Tackling this requires implementation of context-specific fisheries management measures, which are both technically effective and socio-economically feasible. Here we explore the cost-effectiveness of various input-oriented management measures for mitigating capture of seven priority shark taxa (i.e., threatened and CITES-listed species) in a small-scale longline mixed-species shark fishery in Indonesia, where there is a need to balance difficult trade-offs between conservation and socio-economic objectives. We apply Boosted Regression Trees (BRT) to analyse five years of landings and profit data, to identify and assess the relative influence of different plausible management measures (e.g., effort restrictions, gear restrictions, spatio-temporal closures). We then use predictive models to inform a semi-quantitative assessment of the hypothetical cost-effectiveness of these management measures, based on the estimated conservation benefits (reduced risk of capture of priority taxa) and socio-economic cost (relative profit foregone). Our results show that fishery closures in January–March, depth limits at <100 m, hook limits at <500 hooks, and gear restrictions on bottom longlines could have the greatest relative conservation impact for lowest profit foregone. However, there are clear trade-offs between taxa, with these measures primarily benefiting Critically Endangered bottlenose wedgefish (Rhynchobatus Australiae) and scalloped hammerheads (Sphyrna lewini), while potentially increasing pressure on Vulnerable silky sharks (Carcharhinus falciformis) and Endangered mako sharks (Isurus spp.). When shark fishing is important for economic welfare, and entire fishery closures or buy-outs are unfeasible, managing small-scale shark fisheries for multiple outcomes may require hard choices. This may require prioritising slow-growing Critically Endangered taxa for protection – by restricting fishing during seasons and at depths in which they are most susceptible to capture – while faster-growing taxa can continue to provide benefits for coastal communities.

Box, S. J., & Bonilla, R. S. (2009). *An Evaluation of Fishing Practices in the Small Scale Fisheries of the Golfo de Fonseca, Honduras. Recommendations for Management.* Retrieved from https://web.archive.org/web/20140712074615/http://www.utilaecology.org/assets/documents/Artes%20de%20Pesca%20en%20el%20Golfo%20de%20Fonseca%202009%20english_1.pdf

The artisanal and small scale fisheries within the Honduran Golfo de Fonseca underpin the local economy and are an essential livelihood within small coastal communities. As a mixed fishery, confined within the shallow waters and mangrove estuary of the Golfo de Fonseca, the fishermen exploit a range of demersal and bentho-pelagic fish species using gill nets, hook and lines and bottom set long lines. In addition to fish, shrimp are an important resource and are targeted with trammel and cast nets. In the absence of official statistics, anecdotal evidence suggests that all sectors of the fishery are in decline. This study aimed to assess whether unselective practices could be an important contributory factor to the purported decline and to identify management options that aim to increase the sustainability of the fishery. The study re-evaluated existing catch and length frequency data sets and collected new information during field work and through interviews with fishermen and other stakeholders. We found that fishing within the Golfo de Fonseca predominantly uses gears with broad selectivity. Over a third of the landed catch by weight is low grade, low value fish. There is currently no market incentive for selectivity with little price premium for fish size compared to total fish volume. Of extreme concern is that large proportions of fish of commercially valuable species were being landed at sizes below the size

of maturity. Within the group of the commercially most important fin fish, the “Babosas” (Cynoscion spp) the percentage of individuals within the landed catch that were below the estimated size at maturity ranged from 22 % (Babosa; C. squamipinnis) to 81 % (Corvina; C. reticulates). The majority of the landings of low value species and small sized individuals are mainly from the ubiquitous use of trammel nets that target shrimp. For every one pound of shrimp being landed, over five pounds of fin fish are also being landed. The sustainability of fin fishing is likely directly inhibited by the shrimp fishing. Since it is the same fishermen who are reliant on both resources integrating shrimp management and fish management is recommended. Rather than specifying changes in gear types which are unlikely to occur due to limitations in enforcement, a more feasible option based on current management capacity is to identify and instigate a closed season for shrimp fishing that corresponds to peak abundance of small individuals of commercial fish species that use the area as a nursery ground. This would help to minimise the incidental catch of undersize fish by trammel nets which currently reduces the economic efficiency and ecological sustainability of the fishery. In addition the study found that the extensive use of bottom set long-lining was likely to threaten the most ecologically vulnerable species found in the Golfo de Fonseca including the commercially important catfish Bagre pinnimaculatus and large pelagic species including sharks. Based on the precautionary principle of sustainable fisheries management, long lining within the gulf should be prohibited until their effect on these vulnerable species can be investigated. The lack of fishing selectivity was identified to be a clear problem in the Golfo de Fonseca fishery, however it is considered to be symptomatic of wider problems in the ecosystem and with the socioeconomic structure of the fishery as a whole. Other serious threats exist that are evidently going to affect sustainability, including the loss of critical habitat, water pollution and disruption in trophic webs that support the fish. From the perspective of gear selectivity, the current market structure rewards volume over quality and provides no incentive for using more selective methods of fishing. Addressing this problem first is necessary before any regulation in fishing methods will likely be successful.

Brill, R., Bushnell, P., Smith, L., Speaks, C., Sundaram, R., Stroud, E., & Wang, J. (2009). The repulsive and feeding-deterrent effects of electropositive metals on juvenile sandbar sharks (Carcharhinus plumbeus). *Fishery Bulletin,* 107(3), 298-307. Retrieved from https://spo.nmfs.noaa.gov/content/repulsive-and-feeding-deterrent-effects-electropositive-metals-juvenile-sandbar-sharks

Reducing shark bycatch and depredation (i.e., damage caused by sharks to gear, bait, and desired fish species) in pelagic longline fisheries targeting tunas and swordfish is a priority. Electropositive metals (i.e., a mixture of the lanthanide elements lanthanum, cerium, neodymium, and praseodymium) have been shown to deter spiny dogfish (Squalus acanthias, primarily a coastal species) from attacking bait, presumably because of interactions with the electroreceptive system of this shark. We undertook to determine the possible effectiveness of electropositive metals for reducing the interactions of pelagic sharks with longline gear, using sandbar sharks (Carcharhinus plumbeus, family Carcharhinidae) as a model species. The presence of electropositive metal deterred feeding in groups of juvenile sandbar sharks and altered the swimming patterns of individuals in the absence of food motivation (these individuals generally avoided approaching electropositive metal closer than similar to 100 cm). The former effect was relatively short-lived however; primarily (we assume) because competition with other individuals increased feeding motivation. In field trials with bottom longline gear, electropositive metal placed within similar to 10 cm of the hooks reduced the catch of sandbar sharks by approximately two thirds, compared to the catch on hooks in the proximity of plastic pieces of similar dimensions. Electropositive metals therefore appear to have the potential to reduce shark interactions in pelagic

longline fisheries, although the optimal mass, shape, composition, and distance to baited hooks remain to be determined.

Broadhurst, M. K., Butcher, P. A., Millar, R. B., Marshall, J. E., & Peddemors, V. M. (2014). Temporal hooking variability among sharks on south-eastern Australian demersal longlines and implications for their management. *Global Ecology and Conservation,* 2, 181-189. https://doi.org/10.1016/j.gecco.2014.09.005

An experiment was done to quantify species-specific variation in temporal hooking rates from demersal longlines targeting various carcharhinids off south eastern Australia, with a view to reducing the incidental catches of protected species, including the scalloped hammerhead Sphyrna lewini, great hammerhead Sphyrna mokarran and grey nurse Carcharias taurus. The longline comprised a 9600 m mainline, separated into four sections (termed lines) each with 120 gangions (20 m apart) rigged with hook timers and 16/0 circle hooks baited with either sea mullet Mugil cephalus or eastern Australian salmon Arripis trutta. The mainline was deployed on each of 17 nights (between 19:30 and 23:30 h), with two lines retrieved after 7 and 14 h respectively. From a total of 8160 hooks, 246 timers were activated without hooking fish. Twenty-two species comprising 684 individuals were caught, including 52 S. lewini, 12 C. taurus, 11 S. mokarran and 1 loggerhead turtle Caretta caretta. Several environmental factors, including water temperature, moon phase and depth had mostly homogeneous, positive effects on catches. The only identified variables that might be used to considerably reduce the catches of Sphyrna were soak time and/or diurnal gear retrieval, with most individuals hooked during daylight. Simply mandating shorter deployments and within nocturnal retrieval might limit exploitation, especially among juveniles (<150cm total length). For the studied fishery to approach sustainability, future research is required to investigate other gear modifications for improving size and species selectivity, and/or operational procedures for mitigating discard and escape mortalities.

Broadhurst, M. K., & Tolhurst, D. J. (2021). Null effects of decomposing shark tissue on baited-hook catches of elasmobranchs. *Regional Studies in Marine Science,* 46, 101898. https://doi.org/10.1016/j.rsma.2021.101898

The effects of decomposing shark tissue on catches of benthic longlines targeting various carcharhinids were assessed to inform possible use as a semiochemical shark deterrent. During 15 nights fishing, four benthic longlines (each comprising 18–30 hooks baited with mullet, Mugil cephalus) were deployed to 12–56 m overnight for 12–21 h off eastern Australia. Two of the longlines had 2.0–3.0 kg of decomposing shark tissue placed into porous cylindrical canisters (520 × 105 mm polyvinyl chloride) secured to the mainline mostly between every three hooks (15–20 m apart), while the other two longlines had empty canisters. In total, 150 fish were caught, comprising 14 species of elasmobranchs and especially tiger sharks, Galeocerdo cuvier (31% of total). The decomposing shark tissue in the canisters had no effects on catches of any species or groups, with variability among most attributed to fishing depth (positive relationship) and also soak time (negative) for carcharhinids and G. cuvier. Irrespective of the contents of the canisters and the lack of any semiochemical effects, there was some evidence of fewer sharks caught on adjacent hooks as moonlight increased, and possibly because of a visual response. There was no depredation of any decomposing shark tissue in the canisters, but three juvenile hooked sharks were substantially depredated, and presumably by larger individuals. Most (~70%) of the remaining hooked sharks survived. While this study showed no repelling effects of decomposing shark tissue, the conclusions are restricted to the experimental conditions, including the

source of tissue and the distance between hooks, which might be used as upper limit in any future work assessing for effects.

Carruthers, E. H. (2012). *Ecological and societal context of catch and discards: identifying opportunities for bycatch mitigation in swordfish and tuna pelagic longline fisheries.* (Ph.D.), Memorial University of Newfoundland, Retrieved from http://research.library.mun.ca/id/eprint/6095

Bycatch, defined here as catch discarded for regulatory, economic or personal reasons, from pelagic longline fisheries has contributed to wide spread population declines of sharks and sea turtles. Opportunities to reduce impacts in these fisheries occur throughout the fishing process and depend upon the fishing practices within fleets, and upon the behaviour of target and bycatch species. The overall objective of this thesis was to identify bycatch mitigation opportunities within the Canadian Atlantic pelagic longline fishery, which targets swordfish (Xiphias gladius), warm-water tunas (bigeye, Thunnus obesus; yellowfin T. albacares; and albacore, T. alalunga) and mahi-mahi (Coryphaena hippurus). Bycatch includes common sharks and rays (blue shark, Prionace glauca; pelagic stingray, Pteroplatytrygon violacea), and endangered sea turtles (leatherback Dermochelys coriacea; loggerhead, Caretta caretta). Bycatch mitigation approaches such as shifting to circle hooks, increased the likelihood that shark bycatch would be released alive and with less severe hooking injuries. Shorter longline soak times also increased hooking survival among most of the common bycatch species. Shorter soak times would not decrease catch of the most common landed species (swordfish), but this shift in fishing practices could negatively impact fisher safety. Interviews with active longline captains revealed operational difficulties and unintended ecological impacts with proposed bycatch mitigation approaches. Longline captains also reported innovative uses of bycatch mitigation tools that could increase post-release survival of common bycatch species in this and other pelagic longline fleets. Finally, the combined analysis of fisheries observer data, qualitative data from fishers' knowledge interviews, and concurrent environmental data suggested that high blue shark catch rates were related to local oceanography - and did not reflect behavioural differences between blue shark and swordfish. Clearly, there are opportunities for bycatch mitigation within the Canadian pelagic longline fishery for swordfish and tunas. However, the process of interviewing pelagic longline captains revealed both interest in reducing bycatch, but also suspicion of research efforts. Such trust issues will need to be addressed in subsequent research as the combined use of fishery assessments, detailed oceanographic data, practical fishing knowledge, and on-the-water observations will be needed to decrease the amount of and harm to discarded bycatch.

Carruthers, E. H., Neilson, J. D., & Smith, S. C. (2011). Overlooked bycatch mitigation opportunities in pelagic longline fisheries: Soak time and temperature effects on swordfish (Xiphias gladius) and blue shark (Prionace glauca) catch. *Fisheries Research,* 108(1), 112-120. https://doi.org/10.1016/j.fishres.2010.12.008

Bycatch mitigation approaches aim to either reduce the incidence of unwanted catch or reduce bycatch mortalities. In pelagic longline fisheries incidence of unwanted catch can be reduced by limiting the availability of baited hooks (e.g., within bycatch species' preferred depths and water temperatures), whereas bycatch mortalities can be decreased by gear modifications and changes to fishing practices, e.g., by limiting soak time. To evaluate the effects of temperature, depth, and soak time on catch of target and bycatch species, temperature recorders were set along the length of the longline to characterize the environment at which hooks were fishing. Although few instrumented sets were fished,

observations at the within set scale - specifically, that swordfish (Xiphias gladius) catch did not increase with longer soak times - led us to reexamine assumptions made in fleet-wide catch models. Swordfish catch did not increase with soak time in generalized linear models based on fisheries observer data collected from swordfish-targeted sets fished by the Canadian pelagic longline fleet in 2008 and 2009 (n = 42 and n = 78, respectively). Minimum soak time, from end of setting to start of hauling, was used in swordfish catch models. Total soak time is inappropriate for catch models because it includes haulback time, which increases as a function of catch. If landed catch does not increase as a function of soak time, then limiting longline soak time to reduce bycatch mortalities would not cause decreased swordfish catch nor result in economic losses for fishers. While minimum soak time limits would likely decrease bycatch mortality rates in swordfish longline fisheries, impacts on other aspects of the fishing process would need to be considered, such as negative impacts on fisher safety.

Carruthers, E. H., & Neis, B. (2011). Bycatch mitigation in context: Using qualitative interview data to improve assessment and mitigation in a data-rich fishery. *Biological Conservation,* 144(9), 2289-2299. https://doi.org/10.1016/j.biocon.2011.06.007

Bycatch from pelagic longline fisheries has contributed to widespread population declines of turtles, sharks and other pelagic fishes. While large-scale estimates are needed to understand cumulative impacts on these highly migratory species, detailed information on targeting, setting, and discarding practices is needed to develop bycatch mitigation approaches. Data from qualitative fishers' knowledge interviews with Canadian Atlantic pelagic longline captains was used to evaluate current bycatch estimation methods and to identify bycatch mitigation opportunities. Interviewed longline captains reported blue sharks (Prionace glauca) were common bycatch during swordfish-targeted sets, but were sometimes absent from tuna-targeted sets. Discrepancies between longline captains' observations and bycatch assessment methods identified needed improvements to data collection methods. Longline captains reported innovative uses of turtle dehooking gear, which two-thirds of interviewed captains had used to release other bycatch species in addition to turtles. Longline captains reported techniques for discarding pelagic stingray (Pteroplatytrygon violacea), a common bycatch species in Pacific, Atlantic and Mediterranean pelagic longline fisheries. Therefore, such techniques could decrease fisheries impacts globally. While there can be major conservation benefits from fishers' knowledge research, one-quarter of the active longline captains that we contacted declined interviews because they did not trust the larger research process. We urge conservation biologists to carefully design fishers' knowledge research taking into account the often politicized context. Failure to do so may jeopardize future research and conservation efforts.

Carruthers, E. H., Schneider, D. C., & Neilson, J. D. (2009). Estimating the odds of survival and identifying mitigation opportunities for common bycatch in pelagic longline fisheries. *Biological Conservation,* 142(11), 2620-2630. https://doi.org/10.1016/j.biocon.2009.06.010

To evaluate how fishing practices affect bycatch survival and to identify opportunities to reduce bycatch mortality, we estimated the odds of hooking survival for common bycatch species in the Canadian long-line fishery for swordfish (Xiphias gladius) and tunas (Thunnus spp.) fishing in the North Atlantic. Generalized linear models, with binomial response, were based on 859 sets observed between 2001 and 2004 and were tested using data from 2005 and 2006. Bycatch included targeted species in poor condition or below regulatory size limits. Odds of survival were two to five times higher for swordfish, yellowfin tuna (Thunnus albacares), pelagic stingray (Pteroplatytrygon violacea), porbeagle (Lamna

nasus) and blue shark (Prionace glauca) caught on circle hooks compared to J-hooks during the 2001-2004 period. Further, odds of severe hooking injuries decreased for three shark species caught on circle hooks. We found no conservation benefit for loggerhead turtles (Caretta caretta) from circle hook use. Increased circle hook use coincided with increased targeting and higher landings of tunas. Hooking survival rates and, therefore opportunities to reduce bycatch mortalities differed among the 10 species commonly discarded or released. Where the odds of survival to the time of release are high (e.g., loggerhead turtles, pelagic stingray, blue shark), methods to reduce post-release mortality can be considered. Where the odds of hooking survival are low (e.g., swordfish and longnose lancetfish, Alepisaurus ferox). methods to reduce encounter rates would have greater conservation impact.

Clarke, S., Sato, M., Small, C., Sullivan, B., Inoue, Y., & Ochi, D. (2014). Bycatch in longline fisheries for tuna and tuna-like species: a global review of status and mitigation measures. *FAO Fisheries and Aquaculture Technical Paper* (588), 217. Retrieved from http://www.fao.org/3/a-i4017e.pdf

This publication is the third in a series on bycatch in global tuna fisheries. Dealing with longline fisheries, its scope is defined taxonomically to comprise only non-tuna and non-tuna-like species. The history of longline fishing illustrates the role of new technologies, the expansion of fishing grounds, and the operational characteristics of the fleets in shaping today's fishery. More recently, management regulations, the price of oil, the cost of labour, and market demand have also exerted an influence. No more than 23 percent of the tuna in each ocean is longline-caught. However, there may be up to 7 500 tuna longliners globally with almost 60 percent of them less than 24 m in length. Available data suggest that elasmobranch catches have fallen 14 percent since their peak in 2003. In longline fisheries, shark catch rates may be determined by bait type, soak time, hook shape, leader length and material, depth at which the hook is fished, and whether special gear is deployed to target sharks. Vulnerability to hooking, and resilience to haulback and handling, vary by species, size, area and fleet operational practices. Tuna regional fisheries management organizations (t-RFMOs) assess the status of shark populations but data limitations often hinder firm conclusions. There is little information on the implementation or effectiveness of finning bans and no-retention measures. Mitigation measures have been tested but results vary. Six of the seven species of sea turtles are threatened with extinction, and while longline fisheries may have less impact than net-based fisheries, significant population level impacts may be occurring in some regions. The greatest concern is associated with loggerhead-longline interactions in the Atlantic. Circle hooks and using finfish bait have proved effective mitigation techniques either by reducing hooking or hook swallowing. Other methods require further development. Interactions with pelagic longline fisheries kill 50 000-100 000 seabirds annually. Many of these species, particularly albatrosses, are threatened with extinction. Recent advances in tracking technologies have facilitated mapping of where interactions are most likely. The Western and Central Pacific contains more than 45 percent of the global total albatross and giant petrel breeding distributions. The most promising mitigation methods appear to be night setting, side-setting, line weighting and streamer lines, but further research is needed. All five t-RFMOs require use of one or more of these methods in areas that overlap albatross distributions. However, compliance data are limited and improved observer coverage is essential. Marine mammals' interactions with longline fisheries are detrimental to the fishery but may be positive or negative for the mammals. Although it is often unclear which species are involved, pilot whale interactions in the western Atlantic and false killer whale interactions off Hawaii have triggered national mitigation plans. No t-RFMO has adopted management measures for marine mammal interactions. Research and testing of mitigation measures continue in order to ameliorate both marine mammal impacts and economic losses to industry from depredation. At least 650 species of other bony fishes may be caught in association with pelagic longline fisheries, e.g. dolphinfish, opah, oilfish, escolar

and ocean sunfish. Some of these stocks are important as local food supplies. However, it is unclear whether these stocks or the ecosystem they help structure is at risk. More attention should focus on improving fishery statistics and initiating basic monitoring of these stocks' status. The diversity of pelagic longline gear designs and fishing methods, the variety of habitats they are deployed in, the thousands of marine species they may interact with, and the different mechanisms and behaviours that govern those interactions provide an array of topics to be addressed in any discussion of bycatch mitigation. Scientific and technical issues in mitigation including effects across taxa, effects of combinations of measures, economic and safety considerations, underlying biological mechanisms, handling and post-release mortality, and non-fishery impacts must all be addressed. In addition, it is also necessary to consider issues such as who takes the lead for ensuring mitigation is sufficient for the population as a whole, how to devise effective mitigation implementation strategies, and whether gear modification should be used in concert with more sweeping measures.

Coelho, R., Santos, M. N., & Amorim, S. (2012). Effects Of Hook And Bait On Targeted And Bycatch Fishes In An Equatorial Atlantic Pelagic Longline Fishery. *Bulletin of Marine Science,* 88(3), 449-467. https://doi.org/10.5343/bms.2011.1064

We examined the effects of different hook style and bait type combinations on the catches of targeted, bycatch, and discarded fishes in equatorial Atlantic waters. In total, 221 longline sets (>305,000 hooks) were deployed from Portuguese pelagic longline vessels (SELECT-PAL Project) during the February October fishing season. Three different hook styles and two bait types were tested: the traditional J-hook was compared to two circle hooks (one non-offset and one with 10 offset), and squid bait was compared to mackerel. Catch per unit effort (CPUEs) were calculated and compared between the different hook style and bait type combinations, which indicated that the effects of hook style and bait on the CPUEs were species-specific. For example, swordfish CPUEs were higher with J-hooks baited with squid, while for targeted tunas and blue shark only the bait effect was significant, but with opposite effect (i.e., higher catches of tuna with squid bait and higher catches of blue shark with mackerel bait). For the discarded species, at-haulback mortality was also species-specific. Proportions of alive vs dead specimens at time of fishing gear retrieval did not vary significantly by hook style or bait type combinations. The total retained catch was analyzed in value per unit effort (VPUE), and indicated losses in fishery revenue when mackerel was used instead of squid, but not when circle hooks were used instead of J-hooks.

Cosandey-Godin, A., & Morgan, A. (2011). *Fisheries bycatch of sharks: Options for mitigation.* Pew Environment Group, Washington, DC. Retrieved from https://www.sarri.org/storage/app/media/tools_pdfs/PewOSSsharkbycatchreviewpdf.pdf

Bycatch (see definition below) is one of the most significant issues in the management and conservation of global fisheries (Hall et al. 2000, Kelleher 2005, Lewison et al. 2004) and has been identified as one of the leading causes of shark population declines. Sharks are susceptible to high fishing mortality rates because of their life history characteristics, which include slow growth, late ages at maturity, and the production of a limited number of young over a lifetime (Cortes 2002, Heppell et al. 1999, Cortes 1999). In addition, research has shown that several species of sharks have very high rates of mortality associated with the fishing process (Morgan and Burgess 2007, Mandelman et al. 2008), and it has been estimated that species such as sandbar shark (Carcharhinus plumbeus) (Sminkey and Musick 1994, Cortes 1999) and dusky shark (Carcharhinus obscurus) (Simpfendorfer 1999) increase their population

sizes so slowly that they are considered particularly vulnerable to mortality from fishing activities (Musick et al. 2000a). For example, Cortes et al. (2006) found that if fishing for dusky shark stopped for 30 years, their population in the Northwest Atlantic would still be depleted. Over the past two decades, serious population declines have been reported for a number of shark species in several regions around the world (Baum et al. 2003, Ferretti et al. 2008, Robbins et al. 2006, Ferretti et al. 2010, Clarke 2011) and are attributed to both targeted and incidental capture. According to the International Union for Conservation of Nature (IUCN) and other sources, bycatch is one of the primary threats facing sharks (Musick et al. 2000b, Lewison et al. 2004). Despite widespread recognition of shark bycatch issues (Food and Agriculture Organization [FAO] 1999; FAO 2010), few mitigation actions have been established, and there are no clear guidelines about which mitigation actions would be most effective. In addition, there are very few management measures requiring actions to mitigate shark bycatch. However, it is clear that managers and fishermen must aim to reduce both bycatch rates and the harmful effects from bycatch (e.g., injuries from capture on fishing gear). Based on the best available information, this review provides a summary of the current knowledge and understanding of shark bycatch and discusses available management options and technical measures aimed at reducing both the rate at which sharks encounter fishing gear and the associated damaging effects.

Courtney, J., Courtney, Y. e., & Courtney, M. (2014). Review of Magnetic Shark Deterrents: Hypothetical Mechanisms and Evidence for Selectivity. *Aquatic Science and Technology,* 3(1). https://doi.org/10.5296/ast.v3i1.6670

Several papers published since 2006 describe effects of magnetic fields on elasmobranchs and assess their utility in reducing negative interactions between sharks and humans, including bycatch reduction. Most of these repeat a single untested hypothesis regarding physical mechanisms by which elasmobranchs detect magnetic fields and also neglect careful consideration of magnetoreception in teleosts. Several species of teleosts are known to have magnetoreception based in biogenic magnetite, and direct magnetic field detection also has support in several species of elasmobranchs. The overly narrow focus of earlier papers on the unsupported hypothesis that magnetoreception in elasmobranchs is based in the ampullae of Lorenzini creates the impression that all teleosts will be insensitive to magnetic deterrents. However, magnetite based magnetoreception has been demonstrated in several teleosts, and is supported in others. Furthermore, electroreception is present in many teleost species; therefore, the possibility of induction based indirect magnetoreception should be considered. Finally, experiments reported as demonstrating insensitivity in teleost species to magnetic deterrents suffer from inadequate design and sample sizes to reject the hypothesis of magnetic detection in any given species. Since adoption of deterrent hook technologies depends on both deterrent effects in sharks and the absence of effects in target teleosts, the hypothesis of detection in teleost species must be independently tested with adequate sample sizes.

Cronin, M. R., Croll, D. A., Hall, M. A., Lezama-Ochoa, N., Lopez, J., Murua, H., . . . Moreno, G. (2022). Harnessing stakeholder knowledge for the collaborative development of Mobulid bycatch mitigation strategies in tuna fisheries. *ICES Journal of Marine Science*. https://doi.org/10.1093/icesjms/fsac093

Manta and devil rays (Mobulids) face several immediate threats, including incidental capture in industrial tropical tuna fisheries. As a result, efforts have emerged to avoid or mitigate Mobulid bycatch in these fisheries. However, many mitigation efforts fail to incorporate fisher expertise from the outset,

potentially leading to interventions that are not viable. Here, we combine survey and focus group data to synthesize knowledge of Mobulid bycatch and mitigation ideas in Eastern Pacific Ocean purse seine fisheries. Primary obstacles for mitigating Mobulid bycatch, according to respondents, are: (1) an inability to sight Mobulids before capture, (2) the lack of specific equipment on board, and (3) the difficulty of releasing large individuals; we suggest that the latter two can be addressed by simple operational modifications. We also find that Mobulids are most likely to be sighted by fishers after capture, suggesting that this is an important time in the fishing operation for bycatch mitigation interventions that ensure Mobulids survive capture. To address this, we share creative ideas brought by fishers for avoidance of Mobulids. This study provides a model of how to incorporate stakeholder input in the design of bycatch technology in large-scale fisheries and could inform similar efforts around the world.

Curran, D., & Bigelow, K. (2011). Effects of circle hooks on pelagic catches in the Hawaii-based tuna longline fishery. *Fisheries Research,* 109(2), 265-275. https://doi.org/10.1016/j.fishres.2011.02.013

Sixteen vessels within the deep-set Hawaii-based tuna longline fleet tested the catch efficacy, fish size selectivity and survival on longline retrieval of large-size 18/0 circle hooks vs. Japanese style tuna hooks, size 3.6 sun and vs. size 9/0 “J” hooks. Vessels alternated hook types throughout the longline gear and maintained a 1:1 ratio of circle hooks to their existing tuna or J-hooks. Observers monitored a total of 1393 sets; 1182 sets were circle hooks vs. tuna hooks and 211 sets were circle hooks vs. J-hooks. The 18 most-caught species were analyzed representing 97.6% of the total catch by number. Two statistical methods were used to assess differences in catch (randomization test) or catch rate (generalized linear mixed models (GLMMs)). There were no significant catch or catch rate (catchability) differences among hook types for bigeye tuna (Thunnus obesus), the primary target species, with either statistical method. However, GLMMs indicated that catch rates on circle hooks were significantly lower for 16 and 8 species compared to tuna and J-hooks, respectively. There were no significant differences in mean length of bigeye tuna among hook comparisons. Caught condition at retrieval varied considerably among the 18 species. Large circle hooks had greater effects on catch rates than on fish size selectivity and fish survival. We contend that reduced catch rates are a function of 18/0 circle hook shape, where the minimum width (4.9cm) was 57% and 25% wider than the Japanese tuna (3.1cm) and J-hook (3.9cm), respectively. In contrast to tuna hooks, large circle hooks have conservation potential for use in the world's pelagic tuna longline fleets for some highly migratory species, with catch rate reductions of 29.2–48.3% for billfish species and 17.1–27.5% for sharks.

Dapp, D. R., Huveneers, C., Walker, T. I., Drew, M., & Reina, R. D. (2016). Moving from Measuring to Predicting Bycatch Mortality: Predicting the Capture Condition of a Longline-Caught Pelagic Shark. *Frontiers in Marine Science,* 2. https://doi.org/10.3389/fmars.2015.00126

Incidental fisheries capture has been identified as having a major effect on shark populations throughout the world. However, factors that contribute to the mortality of shark bycatch during fisheries capture are not fully understood. Here, we investigated the effects of capture duration, sea surface temperature, and shark total length (snout to the tip of the upper caudal lobe) on the physiology and condition of longline-caught bronze whalers, Carcharhinus brachyurus. Plasma lactate and potassium concentration had a positive linear relationship with capture duration, indicating that this species experiences increasing physiological challenges while on fishing gear. Additionally, we used

stereotype logistic regression models to determine variables that could predict the capture condition of sharks (categorized as "healthy," "sluggish," or "moribund or dead"). In these models, elevated plasma lactate concentration, plasma potassium concentration, and capture duration increased the likelihood of C. brachyurus being captured in a "sluggish" condition or in a "moribund or dead" condition. After plasma lactate concentration exceeded 27.4 mmol/L, plasma potassium concentration exceeded 8.3 mmol/L, or capture durations exceeded 293 min, the majority of captured sharks (>50%) were predicted to be "moribund or dead." We recommend that a reduction in the amount of time longlines are left fishing (soak time) will reduce immediate and post-release mortality in C. brachyurus bycatch and that our methods could be applied to identify causes of fisheries-induced mortality in future studies. The identification of operational, environmental, and biological variables contributing to poor condition will be necessary to implement conservation strategies that reduce mortality during capture.

Das, D., Gonzalez-Irusta, J. M., Morato, T., Fauconnet, L., Catarino, D., Afonso, P., . . . Giacomello, E. (2022). Distribution models of deep-sea elasmobranchs in the Azores, Mid-Atlantic Ridge, to inform spatial planning. *Deep-Sea Research Part I-Oceanographic Research Papers,* 182. https://doi.org/10.1016/j.dsr.2022.103707

Elasmobranchs inhabiting depths beyond 200 m are extremely susceptible to overexploitation but are extracted by fisheries around the world either as target species or as bycatch. There is little information available to formulate management strategies to reduce elasmobranch-fishery interactions in the deep sea. In European Union waters, prohibiting the catches of deep-sea elasmobranchs has provided the necessary impetus to study bycatch avoidance of these threatened species. We used over 20 years of fisheries-independent and fisheries-dependent data to model the spatial distribution of 15 species of deep-sea elasmobranchs (12 sharks and 3 rays) captured frequently in the Exclusive Economic Zone of the Azores Archipelago (Mid-Atlantic Ridge) to explore spatial management to reduce unwanted catches of these species. We applied Generalised Additive Models to predict the probability of presence of 15 species, as well as the abundance of 6 of those species, within the Azores EEZ and neighbouring seamounts (up to 2000 m depth), using environmental and operational variables as predictors. Our results identified that depth is most influential in determining the distribution of these sharks and rays, in addition to seafloor topography. Distinctive bathymetric features such as seamounts and ridges were highlighted as areas where the probability of presence of the greatest number of species overlapped. Although not related to habitat, gear type influenced the capture probability of certain species, with the artisanal handline, gorazeira, having lower captures than bottom longline. Our results support using depth-based, area-based, and gear-based tactics to design management measures to reduce elasmobranch bycatch, for more sustainable deep-sea fisheries.

Diaz, G. A., & Serafy, J. E. (2005). Longline-caught blue shark (Prionace glauca): Factors affecting the numbers available for live release. *Fishery Bulletin,* 103(4), 720-724. Retrieved from https://spo.nmfs.noaa.gov/content/longline-caught-blue-shark-prionace-glauca-factors-affecting-numbers-available-live-release

The blue shark (Prionace glauca) is an oceanic species that occurs in temperate and tropical waters around the globe (Robins and Ray, 1986). This species is a major bycatch of pelagic longline fleets that operate to supply the world's growing demand for tunas and swordfish (Xiphias gladius) (Stevens, 1992; Bailey et al., 1996; Francis, 1998; Francis et al., 2001; Macias and de la Serna, 2002); numerically, the

blue shark is the top nontarget species captured by the U.S. longline pelagic Atlantic fleet (Beerkircher et al.

Dinkel, T. M., & Sanchez-Lizaso, J. L. (2020). Involving stakeholders in the evaluation of management strategies for shortfin mako (Isurus oxyrinchus) and blue shark (Prionace glauca) in the Spanish longline fisheries operating in the Atlantic Ocean. *Marine Policy,* 120. https://doi.org/10.1016/j.marpol.2020.104124

Shortfin mako (Isurus oxyrinchus) and blue shark (Prionace glauca) are a relevant bycatch in the Spanish surface longline fisheries that operate in the Atlantic Ocean. Concern has been raised after the 2017 and 2019 shortfin mako evaluations for the Northern Atlantic stock. It stated the population being overfished and suffering from overfishing. Also blue shark is subject to high extraction rates in the Atlantic Ocean. Few data and uncertainty in assessment results suggest that further management strategies could be taken into account for both species. This study evaluated different fisheries management strategies for shortfin mako and blue shark in the Atlantic Ocean from the stakeholders' perspective. Personal interviews were conducted with Spanish fishermen and surveys were sent to scientists and non-governmental organizations (NGOs). Local Ecological Knowledge was considered to be useful as fishermen possess unique expertise based on their continued interaction with the species and environment. Interviews allowed understanding the fishermen's perception on variations of stock abundance, distribution patterns, size of capture and seasonal fluctuations for both species. SWOT (Strength, Weaknesses, Opportunities and Threats)-analysis was used to study the different management measures. Main management strategies proposed by all stakeholders to reduce the bycatch of both species were spatial-temporal closure, minimum size and quotas. The Sole Bank was suggested as a temporarily closed area to protect blue shark juveniles during the summer months. The participation of stakeholders enriched the knowledge available and provided a broader data set now available for decision makers in the corresponding regional fisheries management organization (RFMOs).

Domingo, A., Pons, M., Jimenez, S., Miller, P., Barcelo, C., & Swimmer, Y. (2012). Circle Hook Performance In The Uruguayan Pelagic Longline Fishery. *Bulletin of Marine Science,* 88(3), 499-511. https://doi.org/10.5343/bms.2011.1069

Circle hooks have been promoted as an alternative to traditional J-hooks in pelagic longline fisheries to minimize bycatch mortality and injury to sea turtles and other marine wildlife. We evaluated the effect of hook type (circle hook vs J-hook) on the catch and length composition of target and non-target species in the Uruguayan pelagic longline fishery, for both American- and Spanish-style longlines. The sample unit used for comparing catches was two consecutive sections of the longline, each with a different hook type. For the American-style longline 39,822 hooks were deployed in 108 paired sections, and for the Spanish-style 45,142 hooks were deployed in 238 paired sections. The catch of albacore tuna, Thunnus alalunga (Bonnaterre, 1788), was higher with circle hooks with both gears. The catch of shortfin mako shark, Isurus oxyrinchus (Rafinesque, 1810), also increased with the use of circle hooks, but only with the American-style longline. A decrease was observed in the catch of pelagic stingray, Pteroplatytrygon violacea (Bonaparte, 1832), with both gears, though it was significant only with the Spanish-style longline. The performance of circle hooks for other target species, such as swordfish, Xiphias gladius (Linnaeus, 1758), and sharks, and for bycatch species including sea turtles and seabirds remains unclear and requires further research.

Driggers, & Hannan, K. M. (2019). Efficacy of 2 common bait types in reducing bycatch of coastal sharks on bottom longline gear in the absence of choice. *Fishery Bulletin,* 117(3), 189-195. https://doi.org/10.7755/fb.117.3.6

A recent study determined that when simultaneously exposed to 2 different commonly used baits, certain shark species demonstrate preferences for a specific bait on bottom longlines. To further investigate the value of bait type to reduce shark bycatch, we conducted single-bait-type bottom longline sets with standardized gear baited with either mackerel or squid. For 4 of the 5 shark species captured, there was no significant difference in catch rates with bait type. However, catch rates of Atlantic sharpnose sharks (Rhizoprionodon terraenovae) were significantly higher on mackerel-baited hooks. Our results indicate that the use of squid as bait can reduce the catch of at least one shark species in the northern Gulf of Mexico while not reducing the catch of a targeted species, in this case, the red snapper (Lutjanus campechanus). However, because some protected species, most notably sea turtles, have been shown to have higher catch rates on squid-baited hooks, it is necessary to assess the effect of a specific bait across all taxa directly or indirectly affected by a particular gear type before adopting any bycatch reduction measure.

Erickson, D. L., & Berkeley, S. A. (2008). Methods to Reduce Bycatch Mortality in Longline Fisheries. In *Sharks of the Open Ocean.* (pp. 462-471) https://doi.org/10.1002/9781444302516.ch36

Potential methods for reducing bycatch mortality in longline fisheries were examined by two independent studies. Experiments were conducted onboard commercial fishing boats in the Gulf of Mexico (pelagic longlines; 1994–1997) and the Gulf of Alaska (demersal long lines; 1999). Hook timers, instruments that record the moment when fish strike at baited hooks, and motion detectors were used to determine the amount of time that fish spent hooked on longlines. For pelagic longlines, which were often soaked longer than 20 hours, hook-timer data revealed that mortality of pelagic fishes (e.g., swordfish, Xiphias gladius) increased with greater time spent on the longline. This mortality varied by species, ranging from 100% within 12 hours for swordfish to 30% after 12 hours for sharks. Motion-detector data showed that most demersal fish (e.g., Pacifi c halibut, Hippoglossus stenolepis) struck at baited hooks within 3 hours after longlines were set, even though sets were soaked for up to 9 hours. Results of these experiments suggest that soaking longlines no more than some optimal duration (e.g., significantly less than 20 hours for pelagic longlines) may increase the survival of bycatch species while maintaining the catch of target species. Optimal soaking duration likely varies by fishery. The surest method for reducing bycatch mortality in any fishery, however, is to avoid hooking unwanted bycatch in the fi rst place. One approach is to develop species-selective baits. We provide an example of an artifi cial bait developed for demersal longline fisheries that caught target species (i.e., Pacific halibut and sablefish, Anoplopoma fimbria) as efficiently as natural bait, while almost eliminating the catch of nontarget species (e.g., squalid sharks and skates).

Favaro, B., & Cote, I. M. (2015). Do by-catch reduction devices in longline fisheries reduce capture of sharks and rays? A global meta-analysis. *Fish and Fisheries,* 16(2), 300-309. https://doi.org/10.1111/faf.12055

By-catch in marine fisheries, particularly those using pelagic and demersal longlines, is a major driver of declines in abundance of sharks and rays around the world. A wide variety of by-catch reduction devices

(BRDs), that is, modified gears designed to reduce incidental captures of a variety of marine species while maintaining target catch rates, have been proposed, but the extent to which BRDs actually reduce the risk of catching sharks and rays remains unclear. We performed a meta-analysis of 27 publications that reported the capture of sharks and rays and, in some cases, of targeted teleosts in longline gear deployed with and without BRDs. The risk of shark and ray capture differed between types of BRDs, but only one BRD type, longlines raised off the bottom, reduced by-catch significantly. Circle hooks did not reduce the risk of capturing sharks and rays but might improve discard survival and are inexpensive, which might make them effective in reducing the detrimental effects of longlining on these species. In addition to being generally ineffective, some devices, such as electropositive and magnetic repellents, are expensive and have inherent construction drawbacks that are likely to make them unsuitable for commercial use. Overall, most BRDs did not affect the likelihood of catching targeted teleosts, but a substantial number of studies did not adequately assess target catch. We identified two poorly studied classes of BRD gear (i.e. raised demersal longlines, and monofilament nylon leaders), which represent promising directions for future research.

Fernandez-Carvalho, J., Coelho, R., Santos, M. N., & Amorim, S. (2015). Effects of hook and bait in a tropical northeast Atlantic pelagic longline fishery: Part II-Target, bycatch and discard fishes. *Fisheries Research,* 164, 312-321. https://doi.org/10.1016/j.fishres.2014.11.009

The incidental bycatch of sea turtle in tuna and swordfish fisheries is currently recognized as one of the major threats to the populations of these species. Therefore a number of mitigation measures have been tested, particularly for longline fisheries targeting swordfish. As mitigation measures may also affect the fish catches, it is important to quantify these impacts both at the ecological and socio-economic levels. Between August 2008 and December 2011, a total of 202 experimental pelagic longline sets were carried out in the Tropical Northeast Atlantic Ocean. The combination J-hook baited with squid (traditionally used by the fishery) was compared against two circle hooks (one non-offset and one with 100 offset) and mackerel bait. Catches per unit effort (CPUE) were calculated and compared between the different hook style and bait combinations for all target, bycatch and discarded fish species. In addition, a GLM (generalized linear model) was applied for swordfish Xiphias gladius and blue shark Prionace glauca (two main target species) and bigeye thresher Alopias superciliosus (most discarded species). The swordfish catches were negatively affected when changing from the traditional gear (J-style hooks baited with squid) to one of the experimental combinations, with the bait type having a stronger influence than the hook style on this reduction. However, the overall target species CPUE and the value of the retained catch (VPUE, value per unit of effort) were not significantly affected, due to an increase on the blue shark CPUE. Furthermore, the hook style and the bait type did not seem to influence the at-haulback mortality rates of most discarded species, which were highly species-specific. Given the apparent lack of impact on the overall value of the retained catch, the use of circle hooks baited with mackerel on this particular fishery and region would be highly beneficial for sea turtle conservation, without affecting the economic viability of the fishery.

Folkins, M. H., Grant, S. M., & Walsh, P. (2021). A feasibility study to determine the use of baited pots in Greenland halibut (Reinhardtius hippoglossoides) fisheries, supported by the use of underwater video observations. *PeerJ,* 9, e10536. https://doi.org/10.7717/peerj.10536

High incidental catches of Greenland shark (Somniosus microcephalus) in Nunavut's Greenland halibut (Reinhardtius hippoglossoides) fishery has led to studies on the feasibility of capturing Greenland halibut

with baited pots. In this study, catch rates among six experimental pots are compared. In addition to this, underwater video observations of Greenland halibut interacting with two of these experimental pot types are quantified in order to help provide recommendations on future pot designs. Catch rates of Greenland halibut differed among pots with different entrance mesh types, and none of the pots produced substantial amounts of bycatch. Strings of pots were deployed within a narrow corridor between baited gillnets targeting Greenland halibut, which may have affected catch results. Video observations revealed Greenland halibut entangled by their teeth significantly more often in entrance funnels constructed with 50 mm than with 19 mm clear monofilament netting and the entrance rate was 45% higher with the 19 mm netting. Greenland halibut that successfully entered a pot repeatedly became entangled by their teeth in 58 mm netting used in the side and end panels and in a horizontal panel used to separate the pot into a lower and upper chamber. The majority (80%) of Greenland halibut were observed to approach a pot against the current. The downstream entrance was aligned with the current in 52% of the observed Greenland halibut approaches. Seventy percent of entry attempts and 67% of successful entries occurred when fish approached against the current and when the entrance was aligned with the current. These observations lead to recommendations that future studies consider developing a four entrance pot to ensure an entrance is always aligned with bottom currents. Based on these observations of entanglements, it is recommended to use 19 mm clear monofilament netting in the entrance funnel, 100 mm polyethylene netting in the exterior panels, and 19 mm polypropylene netting in the horizontal panel when targeting Greenland halibut. Three Greenland sharks were observed interacting with the pots in the video sets, but none were captured or damaged the pots during the potting experiments, providing validity to the use of pots to mitigate the capture of Greenland shark in Nunavut territorial waters.

Foster, D. G., Epperly, S. P., Shah, A. K., & Watson, J. W. (2012). Evaluation Of Hook And Bait Type On The Catch Rates In The Western North Atlantic Ocean Pelagic Longline Fishery. *Bulletin of Marine Science,* 88(3), 529-545. https://doi.org/10.5343/bms.2011.1081

Research was conducted in 2002 and 2003 by NOAA's National Marine Fisheries Service, Southeast Fisheries Science Center, to investigate changes in hook design and bait type to reduce the bycatch of sea turtles on pelagic longlines in the western North Atlantic Ocean. The effectiveness of 18/0-20/0 circle hooks and 10/0 Japanese tuna hooks with squid (Illex spp.) and mackerel bait (Scomber scombrus Linnaeus, 1758) was evaluated against the industry standard 9/0 J-hooks with squid bait with respect to reducing sea turtle and shark interactions while maintaining swordfish (Xiphias gladius Linnaeus, 1758) and tuna (Thunnus spp.) catch rates. In total, 973,734 hooks were deployed during the study. Individually, circle hooks and mackerel bait significantly reduced both loggerhead [Caretta caretta (Linnaeus, 1758)] and leatherback [Dermochelys coriacea (Vandelli, 1761)] sea turtle bycatch. The combination of 18/0 circle hooks with mackerel bait was even more effective for loggerhead sea turtles and had a significant increase in swordfish catch by weight. The combination 18/0 circle hooks with squid bait resulted in a significant decrease in the swordfish catch and a significant increase in the catch rate of blue shark [Prionace glauca (Linnaeus, 1758)], bluefin tuna [Thunnus thynnus (Linnaeus, 1758)1, and albacore tuna [Thunnus alalunga (Bonnaterre, 1788)]. With all hook types, mackerel bait resulted in a significant decrease in blue shark, bigeye tuna [Thunnus obesus (Lowe, 1839)], and albacore tuna, but significantly increased the catch of porbeagle [Lamna nasus (Bonnaterre, 1788)] and shortfin mako (Isurus oxyrinchus Rafinesque, 1810).

Foster, D. G., Pulver, J. R., Scott-Denton, E., & Bergmann, C. (2017). Minimizing bycatch and improving efficiency in the commercial bottom longline fishery in the Eastern Gulf of Mexico. *Fisheries Research,* 196, 117-125. https://doi.org/10.1016/j.fishres.2017.08.007

We investigated the effects of hook soak time on targeted reef species and shark bycatch in the reef fish bottom longline fishery in the Gulf of Mexico. Beginning in 2010, capture time and catch per unit effort (CPUE) for the primary target species red grouper (Epinephelus mono) in the fishery were evaluated using hook timers. Findings indicated that typical duration of hook soak times is longer than necessary to efficiently harvest red grouper and a reduction in gear soak times to less than one hour would result in minimal or no reduction in red grouper CPUE. The mean capture time of sharks and red grouper differed significantly, suggesting that a reduction in soak time would likely reduce the bycatch of sharks in the fishery. The study also revealed barometric pressure, lunar phase, and fish size were significant covariates with red grouper capture times and that different bait types significantly affected CPUE. Implementing shorter hook soak times would likely improve fishery profitability and potentially reduce discards of unwanted species in the fishery.

François, P., Sidonie, C., Caroline, C., & Jean-Marc, G. (2019). The effect of hook type and trailing gear on hook shedding and fate of pelagic stingray (Pteroplatytrygon violacea): New insights to develop effective mitigation approaches. *Marine Policy,* 107, 103594. https://doi.org/10.1016/j.marpol.2019.103594

The pelagic stingray (Pteroplatytrygon violacea) in the French Atlantic bluefin tuna makes up almost half of the catch in numbers, ranking first of the five major species caught. Given the high levels of catches, more attention was given to the impact of this fishery in order to avoid future conservation issues. The effects of the hook shape (circle versus J-type hooks) and trailing gear on hook retention has been investigated on 10 individuals kept in captivity during 125 days. Experiments showed that the J-type hook used commonly by fishers had a fast self-shedding rate which will allow for a quick resumption of feeding and minimal injury which means quicker wound healing and better chance for survival. J-type hooks were all expelled within 6 days while circle hook shedding rates were much longer, taking 44.5 ± 54.4 days (mean ± SD). The mechanism of expulsion of the hook has been clearly described and the impact of the trailing line assessed. Appropriate handling practices maximizing the crew safety and the post-release survival were identified. Other effective mitigation approaches for the fishery are proposed and discussed.

Gamblin, C., Pascal, B., & Lucas, V. (2007). *Comparison of bycatch species captured during daytime and nightime: preliminarily results of longline experiments carried out in Seychelles waters.* IOTC-2007-WPEB-16. Indian Ocean Tuna Commission, Retrieved from https://www.fao.org/3/bj094e/bj094e.pdf

Bycatch and mitigation measures are a keystone issue to assure a sustainable use of marine resources. Many studies focus on gear configuration and not on fishing strategy when fish habitat is a major question in term of gear selectivity. The objective of this study is to compare bycatch that occurred during night sets and day sets. For that purpose, 69 fishing experiments using an instrumented longline (hook timer, temperature depth recorder) were carried out in Seychelles waters from December 2004 to May 2006 on board small scale research longliner. Two types of sets were done: some during night (setting at dusk and hauling at dawn) with shallow basket to principally target swordfish and some

during day (inverse cycle of night set) with shallow and deep basket to target tuna. Each time, bycatch species were identified (species, basket and hook number) and the depth of capture calculated. Results show difference between the two strategies in terms of species composition, quantity, and depth of catch. Day sets induce more bycatch than night sets.

Gassman, J., Laurent, C., & Marcano, J. H. (2015). Ejecución Del Programa Nacional De Observadores A Bordo De La Flota Industrial Atunera Venezolana Del Mar Caribe Y Océano Atlántico Año 2013*. *Collective volume of scientific papers,* 71(6), 3117-3129. Retrieved from https://www.fao.org/fishery/en/openasfa/d5ffd086-117f-472f-8b16-3b77969a82f8

While the INSOPESCA began to implement the National Programme of Onboard Observers from 2011, the first deployments on vessels occurred in 2012. The purpose of the programme, which is aimed at the Venezuelan industrial fishing float operating in the Caribbean Sea and Atlantic Ocean, is to collect information so as to control and establish policies and regulations which ensure sustainable use of fishing resources. The fishing fleets that monitor this programme focus on catches of tropical tunas and other highly migratory bycatch species including billfish and sharks, in which different fishing gears are used such as purse seines, longlines, rods and lines. In 2013, under the programme, 31 fishing trips took place with a total of 812 days onboard, representing a total overall coverage of 6.44% of the total fishing trips and 6.61% of the total number of days at sea. Of them, 21 were longline vessels which recorded a total of 250 sets in which 200,810 hooks were used and a total of 3,759 individuals were caught; the tuna group were the most representative with 2,227 specimens (59.24%), followed by the billfish group with 841 individuals (22.37%), 396 other fish (10.53%), 187 stingrays (4.97%), 75 sharks (1.99%) and 33 specimens of swordfish (0.87%). 4 vessels of the purse seine fleet were boarded on which 133 sets were recorded, 102 (76.69%) of which were positive sets (there was catch). The estimated catch of the purse seine fleet monitored was dominated almost entirely by the tuna group (99.73%), among which yellowfin tuna (YFT) and skipjack (SKJ) were the most representative with 425.39 t (58.55%) and 241.21 t (33.21%), respectively. 6 vessels of the baitboat fleet were boarded in which a total of 226 sets were observed involving 5,230 hooks, and a total catch of 21,851 individuals, among which the most significant species were skipjack (SKJ) with 12,083 specimens (55.29%), followed by yellowfin tuna (YFT) with 9,470 individuals (43.34%), blackfin tuna (BLF) with 225 individuals (1.16%) and frigate tuna (FRI) with 23 individuals (0.1%). In each of these trips, information was collected on catches, effort, discards, bycatches of mammals and sea turtles, fishing areas, as well as distribution and biological information of the different species caught, among other aspects.

Gilman, E., Chaloupka, M., Bach, P., Fennell, H., Hall, M., Musyl, M., . . . Song, L. (2020). Effect of pelagic longline bait type on species selectivity: a global synthesis of evidence. *Reviews in Fish Biology and Fisheries,* 30(3), 535-551. https://doi.org/10.1007/s11160-020-09612-0

Fisheries can profoundly affect bycatch species with 'slow' life history traits. Managing bait type offers one tool to control species selectivity. Different species and sizes of marine predators have different prey, and hence bait, preferences. This preference is a function of a bait's chemical, visual, acoustic and textural characteristics and size, and for seabirds the effect on hook sink rate is also important. We conducted a global meta-analysis of existing estimates of the relative risk of capture on different pelagic longline baits. We applied a Bayesian random effects meta-analytic regression modelling approach to estimate overall expected bait-specific catch rates. For blue shark and marine turtles, there were 34% (95% HDI: 4-59%) and 60% (95% HDI: 44-76%) significantly lower relative risks of capture on forage fish

bait than squid bait, respectively. Overall estimates of bait-specific relative risk were not significantly different for seven other assessed taxa. The lack of a significant overall estimate of relative capture risk for pelagic shark species combined but significant effect for blue sharks suggests there is species-specific variability in bait-specific catch risk within this group. A qualitative literature review suggests that tunas and istiophorid billfishes may have higher catch rates on squid than fish bait, which conflicts with reducing marine turtle and blue shark catch rates. The findings from this synthesis of quantitative and qualitative evidence support identifying economically viable bycatch management measures with acceptable tradeoffs when multispecies conflicts are unavoidable, and highlight research priorities for global pelagic longline fisheries.

Gilman, E., Chaloupka, M., Merrifield, M., Malsol, N. D., & Cook, C. (2016). Standardized catch and survival rates, and effect of a ban on shark retention, Palau pelagic longline fishery. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 26(6), 1031-1062. https://doi.org/10.1002/aqc.2599

1. Pelagic longline fisheries affect both market and vulnerable bycatch species and can have broad effects on community structure and processes. 2. Observer data from the Palau longline fishery were analysed to identify opportunities to mitigate vulnerable species bycatch, determine temporal trends in local abundance, and assess changes following a ban on shark retention and wire leaders. Catch and haulback condition data for bigeye and yellowfin tunas, blue and silky sharks and pelagic stingrays were fitted to standardized catch and survival rate models. 3. The fishery caught silky and blue sharks, olive ridley sea turtles and other species of conservation concern. 4. Changing from shallow sets to deep daytime sets might reduce shark and sea turtle catch rates but increase turtle haulback mortality rates, maintain economically viable tuna catch rates, but increase catch rates of pelagic stingrays, a lower conservation concern than main caught species of sharks and turtles. 5. Focusing fishing effort during the middle of the calendar year would maximize yellowfin tuna and minimize silky shark standardized catch rates, but maximize blue shark catch rates. 6. A large decline in shark fishing mortality rate very likely occurred following a ban on shark retention and wire leaders. This was due to large reductions in the nominal shark catch rate and shark retention, partially offset by decreases in the shark haulback survival rate and pre-catch survival rate. Significantly higher blue shark and lower pelagic stingray nominal catch rates occurred on wire vs. monofilament leaders. Significantly higher blue shark and lower yellowfin tuna nominal catch rates occurred on sets using shallow 'shark lines'. It is a research priority to compare the probability of shark pre-catch survival after escaping from monofilament leaders with an ingested hook and trailing line to the survival probability when captured on wire leaders.

Gilman, E., Chaloupka, M., & Musyl, M. (2018). Effects of pelagic longline hook size on species- and size-selectivity and survival. *Reviews in Fish Biology and Fisheries,* 28(2), 417-433. https://doi.org/10.1007/s11160-017-9509-7

Pelagic fisheries can have profound effects on ecosystem structure and functioning, affecting ecosystem services, including fisheries production, and threaten vulnerable bycatch species. Controlling hook size could manage the species- and size-selectivity and survival of target and incidental catch. To test this hypothesis, we conducted experimental pelagic longline fishing in the western tropical Pacific testing a control hook and two hooks with wider minimum widths. Data such as catch, length and condition were fit to response-specific Bayesian geo-additive generalized additive and linear mixed regression models. Model fits were assessed using posterior predictive check tests. Catch rates of both retained and

discarded species were significantly higher on medium hooks. Target tuna species were significantly larger and had significantly higher at-vessel survival rates on wider hooks. Significantly larger billfishes, also market species, were caught on narrowest hooks. These effects of hook width on length and survival, however, are a much smaller determinant of economic value of the catch than effects on catch rates. If input controls are limiting, then, relative to medium hooks, continued use of narrowest hooks would maintain current economic viability without causing a significant increase in discard catch levels, including of vulnerable sharks. If market species output controls are limiting, because the ratio of retained to discarded catch on medium hooks was greater than on narrowest hooks, medium hooks would generate lower discard levels. Further research assessing single-factor effects of longline hook width is needed to support robust meta-analyses that account for fishery-specific effects.

Gilman, E., Chaloupka, M., Read, A., Dalzell, P., Holetschek, J., & Curtice, C. (2012). Hawaii longline tuna fishery temporal trends in standardized catch rates and length distributions and effects on pelagic and seamount ecosystems. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 22(4), 446-488. https://doi.org/10.1002/aqc.2237

Declines in absolute abundance and altered size distributions from size-selective removals of market species of pelagic apex predators in tuna fisheries alters evolutionary characteristics of populations and ecosystem processes and stability. Pelagic fishing at seamounts, where hyperstability of pelagic predators may occur, can exacerbate declining abundance and have high bycatch of species groups that are highly vulnerable to overexploitation. Generalized additive mixed Poisson regression models (GAMMs) were fitted to Hawaii longline tuna fishery observer data to determine temporal trends in standardized catch rates, an index for local, relative abundance. Temporal trends in expectile length distributions were determined through geoadditive expectile GAMMs. Significant declining trends in relative abundance in this fishery were observed for tunas, sharks and billfish. A decline in seabird standardized catch rate occurred concurrently with the uptake of seabird bycatch mitigation technology. Changed spatial distribution of fishing effort and increased use of wider circle hooks likely contributed to a declining sea turtle standardized catch rate. Tuna and billfish mean lengths significantly increased over the time series due to entire distributions of length classes having shifted towards larger fish. Larger tunas comprised a larger proportion of the catch due to fewer small tunas being caught, and to a lesser extent because mean lengths of larger size classes increased. Conversely, billfish largest length classes experienced the largest increases in average lengths. Changes in spatial and seasonal distributions of fishing effort, increased use of wider circle hooks, and possibly increasing purse seine selective removals of juvenile tunas, may have contributed to increased selectivity for larger fish. Significant differences in standardized catch rates and length distributions at a shallow seamount vs. the open ocean confirms the aggregating effect of seamounts on pelagic predators, including juvenile market species of pelagic fish and species groups relatively vulnerable to overexploitation. Wider circle hooks significantly improved valuable tuna standardized catch rates, but also increased unwanted shark and reduced valuable billfish standardized catch rates.

Gilman, E., Chaloupka, M., Swimmer, Y., & Piovano, S. (2016). A cross-taxa assessment of pelagic longline by-catch mitigation measures: conflicts and mutual benefits to elasmobranchs. *Fish and Fisheries,* 17(3), 748-784. https://doi.org/10.1111/faf.12143

Elasmobranch mortality in pelagic longline fisheries poses a risk to some populations, alters the distribution of abundance between sympatric competitors, changing ecosystem structure, processes

and stability. Individual and synergistic effects on elasmobranch catch and survival from pelagic longline gear factors, including methods prescribed to mitigate bycatch of other vulnerable taxa, were determined. Overall relative risk of higher circle vs. J-shaped hook shark catch rates conditioned on potentially informative moderators, from 30 studies, was estimated using an inverse-precision weighted mixed-effects meta-regression modelling approach. Sharks had a 1.20 times (95% CI: 1.03-1.39) significantly higher pooled relative risk of capture on circle hooks, with two significant moderators. The pooled relative risk estimate of ray circle hook catch from 15 studies was not significant (RR=1.22, 95% CI: 0.89-1.66) with no significant moderators. From a literature review, wire leaders had higher shark catch and haulback mortality than monofilament. Interacting effects of hook, bait and leader affect shark catch rates: hook shape and width and bait type determine hooking position and ability to sever monofilament leaders. Circle hooks increased elasmobranch catch, but reduced haulback mortality and deep hooking relative to J-shaped hooks of the same or narrower width. Using fish vs. squid for bait increased shark catch and deep hooking. Pelagic stingray (Pteroplatytrygon violacea) catch and mortality were lower on wider hooks. Using circle instead of J-shaped hooks and fish instead of squid for bait, while benefitting sea turtles, odontocetes and possibly seabirds, exacerbates elasmobranch catch and injury, therefore warranting fishery-specific assessments to determine relative risks.

Gilman, E., Dalzell, P., Goren, M., Werner, T. B., Clarke, S., Alfaro-Shigueto, J., . . . Thomson, N. (2007). *Shark Depredation and Unwanted Bycatch in Pelagic Longline Fisheries: Industry Practices and Attitudes, and Shark Avoidance Strategies.* Western Pacific Regional Fishery Management Council, Retrieved from https://wedocs.unep.org/20.500.11822/13627

Substantial ecological, economic and social problems result from shark interactions in pelagic longline fisheries. Improved understanding of industry attitudes and practices towards shark interactions assists with managing these problems. Information on fisher knowledge and new strategies for shark avoidance may benefit sharks and fishers. A study of 12 pelagic longline fisheries from eight countries shows that incentives to avoid sharks vary along a continuum, based on whether sharks represent an economic disadvantage or advantage. Shark avoidance practices are limited, including avoiding certain areas, moving when shark interaction rates are high, using fish instead of squid for bait and deeper setting. Some conventionally employed fishing gear and methods used to target non-shark species contribute to shark avoidance. Shark repellents hold promise; more research and development is needed. Development of specifically designed equipment to discard sharks could improve shark post release survival prospects, reduce gear loss and improve crew safety. With expanding exploitation of sharks for fins and meat, improved data collection, monitoring and precautionary shark management measures are needed to ensure shark fishing mortality levels are sustainable.

Gilman, E., & Lundin, C. (2010). Minimising bycatch of sensitive species groups in marine capture fisheries: lessons from tuna fisheries. In *Handbook of Marine Fisheries Conservation and Management.* Q. Grafton, R. Hillborn, D. Squires, M. Tait, & M. Williams (Eds.), (pp. 23): Oxford University Press. Retrieved from http://ecite.utas.edu.au/58808

Bycatch in marine capture fisheries is the retained catch of nontargeted but commercially viable species (referred to as “incidental catch”) plus all discards (Food and Agriculture Organization of the United Nations [FAO] 2005).1 It is an increasingly prominent international issue, raising ecological concerns, as some bycatch species of cetaceans (whales, dolphins, and porpoises), seabirds, sea turtles, elasmobranchs (sharks, skates, and rays), and other fi sh species are particularly vulnerable to

overexploitation and slow to recover from large population declines (FAO 1999a, 1999b, in press; Fowler et al. 2005; Gales 1998; Gilman et al. 2005, 2006a, 2006c, 2008; Lutz and Musick 1997). Bycatch can alter biodiversity and ecosystem functions by removing top predators and prey species at unsustainable levels (Myers et al. 2007). It also alters foraging behavior of species that learn to take advantage of discards. Economic effects of bycatch on fi sheries include loss of bait, reduced availability of baited hooks when they are occupied with unwanted bycatch species, and concomitant reduced catch of marketable species; the imposition of a range of restrictions, closed areas, embargos, and possible closures; allocation among fi sheries, where bycatch in one fi shery reduces target catch in another, and bycatch of juvenile and undersized individuals of a commercial species can adversely affect future catch levels (Brothers et al. 1999; Hall et al. 2000). Discarded bycatch raises a social issue over waste: From 1992 to 2001 an average of 7.3 million metric tons of fi sh were annually discarded, representing 8 percent of the world catch (FAO 2005). Prominent bycatch issues include dolphins and porpoises in purse seine fi sheries and driftnets; fi sh discards in shrimp trawl fi sheries; and seabird, sea turtle, marine mammal, and shark bycatch in longline, purse seine, gillnet, and trawl fi sheries (FAO 1999a, 1999b, 2005, in press; Hall et al. 2000). In commercial tuna fi sheries, the incidental bycatch of sensitive species groups (seabirds, sea turtles, marine mammals, and sharks) and bycatch of juvenile and undersized tunas are allocation and conservation issues. In addition to problematic bycatch, overexploitation and illegal, unreported, and unregulated (IUU) fi shing, which complicates bycatch management, are additional conservation issues facing the management of tuna fi sheries. This chapter employs examples of bycatch in commercial tuna fi sheries to describe (1) the range of options to reduce bycatch, (2) principles and approaches to successfully introduce effective bycatch reduction measures, and (3) initiatives taken by intergovernmental organizations, the fi shing industry, and retailers to address bycatch. Changes needed to improve the sustainability of tuna production are recommended.

Gilman, E. L. (2011). Bycatch governance and best practice mitigation technology in global tuna fisheries. *Marine Policy,* 35(5), 590-609. https://doi.org/10.1016/j.marpol.2011.01.021

Overexploitation of bycatch and target species in marine capture fisheries is the most widespread and direct driver of change and loss of global marine biodiversity. Bycatch in purse seine and pelagic longline tuna fisheries, the two primary gear types for catching tunas, is a primary mortality source of some populations of seabirds, sea turtles, marine mammals and sharks. Bycatch of juvenile tunas and unmarketable species and sizes of other fish in purse seine fisheries, and juvenile swordfish in longline fisheries, contributes to the overexploitation of some stocks, and is an allocation issue. There has been substantial progress in identifying gear technology solutions to seabird and sea turtle bycatch on longlines and to direct dolphin mortality in purse seines. Given sufficient investment, gear technology solutions are probably feasible for the remaining bycatch problems. More comprehensive consideration across species groups is needed to identify conflicts as well as mutual benefits from mitigation methods. Fishery-specific bycatch assessments are necessary to determine the efficacy, economic viability, practicality and safety of alternative mitigation methods. While support for gear technology research and development has generally been strong, political will to achieve broad uptake of best practices has been lacking. The five Regional Fisheries Management Organizations have achieved mixed progress mitigating bycatch. Large gaps remain in both knowledge of ecological risks and governance of bycatch. Most binding conservation and management measures fall short of gear technology best practice. A lack of performance standards, in combination with an inadequate observer coverage for all but large Pacific purse seiners, and incomplete data collection, hinders assessing measures' efficacy. Compliance is probably low due to inadequate surveillance and enforcement. Illegal, unreported and unregulated tuna

fishing hampers governance efforts. Replacing consensus-based decision-making and eliminating opt-out provisions would help. Instituting rights-based management measures could elicit improved bycatch mitigation practices. While gradual improvements in an international governance of bycatch can be expected, market-based mechanisms, including retailers and their suppliers working with fisheries to gradually improve practices and governance, promise to be expeditious and effective.

Godin, A. C., Carlson, J. K., & Burgener, V. (2012). The Effect Of Circle Hooks On Shark Catchability And At-Vessel Mortality Rates In Longlines Fisheries. *Bulletin of Marine Science,* 88(3), 469-483. https://doi.org/10.5343/bms.2011.1054

Circle hooks have gained recent attention as a cost-effective bycatch mitigation tool in pelagic longline fisheries, particularly for marine turtles. Over the last few years, a growing number of studies have investigated the use of circle hooks and their effects on other species, including elasmobranchs. To elucidate the potential value of circle hook use as a tool for shark conservation and management in pelagic longline fisheries, we conducted a quantitative review of all available studies to date. We compiled 15 published and eight gray literature studies and where possible used random effects meta-analysis and analysis of covariance to test the effects of circle hooks on catchability and at-vessel mortality rates. Overall, results suggest that using circle hooks on pelagic longlines do not have a major effect on shark catch rates, but do reduce at-vessel mortality compared to J-hooks. Thus circle hooks should be seen as one potential tool to help reduce bycatch mortality of sharks in longline fisheries. However, the high level of heterogeneity found between studies highlights the need for shark-specific controlled experiments to provide more definitive results.

Godin, A. C., Wimmer, T., Wang, J. H., & Worm, B. (2013). No effect from rare-earth metal deterrent on shark bycatch in a commercial pelagic longline trial. *Fisheries Research,* 143, 131-135. https://doi.org/10.1016/j.fishres.2013.01.020

The indiscriminate capture of non-target organisms (bycatch) in commercial fisheries undermines the sustainable development of marine resources. In the Northwest Atlantic, blue sharks (Prionace glauca) account for most of the bycatch in the Canadian pelagic longline swordfish fishery. Minimizing the capture of this species is of interest to conservationists as well as the fishing industry because the high incidence of shark bycatch negatively affects fishing operations through bait loss and increased handling time. Electropositive metals (e.g., lanthanide) oxidize in seawater and create electric fields, which can alter the swimming and feeding behaviors of several species of sharks. Although electropositive metals appear to have the potential to reduce shark bycatch in pelagic longline fisheries, there have not been any controlled trials reported from a commercial fishery. A total of 7 sets (6300 hooks) with 3 hook treatments (standard hooks, hooks with electropositive metals (neodymium/praseodymium), and hooks with lead weights) were deployed in 2011 on the Scotian Shelf in the Northwest Atlantic. The results of this study show that electropositive metals did not reduce the catch of blue sharks or other common shark bycatch species, and hence do not present a practical bycatch mitigation measure for the Canadian longline fishery.

Graham, J., Kroetz, A. M., Poulakis, G. R., Scharer, R. M., Carlson, J. K., Lowerre-Barbieri, S. K., . . . Grubbs, R. D. (2022). Commercial fishery bycatch risk for large juvenile and adult smalltooth sawfish (Pristis pectinata) in Florida waters. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 32(3), 401-416. https://doi.org/10.1002/aqc.3777

Incidental catch of marine species can create ecological and economic issues, particularly for endangered species. The smalltooth sawfish (Pristis pectinata) is endemic to the Atlantic Ocean and listed as Endangered in the US Endangered Species Act. One of its major threats is bycatch mortality in commercial fisheries. Despite the protection afforded by the US Endangered Species Act, smalltooth sawfish are still captured as bycatch in commercial fisheries. Acoustic and satellite tag data collected on 59 sawfish between 2011 and 2019 were analysed to assess commercial fishery bycatch risk for large juveniles and adults off Florida. This study focused on shrimp trawl, south-east coastal gillnet, and shark bottom longline fisheries, as these were identified in the recovery plan as having the greatest potential threats to recovery. Bycatch risk associated with the shrimp trawl fishery was significantly higher than the other fisheries, indicating that this fishery currently poses the greatest threat to recovery. Bycatch risk was concentrated in all seasons in the Gulf of Mexico adjacent to the lower Florida Keys for the shrimp trawl fishery, off Cape Canaveral in the south-east coastal gillnet fishery, and in the Atlantic Ocean adjacent to the Florida Keys in the shark bottom longline fishery. Tagging location and sex were predictors of bycatch risk. Individuals tagged in Charlotte Harbor had the highest shrimp trawl bycatch risk. Females tagged in south Florida tended to reside in the deepest water, which is where shrimp trawl effort is highest. Therefore, females may be at more risk in these deeper waters. Results from this study indicate a year-round closure of waters off south-west Florida to the shrimp trawl fishery between Charlotte Harbor and the western Florida Keys would reduce sawfish bycatch, and thus mortality, which is in line with recovery plan goals.

Grant, S. M., Munden, J. G., & Hedges, K. J. (2020). Effects of monofilament nylon versus braided multifilament nylon gangions on catch rates of Greenland shark (Somniosus microcephalus) in bottom set longlines. *PeerJ,* 8, e10407. https://doi.org/10.7717/peerj.10407

The Greenland shark (Somniosus microcephalus) is the main bycatch species in established and exploratory inshore longline fisheries for Greenland halibut (Reinhardtius hippoglossoides) on the east coast of Baffin Island, Canada. Bycatch and entanglement in longline gear has at times been substantial and post-release survival is questionable when Greenland sharks are released with trailing fishing gear. This study investigated the effect of the type of fishing line used in the gangion and gangion breaking strength on catch rates of Greenland shark and Greenland halibut in bottom set longlines. Circle (size 14/0, 0 degrees offset) hooks were used throughout the study. Behavior of captured sharks, mode of capture (i.e., jaw hook and/or entanglement), level of entanglement in longline gear, time required to disentangle sharks and biological information (sex, body length and health status) were recorded. Catch rates of Greenland shark were independent of monofilament nylon gangion breaking strength and monofilament gangions captured significantly fewer Greenland sharks than the traditional braided multifilament nylon gangion. Catch rates and body size of Greenland halibut did not differ significantly between gangion treatments. Although most (84%) of the Greenland sharks were hooked by the jaw, a high percentage (76%) were entangled in the mainline. The mean length of mainline entangled around the body and/or caudal peduncle and caudal fin was 28.7 m. Greenland sharks exhibited cannibalistic behavior with 15% of captured sharks cannibalized. All remaining sharks were alive and survived the disentanglement process which can be attributed to their lethargic behavior and lack of resistance when hauled to the surface. Thus, as a conservation measure fishers should be encouraged to remove trailing

fishing gear prior to release. Our results are used to demonstrate benefits to the fishing industry with regard to an overall reduction in the period of time to disentangle sharks and damage to fishing gear by switching from braided multifilament to monofilament gangions in Greenland halibut longline fisheries.

Grant, S. M., Sullivan, R., & Hedges, K. J. (2018). Greenland shark (Somniosus microcephalus) feeding behavior on static fishing gear, effect of SMART (Selective Magnetic and Repellent-Treated) hook deterrent technology, and factors influencing entanglement in bottom longlines. *PeerJ,* 6, e4751. https://doi.org/10.7717/peerj.4751

The Greenland Shark (Somniosus microcephalus) is the most common bycatch in the Greenland halibut (Reinhardtius hippoglossoides) bottom longline fishery in Cumberland Sound, Canada. Historically, this inshore fishery has been prosecuted through the ice during winter but winter storms and unpredictable landfast ice conditions since the mid-1990s have led to interest in developing a summer fishery during the ice-free season. However, bycatch of Greenland shark was found to increase substantially with 570 sharks captured during an experimental Greenland halibut summer fishery (i.e., mean of 6.3 sharks per 1,000 hooks set) and mortality was reported to be about 50% due in part to fishers killing sharks that were severely entangled in longline gear. This study investigated whether the SMART (Selective Magnetic and Repellent-Treated) hook technology is a practical deterrent to Greenland shark predation and subsequent bycatch on bottom longlines. Greenland shark feeding behavior, feeding kinematics, and variables affecting entanglement/ disentanglement and release are also described. The SMART hook failed to deter Greenland shark predation, i.e., all sharks were captured on SMART hooks, some with more than one SMART hook in their jaw. Moreover, recently captured Greenland sharks did not exhibit a behavioral response to SMART hooks. In situ observations of Greenland shark feeding show that this species uses a powerful inertial suction mode of feeding and was able to draw bait into the mouth from a distance of 25-35 cm. This method of feeding is suggested to negate the potential deterrent effects of electropositive metal and magnetic alloy substitutions to the SMART hook technology. The number of hooks entangled by a Greenland shark and time to disentangle and live-release a shark was found to increase with body length.

Grantham, H. S., Petersen, S. L., & Possingham, H. P. (2008). Reducing bycatch in the South African pelagic longline fishery: the utility of different approaches to fisheries closures. *Endangered Species Research,* 5, 291-299. https://doi.org/10.3354/esr00159

Seabirds, turtles and sharks are often of conservation concern because they are frequently bycatch in fisheries. Fisheries managers shifting from a target species focus to an ecosystem-based approach are being required to consider the impact of fisheries on non-target species. There are a range of complementary management tools that help reduce bycatch, such as gear restrictions, temporal restrictions, and bycatch reduction devices. One management approach that is increasingly being considered is fisheries closures. We tested the utility of 3 closure approaches for the improved protection of bycatch species in the South African pelagic longline fishery. As there was some variation where and when different groups of bycatch species were caught, we found that temporary spatial closures were the most effective strategy for both protecting bycatch and minimizing the cost to fishers. This is logical because having mobile closures in space and time provides more flexibility than permanent spatial closures or seasonal closures. However these benefits need to be traded off against the costs and problems of implementing temporary spatial closures. Of the 2 sub-optimal strategies, we discovered that seasonal closures are significantly less effective than spatial closures.

Gulak, S. J. B., & Carlson, J. K. (2021). Less Soak Time Saves Those upon the Line: Capture Times and Hooking Mortality of Sharks Caught on Bottom Longlines. *North American Journal of Fisheries Management,* 41(3), 791-808. https://doi.org/10.1002/nafm.10592

The National Marine Fisheries Service is mandated by the Magnuson-Stevens Fishery Conservation and Management Act to implement effective annual catch limits and accountability measures to prevent overfishing. These requirements compel further research into alternative fishing practices that could reduce mortality of sharks (class Chondrichthyes) and allow fishers to release unwanted sharks to the water alive, while still effectively catching targeted species. We used hook timers and temperature-depth recorders aboard contracted vessels and participants in the National Marine Fisheries Service?s Shark Research Fishery to collect hooking time and time-on-the-line data for 10 species of sharks that were commonly encountered in the fishery. A subset of standardized fishing sets compared the most popular circle hook and J-hook models. Over 60% of sharks were hooked within 4 h of hook soak time. The fastest to bite the hook was the Atlantic Sharpnose Shark Rhizoprionodon terraenovae and the slowest was the Dusky Shark Carcharhinus obscurus. Shark resilience to time on the longline varied among species, with Sandbar Shark C. plumbeus exhibiting the most resilience and Atlantic Sharpnose Shark the least. Shorter set soak times, approximately 2 h, would still maximize catch, while minimizing at-vessel mortality. The most frequently used circle hook model did not significantly reduce at-vessel mortality over large J-style hooks. The recent circle hook requirement will have little effect for fishers that previously used 12/0 J-hooks, but it may be beneficial by preventing the use of smaller J-hooks that are more likely to cause at-vessel mortality.

Gulak, S. J. B., Santiago, A. J. d. R., & Carlson, J. K. (2015). Hooking mortality of scalloped hammerhead Sphyrna lewini and great hammerhead Sphyrna mokarran sharks caught on bottom longlines. *African Journal of Marine Science,* 37(2), 267-273. https://doi.org/10.2989/1814232x.2015.1026842

The scalloped hammerhead Sphyrna lewini and the great hammerhead S. mokarran are typically caught as bycatch in a variety of fisheries and are listed as globally Endangered by the International Union for the Conservation of Nature. Due to very high at-vessel mortality for these species, research is needed on fishing methods to reduce mortality for longline-captured sharks. A series of fishing experiments were conducted employing hook timers and temperature-depth recorders on contracted commercial vessels fishing with bottom-longline gear to assess factors related to mortality. A total of 273 sets were deployed with 54 485 hook timers. Scalloped and great hammerheads had at-vessel mortality rates of 62.9% and 56.0%, respectively. Median hooking times for scalloped and great hammerheads were 3.5 h and 3.4 h, respectively, and 50% mortality was predicted at 3.5 h and 3.8 h. When these data are considered for potential management strategies to reduce the mortality of hammerhead sharks, a limitation on gear soak time would probably improve hammerhead shark survivorship. However, it may prove to be difficult for a fishery to remain economically viable if the soak time is limited to less than the median hooking time for the target species. Additional management options, such as time/area closures, may need to be explored to reduce bycatch mortality of scalloped and great hammerheads.

Howard, S. (2015). *Mitigation options for shark bycatch in longline fisheries*.(New Zealand Aquatic Environment and Biodiversity Report No. 148). Ministry for Primary Industries, New Zealand Retrieved from https://www.bmis-bycatch.org/references/sw9bq7hj

A systematic review of literature addressing methods of reducing shark catch rates on longline fishing gear was conducted using academic publication databases and the Ministry for Primary Industries' publications database. Gear technology as well as operational and environmental variables were evaluated as potential elasmobranch bycatch reduction methods for use in New Zealand commercial longline fisheries. Twenty candidate shark bycatch reduction methods were identified. The criteria used to assess these methods were weighted toward approaches currently ready for deployment in commercial fisheries. The methods of mitigating shark bycatch that ranked highest in this assessment are already used extensively in New Zealand longline fisheries. These are nylon leaders, large hooks and squid bait. Nylon leaders enable sharks to escape by biting off from fishing gear after capture. The 16/0 hooks commonly used in New Zealand surface longline fisheries have been associated with reduced blue shark (Prionace glauca) and pelagic stingray (Pteroplatytrygon violacea) catch rates, compared to 14/0 circle hooks and J-hooks respectively. Circle hooks are more often associated with increased shark catch rates, which may be due to increased retention on the line rather than increased total catches. Circle hooks complement the use of nylon leaders by reducing the incidence of gut hooking, which improves the odds of survival for animals that bite off the leader. 17/0 and 18/0 circle hooks are common in surface longline fisheries internationally and it is possible that a shift to these larger hooks could further reduce elasmobranch bycatch by making gear less available to smaller individuals. Other shark bycatch reduction methods that scored highly in this assessment include a shift in setting depth, the use of weak hooks, eliminating lightsticks, and developing artificial bait. A shift in setting depth holds more promise in bottom longline fisheries than in surface longline fisheries, but the research that lead to this conclusion was conducted outside of New Zealand and addressed species not found in New Zealand waters. Understanding the effect of altering setting depth on local elasmobranch species, target catches and vessel operations would require further investigation. Weak hooks scored highly because they could be very straightforward to implement, but little peer reviewed information was available regarding their impact on shark catch rates, post release survival, or target catch rates, particularly those of large tuna. Likewise, eliminating lightsticks scored highly largely due to ease of implementation. Despite the significant relationships between shark catches and lightstick use reported in the literature, it is probable that the practical significance of such a measure is not great. Unlike weak hooks or eliminating lightsticks, artificial baits manufactured from fish processing waste scored highly in this assessment because they have the potential to strongly reduce shark catch rates. However, this approach would require extensive development, including creating new formulae from locally available waste products, conducting field trials, and establishing manufacturing capability. By condensing and summarising available data on how shark and target species' catch rates are influenced by different operational and environmental parameters, this review makes a large amount of information about shark bycatch mitigation options accessible. The scoring system used to assess those options illustrates how the conclusions presented here were reached. This evidence together with a transparent assessment framework is intended to encourage discussion about future directions for shark bycatch mitigation in New Zealand's longline fisheries.

Howard, S. (2018). *Applying a multidisciplinary framework for developing a shark bycatch reduction device.* (Ph.D.), University of Otago, Retrieved from http://hdl.handle.net/10523/7824

The overarching aim of this multidisciplinary thesis was to contribute to the development of a novel shark bycatch reduction device (BRD) that both meets fishing operators' needs and is economically feasible. Following the multidisciplinary approach evident in existing frameworks developed for addressing bycatch problems, each chapter employed a different methodology drawn from a research discipline that provided a suitable set of tools for investigating a specific problem related to the overall goal.First, a literature review identified and evaluated global options available for mitigating elasmobranch bycatch on longline fishing gear. The aim of this review was to determine whether a shark bycatch reduction method currently exists that New Zealand longline fisheries could use to reduce their shark bycatch rates, and if not, identify promising emergent bycatch reduction methods as candidates for further development. The review found that no effective shark bycatch reduction methods or devices were commercially available to longline fishing operators, and identified electrosensory shark deterrents as an approach that showed potential for further development.Qualitative social research methods were then used to explore New Zealand longline fishing operators' perspectives on shark bycatch. Most interviews occurred in 2014 during a national campaign to legislate against shark finning in New Zealand waters. At this time, widespread popular opinion held that finning made sharks an economically valuable bycatch or even target species in many longline fisheries. If sharks were valued by fishermen for their fins or otherwise targeted then it was unlikely that they would consider a shark BRD useful. Interviews with ling (Genypterus blacodes) and tuna (Thunnus spp.) longline fishermen showed that they viewed spiny dogfish (Squalus acanthias) and blue shark (Prionace glauca) bycatch in their respective fisheries as a significant operational and economic challenge that they were motivated to mitigate but lacked effective tools to do so. Interviews also revealed that fishermen viewed the issue of shark bycatch in the context of maximising target species catch rates rather than minimising shark bycatch rates.Following interviews with skippers, laboratory animal behaviour experiments tested the hypothesis that weak electric stimulus generated by a prototype BRD would deter spiny dogfish or sandbar sharks (Carcharhinus plumbeus) from eating bait. Sandbar sharks were used as a carcharhinid model for an important longline bycatch species, blue sharks. The primary function of the elasmobranch electric sense is to guide predatory strikes during the final stage of prey capture, so electrosensory stimulus could disrupt their close range feeding responses. Weak electric stimulus produced by a microcontroller attached to an array of carbon electrodes and powered by a 9 V battery was used to deter groups of sharks from eating bait. Electric stimulus significantly reduced bait consumption by each species in a laboratory setting. Bait consumption by groups of juvenile sandbar shark median declined by 85 % when bait was located 10 cm from active electrodes compared to when it was 2 m away. Bait consumption by groups of adult spiny dogfish declined by 50 % when bait was located 10 cm from active electrodes compared to when it was located 10 cm from inactive electrodes. Results from laboratory studies of electrosensory shark deterrents tend to produce larger effect sizes than similar stimuli applied in field studies. If these results translated to the field the effect size produced in the sandbar shark experiment could be adequate to meet fishermen's expectations of a successful BRD. Conversely, the smaller effect size and wide interquartile range in spiny dogfish bait consumption means that for this species, improvements in both effectiveness and consistency would be required for the prototype electrosensory BRD to meet fishing industry needs.Following the bait choice experiments, a spatial utilisation experiment tested the hypothesis th t individual sandbar sharks avoided the location of carbon electrodes emitting weak electric stimulus. Sharks were not deterred from the location of either 4 Hz, 33 mA direct current or alternating current stimuli nor did their swimming speed change relative to a non-electric control. The absence of an avoidance response suggests that an electrosensory shark BRD based on this concept may not be applicable to non-baited fishing gears such as purse seine and trawl

nets. The finding electrosensory stimuli that reduced bait consumption in the previous experiments did not also elicit spatial avoidance supports the premise that electrosensory deterrents interrupt shark feeding behaviours rather than eliciting an aversive response.Finally, the economic impact of spiny dogfish in the inshore ling longline fishery was analysed quantitatively. Spiny dogfish and ling catch rates and export markets were assessed, then New Zealand government fisheries observer data were used to investigate a hypothesis that arose during skipper interviews, that spiny dogfish incur costs to inshore ling longline vessels by reducing ling catch rates. Overall, there was a significant weak positive relationship between spiny dogfish catch per unit effort (CPUE) and ling CPUE, which probably reflects these two species' spatial and temporal co-occurrence. On fishing lines in the upper quartile of spiny dogfish CPUE, there was a significant moderate negative relationship between spiny dogfish and ling CPUE. Median total hook occupancy in this fishery was 21 % but spiny dogfish alone could occasionally take up to 90 % of hooks. When spiny dogfish catch rates were high, the negative impact of spiny dogfish on ling CPUE could have been the result of hook occupation by spiny dogfish reducing the number of hooks available to ling. To reduce the highest spiny dogfish catches to a level below that likely to incur an opportunity cost in this fishery, the BRD would need to have an approximately 80 % effect size in the field. Based on the ratio of spiny dogfish to ling, an opportunity cost of high spiny dogfish catches in terms of 'lost' ling was estimated and valued at 34 cents per hook. The novel BRD under development produced weak electrosensory stimulus which was only perceptible to sharks at close range, which meant that every hook would require an individual BRD. Therefore, our estimates suggest a price ceiling of 34 cents per unit, above which the cost of a BRD outweighs its benefit in terms of increased ling catch. Increased durability could allow for the use of a more expensive device. However, based on the views of the three interviewed skippers, willingness to pay for a BRD is very low. Skipper access to better information, including our estimates of spiny dogfish bycatch-associated costs of ling catch, may provide increased incentives for BRD adoption.This thesis shows that an electronic BRD that produces electrosensory stimulus is a promising approach for mitigating carcharhinid shark bycatch, although it would require further development to become effective and reliable enough to be cost effective as a method of mitigating spiny dogfish bycatch in the ling longline fishery. This thesis also provides insight into an improved framework for developing bycatch reduction methods aimed at meeting fishing industry needs. Such a framework should involve initiating bycatch reduction research by conducting social research aimed at understanding fishing industry needs and perspectives on the bycatch problem. This can highlight the potential economic impacts, species of concern and key outcomes that industry would require for BRD uptake to occur. Proceeding to conduct an economic assessment of a bycatch problem's cost in a specific fishery can contribute to BRD cost-per-unit and minimum acceptable effect size estimates, which can then guide subsequent device development.

Howard, S., Brill, R., Hepburn, C., & Rock, J. (2018). Microprocessor-based prototype bycatch reduction device reduces bait consumption by spiny dogfish and sandbar shark. *ICES Journal of Marine Science,* 75(6), 2235-2244. https://doi.org/10.1093/icesjms/fsy098

Elasmobranchs contribute heavily to bycatch in longline fisheries globally, and an effective method of deterring them from baited fishing gear is needed. Electrosensory stimulus holds promise as a method of disrupting elasmobranch close-range feeding responses as their electric sense guides their final strike during prey capture. We used laboratory experiments to test the hypothesis that weak electric stimuli generated by a prototype electronic bycatch reduction device (BRD) could deter sandbar shark (Carcharhinus plumbeus) and spiny dogfish (Squalus acanthias) from eating bait. Voltage gradients <1mVcm(-1) at the location of bait were produced by an Arduino microcontroller powered by a 9 V battery and attached to carbon electrodes. Median bait consumption by groups of juvenile sandbar

shark declined by 74% when bait was located 10 cm vs. 2m from active electrodes. Spiny dogfish median bait consumption halved when bait was located 10 cm from active vs. inactive electrodes. Although laboratory studies often produce a larger effect for electrosensory shark deterrents than can be demonstrated during field trials, if the effects seen in our laboratory studies produced similar effects in the field, it could meet fishermen's requirements for a BRD.

Huang, H.-W., Swimmer, Y., Bigelow, K., Gutierrez, A., & Foster, D. G. (2016). Influence of hook type on catch of commercial and bycatch species in an Atlantic tuna fishery. *Marine Policy,* 65, 68-75. https://doi.org/10.1016/j.marpol.2015.12.016

Experimental sets were conducted on a Taiwanese deep set longline fishing vessel operating in the tropical Atlantic Ocean to evaluate the effects of relatively wide circle hooks vs. Japanese tuna hooks with respect to catch rates of both target and incidental species. On circle hooks there were significantly higher catch rates of bigeye tuna (Thunnus obesus), yellowfin tuna (T. albacares), swordfish (Xiphias gladius) and blue sharks (Prionace glauca) as compared to tuna hooks. Significantly higher rates of albacore (T. alalunga) and longbill spearfish (Tetrapterus pfluegeri) were caught on Japanese tuna hooks as compared to circle hooks. Overall, 55 sea turtles were incidentally captured, most (n=47) of which were leatherback turtles (Dermochelys coriacea), and capture rates were similar between hook type. Immediate survival rates (percentage alive) when landed were statistically similar for all major target fish species and sea turtles independent of hook type. Most (64%) sea turtles were hooked on the first and second branchlines closest to the float, which are the shallowest hooks deployed on a longline. Lengths of six retained species were compared between hook types. Of these, swordfish was the only species to show a significant difference in length by hook type, which were significantly larger on circle hooks compared to tuna hooks. Additional incentives to use circle hooks would be the increased catch rate in targeted bigeye tuna over traditional Japanese tuna hooks. This international collaboration was initiated in direct response to regional fisheries management organization recommendations that encourage member countries to conduct experiments aimed to identify means to reduce bycatch in longline fishing gear. Information presented may be useful for managers in developing international fisheries policies that aim to balance increases in commercial fishery revenue and endangered species protection.

Hutchinson, M., Siders, Z., Stahl, J., & Bigelow, K. (2021). *Quantitative estimates of post-release survival rates of sharks captured in Pacific tuna longline fisheries reveal handling and discard practices that improve survivorship*. (PIFSC data report DR-21-001). Pacific Islands Fisheries Science Center https://doi.org/10.25923/0m3c-2577

Shark catch rates are higher in pelagic longline fisheries than in any other fishery, and sharks are typically discarded (bycatch) at sea. The post-release fate of discarded sharks is largely unobserved and could pose a significant source of unquantified mortality that may change stock assessment outcomes and prevent sound conservation and management advice. This study assessed post-release mortality rates of blue (Prionace glauca), bigeye thresher (Alopias superciliosus), oceanic whitetip (Carcharhinus longimanus), silky (C. falciformis) and shortfin mako (Isurus oxyrhincus) sharks discarded in the Hawaii deep-set and American Samoa longline fisheries targeting tuna in the central Pacific Ocean. The impacts on survival rates were examined considering species, fishery, fishing gear configuration, handling method, animal condition at capture and at release, and the amount of trailing fishing gear remaining on discarded sharks. Bayesian survival analysis showed that the condition at release (good vs. injured),

branchline leader material, and the amount of trailing fishing gear left on the animals were among the factors that had the largest effect on post-release fate—animals captured on monofilament branchline leaders and released in good condition without trailing fishing gear had the highest rates of survival. This study shows that fisher behavior can have a significant impact on pelagic shark post-release mortality. Ensuring that sharks are handled carefully and released with minimal amounts of trailing fishing gear may reduce fishing mortality on shark populations.

Hutchinson, M., Wang, J. H., Swimmer, Y., Holland, K., Kohin, S., Dewar, H., . . . Martinez, J. (2012). The effects of a lanthanide metal alloy on shark catch rates. *Fisheries Research,* 131, 45-51. https://doi.org/10.1016/j.fishres.2012.07.006

Bycatch of sharks in longline fisheries has contributed to declines in shark populations and prompted the need for exploring novel technologies to reduce the incidental capture of sharks. One potential strategy is to exploit the unique electrosensory system of sharks, used to detect weak electric fields. Metals from the lanthanide series, made up of neodymium (Nd) and praseodymium (Pr), produce strong electric fields in water. In this study, we tested the effects of an Nd/Pr alloy on shark catch rates. Using longline fishing gear, we compared the catch rates of baited hooks affixed with either a block of the metal alloy (experimental) or a lead weight (control). Four experiments were conducted in different regions of the Pacific Ocean. Two bottom longline experiments were conducted inside and offshore of Kaneohe Bay, Hawaii. One of these experiments targeted young of the year scalloped hammerhead sharks (Sphyrna lewini), while the other targeted sandbar (Carcharhinus plumbeus) and tiger sharks (Galeocerdo cuvier). In the Southern California Bight (SCB), pelagic longlines were deployed to target mako (Isurus oxyrinchus) and blue sharks (Prionace glauca) and longlines targeting pelagic sharks were set in the Eastern Tropical Pacific (ETP) off Ecuador. There was a significant reduction in juvenile hammerhead sharks caught on hooks with the lanthanide metal compared to the controls. In contrast, there was no difference in the catch rates for experiments targeting sandbar sharks in Hawaii or those conducted in the SCB and Ecuador. These results suggest that there are inter-specific differences regarding the effects of lanthanide metals on catch rates. This may reflect the diverse feeding strategies and sensory modalities used by shark species for detecting and attacking prey.

Jimenez, S., Forselledo, R., & Domingo, A. (2019). Effects of best practices to reduce seabird bycatch in pelagic longline fisheries on other threatened, protected and bycaught megafauna species. *Biodiversity and Conservation,* 28(13), 3657-3667. https://doi.org/10.1007/s10531-019-01842-4

Fisheries bycatch is one of main conservation problems for many threatened seabirds. Currently, it is unknown whether existing best practices to mitigate seabird bycatch in pelagic longline fisheries influence the capture of other vulnerable taxa. We assessed the effect of two seabird mitigation measures for pelagic longline fisheries on 13 threatened, protected and/or bycaught species, including elasmobranchs, teleosts, sea turtles and fur seals. Analyses were from two experimental studies in Uruguay assessing the effect of a bird scaring line (BSL) and branch lines with weights close to the hooks (weighted branch lines) on these taxa. One hundred longline sets with randomized use of a BSL were deployed. In turn, 224 paired longline sections, with control branch lines versus weighted branch lines, were deployed. BSL use did not increase the capture of any of the species addressed. No detectable differences in capture rate were recorded in our branch line weighting study. However, the effect of branch line weighting in the capture of Porbeagle shark (Lamna nasus) remains unclear and requires further research. Our study suggests that effective measures to reduce seabird bycatch in pelagic

longline have no negative connotations for other vulnerable species. Caution should be exercised when interpreting our results as analyses were underpowered to detect small and subtle differences in the catch rates. We strongly encourage researchers to conduct similar studies to elucidate potential regional and across fisheries differences in the effect of seabird mitigation measures in other vulnerable taxa, as well as the effect that mitigation measures for other taxa may have on seabirds.

Kaimmer, S., & Stoner, A. W. (2008). Field investigation of rare-earth metal as a deterrent to spiny dogfish in the Pacific halibut fishery. *Fisheries Research,* 94(1), 43-47. https://doi.org/10.1016/j.fishres.2008.06.015

Spiny dogfish (Squalus acanthias) comprise a Significant unwanted bycatch on demersal longlines set for halibut, sablefish (Anoplopoma fimbria), and Pacific cod (Gadus macrocephalus) in shelf waters of the east and west coasts of North America. Recently. rare-earth magnets and metals have been shown to have deterrent effects on sharks. These effects are likely the result of magnetic or electric fields created by these materials in seawater, which are sensed and avoided by sharks. Our earlier laboratory studies showed that attack rates by spiny dogfish on baits protected with cerium mischmetal (a rare-earth alloy) were reduced and Suggested that this metal might reduce unwanted bycatch of spiny dogfish in setline fishing for Pacific halibut (Hippoglossus stenolepis). We conducted a field study near Homer, Alaska in September 2007 with three hook treatments interspersed on 36 longline sets. These included standard circle hooks used in the halibut fishery, hooks with small pieces of cerium mischmetal attached above the hook. and hooks with a similar (but inert) mild steel piece above the hook. Fewer dogfish were caught on hooks with mischmetal than on either of the two other treatments. Reductions in catch of longnose skate (Raja rhina) also occurred on hooks protected with mischmetal. However, halibut catch did not increase with protected hooks. Limitations in using mischmetal in commercial operations are expense, hazardous nature, and relatively rapid hydrolysis in seawater.

Kaplan, I. C., Cox, S. P., & Kitchell, J. F. (2007). Circle hooks for Pacific longliners: Not a panacea for marlin and shark bycatch, but part of the solution. *Transactions of the American Fisheries Society,* 136(2), 392-401. https://doi.org/10.1577/t05-301.1

Blue marlin Makaira nigricans, striped marlin Tetrapturus audax, and pelagic sharks (e.g., blue shark Prionace glauca) are commonly caught as bycatch by longline fisheries in the central North Pacific Ocean. Recently, concern has increased about depletion of these species. Modifications in longline gear may offer one solution. Here. we test the use of circle hooks, rather than the conventional tuna-style hooks, on longlines using an ecosystem model of the central North Pacific Ocean. The simulations considered span a range of reasonable circle hook catchability and Survival rates for released fish. The results suggest that if circle hooks have higher catchability than the Currently used tuna-style hooks, switching to circle hooks depletes marlin biomass by 25-40% and shark biomass by 15-35% over 30 years. However. these depletions do not occur if circle hook catchability is equal to or lower than that of tuna-style hooks. When the effects of catch-and-release requirements for marlins and sharks were also considered. we found that regardless of assumptions about circle hook catchability and survival rates, a combined policy of using circle hooks and releasing sharks and marlins leads to net increases in marlin and shark abundance. The simulations show a trade-off between the abundance of marlins and sharks and their prey items, yellowfin tuna Thunnus albacares and small blue sharks. There is also evidence of trophic trade-offs between yellowfin tuna and small blue sharks and their prey, small scombrids (Auxis spp.) and mahi mahi Coryphaena hippurus. The results illustrate the importance of understanding

catchability and survival rates for circle hooks compared with those for tuna-style hooks and encourage further research in this area.

Keller, B. A., Swimmer, Y., & Brown, C. A. (2020). *Review on the effect of hook type on the catchability, hooking location, and post-capture mortality of the shortfin mako, Isurus oxyrinchus*.(PIFSC working paper WP-20-003). Pacific Islands Fishery Science Center. Retrieved from https://repository.library.noaa.gov/view/noaa/25889

Due to the assessed vulnerability for the North Atlantic shortfin mako, Isurus oxyrinchus, ICCAT has identified the need to better understand the use of circle hooks as a potential mitigation measure in longline fisheries. We conducted a literature review related to the effect of hook type on the catchability, anatomical hooking location, and post-capture mortality of this species. We found twenty eight papers related to these topics, yet many were limited in interpretation due to small sample sizes and lack of statistical analysis. In regards to catchability, our results were inconclusive, suggesting no clear trend in catch rates by hook type. The use of circle hooks was shown to either decrease or have no effect on at-haulback mortality. Three papers documented post-release mortality, ranging from 23-31%. The use of circle hooks significantly increased the likelihood of mouth hooking, which is associated with lower rates of post-release mortality. Overall, our review suggests minimal differences in catchability of shortfin mako between hook types, but suggests that use of circle hooks likely results in higher post-release survival that may assist population recovery efforts.

Kerstetter, D. W., & Graves, J. E. (2006). Effects of circle versus J-style hooks on target and non-target species in a pelagic longline fishery. *Fisheries Research,* 80(2-3), 239-250. https://doi.org/10.1016/j.fishres.2006.03.032

The U.S. Atlantic coastal pelagic longline fishery that targets tunas and swordfish also interacts with a wide range of non-target species including billfishes and sea turtles. Preliminary studies indicate that a change in terminal gear from J-style hooks to circle hooks may reduce bycatch mortality, but the effects of this change on catch rates of target species are unclear. To evaluate this, we monitored catch composition, catch rates, hooking location, and number of fish alive at haulback during 85 sets in the fall and spring seasonal fisheries from a commercial vessel operating in the western North Atlantic. Circle (size 16/0, 0 degrees offset) and J-style (size 9/0, 10 degrees offset) hooks were deployed in an alternating fashion. Hook-time recorders were used to assess time at hooking and temperature-depth recorders to measure gear behavior. Catch rates for most species categories were not significantly different between hook types (P < 0.05), although circle hooks generally had higher tuna catch rates in the fall and lower swordfish catch rates in the spring. In :he fall, both total catches and catches of pelagic rays were significantly higher on J-style hooks. Yellowfin tuna in the fall and dolphinfish in the spring caught on circle hooks were significantly larger than those caught on J-style hooks. In both seasonal fisheries, circle hooks caught fishes in the mouth more frequently than J-style hooks, which hooked more often in the throat or gut, although these differences between hook types were not statistically significant. Yellowfin tuna in the fall fishery were over four times more likely to be hooked in the mouth with circle hooks than with J-style hooks. Several target and bycatch species showed higher rates of survival at haulback with circle hooks, although only for dolphinfish in the fall fishery was this difference statistically significant. Our results suggest that the use of 0 degrees offset circle hooks in the coastal pelagic longline fishery will increase the survival of bycatch species at haulback with minimal effects on the catches of target species.

Kim, S.-S., Moon, D.-Y., Boggs, C., Koh, J.-R., & An, D.-H. (2006). Comparison of circle hook and J hook catch rate for target and bycatch species taken in the Korean tuna longline fishery. *Journal of the Korean society of Fisheries Technology,* 42(4), 210-216. https://doi.org/10.3796/ksft.2006.42.4.210

The circle hook experiments were conducted to compare the catch rates of target and bycatch species between J hook and circle hooks in the tuna longline fishery of the eastern Pacific Ocean between from July 15 to August 12, 2005. In the target species group no significant differences among 3 types hook, between size 4.0 traditional tuna hooks(J-4) and size 15 circle hooks(C15), and between C15 and size 18 circle hooks(C18) were revealed, but significant differences were found between J-4 and C18. In the bycatch species group significant differences were found among 3 types hook, between J 4 and C15, and between J-4 and C18, but no significant differences were revealed between C15 and C18. Large circle hook(C18) had the lowest catch rate for tunas and for other fishes, and the small circle hook(C15) had lowest rate for billfishes and sharks. The length distributions for bigeye tuna are very similar for the 3 hook types. There were very slight differences in length size between hook types in the bycatch species.

Kumar, K. V. A., Khanolkar, P. S., Pravin, P., Madhu, V. R., & Meenakumari, B. (2013). Effect of hook design on longline catches in Lakshadweep Sea, India. *Indian Journal of Fisheries,* 60(1), 21-27. Retrieved from https://agris.fao.org/agris-search/search.do?recordID=IN2022010629

Tuna longlining is considered as an ecofriendly, economical, species-selective and size-selective fishing technique suitable for harvesting sparsely distributed large predatory fishes. Many non-targeted and protected species like marine turtles, seabirds, cetaceans and sharks are also caught as bycatch in the pelagic longline gear. Investigations were undertaken to evaluate the effect of hook design on the longline catches in Lakshadweep Sea by comparing the species selection efficiency, bait holding efficiency and hooking pattern of the Japanese and circle hook designs. The results indicated that hook design has no effect on the catching efficiency, species selectivity and bait holding ability in pelagic longline fisheries in Lakshadweep Sea. The hooking pattern was found to be significantly different, indicating favorable hooking locations in the case of circle hooks. The results of the present study, indicated the positive effects of circle hooks in minimising the impact of bycatch by hooking on the fish favouring post-release survival of the species.

Kumar, K. V. A., Pravin, P., & Meenakumari, B. (2016). Bait, Bait Loss, and Depredation in Pelagic Longline Fisheries-A Review. *Reviews in Fisheries Science & Aquaculture,* 24(4), 295-304. https://doi.org/10.1080/23308249.2016.1162134

This article reviews the importance of bait, bait loss, and depredation in longline fishery operations worldwide. In general, fish bait is preferred over squid due to reduced sea turtle and elasmobranch bycatch. However, there are many reports which have indicated high shark catch and deep hooking when using fish as bait. High and low hooking rates for blue shark have been reported from different fishing areas when using mackerel as bait, indicating the need for further studies on selection of appropriate baits. Conflicting results from many part of the world on the catching efficiency of different bait species on target and nontarget species indicate the need to consider area, species specific and cross taxa effect of various combinations of baits and hooks, before their adoption in commercial fishing. Baiting pattern has also been reported to affect the catch rates significantly. The review has revealed that bait loss and depredation on the hooked fish cause considerable damage to the fishery

and significant economic loss. Loss rates can be significantly minimized using squids as bait while it may also incur a high catch rate of bycatch. The review has confirmed the superiority of natural baits over alternative and artificial baits during the longline fishing operations. Though an effective substitute for the natural bait has not been developed, so far, such alternatives which make use of the food and foraging behavior and the olfactory response of the fish are necessary for future development of longline fisheries.

Li, J., Song, L., & Li, D. (2013). *The capture depth of the dominant bycatch species and the relationship between their catch rates and the sea surface temperature.* Indian Ocean Tuna Commission, Retrieved from https://www.fao.org/3/bh060e/bh060e.pdf

On the basis of the data collected on a pelagic longline vessel from November 18, 2012 through March 31, 2013 in the fishing area of the Indian Ocean (2°47′N~8°13′S,62°18′E~ 67°49′E), the capture depth of the dominant bycatch species and the relationship between their catch rates and the sea surface temperature were analyzed. The results showed that (1) blue shark (Prionace glauca) mainly inhabited the water layer of 80~160m, the water layer with the highest catch rate was 120~160m, followed by 80~120m, the catch rate of remaining water layers was low; (2) swordfish (Xiphias gladius) mainly inhabited the water layer of 80~200m, the catch rate of this water layer increased at first then decreased, the catch rate in the water layer of 120~160m was the highest and much higher than that of other water layers; (3) blue marlin (Makaira nigricans) was mainly caught in the water layer of 80~200m, the catch rate of this water layer was high, and the catch rate peaked in the water layer of 160~200m. The catch rate in the water layer of 200~280m was low, and decreased with depth; (4)striped marlin (Tetrapturus audax) was caught in the water layer of 80~200m, no striped marlin was caught in other water layer, the catch rates decreased with depth; (5) crocodile shark was caught in the water layer of 200~320m, no crocodile shark was caught in other water layer, the catch rates increased with depth; (6)the catch rates of blue shark increased with the increasing of the sea surface temperature, peaked at 30.1~30.5°C; the catch rates of swordfish and blue marlin peaked at 29.6~30°C; the catch rates of striped marlin were high at 29.6~31°C and peaked at 30.1~30.5°C; the catch rates of crocodile shark peaked at 30.6~31°C. This study suggested that the depth of the pelagic longline hook should be deployed deeper than 160m and shallower than 280m or avoid operation in the area where the sea surface temperature is higher than 29.6°C to reduce the bycatch of blue shark, swordfish, blue marlin and striped marlin.

Massey, Y., Sabarros, P. S., & Bach, P. (2022). Drivers of at-vessel mortality of the blue shark (Prionace glauca) and oceanic whitetip shark (Carcharhinus longimanus) assessed from monitored pelagic longline experiments. *Canadian Journal of Fisheries and Aquatic Sciences,* 79(9), 1407-1419. https://doi.org/10.1139/cjfas-2021-0273

Elasmobranchs make up a significant part of bycatch in pelagic longline fisheries, whose induced mortality can be a major threat to endangered species. It is therefore crucial to understand the drivers of at-vessel mortality (AVM) for this fishing gear to enhance postrelease survival. To this end, we analysed scientific data collected during monitored longline fishing experiments conducted in French Polynesia to (i) estimate AVM for each species based on bootstrapped samples and (ii) to assess AVM drivers using multivariate logistic regression models for the blue shark (Prionace glauca) and oceanic whitetip shark (Carcharhinus longimanus). We found that AVM varies widely between species. Oceanic whitetip sharks are more likely to die when caught in waters outside their comfort temperature range,

and their odds of survival increase with body length. For the blue shark, the only driver related to AVM is hooking duration. These results indicate that to reduce the AVM of these two species, the vertical distribution of hooks and soak duration should be considered as mitigation measures related to pelagic longlining.

McCutcheon, S. M. (2012). *Lanthanide metals as potential shark deterrents.* Florida Atlantic University, Master of Science. Retrieved from https://www.bmis-bycatch.org/references/sa8sgprh

Sharks comprise a large portion of bycatch in pelagic longline fisheries worldwide. Lanthanide metals have been proposed as shark repellents. This study quantified the normalized voltage of lanthanide metals in seawater and found that there was no difference in normalized voltage among the six tested metals. Temperature and salinity had a significant effect on lanthanide normalized voltage. The output at 18C was significantly greater than at both 12 and 24C. The normalized voltage was significantly greater in freshwater than brackish or seawater. The dissolution rate for the lanthanides varied from -1.6 to -0.2g/h. As the metals dissolved the voltage remained constant. In a behavioral assay, neodymium was ineffective at repelling bonnethead sharks (Sphyrna tiburo) tested individually and in groups, and lemon sharks (Negaprion brevirostris) in groups. Due to high cost, fast dissolution rates, and lack of deterrent effects, lanthanide metals are not recommended for use in mitigating shark bycatch.

McCutcheon, S. M., & Kajiura, S. M. (2013). Electrochemical properties of lanthanide metals in relation to their application as shark repellents. *Fisheries Research,* 147, 47-54. https://doi.org/10.1016/j.fishres.2013.04.014

Sharks comprise a large portion of unwanted bycatch in longline fisheries worldwide and various technologies have been proposed to reduce elasmobranch bycatch without impacting the catch of target species. Recently, the naturally electrogenic lanthanide metals have been introduced as an elasmobranch-specific repellent. We quantified the voltage produced by six lanthanide metals in seawater, compared their dissolution rates, and performed a behavioral assay to determine their efficacy against two coastal shark species. We found that there was no difference in the voltage produced by the six tested metals and the voltage decayed as a power function (approximately x(-1.5)) with distance from the metal sample. We calculated that sharks should detect a sample of neodymium from a distance of 65-85 cm in seawater. Voltage was greatest in freshwater and decreased logarithmically with increasing salinity but did not differ above salinities greater than 10 ppt. The dissolution rate for the lanthanides varied from -1.6 to -0.2 g h(-1) and as the metals dissolved, the voltage remained constant. In a behavioral assay, neodymium was ineffective at repelling bonnethead sharks (Sphyrna tiburo) tested individually and in groups, and juvenile lemon sharks (Negaprion brevirostris) in groups.

Michrowski, D., & Quinn. (2015). *Determining Discard Mortality Rates of Longline-Caught Skates (Rajidae)*. Lowell Wakefield Fisheries Symposium Series. Retrieved from https://seagrant.uaf.edu/events/2015/wakefield-data-limited/presentations/Michrowski-Longline-Caught-Skates.pdf

Discard, or release, mortality is a pressing management issue faced by most fisheries. Both target and bycatch species are released after capture for a multitude of reasons, including those of regulatory and

market origins. The difficulties in determining the fate of such discards often require managers to make assumptions of discard mortality based on little to no data, leading to uncertainty in stock assessment models. The repercussions of this uncertainty can be far ranging, with implications on stock rebuilding, access to target species, and ecosystem health. One such case in the North Pacific is that of the skate complex (family: Rajidae), which are caught incidentally in large numbers in many fisheries and across most gear-types. Our current research has focused on estimating the discard mortality of skates after longline capture, as this gear-type is responsible for the majority of the catch in the region. The initial studies have described and codified the injuries sustained by these skates as a result of capture, as well as the effects of handling on injury severity. Further studies are under way to establish both injury class-specific mortality rates and a general discard mortality rate, to be made available to fisheries managers. Our goals with these efforts are to reduce the uncertainty of management models and the potential for effects of incidental catch rates on those of target species.

Munden, J. G. (2013). *Reducing negative ecological impacts of capture fisheries through gear modification.* (Master of Science), Memorial University of Newfoundland, Retrieved from http://research.library.mun.ca/id/eprint/11100

Capture fisheries provide the world with a healthy source of protein than can have minimal environmental impacts if harvested sustainably. Negative environmental impacts of capture fisheries include; overexploitation, modification of food webs, mortality of nontarget species, habitat alteration and biodiversity loss. A mitigation technique often used to reduce ecological impacts of fishing without compromising commercial catches is gear modification. This thesis explores modification of two gear types; shrimp trawl and turbot longline. Modifications were made to shrimp trawl footgear to reduce habitat alteration and to turbot longline gear to reduce Greenland shark bycatch. Testing of modified with traditional gears demonstrated that the modified gears with reduced ecological impacts did not negatively affect commercial catches. The 200 lb monofilament gangion is recommended for commercial testing by turbot longline fishers in Cumberland Sound; however the aligned shrimp trawl requires further modifications due to unexpected increases in turbot bycatch compared to the traditional trawl.

Musyl, M. K., & Gilman, E. L. (2018). Post-release fishing mortality of blue (Prionace glauca) and silky shark (Carcharhinus falciformes) from a Palauan-based commercial longline fishery. *Reviews in Fish Biology and Fisheries,* 28(3), 567-586. https://doi.org/10.1007/s11160-018-9517-2

Accounting for components of fishing mortality, including post-release mortality (Fr), is necessary for robust assessments of the effects of fishing. Forty-eight blue (Prionace glauca) and 35 silky sharks (Carcharhinus falciformes) were tagged with pop-up satellite archival tags to monitor Fr rates from pelagic longline vessels in the western tropical Pacific Ocean. There is a paucity of Fr studies at low latitudes and identifying factors that significantly explain Fr is critical for understanding fishing mortality. Mean Fr rates were 0.17 [95% CI 0.09–0.30] for blue shark and 0.20 [95% CI 0.10–0.36] for silky shark. When it occurred, Fr was acute with 87% of mortalities within 2 days of release. Several prognostic operational, environmental, biological and handling variables were evaluated to assess their influence on survival outcomes. Using Kaplan–Meier survival curves, logistic regression, accelerated failure time and Cox proportional hazards models to screen variables, the only significant prognostic or risk variable was health condition at haulback. There was close correspondence (~ 83% accuracy) between condition at capture and survival outcomes. Reliable methods to classify at-vessel condition represent an

inexpensive and simple metric for estimating both Fr and at-vessel (Fc) mortality rates. Examining Fc rates in detail in longline fisheries using capture information on depth, temperature and dissolved oxygen that may act in synergy with condition code and hooking duration is a research priority. Results suggest that a large proportion of shark survive following release and that Fr rates can be increased by improving the haulback condition of captured sharks.

Nunes, D. M., Hazin, F. H. V., Branco-Nunes, I. S. L., Hazin, H., Pacheco, J. C., Afonso, A. S., . . . Carvalho, F. C. (2019). Survivorship of species caught in a longline tuna fishery in the western equatorial Atlantic Ocean. *Latin American Journal of Aquatic Research,* 47(5), 798-807. https://doi.org/10.3856/vol47-issue5-fulltext-9

Longlines bearing "hook timers" (HTs) and alternating circle (15/0 and 17/0) and "J" (10/0) hooks were employed off the coast of Brazil to measure differences in fishing mortality associated with hook type and on-hook time between capture and boarding. A total of 431 HTs were activated, revealing a clear pattern of the increased mortality rate of fishes associated with increased on-hook time. Swordfish had high mortality rates, unlike blue sharks, which had low mortality rates regardless of hook type and the location in which the hook was transfixed. The six species of tunas and billfishes examined in this study showed a strong association between hooking location and the animal's release condition, with reduced mortality associated with individuals hooked externally. Results suggest that knowledge of factors affecting the survival of pelagic fishes caught in longline fisheries may enable the development and adoption of fishing methods to reduce mortality of longline bycatch.

O'Connell, C. P., Abel, D. C., Stroud, E. M., & Rice, P. H. (2011). Analysis of permanent magnets as elasmobranch bycatch reduction devices in hook-and-line and longline trials. *Fishery Bulletin,* 109(4), 394-401. Retrieved from https://spo.nmfs.noaa.gov/content/analysis-permanent-magnets-elasmobranch-bycatch-reduction-devices-hook-and-line-and

Previous studies indicate that elasmobranch fishes (sharks, skates and rays) detect the Earth's geomagnetic field by indirect magnetoreception through electromagnetic induction, using their ampullae of Lorenzini. Applying this concept, we evaluated the capture of elasmobranchs in the presence of permanent magnets in hook-and-line and inshore longline fishing experiments. Hooks with neodymium-iron-boron magnets significantly reduced the capture of elasmobranchs overall in comparison with control and procedural control hooks in the hook-and-line experiment. Catches of Atlantic sharpnose shark (Rhizoprionodon terraenovae) and smooth dogfish (Mustelus canis) were significantly reduced with magnetic hook-and-line treatments, whereas catches of spiny dogfish (Squalus acanthias) and clearnose skate (Raja eglanteria) were not. Longline hooks with barium-ferrite magnets significantly reduced total elasmobranch capture when compared with control hooks. In the longline study, capture of blacktip sharks (Carcharhinus limbatus) and southern stingrays (Dasyatis americana) was reduced on magnetic hooks, whereas capture of sandbar shark (Carcharhinus plumbeus) was not affected. Teleosts, such as red drum (Sciaenops ocellatus), Atlantic croaker (Micropogonias undulatus), oyster toadfish (Opsanus tau), black sea bass (Centropristis striata), and the bluefish (Pomatomas saltatrix), showed no hook preference in either hook-and-line or longline studies. These results indicate that permanent magnets, although eliciting species-specific capture trends, warrant further investigation in commercial longline and recreational fisheries, where bycatch mortality is a leading contributor to declines in elasmobranch populations.

Ochi, D., Okamoto, K., & Ueno, S. (2022). Multifaceted effects of bycatch mitigation measures on target/non-target species for pelagic longline fisheries and consideration for bycatch management. *bioRxiv*. https://doi.org/10.1101/2022.07.14.500149

The pelagic longline fishery, in an effort to reduce bycatch of sea turtles, have developed and deployed fisheries bycatch mitigation techniques such as replacing J/tuna hooks and squid bait with circle hooks and whole fish bait. However, little emphasis has been placed on the side effects of bycatch mitigation measures on endangered species other than target bycatch species. Several previous studies of the side effects have been marred by lack of control for the covariates. Here, based on long-term data obtained from research cruises by a pelagic longline vessel, we examined the effects of using circle hooks and whole fish bait to replace squid bait on the fishing mortality of target and non-target fishes, and also bycatch species. A quantitative evaluation analysis of our results, based on a Bayesian approach, showed the use of circle hooks to increase mouth hooking in target and bycatch species, and their size to be proportional to the magnitude of the effect. Although deploying circle hooks increased catch per unit effort (CPUE) and fishing mortality per unit effort (MPUE), changing the bait species from squid to fish clearly had a far greater impact on shark mortality than the use of circle hooks. Because the impact of the introduction of bycatch mitigation measures on species other than the focused bycatch species is non-negligible, a quantitative assessment of bycatch mitigation-related fishing mortality is critical before introducing such measures.

Ochi, D., Ueno, S., & Okamoto, K. (2021). Assessment of the Effect of Hook Shape on Fishing Mortality of Multi-Taxa Fish Species Using Experimental Longline Operation Data. *Collective volume of scientific papers,* 78(4), 105-117. Retrieved from https://www.iccat.int/Documents/CVSP/CV078_2021/n_4/CV078040105.pdf

To evaluate the effect of circle hooks (C-hooks) on fishing mortality of fish species (blue shark, shortfin mako, striped marlin and swordfish) other than sea turtles in experimental longline operations, Bayesian estimation using statistical models was used to examine whether there were differences in haulback mortality rate, CPUE, mortality per unit effort (MPUE), and hooking position between 3.8 sun tuna hooks and size-different C-hooks. The results showed that the haulback mortality rate, CPUE, and MPUE did not improve with either size of C-hook, but rather tended to worsen. In addition, the use of the C-hook did not reduce the hook swallowing which can lead to post-release mortality. In addition, the mortality rate may be greatly influenced by environmental factors such as soak time and water temperature. These results suggest that it is necessary to consider the trade-off between the effects on sea turtles and on multi-taxa fish species when discussing the use of C-hooks.

Orbesen, E. S., Snodgrass, D., Shideler, G. S., Brown, C. A., & Walter, J. F. (2017). Diurnal patterns in Gulf of Mexico epipelagic predator interactions with pelagic longline gear: implications for target species catch rates and bycatch mitigation. *Bulletin of Marine Science,* 93(2), 573-589. https://doi.org/10.5343/bms.2016.1008

Bycatch in pelagic longline fisheries is of substantial international concern, and the mitigation of bycatch in the Gulf of Mexico has been considered as an option to help restore lost biomass following the 2010 Deepwater Horizon oil spill. The most effective bycatch mitigation measures operate upon a differential response between target and bycatch species, ideally maintaining target catch while minimizing bycatch.

We investigated whether bycatch vs target catch rates varied between day and night sets for the United States pelagic longline fishery in the Gulf of Mexico by comparing the influence of diel time period and moon illumination on catch rates of 18 commonly caught species/species groups. A generalized linear model approach was used to account for operational and environmental covariates, including: year, season, water temperature, hook type, bait, and maximum hook depth. Time of day or moon phase was found to significantly alter catch rates for 88% of the taxa examined. Six taxa-swordfish (Xiphias gladius Linnaeus, 1758); tiger shark (Galeocerdo cuvier Peron and Lesueur, 1822); silky shark (Carcharhinus falciformis Muller and Henle, 1839); oilfish (Ruvettus pretiosus Cocco, 1833); bigeye thresher shark (Alopias superciliosus Lowe, 1841); and escolar (Lepidocybium flavobrunneum Smith, 1843)-exhibited higher catch rates at night, while eight taxa-skipjack tuna (Katsuwonus pelamis Linnaeus, 1758); wahoo (Acanthocybium solandri Cuvier, 1832); white marlin [Kajikia albida (Poey, 1860]; dolphinfish (Coryphaena sp.); yellowfin tuna (Thunnus albacares Bonnaterre, 1788); rays (Pteroplatytrygon violacea Bonaparte, 1832, Mobulidae sp.); lancetfish (Alepisaurus sp.), and blue marlin (Makaira nigricans Lacepede, 1802)-had higher daytime catch rates. These results reveal that shifts in effort between daytime and nighttime fishing (which are highly correlated with shifts between yellowfin tuna and swordfish targeting strategies) could have substantial, species-specific effects on bycatch rates. Whether driven by fishery conditions, market influences, or management measures, such temporal shifts in the timing of pelagic longline sets may have important implications for species-specific conservation goals and warrant further consideration.

Ortuño-Crespo, G., Griffiths, S. P., & Murua, H. (2022). *Reducing shark bycatch in tuna fisheries: adaptive spatio-temporal management options for the eastern Pacific Ocean.* Working Group on Bycatch Inter-American Tropical Tuna Commission, Retrieved from https://www.bmis-bycatch.org/references/u7srk5zv

Purse-seine tropical tuna fishing in the eastern tropical Pacific Ocean (EPO) results in the bycatch of several sensitive species groups, including elasmobranchs. Effective management of ecosystems balances conservation and resource use, but requires actionable knowledge that accounts for both trade-offs and synergies. Seasonal and adaptive spatial management measures can be effective to reduce the impact of fisheries on non-target species while preserving, or even increasing, target species catch. Exploring the potential distribution and impact of fisheries closures in the open ocean, where highly dynamic environmental conditions drive distributional changes in biological communities throughout the year, requires the identification of persistently high-risk areas, where the likelihood of encountering and catching unwanted bycatch species, relative to the target species, is high. We used fisheries observer data from 1995–2021 to explore the spatio-temporal persistence of areas of high bycatch risk for two species of oceanic sharks, silky shark (Carcharhinus falciformis) and oceanic whitetip shark (Carcharhinus longimanus), and low tuna catch rate areas—defined as areas of high fishing inefficiency (i.e., poor fishing areas). We found that if areas of high fishing inefficiency were closed throughout the study period, and effort reallocated proportionally to reflect historical effort patterns, yearly tuna catch may have increased by 1–11% while the bycatch of silky and oceanic whitetip sharks could have decreased by 10-19% and 9%, respectively. Prior to fishing effort redistribution, bycatch reductions would have accrued to 21–41% and 14% for silky and oceanic whitetip sharks, respectively. Our analysis builds on past evidence and demonstrates the high potential for reducing elasmobranch bycatch in the EPO, while not compromising the catch rates of target tuna species. It also highlights the need to consider new dynamic and adaptive management measures to more efficiently fulfill conservation and sustainability objectives for exploited resources in the EPO.

Pacheco, J. C., Kerstetter, D. W., Hazin, F. H., Hazin, H., Segundo, R. S. S. L., Graves, J. E., . . . Travassos, P. E. (2011). A comparison of circle hook and J hook performance in a western equatorial Atlantic Ocean pelagic longline fishery. *Fisheries Research,* 107(1), 39-45. https://doi.org/10.1016/j.fishres.2010.10.003

Catch composition, catch rates, hooking location, and status at release at haulback were monitored during 81 experimental sets (launches and hauling fishing per day) in a commercial pelagic longline fishery targeting tuna in the equatorial South Atlantic Ocean. Circle hooks (size 18/0, 0° offset) and J-style hooks (size 9/0, 10° offset) with squid baits were deployed in an alternating fashion. The catch composition was not significantly different for most species between the two types of hooks, except for bigeye tuna, which showed a significantly higher proportion of catches on the circle hook ($p \gg 0.001$) and for sailfish, pelagic stingray, and leatherback sea turtle, which had higher catch rates on the J-style hook ($p=0.018$, $p \gg 0.001$, and $p=0.044$, respectively). Bigeye and yellowfin tuna showed significantly higher rates of survival at the time of gear retrieval with circle hooks, and circle hooks hooked bigeye tuna, yellowfin tuna, swordfish, and sailfish significantly more often externally than internally. Our results suggest that the use of size 18/0, 0° offset circle hooks in the equatorial pelagic longline fishery may increase the survival of bycatch species at the time of gear retrieval with minimal effects on the catches of target species.

Patterson, H., Hansen, S. W., & Larcombe, J. (2014). *A review of shark bycatch mitigation in tuna longline fisheries.* Western and Central Pacific Fisheries Commission, Retrieved from https://purl.org/spc/digilib/doc/z22ec

A review of the most studied mitigation methods (generally defined as measures that reduce the incidence of sharks being caught on the gear) is undertaken here and is extended to include measures that reduce mortality once the shark is captured and brought to the boat.

Pilcher, N. J., Nickson, A., McClellan, L., & Cartwright, I. (2006). Hook, line and bycatch workshop setting the agenda for mitigation of bycatch in longline fisheries. *Indian Ocean Turtle Newsletter,* 3, 32. Retrieved from https://www.iotn.org/wp-content/uploads/2015/11/03-8-ANNOUNCEMENT4.pdf

During the IUCN World Conservation Congress in 2004, we identified the need for a forum where bycatch issues could be considered at an ecological, multi-species level rather than on a case-by-case basis. We recognized that several bycatch reduction measures are already in place, but noted that there was insufficient communication and collaboration among the various species groups impacted by longline fisheries, and that opportunities might exist for cross-group information sharing and collaboration. The workshop was intended as a forum to: 1. Exchange knowledge on bycatch problems and mitigation techniques among four key species groups (turtles, seabirds, cetaceans, sharks); 2. Identify conflicts/mutual benefits of mitigation gears and fishing strategies; 3. Share knowledge on the spatial-temporal overlap of distributions of these species; 4. Identify needs, priorities and opportunities for collaborative mitigation research; and, 5. Define a priority global agenda to create a significant and measurable reduction in longline bycatch. The workshop brought together marine resource specialists composed of managers and policy makers, scientists, NGOs, IGOs, industry representatives and fishers, from 14 countries and sharing a wealth of global experience, who worked to identify, develop, and recommend applicable and integrated solutions to reduce interactions of birds, mammals, turtles and

sharks with pelagic longline fisheries. The technical report includes commonalities, synergies and conflicts between species groups and mitigation measures for target (and non-target) species, through the use of a comparative matrix, and identifies criteria for evaluating trade-offs in the application of bycatch mitigation methods. It highlights the potential for the use of risk-based methods for assessing i) bycatch reduction priorities and ii) multi-species effects of bycatch reduction methods and strategies, and suggests means of monitoring and evaluating mitigation efforts with respect to performance indicators and adaptive management approaches, including timing considerations. The outcomes highlight research priorities including filling data gaps, and promising new mitigation methods and strategies aimed at raising awareness of multi-species data needs, to encourage governments and industry to collect standardized multi-species data in all observer programs. The Technical Report is envisioned to form the basis of a 'roadmap' or plan of action with regard to multi-species bycatch mitigation. A second key outcome was a preliminary mathematical model based on existing mitigation measures and intended to assist fisheries managers in decision making. The model is a process through which decision-makers can determine the top priorities for mitigation, both in terms of the bycatch species and the mitigation options, and combinations thereof at a multi-species (ecological) level. The model requires an up front determination of the species being impacted by a given fishery, which are then assigned 'conservation values' or some form of risk assessment weighting based on existing criteria. Based on the groups of species being impacted, a list of all potential bycatch mitigation measures is then assembled, and a matrix drawn up of the potential positive or negative impact of any given measure on each species or species group. A mathematical modeling process then assigns weights to species value, factors these against mitigation measures, and prioritizes the top mitigation measures.

Piovano, S., Clo, S., & Giacoma, C. (2010). Reducing longline bycatch: The larger the hook, the fewer the stingrays. *Biological Conservation,* 143(1), 261-264. https://doi.org/10.1016/j.biocon.2009.10.001

Chondrichthyan populations in the Mediterranean Sea have been heavily affected by the impact of fishing activities. In the last two decades, even fishing gears that were traditionally considered highly selective, such as pelagic longlines, have been revealed to be responsible for the capture of many unwanted species. The pelagic stingray (Pteroplatytrygon violacea) is not an endangered nor a charismatic species, but it largely dominates longlines bycatch fractions. The aim of our study was to investigate the importance of three main variables, bait size, presence and type of light attractors, and hook size and shape, in the capture rate of pelagic stingrays. Ninety-seven longline experimental sets were run. Trials took place on nine vessels in the Strait of Sicily, central Mediterranean Sea, over a period of 3 years from 2005 to 2007. Results showed that the larger the J hook, the lower the stingray capture rate. Moreover, 16/0 circle hooks had a significantly lower number of stingrays captured per 1000 hooks than J hooks, up to approximate to 80%. Bait size, within the range of sizes assessed, and use of light attractors did not have significant effects on stingray catch rate. These results suggest that the adoption of large circle hooks by commercial and artisanal swordfish longlining may be a measure to reduce their environmental footprint.

Piovano, S., & Gilman, E. (2017). Elasmobranch captures in the Fijian pelagic longline fishery. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 27(2), 381-393. https://doi.org/10.1002/aqc.2666

Pelagic longline fisheries for relatively fecund tuna and tuna-like species can have large adverse effects on incidentally caught species with low-fecundity, including elasmobranchs. Analyses of observer programme data from the Fiji longline fishery from 2011 to 2014 were conducted to characterize the shark and ray catch composition and identify factors that significantly explained standardized catch rates. Catch data were fitted to generalized linear models to identify potentially significant explanatory variables. With a nominal catch rate of 0.610 elasmobranchs per 1000 hooks, a total of 27 species of elasmobranchs were captured, 48% of which are categorized as Threatened under the IUCN Red List. Sharks and rays made up 2.4% and 1.4%, respectively, of total fish catch. Blue sharks and pelagic stingrays accounted for 51% and 99% of caught sharks and rays, respectively. There was near elimination of ?shark lines?, branchlines set at or near the sea surface via attachment directly to floats, after 2011. Of caught elasmobranchs, 35% were finned, 11% had the entire carcass retained, and the remainder was released alive or discarded dead. Finning of elasmobranchs listed in CITES Appendix II was not observed in 2014. There were significantly higher standardized shark and ray catch rates on narrower J-shaped hooks than on wider circle hooks. Based on findings from previous studies on single factor effects of hook width and shape, the smaller minimum width of the J-shaped hooks may have caused the higher shark and ray catch rates. For sharks, the effect of hook width may have exceeded the effect of hook shape, where small increases in shark catch rates have been observed on circle vs J-shaped hooks. Shark and ray standardized catch rates were lowest in the latter half of the year. Focusing effort during the second half of the year could reduce elasmobranch catch rates. Copyright ? 2016 John Wiley & Sons, Ltd.

Piovano, S., & Swimmer, Y. (2017). Effects of a hook ring on catch and bycatch in a Mediterranean swordfish longline fishery: small addition with potentially large consequences. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 27(2), 372-380. https://doi.org/10.1002/aqc.2689

1. The purpose of this study was to investigate the effects of a circle hook ring on catch rates of target fish species and bycatch rates of sea turtles, elasmobranchs, and non- commercial fish in a shallow- set Italian swordfish longline fishery. 2. Results were compared from 65 sets from six commercial fishing vessels totalling 50 800 hooks in which ringed and non- ringed 16/ 0 circle hooks with a 10 degrees offset were alternated along the length of the longline. In total, 464 individuals were caught in the 4 years of experiment, with swordfish (Xiphias gladius) comprising 83% of the total number of animals captured. Catch rates of targeted swordfish were significantly higher on ringed hooks (CPUEringed hooks = 8.465, CPUEnon- ringed hooks = 6.654). 3. Results indicate that ringed circle hooks captured significantly more small- sized swordfish than non- ringed circle hooks (27.7% vs. 19.5%, respectively). 4. For species with sufficient sample sizes, the odds ratio (OR) of a capture was in favour of ringed hooks; significantly for swordfish (OR = 1.27 95% CI 1.04- 1.57), and not significantly for bluefin tuna (Thunnus thynnus) (OR = 1.50, 95% CI 0.68- 3.42) nor for pelagic stingray (Pteroplatytrigon violacea) (OR = 1.13, 95% CI 0.54- 2.36). All six loggerhead turtles (Caretta caretta) and three of the four blue sharks (Prionace glauca) were captured on ringed hooks, however, the small sample sizes prevented meaningful statistical analysis. 5. In summary, results from this study suggest that the addition of a ring to 16/ 0 circle hooks confers higher catchability for small- sized commercial swordfish, and does not significantly reduce catch rate of bycatch species and protected species in a Mediterranean shallow

pelagic longline fishery. 6. These findings should motivate fisheries managers to consider factors in addition to hook shape when aiming to promote sustainable fishing practices. The presence of a ring has the potential to negate some conservation benefits.

Poisson, F. (2009). *Fate of the fish caught on longline gears and potential mitigation measures.* IOTC-2009-WPEB-15. Indian Ocean Tuna Commission, Retrieved from https://archimer.ifremer.fr/doc/00129/24056/22023.pdf

This document summarises some major results obtained during experiments conducted in collaboration with the Reunion Island (France) (20°-22°N and 53°-57°N) fishing industry. These studies may aid fishermen in modifying fishing operations and selecting a fishing strategy to increase economic benefits and also to reduce the impact on bycatch mortality. Firstly, we investigated the behaviour of the fishes when caught on the longline gear and the survivorship of fish hooked, using longline gears instrumented with hook time recorders (HT) and temperature depth recorders (TDR). We showed that the percentages of fish recovered alive at hauling varied among species. The percentages of fish recovered alive up to 8 h after capture provides a rough idea of the resistance of each species to the capture process; these rates were recorded for the blue shark (Prionace glauca), the oceanic whitetip shark (Carcharhinus longimanus) and for the bigeye tuna (Thunnus obesus) and were respectively 29%, 23 % and 27% while this rate was lower for the swordfish (8%). Moreover, we demonstrated that shortening the soaking time during the fishing operation could be beneficial in many ways for fishermen. A second study on the reproduction dynamic of the swordfish in the vicinity of Reunion Island showed that the Big Old Fat Fecund Female Fish (BOFFFF) hypothesis could effectively apply to this species. Consequently, the removal of the larger, older individuals could be detrimental for the stock and the current results may be used, in the future, to support new policies preserving population age structure. One management method available to conserve older fish would be to institute slot size limits for retention (minimum and maximum size) but this potential measure to be successful need the individuals to survive their release back to the water. The last study aimed at investigating the possibility of developing a method to reduce the stress of the fishes caught with hooks. Prototypes of “sleeping hook” were developed and tested, using rod and reel, around moored fish aggregating devices (FAD’s). During the fishing experiments a total of 162 fish comprising 3 main species were caught including: yellowfin tuna (Thunnus albacares), skipjack tuna (Katsuwonus pelamis) and dolphinfish (Coryphaena hippurus). Analyses of blood chemistry stress indicators revealed the “sleeping hook” method to be successful in reducing the fish stress. Additional research should be conducted to evaluate the feasibility of reducing the soaking period in the current fishing strategy. However, the “sleeping hook” could contribute to the development of alternative fishing technology enabling also to reduce the side effect of protracted soaking times e.g. by reducing post hooking mortality and increasing the post release survivorship of species of conservation concern and unwanted sized target species.

Poisson, F., Abascal Crespo, F., Ellis, J. R., Chavance, P., Pascal, B., Santos, M. N., . . . Murua, H. (2016). Technical mitigation measures for sharks and rays in fisheries for tuna and tuna-like species: turning possibility into reality. *Aquatic Living Resources,* 29(4). https://doi.org/10.1051/alr/2016030

Tuna fisheries have been identified as one of the major threats to populations of other marine vertebrates, including sea turtles, sharks, seabirds and marine mammals. The development of technical mitigation measures (MM) in fisheries is part of the code of conduct for responsible fisheries. An in-

depth analysis of the available literature regarding bycatch mitigation in tuna fisheries with special reference to elasmobranchs was undertaken. Studies highlighting promising MMs were reviewed for four tuna fisheries (longline, purse seine, driftnets and gillnet, and rod and line - including recreational fisheries). The advantages and disadvantages of different MMs are discussed and assessed based on current scientific knowledge. Current management measures for sharks and rays in tuna Regional Fishery Management Organizations (t-RFMOs) are presented. A review of relevant studies examining at-vessel and postrelease mortality of elasmobranch bycatch is provided. This review aims to help fisheries managers identify pragmatic solutions to reduce mortality on pelagic elasmobranchs (and other higher vertebrates) whilst minimizing impacts on catches of target tuna species. Recent research efforts have identified several effective MMs that, if endorsed by t-RFMOs, could reduce elasmobranchs mortality rate in international tropical purse seine tuna fisheries. In the case of longline fisheries, the number of operational effective MMs is very limited. Fisheries deploying driftnets in pelagic ecosystems are suspected to have a high elasmobranchs bycatch and their discard survival is uncertain, but no effective MMs have been field validated for these fisheries. The precautionary bans of such gear by the EU and by some t-RFMOs seem therefore appropriate. Recreational tuna fisheries should be accompanied by science-based support to reduce potential negative impacts on shark populations. Priorities for research and management are identified and discussed.

Poisson, F., Arnaud-Haond, S., Demarcq, H., Métral, L., Brisset, B., Cornella, D., & Wendling, B. (2019). French Bluefin Tuna Longline Fishery Bycatch Programme. In *Oceanography Challenges to Future Earth.* (pp. 401-405) https://doi.org/10.1007/978-3-030-00138-4_31

During the last decade, particular attention has been paid worldwide to the problem of bycatch and discards in fisheries. Collaborative research between fishermen and scientists is important to fisheries management. Partnerships with commercial longline fishermen were developed to enable them to participate in two research projects in order to integrate their information, experience and expertise. These programmes, financed by the fishing industry and regional councils were designed to describe the activity of the fisheries, to assess the scale of fishery effects on the various taxa, to study the ecology and explore spatial population genetic structure in the western part of the Mediterranean Sea of the blue shark (Prionace glauca) and sting rays (Pteroplatytrygon violacea) and finally to propose mitigation measures to reduce impacts on elasmobranchs, sea birds and sea turtles. Communication, education, post-implementation monitoring and long-standing collaboration are the key factors to success. This presentation shows the progress realized to date.

Poisson, F., Budan, P., Coudray, S., Gilman, E., Kojima, T., Musyl, M., & Takagi, T. (2022). New technologies to improve bycatch mitigation in industrial tuna fisheries. *Fish and Fisheries,* 23(3), 545-563. https://doi.org/10.1111/faf.12631

For many years, tremendous effort has been dedicated to developing new industrial tuna fisheries, while their adverse impacts on threatened marine species have received relatively little attention. In tuna fisheries, bycatch is the major anthropogenic threat to marine megafauna in general, particularly sharks. Research on the development of gear technology for bycatch reduction and potential mitigation measures helped tuna Regional Fisheries Management Organizations adopt bycatch reduction management measures. After reviewing past research on the development of mitigation measures for pelagic longline and tropical purse seine fisheries based on pelagic species' behaviours, we describe promising new approaches integrating recent technological breakthroughs. New innovations include

autonomous underwater vehicles carrying cameras along with miniaturized sensors, aerial drones, computer simulation of fishing gear geometry, environmental DNA assays, computer visualizations and deep learning. The successful application of such tools and methods promises to improve our understanding of factors that influence capture, escape and stress of caught species. Moreover, results emerging from recent ethological research explaining the power of social connection and learning in the "fish world" such as social learning from congeners, habituation to deterrents, and how past fishery interactions affect responses to fishing gear should be taken into account when developing technical mitigation measures.

Poisson, F., Gaertner, J.-C., Taquet, M., Durbec, J.-P., & Bigelow, K. (2010). Effects of lunar cycle and fishing operations on longline-caught pelagic fish: fishing performance, capture time, and survival of fish. *Fishery Bulletin,* 108(3), 268-281. Retrieved from https://spo.nmfs.noaa.gov/content/effects-lunar-cycle-and-fishing-operations-longline-caught-pelagic-fish-fishing-performance

Commercial longline fishing data were analyzed and experiments were conducted with gear equipped with hook timers and time-depth recorders in the Reunion Island fishery (21 degrees 5'S lat., 53 degrees 28'E long.) to elucidate direct and indirect effects of the lunar cycle and other operational factors that affect catch rates, catch composition, fish behavior, capture time, and fish survival. Logbook data from 1998 through 2000, comprising 2009 sets, indicated that swordfish (Xiphias gladius) catch-per unit of effort (CPUE) increased during the first and last quarter of the lunar phase, whereas albacore (Thunnus alalunga) CPUE was highest during the full moon. Swordfish were caught rapidly after the longline was set and, like bigeye tuna (Thunnus obesus), they were caught during days characterized by a weak lunar illumination-mainly during low tide. We found a significant but very low influence of chemical lightsticks on CPUE and catch composition. At the time the longline was retrieved, six of the 11 species in the study had >40% survival. Hook timers indicated that only 8.4% of the swordfish were alive after 8 hours of capture, and two shark species (blue shark [Prionace glauca] and oceanic whitetip shark [Carcharhinus longimanus]) showed a greater resilience to capture: 29.3% and 23.5% were alive after 8 hours, respectively. Our results have implications for current fishing practices and we comment on the possibilities of modifying fishing strategies in order to reduce operational costs, bycatch, loss of target fish at sea, and detrimental impacts on the environment.

Porsmoguer, S. B., Bănaru, D., Boudouresque, C. F., Dekeyser, I., & Almarcha, C. (2015). Hooks equipped with magnets can increase catches of blue shark (Prionace glauca) by longline fishery. *Fisheries Research,* 172, 345-351. https://doi.org/10.1016/j.fishres.2015.07.016

Blue shark (Prionace glauca) populations are decreasing worldwide and the species is currently classified as near threatened. However, it is the main species caught by the Spanish and Portuguese longline fisheries; and blue shark is specifically targeted by a part of these fleets in the northeastern Atlantic Ocean. Sharks are well known to be able to detect electric fields in the microvolt range and this sense has been proposed to provide a mechanism to detect the earth's magnetic field. As a result, the use of magnets has been proposed as a method to reduce shark interactions with fishing gear. We therefore tested two models of high field strength neodymium magnets to effect shark catch rates during commercial longline fishing operations. Our results show that magnets do not reduce blue shark catch rates and can even have an attractive effect. This effect was significantly higher for the larger magnet model tested (26mm×11mm×12mm, 0.885T) compared to the smaller one (20mm×13mm×15mm,

0.464T). We also noted that hooks remain magnetized after removal of the magnets and are even slightly magnetized without any previous contact with a magnet.

Prior, J. (2017). *Protection On The Move: Applying Dynamic Ocean Management To Address Shark Bycatch In Atlantic Canada.* (Masters of Marine Management), Dalhousie University, Retrieved from http://hdl.handle.net/10222/73837

The Canadian North Atlantic pelagic longline fishery for swordfish and tuna has unintended bycatch of porbeagle, shortfin mako, and blue sharks. This creates concerns for species-at-risk populations, ecosystem health, harvesters safety and economic security. This study proposes that a Dynamic Ocean Management (DOM) application could mitigate the pelagic shark bycatch associated with this longline fishery. The document reviews published information on the focal shark species, the fishery, current marine spatial management tools used in Canada, and theory and applications of DOM. Following this, the study evaluates the attitudes of 14 primary stakeholders towards DOM through stakeholder group governance analysis and semi-structured interviews. The associated stakeholders who participated in the project include one participant from each of the regional RFMOs; NAFO and ICCAT, three participants from DFO, one participant from the Nova Scotia Swordfish Association, four NGO perspectives, two academic perspectives, and two private third-party interest groups. In the interviews, all individuals discussed their views on the bycatch challenge, the desirability and feasibility of applying DOM, and the current efforts undertaken by each group. The results of this study show that a DOM application is seen as a desirable potential solution by most and could be feasible depending on project structure and management style. Therefore, based on the considerations of the governance analyses and interview responses, a management plan is proposed and associated requirements, considerations, and concerns are discussed. Specifically, the plan proposes a management tool in the style of a phone app or website interface. This interface would allow harvesters to geo-tag areas where shark bycatch has impacted their catch in near-real time. When overlaid with other data streams, including historical seasonal data, ocean conditions and species tracking, it allows the whole fleet to strategically plan their next location to set their longlines, with an active consideration to avoid sharks.

Promjinda, S., Siriraksophon, S., Darumas, N., & Chaidee, P. (2008). Efficiency of the circle hook in comparison with J-hook in longline fishery. In *The Ecosystem-Based Management Fishery in the Bay of Bengal.* (pp. 167-181): Ministry of Agriculture and Cooperatives, Thailand Retrieved from http://map.seafdec.org/downloads/BIMSTEC/015-Efficiency-Sayan.pdf

Tests were conducted aboard pelagic longline vessels in the Bay of Bengal to determine if there were differences in the catch composition, catch rate, hooking position or length frequency of target and bycatch species caught with circle and J-hooks. Circle hooks caught similar percentages of both target (46.7%) and bycatch (53.3%) species, while J-hooks caught a higher percentage of bycatch (74.5%) species. Catch rates for the target species were higher for circle hooks (2.2 individuals/1,000 hooks) compared to J-hooks (1.9 individuals/1,000 hooks). In contrast, catch rates for the bycatch species were higher on J-hooks (5.6 individuals/1,000 hooks) than circle hooks (2.6 individuals/1,000 hooks). For the target species, swordfish had the higest catch rates for both hook types but catch rates were slightly higher on circle hooks. Close to three quarters (73.3%) of fish were hooked in the mouth when circle hooks were used while only half (53%) were hooked in the mouth, and 38% in the digestive system, when J-hooks were used. Swordfish caught with J-hooks were slightly larger (mode of 250-269 cm) than those caught with circle hooks (mode 210-229 cm).

Reinhardt, J. F., Weaver, J., Latham, P. J., Dell'Apa, A., Serafy, J. E., Browder, J. A., . . . Blankinship, D. R. (2018). Catch rate and at-vessel mortality of circle hooks versus J-hooks in pelagic longline fisheries: A global meta-analysis. *Fish and Fisheries,* 19(3), 413-430. https://doi.org/10.1111/faf.12260

We conducted a meta-analysis of literature reporting on the use of circle hooks and J-hooks in pelagic longline fisheries. Our study included more data than previous meta-analyses of the effects of hook type, due to both a larger number of relevant studies available in recent years and a more general modelling approach. Data from 42 empirical studies were analysed using a random effects model to compare the effects of circle hooks and J-hooks on catch rate (43 species) and at-vessel mortality (31 species) of target and bycatch species. Catch rates with circle hooks were greater for 11 species, including four tuna species, six shark species and one Istiophorid billfish. Catch rates on circle hooks were lower for seven species, including two Istiophorid billfishes and two species of sea turtle. At-vessel mortality was significantly lower with circle hooks in 12 species, including three tuna species, three Istiophorid billfishes, swordfish (Xiphias gladius) and three shark species. No species had significantly greater at-vessel mortality when captured with a circle hook rather than a J-hook. While our general approach increased model variability compared to more detailed studies, results were consistent with trends identified in previous studies that compared the catch rates and at-vessel mortality (between hook types) for a number of species. Our results suggest that circle hooks can be a promising tool to reduce mortality of some bycatch species in pelagic longline fisheries, although the effects depend on the species and the metric (catch rate or at-vessel mortality), emphasizing the need for fishery-specific data in conservation and management decisions.

Rice, P. H., Goodyear, C. P., Prince, E. D., Serafy, J. E., & Snodgrass, D. (2006). Hook Time At Depths For Experimental Longline Sets In The Windward Passage In 2003. *Collective volume of scientific papers,* 59(1), 170-181. Retrieved from https://www.iccat.int/Documents/CVSP/CV059_2006/n_1/CV059010170.pdf

We monitored hook time at depth for experimental longlines set in the Windward Passage in 2003 using time depth recorders (TDRs) attached at regular intervals along the mainline. The TDRs were placed on every 13 th hook (~43 TDRs per set) resulting in a 7-9% coverage at the deepest point in the corresponding basket and once in every section of the set, an additional TDR was placed on the shallowest hook in a specific predetermined basket. The experiment monitored ten pelagic longline sets with an average distance of 46.9 + 2.8 kilometers (25.3 + 1.5 nautical miles). Thirteen taxa of fish were caught by the longline fishing gear. The target species were swordfish (46% total catch) and tuna (24% total catch). Marlin dominated the bycatch (15% of the total catch) and sharks comprised the remainder of the fish by-catch (7% total catch). Time at depth for individual instruments was a poor predictor of time at depth for the other TDRs at the same hook position on the same set, and an even worse predictor of the depths fished on other sets.

Rice, P. H., Serafy, J. E., Snodgrass, D., & Prince, E. D. (2012). Performance Of Non-Offset And 10 Degrees Offset 18/0 Circle Hooks In The United States Pelagic Longline Fishery. *Bulletin of Marine Science,* 88(3), 571-587. https://doi.org/10.5343/bms.2011.1095

Industry standard fishing hooks used prior to 2004 during US commercial pelagic longline (PLL) fishing were the 8/0-10/0 J-hooks with a 20 degrees-25 degrees offset-a lateral deviation of the hook point

relative to the hook shaft. However, federal regulations enacted in 2004 require the US PLL industry to employ circle hooks allowing up to 10 degrees offset during fishing operations. Until recently, there have been no studies directly comparing the performance of non-offset and 10 degrees offset circle hooks in commercial PLL applications. Our study alternated non-offset and 10 degrees offset circle hooks along the gear length on individual PLL deployments in the western North Atlantic, Gulf of Mexico, and Windward Passage in the Caribbean Sea. The study compared the relative performance of both hook types in terms of: (1) catch rates, (2) percent mortality, and (3) the percentage of deep-hooked target and bycatch species. For swordfish, Xiphias gladius (Linnaeus, 1758), several experiments indicate: (1) marginally higher catch rates, (2) significantly lower mortality, and (3) significantly less deep hooking on non-offset than 100 offset circle hooks. Most of the performance differences for blue marlin, Makaira nigricans Lacepede, 1802, were insignificant; however, one study produced significantly higher mortality on 10 degrees offset than non-offset circle hooks. The present study suggests that, relative to non-offset circle hooks, 10 degrees offset circle hooks may reduce fishing efficiency and can counteract the conservation benefits commonly associated with circle hooks (e.g., lower mortality). However, additional research is required to assess the effects of offset hooks on tunas, billfishes, and elasmobranchs.

Roberson, L. A., & Wilcox, C. (2022). Bycatch rates in fisheries largely driven by variation in individual vessel behaviour. *Nature Sustainability*. https://doi.org/10.1038/s41893-022-00865-0

Fisheries bycatch continues to drive the decline of many threatened marine species such as seabirds, sharks, marine mammals and sea turtles. Management frameworks typically address incidental catch with fleet-level controls on fishing. Yet, individual operators differ in their fishing practices and efficiency at catching fish. If operators have differing abilities to target, they should also have differing abilities to avoid bycatch. We analysed variations in threatened species bycatch among individual operators from five industrial fisheries representing different geographic areas, gear types and target species. The individual vessel is a significant predictor of bycatch for 15 of the 16 cases, including species that represent high or low costs to fishers or have economic value as potentially targeted byproducts. Encouragingly, we found high-target and low-bycatch operators in all five sectors, including gears known for high bycatch mortality worldwide. These results show that there is untapped opportunity to reduce negative environmental impacts of fisheries with interventions targeting specific performance groups of individuals, supporting an alternative perspective towards managing global fisheries.

Rodrigues, L. d. S., Kinas, P. G., Cardoso, L. G., & O'Neill, F. (2022). Optimal setting time and season increase the target and reduce the incidental catch in longline fisheries: a Bayesian beta mixed regression approach. *ICES Journal of Marine Science,* 79(4), 1245-1258. https://doi.org/10.1093/icesjms/fsac049

Sustainable fisheries' managers increasingly seek to implement measures that reduce the mortality of threatened species while maintaining or increasing catch of target species. Our study proposed a simple management option for optimizing fishing over daily and seasonal scales to maximize catch success while protecting non-target species in pelagic longline fisheries. We used Bayesian beta mixed regression models to describe the effects of setting times and seasonality on catches in a pelagic longline fishery in the southwest South Atlantic Ocean (SWAO). Targeted species (swordfish, blue shark, and albacore tuna) are typically captured in fully nocturnal sets (started between 16 and 00 h), whereas shortfin mako shark and loggerhead turtles are typically captured during partially nocturnal sets (started

between 00 and 04 h); probably a response to hook depth and circadian behaviours. The results suggest that it is feasible to use only fully nocturnal sets to target preferred species while reducing incidental catch of non-target species. The catch of target species was higher in austral winter, explained by the northward displacement of the subtropical convergence in the SWAO during this season. These results provide a baseline for bycatch mitigation strategies in pelagic longline fisheries at regional and global scales.

Rosa, D., Santos, C. C., & Coelho, R. (2020). Assessing the effects of hook, bait and leader type as potential mitigation measures to reduce bycatch and mortality rates of shortfin mako: a meta-analysis with comparisons for target, bycatch and vulnerable fauna interactions. *Collective volume of scientific papers,* 76, 247-278. Retrieved from http://www.iccat.es/en/pubs_CVSP.htm

A meta-analysis of 24 publications was conducted to assess effects of hook, bait and leader type on retention rates of target, bycatch and vulnerable species of the pelagic longline fishery. Retention rate and at-haulback mortality rate analyses considered hook type, bait type, the combination of both variables and leader type. Turtles and swordfish had a lower retention rate with circle hooks. In contrast, retention rates of 3 sharks and 2 tuna species were greater with circle hooks. Bait type alone did not seem to significantly influence the retention rates of most of the species examined. Results were mixed when considering the combined effects of hook and bait type. Wire leader led to a decrease in retention rates of bony fishes and a mix for elasmobranchs. For at-haulback mortality, hook type was the most influential, while bait type only influenced blue shark at-haulback mortality. Leader type did not have a significant effect. The results presented here should be considered preliminary. Future work will consider information on at-haulback mortality rates for bony fishes and sea turtle and expanded information on fishery characteristics.

Sacchi, J. (2019). *Mitigation Measures for Protected Species.* Paper presented at the Seventh Meeting of the Parties to ACCOBAMS. Retrieved from https://accobams.org/wp-content/uploads/2019/04/MOP7.Doc30_Mitigation-measures-for-protected-species.pdf

Highly migratory for the most part, occupying a wide distribution across the oceans, the marine megafauna undergo all possible forms of human pressure. Among them, bycatch fishery has increased exponentially in recent years and is now considered the most serious threat to these highly vulnerable species. Minimizing bycatch, is therefore a key component of sustainable fisheries management to maintain marine biodiversity and consequently to reduce negative effects on the resources (see Hall, 1996; Hall et al., 2000). The aim of this document is to present various experimented approaches and strategies that could also serve as an example for fisheries facing the same problems. This review of the different mitigation measures draws on the analysis of the available literature, comprising scientific journal articles together with reports from international organisations and documents available on the internet. The presentation adopted here is guided by the principle that it is not species that should be managed but fishing activities (metiers)1 that should be the target of the technical or management measures that are required to reduce the negative impacts of interactions with fisheries. Consequently, for each of the main fishing gear groups (gill and trammel nets, longlines and lines, trawls, purse seines, trapnets and pots) the various solutions found in the documents consulted are classified by the four main groups of protected species (Cetaceans, Birds, Sharks and Sea turtles).

Saidi, B., Echwikhi, K., Enajjar, S., Karaa, S., Jribi, I., & Bradai, M. N. (2020). Are circle hooks effective management measures in the pelagic longline fishery for sharks in the Gulf of Gabès? *Aquatic Conservation: Marine and Freshwater Ecosystems,* 30(6), 1172-1181. https://doi.org/10.1002/aqc.3315

This study evaluated the circle hook use as a tool for shark management in the pelagic longline fishery in the Gulf of Gabès. The usual J-hook No. 2 with 10° offset, which has been traditionally used by the fishery, was compared to the 18/0 non-offset circle hook in an alternating fashion along the main line. In total, 22 experimental longline sets were deployed through the shark fishing seasons of 2016 and 2017 to examine the effects of hook types on the catch composition, the catch rates, the hooking location, and the status at haulback. The catch composition differed significantly among hook types. Moreover, an overall increase in catch rates for the main species, the sandbar shark Carcharhinus plumbeus, and the shortfin mako shark Isurus oxyrinchus, was observed when using circle hooks. There was no size-selective effect of circle hooks for the common species. The circle hooks were not effective at reducing at-haulback mortality of sandbar shark. Conversely, shortfin mako and smooth-hound shark Mustelus mustelus showed significantly lower relative mortality at haulback with circle hooks than with J-hooks. Furthermore, circle hooks were more frequently hooked externally than the J-hooks for the three shark species. Results demonstrated that the use of 18/0 non-offset circle hooks in the pelagic shark longline fishery can reduce mortality at haulback for some species without any benefit for the dominant species, the sandbar shark. Overall, it is difficult to promote the adoption of the use of circle hooks as a management measure in this specialized fishery. Management measures focusing on fishing effort controls, fishing closures in critical habitats, and size limits could have significant benefits for the conservation of shark species and may help to improve the sustainability of the shark fishery in the Gulf of Gabès.

Schaefer, K., Fuller, D., Castillo-Geniz, J. L., Godinez-Padilla, C. J., Dreyfus, M., & Aires-da-Silva, A. (2021). Post-release survival of silky sharks (Carcharhinus falciformis) following capture by Mexican flag longline fishing vessels in the northeastern Pacific Ocean. *Fisheries Research,* 234, 105779. https://doi.org/10.1016/j.fishres.2020.105779

Mexican flag longline fishing vessels operating in tropical waters of the northeastern Pacific Ocean commonly target and land silky sharks (Carcharhinus falciformis). In this study silky sharks captured by Mexican flag longline fishing vessels in the northeastern Pacific Ocean and brought onboard were tagged and released with pop-up satellite archival tags (PSATs), following removal of hooks or cutting gangions as close to the hook as feasible, to evaluate their post-release survival (PRS). The PRS rate estimated using Kaplan - Meier survival analyses was 84.8 % (95 % CI: 71.0 %–100 %) for 63 silky sharks. Utilizing a rope noose to lift sharks aboard vessels was demonstrated to be an effective handling method. The 58 silky shark survivors were at liberty with PSATs attached for an average of 102 days (range: 1–298 d). Average linear displacement for 46 silky sharks at liberty for > 30 d was 512 nmi (range: 45–927 nmi), indicating relatively rapid widespread dispersion from release locations.

Scott, M., Cardona, E., Scidmore-Rossing, K., Royer, M., Stahl, J., & Hutchinson, M. (2022). What's the catch? Examining optimal longline fishing gear configurations to minimize negative impacts on non-target species. *Marine Policy,* 143, 105186. https://doi.org/10.1016/j.marpol.2022.105186

Changes to fishing gear configurations have great potential to decrease fishing interactions, minimize injury and reduce mortality for non-target species in commercial fisheries. In this two-part study, we investigate potential options to optimize fishing gear configurations for United States Pacific pelagic longline vessels to maintain target catch rates whilst reducing bycatch mortality, injury, and harm. In part one, a paired-gear trial was conducted on a deep-set tuna longline vessel to compare catch rates and catch condition of target and non-target species between wire and monofilament leader materials. Temperature-depth recorders were also deployed on hooks to determine sinking rates and fishing depth between the two leader materials. In part two, hooks of different configurations (size, diameter, shape, metal type, and leader material) were soaked in a seawater flume for 360 days to obtain quantitative estimates of breaking strength, as well as the time taken for gear to break apart. We found that switching from wire to monofilament leaders reduced the catch rate of sharks by approximately 41 %, whilst maintaining catch rates of target species (Bigeye tuna, Thunnus obesus). However, trailing gear composed of monofilament did not break apart even after 360 days. In contrast, branchlines with wire leaders began to break at the crimps after approximately 60 days. Additionally, the breaking strength of soaked fishing hooks was greater for larger, forged hooks composed of stainless steel typically used in United States Pacific longline fisheries. These results have direct implications for fisheries management and the operational effectiveness of bycatch mitigation strategies for longline fisheries worldwide.

Serafy, J. E., Orbesen, E. S., Snodgrass, D. J. G., Beerkircher, L. R., & Walter, J. F. (2012). Hooking Survival Of Fishes Captured By The United States Atlantic Pelagic Longline Fishery: Impact Of The 2004 Circle Hook Rule. *Bulletin of Marine Science,* 88(3), 605-621. https://doi.org/10.5343/bms.2011.1080

We examine the impact on pelagic fish hooking survival rates (defined as the proportion of fish alive upon gear retrieval) of the rapid switch from J-hooks to circle hooks that was required of the US pelagic longline fishery operating in the Atlantic Ocean and Gulf of Mexico after August 2004. Our focus was on 12 fish taxa that are commonly caught as bycatch or retained for the market, and for which individual disposition (live or dead) information was available from 1992 to 2010. To test the hypothesis of no change in survival before vs after the circle hook rule went into effect, we utilized a repeated measures logistic regression approach which accounted for variation in several operational, environmental, and biological covariates, including bait, fishery target, fishing zone, soak duration, water temperature, maximum fishing depth, and fish size (length). For white marlin and albacore, results were mixed, with both increases and decreases in hooking survival varying by fishing zone. For blue shark and lancetfish, no significant differences in hooking survival were detected between the pre- and post-circle hook rule time periods. However, for the remaining eight taxa (swordfish, yellowfin tuna, dolphinfish, bigeye tuna, escolar, silky shark, blue marlin, and sailfish), significant increases in survival were evident. Our results are generally consistent with previous experimental and fishery observer longline studies which suggested circle hook use has the potential to increase hooking survival. Results imply that the 2004 circle hook rule has provided increased opportunities for: (1) live release for several bycatch species; and (2) improved quality (and perhaps prices) of targeted and incidentally-caught taxa that are retained for the market.

Silva, P. M., Teixeira, C. M., Pita, C., Cabral, H. N., & Franca, S. (2021). Portuguese Artisanal Fishers' Knowledge About Elasmobranchs-A Case Study. *Frontiers in Marine Science,* 8. https://doi.org/10.3389/fmars.2021.684059

The high economic value of fisheries was historically associated to commercial teleost fishes. Since the 1970s, despite some elasmobranchs becoming an important target or a bycatch, relatively little research has been carried out on this group because of their low economic value. Due to their specific life history characteristics, sharks and rays are particularly vulnerable to overexploitation, taking several decades to recover after reaching an overexploitation status. In Portugal elasmobranch fishery results mainly from targeted longlining and bycatch from different fishing gears. During the last decade, the Total Allowable Catches (TACs) of rays have been decreasing, the European Union (EU) banned the capture of some ray species, the Portuguese government implemented both a closed season and a minimum landing size for some rays, and the EU prohibited target fishing for sharks. All these measures may have been highly responsible for the national and local landings reduction. Official landings from the last decade were analyzed, the landed species conservation status was consulted, and structured interviews using a questionnaire were conducted in the most important fishing port in the Portuguese mainland, the port of Sesimbra. Results led us to conclude that fishers' answers and landings data did not match. It also revealed a lack of awareness by fishers about the state of shark and ray populations, and about some aspects of their biology and ecology, like reproduction season and method. The present study highlights the need to fill in this existing gap in knowledge through the transfer of scientific knowledge and sharing of management responsibilities. Also, we aimed to demonstrate the necessity for awareness and education activities within fishing communities, an essential step to elasmobranch conservation.

Smith, L. E., & O'Connell, C. P. (2014). The effects of neodymium-iron-boron permanent magnets on the behaviour of the small spotted catshark (Scyliorhinus canicula) and the thornback skate (Raja clavata). *Ocean & Coastal Management,* 97, 44-49. https://doi.org/10.1016/j.ocecoaman.2013.05.010

Elasmobranchs (sharks, skates, and rays) are frequently captured as bycatch on a wide variety of fishing gears, such as pelagic longlines and hook-and-line fisheries, and therefore many species have experienced severe population declines. To reduce elasmobranch bycatch, scientists have begun exploring the effectiveness and potential application of elasmobranch-specific repellents, such as permanent magnets and electropositive metals. For the present study, the behavioural responses of captive small spotted catsharks (Scyliorhinus canicula) and thornback skates (Raja clavata) were observed in response to neodymium-iron-boron (Nd2Fe14B) permanent magnets. Results demonstrate that both R. clavata and S. canicula; (1) significantly avoided the Nd2Fe14B magnets more often in comparison to the control and procedural control and (2) significantly fed from the control and procedural control more often in comparison to the Nd2Fe14B magnets. Data also suggests a relationship between water temperature and the avoidance distance by R. clavata, with closer approaches prior to avoidance occurring in association with water temperatures of <= 12 degrees C. Additionally, the tail beat frequency associated with the avoidance behaviour of S. canicula was significantly slower (<= 9 beats/10 s) in water temperatures of <= 12 degrees C. The findings from this study agree with previous electrosensory repellent studies, in that elasmobranchs detect and are deterred by permanent magnets however, the present study also demonstrated that there is a correlation between avoidance speed and distance with water temperature. These findings suggest that water temperature may be correlated to magnetic repellent effectiveness and thus warrants further experimentation.

Song, K. S., Moon, D.-Y., Boggs, C., Koh, J.-R., & An, D.-H. (2006). Comparison of circle hook and J hook catch rate for target bycatch species taken in the Korean tuna longline fisher. *Journal of the Korean Society of Fisheries and Ocean Technology,* 42(4), 210-216. https://doi.org/10.3796/KSFT.2006.42.4.210

The circle hook experiments were conducted to compare the catch rates of target and bycatch species between J hook and circle hooks in the tuna longline fishery of the eastern Pacific Ocean between 1Â°48'S-7Â°00'S and 142Â°00' -149Â°13'W from July 15 to August 12, 2005. In the target species group no significant differences among 3 types hook, between size 4.0 traditional tuna hooks(J-4) and size 15 circle hooks(C15), and between C15 and size 18 circle hooks(C18) were revealed, but significant differences were found between J-4 and C18. In the bycatch species group significant differences were found among 3 types hook, between J 4 and C15, and between J-4 and C18, but no significant differences were revealed between C15 and C18. Large circle hook(C18) had the lowest catch rate for tunas and for other fishes, and the small circle hook(C15) had lowest rate for billfishes and sharks. The length distributions for bigeye tuna are very similar for the 3 hook types. There were very slight differences in length size between hook types in the bycatch species.

Song, L. (2015). Effects of environmental factors and fishing gear on catch rates of silky shark (Carcharhinus falciformis) in waters near Gilbert Islands. *Journal of fisheries of China,* 39(1), 147-159. https://doi.org/10.3724/SP.J.1231.2015.59354

At present, many scientists pay more attention to the incidental catch of top predator of food chain in longline fisheries, such as sharks, sea turtles and sea birds. Given the long life span and relatively low reproductive capacity of many shark species ,reducing the incidental catch of sharks during commercial fishing operations is thus critical in the conservation of shark species. In 1999, FAO promulgated the International Plan of Action for the Conservation and Management of Sharks. In order to protect the marine environment and conserve the shark species,many countries and regions declared a law prohibiting commercial shark fishing in its national waters. Shark's habitat environment is complex with respect to both spatial and temporal variations. Mechanisms of their migration are not fully understood even though many studies suggested that they might be related to the behavior and dynamics of zooplankton. The effective fishing gears and methods to mitigate the incidental catch rate of Carcharhinusfalciformis and the effects of 16/0 and 18/0 circle hooks to the incidental catch rate of C. falciformis should be studied further. Based on these studies, the robust results could be obtained and could be used to reduce the incidental catch rate of C. falciformis effectively. On the other hand, there were many studies about the biological characteristics of C. falciformis, but the studies about the impacts of marine environment on the incidental catch rate of C. falciformis were rare. The aim of this study is to reduce the incidental catch rate of C. falciformis in longline fisheries. In this study, the mean nominal catch rates of C. falciformis and environmental variables were obtained from two longlining surveys in waters near Gilbert Islands from 4 October 2009 through 25 December 2009 and from 20 November 2010 through 20 January 2011. Data included: hook depth data ,temperature, salinity,dissolved oxygen concentration and chlorophyll concentration vertical profile data, operating parameters, catch statistics. Stepwise regression was used to develop the hook depth calculation model. Wilcoxon-test was used to test if there were significant differences among C.falciformis incidental catch rates of four kinds of fishing gear or hook types. Statistics and clustering analysis were used to analyze environmental effects on the C. falciformis catch rate. Results showed that: (1)C.falciformis incidental catch rate can be significantly reduced by using the experimental gear or 18/0 circle hook; (2) the depth, temperature, salinity, chlorophyll concentration and dissolved oxygen (DO) range with the high

incidental catch rate for C.falciformis was 40.0-79.9m,24.0-24.9 degree C and 29.0-29.9 not equal to , 35.40-35.99,0.120-0.199 mu g/L, and 4.50-4.99 mg/L, respectively. This study suggests that: (1) the numbers of 18/0 circle hook or hook deeper than 120 m should be increased; (2)the numbers of hook should be reduced in the higher incidental catch rate ranges of hook depth, temperature, salinity, dissolved oxygen concentration and chlorophyll concentration.

Stoner, A. W., & Kaimmer, S. M. (2008). Reducing elasmobranch bycatch: Laboratory investigation of rare earth metal and magnetic deterrents with spiny dogfish and Pacific halibut. *Fisheries Research,* 92(2-3), 162-168. https://doi.org/10.1016/j.fishres.2008.01.004

Spiny dogfish (Squalus acanthius) comprises a significant unwanted bycatch on demersal longlines set for halibut and cod in shelf waters of the east and west coasts of North America. In this laboratory study, attacks on baits were tested in the presence of two different rare earth materials (neodymium-iron-boride magnets and cerium mischmetal) believed to deter elasmobranch catch. Experiments were made with spiny dogfish and with Pacific halibut (Hippoglossus stenolepis) in pairwise tests of the rare earth materials and inert metal controls. Dogfish attacked and consumed baits tested with cerium mischmetal at a lower frequency than controls. Times to attack the baits were significantly higher in the presence of mischmetal, as were numbers of approaches before first attack. The time differential between mischmetal and control treatments and the number of baits consumed converged with increasing food deprivation (1 h, 2 d, and 4 d), but treatment differences were always significant. Cerium mischmetal appeared to be irritating to dogfish and may disrupt their bait detection and orientation abilities. Magnets also appeared to irritate dogfish but provided no protection for baits in feeding trials. Pacific halibut showed no reaction whatsoever to the rare earth magnets or cerium mischmetal. Mischmetal, therefore, may be useful in reducing spiny dogfish bycatch in the halibut fishery. Disadvantages in using mischmetal in commercial operations are expense, hazardous nature, and relatively rapid hydrolysis in seawater.

Sulikowski, J. A., Golet, W., Hoffmayer, E. R., Driggers, Natanson, L. J., Carlson, A., & Sweezey, B. B. (2020). Observing post-release mortality for dusky sharks, Carcharhinus obscurus, captured in the US pelagic longline fishery. *Fisheries Research,* 221. https://doi.org/10.1016/j.fishres.2019.105341

The latest stock assessment for the dusky shark, Carcharhinus obscutus, in the western North Atlantic Ocean indicates the population is overfished and experiencing overfishing. As part of a rebuilding plan, the commercial and recreational retention of dusky sharks has been prohibited since 2000. Despite this prohibition, dusky sharks are bycatch in multiple fisheries, including the pelagic longline fishery; however, post-release mortality (PRM) rates have not been empirically determined for this gear. Herein we estimated PRM of dusky sharks captured by the US pelagic longline fleet in the western North Atlantic Ocean utilizing pop-up satellite archival transmitting (PSAT) tags. One hundred and twenty three dusky sharks were captured on commercial pelagic longline gear and time on the hook, based on hook timer data, ranged from 0.8 to 8.1 h (4.3 +/- 0.28 h). No at-vessel mortality (AVM) was observed for any dusky sharks in this study. Prior to release, 50 PSAT LIFE tags (Lotek Inc.) were attached to dusky sharks (females n = 12, 209 +/- 8 cm FL; males n = 4, 198 +/- 7 cm FL; unknown sex n = 34, 214 +/- 7 cm FL) to assess PRM rates in the pelagic longline fishery during a 30 day attachment period. Forty-three of the 50 deployed tags reported data with deployment times ranging from 1 to 28 days (11.2 +/- 9.8 days). Four dusky sharks were in poor condition at release and two individuals suffered PRM, which occurred within

two hours after release. Total mortality rate (AVM + PRM) in the current study was 5.1%, far below estimates reported for bottom longline gear (97%), and reinforces the notion that PRM should be evaluated by species, season, and gear type.

Swimmer, Y., & Barcelo, C. (2018). *Blue shark and swordfish catch rates in Hawaii's shallow-set longline fishery: before and after regulations aimed to reduce sea turtle bycatch (DRAFT).* 14th Regular Session of the Scientific Committee WCPFC-SC14-2018/EB-IP-06. Western and Central Pacific Fisheries Commission, Retrieved from https://meetings.wcpfc.int/node/10741

To reduce capture and mortality of endangered and threatened sea turtles, United States longline vessels targeting swordfish in the Pacific Ocean have operated under extensive fisheries regulations since 2004. We analyzed longline observer data from the Pacific Ocean to assess the impact of these regulations on targeted swordfish (Xiphias gladius) and bycatch of blue sharks (Prionace glauca). Using generalized additive mixed models (GAMMs), we investigated relationships between the nominal catch-per unit effort (CPUE) of blue sharks and swordfish and using operational components such as fishing location, hook type, bait type, hooks between floats, use of light sticks, and sea surface temperature. For blue sharks, GAMMs identified a significantly higher catch on J hooks with squid or fish bait relative to circle hooks with fish bait. For swordfish, J hooks with squid bait caught significantly more relative to circle hooks with fish bait, however there was no significant difference of catch when comparing J hooks with fish bait to circle hooks with fish bait. Confounding variables such as year and terminal gear components (hook type, bait) are discussed. Single factor analysis identified that catch rates of blue sharks and swordfish were significantly lower after the regulations, which were lower by over 2.4 times for blue sharks, yet by only ~8% for swordfish. These results indicate that the use of mitigation measures to reduce sea turtle bycatch, specifically large circle hooks and fish bait, can provide a significant conservation value by reducing blue shark bycatch, yet may also result in a slight reduction in targeted swordfish catch rates.

Swimmer, Y., Suter, J., Arauz, R., Bigelow, K., Lopez, A., Zanela, I., . . . Boggs, C. (2011). Sustainable fishing gear: the case of modified circle hooks in a Costa Rican longline fishery. *Marine Biology,* 158(4), 757-767. https://doi.org/10.1007/s00227-010-1604-4

Our research aims to identify longline fishing gear modifications that can improve fishing selectivity and reduce incidental capture of non-target species. Catch rates and anatomical hook locations (AHL) were compared when using a 14/0 standard "control" circle hook with a 00 offset and an experimental "appendage" hook in a Costa Rican longline fishery. With the appendage, the maximum dimension of the appendage hook was increased by 10% and the minimum dimension of the hook by 19%. A total of 1,811 marine animals were captured during five fishing trips. By taxonomic groups, sea turtles represented the largest total catch (27%), followed by sharks (26%), rays (25%), mahimahi (Coryphaenu hippurus) (12%), and tunas and billfish (10%). Non-target and discard species, such as rays and sea turtles, accounted for over half of the total catch. Catch per unit effort (CPUE; number of individuals per 1,000 hooks) was higher with control hooks compared to appendage hooks for all species' categories except rays; appendage hooks caught 52% fewer sea turtles and 23% fewer tunas and billfish than standard hooks, which represents a significant reduction in bycatch of endangered and other species. No differences were found in the AHL for sea turtles, suggesting use of the appendage may not incur additional advantages regarding turtles' post-release survivorship. Despite lower catch rates for marketable species, such as sharks and mahimahi, use of the appendage resulted in dramatic reductions

in catch rates of sea turtles. The results suggest that large scale adoption of hooks with a significantly wider hook dimension could be an effective conservation measure to maintain marine biodiversity while allowing for continued fishing.

Talwar, B., Brooks, E. J., Mandelman, J. W., & Grubbs, R. D. (2017). Stress, post-release mortality, and recovery of commonly discarded deep-sea sharks caught on longlines. *Marine Ecology Progress Series,* 582, 147-161. https://doi.org/10.3354/meps12334

Bycatch interactions with deep-sea elasmobranchs are increasingly common and can lead to dramatic declines in abundance over short time scales. Sharks hooked in the deep sea could face a higher likelihood of severe physiological disturbance, at-vessel mortality, and postrelease mortality (PRM) than their shallower counterparts. Unfortunately, robust PRM rates have not yet been estimated for longline-caught deep-sea sharks, and as such are not currently incorporated into total fishery mortality estimates or bycatch assessments, limiting the effectiveness of current conservation or management initiatives. We empirically estimated PRM for 2 focal taxa of deep-sea shark, the Cuban dogfish Squalus cubensis and the gulper shark Centrophorus sp., using post-release enclosures deployed at-depth. We calculated 24 h PRM rates of 49.7 +/- 8.5% (mean +/- SE) for S. cubensis and 83 +/- 16% for Centrophorus sp. and identified blood lactate, total length, glucose, and vitality scores as predictors of PRM in S. cubensis. We also observed all 24 h PRM within 11 h post-capture and demonstrated the effects of recovery depth and at-vessel blood chemistry metrics on post-release behavior. Our results suggest that PRM rates of deep-sea sharks are high and highlight the need for filling in this gap in fishery mortality estimates for other common discards in the future.

Tixier, P., Lea, M. A., Hindell, M. A., Welsford, D., Mazé, C., Gourguet, S., & Arnould, J. P. Y. (2021). When large marine predators feed on fisheries catches: Global patterns of the depredation conflict and directions for coexistence. *Fish and Fisheries,* 22(1), 31-53. https://doi.org/10.1111/faf.12504

The sustainable mitigation of human–wildlife conflicts has become a major societal and environmental challenge globally. Among these conflicts, large marine predators feeding on fisheries catches, a behaviour termed “depredation,” has emerged concomitantly with the expansion of the world’s fisheries. Depredation poses threats to both the socio-economic viability of fisheries and species conservation, stressing the need for mitigation. This review synthesizes the extent and socio-ecological impacts of depredation by sharks and marine mammals across the world, and the various approaches used to minimize it. Depredation was reported in 214 fisheries between 1979 and 2019 (70% post-2000) and affected fleets from 44 countries, in all sectors (commercial, artisanal and recreational), and in all major fishing techniques (nets, traps and hook-and-lines). A total of 68 predator species were involved in depredation (20 odontocetes, 21 pinnipeds and 27 sharks), and most (73%) were subject to either by-catch and/or retaliatory killing from fishers when interacting with gear. Impacts on fishers were primarily associated with catch losses and gear damage but often lacked assessments. Deterrence was a major mitigation approach but also the least effective. Gear modifications or behavioural adaptation by fishers were more promising. This review highlights the need for improved monitoring, and interdisciplinary and integrated research to quantify the determinants and impacts of depredation in the socio-ecological dimension. More importantly, as the conflict is likely to escalate, efforts directed towards changing perceptions and integrating knowledge through adaptive co-management are raised as key directions towards coexistence between fisheries and large marine predators.

Tolotti, M. T., Bach, P., Hazin, F., Travassos, P., & Dagorn, L. (2015). Vulnerability of the Oceanic Whitetip Shark to Pelagic Longline Fisheries. *Plos One,* 10(10), e0141396. https://doi.org/10.1371/journal.pone.0141396

A combination of fisheries dependent and independent data was used to assess the vulnerability of the oceanic whitetip shark to pelagic longline fisheries. The Brazilian tuna longline fleet, operating in the equatorial and southwestern Atlantic, is used as a case study. Fisheries dependent data include information from logbooks (from 1999 to 2011) and on-board observers (2004 to 2010), totaling 65,277 pelagic longline sets. Fisheries independent data were obtained from 8 oceanic whitetip sharks tagged with pop-up satellite archival tags in the area where longline fleet operated. Deployment periods varied from 60 to 178 days between 2010 and 2012. Tagging and pop-up sites were relatively close to each other, although individuals tended to travel long distances before returning to the tagging area. Some degree of site fidelity was observed. High utilization hotspots of tagged sharks fell inside the area under strongest fishing pressure. Despite the small sample size, a positive correlation between tag recorded information and catch data was detected. All sharks exhibited a strong preference for the warm and shallow waters of the mixed layer, spending on average more than 70% of the time above the thermocline and 95% above 120 m. Results indicate that the removal of shallow hooks on longline gear might be an efficient mitigation measure to reduce the bycatch of this pelagic shark species. The work also highlights the potential of tagging experiments to provide essential information for the development of spatio-temporal management measures.

Tolotti, M. T., Travassos, P., Fredou, F. L., Wor, C., Andrade, H. A., & Hazin, F. (2013). Size, distribution and catch rates of the oceanic whitetip shark caught by the Brazilian tuna longline fleet. *Fisheries Research,* 143, 136-142. https://doi.org/10.1016/j.fishres.2013.01.014

Catch and effort data from 14,835 longline sets conducted by foreign tuna longline vessels chartered by Brazil, from 2004 to 2010, were analyzed aiming at assessing the size, distribution and the relative abundance of the oceanic whitetip shark (Carcharhinus longimanus) in the southwestern and equatorial Atlantic Ocean. The nominal catch per unit of effort (CPUE) exhibited a gradual increase, from 0.04 sharks/1000 hooks, in 2004, the first year of the time series, up to 0.13, in 2007. In 2008, however, the CPUE increased sharply, reaching 0.43, dropping, then, back to 0.15, in 2010. A CPUE standardization was performed using a delta-GLM approach, but the standardized index of abundance did not differ significantly from the nominal CPUE. The models indicated that the catches of oceanic whitetip sharks are higher for the Spanish fishing strategy, which is characterized by the deployment of hooks at shallower depths. These results indicate that the use of deep longline hooks (>100 m) may help to mitigate the bycatch of this species.

Ward, P., Lawrence, E., Darbyshire, R., & Hindmarsh, S. (2008). Large-scale experiment shows that nylon leaders reduce shark bycatch and benefit pelagic longline fishers. *Fisheries Research,* 90(1-3), 100-108. https://doi.org/10.1016/j.fishres.2007.09.034

We assess the performance of wire leaders, which some jurisdictions have banned to reduce shark mortality from pelagic longline fishing. Experiments were conducted off northeastern Australia on commercial vessels that deployed equal numbers of wire and nylon monofilament leaders randomly along their longlines. Catch rates of several species, including sharks, were lower on nylon than on wire leaders, probably because those animals often escape by biting through the nylon leaders. High bite-off

rates indicate that as many animals escape from nylon leaders as are caught on nylon leaders. The fate of escaped animals is not known, although large sharks are more likely to survive than are small animals. By contrast, catch rates of valuable bigeye tuna (Thunnus obesus) were higher on nylon than on wire leaders. Bigeye tuna are probably able to see wire leaders and avoid those hooks. The financial benefits of increased bigeye tuna catches outweigh the costs associated with banning wire leaders, such as increased rates of gear loss. Thus, banning wire leaders is an effective way of reducing shark catches that fishers should be keen to adopt.

Watson, J. T., & Bigelow, K. A. (2014). Trade-offs among Catch, Bycatch, and Landed Value in the American Samoa Longline Fishery. *Conservation Biology,* 28(4), 1012-1022. https://doi.org/10.1111/cobi.12268

The interspecific preferences of fishes for different depths and habitats suggest fishers could avoid unwanted catches of some species while still effectively targeting other species. In pelagic longline fisheries, albacore (Thunnus alalunga) are often caught in relatively cooler, deeper water (>100 m) than many species of conservation concern (e. g., sea turtles, billfishes, and some sharks) that are caught in shallower water (<100 m). From 2007 to 2011, we examined the depth distributions of hooks for 1154 longline sets (3,406,946 hooks) and recorded captures by hook position on 2642 sets (7,829,498 hooks) in the American Samoa longline fishery. Twenty-three percent of hooks had a settled depth <100 m. Individuals captured in the 3 shallowest hook positions accounted for 18.3% of all bycatch. We analyzed hypothetical impacts for 25 of the most abundant species caught in the fishery by eliminating the 3 shallowest hook positions under scenarios with and without redistribution of these hooks to deeper depths. Distributions varied by species: 45.5% (n = 10) of green sea turtle (Chelonia mydas), 59.5% (n = 626) of shortbill spearfish (Tetrapturus angustirostris), 37.3% (n = 435) of silky shark (Carcharhinus falciformis), and 42.6% (n = 150) of oceanic whitetip shark (C. longimanus) were caught on the 3 shallowest hooks. Eleven percent (n = 20,435) of all tuna and 8.5% (n = 10,374) of albacore were caught on the 3 shallowest hooks. Hook elimination reduced landed value by 1.6-9.2%, and redistribution of hooks increased average annual landed value relative to the status quo by 5-11.7%. Based on these scenarios, redistribution of hooks to deeper depths may provide an economically feasible modification to longline gear that could substantially reduce bycatch for a suite of vulnerable species. Our results suggest that this method may be applicable to deep-set pelagic longline fisheries worldwide.

Whitney, N. M., Lear, K. O., Morris, J. J., Hueter, R. E., Carlson, J. K., & Marshall, H. M. (2021). Connecting post-release mortality to the physiological stress response of large coastal sharks in a commercial longline fishery. *Plos One,* 16(9), e0255673. https://doi.org/10.1371/journal.pone.0255673

Bycatch mortality is a major factor contributing to shark population declines. Post-release mortality (PRM) is particularly difficult to quantify, limiting the accuracy of stock assessments. We paired blood-stress physiology with animal-borne accelerometers to quantify PRM rates of sharks caught in a commercial bottom longline fishery. Blood was sampled from the same individuals that were tagged, providing direct correlation between stress physiology and animal fate for sandbar (Carcharhinus plumbeus, N = 130), blacktip (C. limbatus, N = 105), tiger (Galeocerdo cuvier, N = 52), spinner (C. brevipinna, N = 14), and bull sharks (C. leucas, N = 14). PRM rates ranged from 2% and 3% PRM in tiger and sandbar sharks to 42% and 71% PRM in blacktip and spinner sharks, respectively. Decision trees

based on blood values predicted mortality with >67% accuracy in blacktip and spinner sharks, and >99% accuracy in sandbar sharks. Ninety percent of PRM occurred within 5 h after release and 59% within 2 h. Blood physiology indicated that PRM was primarily associated with acidosis and increases in plasma potassium levels. Total fishing mortality reached 62% for blacktip and 89% for spinner sharks, which may be under-estimates given that some soak times were shortened to focus on PRM. Our findings suggest that no-take regulations may be beneficial for sandbar, tiger, and bull sharks, but less effective for more susceptible species such as blacktip and spinner sharks.

Whoriskey, S., Arauz, R., & Baum, J. K. (2011). Potential impacts of emerging mahi-mahi fisheries on sea turtle and elasmobranch bycatch species. *Biological Conservation,* 144(6), 1841-1849. https://doi.org/10.1016/j.biocon.2011.03.021

Mahi-mahi (Coryphaena hippurus) is a resilient pelagic species that could provide long-term highly productive fisheries. Using FAO data we document enormous increases (746%) in reported global mahi-mahi landings since 1950. Detailed mahi-mahi fisheries records are limited, but an observer program monitoring Costa Rica's Pacific mahi-mahi pelagic longline fleet between 1999 and 2008 (n = 217 sets) provided a rare opportunity to quantify bycatch in these fisheries. Several sea turtles and sharks of global conservation concern were caught incidentally: olive ridley turtle (Lepidochelys olivacea; n = 1348, mean = 9.05 per 1000 hooks), silky shark (Carcharhinus falciformis; n = 402, mean = 2.96 per 1000 hooks), thresher sharks (Alopias sp.; n = 158, mean = 1.12 per 1000 hooks), green turtle (Chelonia mydas; n = 49, mean = 0.35 per 1000 hooks), and three other threatened sharks in small numbers. Pelagic stingray (Pteroplatytrygon violacea; a ray of low conservation concern) was also a common bycatch (n = 625, mean = 4.77 per 1000 hooks). Generalized linear models (GLMs) of catch rates showed increases in olive ridley turtles and decreases in mahi-mahi and silky sharks over the decade examined. The high hooking survival rates of olive ridley and green turtles in observed sets (95% and 96% respectively) suggest that widespread training of the fleet in careful gear removal and turtle release methods could be one effective bycatch mitigation strategy for these species. GLMs also provide evidence that closing the fishery during peak olive ridley nesting times (at least near nesting beaches), in combination with reduced gear soak times, could help minimize the fishery's impacts on threatened bycatch species while still maintaining a productive fishery.

Wimmer, T. (2014). *The Use of Zinc and Graphite to Reduce Shark Bycatch in Canadian Pelagic Longline Fisheries.* Paper presented at the American Fisheries Society Annual Meeting. Retrieved from https://afs.confex.com/afs/2014/webprogram/Paper15604.html

Blue sharks (Prionace glauca) represent a significant portion of the catch in the Canadian pelagic longline fishery targeting swordfish and tunas. The capture of sharks represents a significant financial loss to industry, therefore, reducing the capture of sharks is a shared interest between conservationists and fishermen. Sharks have the ability to detect minute electric currents and thus, the use of substances that produce electrical currents upon immersion in salt water are being tested to determine their ability to deter sharks from fishing gear. The combination of zinc and graphite (Zn/Gr) has been tested in experimental trials and has shown to deter sharks. We tested the use of these substances to reduce shark bycatch in a commercial fishery in collaboration with a longline captain off Nova Scotia, Canada. In September 2013, we deployed a total of 9 longline sets (~6300 hooks) with three different treatments: standard hooks, hooks with Zn/Gr and hooks with plastic controls. Sharks, primarily blue sharks, represented 29.6% of the total individuals caught while swordfish (Xiphias gladius), comprised

26.2%. The combination of zinc and graphite did not significantly reduce the bycatch of sharks in this fishery nor did it significantly affect the catch of the target species.

Yokota, K., Kiyota, M., & Minami, H. (2006). Shark catch in a pelagic longline fishery: Comparison of circle and tuna hooks. *Fisheries Research,* 81(2), 337-341. https://doi.org/10.1016/j.fishres.2006.08.006

The effects of circle hooks on blue shark Prionace glauca catch in a pelagic longline fishery were assessed in fishing experiments on two research vessels in the western North Pacific off the coast of Japan from May to September 2005. We used conventional tuna hooks (standard Japanese hook size; 3.8sun) and two sizes of circle hooks (4.3sun and 5.2sun) for each fishing operation and compared catch rates, size compositions and mortalities of blue shark between hooks. One vessel used stainless steel wire leaders and the other vessel used nylon-monofilament leaders. Total numbers of blue shark caught were 755 and 2598 for the respective vessels. Mean catch rates (per 1000 hooks) of blue shark for the 3.8sun tuna hook, the 4.3sun circle hook and the 5.2sun circle hook were 40.5, 37.9 and 36.1, respectively, for one vessel, and 81.6, 95.2 and 93.9, respectively, for the other. Catch rates did not differ significantly between the three hook types on either vessel (P=0.48 and 0.43, two-way ANOVA). Proportions of dead individuals for the 3.8sun tuna hook, the 4.3sun circle hook and the 5.2sun circle hook were 0.03, 0.02 and 0.05, respectively, for one vessel, and 0.10, 0.11 and 0.11, respectively, for the other. The proportion of dead individuals was not significantly different between the three hook types on either vessel (P=0.31 and 0.70, χ2-test of independence). Mean estimated pre-caudal lengths of blue shark caught by each hook type were between 133 and 135cm for one vessel and 193 and 194cm for the other. The difference in mean length between hook types was insignificant for one vessel, but significant for the other (P=1.00 and 0.03, ANOVA). These results indicate that the circle hooks used in this study had little impact on catch rate and mortality of blue shark. We also discuss the possible relationships between hook type, leader material, hooking location, and catch rate of sharks.

Yokota, K., Kiyota, M., & Okamura, H. (2009). Effect of bait species and color on sea turtle bycatch and fish catch in a pelagic longline fishery. *Fisheries Research,* 97(1-2), 53-58. https://doi.org/10.1016/j.fishres.2009.01.003

The effects of bait species (mackerel and squid) and color (blue-dyed and non-dyed) on the loggerhead turtle Caretta caretta bycatch in a pelagic longline fishery in the western North Pacific were assessed in shallow-set longline fishing experiments. The loggerhead turtle catches were analyzed using a generalized linear model (GLM) with a Poisson distribution. The potential factors (bait species, bait color, other species catch, and sea surface temperature) affecting loggerhead turtle catch were incorporated as explanatory variables. The model analyses indicated that bait species affected loggerhead turtle catch, while bait color did not. The model predicted that catch rates of loggerhead turtles were 75% less on mackerel bait to squid bait. This study demonstrated that fish bait choice was very effective in reducing loggerhead turtle bycatch in pelagic longline fisheries, but that the use of blue-dyed bait was not. Similar model analyses were also performed on target and by-product fish species, such as swordfish Xiphias gladius, striped marlin Tetrapturus audax, bigeye tuna Thunnus obesus. blue shark Prionace glauca, and shortfin mako shark Isurus oxyrinchus, and other non-target species. The remarkable differences between bait species and color that were found for loggerhead turtles were not found for these species catches.

Yuwei, L. I. (2011). Numeric modeling of a pelagic longline based on minimum potential energy principle. *Journal of fishery sciences of China,* 18(5), 1170-1178. https://doi.org/10.3724/SP.J.1118.2011.01170

Fishing parameters(such as the shooting speed of mainline,vessel speed,time interval between two hooks,numbers of hooks between two floats) can be adjusted to deploy the hooks to water layers that are preferred by target species,such as tuna.As a result,the catch rate of the target species can be increased and the catch of bycatch species(e.g.,loggerhead turtles,Caretta caretta;blue sharks,Prionace glauca;silky sharks,Car-charhinus falciformis) can be reduced.Together,these actions improve fishing efficiency and help maintain bio-logical diversity.To better understand the relationship between these factors and the fishing depth of longline gear,we developed a numeric model of the behavior of a pelagic longline.We conducted surveys on board Chinese large scale tuna longliners in the Indian Ocean between September 2008 and January 2009.During the surveys,the vessels targeted bigeye tuna(Thunnus obesus)but also caught yellowfin tuna(Thunnus albacares),swordfish(Xiphias gladius),albacore(Thunnus alalunga) and billfishes(Istiophoridae).The hook depths(188 hooks) were measured using temperature depth recorders(TDRs) and the three dimensional current was measured at a range of depths at 24 sites using an acoustic doppler current profiler(ADCP).We developed a three-dimensional numerical longline model(3DNLM) using finite element analysis and the minimum potential energy principle method.We used Matrix Laboratory(MATLAB) software to program and conduct the numerical calculations.The three di-mensional current data were assigned to seven,50 m depth intervals(e.g.,0–50,50–100,or 300–350 m).The co-ordinates of all the nodes of the longline(including the float lines,mainline,and branch lines) were calculated by inputting three-dimensional current profile data,fishing gear parameters(the diameter of the mainline and branch line,the total weight of the branch line and the bait in the water,the density of the mainline and branch line,the elastic modulus of the mainline,the length of the branch line,and the length of the float rope),operating parame-ters(vessel speed,line shooter speed,and the time interval between two hooks) into the numerical model.The model then outputs the shape of the longline under water and the depth of each hook.We verified the model output using experimental data.The model was able to accurately depict the three-dimensional shape and hook depths of the pelagic longline.There was no significant difference between the hook depth measured by TDR and the model estimate of hook depth(P=0.220.05).The average difference between two methods was 12.03 m(range: 0.02–40.36 m,S2=100.30,S=10.01,n=188).The underwater shape of the main line was represented by a wave-shaped curve.The shape was related to the force of the branch line.This load was concentrated at the re-spective node of the main line and made the depth of this node deeper.The main line between two nodes may have floated somewhat because of lift generated by sea currents,especially upwelling currents.The model estimates of the three-dimensional shape and the hook depths were influenced by the value of the drag coefficient(CN90).CN90 was defined as the drag coefficient associated with water flow plumb to the cylinder.The value of the drag coeffi-cient(CN90) was determined based on the Reynolds number(Re) of the study object.

Zainudin, I. M., Patria, M. P., Rahardjo, P., Yasman, Y., Gautama, D. A., & Prawira, W. T. (2017). Bycatch of sharks, marine mammals and seabirds in Indonesian Tuna Longline Fishery. *Biodiversitas, Journal of Biological Diversity,* 18(3), 1179-1189. https://doi.org/10.13057/biodiv/d180341

Zainudin IM, Patria MP, Rahardjo P, Yasman, Gautama DA, Prawira WT. 2017. Bycatch of sharks, marine mammals and seabirds in Indonesian Tuna Longline Fishery. Biodiversitas 18: 1179-1189. Bycatch in longline fishery is recorded to be one of the major factors defining the declined populations of endangered marine species worldwide. This research aimed to identify bycatch level of sharks, marine

mammals and seabirds as well as to pinpoint the mitigation options in Indonesian tuna longline fishery. In this study, a total of 8,564,858 hooks were observed from 5,622 gear settings in Indonesian tuna longline fishery based in two major fishing ports, namely Bitung Fishing Port-North Sulawesi and Benoa Port-Bali from May 2006 to June 2014. The results suggest that the best hook rate per thousand hooks in Indonesian tuna longline fisheries for shark bycatch was 0.2446, followed by 0.0030 for seabird bycatch, 0.0021 for dolphin bycatch and 0.0009 for whale bycatch. Seabirds largely acquired in the dead condition while the other species were found still alive (sharks and marine mammals). Bycatch of seabirds only occured in the vessels based in Benoa Bali, and the correlation value (R2) of sharks and seabirds caught at night time was low while for marine mammals was very strong. Deep setting system of fishing gears and night setting also proved to be more effective to reduce bycatch of those critical marine species.

Zollett, E. A., & Swimmer, Y. (2019). Safe handling practices to increase post-capture survival of cetaceans, sea turtles, seabirds, sharks, and billfish in tuna fisheries. *Endangered Species Research,* 38, 115-125. https://doi.org/10.3354/esr00940

Incidental capture of marine animals in fishing gear may cause immediate or delayed mortality due to injury. Increasing post-capture survival of these species is very important to reducing the widespread impacts of bycatch, particularly on protected and threatened populations. In this paper, we review recent literature on safe handling of sea turtles, cetaceans, seabirds, sharks, and billfish and summarize the most effective measures for improving survivability of these species after interactions with gillnet, pelagic longline, and purse seine gear. We also review the current tuna Regional Fishery Management Organization (tRFMO) measures on safe handling and release to identify gaps in implementation of safe handling practices. Strategies that increase post-capture survival of marine species can be grouped into 3 primary categories: reducing immediate mortality, minimizing injury that results in delayed mortality, and reducing stress that can lead to death. Routine training of fishermen on safe handling practices greatly improves the effectiveness of these measures. When bycatch does occur, the strategies to increase post-release survival become key for protecting vulnerable marine populations. This inventory highlights the great conservation value that can be provided by the tRFMOs by providing guidance and training on safe handling practices to increase post-release survival across taxa.

1.4 Purse Seine Fisheries

Ambrus, S. (2009). Panama accused of undermining marine preserve -- Bogota, Colombia. *EcoAmericas*. Retrieved from https://www.ecoamericas.com/issues/article/2009/1/BFB897CB-01E4-429D-83DC-4D0900CD9C56

Four years after banning commercial fishing in species-rich Coiba National Park, Panamas National Assembly revoked a critical article of the law prohibiting the use of purse-seine nets for tuna fishing in the 1,040- square-mile (2,700-sq-km) marine preserve. Environmentalists say the June 30 repeal of the ban on purse-seine tuna fishing in Coiba, reportedly influenced by Spanish tuna companies, could pose added risks to endangered marine turtles and dozens of species of sharks, whales and dolphins, which can become trapped in the purse seines as bycatch. They also say it undermines Panamas commitments under a 2004 treaty that the country signed with Colombia, Costa Rica and Ecuador to protect migratory marine species in a vast swath of ocean since named the Marine Conservation Corridor of the Eastern Tropical Pacific.

Bettis, S. (2017). *Shark Bycatch in Commercial Fisheries: A Global Perspective.* (Master of Science), Nova Southeastern University, Retrieved from https://nsuworks.nova.edu/cnso_stucap/331/

Many shark species have global distributions and are caught incidentally in different types of fisheries. Over the last two decades, shark populations have declined tremendously, with one of the leading causes of this decline bycatch in primarily teleost fisheries. Bycatch occurs throughout the world's fisheries, but is not well documented in terms of species composition and numbers of each species captured. Information on shark bycatch is spread through the primary and grey literature, but has not been compiled in summary to date. The goal of my capstone is to present global shark bycatch data and provide a comparative review to determine fishery types that affect shark populations and identify shark species at risk as a result of bycatch. Longline fisheries caught a larger variety of shark species, and the post-release mortality was generally low. In contrast, trawl fisheries caught mostly the same few species, but post-release mortality was extremely high. Blue sharks (Prionace glauca), silky sharks (Carcharhinus falciformis), and spiny dogfish (Squalus acanthias) were caught most often in trawl fisheries, and in large numbers that likely adds to risk of overexploitation of their populations. This literature review revealed a severe lack of standardization in bycatch data reporting by different fishing nations, and in documents prepared by management agencies and scientists, including the definition of bycatch used and the way it was recorded. Establishing a universal definition of bycatch and standardizing its reporting would vastly improve ability to assess the scale and composition of shark bycatch and its impacts on shark populations. Systematic and standardized accounting of shark bycatch would provide information helpful for collaboration among regulatory agencies. Rather than simply document bycatch, a number of fishing gear alterations show promise for bycatch reduction and are worthy of integration into fisheries by managers. Additional important steps that can improve bycatch assessment is increased observer coverage in fisheries, marine protected areas, and making bycatch data public.

Cosandey-Godin, A., & Morgan, A. (2011). *Fisheries bycatch of sharks: Options for mitigation.* Pew Environment Group, Washington, DC. Retrieved from https://www.sarri.org/storage/app/media/tools_pdfs/PewOSSsharkbycatchreviewpdf.pdf

Bycatch (see definition below) is one of the most significant issues in the management and conservation of global fisheries (Hall et al. 2000, Kelleher 2005, Lewison et al. 2004) and has been identified as one of the leading causes of shark population declines. Sharks are susceptible to high fishing mortality rates because of their life history characteristics, which include slow growth, late ages at maturity, and the production of a limited number of young over a lifetime (Cortes 2002, Heppell et al. 1999, Cortes 1999). In addition, research has shown that several species of sharks have very high rates of mortality associated with the fishing process (Morgan and Burgess 2007, Mandelman et al. 2008), and it has been estimated that species such as sandbar shark (Carcharhinus plumbeus) (Sminkey and Musick 1994, Cortes 1999) and dusky shark (Carcharhinus obscurus) (Simpfendorfer 1999) increase their population sizes so slowly that they are considered particularly vulnerable to mortality from fishing activities (Musick et al. 2000a). For example, Cortes et al. (2006) found that if fishing for dusky shark stopped for 30 years, their population in the Northwest Atlantic would still be depleted. Over the past two decades, serious population declines have been reported for a number of shark species in several regions around the world (Baum et al. 2003, Ferretti et al. 2008, Robbins et al. 2006, Ferretti et al. 2010, Clarke 2011) and are attributed to both targeted and incidental capture. According to the International Union for Conservation of Nature (IUCN) and other sources, bycatch is one of the primary threats facing sharks (Musick et al. 2000b, Lewison et al. 2004). Despite widespread recognition of shark bycatch issues (Food and Agriculture Organization [FAO] 1999; FAO 2010), few mitigation actions have been established, and there are no clear guidelines about which mitigation actions would be most effective. In addition, there are very few management measures requiring actions to mitigate shark bycatch. However, it is clear that managers and fishermen must aim to reduce both bycatch rates and the harmful effects from bycatch (e.g., injuries from capture on fishing gear). Based on the best available information, this review provides a summary of the current knowledge and understanding of shark bycatch and discusses available management options and technical measures aimed at reducing both the rate at which sharks encounter fishing gear and the associated damaging effects.

Croll, D. A., Dewar, H., Dulvy, N. K., Fernando, D., Francis, M. P., Galvan-Magana, F., . . . White, W. T. (2016). Vulnerabilities and fisheries impacts: the uncertain future of manta and devil rays. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 26(3), 562-575. https://doi.org/10.1002/aqc.2591

1. Manta and devil rays of the subfamily Mobulinae (mobulids) are rarely studied, large, pelagic elasmobranchs, with all eight of well-evaluated species listed on the IUCN Red List as threatened or near threatened. 2. Mobulids have life history characteristics (matrotrophic reproduction, extremely low fecundity, and delayed age of first reproduction) that make them exceptionally susceptible to overexploitation. 3. Targeted and bycatch mortality from fisheries is a globally important and increasing threat, and targeted fisheries are incentivized by the high value of the global trade in mobulid gill plates. 4. Fisheries bycatch of mobulids is substantial in tuna purse seine fisheries. 5. Thirteen fisheries in 12 countries specifically targeting mobulids, and 30 fisheries in 23 countries with mobulid bycatch were identified. 6. Aside from a few recently enacted national restrictions on capture, there is no comprehensive monitoring, assessment or control of mobulid fisheries or bycatch. Recent listing through the Convention on the International Trade in Endangered Species (CITES) may benefit mobulids

of the genus Manta (manta rays), but none of the mobulids in the genus Mobula (devil rays) are protected. 7. The relative economic costs of catch mitigation are minimal, particularly compared with a broad range of other, more complicated, marine conservation issues.

Cronin, M. R., Croll, D. A., Hall, M. A., Lezama-Ochoa, N., Lopez, J., Murua, H., . . . Moreno, G. (2022). Harnessing stakeholder knowledge for the collaborative development of Mobulid bycatch mitigation strategies in tuna fisheries. *ICES Journal of Marine Science*. https://doi.org/10.1093/icesjms/fsac093

Manta and devil rays (Mobulids) face several immediate threats, including incidental capture in industrial tropical tuna fisheries. As a result, efforts have emerged to avoid or mitigate Mobulid bycatch in these fisheries. However, many mitigation efforts fail to incorporate fisher expertise from the outset, potentially leading to interventions that are not viable. Here, we combine survey and focus group data to synthesize knowledge of Mobulid bycatch and mitigation ideas in Eastern Pacific Ocean purse seine fisheries. Primary obstacles for mitigating Mobulid bycatch, according to respondents, are: (1) an inability to sight Mobulids before capture, (2) the lack of specific equipment on board, and (3) the difficulty of releasing large individuals; we suggest that the latter two can be addressed by simple operational modifications. We also find that Mobulids are most likely to be sighted by fishers after capture, suggesting that this is an important time in the fishing operation for bycatch mitigation interventions that ensure Mobulids survive capture. To address this, we share creative ideas brought by fishers for avoidance of Mobulids. This study provides a model of how to incorporate stakeholder input in the design of bycatch technology in large-scale fisheries and could inform similar efforts around the world.

Dagorn, L., Filmalter, J. D., Forget, F., Amandè, M. J., Hall, M., Williams, P., . . . Bez, N. (2012). Targeting bigger schools can reduce ecosystem impacts of fisheries. *Canadian Journal of Fisheries and Aquatic Sciences,* 69(9). https://doi.org/10.1139/f2012-089

Sustainability of living resource exploitation relies on an ecosystem management approach. Within tropical tuna purse seine fisheries using fish aggregating devices (FADs), such an approach incorporates the reduction of bycatch, in par- ticular vulnerable species such as elasmobranchs. The levels of total bycatch (in mass) from fishing operations using FADs is known to be five times higher than when tuna are caught in free-swimming schools. We intend to find practical solutions to reduce bycatch in FAD sets through the investigation of the relationships between the ratio of bycatch to target catch across different set size classes in all oceans. Ratios were always highest when catches were small, with the smallest class of catches responsible for the highest total portion of bycatch (23%-43%) while only contributing negligibly to the total tar- get catch (3%-10%). Reducing the number of fishing sets (a part of the total effort) while maintaining the same total yield could contribute to a substantial reduction in the impacts of human activities.

Diaz-Delgado, E., Crespo-Neto, O., & Martinez-Rincon, R. O. (2021). Environmental preferences of sharks bycaught by the tuna purse-seine fishery in the Eastern Pacific Ocean. *Fisheries Research,* 243. https://doi.org/10.1016/j.fishres.2021.106076

Sharks play important ecological roles in marine ecosystems. However, due to their life-history traits and low resilience, their vulnerability increases with overexploitation. The Eastern Pacific Ocean (EPO) purse-seine fishery catches several pelagic sharks as bycatch. Therefore, describing the environmental preferences of bycaught sharks is crucial to improve fisheries management. This study aims to describe the environmental preferences and spatiotemporal distribution of most bycaught shark species within the EPO through Generalized Additive Models (GAMs). Results show that the silky shark (C. falciformis) is bycaught in oceanic waters on floating objects, and close to the coast in unassociated and dolphin sets. This species inhabits warm waters with low or high productivity. Oceanic whitetip shark (C. longimanus) is bycaught in warm and oceanic waters with low productivity. Meanwhile, scalloped and smooth hammerhead sharks (Sphyrna lewini & S. zygaena) are bycaught in temperate and productive waters offshore of Peru. The obtained results allowed us to identify hotspots where fisheries management can be implemented, improved, or modified (e.g., temporal closures) for reducing shark bycatch.

Duffy, L. M., Lennert-Cody, C. E., Olson, R. J., Minte-Vera, C. V., & Griffiths, S. P. (2019). Assessing vulnerability of bycatch species in the tuna purse-seine fisheries of the eastern Pacific Ocean. *Fisheries Research,* 219, 105316. https://doi.org/10.1016/j.fishres.2019.105316

Ecological risk assessment (ERA), including Productivity-Susceptibility Analysis (PSA), is becoming increasingly used to assess the relative vulnerability of data-limited non-target species to the impacts by fishing. PSA was developed for the eastern Pacific Ocean (EPO) tuna purse-seine fishery to assess the vulnerability of incidentally-caught species for three set types, “dolphin sets”, “unassociated sets” and “floating-object sets”, during 2005–2013. Because of operational differences between these set types, susceptibility values were combined for each species across the three set types to produce an overall fleet-wide susceptibility estimate. Vulnerability was highest for elasmobranchs, namely the giant manta ray, bigeye and pelagic thresher sharks, smooth and scalloped hammerhead sharks, and silky shark. Billfishes, dolphins, other rays, ocean sunfish, and yellowfin and bigeye tunas were classified as moderately vulnerable while the remaining species, all teleosts, had the lowest vulnerability scores. This purse-seine fleet-wide PSA identified potentially vulnerable species that can be compared with PSAs for other fisheries operating in the EPO, once detailed catch information becomes available for those fisheries. Such information can assist managers with prioritising fishery- and species-specific research programs and/or mitigation measures.

Eddy, C., Brill, R., & Bernal, D. (2016). Rates of at-vessel mortality and post-release survival of pelagic sharks captured with tuna purse seines around drifting fish aggregating devices (FADs) in the equatorial eastern Pacific Ocean. *Fisheries Research,* 174, 109-117. https://doi.org/10.1016/j.fishres.2015.09.008

Pelagic fishes are well known to aggregate in large numbers under floating objects and this behavior is frequently exploited by purse seine fisheries targeting tunas. Non-target species (e.g., sharks) are often caught as well, but they are typically discarded as they do not have sufficient commercial value. To

investigate the total mortality of pelagic sharks in the equatorial Eastern Pacific Ocean associated with the tuna purse seine fishery deploying drifting fish aggregating devices (FADS), we measured rates of at-vessel mortality and deployed pop-up satellite archival tags (PSATs) to monitor post-release survival and behavior. Between 2011 and 2012, at-vessel mortality rate ranged from 15% to 70%, and total mortality rate (i.e. the combination of at-vessel and post-release mortalities) ranged from 80% to 95%. Taken together, our findings document the high mortality of sharks incidentally captured in the tuna purse seine fishery that employs drifting FADS, indicate a correlation to set size, and suggest the need to develop methods that minimize shark bycatch in this fishery.

Escalle, L., Gaertner, D., Chavance, P., Delgado de Molina, A., Ariz, J., & Merigot, B. (2016). Consequences of fishing moratoria on catch and bycatch: the case of tropical tuna purse-seiners and whale and whale shark associated sets. *Biodiversity and Conservation,* 25(9), 1637-1659. https://doi.org/10.1007/s10531-016-1146-2

Time–area regulations have been introduced to manage stocks of tropical tuna, given the increased use of drifting fish aggregation devices (FADs). However, the consequences in terms of changes in fishing strategies and effort reallocation may not always be as expected. For instance, in the eastern Pacific Ocean, previous studies have highlighted that the increase use of FAD-fishing following the demand for tuna caught without dolphin mortality has raised concerns about the bycatch and the capture of juvenile tuna. In the tropical eastern Atlantic and western Indian Oceans, this study aimed to (1) assess, using before–after analysis, the consequences of previous time–area regulations on FAD sets on the fishing effort allocated to megafauna associated sets, and (2) evaluate through Monte Carlo simulations the potential effect of new regulations banning whale or/and whale shark associated sets. Firstly, we showed that previous time–area regulations, which were mainly implemented during seasons with few whale and whale shark associated sets, generally had thus little effect on the number of megafauna associated sets. Secondly, some simulations, particularly when both whale and whale shark associated sets were banned, predicted consequences of changes in fishing strategy. Indeed, these types of ban could lead to an increase in the number of FAD and free school sets but no change in the tuna catch, as well as a slight decrease in bycatch. These results indicate that an ecosystem approach to fisheries, by taking into account megafauna associated sets and bycatch, should thus be adopted when implementing management or conservation measures.

Filmalter, J. D., Bauer, R. K., Forget, F., Cowley, P. D., & Dagorn, L. (2021). Movement behaviour and fishery interaction of silky sharks (Carcharhinus falciformis) in the tropical tuna purse seine fishery in the Western Indian Ocean. *ICES Journal of Marine Science,* 78(7), 2474-2485. https://doi.org/10.1093/icesjms/fsab119

The silky shark Carcharhinus falciformis regularly associates with floating objects in the open ocean, resulting in relatively high levels of bycatch in industrial tuna purse seine fisheries using drifting fish aggregating devices (FADs). This bycatch has contributed to concerns regarding the sustainability of this fishery and its impact on silky shark populations. To investigate fishery interactions, movements of 28 silky sharks (86-235 cm TL, mean = 118 cm) fitted with pop-up and archival tags in the western Indian Ocean, between 2010 and 2012, were examined. Monthly overlap between probability surfaces of sharks and two fishery metrics (FAD-tuna catches and FAD positions) were calculated. Vertical habitat

use overlapped almost entirely with operational gear depth. Horizontal movements were extensive (3-5024 km) and covered large areas of the western Indian Ocean. Monthly overlap with FAD distributions was consistently high (64.03-100%) highlighting the need for compliance with FAD design regulations to avoid entanglement. Monthly overlap with tuna catches was more variable (8.43-51.83%). The observed movement patterns suggest static spatial management measures would be have limited conservation impact, however dynamic approaches could be appropriate. Limiting fishery activities directly will likely have the greatest conservation outcomes for silky sharks in the purse seine fishery.

Forget, F. G., Capello, M., Filmalter, J. D., Govinden, R., Soria, M., Cowley, P. D., & Dagorn, L. (2015). Behaviour and vulnerability of target and non-target species at drifting fish aggregating devices (FADs) in the tropical tuna purse seine fishery determined by acoustic telemetry. *Canadian Journal of Fisheries and Aquatic Sciences,* 72(9), 1398-1405. https://doi.org/10.1139/cjfas-2014-0458

Characterizing the vulnerability of both target and non-target (bycatch) species to a fishing gear is a key step towards an ecosystem-based fisheries management approach. This study addresses this issue for the tropical tuna purse seine fishery that uses fish aggregating devices (FADs). We used passive acoustic telemetry to characterize, on a 24 h scale, the associative patterns and the vertical distribution of skipjack (Katsuwonus pelamis), yellowfin (Thunnus albacares), and bigeye tuna (Thunnus obesus) (target species), as well as silky shark (Carcharhinus falciformis), oceanic triggerfish (Canthidermis maculata), and rainbow runner (Elagatis bipinnulata) (major non-target species). Distinct diel associative patterns were observed; the tunas and the silky sharks were more closely associated with FADs during daytime, while the rainbow runner and the oceanic triggerfish were more closely associated during the night. Minor changes in bycatch to catch ratio of rainbow runner and oceanic triggerfish could possibly be achieved by fishing at FADs after sunrise. However, as silky sharks display a similar associative pattern as tunas, no specific change in fishing time could mitigate the vulnerability of this more sensitive species. For the vertical distribution, there was no particular time of the day when any species occurred beyond the depth of a typical purse seine net. While this study does not provide an immediate solution to reduce the bycatch to catch ratios of the FAD-based fishery in the western Indian Ocean, the method described here could be applied to other regions where similar fisheries exist so as to evaluate potential solutions to reducing fishing mortality of non-target species.

Francis, M. P., & Jones, E. G. (2017). Movement, depth distribution and survival of spinetail devilrays (Mobula japanica) tagged and released from purse-seine catches in New Zealand. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 27(1), 219-236. https://doi.org/10.1002/aqc.2641

Mobulid rays are protected in New Zealand, but the spinetail devilray Mobula japanica is caught as bycatch in skipjack tuna purse seine fisheries. Between 2005 and 2014, rays were recorded in 8.2% of observed purse seine sets. Rays were caught during summer, with a hotspot' (24.3% of sets) near the shelf edge off North Island over seabed depths of 150-350m. Rays were usually brailed aboard with the tuna catch from successful sets, but were often entangled in the bunt of the net during unsuccessful sets. Observers tagged nine rays with popup archival tags to obtain preliminary information on their post-release survival, and spatial and vertical movements. Seven of the nine tags reported data, and

four of those rays died within 2-4days of release. All four rays that died had been brought aboard entangled in the bunt. The three surviving rays were all brailed aboard with the tuna catch. One surviving ray remained near New Zealand for 2.7months during summer, and the other two migrated 1400-1800km northward to tropical waters near Vanuatu and Fiji at minimum speeds of 47 and 63kmday(-1) at the end of summer. Archive data from one ray showed that it made regular vertical movements of 25-100m amplitude, but spent most of its time shallower than 50m, more so during the night (89.6%) than the day (76.6%), and mainly experienced temperatures of 18-22 degrees C. Dives deeper than 200m were usually made during the day or twilight. All three surviving rays typically moved between the surface and 200-300m daily, and reached greatest depths of 649m, 1000m and 1112m, respectively, substantially exceeding the previous depth record for this species of 445m. Recommendations are made for reducing purse seine mortality of mobulid rays by avoiding areas of high ray abundance, avoiding setting on ray-associated tuna schools, and adopting best-practice methods of returning rays to the sea from the net or vessel.

Gassman, J., Laurent, C., & Marcano, J. H. (2015). Ejecución Del Programa Nacional De Observadores A Bordo De La Flota Industrial Atunera Venezolana Del Mar Caribe Y Océano Atlántico Año 2013*. *Collective volume of scientific papers,* 71(6), 3117-3129. Retrieved from https://www.fao.org/fishery/en/openasfa/d5ffd086-117f-472f-8b16-3b77969a82f8

While the INSOPESCA began to implement the National Programme of Onboard Observers from 2011, the first deployments on vessels occurred in 2012. The purpose of the programme, which is aimed at the Venezuelan industrial fishing float operating in the Caribbean Sea and Atlantic Ocean, is to collect information so as to control and establish policies and regulations which ensure sustainable use of fishing resources. The fishing fleets that monitor this programme focus on catches of tropical tunas and other highly migratory bycatch species including billfish and sharks, in which different fishing gears are used such as purse seines, longlines, rods and lines. In 2013, under the programme, 31 fishing trips took place with a total of 812 days onboard, representing a total overall coverage of 6.44% of the total fishing trips and 6.61% of the total number of days at sea. Of them, 21 were longline vessels which recorded a total of 250 sets in which 200,810 hooks were used and a total of 3,759 individuals were caught; the tuna group were the most representative with 2,227 specimens (59.24%), followed by the billfish group with 841 individuals (22.37%), 396 other fish (10.53%), 187 stingrays (4.97%), 75 sharks (1.99%) and 33 specimens of swordfish (0.87%). 4 vessels of the purse seine fleet were boarded on which 133 sets were recorded, 102 (76.69%) of which were positive sets (there was catch). The estimated catch of the purse seine fleet monitored was dominated almost entirely by the tuna group (99.73%), among which yellowfin tuna (YFT) and skipjack (SKJ) were the most representative with 425.39 t (58.55%) and 241.21 t (33.21%), respectively. 6 vessels of the baitboat fleet were boarded in which a total of 226 sets were observed involving 5,230 hooks, and a total catch of 21,851 individuals, among which the most significant species were skipjack (SKJ) with 12,083 specimens (55.29%), followed by yellowfin tuna (YFT) with 9,470 individuals (43.34%), blackfin tuna (BLF) with 225 individuals (1.16%) and frigate tuna (FRI) with 23 individuals (0.1%). In each of these trips, information was collected on catches, effort, discards, bycatches of mammals and sea turtles, fishing areas, as well as distribution and biological information of the different species caught, among other aspects.

Gilman, E., & Lundin, C. (2010). Minimising bycatch of sensitive species groups in marine capture fisheries: lessons from tuna fisheries. In *Handbook of Marine Fisheries Conservation and Management.* Q. Grafton, R. Hillborn, D. Squires, M. Tait, & M. Williams (Eds.), (pp. 23): Oxford University Press Retrieved from http://ecite.utas.edu.au/58808

Bycatch in marine capture fisheries is the retained catch of nontargeted but commercially viable species (referred to as "incidental catch") plus all discards (Food and Agriculture Organization of the United Nations [FAO] 2005).1 It is an increasingly prominent international issue, raising ecological concerns, as some bycatch species of cetaceans (whales, dolphins, and porpoises), seabirds, sea turtles, elasmobranchs (sharks, skates, and rays), and other fi sh species are particularly vulnerable to overexploitation and slow to recover from large population declines (FAO 1999a, 1999b, in press; Fowler et al. 2005; Gales 1998; Gilman et al. 2005, 2006a, 2006c, 2008; Lutz and Musick 1997). Bycatch can alter biodiversity and ecosystem functions by removing top predators and prey species at unsustainable levels (Myers et al. 2007). It also alters foraging behavior of species that learn to take advantage of discards. Economic effects of bycatch on fi sheries include loss of bait, reduced availability of baited hooks when they are occupied with unwanted bycatch species, and concomitant reduced catch of marketable species; the imposition of a range of restrictions, closed areas, embargos, and possible closures; allocation among fi sheries, where bycatch in one fi shery reduces target catch in another, and bycatch of juvenile and undersized individuals of a commercial species can adversely affect future catch levels (Brothers et al. 1999; Hall et al. 2000). Discarded bycatch raises a social issue over waste: From 1992 to 2001 an average of 7.3 million metric tons of fi sh were annually discarded, representing 8 percent of the world catch (FAO 2005). Prominent bycatch issues include dolphins and porpoises in purse seine fi sheries and driftnets; fi sh discards in shrimp trawl fi sheries; and seabird, sea turtle, marine mammal, and shark bycatch in longline, purse seine, gillnet, and trawl fi sheries (FAO 1999a, 1999b, 2005, in press; Hall et al. 2000). In commercial tuna fi sheries, the incidental bycatch of sensitive species groups (seabirds, sea turtles, marine mammals, and sharks) and bycatch of juvenile and undersized tunas are allocation and conservation issues. In addition to problematic bycatch, overexploitation and illegal, unreported, and unregulated (IUU) fi shing, which complicates bycatch management, are additional conservation issues facing the management of tuna fi sheries. This chapter employs examples of bycatch in commercial tuna fi sheries to describe (1) the range of options to reduce bycatch, (2) principles and approaches to successfully introduce effective bycatch reduction measures, and (3) initiatives taken by intergovernmental organizations, the fi shing industry, and retailers to address bycatch. Changes needed to improve the sustainability of tuna production are recommended.

Gilman, E. L. (2011). Bycatch governance and best practice mitigation technology in global tuna fisheries. *Marine Policy,* 35(5), 590-609. https://doi.org/10.1016/j.marpol.2011.01.021

Overexploitation of bycatch and target species in marine capture fisheries is the most widespread and direct driver of change and loss of global marine biodiversity. Bycatch in purse seine and pelagic longline tuna fisheries, the two primary gear types for catching tunas, is a primary mortality source of some populations of seabirds, sea turtles, marine mammals and sharks. Bycatch of juvenile tunas and unmarketable species and sizes of other fish in purse seine fisheries, and juvenile swordfish in longline fisheries, contributes to the overexploitation of some stocks, and is an allocation issue. There has been substantial progress in identifying gear technology solutions to seabird and sea turtle bycatch on longlines and to direct dolphin mortality in purse seines. Given sufficient investment, gear technology

solutions are probably feasible for the remaining bycatch problems. More comprehensive consideration across species groups is needed to identify conflicts as well as mutual benefits from mitigation methods. Fishery-specific bycatch assessments are necessary to determine the efficacy, economic viability, practicality and safety of alternative mitigation methods. While support for gear technology research and development has generally been strong, political will to achieve broad uptake of best practices has been lacking. The five Regional Fisheries Management Organizations have achieved mixed progress mitigating bycatch. Large gaps remain in both knowledge of ecological risks and governance of bycatch. Most binding conservation and management measures fall short of gear technology best practice. A lack of performance standards, in combination with an inadequate observer coverage for all but large Pacific purse seiners, and incomplete data collection, hinders assessing measures' efficacy. Compliance is probably low due to inadequate surveillance and enforcement. Illegal, unreported and unregulated tuna fishing hampers governance efforts. Replacing consensus-based decision-making and eliminating opt-out provisions would help. Instituting rights-based management measures could elicit improved bycatch mitigation practices. While gradual improvements in an international governance of bycatch can be expected, market-based mechanisms, including retailers and their suppliers working with fisheries to gradually improve practices and governance, promise to be expeditious and effective.

Griffiths, S. P., & Lezama-Ochoa, N. (2021). A 40-year chronology of the vulnerability of spinetail devil ray (Mobula mobular) to eastern Pacific tuna fisheries and options for future conservation and management. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 31(10), 2910-2925. https://doi.org/10.1002/aqc.3667

Tuna fisheries are among the largest and most valuable fisheries in the world, but most interact with many non-target species, including several of high conservation importance. The spinetail devil ray (Mobula mobular) - listed as 'Endangered' on the IUCN Red List of Threatened Species - is a commonly discarded bycatch species, particularly in the eastern Pacific Ocean, yet insufficient data exist to undertake a traditional population assessment. A new ecological risk assessment approach designed for data-limited settings - Ecological Assessment of the Sustainable Impacts of Fisheries (EASI-Fish) - was used to reconstruct the historical vulnerability status of M. mobular and to simulate potential changes in its status under 45 hypothetical conservation and management measures. These involved various temporal closures of the eastern Pacific Ocean tuna fishery, decreasing post-capture mortality by improved handling and release practices, and combinations of the two. The species was classified as 'Least Vulnerable' between 1979 and 1993, but became 'Most Vulnerable' from 1994, which coincided with a rapid spatial expansion of the industrial purse-seine fishery, and especially from 2011 following the rapid increase in the number of sets made on floating objects. Simulating the conservation and management measures in place in 2018 revealed that 31 of the 45 scenarios resulted in a change in classification of the species to 'Least Vulnerable', which primarily involved a reduction of post-capture mortality by as little as 20%. It is fortuitous in that education of fishers to implement appropriate best handling and release practices is simpler, more rapid and more cost-effective than the implementation of fishery closures or gear modifications, which can be expensive and complex to implement and monitor and will probably result in substantial reduction in the catches of target species.

Hutchinson, M., Coffey, D. M., Holland, K., Itano, D., Leroy, B., Kohin, S., . . . Wren, J. (2019). Movements and habitat use of juvenile silky sharks in the Pacific Ocean inform conservation strategies. *Fisheries Research,* 210, 131-142. https://doi.org/10.1016/j.fishres.2018.10.016

Understanding the habitat use and behavior of commercially exploited species throughout ontogeny is useful for devising effective management and conservation strategies. Differences in habitat use can often be exploited to separate target and non-target species, and determinations of home range size can inform the proper scale of conservation actions. In tropical tuna purse seine fisheries in the Pacific Ocean, juvenile silky sharks, Carcharhinus falciformis, comprise a large proportion of the total elasmobranch bycatch. There is now growing recognition of declines in silky shark populations and the need for international collaboration in conservation efforts. Yet, very little is known about the movement behavior or habitat use for this species. In this study, movement behavior of juvenile silky sharks was investigated using pop-up satellite archival tags placed on sharks that were captured during chartered research cruises on a commercial tuna purse seine fishing vessel using drifting Fish Aggregating Devices (FADs) in the western and central Pacific Ocean and on sharks captured using pelagic longlines in the eastern tropical Pacific. Analysis of horizontal and vertical movement behavior revealed silky sharks spend nearly 100% of their time in the shallow, warm waters of the mixed layer. Juvenile silky shark depth and thermal preferences overlapped with the preferred habitat of the primary target tuna species, indicating vulnerability to capture in purse seine and shallow-set longline fisheries throughout the tropical and subtropical regions of the Pacific Ocean where temperatures range between 24 and 29 degrees C. Reconstruction of horizontal movements showed dispersal between adjacent national jurisdictions and international waters, highlighting the need for international collaborations in the implementation of conservation measures.

International Seafood Sustainability Foundation. (2019). *Non-Entangling and Biodegradable FADs Guide.* Retrieved from https://www.iss-foundation.org/research-advocacy-recommendations/our-scientific-program/scientific-reports/download-info/non-entangling-and-biodegradable-fads-guide-english/

This guide is an August 2019 update of the ISSF Guide for Non-entangling FADs, first published in 2012 and last updated in 2015.We have created this version of the guide for tuna fishers, Regional Fisheries Management Organizations (RFMOs), governments and vessel owners. It shows best practices in Fish Aggregating Device (FAD) design, both to avoid bycatch — especially of sharks and sea turtles — and to reduce marine pollution.New to this version of the guide is a focus on constructing FADs that are not only non-entangling to bycatch species but also biodegradable. Illustrations (p. 6) show how to design and build non-entangling biodegradable FADs without netting using natural materials. Those guidelines are contrasted with other FAD designs fishers have used that pose some degree of entanglement risk (low to high) to marine species.The four tuna RFMOs already require fleets that fish with FADs to use only non-entangling designs. Some RFMOs also encourage fleets to use biodegradable materials in those non-entangling FADs.The guide, which reflects the latest scientific research, was produced with input from ISSF's Scientific Advisory Committee and Bycatch Steering Committee.

Itano, D., Muir, J., Hutchinson, M., & Leroy, B. (2012). *Development and testing of a release panel for sharks and non-target finfish in purse seine gear.* WCPFC-SC8-2012/EB-WP-14 Western and Central Pacific Fisheries Commission, Retrieved from https://meetings.wcpfc.int/node/7833

An experimental release panel was installed in purse seine nets to determine their ability to release both silky sharks and non-target finfish. The release panels (5.5 m wide, extending down from the corkline for 11 m) were installed in a portion of the net that forms a "pocket" toward the end of net retrieval. Dive surveys previously reported that silky sharks tend to segregate and collect in this section of the net. The release panel was tested during seven purse seine sets, but only two silky sharks (out of 105) exited through this panel. In net observations indicated that sharks and other non-target finfish did not appear to recognize the opening as an escape route out of the net. Despite this initial failure of the release panel, the authors feel refinement of the panel and additional testing is still warranted.

Kondel, J., & Rusin, J. (2007). *Report of the 2nd Workshop on Bycatch Reduction in the ETP (Eastern Tropical Pacific) Purse-Seine Fishery (2nd). Held in La Jolla, California on October 3-4, 2006*.(Administrative report LJ 07-04). Southwest Fisheries Science Center Retrieved from https://repository.library.noaa.gov/view/noaa/4680

Purse-seine fisheries for tunas in the eastern tropical Pacific Ocean (ETP) utilize three techniques to catch tuna: dolphin fishing, school fishing, and fishing on floating objects (primarily fish aggregating devices FADs), each of which has significant differences in area, production, and size and composition of target catch and bycatch. Of the three, FAD-fishing is estimated to generate the largest amount of bycatch of many species, including sharks, sea turtles, mahi mahi, wahoo and small individuals of the target tuna species. Skipjack tuna compose the greatest amount of the bycatch of targeted tuna species. The distribution of bycatch varies both temporally and spatially. The least sustainable bycatch in floating object sets is believed to be sea turtles, small bigeye tuna, and silky and oceanic whitetip sharks. However, as there are no stock assessments for most of these species, the significance of the bycatch is not generally known either from the point of view of the stock or the ecosystem. Improvements in the identification and estimation of bycatch are currently underway in this fishery.

Lezama-Ochoa, N., Hall, M. A., Pennino, M. G., Stewart, J. D., Lopez, J., & Murua, H. (2019). Environmental characteristics associated with the presence of the Spinetail devil ray (Mobula mobular) in the eastern tropical Pacific. *Plos One,* 14(8), e0220854. https://doi.org/10.1371/journal.pone.0220854

In the eastern Pacific Ocean, the tropical tuna purse-seine fishery incidentally captures high numbers of five mobulid bycatch species; all of which are classified as mortalities by the Inter-American Tropical Tuna Commission due to uncertainties in post-release mortality rates. To date, the factors (operational or environmental) leading to the capture of these species by the fishery have not been well studied. Here, we developed Generalized Additive Models for fisheries observer data to analyze the relationships between the presence/absence of Mobula mobular bycatch and oceanographic conditions, the spatial and temporal variability in fishing location, and the set type (associated with dolphins, free-swimming tuna schools or floating objects). Our results suggest that chlorophyll concentration and sea surface height are the most important variables to describe the presence of M. mobular in conjunction with geographic location (latitude and longitude) and set type. Presence of the species was predicted in

waters with chlorophyll concentrations between 0.5-1 mg.m(-3) and with sea surface height values close to 0; which indicates direct relationships with productive upwelling systems. Seasonally, M. mobular was observed more frequently during December-January and August-September. We also found the highest probability of presence observed in School sets, followed by Dolphin sets. Three areas were observed as important hotspots: the area close to the coastal upwelling of northern Peru, the area west to Islands Colon Archipelago (Galapagos) and the area close to the Costa Rica Dome. This information is crucial to identify the mobulids habitat and hotspots that could be managed and protected under dynamic spatial management measures to reduce the mortality of mobulid rays in the eastern Pacific purse-seine fishery and, hence, ensure the sustainability of the populations of these iconic species.

Mannocci, L., Forget, F., Tolotti, M. T., Bach, P., Bez, N., Demarcq, H., . . . Dagorn, L. (2020). Predicting bycatch hotspots in tropical tuna purse seine fisheries at the basin scale. *Global Ecology and Conservation,* 24. https://doi.org/10.1016/j.gecco.2020.e01393

Fisheries observer programs represent the most reliable way to collect data on fisheries bycatch. However, their limited coverage leads to important data gaps that preclude bycatch mitigation at the basin scale. Habitat models developed from available fisheries observer programs offer a potential solution to fill these gaps. We focus on tropical tuna purse seine fisheries (TTPSF) that span across the tropics and extensively rely on floating objects (FOBs) for catching tuna schools, leading to the bycatch of other species associated with these objects. Bycatch under floating objects is dominated by five species, including the vulnerable silky shark Carcharhinus falciformis and four bony fishes (oceanic triggerfish Canthidermis maculata, rainbow runner Elagatis bipinnulata, wahoo Acanthocybium solandri, and dolphinfish Coryphaena hippurus). Our objective was to predict possible bycatch hotspots associated with FOBs for these five species across two tropical oceans. We used bycatch data collected from observer programs onboard purse seiners in the Atlantic and Indian oceans. We developed a generalized additive model per species and per ocean relating bycatch to a set of environmental covariates (depth, chlorophyll-a concentration, sea surface temperature, mixed layer depth, surface salinity, total kinetic energy and the density of floating objects) and temporal covariates (year and month). We extrapolated modeled relationships across each ocean within the range of environmental covariates associated with the bycatch data and derived quarterly predictions. We then detected bycatch hotspots as the 90th percentiles of predictions. In the Atlantic Ocean, bycatch hotspots were predicted throughout tropical and subtropical waters with little overlap between species. By contrast in the Indian Ocean, major overlapping hotspots were predicted in the Arabian Sea throughout most of the year for four species, including the silky shark. Our modeling approach provides a new analytical way to fill data gaps in fisheries bycatch. Even with the lack of evaluation inherent to extrapolations, our modeling effort represents the first step to assist bycatch mitigation in TTPSF and is applicable beyond these fisheries.

Murua, J., Ferarios, J. M., Grande, M., Onandia, L., & Santiago, J. (2021). *Improving on deck best handling and release practices for sharks in tuna purse seiners using hopper with ramp devices.* Scientific Committee Seventeenth Regular Session WCPFC-SC17-2021/EB-IP-13. Western and Central Pacific Fisheries Commission, Retrieved from https://meetings.wcpfc.int/node/12489

A possible bycatch reduction device (BRD) that tuna purse seiners could employ to promote safer and faster release of vulnerable bycatch, such as sharks, are hoppers with ramps. These selective hopper trays can take many shapes and sizes depending on the vessels' top deck configuration. Not all hoppers are equally valuable for bycatch release as some are either too small to access the bycatch or act as funnels with no stop mechanism to allow for time to detect and take out nontarget species. In this study four class A purse seiners operating in the Pacific Ocean and fitted with mobile hoppers were examined for shark release efficiency. Observer data results indicated that when hoppers were used on the vessels between 92% and 98% of the sharks were released from the top deck, against 21% to 46% with no hopper. Hoppers can increase shark survival because their mortality greatly increases once they reach the lower deck, where release times are delayed if there is no release exit from this area, resulting in sharks having to be carried manually upstairs. In addition, release ramps were built and trialled with the hoppers, which acted as wet slides to facilitate faster and safer release of sharks and other bycatches with minimal handling. While designs of hopper and ramps for bycatch release can still be improved, they offer a promising tool for fleets to implement best release practices of vulnerable species. Future trials will employ satellite pop-up tags to properly assess survival rates with and without hoppers. We recommend that tuna RFMOs concerned with best bycatch mitigation and crew safety practices consider the implementation of hoppers with ramps as an efficient BRD in tropical tuna purse seiners which would be in line with shark protection recommendations in CMM-2019-04 paragraph 17.

Murua, J., Moreno, G., Hall, M., Dagorn, L., Itano, D., & Restrepo, V. R. (2017). *ISSF 2017-07: Towards Global Non-Entangling Fish Aggregating Device (FAD) Use in Tropical Tuna Purse Seine Fisheries Through a Participatory Approach.* International Seafood Sustainability Foundation, Retrieved from https://www.iss-foundation.org/research-advocacy-recommendations/our-scientific-program/scientific-reports/download-info/issf-2017-07-towards-global-non-entangling-fish-aggregating-device-fad-use-in-tropical-tuna-purse-seine-fisheries-through-a-participatory-approach/

The impact of bycatch caused by cryptic fishing, including ghost fishing by gear lost at sea, is poorly understood. Since the 1980s, purse seine fishers have deployed floating objects at sea, with ten to a hundred meters deep large mesh net panels hanging beneath a floating structure, to aggregate tuna schools. Known as drifting fish aggregating devices (dFADs) their numbers have rapidly increased globally. Unexpectedly high shark entanglement levels in dFAD netting were first identified in the Indian Ocean in 2012, when all dFADs had loosely hanging large mesh size net panels with potential for higher entanglement risk of dFAD associated species (HERFADs).Many fleets since have adopted lower entanglement risk FADs (LERFADs) and non-entangling FADs (NEFADs), which were initially designed by fishers in collaboration with scientists to minimize entanglement. The move to more sustainable FAD designs has not affected target tuna catches in any of the oceans. These advances have been supported by FAD entanglement-mitigating management measures adopted by regional fisheries management organizations (RFMOs) in the Indian, Atlantic and Eastern Pacific Oceans. Only the Western and Central Pacific region has no FAD entanglement preventive recommendations put forth by its RFMO at present.Information gathered in workshops held in all RFMO regions with skippers and vessel visits at

key tuna ports indicate that LERFAD and NEFAD implementation is almost one hundred percent in the Indian and Atlantic Oceans, and very high in the Eastern Pacific Ocean. On the other hand, in the Western and Central Pacific Ocean, except for anchored FADs (aFADs), most are HERFADs. Ocean-specific studies examining shark ghost fishing rates by different FAD types are currently lacking.In addition, harmonization of NEFAD definitions and observer data collection methods across RFMOs would be useful to scientists and industry. Given the increasing number of dFADs and the vulnerable life history and poor population status of sharks, the replacement of HERFADS in the Western and Central Pacific Ocean, the largest tuna fishery in the world, for entanglement reducing designs should be promoted.

Ortuño-Crespo, G., Griffiths, S. P., & Murua, H. (2022). *Reducing shark bycatch in tuna fisheries: adaptive spatio-temporal management options for the eastern Pacific Ocean.* Working Group on Bycatch Inter-American Tropical Tuna Commission, Retrieved from https://www.bmis-bycatch.org/references/u7srk5zv

Purse-seine tropical tuna fishing in the eastern tropical Pacific Ocean (EPO) results in the bycatch of several sensitive species groups, including elasmobranchs. Effective management of ecosystems balances conservation and resource use, but requires actionable knowledge that accounts for both trade-offs and synergies. Seasonal and adaptive spatial management measures can be effective to reduce the impact of fisheries on non-target species while preserving, or even increasing, target species catch. Exploring the potential distribution and impact of fisheries closures in the open ocean, where highly dynamic environmental conditions drive distributional changes in biological communities throughout the year, requires the identification of persistently high-risk areas, where the likelihood of encountering and catching unwanted bycatch species, relative to the target species, is high. We used fisheries observer data from 1995–2021 to explore the spatio-temporal persistence of areas of high bycatch risk for two species of oceanic sharks, silky shark (Carcharhinus falciformis) and oceanic whitetip shark (Carcharhinus longimanus), and low tuna catch rate areas—defined as areas of high fishing inefficiency (i.e., poor fishing areas). We found that if areas of high fishing inefficiency were closed throughout the study period, and effort reallocated proportionally to reflect historical effort patterns, yearly tuna catch may have increased by 1–11% while the bycatch of silky and oceanic whitetip sharks could have decreased by 10-19% and 9%, respectively. Prior to fishing effort redistribution, bycatch reductions would have accrued to 21–41% and 14% for silky and oceanic whitetip sharks, respectively. Our analysis builds on past evidence and demonstrates the high potential for reducing elasmobranch bycatch in the EPO, while not compromising the catch rates of target tuna species. It also highlights the need to consider new dynamic and adaptive management measures to more efficiently fulfill conservation and sustainability objectives for exploited resources in the EPO.

Poisson, F., Abascal Crespo, F., Ellis, J. R., Chavance, P., Pascal, B., Santos, M. N., . . . Murua, H. (2016). Technical mitigation measures for sharks and rays in fisheries for tuna and tuna-like species: turning possibility into reality. *Aquatic Living Resources,* 29(4). https://doi.org/10.1051/alr/2016030

Tuna fisheries have been identified as one of the major threats to populations of other marine vertebrates, including sea turtles, sharks, seabirds and marine mammals. The development of technical

mitigation measures (MM) in fisheries is part of the code of conduct for responsible fisheries. An in-depth analysis of the available literature regarding bycatch mitigation in tuna fisheries with special reference to elasmobranchs was undertaken. Studies highlighting promising MMs were reviewed for four tuna fisheries (longline, purse seine, driftnets and gillnet, and rod and line - including recreational fisheries). The advantages and disadvantages of different MMs are discussed and assessed based on current scientific knowledge. Current management measures for sharks and rays in tuna Regional Fishery Management Organizations (t-RFMOs) are presented. A review of relevant studies examining at-vessel and postrelease mortality of elasmobranch bycatch is provided. This review aims to help fisheries managers identify pragmatic solutions to reduce mortality on pelagic elasmobranchs (and other higher vertebrates) whilst minimizing impacts on catches of target tuna species. Recent research efforts have identified several effective MMs that, if endorsed by t-RFMOs, could reduce elasmobranchs mortality rate in international tropical purse seine tuna fisheries. In the case of longline fisheries, the number of operational effective MMs is very limited. Fisheries deploying driftnets in pelagic ecosystems are suspected to have a high elasmobranchs bycatch and their discard survival is uncertain, but no effective MMs have been field validated for these fisheries. The precautionary bans of such gear by the EU and by some t-RFMOs seem therefore appropriate. Recreational tuna fisheries should be accompanied by science-based support to reduce potential negative impacts on shark populations. Priorities for research and management are identified and discussed.

Poisson, F., Budan, P., Coudray, S., Gilman, E., Kojima, T., Musyl, M., & Takagi, T. (2022). New technologies to improve bycatch mitigation in industrial tuna fisheries. *Fish and Fisheries,* 23(3), 545-563. https://doi.org/10.1111/faf.12631

For many years, tremendous effort has been dedicated to developing new industrial tuna fisheries, while their adverse impacts on threatened marine species have received relatively little attention. In tuna fisheries, bycatch is the major anthropogenic threat to marine megafauna in general, particularly sharks. Research on the development of gear technology for bycatch reduction and potential mitigation measures helped tuna Regional Fisheries Management Organizations adopt bycatch reduction management measures. After reviewing past research on the development of mitigation measures for pelagic longline and tropical purse seine fisheries based on pelagic species' behaviours, we describe promising new approaches integrating recent technological breakthroughs. New innovations include autonomous underwater vehicles carrying cameras along with miniaturized sensors, aerial drones, computer simulation of fishing gear geometry, environmental DNA assays, computer visualizations and deep learning. The successful application of such tools and methods promises to improve our understanding of factors that influence capture, escape and stress of caught species. Moreover, results emerging from recent ethological research explaining the power of social connection and learning in the "fish world" such as social learning from congeners, habituation to deterrents, and how past fishery interactions affect responses to fishing gear should be taken into account when developing technical mitigation measures.

Restrepo, V. R., Dagorn, L., & Moreno, G. (2016). *ISSF 2016-17: Mitigation of Silky Shark Bycatch in Tropical Tuna Purse Seine Fisheries.* International Seafood Sustainability Foundation, Retrieved from https://www.iss-foundation.org/research-advocacy-recommendations/our-scientific-program/scientific-reports/download-info/issf-2016-17-mitigation-of-silky-shark-bycatch-in-tropical-tuna-purse-seine-fisheries/

Pelagic sharks are not targeted by tropical tuna purse seine fisheries, but they are caught incidentally, especially around floating objects like FADs. The shark bycatch-to-tuna catch ratio in purse seine fisheries is quite small, on average, less than 0.5% in weight. Over 90% of that bycatch is composed of silky sharks, Carcharhinus falciformis. Because of their low reproductive rates and other life history characteristics, silky sharks are a vulnerable species.The contribution of purse seining to the total catch of this species varies by ocean: from 4% in the Indian and Eastern Pacific Oceans, to about 25% in the Western and Central Pacific Ocean regions. The global magnitude of catch of the purse seine fishery is quite large, so reducing the mortality caused by these fisheries can contribute to global conservation efforts. This document summarizes mitigation techniques that can be used in this fishery.

Restrepo, V. R., Dagorn, L., Moreno, G., Schaefer, K., Forget, F., Sancristobal, I., . . . Hutchinson, M. (2018). *ISSF 2018-20: Compendium of at-Sea Bycatch Mitigation Research Activities as of September 2018.* International Seafood Sustainability Foundation, Retrieved from https://www.iss-foundation.org/research-advocacy-recommendations/our-scientific-program/scientific-reports/download-info/issf-2018-20-compendium-of-at-sea-bycatch-mitigation-research-activities-as-of-september-2018/

ISSF conducts at-sea research to investigate potential mitigation measures for tropical tuna purse seiners, especially to reduce catches of bigeye tuna and sharks. Research activities can be classified in one of four hierarchical stages along a fishing trip: 1) Passive mitigation, 2) Avoid catching bycatch, 3) Release bycatch from the net, and 4) Release bycatch from the deck.This Technical Report summarizes all of the at-sea research that ISSF has conducted through September 2018, in chronological order. Most of the research has been done onboard tuna purse-seine fishing vessels, but other vessel types have been used.For each research activity, a table that summarizes the objectives, methods, results and conclusions is presented. Following each research activity, there is a list of publications (peer reviewed as well as other literature) derived from that activity.The Conclusions section at the end of this report highlights some of the main findings of these research activities, with a focus on sharks, bigeye tuna, and turtles.This report is an update of ISSF 2016-13A, which covered research activities through December 2016.

Sacchi, J. (2019). *Mitigation Measures for Protected Species.* Paper presented at the Seventh Meeting of the Parties to ACCOBAMS. Retrieved from https://accobams.org/wp-content/uploads/2019/04/MOP7.Doc30_Mitigation-measures-for-protected-species.pdf

Highly migratory for the most part, occupying a wide distribution across the oceans, the marine megafauna undergo all possible forms of human pressure. Among them, bycatch fishery has increased exponentially in recent years and is now considered the most serious threat to these highly vulnerable species. Minimizing bycatch, is therefore a key component of sustainable fisheries management to maintain marine biodiversity and consequently to reduce negative effects on the resources (see Hall,

1996; Hall et al., 2000). The aim of this document is to present various experimented approaches and strategies that could also serve as an example for fisheries facing the same problems. This review of the different mitigation measures draws on the analysis of the available literature, comprising scientific journal articles together with reports from international organisations and documents available on the internet. The presentation adopted here is guided by the principle that it is not species that should be managed but fishing activities (metiers)1 that should be the target of the technical or management measures that are required to reduce the negative impacts of interactions with fisheries. Consequently, for each of the main fishing gear groups (gill and trammel nets, longlines and lines, trawls, purse seines, trapnets and pots) the various solutions found in the documents consulted are classified by the four main groups of protected species (Cetaceans, Birds, Sharks and Sea turtles).

Sancristobal, I., Martinez, U., Boyra, G., Muir, J., Moreno, G., & Restrepo, V. R. (2017). Issf Bycatch Reduction Research Cruise On The F/V Mar De Sergio In 2016. *Collective volume of scientific papers,* 73(9), 3152-3162. Retrieved from https://www.iccat.int/Documents/CVSP/CV073_2017/n_9/CV073093152.pdf

A research cruise in support of the International Seafood Sustainability Foundation (ISSF) bycatch reduction project was conducted on the tuna purse seine vessel MAR DE SERGIO, during March-April 2016 in the eastern tropical Atlantic Ocean. During a 4-week period a group of three scientists joined the fishing trip with the following objectives: (1) Improving pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs using acoustics: Attaching fishers´ echo-sounder buoys from four different brands to the FADs to compare signals; (2) Use of three scientific echo-sounders with frequencies of 38, 120 and 200 kHz and an EK80 wideband echo-sounder for the frequency band from 85 kHz to 170 kHz onboard a work boat, followed by intensive spill sampling to compare acoustic data and species composition; (3) Study of fish behavior inside the net; (4) shark fish and release from the net; (5) Making other observations that could lead to further tests of mitigation techniques. Preliminary results of these studies are presented.

Tixier, P., Lea, M. A., Hindell, M. A., Welsford, D., Mazé, C., Gourguet, S., & Arnould, J. P. Y. (2021). When large marine predators feed on fisheries catches: Global patterns of the depredation conflict and directions for coexistence. *Fish and Fisheries,* 22(1), 31-53. https://doi.org/10.1111/faf.12504

The sustainable mitigation of human–wildlife conflicts has become a major societal and environmental challenge globally. Among these conflicts, large marine predators feeding on fisheries catches, a behaviour termed “depredation,” has emerged concomitantly with the expansion of the world’s fisheries. Depredation poses threats to both the socio-economic viability of fisheries and species conservation, stressing the need for mitigation. This review synthesizes the extent and socio-ecological impacts of depredation by sharks and marine mammals across the world, and the various approaches used to minimize it. Depredation was reported in 214 fisheries between 1979 and 2019 (70% post-2000) and affected fleets from 44 countries, in all sectors (commercial, artisanal and recreational), and in all major fishing techniques (nets, traps and hook-and-lines). A total of 68 predator species were involved in depredation (20 odontocetes, 21 pinnipeds and 27 sharks), and most (73%) were subject to either by-catch and/or retaliatory killing from fishers when interacting with gear. Impacts on fishers were primarily associated with catch losses and gear damage but often lacked assessments. Deterrence was a

major mitigation approach but also the least effective. Gear modifications or behavioural adaptation by fishers were more promising. This review highlights the need for improved monitoring, and interdisciplinary and integrated research to quantify the determinants and impacts of depredation in the socio-ecological dimension. More importantly, as the conflict is likely to escalate, efforts directed towards changing perceptions and integrating knowledge through adaptive co-management are raised as key directions towards coexistence between fisheries and large marine predators.

Tolotti, M. T., Forget, F., Capello, M., Filmalter, J. D., Hutchinson, M., Itano, D., . . . Dagorn, L. (2020). Association dynamics of tuna and purse seine bycatch species with drifting fish aggregating devices (FADs) in the tropical eastern Atlantic Ocean. *Fisheries Research,* 226. https://doi.org/10.1016/j.fishres.2020.105521

Several pelagic fish species are known to regularly associate with floating objects in the open ocean, including commercially valuable species. The tuna purse seine industry takes advantage of this associative behavior and has been increasingly deploying free-drifting man-made floating objects, also known as fish aggregating devices (FADs). Using passive acoustic telemetry, this study describes the associative dynamics of the main targeted tropical tuna species (Thunnus albacores, T. obelus and Katsuwonus pelamis), as well as three major bycatch species, silky shark (Carcharhinus falciformis), rainbow runner (Elagatis bipinmdata) and oceanic triggerfish (Canthidermis maculata). Short-term excursions away from the FADs were frequently performed by all tuna species as well by silky sharks. These excursions were characterized by a marked diel pattern, mainly occurring during nighttime. Rainbow runners and oceanic triggerfish were much more present at the FADs and rarely performed excursions. Average continuous residence times (CRTs) ranged from 6 days, for silky shark, up to 25 days for bigeye tuna. Similar to silky shark, average CRTs for skipjack tuna and oceanic triggerfish were less than 10 days. For yellowfin tuna and rainbow runner, CRTs averaged 19 and 16 days, respectively. Bigeye and yellowfin tuna remained associated to a single drifting FAD for a record of 55 days and 607 km traveled.

Watson, J. T., Essington, T. E., Lennert-Cody, C. E., & Hall, M. A. (2009). Trade-Offs in the Design of Fishery Closures: Management of Silky Shark Bycatch in the Eastern Pacific Ocean Tuna Fishery. *Conservation Biology,* 23(3), 626-635. https://doi.org/10.1111/j.1523-1739.2008.01121.x

Bycatch-the incidental catch of nontarget species-is a principal concern in marine conservation and fisheries management. In the eastern Pacific Ocean tuna fishery, a large fraction of nonmammal bycatch is captured by purse-seine gear when nets are deployed around floating objects. We examined the spatial distribution of a dominant species in this fishery's bycatch, the apex predator silky shark (Carcharhinus falciformis), from 1994 to 2005 to determine whether spatial closures, areas where fishing is prohibited, might effectively reduce the bycatch of this species. We then identified candidate locations for fishery closures that specifically considered the trade-off between bycatch reduction and the loss of tuna catch and evaluated ancillary conservation benefits to less commonly captured taxa. Smoothed spatial distributions of silky shark bycatch did not indicate persistent small areas of especially high bycatch for any size class of shark over the 12-year period. Nevertheless, bycatch of small silky sharks (< 90 cm total length) was consistently higher north of the equator during all years. On the basis of this distribution, we evaluated nearly 100 candidate closure areas between 5 degrees N and 15

degrees N that could have reduced, by as much as 33%, the total silky shark bycatch while compromising only 12% of the tuna catch. Although silky sharks are the predominant species of elasmobranchs caught as bycatch in this fishery, closures also suggested reductions in the bycatch of other vulnerable taxa, including other shark species and turtles. Our technique provides an effective method with which to balance the costs and benefits of conservation in fisheries management. Spatial closures are a viable management tool, but implementation should be preceded by careful consideration of the consequences of fishing reallocation.

Zollett, E. A., & Swimmer, Y. (2019). Safe handling practices to increase post-capture survival of cetaceans, sea turtles, seabirds, sharks, and billfish in tuna fisheries. *Endangered Species Research,* 38, 115-125. https://doi.org/10.3354/esr00940

Incidental capture of marine animals in fishing gear may cause immediate or delayed mortality due to injury. Increasing post-capture survival of these species is very important to reducing the widespread impacts of bycatch, particularly on protected and threatened populations. In this paper, we review recent literature on safe handling of sea turtles, cetaceans, seabirds, sharks, and billfish and summarize the most effective measures for improving survivability of these species after interactions with gillnet, pelagic longline, and purse seine gear. We also review the current tuna Regional Fishery Management Organization (tRFMO) measures on safe handling and release to identify gaps in implementation of safe handling practices. Strategies that increase post-capture survival of marine species can be grouped into 3 primary categories: reducing immediate mortality, minimizing injury that results in delayed mortality, and reducing stress that can lead to death. Routine training of fishermen on safe handling practices greatly improves the effectiveness of these measures. When bycatch does occur, the strategies to increase post-release survival become key for protecting vulnerable marine populations. This inventory highlights the great conservation value that can be provided by the tRFMOs by providing guidance and training on safe handling practices to increase post-release survival across taxa.

1.5 Trawling Fisheries

Abrantes, K. G., Barnett, A., Soetaert, M., Kyne, P., Laird, A., Seymour, J., . . . Huveneers, C. (2020). *Can sawfish bycatch within the Northern Prawn Fishery be mitigated using an electric field?* FRDC Project No 2016-058 Retrieved from https://www.frdc.com.au/sites/default/files/products/2016-058-DLD.pdf

This project aimed to test the effect of electric fields on sawfish behaviour and to assess the potential for electric pulses to mitigate sawfish bycatch in prawn fisheries. The project was developed in collaboration with the Northern Prawn Fishery Industry Projects Manager Adrianne Laird and Dr Peter Kyne, principal investigator of National Environmental Research Programme/National Environmental Science Program Marine Biodiversity Hubs projects specialised in Northern Australia threatened species, including sawfishes.

Belcher, C. N., & Jennings, C. A. (2011). Identification and evaluation of shark bycatch in Georgia's commercial shrimp trawl fishery with implications for management. *Fisheries Management and Ecology,* 18(2), 104-112. https://doi.org/10.1111/j.1365-2400.2010.00757.x

Many US states have recreational and commercial fisheries that occur in nursery areas occupied by subadult sharks and can potentially affect their survival. Georgia is one of few US states without a directed commercial shark fishery, but the state has a large, nearshore penaeid shrimp trawl fishery in which small sharks occur as bycatch. During our 1995-1998 investigation of bycatch in fishery-dependent sampling events, 34% of 127 trawls contained sharks. This bycatch totalled 217 individuals from six species, with Atlantic sharpnose shark, Rhizoprionodon terraenovae (Richardson), the most common and finetooth shark, Carcharhinus isodon (Muller & Henle) and spinner shark, Carcharhinus brevipinna (Muller & Henle), the least common. The highest catch rates for sharks occurred during June and July and coincided with the peak months of the pupping season for many species. Trawl tow speed and tow time did not significantly influence catch rates for shark species. Gear configurations [net type, turtle excluder device (TED), bycatch reduction device] affected catch rates for shark species. Results of this study indicate gear restrictions, a delayed season opening, or reduced bar spacing on TEDs may reduce shark bycatch in this fishery.

Bettis, S. (2017). *Shark Bycatch in Commercial Fisheries: A Global Perspective.* (Master of Science), Nova Southeastern University, Retrieved from https://nsuworks.nova.edu/cnso_stucap/331/

Many shark species have global distributions and are caught incidentally in different types of fisheries. Over the last two decades, shark populations have declined tremendously, with one of the leading causes of this decline bycatch in primarily teleost fisheries. Bycatch occurs throughout the world's fisheries, but is not well documented in terms of species composition and numbers of each species captured. Information on shark bycatch is spread through the primary and grey literature, but has not been compiled in summary to date. The goal of my capstone is to present global shark bycatch data and provide a comparative review to determine fishery types that affect shark populations and identify shark species at risk as a result of bycatch. Longline fisheries caught a larger variety of shark species, and the post-release mortality was generally low. In contrast, trawl fisheries caught mostly the same few

species, but post-release mortality was extremely high. Blue sharks (Prionace glauca), silky sharks (Carcharhinus falciformis), and spiny dogfish (Squalus acanthias) were caught most often in trawl fisheries, and in large numbers that likely adds to risk of overexploitation of their populations. This literature review revealed a severe lack of standardization in bycatch data reporting by different fishing nations, and in documents prepared by management agencies and scientists, including the definition of bycatch used and the way it was recorded. Establishing a universal definition of bycatch and standardizing its reporting would vastly improve ability to assess the scale and composition of shark bycatch and its impacts on shark populations. Systematic and standardized accounting of shark bycatch would provide information helpful for collaboration among regulatory agencies. Rather than simply document bycatch, a number of fishing gear alterations show promise for bycatch reduction and are worthy of integration into fisheries by managers. Additional important steps that can improve bycatch assessment is increased observer coverage in fisheries, marine protected areas, and making bycatch data public.

Beutel, D., Skrobe, L., Castro, K., Ruhle, O'Grady, J., & Knight, J. (2008). Bycatch reduction in the Northeast USA directed haddock bottom trawl fishery. *Fisheries Research,* 94(2), 190-198. https://doi.org/10.1016/j.fishres.2008.08.008

We investigated the performance of a large mesh faced (upper and lower wings, side panels, first bottom belly) bottom trawl designed to capture haddock (Melanogrammus aeglefinus) while reducing the bycatch of cod (Gadus morhua) and other species. This experimental net, named the Eliminator Trawl (TM), was tested using two vessels, F/V Iron Horse and F/V Sea Breeze, in side-by-side catch comparison hauls with the currently regulated net. A total of 100 successful comparison tows were completed. All species captured were weighed for total weight. Haddock, cod, and the majority of the flounders were measured. The Eliminator Trawl (TM) significantly reduced the catch of stocks of concern including cod, yellowtail flounder (Limanda ferruginea), winter flounder (Pseudopleuronectes americanus), witch flounder (Glyptocephalus cynoglossus), and American plaice (Hippoglossoides platessoides). Other species such as monkfish (Lophius americanus) and skate (unclassified) also showed a significant decrease in catch in the Eliminator Trawl (TM). In addition, the catch of haddock, the target species, did not differ significantly between nets. The results of this study indicate that the Eliminator Trawl (TM) would be an efficient tool in gaining access to closed areas and used in recovery programs to exploit more abundant fish species. Examples in the Northeast USA include a B Days-at-Sea Program (DAS) as well as a Special Access Program (SAP) where the Eliminator Trawl (TM) appears to meet the minimum bycatch requirements to be considered for both these programs.

Brcic, J., Herrmann, B., De Carlo, F., & Sala, A. (2015). Selective characteristics of a shark-excluding grid device in a Mediterranean trawl. *Fisheries Research,* 172, 352-360. https://doi.org/10.1016/j.fishres.2015.07.035

Galeus melastomus (blackmouth catshark) is often caught as bycatch in demersal trawls in the Mediterranean. In order to reduce bycatches of shark we tested an excluder grid with 90 mm bar spacing during experimental fishing in the Tyrrhenian Sea (Western Mediterranean). Data collected made it possible to simultaneously evaluate catch losses of two commercial species: Nephrops norvegicus (Norway lobster) and Phycis blennoides (greater forkbeard). The escape outlet ahead of the

grid and the codend were both mounted with a cover in order to collect escaped fish ahead of the grid and through the codend meshes. We used a structural model to estimate the contribution of the individual selective processes consisting of the excluder grid and the size selective codend. The 90 mm excluder grid did not prove to be efficient in excluding G. melastomus, while it excuded more of P. blennoides. Catches of N. norvegicus were also affected by the presence of the grid, but not as much as the catches of other two species. The results obtained for the experimental grid + codend setup were then compared with the estimated selectivity for the "codend alone" setup. Furthermore, byway of explorative simulation with other grid bar spacing, we concluded that reducing the grid bar spacing to 70 mm would provide better compromise between the reduction of G. melastomus as bycatch and the catch rate of P. blennoides and N. norvegicus.

Brewer, D., Heales, D., Milton, D., Dell, Q., Fry, G., Venables, B., & Jones, P. (2006). The impact of turtle excluder devices and bycatch reduction devices on diverse tropical marine communities in Australia's northern prawn trawl fishery. *Fisheries Research,* 81(2-3), 176-188. https://doi.org/10.1016/j.fishres.2006.07.009

In 2001, paired-trawl comparisons were made during prawn trawl operations to assess the effect of turtle excluder devices and bycatch reduction devices on a range of species groups caught in tropical Australia. This study is one of the first to evaluate the commercial use of these devices in a tropical fishery. Nets with a combination of a turtle excluder device and bycatch reduction device reduced the catches of turtles by 99%, seasnakes by 5%, sharks by 17.7%, rays by 36.3%, large sponges by 85.3%, and small bycatch by 8%, however, these results were largely attributable to the influence of the turtle excluder devices. Nets with both devices also reduced the catch of commercially important prawns by 6%, but the proportion of soft and damaged prawns was reduced by 41%. The combination of these devices had no measurable impact on catches of any of the three byproduct species groups: Thenus spp. (Moreton Bay bugs), Teuthoidea spp. (squid) and Amusium pleuronectes (scallops). Turtles excluder devices reduced the numbers of larger sharks and rays (> 1 m) by 86% and 94%, respectively. They did not reduce the total number of sawfish caught, but did reduce the number of the most commonly caught species - the narrow sawfish (Anoxypristis cuspidata) - by 73.3%. Upward- and downward-excluding turtle excluder devices performed about equally for most species groups, although upward excluders were more effective for sharks and less effective for large sponges. The performance of BRDs was poor for most groups and could be improved by using them in more effective positions such as closer to the codend catch. The use of these devices is a major step towards ensuring the long-term conservation of many species, especially endangered sea turtles and vulnerable elasmobranchs. As fishers become more experienced in their use, we are optimistic that the fishery's impact on bycatch will reduce even further.

Chosid, D. M., Pol, M., Szymanski, M., Mirarchi, F., & Mirarchi, A. (2012). Development and observations of a spiny dogfish Squalus acanthias reduction device in a raised footrope silver hake Merluccius bilinearis trawl. *Fisheries Research,* 114, 66-75. https://doi.org/10.1016/j.fishres.2011.03.007

A spiny dogfish Squalus acanthias excluder grate (grid) within the extension of a silver hake (whiting) Merluccius bilinearis trawl net was designed and tested in Massachusetts Bay, USA between October 2008 and August 2009 using a live-fed underwater video camera. Grates with 50mm spacing were

investigated for effects from color (white or black), angle, and direction (leading to a top or bottom escape vent). Spiny dogfish numbers were greatly reduced for all gear configurations based on video observations and data collected from the codend, while target species were caught in commercial quantities. Four tows (of various gear configurations) resulted in spiny dogfish blockages in front of the grate. The reduction of spiny dogfish led to increases in the quality of marketable catches, likely reductions in non-target species mortality, and decreases in the codend catch handling times.

Christensen, C. (2014). *Opportunities for the Reduction of Skate Bycatch in Atlantic Canada Trawl Fisheries: A Case Study of two Innovative Trawl Gear Designs.* (Master of Marine Management), Dalhousie University, Retrieved from http://hdl.handle.net/10222/56203

Skates are fish under the Subclass of elasmobranchii, typically found in temperate or arctic waters. Catch of skates pose a number of issues for fishers as bycatch including increased handling effort, reduced value of target catch, and clogging of gear. Discarding of skates in Canadian trawl fisheries has led to significant declines in the abundance of a number of skate species. The Eliminator TrawlTM, designed in the US has shown success in reducing the catch of skates and other groundfish. Similarly, the Radial Escape Section trawl gear has also proven useful in reducing bycatch of larger fish. The ability of either gear to reduce catch of groundfish is key to aiding in the recovery of a number of groundfish species currently under moratorium. Specifically, use of the Eliminator TrawlTM is promising given its success with reducing bycatch both in benthic and pelagic trawls. A pilot project testing these gears at-sea and benefiting from fishers' knowledge of the fishery is an ideal first step towards use of either of these trawls and the recovery of threatened skates populations.

Clarke, J., Milligan, R. J., Bailey, D. M., & Neat, F. C. (2015). A Scientific Basis for Regulating Deep-Sea Fishing by Depth. *Current Biology,* 25(18), 2425-2429. https://doi.org/10.1016/j.cub.2015.07.070

The deep sea is the world's largest ecosystem [1], with high levels of biodiversity [2, 3] and many species that exhibit life-history characteristics that make them vulnerable to high levels of exploitation [4]. Many fisheries in the deep sea have a track record of being unsustainable [5, 6]. In the northeast Atlantic, there has been a decline in the abundance of commercial fish species since deep-sea fishing commenced in the 1970s [7, 8]. Current management is by effort restrictions and total allowable catch (TAC), but there remain problems with compliance [9] and high levels of by-catch of vulnerable species such as sharks [10]. The European Union is currently considering new legislation to manage deep-sea fisheries, including the introduction of a depth limit to bottom trawling. However, there is little evidence to suggest an appropriate depth limit. Here we use survey data to show that biodiversity of the demersal fish community, the ratio of discarded to commercial biomass, and the ratio of Elasmobranchii (sharks and rays) to commercial biomass significantly increases between 600 and 800 m depth while commercial value decreases. These results suggest that limiting bottom trawling to a maximum depth of 600 m could be an effective management strategy that would fit the needs of European legislations such as the Common Fisheries Policy (EC no. 1380/2013) [11] and the Marine Strategy Framework Directive (2008/56/EC) [12].

Clarke, T. M., Espinoza, M., & Wehrtmann, I. S. (2014). Reproductive ecology of demersal elasmobranchs from a data-deficient fishery, Pacific of Costa Rica, Central America. *Fisheries Research,* 157, 96-105. https://doi.org/10.1016/j.fishres.2014.04.003

The elasmobranch bycatch associated with the Costa Rican deepwater shrimp fishery is mainly comprised of four species: Raja velezi, Mustelus henlei, Zapteryx xyster and Torpedo peruana. In data-deficient fisheries such as this one, knowledge of the reproductive ecology of a species may serve as a valuable management tool to determine its vulnerability and apply precautionary measures to ensure its long-term conservation. This study examined the reproductive ecology of R. velezi, M. henlei, Z. xyster and T. peruana based on data collected during demersal trawling along the Pacific coast of Costa Rica, Central America. A total of 290 trawls was analyzed at depths of 18-350 m (March 2010-August 2012). While R. velezi, M. henlei and Z xyster matured at similar sizes (range: 37-60 cm TL), T. peruana matured at a larger size (70 cm TL in females). The four elasmobranch species exhibited strong sex and size segregation patterns, which were mainly influenced by depth. Adults were more common at depths >50 m, whereas neonates and gravid females were more abundant in shallow estuarine waters (<50 m). Moreover, large aggregations of immature R. velezi and M. henlei occurred near coastal wetlands, bays and estuaries of the central Pacific region. These results suggest that shallow estuarine habitats may be important for early life stages of demersal elasmobranchs caught in the Costa Rican trawling fishery. However, our knowledge of critical habitats for elasmobranch along the entire Pacific of Costa Rica is still limited, and thus future studies are needed to identify and understand the role of these habitats in the early life-history of sharks, skates and rays.

Cosandey-Godin, A., & Morgan, A. (2011). *Fisheries bycatch of sharks: Options for mitigation.* Pew Environment Group, Washington, DC. Retrieved from https://www.sarri.org/storage/app/media/tools_pdfs/PewOSSsharkbycatchreviewpdf.pdf

Bycatch (see definition below) is one of the most significant issues in the management and conservation of global fisheries (Hall et al. 2000, Kelleher 2005, Lewison et al. 2004) and has been identified as one of the leading causes of shark population declines. Sharks are susceptible to high fishing mortality rates because of their life history characteristics, which include slow growth, late ages at maturity, and the production of a limited number of young over a lifetime (Cortes 2002, Heppell et al. 1999, Cortes 1999). In addition, research has shown that several species of sharks have very high rates of mortality associated with the fishing process (Morgan and Burgess 2007, Mandelman et al. 2008), and it has been estimated that species such as sandbar shark (Carcharhinus plumbeus) (Sminkey and Musick 1994, Cortes 1999) and dusky shark (Carcharhinus obscurus) (Simpfendorfer 1999) increase their population sizes so slowly that they are considered particularly vulnerable to mortality from fishing activities (Musick et al. 2000a). For example, Cortes et al. (2006) found that if fishing for dusky shark stopped for 30 years, their population in the Northwest Atlantic would still be depleted. Over the past two decades, serious population declines have been reported for a number of shark species in several regions around the world (Baum et al. 2003, Ferretti et al. 2008, Robbins et al. 2006, Ferretti et al. 2010, Clarke 2011) and are attributed to both targeted and incidental capture. According to the International Union for Conservation of Nature (IUCN) and other sources, bycatch is one of the primary threats facing sharks (Musick et al. 2000b, Lewison et al. 2004). Despite widespread recognition of shark bycatch issues (Food and Agriculture Organization [FAO] 1999; FAO 2010), few mitigation actions have been established, and there are no clear guidelines about which mitigation actions would be most effective. In addition, there are very few management measures requiring actions to mitigate shark bycatch. However, it is clear that

managers and fishermen must aim to reduce both bycatch rates and the harmful effects from bycatch (e.g., injuries from capture on fishing gear). Based on the best available information, this review provides a summary of the current knowledge and understanding of shark bycatch and discusses available management options and technical measures aimed at reducing both the rate at which sharks encounter fishing gear and the associated damaging effects.

Courtney, A. J., Haddy, J. A., Campbell, M. J., Roy, D. P., Tonks, M. L., Gaddes, S. W., . . . Taylor, J. (2007). *Bycatch weight, composition and preliminary estimates of the impact of bycatch reduction devices in Queensland's trawl fishery*. Queensland Department of Primary Industries and Fisheries Retrieved from https://www.daf.qld.gov.au/__data/assets/pdf_file/0003/49836/BycatchFinalReport2007-FullReport-part1-Sections1to4.pdf

This report provides quantitative information on the effects of turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) on the catch rates of bycatch, prawns, scallops and byproduct species, such as Moreton Bay bugs and Balmain bugs, in Queensland's major trawl fishing sectors. It also provides biological information on, and management advice for several species referred to in the Fishery Management Plan as the permitted species. Several recommendations are included for reducing bycatch in the trawl fishery and for sustaining stocks of the permitted species.

Duarte, D. L. V., Broadhurst, M. K., & Dumont, L. F. C. (2019). Challenges in adopting turtle excluder devices (TEDs) in Brazilian penaeid-trawl fisheries. *Marine Policy,* 99, 374-381. https://doi.org/10.1016/j.marpol.2018.10.048

The incidental capture and mortality of endangered, threatened and protected (ETP) marine species remains a global problem. Among the most problematic fishing methods is penaeid trawling, which is responsible for one quarter of the world's discarded bycatch and remains a key threatening process to ETP species (turtles and some elasmobranchs). So-called 'turtle excluder devices' (TEDs) legislated among USA penaeid trawlers and subsequently fleets in other countries during the 1990s alleviated some concerns over impacts to ETP species, but adoption has not been global. One country characterised by resistance to TEDs is Brazil—despite federal legislation mandating usage for almost 25 years. The reasons for this deficit, reiterated here via interviews with 64 southern penaeid-trawler captains, are threefold. First, are perceived issues with mandated designs and minimal third-party expertise, leading to a sustained misconception that TEDs simply do not work in Brazilian penaeid trawls. Second, is the perpetuated belief of minimum negative impacts to ETP species; exacerbated by few quantitative data. Third, is jurisdictional failure to promote the concept that slight economic loss associated with not catching ETP species (elasmobranchs) is necessary for broader ecological sustainability. We propose TED use among Brazilian penaeid-trawl fisheries might be promoted via a co-management strategy facilitated by sustained education and technical expertise from research providers encouraging fishers to develop fishery-specific solutions. If industries can be encouraged to accept the concept of TEDs, they might then be expected to refine and develop ownership of the most appropriate configurations.

Duarte, D. L. V., Broadhurst, M. K., Ortega, I., Pias, B. S., & Dumont, L. F. C. (2018). Quantifying the morphology of key species caught in the southern Brazilian penaeid-trawl fishery as a precursor to improving selection. *Latin American Journal of Aquatic Research,* 46(4), 799-809. https://doi.org/10.3856/vol46-issue4-fulltext-17

Penaeid trawls are poorly selective fishing gears; contributing towards approximately 27% of global marine fisheries discards. Various options are available for mitigating penaeid-trawl bycatch, including gear modifications such as 'bycatch reduction devices' (BRDs) or codend mesh-size regulations. A precursor to developing modifications is information about the key target and bycatch species in terms of their sizes and morphology. Here we describe the relationships between these characteristics for the southern Brazilian industrial penaeid-trawl fishery within a broader objective of proposing more selective trawl configurations. Catches were sampled during 37 tows. Fifty-two species were caught, including two loggerhead turtles, Caretta caretta, one green turtle, Chelonia mydas, as well as 61 individuals of seven ray species classified as Endangered or Critically Endangered. One penaeid (Pleoticus muelleri) and 11 teleosts were assessed for various morphological relationships. The data demonstrated that both the existing conventionally used 26 mm (stretched mesh opening; SMO) mesh and a legislated size of 30 mm SMO are too small. Using morphological relationships, we propose testing a minimum diamond-shaped mesh size of at least 35 mm and a square-mesh window in the top of the codend comprising at least 48 mm mesh. Such a configuration would probably retain penaeids and larger teleosts, but allow many small teleosts to escape. Anteriorly located grids are also required to reduce the bycatch of charismatic species like turtles and rays. Wide-scale use of such BRDs should considerably reduce bycatches and the ancillary impacts of regional penaeid-trawl fisheries.

Fakioglu, Y. E., Ozbilgin, H., Gokce, G., & Herrmann, B. (2022). Effect of ground gear modification on bycatch of rays in mediterranean bottom trawl fishery. *Ocean & Coastal Management,* 223. https://doi.org/10.1016/j.ocecoaman.2022.106134

Bycatch of rays and skates in towed fishing gears represents one of the major threats to these relatively slow growing marine species. The objective of this study was to modify ground gear in a bottom trawl fishery to increase the escape of these species during towing without associated loss of target catch. Sea trials were carried out with a research vessel in Mersin Bay, North-eastern Mediterranean. Experimental ground gear was modified by cutting the rigging twine between the fishing line and the footrope in the central part of the ground gear. Capture of three unwanted bycatch species were estimated. The probability of capture of guitarfish (Rhinobatos sp.) and common stingray (Dasyatis pastinaca) was significantly reduced to 8% and 20% for guitarfish and stingray, respectively compared to standard ground gear. The results for spiny butterfly ray (Gymnura altavela) were inconclusive due to the wide confidence intervals. Further, the catch comparison results for five out of six target species investigated did not show significant reduction in catch efficiency when using experimental gear compared to the standard trawl. Only for common sole (Solea solea) the modified trawl had significantly lower catch efficiency than the standard trawl. We believe that this technical measure for reducing unwanted bycatch in bottom trawls has a potential to be adopted by the fishery due to being an efficient, low-cost measure which does not create additional challenges during handling of the gear.

Fennessy, S. T., & Isaksen, B. (2007). Can bycatch reduction devices be implemented successfully on prawn trawlers in the Western Indian Ocean? *African Journal of Marine Science,* 29(3), 453-463. https://doi.org/10.2989/ajms.2007.29.3.12.342

Bycatch reduction devices (BRDs) are increasingly being used in prawn trawl fisheries worldwide. This paper describes an experiment with a Nordmore grid and a square-mesh panel on a prawn trawler off Mocambique. Although numbers of hauls that caught elasmobranchs were low, 75% of hauls with grids caught fewer large rays than those without grids; hauls using grids caught no large sharks at all. In its final configuration, the grid respectively reduced prawn, discard and retained fish catches by 5%, 25% and 32% relative to control hauls; the square-mesh panel increased prawn catches by 3% and respectively reduced discard and retained fish catches by 23% and 18% relative to control hauls. Changes in prawn catches were not statistically significant; however, when the grid and the square-mesh panel were used together, they reduced prawn, discard and retained fish catches by 25%, 47% and 26% respectively relative to control hauls (all significant except for retained fish catches). Overall, the Nordmore grid successfully released large elasmobranchs, and the grid and the square-mesh panel individually reduced bycatch without reducing prawn catches. In combination, the two BRDs also reduced bycatch, but at the cost of substantially reduced prawn catches. The results indicate that there is scope for the wider use of BRDs on prawn trawlers in the Western Indian Ocean region, although this would require increased support from management agencies and industry.

Garces-Garcia, K. C., Tovar-Avila, J., Vargas-Trejo, B., Chavez-Arrenquin, D. A., Walker, T. I., & Day, R. W. (2020). Elasmobranch bycatch by prawn trawls in the Gulf of California: First comprehensive analysis and the effect of fish escape devices. *Fisheries Research,* 230. https://doi.org/10.1016/j.fishres.2020.105639

We report results from the first detailed investigation of elasmobranch bycatch that contains data on species, sex, and length-frequency distributions of animals collected in the coastal south-eastern and entrance region of the Gulf of California. Using data from fishery-independent prawn trawl surveys between 2011-17, we found differences between years and zones in the number of species per tow in summer when more samples were taken, but we did not find differences in autumn and winter. We present size-frequency distributions with size at first maturity for Urobatis halleri, Urotrygon chilensis, Rhinoptera steindachneri, Hypanus dipterurus, Gymnura marmorata, and Pseudobatos glaucostigmus, which were the species most frequently present in the prawn trawls during the surveys. These distributions are presented by zone, depth stratum, and season (mainly summer, when commercial prawn trawling is prohibited, and thus information from commercial catches is not available). We found significant differences in the mean size between mature females and mature males for five of these six species. We also found that fish escape devices installed in the prawn nets early in 2016 improved the escape of mid-sized rays, demonstrating size selectivity of the fishery and suggesting the potential to improve further the escape of large-sized rays by modifying fish escape devices. Furthermore, the large number of rays caught (21 species) compared with the number of sharks caught (four species) suggests much lower catchabilities for sharks than for rays in demersal prawn trawl gear.

Garstin, A., & Oxenford, H. A. (2018). Reducing Elasmobranch Bycatch in the Atlantic Seabob (Xiphopenaeus kroyeri) Trawl Fishery of Guyana. *Gulf and Caribbean Research,* 29(1), GCFI10-GCFI20. https://doi.org/10.18785/gcr.2901.04

The Atlantic seabob (Xiphopenaeus kroyeri) trawl fishery is very important to Guyana, with 88 licensed industrial vessels harvesting about 15,000 mt annually, representing Guyana's most valuable seafood export. All vessels are already using both teleost by—catch reduction devices (BRDs) and turtle excluder devices (TEDs) to satisfy international market standards. However, the key stakeholder, the Guyana Association of Private Trawler Owners and Seafood Processors, is now seeking to access sustainable seafood markets through pursuing Marine Stewardship Council (MSC) certification. To this end, this study documents elasmobranch by—catch in the current fishery and examines the effectiveness of a modified TED (with a reduced bar spacing and the addition of a brace bar) in reducing elasmobranch by—catch. From July—August 2014, 131 tows were made, 80 of which represented simultaneous hauls with control and modified TEDs. One shark and 8 ray species were recorded. A statistically significant 40% decline in the elasmobranch catch rate was observed when using modified TEDs compared with control TEDs (mean by—catch rate dropped from 2.3 to 1.4 individuals per twin—trawl/h). Furthermore, modified TEDs significantly reduced the mean size of rays caught by 6.3%. This also resulted in a virtual elimination of 3 IUCN—designated 'Near Threatened' ray species in the by—catch, although having little effect on the capture of small—sized elasmobranch species, including the 'Critically Endangered' Caribbean Electric Ray (Narcine bancroftii). We conclude that the modified TED was successful in reducing the by—catch of vulnerable elasmobranch species and should advance progress towards attaining by—catch standards required for MSC certification.

Garstin, A., Oxenford, H. A., & Maison, D. (2017). *The effectiveness of a modified turtle excluder device (TED) in reducing the bycatch of elasmobranchs in the Atlantic seabob (Xiphopenaeus kroyeri) industrial trawl fishery of Guyana.* CERMES Technical Report No. 87. Centre for Resource Management and Environmental Studies (CERMES), Retrieved from https://www.cavehill.uwi.edu/cermes/getdoc/d2f2bd90-29c1-4e3e-9aba-c30ad93e5dcf/garstin_et_al_2017_elasmobranch_bycatch_guyana_sea.aspx

The Atlantic seabob (Xiphopenaeus kroyeri) trawl fishery is extremely important to Guyana, with some 88 licensed industrial trawling vessels harvesting around 15,000 mt per year, almost all of which is exported to the US and EU, representing Guyana's most valuable seafood export. The key player in this industry, the Guyana Association of Private Trawler Owners and Seafood Processors (GAPTO&SP) is taking pro-active steps in pursuing Marine Stewardship Council certification for the seabob trawl fishery to ensure top market prices and long-term sustainability of the seabob stock. To this end, all commercial vessels in the fleet are using turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) in their trawl nets. However, the effectiveness of these devices in reducing the bycatch of vulnerable sharks and rays has not yet been examined. This study, requested by GAPTO&SP, represents the first attempt to document the bycatch of these discarded species by the seabob trawl fleet, and to compare the effectiveness of two different TED designs. Over the period July-August 2014, five trips were taken on three different seabob vessels to document the species, sizes and condition of all sharks and rays landed and discarded during the normal 24 hour-day operation of the vessels. Wherever possible, vessels deployed nets fitted with a standard control TED, simultaneously with nets fitted with a modified test TED for comparison of bycatch by the two gears. A total of 131 tows were sampled, 80 of which represented simultaneous tows of both the control and modified test TEDs. Shark and ray bycatch in the

nets with control TEDs comprised eight ray species and one shark species including, among the infrequently landed species, three 'Near Threatened' and one 'Critically Endangered' ray species according to the IUCN Red List. The use of the modified TEDs significantly reduced the overall mean size of individuals in the elasmobranch bycatch by 6.3%. Most importantly the mean sizes of the two ray species representing more than 80% by number of elasmobranchs taken as bycatch were reduced by 9.4% and this resulted in a near elimination of mature females in the bycatch. By excluding larger individuals from the cod-end, a statistically significant and substantial decline in the catch rate (by 40%) was observed when using the test TED compared with the control TED (mean elasmobranch bycatch rate dropped from 2.29 to just 1.37 individuals per twin-net hr-1). This also resulted in a virtual elimination of the three 'Near Threatened' ray species in the bycatch, although it had little effect on the capture of the small-sized ray and shark species, including the 'Critically Endangered' Bancroft's numbfish. We conclude that the modified TED was very successful in reducing important elements of the elasmobranch bycatch and should advance the progress towards attaining the bycatch standards required for MSC certification. We further recommend that the impact of this TED on the capture rate of the target seabob, which was beyond the scope of this study, should be examined to inform the decision on mandatory adoption of this gear modification.

Gilman, E., & Lundin, C. (2010). Minimising bycatch of sensitive species groups in marine capture fisheries: lessons from tuna fisheries. In *Handbook of Marine Fisheries Conservation and Management.* Q. Grafton, R. Hillborn, D. Squires, M. Tait, & M. Williams (Eds.), (pp. 23): Oxford University Press Retrieved from http://ecite.utas.edu.au/58808

Bycatch in marine capture fisheries is the retained catch of nontargeted but commercially viable species (referred to as “incidental catch”) plus all discards (Food and Agriculture Organization of the United Nations [FAO] 2005).1 It is an increasingly prominent international issue, raising ecological concerns, as some bycatch species of cetaceans (whales, dolphins, and porpoises), seabirds, sea turtles, elasmobranchs (sharks, skates, and rays), and other fi sh species are particularly vulnerable to overexploitation and slow to recover from large population declines (FAO 1999a, 1999b, in press; Fowler et al. 2005; Gales 1998; Gilman et al. 2005, 2006a, 2006c, 2008; Lutz and Musick 1997). Bycatch can alter biodiversity and ecosystem functions by removing top predators and prey species at unsustainable levels (Myers et al. 2007). It also alters foraging behavior of species that learn to take advantage of discards. Economic effects of bycatch on fi sheries include loss of bait, reduced availability of baited hooks when they are occupied with unwanted bycatch species, and concomitant reduced catch of marketable species; the imposition of a range of restrictions, closed areas, embargos, and possible closures; allocation among fi sheries, where bycatch in one fi shery reduces target catch in another, and bycatch of juvenile and undersized individuals of a commercial species can adversely affect future catch levels (Brothers et al. 1999; Hall et al. 2000). Discarded bycatch raises a social issue over waste: From 1992 to 2001 an average of 7.3 million metric tons of fi sh were annually discarded, representing 8 percent of the world catch (FAO 2005). Prominent bycatch issues include dolphins and porpoises in purse seine fi sheries and driftnets; fi sh discards in shrimp trawl fi sheries; and seabird, sea turtle, marine mammal, and shark bycatch in longline, purse seine, gillnet, and trawl fi sheries (FAO 1999a, 1999b, 2005, in press; Hall et al. 2000). In commercial tuna fi sheries, the incidental bycatch of sensitive species groups (seabirds, sea turtles, marine mammals, and sharks) and bycatch of juvenile and undersized tunas are allocation and conservation issues. In addition to problematic bycatch, overexploitation and illegal, unreported, and unregulated (IUU) fi shing, which complicates bycatch management, are additional conservation issues facing the management of tuna fi sheries. This chapter

employs examples of bycatch in commercial tuna fi sheries to describe (1) the range of options to reduce bycatch, (2) principles and approaches to successfully introduce effective bycatch reduction measures, and (3) initiatives taken by intergovernmental organizations, the fi shing industry, and retailers to address bycatch. Changes needed to improve the sustainability of tuna production are recommended.

Gorman, D., & Dixon, C. (2015). Reducing discards in a temperate prawn trawl fishery: a collaborative approach to bycatch research in South Australia. *ICES Journal of Marine Science,* 72(9), 2609-2617. https://doi.org/10.1093/icesjms/fsv147

We present the outcomes of a collaborative research programme tasked with reducing bycatch, and thus discards in a temperate Australian prawn trawl fishery. Sea trials in the Gulf of St Vincent, South Australia, assessed the performance of a modified trawlnet that incorporated a rigid polyethylene grid and a T90-mesh codend. Compared with conventional designs, the modified net yielded marked reductions in bycatch (cumulatively >81% by weight), with pronounced decreases in sponge (92%), elasmobranchs (80%), teleost fish (71%), molluscs (61%), and crustaceans (78%). Using commercial logbook data, we estimate that the use of modified nets could reduce discards by similar to 240 tons per year. This outcome was achieved with moderate declines in the catch rate (kg h(-1)) of the target species, Western King Prawn (mean similar to 15%), of which almost all were small adults of low commercial value. Adoption of the modified net by industry was realized in March 2012, because it met environmental objectives (i.e. reducing bycatch and improving public perceptions of sustainability), reduced prawn damage, demonstrated commensurate financial returns, and engaged stakeholders throughout the development process. Overall, the project provides a useful example of bycatch research with demonstrable outcomes of improving the ecological and economic sustainability of prawn harvests.

Graham, J., Kroetz, A. M., Poulakis, G. R., Scharer, R. M., Carlson, J. K., Lowerre-Barbieri, S. K., . . . Grubbs, R. D. (2022). Commercial fishery bycatch risk for large juvenile and adult smalltooth sawfish (Pristis pectinata) in Florida waters. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 32(3), 401-416. https://doi.org/10.1002/aqc.3777

Incidental catch of marine species can create ecological and economic issues, particularly for endangered species. The smalltooth sawfish (Pristis pectinata) is endemic to the Atlantic Ocean and listed as Endangered in the US Endangered Species Act. One of its major threats is bycatch mortality in commercial fisheries. Despite the protection afforded by the US Endangered Species Act, smalltooth sawfish are still captured as bycatch in commercial fisheries. Acoustic and satellite tag data collected on 59 sawfish between 2011 and 2019 were analysed to assess commercial fishery bycatch risk for large juveniles and adults off Florida. This study focused on shrimp trawl, south-east coastal gillnet, and shark bottom longline fisheries, as these were identified in the recovery plan as having the greatest potential threats to recovery. Bycatch risk associated with the shrimp trawl fishery was significantly higher than the other fisheries, indicating that this fishery currently poses the greatest threat to recovery. Bycatch risk was concentrated in all seasons in the Gulf of Mexico adjacent to the lower Florida Keys for the shrimp trawl fishery, off Cape Canaveral in the south-east coastal gillnet fishery, and in the Atlantic Ocean adjacent to the Florida Keys in the shark bottom longline fishery. Tagging location and sex were predictors of bycatch risk. Individuals tagged in Charlotte Harbor had the highest shrimp trawl bycatch

risk. Females tagged in south Florida tended to reside in the deepest water, which is where shrimp trawl effort is highest. Therefore, females may be at more risk in these deeper waters. Results from this study indicate a year-round closure of waters off south-west Florida to the shrimp trawl fishery between Charlotte Harbor and the western Florida Keys would reduce sawfish bycatch, and thus mortality, which is in line with recovery plan goals.

Gupta, T., Booth, H., Arlidge, W., Rao, C., Manoharakrishnan, M., Namboothri, N., . . . Milner-Gulland, E. J. (2020). Mitigation of Elasmobranch Bycatch in Trawlers: A Case Study in Indian Fisheries. *Frontiers in Marine Science,* 7. https://doi.org/10.3389/fmars.2020.00571

Bycatch poses a significant threat to marine megafauna, such as elasmobranchs. India has one of the highest elasmobranch landings globally, through both targeted catch and bycatch. As elasmobranchs contribute to food and livelihood security, there is a need for holistic approaches to bycatch mitigation. We adopt an interdisciplinary approach to critically assess a range of hypothetical measures for reducing elasmobranch capture in a trawler fishery on India's west coast, using a risk-based mitigation hierarchy framework. Data were collected through landing surveys, interviews and a literature review, to assess the following potential management options for their technical effectiveness and socio-economic feasibility: (1) spatio-temporal closures; (2) net restrictions; (3) bycatch reduction devices (BRDs); and (4) live onboard release. Our study provides the first evidence-based and nuanced understanding of elasmobranch bycatch management for this fishery, and suggestions for future conservation and research efforts. Onboard release may be viable for species like guitarfish, with moderate chances of survival, and was the favored option among interview respondents due to minimal impact on earnings. While closures, net restrictions and BRDs may reduce elasmobranch capture, implementation will be challenging under present circumstances due to the potentially high impact on fisher income. Interventions for live release can therefore be used as a step toward ameliorating bycatch, while initiating longer-term engagement with the fishing community. Participatory monitoring can help address critical knowledge gaps in elasmobranch ecology. Spatio-temporal closures and gear restriction measures may then be developed through a bottom-up approach in the long term. Overall, the framework facilitated a holistic assessment of bycatch management to guide decision-making. Scaling-up and integrating such case studies across different species, fisheries and sites would support the formulation of a meaningful management plan for elasmobranch fisheries in India.

Jaiteh, V. F., Allen, S. J., Meeuwig, J. J., & Loneragan, N. R. (2014). Combining in-trawl video with observer coverage improves understanding of protected and vulnerable species by-catch in trawl fisheries. *Marine and Freshwater Research,* 65(9), 830-837. https://doi.org/10.1071/mf13130

Assessments of incidental wildlife mortality resulting from fishing rarely account for unobserved by-catch. We assessed by-catch of protected and vulnerable wildlife species in an Australian trawl fishery by comparing in-trawl video footage with data collected by an on-board observer. Data were obtained from 44 commercial trawls with two different by-catch reduction devices (BRDs). Eighty-six individuals from six major taxa (dolphins, sharks, rays, sea snakes, turtles and sygnathids) were documented from video analysis, including the endangered scalloped hammerhead shark (Sphyrna lewini) and the critically endangered green sawfish (Pristis zijsron). On the basis of the 2008–2009 fishing effort of 4149 trawls

and scaling from these results, we estimated the annual catch of protected and vulnerable species (± 1 s.e.) at 8109 ± 910 individuals. Only 34% of by-catch was expelled through the BRDs. Independent observer data for the 44 trawls showed that 77% of the landed by-catch from these taxa were dead when discarded. The results indicate that unaccounted by-catch in trawl fisheries can be substantial, and that current methods of recording by-catch on-board vessels are likely to underestimate total fishing mortality. We recommend gear modifications and their validation through dedicated observer coverage, combined with in-trawl video camera deployments to improve current approaches to by-catch mitigation.

Kennelly, S. J., Melli, V., & Broadhurst, M. K. (2018). *Reducing bycatch using modifications to sweeps and lines anterior to the trawl mouth - collaboration with the Technical University of Denmark.* FRDC project No. 2017/097 Retrieved from https://www.frdc.com.au/project/2017-097

Prawn trawling is among the world's least selective fishing methods and there has been a great deal of work done over the past few decades to develop modifications that reduce unwanted bycatches. Much of this work has focussed on modifications at, or near, the codend (at the aft section) of trawls, but more recent efforts have examined ways to stop fish entering the trawl at all—via modifications to their anterior components (or forward section).New South Wales (NSW) Department of Primary Industries (DPI) Fisheries Conservation Technology Unit (FCTU) has led such work with prawn trawls in Australia. Another group based in Denmark (the Danish Technical University's team in Hirtshals – DTU Aqua) has grown to be among the European leaders with similar work directed at Nephrops and fish trawls and is a major centre for work being done to underpin the European 'landings obligation' (often termed the 'discard ban'). The current project took advantage of a travel grant for a PhD student at DTU Aqua to: (i) establish a link and exchange of ideas between the Australian and the Danish teams; whilst (ii) exploring ways of refining anterior-trawl modifications to reduce bycatch in our prawn fisheries.

Kyne, P. (2008). *Chondrichthyans and the Queensland East Coast Trawl Fishery: Bycatch reduction, biology, conservation status and sustainability.* (Ph.D.), University of Queensland, Retrieved from https://espace.library.uq.edu.au/view/UQ:190019

The chondrichthyan (shark, batoid and holocephalan) bycatch of the Queensland East Coast Trawl Fishery (ECTF) was examined through a series of fishery-independent trawl surveys, together with fishery-dependent (opportunistic) sampling. Project aims were to document the chondrichthyan bycatch composition in order to test the effectiveness of turtle exclusion devices (TEDs) and bycatch reduction devices (BRDs), to examine biological aspects of bycatch species, and to combine data collected through these parts to assess the conservation status and sustainability of bycatch species. A total of 37 chondrichthyan species (one holocephalan, 19 batoids and 17 sharks) from 18 families were recorded in the bycatch of the fishery. The most speciose families recorded were the stingrays (Dasyatidae; 7 species), the requiem sharks (Carcharhinidae; 5 species), the catsharks (Scyliorhinidae; 4 species) and the stingarees (Urolophidae; 3 species). Chondrichthyan bycatch was highly variable between fishery sectors; catch rates were low in the tiger/Endeavour prawn sector (north Queensland; 0.02–0.12 individuals ha-1 trawled) and in the eastern king prawn (deepwater) sector (southern Queensland; 0.08 individuals ha-1 trawled), intermediate in Hervey Bay (southern Queensland; 0.25 individuals ha-1 trawled) and in the scallop sector (central Queensland coast; 0.31 individuals ha-1 trawled) and highest

in the eastern king prawn (shallow water) sector (southern Queensland; 0.96 individuals ha-1 trawled). Chondrichthyan bycatch in the eastern king prawn (shallow water) sector was dominated by the three batoids Aptychotrema rostrata, Trygonoptera testacea and Urolophus kapalensis (~92% of the chondrichthyan bycatch by number), in the eastern king prawn (deepwater) sector by the skate Dipturus polyommata and the two catsharks Asymbolus rubiginosus and Figaro boardmani (~83% of the chondrichthyan bycatch by number), in the scallop sector by the three batoids A. rostrata, Neotrygon kuhlii and Neotrygon picta (~91% of the chondrichthyan bycatch by number), and in the tiger/Endeavour prawn sector by the two batoids Himantura astra and Gymnura australis and the two sharks Chiloscyllium punctatum and Hemigaleus australiensis (~67% of the chondrichthyan bycatch by number). The testing of TEDs and BRDs, which are mandatory throughout the fishery, demonstrated only a limited ability to reduce chondrichthyan bycatch in the ECTF, which is comprised mainly of relatively small species. The shorter trawl durations of the surveys compared with normal commercial activities may have under-represented larger species. No significant reductions in chondrichthyan bycatch were found using a TED and a radial escape section BRD in the eastern king prawn (shallow water) sector, using a TED and a square-mesh codend BRD in the eastern king prawn (deepwater) sector, or using a TED and a fisheye BRD in Hervey Bay. There was however, a significant difference in the probability of capturing the group 'sharks and guitarfishes' (comprised largely of A. rostrata) between codend types in the scallop sector, with the lowest probability of capture in nets fitted with both a TED and a square-mesh codend BRD (the difference was largely attributed to the effects of the TED). In the tiger/Endeavour prawn sector, in which three different BRDs were trialed (fisheye, square-mesh codend, square-mesh panel), the probability of capturing chondrichthyans was significantly lower in nets fitted with a fisheye BRD than in the standard (control) net, and the probability of capturing batoids was significantly lower in nets fitted with a fisheye BRD or with a square-mesh codend BRD than in the standard (control) net. The small sample size of chondrichthyan catches in some sectors may have reduced to power to detect bycatch reduction. The biology of several bycatch species from the families Rajidae, Rhinobatidae, Urolophidae and Scyliorhinidae was examined. For D. polyommata, size at birth was estimated at ~100–110 mm total length (LT), size at first feeding at ~105–110mm LT, size at % maturity (LT50 and 95% CI) at 321 (305–332) mm LT for females and 300 (285–306) mm LT for males. Diet (described by the index of relative importance as a percentage) was predominantly crustacean based, with carid shrimps (53.6%) and penaeoid prawns (23.3%) being the most significant prey groups. For A. rostrata, size at birth was estimated at <170 mm LT, size at 50% maturity (LT50 and 95% CI) at 640 (618–663) mm LT for females and 597 (551–649) mm LT for males, and litter size was 9–20 (n = 9; mean ± S.E. = 15.1 ± 1.2). For T. testacea, size at birth was estimated at 77–100 mm disc width (WD), size at 50% maturity (WD50 and 95% CI) at 163 (156–169) mm WD for females and 146 (140–150) mm WD for males, and litter size was always one (n = 6). For U. kapalensis, size at birth was estimated at 75–100 mm WD, size at 50% maturity (WD50 and 95% CI) at 154 (145–160) mm WD for females and 155 (149–159) mm WD for males, and litter size was always one (n = 16). The catsharks A. analis, A. rubiginosus and F. boardmani were all confirmed as single oviparous species (carrying only one egg case in each uterus at one time). Ovarian fecundity (the number of vitellogenic follicles) averaged 13.6 (range 13–20) in A. analis, 13.5 (range 5–23) in A. rubiginosus and 10.4 (range 9–13) in F. boardmani. While only limited data were available from southern Queensland, several indicators suggest that Asymbolus catsharks are reproductively active year-round. A general lack of small-sized or immature catsharks captured during the study made assessments of size at maturity difficult for these species. The conservation status of ECTF bycatch species was examined through the application of the IUCN Red List of Threatened SpeciesTM Categories and Criteria, which considers extinction risk at the global level. Of the 24 ECTF chondrichthyan bycatch species evaluated against the IUCN Red List Categories and Criteria, four have been assessed globally as Vulnerable (a threatened category indicating that a species is 'facing a high risk of extinction in the wild'), seven as Near Threatened, 11 as Least Concern and two as Data

Deficient. While the four globally threatened species (A. nichofii, Heteroscyllium colcloughi, Rhynchobatus australiae and Urolophus sufflavus) were only minor components of the ECTF bycatch, their global conservation status warrants that fisheries management and industry should act to ensure minimal impacts on these species. An ecological risk assessment method (Susceptibility-Recovery Analysis) was used to assess the relative sustainability or risk of individual species to the fishing activities of the ECTF. Two separate approaches were taken to the technique, which considers sustainability to be dependent on the susceptibility of a species to the fishery and the recovery potential of a species after depletion by fishing activities. The first approach applied the precautionary principal when data were lacking for the calculation of recovery attributes, while the second used biological data from similar species when species-specific data were lacking. The precautionary approach tended to overestimate risk to poorly known oviparous species. The biological approach suggested that A. nichofii, F. boardmani, Rhizoprionodon acutus, Rhizoprionodon taylori and Rhynchobatus palpebratus face the least risk (i.e. were the most sustainable) while several medium-large batoids and the sharks Loxodon macrorhinus and Heteroscyllium colcloughi were the species most at risk (i.e. least sustainable). Demonstrating ecological sustainability of the ECTF will need to be a continued management objective into the future. To further improve the ecological sustainability of the fishery in relation to sharks, batoids and holocephalans, a number of management recommendations are proposed: (1) give warranted conservation consideration to listed threatened species as well as species identified as being at risk; (2) expand required logbook information on chondrichthyan species to include recording of catches of these species; (3) e courage safe release practices for all chondrichthyans to maximise survivorship of discards; (4) initiate research into the survivorship of discards; (5) ensure long-term observer coverage on commercial vessels to monitor bycatch levels; and, (6) test and quantify reduced TED bar spacings (presently 120 mm) in fishery sectors which show the highest chondrichthyan bycatch levels, that is, the eastern king prawn (shallow water) and scallop sectors.

Kynoch, R. J., Fryer, R. J., & Neat, F. C. (2015). A simple technical measure to reduce bycatch and discard of skates and sharks in mixed-species bottom-trawl fisheries. *ICES Journal of Marine Science,* 72(6), 1861-1868. https://doi.org/10.1093/icesjms/fsv037

Due to global declines, skates and sharks have become a focus of marine conservation in recent years. Despite protective measures, they remain vulnerable to bycatch by fisheries, especially bottom-trawls and pose a problem for fisheries management measures that aim to eliminate discards in the future. In the mixed-species bottom-trawl fisheries of the North Atlantic catches can be increased by fitting a length of chain known as a "tickler" in front of the groundgear of the trawl. It was hypothesized that the tickler is especially effective at catching skates and rays that may otherwise escape beneath the net. A trial was undertaken with paired tows with and without the tickler chain. The trial demonstrated that the catch rate of skates and sharks can be significantly lowered by removing the tickler. A set of secondary nets (groundgear bags) attached behind the groundgear of the main net allowed the number of fish escaping under the net to be estimated and showed that the reduction of skates and sharks in the main net was accompanied by an increase in number in the groundgear bags. This suggests that prohibition of the use of tickler chains in areas that are known to be especially important to skates and sharks could have conservation benefits. The removal of the tickler chain had little effect on catch rates of haddock, whiting, and flatfish, but caused a marked decrease in the catch rate of commercially valuable anglerfish.

Munden, J. G. (2013). *Reducing negative ecological impacts of capture fisheries through gear modification.* (Master of Science), Memorial University of Newfoundland, Retrieved from http://research.library.mun.ca/id/eprint/11100

Capture fisheries provide the world with a healthy source of protein than can have minimal environmental impacts if harvested sustainably. Negative environmental impacts of capture fisheries include; overexploitation, modification of food webs, mortality of nontarget species, habitat alteration and biodiversity loss. A mitigation technique often used to reduce ecological impacts of fishing without compromising commercial catches is gear modification. This thesis explores modification of two gear types; shrimp trawl and turbot longline. Modifications were made to shrimp trawl footgear to reduce habitat alteration and to turbot longline gear to reduce Greenland shark bycatch. Testing of modified with traditional gears demonstrated that the modified gears with reduced ecological impacts did not negatively affect commercial catches. The 200 lb monofilament gangion is recommended for commercial testing by turbot longline fishers in Cumberland Sound; however the aligned shrimp trawl requires further modifications due to unexpected increases in turbot bycatch compared to the traditional trawl.

Paesch, L., Rey, M., Massa, A., Hozbor, N., & Colonello, J. (2010). Demersal Chondrichthyes: general aspects of fisheries and considerations of the working group. *Frente maritimo,* 21, 147-153. Retrieved from https://www.researchgate.net/publication/258510955_Condrictios_demersales_aspectos_generales_de_las_pesquerias_y_consideraciones_del_Grupo_de_Trabajo_Volumen_sobre_las_Jornadas_de_Discusion_Tecnica_sobre_la_Problematica_de_la_Pesqueria_Costera_en_el_A

Chondrichthyan exploitation in the Argentine-Uruguayan Common Fishing Zone (ZCPAU) includes target fisheries, bycatch and the coastal multispecific fishery. According to fishery statistics of Argentina and Uruguay, higher global landings correspond to skates (Rajidae), the Narrownose smoothhound (Mustelus schimitti) and the Angular angel shark (Squatina spp.). In recent years, landings of this sharks remain steady, however skates landings have been raising. This paper provides a summary of the main fisheries recommendations suggested by the work group, regulations adopted by the Technical Commission of the Maritime Front, and guidelines and necessities for specific management strategies of chondrichthyes in the ZCPAU. Also the results of the first bottom-trawl survey to study chondrichthyan species carried out by both countries are presented.

Raborn, S. W., Gallaway, B. J., Cole, J. G., Gazey, W. J., & Andrews, K. I. (2012). Effects of Turtle Excluder Devices (TEDs) on the Bycatch of Three Small Coastal Sharks in the Gulf of Mexico Penaeid Shrimp Fishery. *North American Journal of Fisheries Management,* 32(2), 333-345. https://doi.org/10.1080/02755947.2012.678962

The stock of blacknose sharks Carcharhinus acronotus in the U.S. South Atlantic and the Gulf of Mexico is overfished, and according to the 2007 stock assessment conducted by the National Marine Fisheries Service overfishing continues to occur. Penaeid shrimp trawl bycatch rates in the Gulf of Mexico were modeled for this species as well as for the Atlantic sharpnose shark Rhizoprionodon terraenovae and bonnethead shark Sphyrna tiburo using a combination of research trawl and observer data. Research trawls have never used turtle excluder devices (TEDs), which are expected to exclude larger specimens

of blacknose sharks. Most of the observer data that contain blacknose shark occurrences were collected during the pre-TED era when the two data sets tracked one another. Minimum observer data were available for the post-TED period (1990-present). As a consequence, the pre-TED (1972-1989) relationship between observer and research trawl catch per unit effort (CPUE) is driving the observer CPUE estimates from 1990 to the present, a period characterized by increased blacknose shark abundance. We suspected that the increase in predicted observer CPUE in the post-TED era is an artifact of application of the pre-TED observer and research trawl relationship to the post-TED era. This suspicion led us to question whether the bycatch of these species was altered due to the use of TEDs. We used negative binomial regression in a before-after-control-impact setting to test the effects of TEDs on the bycatch rates of these small coastal sharks. The TED effect was found to substantially reduce the bycatch of blacknose sharks (by 94%) and to do so moderately for bonnethead sharks (31%); the results were inconclusive for Atlantic sharpnose sharks. The management implication of our findings is that the existing small coastal shark-penaeid shrimp fishery bycatch model needs to be modified or replaced with a model that explicitly incorporates the potential for a TED effect.

Raudzens, E. (2007). *At sea testing of the Popeye Fishbox bycatch reduction device onboard the FV Adelaide Pearl for approval in Australia's northern prawn fishery*. Australian Fisheries Management Authority Retrieved from https://www.fish.gov.au/Archived-Reports/2014/Documents/Raudzens_2007.pdf

Tests were conducted to determine if twin trawl nets containing a Turtle Excluder Device (TED) and a Popeye Fishbox caught less bycatch then nets fitted only with a TED. Nets that had the Popeye Fishbox located 70 meshes from the codend draw strings had a 48% reduction in the weight of small bycatch, an 87% reduction in number of sea snakes and a 35% reduction in the number of sharks and rays caught. When the Popeye Fishbox was placed 100 meshes from the codend draw strings, the weight of small bycatch was reduced by 28% and the number of sharks and rays was reduced by 27%. No analysis of sea snake bycatch at this distance was carried out. There was no significant difference in the catch of targeted prawns between nets with and without the Popeye Fishbox.

Roberson, L. A., & Wilcox, C. (2022). Bycatch rates in fisheries largely driven by variation in individual vessel behaviour. *Nature Sustainability*. https://doi.org/10.1038/s41893-022-00865-0

Fisheries bycatch continues to drive the decline of many threatened marine species such as seabirds, sharks, marine mammals and sea turtles. Management frameworks typically address incidental catch with fleet-level controls on fishing. Yet, individual operators differ in their fishing practices and efficiency at catching fish. If operators have differing abilities to target, they should also have differing abilities to avoid bycatch. We analysed variations in threatened species bycatch among individual operators from five industrial fisheries representing different geographic areas, gear types and target species. The individual vessel is a significant predictor of bycatch for 15 of the 16 cases, including species that represent high or low costs to fishers or have economic value as potentially targeted byproducts. Encouragingly, we found high-target and low-bycatch operators in all five sectors, including gears known for high bycatch mortality worldwide. These results show that there is untapped opportunity to reduce negative environmental impacts of fisheries with interventions targeting specific performance groups of individuals, supporting an alternative perspective towards managing global fisheries.

Sacchi, J. (2019). *Mitigation Measures for Protected Species.* Paper presented at the Seventh Meeting of the Parties to ACCOBAMS. Retrieved from https://accobams.org/wp-content/uploads/2019/04/MOP7.Doc30_Mitigation-measures-for-protected-species.pdf

Highly migratory for the most part, occupying a wide distribution across the oceans, the marine megafauna undergo all possible forms of human pressure. Among them, bycatch fishery has increased exponentially in recent years and is now considered the most serious threat to these highly vulnerable species. Minimizing bycatch, is therefore a key component of sustainable fisheries management to maintain marine biodiversity and consequently to reduce negative effects on the resources (see Hall, 1996; Hall et al., 2000). The aim of this document is to present various experimented approaches and strategies that could also serve as an example for fisheries facing the same problems. This review of the different mitigation measures draws on the analysis of the available literature, comprising scientific journal articles together with reports from international organisations and documents available on the internet. The presentation adopted here is guided by the principle that it is not species that should be managed but fishing activities (metiers)1 that should be the target of the technical or management measures that are required to reduce the negative impacts of interactions with fisheries. Consequently, for each of the main fishing gear groups (gill and trammel nets, longlines and lines, trawls, purse seines, trapnets and pots) the various solutions found in the documents consulted are classified by the four main groups of protected species (Cetaceans, Birds, Sharks and Sea turtles).

Schram, E., Molenaar, P., Kleppe, R., & Rijnsdorp, A. D. (2020). *Condition and survival of discards in tickler chain beam trawl fisheries.* Wageningen Marine Research, https://doi.org/10.18174/519613

Dutch demersal fisheries in the North Sea is a mixed fishery that mainly targets Dover sole (Solea solea) with plaice (Pleuronectes platessa), turbot (Scophthalmus maximus), brill (Scophthalmus rhombus) and other species as valuable bycatches. The fleet currently uses two gear types: pulse beam trawls and conventional tickler chain beam trawls. Pulse beam trawlers operate with a temporary exemption from the EU prohibition to use electric stimulation in fishing gears, of which the last exemptions will expire in June 2021.To assess the consequences of transitions between pulse and tickler chain beam trawling for discards mortality, knowledge on the discards survival probabilities as well as the amount of discards is required for both gear types. The objective of the current study was to estimate discards survival probabilities for undersized plaice, sole, turbot, brill and thornback ray discarded by tickler chain beam trawl fisheries using fish condition as a proxy for survival probability. To this end the condition and reflex impairment of undersized fish in the catches of tickler chain beam trawlers were assessed and compared to similar data collected from pulse trawl fisheries. For spotted ray we assessed fish condition in tickler chain beam trawling but could not estimate its discards survival probability because a relation between survival probability and fish condition is lacking for this species. In this study direct mortality imposed by the tickler chain beam trawling ranged between 10 and 32% in flatfish species and was between 2-4 times higher than in pulse beam trawling. Direct mortality in ray species was lowest among the investigated species (2-8%) and did not differ between the two gear types. Differences in direct mortality were reflected in the condition scores. Direct mortality of sole was higher in tickler chain beam trawling (17%) than in pulse beam trawling (8%). Brill, turbot and plaice discarded by pulse beam trawling are in better condition than when discarded by tickler chain beam trawl fisheries. For sole no effect of gear type on fish condition could be detected. We consider the lower fish condition scores of brill, plaice and turbot from tickler chain beam trawling a direct reflection of the higher mechanical

impact of this gear on the fish. For thornback ray and spotted ray no effect of gear type on fish condition could be detected. The predicted survival of plaice, brill and turbot discards indicate that discards survival could indeed be lower in tickler chain beam trawl fisheries compared to pulse beam trawl fisheries. For sole and thornback ray discards we found no evidence for such difference between gear types. The discards survival probabilities for tickler chain beam trawling as presented in this study should be considered as predictions based on the currently best available information instead of definite values. Actual measurements of discards survival at sea are needed to confirm and quantify survival probabilities in tickler chain beam trawling.

Stephenson, P. C., Wells, S., & King, J. A. (2008). *Evaluation of exclusion grids to reduce the bycatch of dolphins, turtles, sharks and rays in the Pilbara trawl fishery DBIF funded Project.* Fisheries Research Report 171. Department of Fisheries of Western Australia, Retrieved from https://www.bycatch.org/articles/evaluation-exclusion-grids-reduce-bycatch-dolphins-turtles-sharks-and-rays-pilbara-trawl-fi

A semi-flexible exclusion grid with a bar spacing of 15.5 cm reduced dolphin bycatch in the Pilbara trawl fishery by close to 50% and reduced the bycatch of sea turtles, large sharks and rays. However, the fate of the dolphins that encountered the grid and escaped is unknown.

Thiam, N., Sow, F. N., Fall, M., Plourde, Y., Thiaw, M., Dème, M., . . . Faye, B. (2018). Nordmøre Grid Trial in Large Prawn Senegalese Fishery: Interest to Reduce By-catch not Evidenced. *Universal Journal of Agricultural Research,* 6(6), 181-193. https://doi.org/10.13189/ujar.2018.060601

Demersal shrimp fisheries, which are not very selective, generate significant discards and / or bycatch, generally composed of crustaceans, fish and molluscs of different size classes. As part of the implementation of the management plan for the deepwater shrimp Parapenaeus longirostris in Senegal, selectivity tests of the Nordmore device were conducted. Thus, three Nordmore grids characterized by different spacings between the bars (24, 28 and 30 mm) were tested on the experimental trawl in the Senegalese Economic Zone. Regardless of spacing, the Nordmore Grid completely removed large individuals from several species of commercial interest (John dory and Bearded brotula) or not (rays, sharks, etc.). Gamba shrimp loss analyzes indicate a significant difference (α <0.05) between the three spacer grids 24, 28 and 30 mm. Regardless of the type of grid, the amount of shrimp sorted per minute is larger for the experimental trawl; and this quantity increases with the spacing of the grid. The 30mm grid stands out with percentages of gamba shrimp losses ranging from 3 to 20% with an average of 8%; and a ratio of bycatch / gamba shrimp catch around 2.2 / 1, below the world average for this type of fishery (5/1).

Tixier, P., Lea, M. A., Hindell, M. A., Welsford, D., Mazé, C., Gourguet, S., & Arnould, J. P. Y. (2021). When large marine predators feed on fisheries catches: Global patterns of the depredation conflict and directions for coexistence. *Fish and Fisheries,* 22(1), 31-53. https://doi.org/10.1111/faf.12504

The sustainable mitigation of human–wildlife conflicts has become a major societal and environmental challenge globally. Among these conflicts, large marine predators feeding on fisheries catches, a behaviour termed "depredation," has emerged concomitantly with the expansion of the world's fisheries. Depredation poses threats to both the socio-economic viability of fisheries and species conservation, stressing the need for mitigation. This review synthesizes the extent and socio-ecological impacts of depredation by sharks and marine mammals across the world, and the various approaches used to minimize it. Depredation was reported in 214 fisheries between 1979 and 2019 (70% post-2000) and affected fleets from 44 countries, in all sectors (commercial, artisanal and recreational), and in all major fishing techniques (nets, traps and hook-and-lines). A total of 68 predator species were involved in depredation (20 odontocetes, 21 pinnipeds and 27 sharks), and most (73%) were subject to either by-catch and/or retaliatory killing from fishers when interacting with gear. Impacts on fishers were primarily associated with catch losses and gear damage but often lacked assessments. Deterrence was a major mitigation approach but also the least effective. Gear modifications or behavioural adaptation by fishers were more promising. This review highlights the need for improved monitoring, and interdisciplinary and integrated research to quantify the determinants and impacts of depredation in the socio-ecological dimension. More importantly, as the conflict is likely to escalate, efforts directed towards changing perceptions and integrating knowledge through adaptive co-management are raised as key directions towards coexistence between fisheries and large marine predators.

Wakefield, C. B., Blight, S., Dorman, S. R., Denham, A., Newman, S. J., Wakeford, J., . . . O'Donoghue, S. (2014). *Independent observations of catches and subsurface mitigation efficiencies of modified trawl nets for endangered, threatened and protected megafauna bycatch in the Pilbara Fish Trawl Fishery*.(Fisheries Research Report No. 244). Department of Fisheries, Western Australia Retrieved from https://researchrepository.murdoch.edu.au/id/eprint/21296/

Mitigation of endangered, threatened and protected (ETP) species is a challenge in many commercial fisheries globally and independent observer programs are often implemented to determine accurate estimates of interaction rates. However, interactions with ETP species may be extremely rare requiring very high and therefore costly levels of observer coverage to provide adequate statistical rigor for such programs. The Pilbara Fish Trawl (Interim Managed) Fishery (PFTF) has a long history of developing and adopting mitigation measures that have resulted in very low capture rates of ETP megafauna, i.e. dolphins, turtles, sea snakes and sawfish. However, there has been uncertainty over the potential for unaccounted mortality of ETP megafauna from subsurface expulsion in poor condition through escape hatches in the PFTF trawl nets (particularly air breathing species). To examine this issue, all trawl vessels in the PFTF (n = 3) were fitted with dual-lens above water and subsurface within-net camera systems from June to December 2012. Above water cameras recorded continuously (except during malfunctions) and all video files were stored in read only folders and encrypted with passwords to prevent tampering. At the end of each trip these secure folders containing the video files were transferred onto external hard drives by Department of Fisheries staff for later analysis. The observer coverage rates of 85.2% of trawl catches above water (n = 1,916 trawls observed), and 71.7% of day-trawls (n = 774 trawls observed) and 53.9% of day-trawl hours (n = 1,013 h observed) below water, far exceeded that stipulated in the Bycatch Action Plan (22%) and levels achieved from previous studies from the PFTF.

Captures of ETP megafauna were rare, despite very high levels of attendance in and around trawl nets by bottlenose dolphins (> 75% of trawls). All observed catches of ETP species were reported in statutory logbooks and these catches were consistent with previous data since exclusion grids were mandated in March 2006. Therefore, there was no evidence to suggest that captures of ETP species were being unreported by commercial fishers. About two thirds of all megafauna, including chondrichthyans, were expelled from escape hatches during trawling, with the majority of megafauna expelled relatively quickly (< 10 min). This resulted in more than half of the trawl catches containing no megafauna (51.4%). A total of 705 megafauna individuals were observed to exit the nets through an escape hatch during trawling. Of these megafauna, only one bottlenose dolphin was observed to exit these trawls in poor condition. A large turtle was observed to persist in a trawl for an extended period (60.1 min). However, despite its condition being inconclusive upon exiting, its duration in the net was well within the breath holding capabilities for marine turtles. Thus, the subsurface expulsion of megafauna in poor condition was extremely rare. No megafauna were observed to exit through the top opening escape slit. However, an upward excluding grid with a top opening escape hatch resulted in a higher proportion of escapement for most chondrichthyans. The loss of targeted scalefish through escape hatches occurred during less than 3% of trawls. Extensive subsurface observations determined that current mitigation strategies are highly effective for sea snakes, turtles and chondrichthyans (except sawfish), and that further investigation in the forward sections of trawl nets may provide useful information to improve mitigation strategies for dolphins and sawfish. The very low rates of mortalities of these ETP megafauna by the PFTF were considered to pose a negligible risk to their sustainability based on 1) these rates likely to be less than their natural mortality rates (e.g. at least 371 bottlenose dolphins stranded from 1981-2010), 2) they appear abundant in Western Australian waters despite large scale mortalities from historic foreign fishing (e.g. 13,459 cetacean mortalities from Taiwanese fishing from 1981-86), and 3) they have wide distributions and are h ghly mobile.

Wakefield, C. B., Santana-Garcon, J., Dorman, S. R., Blight, S., Denham, A., Wakeford, J., . . . Newman, S. J. (2017). Performance of bycatch reduction devices varies for chondrichthyan, reptile, and cetacean mitigation in demersal fish trawls: assimilating subsurface interactions and unaccounted mortality. *ICES Journal of Marine Science,* 74(1), 343-358. https://doi.org/10.1093/icesjms/fsw143

To improve bycatch mitigation of chondrichthyans, reptiles and cetaceans for a tropical demersal fish-trawl fishery, species-specific responses to bycatch reduction devices (BRDs) were investigated using both in situ subsurface and onboard observations. There are few, if any, studies that have determined mitigation performances of BRDs from subsurface interactions for these species, as most are rarely encountered and thus require substantial levels of observer coverage for robust assessments. This study combined in-net and onboard (774 day trawls and 1320 day trawl hours of subsurface observer coverage) electronic monitoring on all fish-trawl vessels (n = 3) to compare bycatch mitigation performances among nine megafauna groups, based on escape rates and interaction durations for three BRDs over 6 months (June to December 2012). Overall, 26.9% of day trawls had no megafauna interactions and 38.3% of the 1826 interactions escaped, with most in rapid time (91.4% in <= 5 min). The upward inclined exclusion grid significantly improved the escape proportions for most chondrichthyans by 20-30%. All BRDs were highly effective in reducing reptile (turtles and seasnakes) bycatch, but irrelevant for the few sawfish (n = 13) that readily entangled in the anterior of the net. Cetacean (bottlenose dolphins only) interactions with BRDs were very rare (n = 7) despite high levels of attendance and depredation during trawling. Loss of targeted teleosts through the BRD hatch was rare

(1.3% of day trawls). This relatively cost-effective method of electronic monitoring achieved very high levels of subsurface observer coverage (60% of day trawls or 56% of day trawl hours), and provided evidence that the subsurface expulsion of megafauna in poor condition is negligible. Furthermore, this study provides species-specific improvements toward bycatch mitigation strategies for demersal fish trawling.

Walker, N. D., Maxwell, D. L., Le Quesne, W. J. F., & Jennings, S. (2017). Estimating efficiency of survey and commercial trawl gears from comparisons of catch-ratios. *ICES Journal of Marine Science,* 74(5), 1448-1457. https://doi.org/10.1093/icesjms/fsw250

Assumptions about gear efficiency and catchability influence estimates of abundance, mortality, reference points and catch potential. Despite the need to better quantify fishing effects on some target species and on many non-target species taken as bycatch, there are few gear efficiency estimates for some of the most widely deployed towed fishing gears in the northeast Atlantic. Here, we develop a method that applies generalised additive models to catch-at-length data from trawl surveys and a commercial catch and discard monitoring program in the North Sea to estimate catch-ratios. We then rescale these catch-ratios and fit relationships to estimate gear efficiency. When catches of individuals by species were too low to enable species-specific estimates, gear efficiency was estimated for species-groups. Gear efficiency (and associated uncertainty) at length was ultimately estimated for 75 species, seven species-groups and for up to six types of trawl gear per species or species-group. Results are illustrated for dab (Limanda limanda), grey gurnard (Eutrigula gurnardus) and thornback ray (Raja clavata), two common non-target species and a depleted elasmobranch. All estimates of gear efficiency and uncertainty, by length, species, species-group and gear, are made available in a supplementary data file.

Willems, T., Depestele, J., De Backer, A., & Hostens, K. (2016). Ray bycatch in a tropical shrimp fishery: Do Bycatch Reduction Devices and Turtle Excluder Devices effectively exclude rays? *Fisheries Research,* 175, 35-42. https://doi.org/10.1016/j.fishres.2015.11.009

Worldwide, many species of elasmobranchs (Chondrichthyes: Elasmobranchii) are currently threatened by marine fisheries activity and are on the Red List of the International Union for Conservation of Nature (IUCN). Although Bycatch Reduction Devices (BRDs) for teleost fish and Turtle Excluder Devices (TEDs) are now widespread in tropical shrimp trawling, information on their ability to mitigate bycatch of elasmobranchs, particularly rays (Batoidea), is scarce and limited to only a few isolated fisheries. The objective of this study was to evaluate the potential of trawls fitted with a square-mesh panel BRD and supershooter TED in reducing ray bycatch. In this study, 65 catch-comparison hauls were conducted in the Atlantic seabob shrimp (Xiphopenaeus kroyeri) fishery off Suriname. Trawls with a BRD and TED combination reduced ray catch rate by 36%. A 21% reduction in mean size indicated the preferential exclusion of large rays. Hence, high escape ratios were observed for Dasyatis geijskesi (77%), a large-sized species, while exclusion of the small species Urotrygon microphthalmum was not significant, although their disc width is small enough to pass through the meshes of the BRD. Furthermore, a size-dependent escape for the two most abundant mid-sized ray species Dasyatis guttata and Gymnura micrura was observed. Exclusion-at-size differed for both species, however, likely related to species-specific morphology or behavior in response to the TED. This study shows that the combination of BRD

and TED causes an important reduction in ray bycatch in seabob shrimp fisheries off Suriname. The great reduction in catch of large-sized rays is positive, but the mortality of juvenile rays is likely to have negative consequences for their populations. We therefore recommend gear-based and non-gear adaptations to further reduce the bycatch of small-sized rays.

Young, H. J., Raoult, V., Platell, M. E., Williamson, J. E., & Gaston, T. F. (2019). Within-genus differences in catchability of elasmobranchs during trawling. *Fisheries Research,* 211, 141-147. https://doi.org/10.1016/j.fishres.2018.11.015

Elasmobranchs make a large contribution to bycatch in commercial trawl fisheries, which reduces the efficiency (and thus profitability of those fisheries), results in injury and mortality of those elasmobranchs, and can lead to unsustainable rates of catches. The development of bycatch reduction devices (BRDs) for elasmobranchs has been hindered, among other things, by a lack of knowledge of their avoidance behaviours and thus their vulnerability to capture (catchability). This lack of knowledge potentially affects assessments of the impact of fishing on those bycatch species. Here we examined underwater behaviours, using video analysis, of three species of elasmobranchs (two stingarees, i.e. Urolophus cruciatus and U. paucimaculatus, and one draughtboard shark, Cephalocyllium laticeps) in response to an approaching demersal trawl to quantify behavioural factors that affect their catchability. The morphologically similar U.cruciatus and U. paucimaculatus were similarly abundant, i.e. 290 and 218 individuals, respectively, but displayed different net avoidance behaviours, with U. paucimaculatus being far more likely to enter the trawl. The greater catchability of U. paucimaculatus would falsely suggest this less common species was more abundant than U. cruciatus, which has implications for any assessments of the impacts of trawling on these two elasmobranchs. Collision with trawl gear was relatively common for both Urolophus spp., and this was shown to decrease their likelihood of capture. In contrast, only 1 of the 68 individuals of the morphologically-different C. laticeps collided with gear. These results will help inform future development of BRDs and highlight that understanding the behaviour of elasmobranchs in response to capture methods should form an integral component of assessments of the impacts of trawling on this highly affected group.

Zea-de la Cruz, H., Tovar-Avila, J., Meiners-Mandujano, C., Jimenez-Badillo, L., & Luis Oviedo-Perez, J. (2021). Determining potential management strategies for the elasmobranchs bycatch of the Mexican shrimp trawl fishery of the Gulf of Mexico through a vulnerability analysis. *Regional Studies in Marine Science,* 42. https://doi.org/10.1016/j.rsma.2021.101626

Shrimp trawl fisheries capture several species of elasmobranchs as bycatch that are commonly unreported, this lack of data makes it difficult to assess their populations using quantitative stock assessment methods. Rapid evaluations like the productivity and susceptibility analysis (PSA), can help to determine species at risk of overexploitation and prioritize research, management and conservation efforts. The relative vulnerability (V) of 16 elasmobranch species associated to the Mexican shrimp trawl fishery in the Gulf of Mexico was determined using a PSA. The information of bycatch elasmobranch was collected by observer's onboard shrimp fishing vessels in 55 fishing trips during the 2013-2017 period. Two hypothetical scenarios to test potential management strategies were developed to observe changes in V based on the current fishing practices. We determined that most elasmobranch species (n= 14) had low V (<1.8) related to this fishery, mostly as a result of the high productivity (P) of the

coastal-demersal species and the low susceptibility (S) of the coastalsemioceanic ones. Only two species had a moderate V, Pseudobatos lentiginosus (1.87) and Squatina dumeril (1.85). The vulnerability of these two species could decrease through ensuring post-capture release practices and the protection of their aggregation, since both actions would lower their S and V. Post-capture release might be the most feasible potential strategy for both species, whereas protection of species aggregations would require further investigation to support its effect in the mitigation of mortality from bycatch.

Zeeberg, J., Corten, A., & De Graaf, E. (2006). Bycatch and release of pelagic megafauna in industrial trawler fisheries off Northwest Africa. *Fisheries Research,* 78(2-3), 186-195. https://doi.org/10.1016/j.fishres.2006.01.012

The accidental capture of large animals such as sharks, manta rays, sea turtles, and dolphins in pelagic trawler fisheries remains controversial because it threatens biological diversity in many biogeographical regions, including the subtropical eastern North Atlantic. Bycatch rates observed during more than 1400 trawl sets off Mauritania, Northwest Africa, are shown to have been considerable during the past 4 years, with high animal abundance in Summer when the Northwest African shelf is occupied by subtropical water. We demonstrate the urgency for bycatch reduction and evaluate the use of species-selective gear, a conservation method immediately available and immediately effective in waters fished through international access agreements. A modification tested in commercial trawls during the observer program guides pelagic megafauna deflected by a filter to an escape tunnel along the bottom of the trawl. This "excluder" reduces bycatch mortality of the most vulnerable megafauna species by at least 40-100%.

Zhou, S., & Griffiths, S. P. (2008). Sustainability Assessment for Fishing Effects (SAFE): A new quantitative ecological risk assessment method and its application to elasmobranch bycatch in an Australian trawl fishery. *Fisheries Research,* 91(1), 56-68. https://doi.org/10.1016/j.fishres.2007.11.007

We present a quantitative approach to the ecological Sustainability Assessment for Fishing Effects (SAFE) on diverse and data-poor bycatch assemblages. The method estimates fishing impact and compares the impact to sustainability reference points based on basic life-history parameters. We demonstrate the effectiveness of this method by assessing the impact of Australia's Northern Prawn Fishery (NPF) on the sustainability of 51 elasmobranch bycatch species. We estimated the proportion of the population distributed within trawled areas, from detection-nondetection data collected from scientific surveys. This estimate of species' abundance was then included in a model incorporating catch rate and escapement probability to give an estimate of the fishing mortality rate of each species. To guide management of bycatch species, we established two reference points based on natural mortality rate and growth rate: maximum sustainable fishing mortality and minimum unsustainable fishing mortality. The proportion of the 51 species' populations distributed within the fished area ranged between 0.02 and 1.00 (mean 0.36 +/- S.D. 0.31). Our results indicated that fishing impacts may have exceeded the maximum sustainable fishing mortality for 19 species, and exceeded the minimum unsustainable fishing mortality for 9 species. However, the estimates were highly uncertain for some species. SAFE can also be used by scientists and fishery managers to focus monitoring programs on potentially at-risk species to obtain additional data for further sustainability evaluation. Because the framework of SAFE is

compatible with the management of target species, it can be incorporated into existing fishery management strategies, and may fulfill emerging ecosystem-based fishery management objectives.

2. Bycatch Reduction Methods

2.1 Fishing Behavior Modifications

Afonso, A. S., Hazin, F. H. V., Carvalho, F., Pacheco, J. C., Hazin, H., Kerstetter, D. W., . . . Burgess, G. H. (2011). Fishing gear modifications to reduce elasmobranch mortality in pelagic and bottom longline fisheries off Northeast Brazil. *Fisheries Research,* 108(2-3), 336-343. https://doi.org/10.1016/j.fishres.2011.01.007

One of the biggest challenges of fisheries research is reducing the bycatch of unwanted species. The incidental fishing mortality of species with low reproductive rates, such as elasmobranchs (sharks, skates, and rays), is recognized as a key threat for their populations. In the present study, gear modifications related to the type of hook and position of the hook in the water column were tested to examine their effects on catch rates and mortality of elasmobranch species in both pelagic and coastal environments. Comparisons between circle (size 18/0,0 degrees offset) and J-style (size 9/0, 10 degrees offset) hooks demonstrated that the circle hooks have a greater efficiency in reducing the mortality of most species caught, both in pelagic and coastal longline fisheries. Internal lodging of the hook was significantly less frequent for the individuals caught with circle hooks, which likely contributed to their higher survival rate at haulback. Additionally, circle hooks also increased the CPUE of elasmobranchs caught in the pelagic longline fishery, which was particularly evident for Carcharhinus falciformis and Prionace glauca. The position of the hook in the water column exhibited a strong influence on the species caught in the coastal bottom longline fishery. Suspending hooks in the middle of the water column reduced the bycatch of common demersal species, such as Carcharhinus acronotus, Ginglymostoma cirratum, and Dasyatis americana, while increasing the CPUE of potentially aggressive species, such as Galeocerdo cuvier and Carcharhinus leucas. The interaction of the type of hook utilized with its position in the water column appears to be an essential factor in the optimization of longline selectivity and minimization of bycatch mortality.

Auger, L., Trombetta, T., Sabarros, P., Rabearisoa, N., Romanov, E., & Bach, P. (2015). *Optimal fishing time window: an approach to mitigate bycatch in longline fisheries.* IOTC–2015–WPEB11–15. Indian Ocean Tuna Commission, Retrieved from https://www.bmis-bycatch.org/system/files/zotero_attachments/library_1/9HQDDHIW%20-%20IOTC-2015-WPEB11-15_-_Optimal_time_window.pdf

One of the main concerns of the ecosystem approach to fisheries is the mitigation of bycatch, especially in pelagic longline fisheries. Bycatch represent unmarketable species and protected species for some of them. Various mitigation measures already exist to reduce bycatch in longline fisheries, notably concerning the equipment used and the strategy of fishing gear deployment. However, measures that concern the hours of gear deployment remain poorly studied. Using hook-timer data collected during scientific longline fishing campaigns between 2004 and 2014 in the South West Indian Ocean, we developed a method to identify optimal fishing practice that maximizes bycatch reduction and swordfish yield (in number). Here we found that hourly capture patterns of swordfish and bycatch (sharks, turtles) are different and allow to identify an optimal fishing practice that consists in fishing between 18pm and

9am. This methodology certainly provides a relevant bycatch mitigation approach that benefits to fishermen but also allow to mitigate the impact of longline fisheries on the ecosystem.

Benson, J. F., Jorgensen, S. J., O'Sullivan, J. B., Winkler, C., White, C. F., Garcia-Rodriguez, E., . . . Lowe, C. G. (2018). Juvenile survival, competing risks, and spatial variation in mortality risk of a marine apex predator. *Journal of Applied Ecology,* 55(6), 2888-2897. https://doi.org/10.1111/1365-2664.13158

1. Reliable estimates of mortality have been a major gap in our understanding of population ecology for marine animals. This is especially true for juveniles, which are often the most vulnerable age class and whose survival can strongly influence population growth. Thousands of pop-up archival satellite tags (PAT) have been deployed on a variety of marine species, but analysis of these data has mainly been restricted to movement ecology and post-handling survival following fisheries bycatch. We used PAT data to provide empirical estimates of annual survival and cause-specific mortality for juveniles of a marine top predator. 2. We tagged and tracked juvenile white sharks in the northeastern Pacific Ocean to (1) estimate survival rates and competing risks and (2) investigate intrinsic and environmental influences on mortality risk. We also evaluated the use of PAT data with respect to meeting assumptions of known-fate survival models. 3. Annual juvenile survival rate was 0.632 (SE = 0.15) and annual natural mortality rate (0.08, SE = 0.06) was lower than the rate of gillnet interactions (0.48, SE = 0.15). Mortality risk decreased with greater body length and was significantly greater (hazard ratio = 9.05, SE = 0.70) for juvenile sharks in Mexican waters, relative to California waters. 4. The PAT data allowed for unambiguous determination of fate in most cases, aided by collaborative relationships with fishers and secondary tags deployed on a subset of sharks. Although caution must be exercised to establish whether assumptions are met, our work demonstrates that PAT data represent a widely available, untapped data source that could dramatically increase our understanding of marine population ecology. 5. Synthesis and applications. Our research shows fisheries bycatch to be the main source of mortality for juvenile white sharks in the northeastern Pacific Ocean, highlighting the need for best practices, such as releasing sharks quickly following incidental capture. Furthermore, mortality risk for juveniles was greater in Mexican waters, such that survival may be lower in colder years when juveniles are likely to move south seeking warmer water. This could increase stochasticity in juvenile survival and negatively influence population growth for this apex predator.

Beverly, S., Curran, D., Musyl, M., & Molony, B. (2009). Effects of eliminating shallow hooks from tuna longline sets on target and non-target species in the Hawaii-based pelagic tuna fishery. *Fisheries Research,* 96(2-3), 281-288. https://doi.org/10.1016/j.fishres.2008.12.010

A longline experiment consisting of 45 paired sets (90 sets total) was carried out to evaluate a technique which maintains target catch rates while reducing non-target catch rates. Control sets were compared to experimental sets which eliminates the shallowest hooks (similar to less than 100 m depth). Researchers hypothesized that by eliminating shallow hooks, target catch of deeper dwelling species such as bigeye tuna (Thunnus obesus) would be maximized while incidental catch of many other non-target, but marketable epi-pelagic species (e.g, billfish), bycatch (discards) of other fishes and elasmobranchs, and protected sea turtles and marine mammals would be simultaneously reduced. To control for differences in fishing power, gear, and deployment techniques: a single vessel was

contracted to perform all 90 paired longline sets (45 experimental sets using no-shallow-hooks and 45 control sets using standard methods). Control sets consisted of longlines that were suspended by floats on typical 30m long floatlines in catenary-type shapes that fished a range of depths. determined by temperature-depth recorders (TDRs) to be 44-211 m (27.5-11.2 C). By contrast, elimination of shallow hooks in the upper 100m of the water column (hereinafter referred to as experimental sets) was achieved by suspending the fishing portion of the mainline on 75-m long, 3 kg weighted vertical sections of mainline suspended by floats on 30 m floatlines. As determined by TDRs, this arrangement ensured that all hooks fished at depths >100 m (103-248 m: 24.8-11.3 C). Thirty percent of hooks in control sets fished at depths less than 100 in while all hooks on experimental gear fished greater than 100 m. Because many factors influence catchability, longline sets are by nature multivariate, and statistical comparisons were made between the two set types using canonical discriminant analysis (CDA). Except for the depth of shallow hooks, operational characteristics between experimental and control sets were the same. The catch rates of bigeye tuna were similar on the two sets types but the catch rate of sickle pomfret (Taractichthys steindachneri) was significantly higher ($p = 0.011$) in the experimental sets as compared to control sets. However, statistically fewer wahoo (Acanthocybium solandri, $p = 0.019$), dolphinfish (Coryphaena hippurus, $p = 0.008$), blue marlin (Makaira nigricans, $p = 0.001$), striped marlin (Kajikia audax, $p = 0.018$) and shortbill spearfish (Tetrapturus angustirostris, $p = 0.006$) were captured on the experimental sets; thus longline interactions and impacts on these species were reduced with the experimental gear. The reason for the differences in catch rates between gear types is likely due to the vertical habitat preferences of the species involved; interactions with epi-pelagic species with shallow distributions in the uniform mixed layer were reduced by deploying hooks greater than 100 m. By logical extension, the experimental gear will also likely reduce interactions with sea turtles. Except for additional lead weights, floats, and floatlines, only slight modification of existing longline fishing gear and methods were required to deploy the experimental gear. The main drawback of this method was the increase in time to both deploy (approximate to 0.5 h) and retrieve (approximate to 2 h) the gear. Knowledge of species vertical distribution patterns can play an important role in modifying fishing gear to reduce bycatch and can also assist managers in regulating fishing practices with a higher degree of likelihood of predicting catch rates and species captured in different gea types.

Booth, H., Powell, G., Yulianto, I., Simeon, B., Muhsin, Adrianto, L., & Milner-Gulland, E. J. (2022). Exploring cost-effective management measures for reducing risks to threatened sharks in a problematic longline fishery. *Ocean & Coastal Management,* 225, 106197. https://doi.org/10.1016/j.ocecoaman.2022.106197

Many shark and ray species (Class Chondrichthyes, herein ‘sharks’) are threatened by overfishing. Tackling this requires implementation of context-specific fisheries management measures, which are both technically effective and socio-economically feasible. Here we explore the cost-effectiveness of various input-oriented management measures for mitigating capture of seven priority shark taxa (i.e., threatened and CITES-listed species) in a small-scale longline mixed-species shark fishery in Indonesia, where there is a need to balance difficult trade-offs between conservation and socio-economic objectives. We apply Boosted Regression Trees (BRT) to analyse five years of landings and profit data, to identify and assess the relative influence of different plausible management measures (e.g., effort restrictions, gear restrictions, spatio-temporal closures). We then use predictive models to inform a semi-quantitative assessment of the hypothetical cost-effectiveness of these management measures, based on the estimated conservation benefits (reduced risk of capture of priority taxa) and socio-economic cost (relative profit foregone). Our results show that fishery closures in January–March, depth

limits at <100 m, hook limits at <500 hooks, and gear restrictions on bottom longlines could have the greatest relative conservation impact for lowest profit foregone. However, there are clear trade-offs between taxa, with these measures primarily benefiting Critically Endangered bottlenose wedgefish (Rhynchobatus Australiae) and scalloped hammerheads (Sphyrna lewini), while potentially increasing pressure on Vulnerable silky sharks (Carcharhinus falciformis) and Endangered mako sharks (Isurus spp.). When shark fishing is important for economic welfare, and entire fishery closures or buy-outs are unfeasible, managing small-scale shark fisheries for multiple outcomes may require hard choices. This may require prioritising slow-growing Critically Endangered taxa for protection – by restricting fishing during seasons and at depths in which they are most susceptible to capture – while faster-growing taxa can continue to provide benefits for coastal communities.

Broadhurst, M. K., Butcher, P. A., Millar, R. B., Marshall, J. E., & Peddemors, V. M. (2014). Temporal hooking variability among sharks on south-eastern Australian demersal longlines and implications for their management. *Global Ecology and Conservation,* 2, 181-189. https://doi.org/10.1016/j.gecco.2014.09.005

An experiment was done to quantify species-specific variation in temporal hooking rates from demersal longlines targeting various carcharhinids off south eastern Australia, with a view to reducing the incidental catches of protected species, including the scalloped hammerhead Sphyrna lewini, great hammerhead Sphyrna mokarran and grey nurse Carcharias taurus. The longline comprised a 9600 m mainline, separated into four sections (termed lines) each with 120 gangions (20 m apart) rigged with hook timers and 16/0 circle hooks baited with either sea mullet Mugil cephalus or eastern Australian salmon Arripis trutta. The mainline was deployed on each of 17 nights (between 19:30 and 23:30 h), with two lines retrieved after 7 and 14 h respectively. From a total of 8160 hooks, 246 timers were activated without hooking fish. Twenty-two species comprising 684 individuals were caught, including 52 S. lewini, 12 C. taurus, 11 S. mokarran and 1 loggerhead turtle Caretta caretta. Several environmental factors, including water temperature, moon phase and depth had mostly homogeneous, positive effects on catches. The only identified variables that might be used to considerably reduce the catches of Sphyrna were soak time and/or diurnal gear retrieval, with most individuals hooked during daylight. Simply mandating shorter deployments and within nocturnal retrieval might limit exploitation, especially among juveniles (<150cm total length). For the studied fishery to approach sustainability, future research is required to investigate other gear modifications for improving size and species selectivity, and/or operational procedures for mitigating discard and escape mortalities.

Carruthers, E. H. (2012). *Ecological and societal context of catch and discards: identifying opportunities for bycatch mitigation in swordfish and tuna pelagic longline fisheries.* (Ph.D.), Memorial University of Newfoundland, Retrieved from http://research.library.mun.ca/id/eprint/6095

Bycatch, defined here as catch discarded for regulatory, economic or personal reasons, from pelagic longline fisheries has contributed to wide spread population declines of sharks and sea turtles. Opportunities to reduce impacts in these fisheries occur throughout the fishing process and depend upon the fishing practices within fleets, and upon the behaviour of target and bycatch species. The overall objective of this thesis was to identify bycatch mitigation opportunities within the Canadian Atlantic pelagic longline fishery, which targets swordfish (Xiphias gladius), warm-water tunas (bigeye,

Thunnus obesus; yellowfin T. albacares; and albacore, T. alalunga) and mahi-mahi (Coryphaena hippurus). Bycatch includes common sharks and rays (blue shark, Prionace glauca; pelagic stingray, Pteroplatytrygon violacea), and endangered sea turtles (leatherback Dermochelys coriacea; loggerhead, Caretta caretta). Bycatch mitigation approaches such as shifting to circle hooks, increased the likelihood that shark bycatch would be released alive and with less severe hooking injuries. Shorter longline soak times also increased hooking survival among most of the common bycatch species. Shorter soak times would not decrease catch of the most common landed species (swordfish), but this shift in fishing practices could negatively impact fisher safety. Interviews with active longline captains revealed operational difficulties and unintended ecological impacts with proposed bycatch mitigation approaches. Longline captains also reported innovative uses of bycatch mitigation tools that could increase post-release survival of common bycatch species in this and other pelagic longline fleets. Finally, the combined analysis of fisheries observer data, qualitative data from fishers' knowledge interviews, and concurrent environmental data suggested that high blue shark catch rates were related to local oceanography - and did not reflect behavioural differences between blue shark and swordfish. Clearly, there are opportunities for bycatch mitigation within the Canadian pelagic longline fishery for swordfish and tunas. However, the process of interviewing pelagic longline captains revealed both interest in reducing bycatch, but also suspicion of research efforts. Such trust issues will need to be addressed in subsequent research as the combined use of fishery assessments, detailed oceanographic data, practical fishing knowledge, and on-the-water observations will be needed to decrease the amount of and harm to discarded bycatch.

Carruthers, E. H., Neilson, J. D., & Smith, S. C. (2011). Overlooked bycatch mitigation opportunities in pelagic longline fisheries: Soak time and temperature effects on swordfish (Xiphias gladius) and blue shark (Prionace glauca) catch. *Fisheries Research,* 108(1), 112-120. https://doi.org/10.1016/j.fishres.2010.12.008

Bycatch mitigation approaches aim to either reduce the incidence of unwanted catch or reduce bycatch mortalities. In pelagic longline fisheries incidence of unwanted catch can be reduced by limiting the availability of baited hooks (e.g., within bycatch species' preferred depths and water temperatures), whereas bycatch mortalities can be decreased by gear modifications and changes to fishing practices, e.g., by limiting soak time. To evaluate the effects of temperature, depth, and soak time on catch of target and bycatch species, temperature recorders were set along the length of the longline to characterize the environment at which hooks were fishing. Although few instrumented sets were fished, observations at the within set scale - specifically, that swordfish (Xiphias gladius) catch did not increase with longer soak times - led us to reexamine assumptions made in fleet-wide catch models. Swordfish catch did not increase with soak time in generalized linear models based on fisheries observer data collected from swordfish-targeted sets fished by the Canadian pelagic longline fleet in 2008 and 2009 (n = 42 and n = 78, respectively). Minimum soak time, from end of setting to start of hauling, was used in swordfish catch models. Total soak time is inappropriate for catch models because it includes haulback time, which increases as a function of catch. If landed catch does not increase as a function of soak time, then limiting longline soak time to reduce bycatch mortalities would not cause decreased swordfish catch nor result in economic losses for fishers. While minimum soak time limits would likely decrease bycatch mortality rates in swordfish longline fisheries, impacts on other aspects of the fishing process would need to be considered, such as negative impacts on fisher safety.

Carruthers, E. H., & Neis, B. (2011). Bycatch mitigation in context: Using qualitative interview data to improve assessment and mitigation in a data-rich fishery. *Biological Conservation,* 144(9), 2289-2299. https://doi.org/10.1016/j.biocon.2011.06.007

Bycatch from pelagic longline fisheries has contributed to widespread population declines of turtles, sharks and other pelagic fishes. While large-scale estimates are needed to understand cumulative impacts on these highly migratory species, detailed information on targeting, setting, and discarding practices is needed to develop bycatch mitigation approaches. Data from qualitative fishers' knowledge interviews with Canadian Atlantic pelagic longline captains was used to evaluate current bycatch estimation methods and to identify bycatch mitigation opportunities. Interviewed longline captains reported blue sharks (Prionace glauca) were common bycatch during swordfish-targeted sets, but were sometimes absent from tuna-targeted sets. Discrepancies between longline captains' observations and bycatch assessment methods identified needed improvements to data collection methods. Longline captains reported innovative uses of turtle dehooking gear, which two-thirds of interviewed captains had used to release other bycatch species in addition to turtles. Longline captains reported techniques for discarding pelagic stingray (Pteroplatytrygon violacea), a common bycatch species in Pacific, Atlantic and Mediterranean pelagic longline fisheries. Therefore, such techniques could decrease fisheries impacts globally. While there can be major conservation benefits from fishers' knowledge research, one-quarter of the active longline captains that we contacted declined interviews because they did not trust the larger research process. We urge conservation biologists to carefully design fishers' knowledge research taking into account the often politicized context. Failure to do so may jeopardize future research and conservation efforts.

Carruthers, E. H., Schneider, D. C., & Neilson, J. D. (2009). Estimating the odds of survival and identifying mitigation opportunities for common bycatch in pelagic longline fisheries. *Biological Conservation,* 142(11), 2620-2630. https://doi.org/10.1016/j.biocon.2009.06.010

To evaluate how fishing practices affect bycatch survival and to identify opportunities to reduce bycatch mortality, we estimated the odds of hooking survival for common bycatch species in the Canadian long-line fishery for swordfish (Xiphias gladius) and tunas (Thunnus spp.) fishing in the North Atlantic. Generalized linear models, with binomial response, were based on 859 sets observed between 2001 and 2004 and were tested using data from 2005 and 2006. Bycatch included targeted species in poor condition or below regulatory size limits. Odds of survival were two to five times higher for swordfish, yellowfin tuna (Thunnus albacares), pelagic stingray (Pteroplatytrygon violacea), porbeagle (Lamna nasus) and blue shark (Prionace glauca) caught on circle hooks compared to J-hooks during the 2001-2004 period. Further, odds of severe hooking injuries decreased for three shark species caught on circle hooks. We found no conservation benefit for loggerhead turtles (Caretta caretta) from circle hook use. Increased circle hook use coincided with increased targeting and higher landings of tunas. Hooking survival rates and, therefore opportunities to reduce bycatch mortalities differed among the 10 species commonly discarded or released. Where the odds of survival to the time of release are high (e.g., loggerhead turtles, pelagic stingray, blue shark), methods to reduce post-release mortality can be considered. Where the odds of hooking survival are low (e.g., swordfish and longnose lancetfish, Alepisaurus ferox). methods to reduce encounter rates would have greater conservation impact.

Clarke, S., Sato, M., Small, C., Sullivan, B., Inoue, Y., & Ochi, D. (2014). Bycatch in longline fisheries for tuna and tuna-like species: a global review of status and mitigation measures. *FAO fisheries and aquaculture technical paper*(588), 217. Retrieved from http://www.fao.org/3/a-i4017e.pdf

This publication is the third in a series on bycatch in global tuna fisheries. Dealing with longline fisheries, its scope is defined taxonomically to comprise only non-tuna and non-tuna-like species. The history of longline fishing illustrates the role of new technologies, the expansion of fishing grounds, and the operational characteristics of the fleets in shaping today's fishery. More recently, management regulations, the price of oil, the cost of labour, and market demand have also exerted an influence. No more than 23 percent of the tuna in each ocean is longline-caught. However, there may be up to 7 500 tuna longliners globally with almost 60 percent of them less than 24 m in length. Available data suggest that elasmobranch catches have fallen 14 percent since their peak in 2003. In longline fisheries, shark catch rates may be determined by bait type, soak time, hook shape, leader length and material, depth at which the hook is fished, and whether special gear is deployed to target sharks. Vulnerability to hooking, and resilience to haulback and handling, vary by species, size, area and fleet operational practices. Tuna regional fisheries management organizations (t-RFMOs) assess the status of shark populations but data limitations often hinder firm conclusions. There is little information on the implementation or effectiveness of finning bans and no-retention measures. Mitigation measures have been tested but results vary. Six of the seven species of sea turtles are threatened with extinction, and while longline fisheries may have less impact than net-based fisheries, significant population level impacts may be occurring in some regions. The greatest concern is associated with loggerhead-longline interactions in the Atlantic. Circle hooks and using finfish bait have proved effective mitigation techniques either by reducing hooking or hook swallowing. Other methods require further development. Interactions with pelagic longline fisheries kill 50 000-100 000 seabirds annually. Many of these species, particularly albatrosses, are threatened with extinction. Recent advances in tracking technologies have facilitated mapping of where interactions are most likely. The Western and Central Pacific contains more than 45 percent of the global total albatross and giant petrel breeding distributions. The most promising mitigation methods appear to be night setting, side-setting, line weighting and streamer lines, but further research is needed. All five t-RFMOs require use of one or more of these methods in areas that overlap albatross distributions. However, compliance data are limited and improved observer coverage is essential. Marine mammals' interactions with longline fisheries are detrimental to the fishery but may be positive or negative for the mammals. Although it is often unclear which species are involved, pilot whale interactions in the western Atlantic and false killer whale interactions off Hawaii have triggered national mitigation plans. No t-RFMO has adopted management measures for marine mammal interactions. Research and testing of mitigation measures continue in order to ameliorate both marine mammal impacts and economic losses to industry from depredation. At least 650 species of other bony fishes may be caught in association with pelagic longline fisheries, e.g. dolphinfish, opah, oilfish, escolar and ocean sunfish. Some of these stocks are important as local food supplies. However, it is unclear whether these stocks or the ecosystem they help structure is at risk. More attention should focus on improving fishery statistics and initiating basic monitoring of these stocks' status. The diversity of pelagic longline gear designs and fishing methods, the variety of habitats they are deployed in, the thousands of marine species they may interact with, and the different mechanisms and behaviours that govern those interactions provide an array of topics to be addressed in any discussion of bycatch mitigation. Scientific and technical issues in mitigation including effects across taxa, effects of combinations of measures, economic and safety considerations, underlying biological mechanisms, handling and post-release mortality, and non-fishery impacts must all be addressed. In addition, it is also necessary to consider issues such as who takes the lead for ensuring mitigation is sufficient for the population as a whole, how

to devise effective mitigation implementation strategies, and whether gear modification should be used in concert with more sweeping measures.

Clarke, T. M., Espinoza, M., & Wehrtmann, I. S. (2014). Reproductive ecology of demersal elasmobranchs from a data-deficient fishery, Pacific of Costa Rica, Central America. *Fisheries Research,* 157, 96-105. https://doi.org/10.1016/j.fishres.2014.04.003

The elasmobranch bycatch associated with the Costa Rican deepwater shrimp fishery is mainly comprised of four species: Raja velezi, Mustelus henlei, Zapteryx xyster and Torpedo peruana. In data-deficient fisheries such as this one, knowledge of the reproductive ecology of a species may serve as a valuable management tool to determine its vulnerability and apply precautionary measures to ensure its long-term conservation. This study examined the reproductive ecology of R. velezi, M. henlei, Z. xyster and T. peruana based on data collected during demersal trawling along the Pacific coast of Costa Rica, Central America. A total of 290 trawls was analyzed at depths of 18-350 m (March 2010-August 2012). While R. velezi, M. henlei and Z xyster matured at similar sizes (range: 37-60 cm TL), T. peruana matured at a larger size (70 cm TL in females). The four elasmobranch species exhibited strong sex and size segregation patterns, which were mainly influenced by depth. Adults were more common at depths >50 m, whereas neonates and gravid females were more abundant in shallow estuarine waters (<50 m). Moreover, large aggregations of immature R. velezi and M. henlei occurred near coastal wetlands, bays and estuaries of the central Pacific region. These results suggest that shallow estuarine habitats may be important for early life stages of demersal elasmobranchs caught in the Costa Rican trawling fishery. However, our knowledge of critical habitats for elasmobranch along the entire Pacific of Costa Rica is still limited, and thus future studies are needed to identify and understand the role of these habitats in the early life-history of sharks, skates and rays.

Corgos, A., & Rosende-Pereiro, A. (2022). Nursery habitat use patterns of the scalloped hammerhead shark, Sphyrna lewini, in coastal areas of the central Mexican Pacific. *Journal of Fish Biology,* 100(1), 117-133. https://doi.org/10.1111/jfb.14925

This work aimed to characterize the nursery habitat use patterns of the scalloped hammerhead shark, Sphyrna lewini (SPL), in coastal areas of Jalisco and Colima, through the birth pattern, space-time distribution and relationship with environmental conditions. Information was combined from three sources: monitoring bycatch from the artisanal fishery, fishery-independent samplings, and acoustic tracking and monitoring. From September 2013 to May 2017, 408 juvenile SPL (41.6-100.1 cm total length) were recorded. Births occurred between May and December (rainy-warmer season), within a radius of 2 km from river mouths in Marabasco, Navidad Bay, Rebalsito-Tecuan and Cuitzmala mainly in shallow (<20 m), turbid and soft-bottom areas. Some tagged SPL moved from Marabasco and Rebalsito to Navidad Bay. The peak of catch and births occurred in June-August. Tagged SPL remained near the river mouth in Rebalsito for up to 27 days, showing a mean residency index of 0.29, a home range of 5.55 km(2) with a core area of 1.23 km(2) located within a 1.5 km radius from the river mouth. In December-January SPL left the river mouth areas and the catch was scarce until the following May-June, except in January 2016, when the catch was high due to El Nino 2015. SPL bycatch was significantly associated with temperature, precipitation and the Oceanic Nino Index.

Cosandey-Godin, A., & Morgan, A. (2011). *Fisheries bycatch of sharks: Options for mitigation.* Pew Environment Group, Washington, DC. Retrieved from https://www.sarri.org/storage/app/media/tools_pdfs/PewOSSsharkbycatchreviewpdf.pdf

Bycatch (see definition below) is one of the most significant issues in the management and conservation of global fisheries (Hall et al. 2000, Kelleher 2005, Lewison et al. 2004) and has been identified as one of the leading causes of shark population declines. Sharks are susceptible to high fishing mortality rates because of their life history characteristics, which include slow growth, late ages at maturity, and the production of a limited number of young over a lifetime (Cortes 2002, Heppell et al. 1999, Cortes 1999). In addition, research has shown that several species of sharks have very high rates of mortality associated with the fishing process (Morgan and Burgess 2007, Mandelman et al. 2008), and it has been estimated that species such as sandbar shark (Carcharhinus plumbeus) (Sminkey and Musick 1994, Cortes 1999) and dusky shark (Carcharhinus obscurus) (Simpfendorfer 1999) increase their population sizes so slowly that they are considered particularly vulnerable to mortality from fishing activities (Musick et al. 2000a). For example, Cortes et al. (2006) found that if fishing for dusky shark stopped for 30 years, their population in the Northwest Atlantic would still be depleted. Over the past two decades, serious population declines have been reported for a number of shark species in several regions around the world (Baum et al. 2003, Ferretti et al. 2008, Robbins et al. 2006, Ferretti et al. 2010, Clarke 2011) and are attributed to both targeted and incidental capture. According to the International Union for Conservation of Nature (IUCN) and other sources, bycatch is one of the primary threats facing sharks (Musick et al. 2000b, Lewison et al. 2004). Despite widespread recognition of shark bycatch issues (Food and Agriculture Organization [FAO] 1999; FAO 2010), few mitigation actions have been established, and there are no clear guidelines about which mitigation actions would be most effective. In addition, there are very few management measures requiring actions to mitigate shark bycatch. However, it is clear that managers and fishermen must aim to reduce both bycatch rates and the harmful effects from bycatch (e.g., injuries from capture on fishing gear). Based on the best available information, this review provides a summary of the current knowledge and understanding of shark bycatch and discusses available management options and technical measures aimed at reducing both the rate at which sharks encounter fishing gear and the associated damaging effects.

Coulter, J. (2019). *Evaluating Current Knowledge and Future Directions of Visual Cues as Bycatch Reduction Technologies in Passive Net Fisheries.* (Master of Environmental Management), Duke University, Retrieved from https://hdl.handle.net/10161/18435

Fisheries bycatch is consistently identified as a leading cause of population decline for many species of sea turtles, seabirds, and marine mammals. Many of these species rely primarily, or in part, on visual cues to perceive their environment, and visual cues can affect behavior. Recent research suggests that utilizing visual cues on passive fishing gear, such as gillnets, can reduce incidental interactions and associated mortality. This review synthesizes studies on visual cue bycatch reduction technologies (BRTs), focusing on the use of colored nets and net illumination. It draws upon existing knowledge to discuss both potential benefits, including streamlining bycatch reduction of multiple species, and challenges, such as current cost and maintenance requirements, associated with visual cue BRT development and implementation. The success of visual cue BRTs in initial studies, primarily on gillnets, holds much promise for bycatch reduction of air-breathing megafauna in passive gear fisheries. However, this research is still in its early stages, and future studies must expand research to more passive gear types, identify and conduct local studies in applicable fisheries, consider their potential use

with other stimuli as multi-sensory BRTs, and support the development of new light-emitting diode (LED) technologies that reduce cost and maintenance requirements. As a case study, I present the preliminary findings from the first year of a multi-year study on the use of green LEDs as a sea turtle BRT on pound nets in the North Carolina flounder fishery. We compared the catch per unit effort (CPUE) of experimental green LEDs and control inactive LEDs on three pound nets in Core Sound (near Harker's Island, NC). Preliminary analyses suggest that green LEDs reduced sea turtle and elasmobranch bycatch rates but also reduced the target catch rate of flounder and other fish species. However, these results do not account for the potential influence of environmental conditions, and variables, including wind speed, reveal trends that may indicate influence on catch rates. These effects will need to be further considered after additional data collection. This research demonstrates one example of current, continued efforts to expand visual cue BRT research to multiple passive gear fisheries to increase their applicability.

Cronin, M. R., Croll, D. A., Hall, M. A., Lezama-Ochoa, N., Lopez, J., Murua, H., . . . Moreno, G. (2022). Harnessing stakeholder knowledge for the collaborative development of Mobulid bycatch mitigation strategies in tuna fisheries. *ICES Journal of Marine Science*. https://doi.org/10.1093/icesjms/fsac093

Manta and devil rays (Mobulids) face several immediate threats, including incidental capture in industrial tropical tuna fisheries. As a result, efforts have emerged to avoid or mitigate Mobulid bycatch in these fisheries. However, many mitigation efforts fail to incorporate fisher expertise from the outset, potentially leading to interventions that are not viable. Here, we combine survey and focus group data to synthesize knowledge of Mobulid bycatch and mitigation ideas in Eastern Pacific Ocean purse seine fisheries. Primary obstacles for mitigating Mobulid bycatch, according to respondents, are: (1) an inability to sight Mobulids before capture, (2) the lack of specific equipment on board, and (3) the difficulty of releasing large individuals; we suggest that the latter two can be addressed by simple operational modifications. We also find that Mobulids are most likely to be sighted by fishers after capture, suggesting that this is an important time in the fishing operation for bycatch mitigation interventions that ensure Mobulids survive capture. To address this, we share creative ideas brought by fishers for avoidance of Mobulids. This study provides a model of how to incorporate stakeholder input in the design of bycatch technology in large-scale fisheries and could inform similar efforts around the world.

Dagorn, L., Filmalter, J. D., Forget, F., Amandè, M. J., Hall, M., Williams, P., . . . Bez, N. (2012). Targeting bigger schools can reduce ecosystem impacts of fisheries. *Canadian Journal of Fisheries and Aquatic Sciences,* 69(9). https://doi.org/10.1139/f2012-089

Sustainability of living resource exploitation relies on an ecosystem management approach. Within tropical tuna purse seine fisheries using fish aggregating devices (FADs), such an approach incorporates the reduction of bycatch, in par- ticular vulnerable species such as elasmobranchs. The levels of total bycatch (in mass) from fishing operations using FADs is known to be five times higher than when tuna are caught in free-swimming schools. We intend to find practical solutions to reduce bycatch in FAD sets through the investigation of the relationships between the ratio of bycatch to target catch across different set size classes in all oceans. Ratios were always highest when catches were small, with the

smallest class of catches responsible for the highest total portion of bycatch (23%-43%) while only contributing negligibly to the total tar- get catch (3%-10%). Reducing the number of fishing sets (a part of the total effort) while maintaining the same total yield could contribute to a substantial reduction in the impacts of human activities.

Dapp, D. R., Huveneers, C., Walker, T. I., Drew, M., & Reina, R. D. (2016). Moving from Measuring to Predicting Bycatch Mortality: Predicting the Capture Condition of a Longline-Caught Pelagic Shark. *Frontiers in Marine Science,* 2. https://doi.org/10.3389/fmars.2015.00126

Incidental fisheries capture has been identified as having a major effect on shark populations throughout the world. However, factors that contribute to the mortality of shark bycatch during fisheries capture are not fully understood. Here, we investigated the effects of capture duration, sea surface temperature, and shark total length (snout to the tip of the upper caudal lobe) on the physiology and condition of longline-caught bronze whalers, Carcharhinus brachyurus. Plasma lactate and potassium concentration had a positive linear relationship with capture duration, indicating that this species experiences increasing physiological challenges while on fishing gear. Additionally, we used stereotype logistic regression models to determine variables that could predict the capture condition of sharks (categorized as "healthy," "sluggish," or "moribund or dead"). In these models, elevated plasma lactate concentration, plasma potassium concentration, and capture duration increased the likelihood of C. brachyurus being captured in a "sluggish" condition or in a "moribund or dead" condition. After plasma lactate concentration exceeded 27.4 mmol/L, plasma potassium concentration exceeded 8.3 mmol/L, or capture durations exceeded 293 min, the majority of captured sharks (>50%) were predicted to be "moribund or dead." We recommend that a reduction in the amount of time longlines are left fishing (soak time) will reduce immediate and post-release mortality in C. brachyurus bycatch and that our methods could be applied to identify causes of fisheries-induced mortality in future studies. The identification of operational, environmental, and biological variables contributing to poor condition will be necessary to implement conservation strategies that reduce mortality during capture.

Das, D., Gonzalez-Irusta, J. M., Morato, T., Fauconnet, L., Catarino, D., Afonso, P., . . . Giacomello, E. (2022). Distribution models of deep-sea elasmobranchs in the Azores, Mid-Atlantic Ridge, to inform spatial planning. *Deep-Sea Research Part I-Oceanographic Research Papers,* 182. https://doi.org/10.1016/j.dsr.2022.103707

Elasmobranchs inhabiting depths beyond 200 m are extremely susceptible to overexploitation but are extracted by fisheries around the world either as target species or as bycatch. There is little information available to formulate management strategies to reduce elasmobranch-fishery interactions in the deep sea. In European Union waters, prohibiting the catches of deep-sea elasmobranchs has provided the necessary impetus to study bycatch avoidance of these threatened species. We used over 20 years of fisheries-independent and fisheries-dependent data to model the spatial distribution of 15 species of deep-sea elasmobranchs (12 sharks and 3 rays) captured frequently in the Exclusive Economic Zone of the Azores Archipelago (Mid-Atlantic Ridge) to explore spatial management to reduce unwanted catches of these species. We applied Generalised Additive Models to predict the probability of presence of 15 species, as well as the abundance of 6 of those species, within the Azores EEZ and neighbouring seamounts (up to 2000 m depth), using environmental and operational variables as predictors. Our

results identified that depth is most influential in determining the distribution of these sharks and rays, in addition to seafloor topography. Distinctive bathymetric features such as seamounts and ridges were highlighted as areas where the probability of presence of the greatest number of species overlapped. Although not related to habitat, gear type influenced the capture probability of certain species, with the artisanal handline, gorazeira, having lower captures than bottom longline. Our results support using depth-based, area-based, and gear-based tactics to design management measures to reduce elasmobranch bycatch, for more sustainable deep-sea fisheries.

Forget, F. G., Capello, M., Filmalter, J. D., Govinden, R., Soria, M., Cowley, P. D., & Dagorn, L. (2015). Behaviour and vulnerability of target and non-target species at drifting fish aggregating devices (FADs) in the tropical tuna purse seine fishery determined by acoustic telemetry. *Canadian Journal of Fisheries and Aquatic Sciences,* 72(9), 1398-1405. https://doi.org/10.1139/cjfas-2014-0458

Characterizing the vulnerability of both target and non-target (bycatch) species to a fishing gear is a key step towards an ecosystem-based fisheries management approach. This study addresses this issue for the tropical tuna purse seine fishery that uses fish aggregating devices (FADs). We used passive acoustic telemetry to characterize, on a 24 h scale, the associative patterns and the vertical distribution of skipjack (Katsuwonus pelamis), yellowfin (Thunnus albacares), and bigeye tuna (Thunnus obesus) (target species), as well as silky shark (Carcharhinus falciformis), oceanic triggerfish (Canthidermis maculata), and rainbow runner (Elagatis bipinnulata) (major non-target species). Distinct diel associative patterns were observed; the tunas and the silky sharks were more closely associated with FADs during daytime, while the rainbow runner and the oceanic triggerfish were more closely associated during the night. Minor changes in bycatch to catch ratio of rainbow runner and oceanic triggerfish could possibly be achieved by fishing at FADs after sunrise. However, as silky sharks display a similar associative pattern as tunas, no specific change in fishing time could mitigate the vulnerability of this more sensitive species. For the vertical distribution, there was no particular time of the day when any species occurred beyond the depth of a typical purse seine net. While this study does not provide an immediate solution to reduce the bycatch to catch ratios of the FAD-based fishery in the western Indian Ocean, the method described here could be applied to other regions where similar fisheries exist so as to evaluate potential solutions to reducing fishing mortality of non-target species.

Foster, D. G., Pulver, J. R., Scott-Denton, E., & Bergmann, C. (2017). Minimizing bycatch and improving efficiency in the commercial bottom longline fishery in the Eastern Gulf of Mexico. *Fisheries Research,* 196, 117-125. https://doi.org/10.1016/j.fishres.2017.08.007

We investigated the effects of hook soak time on targeted reef species and shark bycatch in the reef fish bottom longline fishery in the Gulf of Mexico. Beginning in 2010, capture time and catch per unit effort (CPUE) for the primary target species red grouper (Epinephelus mono) in the fishery were evaluated using hook timers. Findings indicated that typical duration of hook soak times is longer than necessary to efficiently harvest red grouper and a reduction in gear soak times to less than one hour would result in minimal or no reduction in red grouper CPUE. The mean capture time of sharks and red grouper differed significantly, suggesting that a reduction in soak time would likely reduce the bycatch of sharks in the fishery. The study also revealed barometric pressure, lunar phase, and fish size were significant

covariates with red grouper capture times and that different bait types significantly affected CPUE. Implementing shorter hook soak times would likely improve fishery profitability and potentially reduce discards of unwanted species in the fishery.

Francis, M. P., & Jones, E. G. (2017). Movement, depth distribution and survival of spinetail devilrays (Mobula japanica) tagged and released from purse-seine catches in New Zealand. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 27(1), 219-236. https://doi.org/10.1002/aqc.2641

Mobulid rays are protected in New Zealand, but the spinetail devilray Mobula japanica is caught as bycatch in skipjack tuna purse seine fisheries. Between 2005 and 2014, rays were recorded in 8.2% of observed purse seine sets. Rays were caught during summer, with a hotspot' (24.3% of sets) near the shelf edge off North Island over seabed depths of 150-350m. Rays were usually brailed aboard with the tuna catch from successful sets, but were often entangled in the bunt of the net during unsuccessful sets. Observers tagged nine rays with popup archival tags to obtain preliminary information on their post-release survival, and spatial and vertical movements. Seven of the nine tags reported data, and four of those rays died within 2-4days of release. All four rays that died had been brought aboard entangled in the bunt. The three surviving rays were all brailed aboard with the tuna catch. One surviving ray remained near New Zealand for 2.7months during summer, and the other two migrated 1400-1800km northward to tropical waters near Vanuatu and Fiji at minimum speeds of 47 and 63kmday(-1) at the end of summer. Archive data from one ray showed that it made regular vertical movements of 25-100m amplitude, but spent most of its time shallower than 50m, more so during the night (89.6%) than the day (76.6%), and mainly experienced temperatures of 18-22 degrees C. Dives deeper than 200m were usually made during the day or twilight. All three surviving rays typically moved between the surface and 200-300m daily, and reached greatest depths of 649m, 1000m and 1112m, respectively, substantially exceeding the previous depth record for this species of 445m. Recommendations are made for reducing purse seine mortality of mobulid rays by avoiding areas of high ray abundance, avoiding setting on ray-associated tuna schools, and adopting best-practice methods of returning rays to the sea from the net or vessel.

Gamblin, C., Pascal, B., & Lucas, V. (2007). *Comparison of bycatch species captured during daytime and nightime: preliminarily results of longline experiments carried out in Seychelles waters.* IOTC-2007-WPEB-16. Indian Ocean Tuna Commission, Retrieved from https://www.fao.org/3/bj094e/bj094e.pdf

Bycatch and mitigation measures are a keystone issue to assure a sustainable use of marine resources. Many studies focus on gear configuration and not on fishing strategy when fish habitat is a major question in term of gear selectivity. The objective of this study is to compare bycatch that occurred during night sets and day sets. For that purpose, 69 fishing experiments using an instrumented longline (hook timer, temperature depth recorder) were carried out in Seychelles waters from December 2004 to May 2006 on board small scale research longliner. Two types of sets were done: some during night (setting at dusk and hauling at dawn) with shallow basket to principally target swordfish and some during day (inverse cycle of night set) with shallow and deep basket to target tuna. Each time, bycatch species were identified (species, basket and hook number) and the depth of capture calculated. Results

show difference between the two strategies in terms of species composition, quantity, and depth of catch. Day sets induce more bycatch than night sets.

Garcia-Rodriguez, E., & Sosa-Nishizaki, O. (2020). Artisanal fishing activities and their documented interactions with juvenile white sharks inside a nursery area. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 30(5), 903-914. https://doi.org/10.1002/aqc.3300

Juvenile white sharks distribute in coastal nursery areas, which are essential for population growth. Bahia Sebastian Vizcaino (BSV), Mexico, is a white shark nursery area in the north-eastern Pacific. Despite existing regulations forbidding the capture of white sharks, incidental catches still occur in some areas. Artisanal fisheries constitute one of the most important economic activities in BSV, yet no formal description of either these fisheries or the incidental catch of juvenile white sharks exists due to the poor data reporting system, thus preventing a clear understanding of the implications of these catches for the white shark population of the north-eastern Pacific. Artisanal fishing activities and their interactions with juvenile white sharks in BSV are described based on fishermen's knowledge. Artisanal fisheries in BSV are multi-specific, targeting mostly bottom-related species (e.g. white seabass and California halibut) that are also common prey for juvenile white sharks. These activities are the only source of income for the majority of fishermen in BSV and are conducted throughout the year, with gillnets being the main fishing gear. White sharks are incidentally caught in bottom gillnets mainly during the summer, although another peak in incidental catch was recorded during winter, possibly related to the presence of juvenile white sharks from California, USA. The most common size of juvenile white sharks incidentally caught was <2 m in the nearshore areas close to the mouth of the Ojo de Liebre Lagoon; larger juveniles (similar to 3 m) were caught in areas near Cedros, Natividad, and San Benito Islands. The multi-specific nature of BSV artisanal fisheries and their socio-economic value, and the high post-release survival of juvenile white sharks suggest that future regulatory actions should focus on the release of incidentally caught live juvenile white sharks and the involvement of the BSV fishing community to increase the effectiveness of management efforts.

Gilman, E., Chaloupka, M., Merrifield, M., Malsol, N. D., & Cook, C. (2016). Standardized catch and survival rates, and effect of a ban on shark retention, Palau pelagic longline fishery. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 26(6), 1031-1062. https://doi.org/10.1002/aqc.2599

1. Pelagic longline fisheries affect both market and vulnerable bycatch species and can have broad effects on community structure and processes. 2. Observer data from the Palau longline fishery were analysed to identify opportunities to mitigate vulnerable species bycatch, determine temporal trends in local abundance, and assess changes following a ban on shark retention and wire leaders. Catch and haulback condition data for bigeye and yellowfin tunas, blue and silky sharks and pelagic stingrays were fitted to standardized catch and survival rate models. 3. The fishery caught silky and blue sharks, olive ridley sea turtles and other species of conservation concern. 4. Changing from shallow sets to deep daytime sets might reduce shark and sea turtle catch rates but increase turtle haulback mortality rates, maintain economically viable tuna catch rates, but increase catch rates of pelagic stingrays, a lower conservation concern than main caught species of sharks and turtles. 5. Focusing fishing effort during the middle of the calendar year would maximize yellowfin tuna and minimize silky shark standardized

catch rates, but maximize blue shark catch rates. 6. A large decline in shark fishing mortality rate very likely occurred following a ban on shark retention and wire leaders. This was due to large reductions in the nominal shark catch rate and shark retention, partially offset by decreases in the shark haulback survival rate and pre-catch survival rate. Significantly higher blue shark and lower pelagic stingray nominal catch rates occurred on wire vs. monofilament leaders. Significantly higher blue shark and lower yellowfin tuna nominal catch rates occurred on sets using shallow 'shark lines'. It is a research priority to compare the probability of shark pre-catch survival after escaping from monofilament leaders with an ingested hook and trailing line to the survival probability when captured on wire leaders.

Gilman, E., Dalzell, P., Goren, M., Werner, T. B., Clarke, S., Alfaro-Shigueto, J., . . . Thomson, N. (2007). *Shark Depredation and Unwanted Bycatch in Pelagic Longline Fisheries: Industry Practices and Attitudes, and Shark Avoidance Strategies.* Western Pacific Regional Fishery Management Council, Retrieved from https://wedocs.unep.org/20.500.11822/13627

Substantial ecological, economic and social problems result from shark interactions in pelagic longline fisheries. Improved understanding of industry attitudes and practices towards shark interactions assists with managing these problems. Information on fisher knowledge and new strategies for shark avoidance may benefit sharks and fishers. A study of 12 pelagic longline fisheries from eight countries shows that incentives to avoid sharks vary along a continuum, based on whether sharks represent an economic disadvantage or advantage. Shark avoidance practices are limited, including avoiding certain areas, moving when shark interaction rates are high, using fish instead of squid for bait and deeper setting. Some conventionally employed fishing gear and methods used to target non-shark species contribute to shark avoidance. Shark repellents hold promise; more research and development is needed. Development of specifically designed equipment to discard sharks could improve shark post release survival prospects, reduce gear loss and improve crew safety. With expanding exploitation of sharks for fins and meat, improved data collection, monitoring and precautionary shark management measures are needed to ensure shark fishing mortality levels are sustainable.

Gilman, E., & Lundin, C. (2010). Minimising bycatch of sensitive species groups in marine capture fisheries: lessons from tuna fisheries. In *Handbook of Marine Fisheries Conservation and Management.* Q. Grafton, R. Hillborn, D. Squires, M. Tait, & M. Williams (Eds.), (pp. 23): Oxford University Press Retrieved from http://ecite.utas.edu.au/58808

Bycatch in marine capture fisheries is the retained catch of nontargeted but commercially viable species (referred to as “incidental catch”) plus all discards (Food and Agriculture Organization of the United Nations [FAO] 2005).1 It is an increasingly prominent international issue, raising ecological concerns, as some bycatch species of cetaceans (whales, dolphins, and porpoises), seabirds, sea turtles, elasmobranchs (sharks, skates, and rays), and other fi sh species are particularly vulnerable to overexploitation and slow to recover from large population declines (FAO 1999a, 1999b, in press; Fowler et al. 2005; Gales 1998; Gilman et al. 2005, 2006a, 2006c, 2008; Lutz and Musick 1997). Bycatch can alter biodiversity and ecosystem functions by removing top predators and prey species at unsustainable levels (Myers et al. 2007). It also alters foraging behavior of species that learn to take advantage of discards. Economic effects of bycatch on fi sheries include loss of bait, reduced availability of baited hooks when they are occupied with unwanted bycatch species, and concomitant reduced catch of

marketable species; the imposition of a range of restrictions, closed areas, embargos, and possible closures; allocation among fi sheries, where bycatch in one fi shery reduces target catch in another, and bycatch of juvenile and undersized individuals of a commercial species can adversely affect future catch levels (Brothers et al. 1999; Hall et al. 2000). Discarded bycatch raises a social issue over waste: From 1992 to 2001 an average of 7.3 million metric tons of fi sh were annually discarded, representing 8 percent of the world catch (FAO 2005). Prominent bycatch issues include dolphins and porpoises in purse seine fi sheries and driftnets; fi sh discards in shrimp trawl fi sheries; and seabird, sea turtle, marine mammal, and shark bycatch in longline, purse seine, gillnet, and trawl fi sheries (FAO 1999a, 1999b, 2005, in press; Hall et al. 2000). In commercial tuna fi sheries, the incidental bycatch of sensitive species groups (seabirds, sea turtles, marine mammals, and sharks) and bycatch of juvenile and undersized tunas are allocation and conservation issues. In addition to problematic bycatch, overexploitation and illegal, unreported, and unregulated (IUU) fi shing, which complicates bycatch management, are additional conservation issues facing the management of tuna fi sheries. This chapter employs examples of bycatch in commercial tuna fi sheries to describe (1) the range of options to reduce bycatch, (2) principles and approaches to successfully introduce effective bycatch reduction measures, and (3) initiatives taken by intergovernmental organizations, the fi shing industry, and retailers to address bycatch. Changes needed to improve the sustainability of tuna production are recommended.

Grant, S. M., Munden, J. G., & Hedges, K. J. (2020). Effects of monofilament nylon versus braided multifilament nylon gangions on catch rates of Greenland shark (Somniosus microcephalus) in bottom set longlines. *PeerJ,* 8, e10407. https://doi.org/10.7717/peerj.10407

The Greenland shark (Somniosus microcephalus) is the main bycatch species in established and exploratory inshore longline fisheries for Greenland halibut (Reinhardtius hippoglossoides) on the east coast of Baffin Island, Canada. Bycatch and entanglement in longline gear has at times been substantial and post-release survival is questionable when Greenland sharks are released with trailing fishing gear. This study investigated the effect of the type of fishing line used in the gangion and gangion breaking strength on catch rates of Greenland shark and Greenland halibut in bottom set longlines. Circle (size 14/0, 0 degrees offset) hooks were used throughout the study. Behavior of captured sharks, mode of capture (i.e., jaw hook and/or entanglement), level of entanglement in longline gear, time required to disentangle sharks and biological information (sex, body length and health status) were recorded. Catch rates of Greenland shark were independent of monofilament nylon gangion breaking strength and monofilament gangions captured significantly fewer Greenland sharks than the traditional braided multifilament nylon gangion. Catch rates and body size of Greenland halibut did not differ significantly between gangion treatments. Although most (84%) of the Greenland sharks were hooked by the jaw, a high percentage (76%) were entangled in the mainline. The mean length of mainline entangled around the body and/or caudal peduncle and caudal fin was 28.7 m. Greenland sharks exhibited cannibalistic behavior with 15% of captured sharks cannibalized. All remaining sharks were alive and survived the disentanglement process which can be attributed to their lethargic behavior and lack of resistance when hauled to the surface. Thus, as a conservation measure fishers should be encouraged to remove trailing fishing gear prior to release. Our results are used to demonstrate benefits to the fishing industry with regard to an overall reduction in the period of time to disentangle sharks and damage to fishing gear by switching from braided multifilament to monofilament gangions in Greenland halibut longline fisheries.

Griffiths, S. P., & Lezama-Ochoa, N. (2021). A 40-year chronology of the vulnerability of spinetail devil ray (Mobula mobular) to eastern Pacific tuna fisheries and options for future conservation and management. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 31(10), 2910-2925. https://doi.org/10.1002/aqc.3667

Tuna fisheries are among the largest and most valuable fisheries in the world, but most interact with many non-target species, including several of high conservation importance. The spinetail devil ray (Mobula mobular) - listed as 'Endangered' on the IUCN Red List of Threatened Species - is a commonly discarded bycatch species, particularly in the eastern Pacific Ocean, yet insufficient data exist to undertake a traditional population assessment. A new ecological risk assessment approach designed for data-limited settings - Ecological Assessment of the Sustainable Impacts of Fisheries (EASI-Fish) - was used to reconstruct the historical vulnerability status of M. mobular and to simulate potential changes in its status under 45 hypothetical conservation and management measures. These involved various temporal closures of the eastern Pacific Ocean tuna fishery, decreasing post-capture mortality by improved handling and release practices, and combinations of the two. The species was classified as 'Least Vulnerable' between 1979 and 1993, but became 'Most Vulnerable' from 1994, which coincided with a rapid spatial expansion of the industrial purse-seine fishery, and especially from 2011 following the rapid increase in the number of sets made on floating objects. Simulating the conservation and management measures in place in 2018 revealed that 31 of the 45 scenarios resulted in a change in classification of the species to 'Least Vulnerable', which primarily involved a reduction of post-capture mortality by as little as 20%. It is fortuitous in that education of fishers to implement appropriate best handling and release practices is simpler, more rapid and more cost-effective than the implementation of fishery closures or gear modifications, which can be expensive and complex to implement and monitor and will probably result in substantial reduction in the catches of target species.

Gulak, S. J. B., Santiago, A. J. d. R., & Carlson, J. K. (2015). Hooking mortality of scalloped hammerhead Sphyrna lewini and great hammerhead Sphyrna mokarran sharks caught on bottom longlines. *African Journal of Marine Science,* 37(2), 267-273. https://doi.org/10.2989/1814232x.2015.1026842

The scalloped hammerhead Sphyrna lewini and the great hammerhead S. mokarran are typically caught as bycatch in a variety of fisheries and are listed as globally Endangered by the International Union for the Conservation of Nature. Due to very high at-vessel mortality for these species, research is needed on fishing methods to reduce mortality for longline-captured sharks. A series of fishing experiments were conducted employing hook timers and temperature-depth recorders on contracted commercial vessels fishing with bottom-longline gear to assess factors related to mortality. A total of 273 sets were deployed with 54 485 hook timers. Scalloped and great hammerheads had at-vessel mortality rates of 62.9% and 56.0%, respectively. Median hooking times for scalloped and great hammerheads were 3.5 h and 3.4 h, respectively, and 50% mortality was predicted at 3.5 h and 3.8 h. When these data are considered for potential management strategies to reduce the mortality of hammerhead sharks, a limitation on gear soak time would probably improve hammerhead shark survivorship. However, it may prove to be difficult for a fishery to remain economically viable if the soak time is limited to less than the median hooking time for the target species. Additional management options, such as time/area closures, may need to be explored to reduce bycatch mortality of scalloped and great hammerheads.

Gupta, T., Booth, H., Arlidge, W., Rao, C., Manoharakrishnan, M., Namboothri, N., . . . Milner-Gulland, E. J. (2020). Mitigation of Elasmobranch Bycatch in Trawlers: A Case Study in Indian Fisheries. *Frontiers in Marine Science,* 7. https://doi.org/10.3389/fmars.2020.00571

Bycatch poses a significant threat to marine megafauna, such as elasmobranchs. India has one of the highest elasmobranch landings globally, through both targeted catch and bycatch. As elasmobranchs contribute to food and livelihood security, there is a need for holistic approaches to bycatch mitigation. We adopt an interdisciplinary approach to critically assess a range of hypothetical measures for reducing elasmobranch capture in a trawler fishery on India's west coast, using a risk-based mitigation hierarchy framework. Data were collected through landing surveys, interviews and a literature review, to assess the following potential management options for their technical effectiveness and socio-economic feasibility: (1) spatio-temporal closures; (2) net restrictions; (3) bycatch reduction devices (BRDs); and (4) live onboard release. Our study provides the first evidence-based and nuanced understanding of elasmobranch bycatch management for this fishery, and suggestions for future conservation and research efforts. Onboard release may be viable for species like guitarfish, with moderate chances of survival, and was the favored option among interview respondents due to minimal impact on earnings. While closures, net restrictions and BRDs may reduce elasmobranch capture, implementation will be challenging under present circumstances due to the potentially high impact on fisher income. Interventions for live release can therefore be used as a step toward ameliorating bycatch, while initiating longer-term engagement with the fishing community. Participatory monitoring can help address critical knowledge gaps in elasmobranch ecology. Spatio-temporal closures and gear restriction measures may then be developed through a bottom-up approach in the long term. Overall, the framework facilitated a holistic assessment of bycatch management to guide decision-making. Scaling-up and integrating such case studies across different species, fisheries and sites would support the formulation of a meaningful management plan for elasmobranch fisheries in India.

Hyatt, M. W., Anderson, P. A., & O'Donnell, P. M. (2018). Influence of Temperature, Salinity, and Dissolved Oxygen on the Stress Response of Bull (Carcharhinus leucas) and Bonnethead (Sphyrna tiburo) Sharks after Capture and Handling. *Journal of Coastal Research,* 34(4), 818-827. https://doi.org/10.2112/jcoastres-d-17-00118.1

Capture and handling stress can induce acidosis in sharks. This response, endured during commercial bycatch and in catch-and-release recreational fisheries, could be exacerbated in certain environmental conditions. To assess environmental influence on stress response, changes in acid-base, blood gas, and metabolite analytes (pH, pCO(2), and lactate) measured with the i-STAT portable clinical analyzer were evaluated immediately after capture and removal from gillnets among wild bull (Carcharhinus leucas) and bonnethead (Sphyrna tiburo) sharks caught in waters of differing temperature (T), salinity (Sal), and dissolved oxygen (DO). Time from capture to blood collection (C-BD) was also recorded. Effects of T, Sal, DO, and C-BD on acid-base physiology were evaluated by modeling their ability to predict pH, pCO(2), and lactate concentrations using ordinal logistic regression (OLR). The OLR models suggest that C. leucas sharks experienced a mixed metabolic and respiratory acidosis in warmer waters and at the low end of their salinity tolerance, and that S. tiburo sharks experienced a metabolic acidosis in warmer waters with a potential for respiratory acidosis at the high end of their salinity tolerance. In S. tiburo, capture and handling time exacerbated acidosis. Based on these findings, it is recommended that commercial and catch-and-release fisheries conduct operations cautiously during times of the year when water temperatures are high and salinities are at either extreme, by decreasing soak times, using the strongest

proper tackle gear to reduce fight times, and releasing sharks as soon as possible after capture and detection.

Lezama-Ochoa, N., Hall, M. A., Pennino, M. G., Stewart, J. D., Lopez, J., & Murua, H. (2019). Environmental characteristics associated with the presence of the Spinetail devil ray (Mobula mobular) in the eastern tropical Pacific. *Plos One,* 14(8), e0220854. https://doi.org/10.1371/journal.pone.0220854

In the eastern Pacific Ocean, the tropical tuna purse-seine fishery incidentally captures high numbers of five mobulid bycatch species; all of which are classified as mortalities by the Inter-American Tropical Tuna Commission due to uncertainties in post-release mortality rates. To date, the factors (operational or environmental) leading to the capture of these species by the fishery have not been well studied. Here, we developed Generalized Additive Models for fisheries observer data to analyze the relationships between the presence/absence of Mobula mobular bycatch and oceanographic conditions, the spatial and temporal variability in fishing location, and the set type (associated with dolphins, free-swimming tuna schools or floating objects). Our results suggest that chlorophyll concentration and sea surface height are the most important variables to describe the presence of M. mobular in conjunction with geographic location (latitude and longitude) and set type. Presence of the species was predicted in waters with chlorophyll concentrations between 0.5-1 mg.m(-3) and with sea surface height values close to 0; which indicates direct relationships with productive upwelling systems. Seasonally, M. mobular was observed more frequently during December-January and August-September. We also found the highest probability of presence observed in School sets, followed by Dolphin sets. Three areas were observed as important hotspots: the area close to the coastal upwelling of northern Peru, the area west to Islands Colon Archipelago (Galapagos) and the area close to the Costa Rica Dome. This information is crucial to identify the mobulids habitat and hotspots that could be managed and protected under dynamic spatial management measures to reduce the mortality of mobulid rays in the eastern Pacific purse-seine fishery and, hence, ensure the sustainability of the populations of these iconic species.

Massey, Y., Sabarros, P. S., & Bach, P. (2022). Drivers of at-vessel mortality of the blue shark (Prionace glauca) and oceanic whitetip shark (Carcharhinus longimanus) assessed from monitored pelagic longline experiments. *Canadian Journal of Fisheries and Aquatic Sciences,* 79(9), 1407-1419. https://doi.org/10.1139/cjfas-2021-0273

Elasmobranchs make up a significant part of bycatch in pelagic longline fisheries, whose induced mortality can be a major threat to endangered species. It is therefore crucial to understand the drivers of at-vessel mortality (AVM) for this fishing gear to enhance postrelease survival. To this end, we analysed scientific data collected during monitored longline fishing experiments conducted in French Polynesia to (i) estimate AVM for each species based on bootstrapped samples and (ii) to assess AVM drivers using multivariate logistic regression models for the blue shark (Prionace glauca) and oceanic whitetip shark (Carcharhinus longimanus). We found that AVM varies widely between species. Oceanic whitetip sharks are more likely to die when caught in waters outside their comfort temperature range, and their odds of survival increase with body length. For the blue shark, the only driver related to AVM is hooking duration. These results indicate that to reduce the AVM of these two species, the vertical

distribution of hooks and soak duration should be considered as mitigation measures related to pelagic longlining.

Michrowski, D., & Quinn. (2015). *Determining Discard Mortality Rates of Longline-Caught Skates (Rajidae)*. Lowell Wakefield Fisheries Symposium Series. Retrieved from https://seagrant.uaf.edu/events/2015/wakefield-data-limited/presentations/Michrowski-Longline-Caught-Skates.pdf

Discard, or release, mortality is a pressing management issue faced by most fisheries. Both target and bycatch species are released after capture for a multitude of reasons, including those of regulatory and market origins. The difficulties in determining the fate of such discards often require managers to make assumptions of discard mortality based on little to no data, leading to uncertainty in stock assessment models. The repercussions of this uncertainty can be far ranging, with implications on stock rebuilding, access to target species, and ecosystem health. One such case in the North Pacific is that of the skate complex (family: Rajidae), which are caught incidentally in large numbers in many fisheries and across most gear-types. Our current research has focused on estimating the discard mortality of skates after longline capture, as this gear-type is responsible for the majority of the catch in the region. The initial studies have described and codified the injuries sustained by these skates as a result of capture, as well as the effects of handling on injury severity. Further studies are under way to establish both injury class-specific mortality rates and a general discard mortality rate, to be made available to fisheries managers. Our goals with these efforts are to reduce the uncertainty of management models and the potential for effects of incidental catch rates on those of target species.

Murua, J., Ferarios, J. M., Grande, M., Onandia, L., & Santiago, J. (2021). *Improving on deck best handling and release practices for sharks in tuna purse seiners using hopper with ramp devices.* Scientific Committee Seventeenth Regular Session WCPFC-SC17-2021/EB-IP-13. Western and Central Pacific Fisheries Commission, Retrieved from https://meetings.wcpfc.int/node/12489

A possible bycatch reduction device (BRD) that tuna purse seiners could employ to promote safer and faster release of vulnerable bycatch, such as sharks, are hoppers with ramps. These selective hopper trays can take many shapes and sizes depending on the vessels' top deck configuration. Not all hoppers are equally valuable for bycatch release as some are either too small to access the bycatch or act as funnels with no stop mechanism to allow for time to detect and take out nontarget species. In this study four class A purse seiners operating in the Pacific Ocean and fitted with mobile hoppers were examined for shark release efficiency. Observer data results indicated that when hoppers were used on the vessels between 92% and 98% of the sharks were released from the top deck, against 21% to 46% with no hopper. Hoppers can increase shark survival because their mortality greatly increases once they reach the lower deck, where release times are delayed if there is no release exit from this area, resulting in sharks having to be carried manually upstairs. In addition, release ramps were built and trialled with the hoppers, which acted as wet slides to facilitate faster and safer release of sharks and other bycatches with minimal handling. While designs of hopper and ramps for bycatch release can still be improved, they offer a promising tool for fleets to implement best release practices of vulnerable species. Future trials will employ satellite pop-up tags to properly assess survival rates with and without hoppers. We recommend that tuna RFMOs concerned with best bycatch mitigation and crew safety practices

consider the implementation of hoppers with ramps as an efficient BRD in tropical tuna purse seiners which would be in line with shark protection recommendations in CMM-2019-04 paragraph 17.

Musyl, M. K., & Gilman, E. L. (2018). Post-release fishing mortality of blue (Prionace glauca) and silky shark (Carcharhinus falciformes) from a Palauan-based commercial longline fishery. *Reviews in Fish Biology and Fisheries,* 28(3), 567-586. https://doi.org/10.1007/s11160-018-9517-2

Accounting for components of fishing mortality, including post-release mortality (Fr), is necessary for robust assessments of the effects of fishing. Forty-eight blue (Prionace glauca) and 35 silky sharks (Carcharhinus falciformes) were tagged with pop-up satellite archival tags to monitor Fr rates from pelagic longline vessels in the western tropical Pacific Ocean. There is a paucity of Fr studies at low latitudes and identifying factors that significantly explain Fr is critical for understanding fishing mortality. Mean Fr rates were 0.17 [95% CI 0.09–0.30] for blue shark and 0.20 [95% CI 0.10–0.36] for silky shark. When it occurred, Fr was acute with 87% of mortalities within 2 days of release. Several prognostic operational, environmental, biological and handling variables were evaluated to assess their influence on survival outcomes. Using Kaplan–Meier survival curves, logistic regression, accelerated failure time and Cox proportional hazards models to screen variables, the only significant prognostic or risk variable was health condition at haulback. There was close correspondence (~ 83% accuracy) between condition at capture and survival outcomes. Reliable methods to classify at-vessel condition represent an inexpensive and simple metric for estimating both Fr and at-vessel (Fc) mortality rates. Examining Fc rates in detail in longline fisheries using capture information on depth, temperature and dissolved oxygen that may act in synergy with condition code and hooking duration is a research priority. Results suggest that a large proportion of shark survive following release and that Fr rates can be increased by improving the haulback condition of captured sharks.

Orbesen, E. S., Snodgrass, D., Shideler, G. S., Brown, C. A., & Walter, J. F. (2017). Diurnal patterns in Gulf of Mexico epipelagic predator interactions with pelagic longline gear: implications for target species catch rates and bycatch mitigation. *Bulletin of Marine Science,* 93(2), 573-589. https://doi.org/10.5343/bms.2016.1008

Bycatch in pelagic longline fisheries is of substantial international concern, and the mitigation of bycatch in the Gulf of Mexico has been considered as an option to help restore lost biomass following the 2010 Deepwater Horizon oil spill. The most effective bycatch mitigation measures operate upon a differential response between target and bycatch species, ideally maintaining target catch while minimizing bycatch. We investigated whether bycatch vs target catch rates varied between day and night sets for the United States pelagic longline fishery in the Gulf of Mexico by comparing the influence of diel time period and moon illumination on catch rates of 18 commonly caught species/species groups. A generalized linear model approach was used to account for operational and environmental covariates, including: year, season, water temperature, hook type, bait, and maximum hook depth. Time of day or moon phase was found to significantly alter catch rates for 88% of the taxa examined. Six taxa-swordfish (Xiphias gladius Linnaeus, 1758); tiger shark (Galeocerdo cuvier Peron and Lesueur, 1822); silky shark (Carcharhinus falciformis Muller and Henle, 1839); oilfish (Ruvettus pretiosus Cocco, 1833); bigeye thresher shark (Alopias superciliosus Lowe, 1841); and escolar (Lepidocybium flavobrunneum Smith, 1843)-exhibited higher catch rates at night, while eight taxa-skipjack tuna (Katsuwonus pelamis Linnaeus, 1758); wahoo

(Acanthocybium solandri Cuvier, 1832); white marlin [Kajikia albida (Poey, 1860]; dolphinfish (Coryphaena sp.); yellowfin tuna (Thunnus albacares Bonnaterre, 1788); rays (Pteroplatytrygon violacea Bonaparte, 1832, Mobulidae sp.); lancetfish (Alepisaurus sp.), and blue marlin (Makaira nigricans Lacepede, 1802)-had higher daytime catch rates. These results reveal that shifts in effort between daytime and nighttime fishing (which are highly correlated with shifts between yellowfin tuna and swordfish targeting strategies) could have substantial, species-specific effects on bycatch rates. Whether driven by fishery conditions, market influences, or management measures, such temporal shifts in the timing of pelagic longline sets may have important implications for species-specific conservation goals and warrant further consideration.

Piovano, S., & Gilman, E. (2017). Elasmobranch captures in the Fijian pelagic longline fishery. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 27(2), 381-393. https://doi.org/10.1002/aqc.2666

Pelagic longline fisheries for relatively fecund tuna and tuna-like species can have large adverse effects on incidentally caught species with low-fecundity, including elasmobranchs. Analyses of observer programme data from the Fiji longline fishery from 2011 to 2014 were conducted to characterize the shark and ray catch composition and identify factors that significantly explained standardized catch rates. Catch data were fitted to generalized linear models to identify potentially significant explanatory variables. With a nominal catch rate of 0.610 elasmobranchs per 1000 hooks, a total of 27 species of elasmobranchs were captured, 48% of which are categorized as Threatened under the IUCN Red List. Sharks and rays made up 2.4% and 1.4%, respectively, of total fish catch. Blue sharks and pelagic stingrays accounted for 51% and 99% of caught sharks and rays, respectively. There was near elimination of ?shark lines?, branchlines set at or near the sea surface via attachment directly to floats, after 2011. Of caught elasmobranchs, 35% were finned, 11% had the entire carcass retained, and the remainder was released alive or discarded dead. Finning of elasmobranchs listed in CITES Appendix II was not observed in 2014. There were significantly higher standardized shark and ray catch rates on narrower J-shaped hooks than on wider circle hooks. Based on findings from previous studies on single factor effects of hook width and shape, the smaller minimum width of the J-shaped hooks may have caused the higher shark and ray catch rates. For sharks, the effect of hook width may have exceeded the effect of hook shape, where small increases in shark catch rates have been observed on circle vs J-shaped hooks. Shark and ray standardized catch rates were lowest in the latter half of the year. Focusing effort during the second half of the year could reduce elasmobranch catch rates. Copyright ? 2016 John Wiley & Sons, Ltd.

Poisson, F. (2009). *Fate of the fish caught on longline gears and potential mitigation measures.* IOTC-2009-WPEB-15. Indian Ocean Tuna Commission, Retrieved from https://archimer.ifremer.fr/doc/00129/24056/22023.pdf

This document summarises some major results obtained during experiments conducted in collaboration with the Reunion Island (France) (20°-22°N and 53°-57°N) fishing industry. These studies may aid fishermen in modifying fishing operations and selecting a fishing strategy to increase economic benefits and also to reduce the impact on bycatch mortality. Firstly, we investigated the behaviour of the fishes when caught on the longline gear and the survivorship of fish hooked, using longline gears instrumented

with hook time recorders (HT) and temperature depth recorders (TDR). We showed that the percentages of fish recovered alive at hauling varied among species. The percentages of fish recovered alive up to 8 h after capture provides a rough idea of the resistance of each species to the capture process; these rates were recorded for the blue shark (Prionace glauca), the oceanic whitetip shark (Carcharhinus longimanus) and for the bigeye tuna (Thunnus obesus) and were respectively 29%, 23 % and 27% while this rate was lower for the swordfish (8%). Moreover, we demonstrated that shortening the soaking time during the fishing operation could be beneficial in many ways for fishermen. A second study on the reproduction dynamic of the swordfish in the vicinity of Reunion Island showed that the Big Old Fat Fecund Female Fish (BOFFFF) hypothesis could effectively apply to this species. Consequently, the removal of the larger, older individuals could be detrimental for the stock and the current results may be used, in the future, to support new policies preserving population age structure. One management method available to conserve older fish would be to institute slot size limits for retention (minimum and maximum size) but this potential measure to be successful need the individuals to survive their release back to the water. The last study aimed at investigating the possibility of developing a method to reduce the stress of the fishes caught with hooks. Prototypes of “sleeping hook” were developed and tested, using rod and reel, around moored fish aggregating devices (FAD’s). During the fishing experiments a total of 162 fish comprising 3 main species were caught including: yellowfin tuna (Thunnus albacares), skipjack tuna (Katsuwonus pelamis) and dolphinfish (Coryphaena hippurus). Analyses of blood chemistry stress indicators revealed the “sleeping hook” method to be successful in reducing the fish stress. Additional research should be conducted to evaluate the feasibility of reducing the soaking period in the current fishing strategy. However, the “sleeping hook” could contribute to the development of alternative fishing technology enabling also to reduce the side effect of protracted soaking times e.g. by reducing post hooking mortality and increasing the post release survivorship of species of conservation concern and unwanted sized target species.

Poisson, F., Abascal Crespo, F., Ellis, J. R., Chavance, P., Pascal, B., Santos, M. N., . . . Murua, H. (2016). Technical mitigation measures for sharks and rays in fisheries for tuna and tuna-like species: turning possibility into reality. *Aquatic Living Resources,* 29(4). https://doi.org/10.1051/alr/2016030

Tuna fisheries have been identified as one of the major threats to populations of other marine vertebrates, including sea turtles, sharks, seabirds and marine mammals. The development of technical mitigation measures (MM) in fisheries is part of the code of conduct for responsible fisheries. An in-depth analysis of the available literature regarding bycatch mitigation in tuna fisheries with special reference to elasmobranchs was undertaken. Studies highlighting promising MMs were reviewed for four tuna fisheries (longline, purse seine, driftnets and gillnet, and rod and line - including recreational fisheries). The advantages and disadvantages of different MMs are discussed and assessed based on current scientific knowledge. Current management measures for sharks and rays in tuna Regional Fishery Management Organizations (t-RFMOs) are presented. A review of relevant studies examining at-vessel and postrelease mortality of elasmobranch bycatch is provided. This review aims to help fisheries managers identify pragmatic solutions to reduce mortality on pelagic elasmobranchs (and other higher vertebrates) whilst minimizing impacts on catches of target tuna species. Recent research efforts have identified several effective MMs that, if endorsed by t-RFMOs, could reduce elasmobranchs mortality rate in international tropical purse seine tuna fisheries. In the case of longline fisheries, the number of operational effective MMs is very limited. Fisheries deploying driftnets in pelagic ecosystems are suspected to have a high elasmobranchs bycatch and their discard survival is uncertain, but no effective

MMs have been field validated for these fisheries. The precautionary bans of such gear by the EU and by some t-RFMOs seem therefore appropriate. Recreational tuna fisheries should be accompanied by science-based support to reduce potential negative impacts on shark populations. Priorities for research and management are identified and discussed.

Poisson, F., Gaertner, J.-C., Taquet, M., Durbec, J.-P., & Bigelow, K. (2010). Effects of lunar cycle and fishing operations on longline-caught pelagic fish: fishing performance, capture time, and survival of fish. *Fishery Bulletin,* 108(3), 268-281. Retrieved from https://spo.nmfs.noaa.gov/content/effects-lunar-cycle-and-fishing-operations-longline-caught-pelagic-fish-fishing-performance

Commercial longline fishing data were analyzed and experiments were conducted with gear equipped with hook timers and time-depth recorders in the Reunion Island fishery (21 degrees 5'S lat., 53 degrees 28'E long.) to elucidate direct and indirect effects of the lunar cycle and other operational factors that affect catch rates, catch composition, fish behavior, capture time, and fish survival. Logbook data from 1998 through 2000, comprising 2009 sets, indicated that swordfish (Xiphias gladius) catch-per unit of effort (CPUE) increased during the first and last quarter of the lunar phase, whereas albacore (Thunnus alalunga) CPUE was highest during the full moon. Swordfish were caught rapidly after the longline was set and, like bigeye tuna (Thunnus obesus), they were caught during days characterized by a weak lunar illumination-mainly during low tide. We found a significant but very low influence of chemical lightsticks on CPUE and catch composition. At the time the longline was retrieved, six of the 11 species in the study had >40% survival. Hook timers indicated that only 8.4% of the swordfish were alive after 8 hours of capture, and two shark species (blue shark [Prionace glauca] and oceanic whitetip shark [Carcharhinus longimanus]) showed a greater resilience to capture: 29.3% and 23.5% were alive after 8 hours, respectively. Our results have implications for current fishing practices and we comment on the possibilities of modifying fishing strategies in order to reduce operational costs, bycatch, loss of target fish at sea, and detrimental impacts on the environment.

Prior, J. (2017). *Protection On The Move: Applying Dynamic Ocean Management To Address Shark Bycatch In Atlantic Canada.* (Masters of Marine Management), Dalhousie University, Retrieved from http://hdl.handle.net/10222/73837

The Canadian North Atlantic pelagic longline fishery for swordfish and tuna has unintended bycatch of porbeagle, shortfin mako, and blue sharks. This creates concerns for species-at-risk populations, ecosystem health, harvesters safety and economic security. This study proposes that a Dynamic Ocean Management (DOM) application could mitigate the pelagic shark bycatch associated with this longline fishery. The document reviews published information on the focal shark species, the fishery, current marine spatial management tools used in Canada, and theory and applications of DOM. Following this, the study evaluates the attitudes of 14 primary stakeholders towards DOM through stakeholder group governance analysis and semi-structured interviews. The associated stakeholders who participated in the project include one participant from each of the regional RFMOs; NAFO and ICCAT, three participants from DFO, one participant from the Nova Scotia Swordfish Association, four NGO perspectives, two academic perspectives, and two private third-party interest groups. In the interviews, all individuals discussed their views on the bycatch challenge, the desirability and feasibility of applying

DOM, and the current efforts undertaken by each group. The results of this study show that a DOM application is seen as a desirable potential solution by most and could be feasible depending on project structure and management style. Therefore, based on the considerations of the governance analyses and interview responses, a management plan is proposed and associated requirements, considerations, and concerns are discussed. Specifically, the plan proposes a management tool in the style of a phone app or website interface. This interface would allow harvesters to geo-tag areas where shark bycatch has impacted their catch in near-real time. When overlaid with other data streams, including historical seasonal data, ocean conditions and species tracking, it allows the whole fleet to strategically plan their next location to set their longlines, with an active consideration to avoid sharks.

Roberson, L. A., & Wilcox, C. (2022). Bycatch rates in fisheries largely driven by variation in individual vessel behaviour. *Nature Sustainability*. https://doi.org/10.1038/s41893-022-00865-0

Fisheries bycatch continues to drive the decline of many threatened marine species such as seabirds, sharks, marine mammals and sea turtles. Management frameworks typically address incidental catch with fleet-level controls on fishing. Yet, individual operators differ in their fishing practices and efficiency at catching fish. If operators have differing abilities to target, they should also have differing abilities to avoid bycatch. We analysed variations in threatened species bycatch among individual operators from five industrial fisheries representing different geographic areas, gear types and target species. The individual vessel is a significant predictor of bycatch for 15 of the 16 cases, including species that represent high or low costs to fishers or have economic value as potentially targeted byproducts. Encouragingly, we found high-target and low-bycatch operators in all five sectors, including gears known for high bycatch mortality worldwide. These results show that there is untapped opportunity to reduce negative environmental impacts of fisheries with interventions targeting specific performance groups of individuals, supporting an alternative perspective towards managing global fisheries.

Rodrigues, L. d. S., Kinas, P. G., Cardoso, L. G., & O'Neill, F. (2022). Optimal setting time and season increase the target and reduce the incidental catch in longline fisheries: a Bayesian beta mixed regression approach. *ICES Journal of Marine Science,* 79(4), 1245-1258. https://doi.org/10.1093/icesjms/fsac049

Sustainable fisheries' managers increasingly seek to implement measures that reduce the mortality of threatened species while maintaining or increasing catch of target species. Our study proposed a simple management option for optimizing fishing over daily and seasonal scales to maximize catch success while protecting non-target species in pelagic longline fisheries. We used Bayesian beta mixed regression models to describe the effects of setting times and seasonality on catches in a pelagic longline fishery in the southwest South Atlantic Ocean (SWAO). Targeted species (swordfish, blue shark, and albacore tuna) are typically captured in fully nocturnal sets (started between 16 and 00 h), whereas shortfin mako shark and loggerhead turtles are typically captured during partially nocturnal sets (started between 00 and 04 h); probably a response to hook depth and circadian behaviours. The results suggest that it is feasible to use only fully nocturnal sets to target preferred species while reducing incidental catch of non-target species. The catch of target species was higher in austral winter, explained by the northward displacement of the subtropical convergence in the SWAO during this season. These results

provide a baseline for bycatch mitigation strategies in pelagic longline fisheries at regional and global scales.

Sacchi, J. (2019). *Mitigation Measures for Protected Species.* Paper presented at the Seventh Meeting of the Parties to ACCOBAMS. Retrieved from https://accobams.org/wp-content/uploads/2019/04/MOP7.Doc30_Mitigation-measures-for-protected-species.pdf

Highly migratory for the most part, occupying a wide distribution across the oceans, the marine megafauna undergo all possible forms of human pressure. Among them, bycatch fishery has increased exponentially in recent years and is now considered the most serious threat to these highly vulnerable species. Minimizing bycatch, is therefore a key component of sustainable fisheries management to maintain marine biodiversity and consequently to reduce negative effects on the resources (see Hall, 1996; Hall et al., 2000). The aim of this document is to present various experimented approaches and strategies that could also serve as an example for fisheries facing the same problems. This review of the different mitigation measures draws on the analysis of the available literature, comprising scientific journal articles together with reports from international organisations and documents available on the internet. The presentation adopted here is guided by the principle that it is not species that should be managed but fishing activities (metiers)1 that should be the target of the technical or management measures that are required to reduce the negative impacts of interactions with fisheries. Consequently, for each of the main fishing gear groups (gill and trammel nets, longlines and lines, trawls, purse seines, trapnets and pots) the various solutions found in the documents consulted are classified by the four main groups of protected species (Cetaceans, Birds, Sharks and Sea turtles).

Schaefer, K., Fuller, D., Castillo-Geniz, J. L., Godinez-Padilla, C. J., Dreyfus, M., & Aires-da-Silva, A. (2021). Post-release survival of silky sharks (Carcharhinus falciformis) following capture by Mexican flag longline fishing vessels in the northeastern Pacific Ocean. *Fisheries Research,* 234, 105779. https://doi.org/10.1016/j.fishres.2020.105779

Mexican flag longline fishing vessels operating in tropical waters of the northeastern Pacific Ocean commonly target and land silky sharks (Carcharhinus falciformis). In this study silky sharks captured by Mexican flag longline fishing vessels in the northeastern Pacific Ocean and brought onboard were tagged and released with pop-up satellite archival tags (PSATs), following removal of hooks or cutting gangions as close to the hook as feasible, to evaluate their post-release survival (PRS). The PRS rate estimated using Kaplan - Meier survival analyses was 84.8 % (95 % CI: 71.0 %–100 %) for 63 silky sharks. Utilizing a rope noose to lift sharks aboard vessels was demonstrated to be an effective handling method. The 58 silky shark survivors were at liberty with PSATs attached for an average of 102 days (range: 1–298 d). Average linear displacement for 46 silky sharks at liberty for > 30 d was 512 nmi (range: 45–927 nmi), indicating relatively rapid widespread dispersion from release locations.

Talwar, B., Brooks, E. J., Mandelman, J. W., & Grubbs, R. D. (2017). Stress, post-release mortality, and recovery of commonly discarded deep-sea sharks caught on longlines. *Marine Ecology Progress Series,* 582, 147-161. https://doi.org/10.3354/meps12334

Bycatch interactions with deep-sea elasmobranchs are increasingly common and can lead to dramatic declines in abundance over short time scales. Sharks hooked in the deep sea could face a higher likelihood of severe physiological disturbance, at-vessel mortality, and postrelease mortality (PRM) than their shallower counterparts. Unfortunately, robust PRM rates have not yet been estimated for longline-caught deep-sea sharks, and as such are not currently incorporated into total fishery mortality estimates or bycatch assessments, limiting the effectiveness of current conservation or management initiatives. We empirically estimated PRM for 2 focal taxa of deep-sea shark, the Cuban dogfish Squalus cubensis and the gulper shark Centrophorus sp., using post-release enclosures deployed at-depth. We calculated 24 h PRM rates of 49.7 +/- 8.5% (mean +/- SE) for S. cubensis and 83 +/- 16% for Centrophorus sp. and identified blood lactate, total length, glucose, and vitality scores as predictors of PRM in S. cubensis. We also observed all 24 h PRM within 11 h post-capture and demonstrated the effects of recovery depth and at-vessel blood chemistry metrics on post-release behavior. Our results suggest that PRM rates of deep-sea sharks are high and highlight the need for filling in this gap in fishery mortality estimates for other common discards in the future.

Tixier, P., Lea, M. A., Hindell, M. A., Welsford, D., Mazé, C., Gourguet, S., & Arnould, J. P. Y. (2021). When large marine predators feed on fisheries catches: Global patterns of the depredation conflict and directions for coexistence. *Fish and Fisheries,* 22(1), 31-53. https://doi.org/10.1111/faf.12504

The sustainable mitigation of human–wildlife conflicts has become a major societal and environmental challenge globally. Among these conflicts, large marine predators feeding on fisheries catches, a behaviour termed “depredation,” has emerged concomitantly with the expansion of the world’s fisheries. Depredation poses threats to both the socio-economic viability of fisheries and species conservation, stressing the need for mitigation. This review synthesizes the extent and socio-ecological impacts of depredation by sharks and marine mammals across the world, and the various approaches used to minimize it. Depredation was reported in 214 fisheries between 1979 and 2019 (70% post-2000) and affected fleets from 44 countries, in all sectors (commercial, artisanal and recreational), and in all major fishing techniques (nets, traps and hook-and-lines). A total of 68 predator species were involved in depredation (20 odontocetes, 21 pinnipeds and 27 sharks), and most (73%) were subject to either by-catch and/or retaliatory killing from fishers when interacting with gear. Impacts on fishers were primarily associated with catch losses and gear damage but often lacked assessments. Deterrence was a major mitigation approach but also the least effective. Gear modifications or behavioural adaptation by fishers were more promising. This review highlights the need for improved monitoring, and interdisciplinary and integrated research to quantify the determinants and impacts of depredation in the socio-ecological dimension. More importantly, as the conflict is likely to escalate, efforts directed towards changing perceptions and integrating knowledge through adaptive co-management are raised as key directions towards coexistence between fisheries and large marine predators.

Wosnick, N., Awruch, C. A., Adams, K. R., Gutierre, S. M. M., Bornatowski, H., Prado, A. C., & Freire, C. A. (2019). Impacts of fisheries on elasmobranch reproduction: high rates of abortion and subsequent maternal mortality in the shortnose guitarfish. *Animal Conservation,* 22(2), 198-206. https://doi.org/10.1111/acv.12458

The fate of bycatch species released back into the water is crucial to estimate population status and consequent decisions to implement adequate management measurements for elasmobranchs. The shortnose guitarfish, Zapteryx brevirostris, is an endemic species of the Southwest Atlantic. It is currently listed as 'Vulnerable' both in the International Union for Conservation of Nature and Brazilian red lists. Although this species displays high tolerance to capture and transportation by fishers from the capture site to the fish market, a significant reduction in survival rates is observed during the reproductive period. Thus, the aim of the present study was to examine post-capture and post-commercial transportation consequences in pregnant females obtained as bycatch from artisanal fisheries in Southern Brazil. Results showed high abortion rates and reduced maternal survival after abortion, with all abortions occurring within 28 h of monitoring in laboratory. Stress plasma markers were also evaluated, to determine the physiological consequences of capture-induced parturition to pregnant females. Results showed alteration in all markers measured (plasma urea, pH, lactate, phosphorus, and potassium) with values for dead pregnant females being different from non-pregnant females and those which survived capture and subsequent abortions. The mortality caused by fisheries bycatch may prove difficult to manage, with immediate release and specific handling protocols for pregnant females implemented through environmental education environmental education and fishermen training programs, potential options to maintain adequate maternal survival and recruitment for this species.

Zainudin, I. M., Patria, M. P., Rahardjo, P., Yasman, Y., Gautama, D. A., & Prawira, W. T. (2017). Bycatch of sharks, marine mammals and seabirds in Indonesian Tuna Longline Fishery. *Biodiversitas, Journal of Biological Diversity,* 18(3), 1179-1189. https://doi.org/10.13057/biodiv/d180341

Zainudin IM, Patria MP, Rahardjo P, Yasman, Gautama DA, Prawira WT. 2017. Bycatch of sharks, marine mammals and seabirds in Indonesian Tuna Longline Fishery. Biodiversitas 18: 1179-1189. Bycatch in longline fishery is recorded to be one of the major factors defining the declined populations of endangered marine species worldwide. This research aimed to identify bycatch level of sharks, marine mammals and seabirds as well as to pinpoint the mitigation options in Indonesian tuna longline fishery. In this study, a total of 8,564,858 hooks were observed from 5,622 gear settings in Indonesian tuna longline fishery based in two major fishing ports, namely Bitung Fishing Port-North Sulawesi and Benoa Port-Bali from May 2006 to June 2014. The results suggest that the best hook rate per thousand hooks in Indonesian tuna longline fisheries for shark bycatch was 0.2446, followed by 0.0030 for seabird bycatch, 0.0021 for dolphin bycatch and 0.0009 for whale bycatch. Seabirds largely acquired in the dead condition while the other species were found still alive (sharks and marine mammals). Bycatch of seabirds only occured in the vessels based in Benoa Bali, and the correlation value (R2) of sharks and seabirds caught at night time was low while for marine mammals was very strong. Deep setting system of fishing gears and night setting also proved to be more effective to reduce bycatch of those critical marine species.

Zea-de la Cruz, H., Tovar-Avila, J., Meiners-Mandujano, C., Jimenez-Badillo, L., & Luis Oviedo-Perez, J. (2021). Determining potential management strategies for the elasmobranchs bycatch of the Mexican shrimp trawl fishery of the Gulf of Mexico through a vulnerability analysis. *Regional Studies in Marine Science,* 42. https://doi.org/10.1016/j.rsma.2021.101626

Shrimp trawl fisheries capture several species of elasmobranchs as bycatch that are commonly unreported, this lack of data makes it difficult to assess their populations using quantitative stock assessment methods. Rapid evaluations like the productivity and susceptibility analysis (PSA), can help to determine species at risk of overexploitation and prioritize research, management and conservation efforts. The relative vulnerability (V) of 16 elasmobranch species associated to the Mexican shrimp trawl fishery in the Gulf of Mexico was determined using a PSA. The information of bycatch elasmobranch was collected by observer's onboard shrimp fishing vessels in 55 fishing trips during the 2013-2017 period. Two hypothetical scenarios to test potential management strategies were developed to observe changes in V based on the current fishing practices. We determined that most elasmobranch species (n= 14) had low V (<1.8) related to this fishery, mostly as a result of the high productivity (P) of the coastal-demersal species and the low susceptibility (S) of the coastalsemioceanic ones. Only two species had a moderate V, Pseudobatos lentiginosus (1.87) and Squatina dumeril (1.85). The vulnerability of these two species could decrease through ensuring post-capture release practices and the protection of their aggregation, since both actions would lower their S and V. Post-capture release might be the most feasible potential strategy for both species, whereas protection of species aggregations would require further investigation to support its effect in the mitigation of mortality from bycatch.

Zollett, E. A., & Swimmer, Y. (2019). Safe handling practices to increase post-capture survival of cetaceans, sea turtles, seabirds, sharks, and billfish in tuna fisheries. *Endangered Species Research,* 38, 115-125. https://doi.org/10.3354/esr00940

Incidental capture of marine animals in fishing gear may cause immediate or delayed mortality due to injury. Increasing post-capture survival of these species is very important to reducing the widespread impacts of bycatch, particularly on protected and threatened populations. In this paper, we review recent literature on safe handling of sea turtles, cetaceans, seabirds, sharks, and billfish and summarize the most effective measures for improving survivability of these species after interactions with gillnet, pelagic longline, and purse seine gear. We also review the current tuna Regional Fishery Management Organization (tRFMO) measures on safe handling and release to identify gaps in implementation of safe handling practices. Strategies that increase post-capture survival of marine species can be grouped into 3 primary categories: reducing immediate mortality, minimizing injury that results in delayed mortality, and reducing stress that can lead to death. Routine training of fishermen on safe handling practices greatly improves the effectiveness of these measures. When bycatch does occur, the strategies to increase post-release survival become key for protecting vulnerable marine populations. This inventory highlights the great conservation value that can be provided by the tRFMOs by providing guidance and training on safe handling practices to increase post-release survival across taxa.

2.2 Gear Modifications

Abrantes, K. G., Barnett, A., Soetaert, M., Kyne, P., Laird, A., Seymour, J., . . . Huveneers, C. (2020). *Can sawfish bycatch within the Northern Prawn Fishery be mitigated using an electric field?* FRDC Project No 2016-058 Retrieved from https://www.frdc.com.au/sites/default/files/products/2016-058-DLD.pdf

This project aimed to test the effect of electric fields on sawfish behaviour and to assess the potential for electric pulses to mitigate sawfish bycatch in prawn fisheries. The project was developed in collaboration with the Northern Prawn Fishery Industry Projects Manager Adrianne Laird and Dr Peter Kyne, principal investigator of National Environmental Research Programme/National Environmental Science Program Marine Biodiversity Hubs projects specialised in Northern Australia threatened species, including sawfishes.

Afonso, A. S., Hazin, F. H. V., Carvalho, F., Pacheco, J. C., Hazin, H., Kerstetter, D. W., . . . Burgess, G. H. (2011). Fishing gear modifications to reduce elasmobranch mortality in pelagic and bottom longline fisheries off Northeast Brazil. *Fisheries Research,* 108(2-3), 336-343. https://doi.org/10.1016/j.fishres.2011.01.007

One of the biggest challenges of fisheries research is reducing the bycatch of unwanted species. The incidental fishing mortality of species with low reproductive rates, such as elasmobranchs (sharks, skates, and rays), is recognized as a key threat for their populations. In the present study, gear modifications related to the type of hook and position of the hook in the water column were tested to examine their effects on catch rates and mortality of elasmobranch species in both pelagic and coastal environments. Comparisons between circle (size 18/0,0 degrees offset) and J-style (size 9/0, 10 degrees offset) hooks demonstrated that the circle hooks have a greater efficiency in reducing the mortality of most species caught, both in pelagic and coastal longline fisheries. Internal lodging of the hook was significantly less frequent for the individuals caught with circle hooks, which likely contributed to their higher survival rate at haulback. Additionally, circle hooks also increased the CPUE of elasmobranchs caught in the pelagic longline fishery, which was particularly evident for Carcharhinus falciformis and Prionace glauca. The position of the hook in the water column exhibited a strong influence on the species caught in the coastal bottom longline fishery. Suspending hooks in the middle of the water column reduced the bycatch of common demersal species, such as Carcharhinus acronotus, Ginglymostoma cirratum, and Dasyatis americana, while increasing the CPUE of potentially aggressive species, such as Galeocerdo cuvier and Carcharhinus leucas. The interaction of the type of hook utilized with its position in the water column appears to be an essential factor in the optimization of longline selectivity and minimization of bycatch mortality.

Afonso, A. S., Santiago, R., Hazin, H., & Hazin, F. H. V. (2012). Shark bycatch and mortality and hook bite-offs in pelagic longlines: Interactions between hook types and leader materials. *Fisheries Research,* 131, 9-14. https://doi.org/10.1016/j.fishres.2012.07.001

This study addressed the influence of hook type (circle vs J-hook) and leader material (nylon vs wire) on longline catch and mortality rates of target and bycatch species in a pelagic longline fishery targeting swordfish. Xiphias gladius, and tunas. A total of 603 individuals (53% classified as bycatch) were caught

on 17,000 hooks. Sharks constituted 45% of the bycatch. Bite-offs (i.e. missing hooks) corresponded to similar to 33% of the shark catch and occurred mostly on nylon leaders (97%). Hook type had no significant effect on catchability or mortality of any species or groups. However, nylon leaders caught more bigeye tuna. Thunnus obesus and all target species combined, while wire leaders caught more blue shark. Prionace glauca and all sharks combined. If bite-offs were assumed to be undetected sharks, differences in shark catchability between leader types disappear. Moreover, significant differences in blue shark catch rate between leader types was found in J-hook treatments only. Higher proportions of live sharks were found on wire leaders. The catch and mortality rates of sharks in longline fisheries may be underestimated when monofilament leaders are used. This study highlights the need for understanding the role of every longline component in gear performance analysis.

Amorim, S., Santos, M. N., Coelho, R., & Fernandez-Carvalho, J. (2015). Effects of 17/0 circle hooks and bait on fish catches in a Southern Atlantic swordfish longline fishery. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 25(4), 518-533. https://doi.org/10.1002/aqc.2443

This paper reports the results of using different hook style and bait type combinations on the catches of targeted, bycatch and discarded fishes in the Portuguese commercial longline fishery targeting swordfish (Xiphias gladius) in the South Atlantic Ocean. In total, 310 longline experimental sets (446 400 hooks) were deployed between October 2008 and February 2012. Three different hook styles were tested; the traditional J-hook (9/0) 10(o) offset was compared with two 17/0 circle hooks (a non-offset and a 10(o) offset), and squid (Illex spp.) bait was compared with mackerel (Scomber spp.). Catch per unit effort (CPUE) was calculated for each fish species per fishing set and compared between the different hook style and bait type combinations. Results indicated that the effects of hook style and bait on the CPUEs were species-specific. For example, swordfish (target species, Xiphias gladius) CPUEs were higher with J-hooks baited with squid, while for the blue shark (most important bycatch species, Prionace glauca) the highest CPUEs were obtained with circle hooks baited with mackerel. For tuna (Thunnus spp.) and marlin (blue, Makaira nigricans and white, Kajikia albida) only the bait effect was significant, with higher catches with squid. For the discarded species, the proportions of alive vs dead specimens at the time of fishing gear retrieval were also species-specific. The total retained catch value per unit of effort (VPUE) did not changed between the different hook and bait combinations, but these VPUEs are highly dependent on market fluctuations.

Andraka, S., Mug, M., Hall, M., Pons, M., Pacheco, L., Parrales, M., . . . Vogel, N. (2013). Circle hooks: Developing better fishing practices in the artisanal longline fisheries of the Eastern Pacific Ocean. *Biological Conservation,* 160, 214-224. https://doi.org/10.1016/j.biocon.2013.01.019

Since 2004, governments and non-governmental organizations, together with the fishing communities from nine countries, from Mexico to Peru, have implemented joint efforts to reduce incidental mortality of sea turtles in artisanal longline fisheries of the Eastern Pacific Ocean (EPO). These countries are involved in a Regional Sea Turtle Bycatch Program to achieve this goal. Circle hooks have been proposed as a way to mitigate incidental mortality of sea turtles. Thus, we analyze the performance of circle hooks in relation to)style and tuna hooks on the hooking rates of target and non-target species in the artisanal surface longline fisheries of three of the participating countries with the largest sample sizes (Ecuador, Panama and Costa Rica). These fisheries target mahi-mahi, Coryphaena hippurus, or a combination of tunas, billfishes and sharks (TBS), and use different techniques and gear configurations to catch their targets. For the TBS fishery we presented the results of comparisons between tuna hooks and 16/0

circle hooks from Ecuador, Panama and Costa Rica, and between tuna hooks and 18/0 circle hooks in Costa Rica. For the mahi-mahi fishery, we analyzed the performance of 14/0 and 15/0 circle hooks in Ecuadorian vessels and 16/0 circle hooks in Costa Rican vessels vs. the traditional J-style hooks. A total of 730,362 hooks were observed in 3126 sets. Hooking rates for target and non-target species were not consistent for all fisheries and countries analyzed. However, circle hooks reduced sea turtle hooking rates in most of the comparisons.

Ariz, J., Delgado de Molina, A., Ramos, M., & Santana, J. (2006). *Check list and catch rate data by hook type and bait for Bycatch species caught by Spanish experimental longline cruises in the South-western Indian Ocean during 2005.* Western and Central Pacific Fisheries Commission, Retrieved from https://meetings.wcpfc.int/node/6339

In this paper, catch data are presented, in number of individuals and round weight (Kg), per a thousand hooks, from data obtained in the experimental cruises carried out by the Instituto Espanol de Oceanografia (IEO) in two surface Spanish longliners in international waters of South-western Indian Ocean between 25ºS - 35ºS and 30ºE - 50ºE. This pilot action, which was followed continuously by scientific observers, was carried out in 2005 and several types of hooks and baits were experimentally used. Although there is space-time stratification for sampling in the prospecting area, it has not been taken into consideration for this document. Joint analysis has been made of all the specimens sampled since activities began (539 sets with a total of 531916 hooks) for the entire area. Total catch raised 1162t, from which 30t are considered true bycatch. The related species included in this group were 2.6% of total tons caught. Sharks and Rays, and Other Fishes are species which inclusion in ship holds depends on the fleet and has varied according to the trade. Detailed information is presented about the catch of sea turtles, marine mammals and sea birds. This document presents, in the same way, the total catch, in number and weight, for all and each one of the species or groups captured in this Pilot Action, indicating if they were included as commercial catch or as bycatch.

Bayse, S. M., & Grant, S. M. (2020). Effect of baiting gillnets in the Canadian Greenland halibut fishery. *Fisheries Management and Ecology,* 27(5), 523-530. https://doi.org/10.1111/fme.12434

Catch rates were compared between gillnets with and without bait in the Greenland halibut Reinhardtius hippoglossoides (Walbaum) fishery off Baffin Island, Canada. Two different types of baiting techniques were compared: bait bags where squid were placed into 2-mm mesh bags, and tied bait where squid were tied into meshes. Both types of baited gillnets significantly increased the capture of the target species, Greenland halibut, with increases of 253.8% and 149.7% for the bait bag and tied bait, respectively. Common bycatch species showed mixed effects, with roughhead grenadier Macrourus berglax Lacepede showing no increase in catch per unit effort (CPUE) for either bait type (p > 0.05), and porcupine crab Neolithodes grimaldii (Milne-Edwards and Bouvier) only had a higher CPUE with baited gillnets when bait bags were placed on the footrope. Less common bycatch species-but with threatened populations-showed an increase in CPUE, including Greenland shark Somniosus microcephalus (Bloch and Schneider) and Northern wolffish Anarhichas denticulatus Kroyer. Baiting gillnets affected the CPUE of gillnets in the Greenland halibut fishery, and management should consider how the increased CPUE of both target and bycatch species are affected by this new fishery trend.

Bayse, S. M., & Kerstetter, D. W. (2010). Assessing Bycatch Reduction Potential Of Variable Strength Hooks For Pilot Whales In A Western North Atlantic Pelagic Longline Fishery. *Journal of the North Carolina Academy of Science,* 126(1), 6-14. Retrieved from http://www.jstor.org/stable/24336337

The pelagic longline fishery off Cape Hattaras in the western North Atlantic Ocean, which targets swordfish (Xiphias gladius, Linnaeus 1758) and tunas (Thunnus spp.), has a high frequency of interactions with marine mammals, particularly pilot whales (Globicephala spp.). The typical hooks used in the this fishery are size 16/0 "strong" hooks that straighten at 250 lb of pull (113 kg); some fishermen use alternative "weak" hooks that straighten at 150 lb of pull (68 kg). Other commonly used hooks in this fishery are size 18/0 strong hooks that straighten at 350 lb (159 kg) of pull, and the weak equivalent hooks that straighten at 225 lb (102 kg). Taking advantage of the size difference between large bycatch animals and relatively smaller target species, weak hooks could be implemented to reduce bycatch. Twenty-one pelagic longline sets were made targeting yellowfin tuna (T. albacares, Bonnaterre 1788) and bigeye tuna (T. obesus, Lowe 1839) using alternating 16/0 strong and weak hooks. Nine additional sets targeted swordfish with size 18/0 hooks and the same alternating hook methodology. No significant reduction in total tuna catch (α < 0.05) or of any target species, although weak hooks exhibited higher catch per unit effort (CPUE) for tuna and swordfish. The only species with a significant difference in total catch between strong and weak 16/0 hooks was the pelagic stingray (Pteroplatytrygon violacea, Bonaparte, 1832), with more individuals caught by the strong hook. The sets with 18/0 hooks had similar catches for all species, except the target species swordfish. Swordfish CPUE was higher with the strong hooks, and had significantly higher total catches. Seven weak hooks were retrieved straightened, and one of these hooks was observed being straightened by a pilot whale. While not conclusive, such results suggest further research into weak hooks for the reduction of large animal bycatch in the pelagic longline fishery.

Belcher, C. N., & Jennings, C. A. (2011). Identification and evaluation of shark bycatch in Georgia's commercial shrimp trawl fishery with implications for management. *Fisheries Management and Ecology,* 18(2), 104-112. https://doi.org/10.1111/j.1365-2400.2010.00757.x

Many US states have recreational and commercial fisheries that occur in nursery areas occupied by subadult sharks and can potentially affect their survival. Georgia is one of few US states without a directed commercial shark fishery, but the state has a large, nearshore penaeid shrimp trawl fishery in which small sharks occur as bycatch. During our 1995-1998 investigation of bycatch in fishery-dependent sampling events, 34% of 127 trawls contained sharks. This bycatch totalled 217 individuals from six species, with Atlantic sharpnose shark, Rhizoprionodon terraenovae (Richardson), the most common and finetooth shark, Carcharhinus isodon (Muller & Henle) and spinner shark, Carcharhinus brevipinna (Muller & Henle), the least common. The highest catch rates for sharks occurred during June and July and coincided with the peak months of the pupping season for many species. Trawl tow speed and tow time did not significantly influence catch rates for shark species. Gear configurations [net type, turtle excluder device (TED), bycatch reduction device] affected catch rates for shark species. Results of this study indicate gear restrictions, a delayed season opening, or reduced bar spacing on TEDs may reduce shark bycatch in this fishery.

Bettis, S. (2017). *Shark Bycatch in Commercial Fisheries: A Global Perspective.* (Master of Science), Nova Southeastern University, Retrieved from https://nsuworks.nova.edu/cnso_stucap/331/

Many shark species have global distributions and are caught incidentally in different types of fisheries. Over the last two decades, shark populations have declined tremendously, with one of the leading causes of this decline bycatch in primarily teleost fisheries. Bycatch occurs throughout the world's fisheries, but is not well documented in terms of species composition and numbers of each species captured. Information on shark bycatch is spread through the primary and grey literature, but has not been compiled in summary to date. The goal of my capstone is to present global shark bycatch data and provide a comparative review to determine fishery types that affect shark populations and identify shark species at risk as a result of bycatch. Longline fisheries caught a larger variety of shark species, and the post-release mortality was generally low. In contrast, trawl fisheries caught mostly the same few species, but post-release mortality was extremely high. Blue sharks (Prionace glauca), silky sharks (Carcharhinus falciformis), and spiny dogfish (Squalus acanthias) were caught most often in trawl fisheries, and in large numbers that likely adds to risk of overexploitation of their populations. This literature review revealed a severe lack of standardization in bycatch data reporting by different fishing nations, and in documents prepared by management agencies and scientists, including the definition of bycatch used and the way it was recorded. Establishing a universal definition of bycatch and standardizing its reporting would vastly improve ability to assess the scale and composition of shark bycatch and its impacts on shark populations. Systematic and standardized accounting of shark bycatch would provide information helpful for collaboration among regulatory agencies. Rather than simply document bycatch, a number of fishing gear alterations show promise for bycatch reduction and are worthy of integration into fisheries by managers. Additional important steps that can improve bycatch assessment is increased observer coverage in fisheries, marine protected areas, and making bycatch data public.

Beutel, D., Skrobe, L., Castro, K., Ruhle, O'Grady, J., & Knight, J. (2008). Bycatch reduction in the Northeast USA directed haddock bottom trawl fishery. *Fisheries Research,* 94(2), 190-198. https://doi.org/10.1016/j.fishres.2008.08.008

We investigated the performance of a large mesh faced (upper and lower wings, side panels, first bottom belly) bottom trawl designed to capture haddock (Melanogrammus aeglefinus) while reducing the bycatch of cod (Gadus morhua) and other species. This experimental net, named the Eliminator Trawl (TM), was tested using two vessels, F/V Iron Horse and F/V Sea Breeze, in side-by-side catch comparison hauls with the currently regulated net. A total of 100 successful comparison tows were completed. All species captured were weighed for total weight. Haddock, cod, and the majority of the flounders were measured. The Eliminator Trawl (TM) significantly reduced the catch of stocks of concern including cod, yellowtail flounder (Limanda ferruginea), winter flounder (Pseudopleuronectes americanus), witch flounder (Glyptocephalus cynoglossus), and American plaice (Hippoglossoides platessoides). Other species such as monkfish (Lophius americanus) and skate (unclassified) also showed a significant decrease in catch in the Eliminator Trawl (TM). In addition, the catch of haddock, the target species, did not differ significantly between nets. The results of this study indicate that the Eliminator Trawl (TM) would be an efficient tool in gaining access to closed areas and used in recovery programs to exploit more abundant fish species. Examples in the Northeast USA include a B Days-at-Sea Program (DAS) as well as a Special Access Program (SAP) where the Eliminator Trawl (TM) appears to meet the minimum bycatch requirements to be considered for both these programs.

Beverly, S., Curran, D., Musyl, M., & Molony, B. (2009). Effects of eliminating shallow hooks from tuna longline sets on target and non-target species in the Hawaii-based pelagic tuna fishery. *Fisheries Research,* 96(2-3), 281-288. https://doi.org/10.1016/j.fishres.2008.12.010

A longline experiment consisting of 45 paired sets (90 sets total) was carried out to evaluate a technique which maintains target catch rates while reducing non-target catch rates. Control sets were compared to experimental sets which eliminates the shallowest hooks (similar to less than 100 m depth). Researchers hypothesized that by eliminating shallow hooks, target catch of deeper dwelling species such as bigeye tuna (Thunnus obesus) would be maximized while incidental catch of many other non-target, but marketable epi-pelagic species (e.g, billfish), bycatch (discards) of other fishes and elasmobranchs, and protected sea turtles and marine mammals would be simultaneously reduced. To control for differences in fishing power, gear, and deployment techniques: a single vessel was contracted to perform all 90 paired longline sets (45 experimental sets using no-shallow-hooks and 45 control sets using standard methods). Control sets consisted of longlines that were suspended by floats on typical 30m long floatlines in catenary-type shapes that fished a range of depths. determined by temperature-depth recorders (TDRs) to be 44-211 m (27.5-11.2 C). By contrast, elimination of shallow hooks in the upper 100m of the water column (hereinafter referred to as experimental sets) was achieved by suspending the fishing portion of the mainline on 75-m long, 3 kg weighted vertical sections of mainline suspended by floats on 30 m floatlines. As determined by TDRs, this arrangement ensured that all hooks fished at depths >100 m (103-248 m: 24.8-11.3 C). Thirty percent of hooks in control sets fished at depths less than 100 in while all hooks on experimental gear fished greater than 100 m. Because many factors influence catchability, longline sets are by nature multivariate, and statistical comparisons were made between the two set types using canonical discriminant analysis (CDA). Except for the depth of shallow hooks, operational characteristics between experimental and control sets were the same. The catch rates of bigeye tuna were similar on the two sets types but the catch rate of sickle pomfret (Taractichthys steindachneri) was significantly higher ($p = 0.011$) in the experimental sets as compared to control sets. However, statistically fewer wahoo (Acanthocybium solandri, $p = 0.019$), dolphinfish (Coryphaena hippurus, $p = 0.008$), blue marlin (Makaira nigricans, $p = 0.001$), striped marlin (Kajikia audax, $p = 0.018$) and shortbill spearfish (Tetrapturus angustirostris, $p = 0.006$) were captured on the experimental sets; thus longline interactions and impacts on these species were reduced with the experimental gear. The reason for the differences in catch rates between gear types is likely due to the vertical habitat preferences of the species involved; interactions with epi-pelagic species with shallow distributions in the uniform mixed layer were reduced by deploying hooks greater than 100 m. By logical extension, the experimental gear will also likely reduce interactions with sea turtles. Except for additional lead weights, floats, and floatlines, only slight modification of existing longline fishing gear and methods were required to deploy the experimental gear. The main drawback of this method was the increase in time to both deploy (approximate to 0.5 h) and retrieve (approximate to 2 h) the gear. Knowledge of species vertical distribution patterns can play an important role in modifying fishing gear to reduce bycatch and can also assist managers in regulating fishing practices with a higher degree of likelihood of predicting catch rates and species captured in different gea types.

, H., Powell, G., Yulianto, I., Simeon, B., Muhsin, Adrianto, L., & Milner-Gulland, E. J. (2022). Exploring cost-effective management measures for reducing risks to threatened sharks in a problematic longline fishery. *Ocean & Coastal Management,* 225, 106197. https://doi.org/10.1016/j.ocecoaman.2022.106197

Many shark and ray species (Class Chondrichthyes, herein 'sharks') are threatened by overfishing. Tackling this requires implementation of context-specific fisheries management measures, which are both technically effective and socio-economically feasible. Here we explore the cost-effectiveness of various input-oriented management measures for mitigating capture of seven priority shark taxa (i.e., threatened and CITES-listed species) in a small-scale longline mixed-species shark fishery in Indonesia, where there is a need to balance difficult trade-offs between conservation and socio-economic objectives. We apply Boosted Regression Trees (BRT) to analyse five years of landings and profit data, to identify and assess the relative influence of different plausible management measures (e.g., effort restrictions, gear restrictions, spatio-temporal closures). We then use predictive models to inform a semi-quantitative assessment of the hypothetical cost-effectiveness of these management measures, based on the estimated conservation benefits (reduced risk of capture of priority taxa) and socio-economic cost (relative profit foregone). Our results show that fishery closures in January–March, depth limits at <100 m, hook limits at <500 hooks, and gear restrictions on bottom longlines could have the greatest relative conservation impact for lowest profit foregone. However, there are clear trade-offs between taxa, with these measures primarily benefiting Critically Endangered bottlenose wedgefish (Rhynchobatus Australiae) and scalloped hammerheads (Sphyrna lewini), while potentially increasing pressure on Vulnerable silky sharks (Carcharhinus falciformis) and Endangered mako sharks (Isurus spp.). When shark fishing is important for economic welfare, and entire fishery closures or buy-outs are unfeasible, managing small-scale shark fisheries for multiple outcomes may require hard choices. This may require prioritising slow-growing Critically Endangered taxa for protection – by restricting fishing during seasons and at depths in which they are most susceptible to capture – while faster-growing taxa can continue to provide benefits for coastal communities.

Box, S. J., & Bonilla, R. S. (2009). *An Evaluation of Fishing Practices in the Small Scale Fisheries of the Golfo de Fonseca, Honduras. Recommendations for Management.* Retrieved from https://web.archive.org/web/20140712074615/http://www.utilaecology.org/assets/documents/Artes%20de%20Pesca%20en%20el%20Golfo%20de%20Fonseca%202009%20english_1.pdf

The artisanal and small scale fisheries within the Honduran Golfo de Fonseca underpin the local economy and are an essential livelihood within small coastal communities. As a mixed fishery, confined within the shallow waters and mangrove estuary of the Golfo de Fonseca, the fishermen exploit a range of demersal and bentho-pelagic fish species using gill nets, hook and lines and bottom set long lines. In addition to fish, shrimp are an important resource and are targeted with trammel and cast nets. In the absence of official statistics, anecdotal evidence suggests that all sectors of the fishery are in decline. This study aimed to assess whether unselective practices could be an important contributory factor to the purported decline and to identify management options that aim to increase the sustainability of the fishery. The study re-evaluated existing catch and length frequency data sets and collected new information during field work and through interviews with fishermen and other stakeholders. We found that fishing within the Golfo de Fonseca predominantly uses gears with broad selectivity. Over a third of the landed catch by weight is low grade, low value fish. There is currently no market incentive for selectivity with little price premium for fish size compared to total fish volume. Of extreme concern is that large proportions of fish of commercially valuable species were being landed at sizes below the size

of maturity. Within the group of the commercially most important fin fish, the “Babosas” (Cynoscion spp) the percentage of individuals within the landed catch that were below the estimated size at maturity ranged from 22 % (Babosa; C. squamipinnis) to 81 % (Corvina; C. reticulates). The majority of the landings of low value species and small sized individuals are mainly from the ubiquitous use of trammel nets that target shrimp. For every one pound of shrimp being landed, over five pounds of fin fish are also being landed. The sustainability of fin fishing is likely directly inhibited by the shrimp fishing. Since it is the same fishermen who are reliant on both resources integrating shrimp management and fish management is recommended. Rather than specifying changes in gear types which are unlikely to occur due to limitations in enforcement, a more feasible option based on current management capacity is to identify and instigate a closed season for shrimp fishing that corresponds to peak abundance of small individuals of commercial fish species that use the area as a nursery ground. This would help to minimise the incidental catch of undersize fish by trammel nets which currently reduces the economic efficiency and ecological sustainability of the fishery. In addition the study found that the extensive use of bottom set long-lining was likely to threaten the most ecologically vulnerable species found in the Golfo de Fonseca including the commercially important catfish Bagre pinnimaculatus and large pelagic species including sharks. Based on the precautionary principle of sustainable fisheries management, long lining within the gulf should be prohibited until their effect on these vulnerable species can be investigated. The lack of fishing selectivity was identified to be a clear problem in the Golfo de Fonseca fishery, however it is considered to be symptomatic of wider problems in the ecosystem and with the socioeconomic structure of the fishery as a whole. Other serious threats exist that are evidently going to affect sustainability, including the loss of critical habitat, water pollution and disruption in trophic webs that support the fish. From the perspective of gear selectivity, the current market structure rewards volume over quality and provides no incentive for using more selective methods of fishing. Addressing this problem first is necessary before any regulation in fishing methods will likely be successful.

Brcic, J., Herrmann, B., De Carlo, F., & Sala, A. (2015). Selective characteristics of a shark-excluding grid device in a Mediterranean trawl. *Fisheries Research,* 172, 352-360. https://doi.org/10.1016/j.fishres.2015.07.035

Galeus melastomus (blackmouth catshark) is often caught as bycatch in demersal trawls in the Mediterranean. In order to reduce bycatches of shark we tested an excluder grid with 90 mm bar spacing during experimental fishing in the Tyrrhenian Sea (Western Mediterranean). Data collected made it possible to simultaneously evaluate catch losses of two commercial species: Nephrops norvegicus (Norway lobster) and Phycis blennoides (greater forkbeard). The escape outlet ahead of the grid and the codend were both mounted with a cover in order to collect escaped fish ahead of the grid and through the codend meshes. We used a structural model to estimate the contribution of the individual selective processes consisting of the excluder grid and the size selective codend. The 90 mm excluder grid did not prove to be efficient in excluding G. melastomus, while it excuded more of P. blennoides. Catches of N. norvegicus were also affected by the presence of the grid, but not as much as the catches of other two species. The results obtained for the experimental grid + codend setup were then compared with the estimated selectivity for the "codend alone" setup. Furthermore, byway of explorative simulation with other grid bar spacing, we concluded that reducing the grid bar spacing to 70 mm would provide better compromise between the reduction of G. melastomus as bycatch and the catch rate of P. blennoides and N. norvegicus.

Brewer, D., Heales, D., Milton, D., Dell, Q., Fry, G., Venables, B., & Jones, P. (2006). The impact of turtle excluder devices and bycatch reduction devices on diverse tropical marine communities in Australia's northern prawn trawl fishery. *Fisheries Research,* 81(2-3), 176-188. https://doi.org/10.1016/j.fishres.2006.07.009

In 2001, paired-trawl comparisons were made during prawn trawl operations to assess the effect of turtle excluder devices and bycatch reduction devices on a range of species groups caught in tropical Australia. This study is one of the first to evaluate the commercial use of these devices in a tropical fishery. Nets with a combination of a turtle excluder device and bycatch reduction device reduced the catches of turtles by 99%, seasnakes by 5%, sharks by 17.7%, rays by 36.3%, large sponges by 85.3%, and small bycatch by 8%, however, these results were largely attributable to the influence of the turtle excluder devices. Nets with both devices also reduced the catch of commercially important prawns by 6%, but the proportion of soft and damaged prawns was reduced by 41%. The combination of these devices had no measurable impact on catches of any of the three byproduct species groups: Thenus spp. (Moreton Bay bugs), Teuthoidea spp. (squid) and Amusium pleuronectes (scallops). Turtles excluder devices reduced the numbers of larger sharks and rays (> 1 m) by 86% and 94%, respectively. They did not reduce the total number of sawfish caught, but did reduce the number of the most commonly caught species - the narrow sawfish (Anoxypristis cuspidata) - by 73.3%. Upward- and downward-excluding turtle excluder devices performed about equally for most species groups, although upward excluders were more effective for sharks and less effective for large sponges. The performance of BRDs was poor for most groups and could be improved by using them in more effective positions such as closer to the codend catch. The use of these devices is a major step towards ensuring the long-term conservation of many species, especially endangered sea turtles and vulnerable elasmobranchs. As fishers become more experienced in their use, we are optimistic that the fishery's impact on bycatch will reduce even further.

Brill, R., Bushnell, P., Smith, L., Speaks, C., Sundaram, R., Stroud, E., & Wang, J. (2009). The repulsive and feeding-deterrent effects of electropositive metals on juvenile sandbar sharks (Carcharhinus plumbeus). *Fishery Bulletin,* 107(3), 298-307. Retrieved from https://spo.nmfs.noaa.gov/content/repulsive-and-feeding-deterrent-effects-electropositive-metals-juvenile-sandbar-sharks

Reducing shark bycatch and depredation (i.e., damage caused by sharks to gear, bait, and desired fish species) in pelagic longline fisheries targeting tunas and swordfish is a priority. Electropositive metals (i.e., a mixture of the lanthanide elements lanthanum, cerium, neodymium, and praseodymium) have been shown to deter spiny dogfish (Squalus acanthias, primarily a coastal species) from attacking bait, presumably because of interactions with the electroreceptive system of this shark. We undertook to determine the possible effectiveness of electropositive metals for reducing the interactions of pelagic sharks with longline gear, using sandbar sharks (Carcharhinus plumbeus, family Carcharhinidae) as a model species. The presence of electropositive metal deterred feeding in groups of juvenile sandbar sharks and altered the swimming patterns of individuals in the absence of food motivation (these individuals generally avoided approaching electropositive metal closer than similar to 100 cm). The former effect was relatively short-lived however; primarily (we assume) because competition with other individuals increased feeding motivation. In field trials with bottom longline gear, electropositive metal placed within similar to 10 cm of the hooks reduced the catch of sandbar sharks by approximately two thirds, compared to the catch on hooks in the proximity of plastic pieces of similar dimensions. Electropositive metals therefore appear to have the potential to reduce shark interactions in pelagic

longline fisheries, although the optimal mass, shape, composition, and distance to baited hooks remain to be determined.

Broadhurst, M. K., & Tolhurst, D. J. (2021). Null effects of decomposing shark tissue on baited-hook catches of elasmobranchs. *Regional Studies in Marine Science,* 46, 101898. https://doi.org/10.1016/j.rsma.2021.101898

The effects of decomposing shark tissue on catches of benthic longlines targeting various carcharhinids were assessed to inform possible use as a semiochemical shark deterrent. During 15 nights fishing, four benthic longlines (each comprising 18–30 hooks baited with mullet, Mugil cephalus) were deployed to 12–56 m overnight for 12–21 h off eastern Australia. Two of the longlines had 2.0–3.0 kg of decomposing shark tissue placed into porous cylindrical canisters (520 × 105 mm polyvinyl chloride) secured to the mainline mostly between every three hooks (15–20 m apart), while the other two longlines had empty canisters. In total, 150 fish were caught, comprising 14 species of elasmobranchs and especially tiger sharks, Galeocerdo cuvier (31% of total). The decomposing shark tissue in the canisters had no effects on catches of any species or groups, with variability among most attributed to fishing depth (positive relationship) and also soak time (negative) for carcharhinids and G. cuvier. Irrespective of the contents of the canisters and the lack of any semiochemical effects, there was some evidence of fewer sharks caught on adjacent hooks as moonlight increased, and possibly because of a visual response. There was no depredation of any decomposing shark tissue in the canisters, but three juvenile hooked sharks were substantially depredated, and presumably by larger individuals. Most (~70%) of the remaining hooked sharks survived. While this study showed no repelling effects of decomposing shark tissue, the conclusions are restricted to the experimental conditions, including the source of tissue and the distance between hooks, which might be used as upper limit in any future work assessing for effects.

Carruthers, E. H. (2012). *Ecological and societal context of catch and discards: identifying opportunities for bycatch mitigation in swordfish and tuna pelagic longline fisheries.* (Ph.D.), Memorial University of Newfoundland, Retrieved from http://research.library.mun.ca/id/eprint/6095

Bycatch, defined here as catch discarded for regulatory, economic or personal reasons, from pelagic longline fisheries has contributed to wide spread population declines of sharks and sea turtles. Opportunities to reduce impacts in these fisheries occur throughout the fishing process and depend upon the fishing practices within fleets, and upon the behaviour of target and bycatch species. The overall objective of this thesis was to identify bycatch mitigation opportunities within the Canadian Atlantic pelagic longline fishery, which targets swordfish (Xiphias gladius), warm-water tunas (bigeye, Thunnus obesus; yellowfin T. albacares; and albacore, T. alalunga) and mahi-mahi (Coryphaena hippurus). Bycatch includes common sharks and rays (blue shark, Prionace glauca; pelagic stingray, Pteroplatytrygon violacea), and endangered sea turtles (leatherback Dermochelys coriacea; loggerhead, Caretta caretta). Bycatch mitigation approaches such as shifting to circle hooks, increased the likelihood that shark bycatch would be released alive and with less severe hooking injuries. Shorter longline soak times also increased hooking survival among most of the common bycatch species. Shorter soak times would not decrease catch of the most common landed species (swordfish), but this shift in fishing practices could negatively impact fisher safety. Interviews with active longline captains revealed operational difficulties and unintended ecological impacts with proposed bycatch mitigation approaches. Longline captains also reported innovative uses of bycatch mitigation tools that could

increase post-release survival of common bycatch species in this and other pelagic longline fleets. Finally, the combined analysis of fisheries observer data, qualitative data from fishers' knowledge interviews, and concurrent environmental data suggested that high blue shark catch rates were related to local oceanography - and did not reflect behavioural differences between blue shark and swordfish. Clearly, there are opportunities for bycatch mitigation within the Canadian pelagic longline fishery for swordfish and tunas. However, the process of interviewing pelagic longline captains revealed both interest in reducing bycatch, but also suspicion of research efforts. Such trust issues will need to be addressed in subsequent research as the combined use of fishery assessments, detailed oceanographic data, practical fishing knowledge, and on-the-water observations will be needed to decrease the amount of and harm to discarded bycatch.

Carruthers, E. H., Schneider, D. C., & Neilson, J. D. (2009). Estimating the odds of survival and identifying mitigation opportunities for common bycatch in pelagic longline fisheries. *Biological Conservation,* 142(11), 2620-2630. https://doi.org/10.1016/j.biocon.2009.06.010

To evaluate how fishing practices affect bycatch survival and to identify opportunities to reduce bycatch mortality, we estimated the odds of hooking survival for common bycatch species in the Canadian long-line fishery for swordfish (Xiphias gladius) and tunas (Thunnus spp.) fishing in the North Atlantic. Generalized linear models, with binomial response, were based on 859 sets observed between 2001 and 2004 and were tested using data from 2005 and 2006. Bycatch included targeted species in poor condition or below regulatory size limits. Odds of survival were two to five times higher for swordfish, yellowfin tuna (Thunnus albacares), pelagic stingray (Pteroplatytrygon violacea), porbeagle (Lamna nasus) and blue shark (Prionace glauca) caught on circle hooks compared to J-hooks during the 2001-2004 period. Further, odds of severe hooking injuries decreased for three shark species caught on circle hooks. We found no conservation benefit for loggerhead turtles (Caretta caretta) from circle hook use. Increased circle hook use coincided with increased targeting and higher landings of tunas. Hooking survival rates and, therefore opportunities to reduce bycatch mortalities differed among the 10 species commonly discarded or released. Where the odds of survival to the time of release are high (e.g., loggerhead turtles, pelagic stingray, blue shark), methods to reduce post-release mortality can be considered. Where the odds of hooking survival are low (e.g., swordfish and longnose lancetfish, Alepisaurus ferox). methods to reduce encounter rates would have greater conservation impact.

Chosid, D. M., Pol, M., Szymanski, M., Mirarchi, F., & Mirarchi, A. (2012). Development and observations of a spiny dogfish Squalus acanthias reduction device in a raised footrope silver hake Merluccius bilinearis trawl. *Fisheries Research,* 114, 66-75. https://doi.org/10.1016/j.fishres.2011.03.007

A spiny dogfish Squalus acanthias excluder grate (grid) within the extension of a silver hake (whiting) Merluccius bilinearis trawl net was designed and tested in Massachusetts Bay, USA between October 2008 and August 2009 using a live-fed underwater video camera. Grates with 50mm spacing were investigated for effects from color (white or black), angle, and direction (leading to a top or bottom escape vent). Spiny dogfish numbers were greatly reduced for all gear configurations based on video observations and data collected from the codend, while target species were caught in commercial quantities. Four tows (of various gear configurations) resulted in spiny dogfish blockages in front of the grate. The reduction of spiny dogfish led to increases in the quality of marketable catches, likely reductions in non-target species mortality, and decreases in the codend catch handling times.

Christensen, C. (2014). *Opportunities for the Reduction of Skate Bycatch in Atlantic Canada Trawl Fisheries: A Case Study of two Innovative Trawl Gear Designs.* (Master of Marine Management), Dalhousie University, Retrieved from http://hdl.handle.net/10222/56203

Skates are fish under the Subclass of elasmobranchii, typically found in temperate or arctic waters. Catch of skates pose a number of issues for fishers as bycatch including increased handling effort, reduced value of target catch, and clogging of gear. Discarding of skates in Canadian trawl fisheries has led to significant declines in the abundance of a number of skate species. The Eliminator TrawlTM, designed in the US has shown success in reducing the catch of skates and other groundfish. Similarly, the Radial Escape Section trawl gear has also proven useful in reducing bycatch of larger fish. The ability of either gear to reduce catch of groundfish is key to aiding in the recovery of a number of groundfish species currently under moratorium. Specifically, use of the Eliminator TrawlTM is promising given its success with reducing bycatch both in benthic and pelagic trawls. A pilot project testing these gears at-sea and benefiting from fishers' knowledge of the fishery is an ideal first step towards use of either of these trawls and the recovery of threatened skates populations.

Clarke, S., Sato, M., Small, C., Sullivan, B., Inoue, Y., & Ochi, D. (2014). Bycatch in longline fisheries for tuna and tuna-like species: a global review of status and mitigation measures. *FAO Fisheries And Aquaculture Technical Paper* (588), 217. Retrieved from http://www.fao.org/3/a-i4017e.pdf

This publication is the third in a series on bycatch in global tuna fisheries. Dealing with longline fisheries, its scope is defined taxonomically to comprise only non-tuna and non-tuna-like species. The history of longline fishing illustrates the role of new technologies, the expansion of fishing grounds, and the operational characteristics of the fleets in shaping today's fishery. More recently, management regulations, the price of oil, the cost of labour, and market demand have also exerted an influence. No more than 23 percent of the tuna in each ocean is longline-caught. However, there may be up to 7 500 tuna longliners globally with almost 60 percent of them less than 24 m in length. Available data suggest that elasmobranch catches have fallen 14 percent since their peak in 2003. In longline fisheries, shark catch rates may be determined by bait type, soak time, hook shape, leader length and material, depth at which the hook is fished, and whether special gear is deployed to target sharks. Vulnerability to hooking, and resilience to haulback and handling, vary by species, size, area and fleet operational practices. Tuna regional fisheries management organizations (t-RFMOs) assess the status of shark populations but data limitations often hinder firm conclusions. There is little information on the implementation or effectiveness of finning bans and no-retention measures. Mitigation measures have been tested but results vary. Six of the seven species of sea turtles are threatened with extinction, and while longline fisheries may have less impact than net-based fisheries, significant population level impacts may be occurring in some regions. The greatest concern is associated with loggerhead-longline interactions in the Atlantic. Circle hooks and using finfish bait have proved effective mitigation techniques either by reducing hooking or hook swallowing. Other methods require further development. Interactions with pelagic longline fisheries kill 50 000-100 000 seabirds annually. Many of these species, particularly albatrosses, are threatened with extinction. Recent advances in tracking technologies have facilitated mapping of where interactions are most likely. The Western and Central Pacific contains more than 45 percent of the global total albatross and giant petrel breeding distributions. The most promising mitigation methods appear to be night setting, side-setting, line weighting and streamer lines, but further research is needed. All five t-RFMOs require use of one or more of these methods in areas that overlap albatross distributions. However, compliance data are limited and improved observer coverage is essential. Marine mammals' interactions with longline fisheries are detrimental to the fishery but may

be positive or negative for the mammals. Although it is often unclear which species are involved, pilot whale interactions in the western Atlantic and false killer whale interactions off Hawaii have triggered national mitigation plans. No t-RFMO has adopted management measures for marine mammal interactions. Research and testing of mitigation measures continue in order to ameliorate both marine mammal impacts and economic losses to industry from depredation. At least 650 species of other bony fishes may be caught in association with pelagic longline fisheries, e.g. dolphinfish, opah, oilfish, escolar and ocean sunfish. Some of these stocks are important as local food supplies. However, it is unclear whether these stocks or the ecosystem they help structure is at risk. More attention should focus on improving fishery statistics and initiating basic monitoring of these stocks' status. The diversity of pelagic longline gear designs and fishing methods, the variety of habitats they are deployed in, the thousands of marine species they may interact with, and the different mechanisms and behaviours that govern those interactions provide an array of topics to be addressed in any discussion of bycatch mitigation. Scientific and technical issues in mitigation including effects across taxa, effects of combinations of measures, economic and safety considerations, underlying biological mechanisms, handling and post-release mortality, and non-fishery impacts must all be addressed. In addition, it is also necessary to consider issues such as who takes the lead for ensuring mitigation is sufficient for the population as a whole, how to devise effective mitigation implementation strategies, and whether gear modification should be used in concert with more sweeping measures.

Coelho, R., Santos, M. N., & Amorim, S. (2012). Effects Of Hook And Bait On Targeted And Bycatch Fishes In An Equatorial Atlantic Pelagic Longline Fishery. *Bulletin of Marine Science,* 88(3), 449-467. https://doi.org/10.5343/bms.2011.1064

We examined the effects of different hook style and bait type combinations on the catches of targeted, bycatch, and discarded fishes in equatorial Atlantic waters. In total, 221 longline sets (>305,000 hooks) were deployed from Portuguese pelagic longline vessels (SELECT-PAL Project) during the February October fishing season. Three different hook styles and two bait types were tested: the traditional J-hook was compared to two circle hooks (one non-offset and one with 10 offset), and squid bait was compared to mackerel. Catch per unit effort (CPUEs) were calculated and compared between the different hook style and bait type combinations, which indicated that the effects of hook style and bait on the CPUEs were species-specific. For example, swordfish CPUEs were higher with J-hooks baited with squid, while for targeted tunas and blue shark only the bait effect was significant, but with opposite effect (i.e., higher catches of tuna with squid bait and higher catches of blue shark with mackerel bait). For the discarded species, at-haulback mortality was also species-specific. Proportions of alive vs dead specimens at time of fishing gear retrieval did not vary significantly by hook style or bait type combinations. The total retained catch was analyzed in value per unit effort (VPUE), and indicated losses in fishery revenue when mackerel was used instead of squid, but not when circle hooks were used instead of J-hooks.

Cosandey-Godin, A., & Morgan, A. (2011). *Fisheries bycatch of sharks: Options for mitigation.* Pew Environment Group, Washington, DC. Retrieved from https://www.sarri.org/storage/app/media/tools_pdfs/PewOSSsharkbycatchreviewpdf.pdf

Bycatch (see definition below) is one of the most significant issues in the management and conservation of global fisheries (Hall et al. 2000, Kelleher 2005, Lewison et al. 2004) and has been identified as one of the leading causes of shark population declines. Sharks are susceptible to high fishing mortality rates

because of their life history characteristics, which include slow growth, late ages at maturity, and the production of a limited number of young over a lifetime (Cortes 2002, Heppell et al. 1999, Cortes 1999). In addition, research has shown that several species of sharks have very high rates of mortality associated with the fishing process (Morgan and Burgess 2007, Mandelman et al. 2008), and it has been estimated that species such as sandbar shark (Carcharhinus plumbeus) (Sminkey and Musick 1994, Cortes 1999) and dusky shark (Carcharhinus obscurus) (Simpfendorfer 1999) increase their population sizes so slowly that they are considered particularly vulnerable to mortality from fishing activities (Musick et al. 2000a). For example, Cortes et al. (2006) found that if fishing for dusky shark stopped for 30 years, their population in the Northwest Atlantic would still be depleted. Over the past two decades, serious population declines have been reported for a number of shark species in several regions around the world (Baum et al. 2003, Ferretti et al. 2008, Robbins et al. 2006, Ferretti et al. 2010, Clarke 2011) and are attributed to both targeted and incidental capture. According to the International Union for Conservation of Nature (IUCN) and other sources, bycatch is one of the primary threats facing sharks (Musick et al. 2000b, Lewison et al. 2004). Despite widespread recognition of shark bycatch issues (Food and Agriculture Organization [FAO] 1999; FAO 2010), few mitigation actions have been established, and there are no clear guidelines about which mitigation actions would be most effective. In addition, there are very few management measures requiring actions to mitigate shark bycatch. However, it is clear that managers and fishermen must aim to reduce both bycatch rates and the harmful effects from bycatch (e.g., injuries from capture on fishing gear). Based on the best available information, this review provides a summary of the current knowledge and understanding of shark bycatch and discusses available management options and technical measures aimed at reducing both the rate at which sharks encounter fishing gear and the associated damaging effects.

Courtney, A. J., Haddy, J. A., Campbell, M. J., Roy, D. P., Tonks, M. L., Gaddes, S. W., . . . Taylor, J. (2007). *Bycatch weight, composition and preliminary estimates of the impact of bycatch reduction devices in Queensland's trawl fishery*. Queensland Department of Primary Industries and Fisheries Retrieved from https://www.daf.qld.gov.au/__data/assets/pdf_file/0003/49836/BycatchFinalReport2007-FullReport-part1-Sections1to4.pdf

This report provides quantitative information on the effects of turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) on the catch rates of bycatch, prawns, scallops and byproduct species, such as Moreton Bay bugs and Balmain bugs, in Queensland's major trawl fishing sectors. It also provides biological information on, and management advice for several species referred to in the Fishery Management Plan as the permitted species. Several recommendations are included for reducing bycatch in the trawl fishery and for sustaining stocks of the permitted species.

Courtney, J., Courtney, Y. e., & Courtney, M. (2014). Review of Magnetic Shark Deterrents: Hypothetical Mechanisms and Evidence for Selectivity. *Aquatic Science and Technology,* 3(1). https://doi.org/10.5296/ast.v3i1.6670

Several papers published since 2006 describe effects of magnetic fields on elasmobranchs and assess their utility in reducing negative interactions between sharks and humans, including bycatch reduction. Most of these repeat a single untested hypothesis regarding physical mechanisms by which elasmobranchs detect magnetic fields and also neglect careful consideration of magnetoreception in teleosts. Several species of teleosts are known to have magnetoreception based in biogenic magnetite,

and direct magnetic field detection also has support in several species of elasmobranchs. The overly narrow focus of earlier papers on the unsupported hypothesis that magnetoreception in elasmobranchs is based in the ampullae of Lorenzini creates the impression that all teleosts will be insensitive to magnetic deterrents. However, magnetite based magnetoreception has been demonstrated in several teleosts, and is supported in others. Furthermore, electroreception is present in many teleost species; therefore, the possibility of induction based indirect magnetoreception should be considered. Finally, experiments reported as demonstrating insensitivity in teleost species to magnetic deterrents suffer from inadequate design and sample sizes to reject the hypothesis of magnetic detection in any given species. Since adoption of deterrent hook technologies depends on both deterrent effects in sharks and the absence of effects in target teleosts, the hypothesis of detection in teleost species must be independently tested with adequate sample sizes.

Curran, D., & Bigelow, K. (2011). Effects of circle hooks on pelagic catches in the Hawaii-based tuna longline fishery. *Fisheries Research,* 109(2), 265-275. https://doi.org/10.1016/j.fishres.2011.02.013

Sixteen vessels within the deep-set Hawaii-based tuna longline fleet tested the catch efficacy, fish size selectivity and survival on longline retrieval of large-size 18/0 circle hooks vs. Japanese style tuna hooks, size 3.6 sun and vs. size 9/0 “J” hooks. Vessels alternated hook types throughout the longline gear and maintained a 1:1 ratio of circle hooks to their existing tuna or J-hooks. Observers monitored a total of 1393 sets; 1182 sets were circle hooks vs. tuna hooks and 211 sets were circle hooks vs. J-hooks. The 18 most-caught species were analyzed representing 97.6% of the total catch by number. Two statistical methods were used to assess differences in catch (randomization test) or catch rate (generalized linear mixed models (GLMMs)). There were no significant catch or catch rate (catchability) differences among hook types for bigeye tuna (Thunnus obesus), the primary target species, with either statistical method. However, GLMMs indicated that catch rates on circle hooks were significantly lower for 16 and 8 species compared to tuna and J-hooks, respectively. There were no significant differences in mean length of bigeye tuna among hook comparisons. Caught condition at retrieval varied considerably among the 18 species. Large circle hooks had greater effects on catch rates than on fish size selectivity and fish survival. We contend that reduced catch rates are a function of 18/0 circle hook shape, where the minimum width (4.9cm) was 57% and 25% wider than the Japanese tuna (3.1cm) and J-hook (3.9cm), respectively. In contrast to tuna hooks, large circle hooks have conservation potential for use in the world's pelagic tuna longline fleets for some highly migratory species, with catch rate reductions of 29.2–48.3% for billfish species and 17.1–27.5% for sharks.

Das, D., Gonzalez-Irusta, J. M., Morato, T., Fauconnet, L., Catarino, D., Afonso, P., . . . Giacomello, E. (2022). Distribution models of deep-sea elasmobranchs in the Azores, Mid-Atlantic Ridge, to inform spatial planning. *Deep-Sea Research Part I-Oceanographic Research Papers,* 182. https://doi.org/10.1016/j.dsr.2022.103707

Elasmobranchs inhabiting depths beyond 200 m are extremely susceptible to overexploitation but are extracted by fisheries around the world either as target species or as bycatch. There is little information available to formulate management strategies to reduce elasmobranch-fishery interactions in the deep sea. In European Union waters, prohibiting the catches of deep-sea elasmobranchs has provided the necessary impetus to study bycatch avoidance of these threatened species. We used over 20 years of fisheries-independent and fisheries-dependent data to model the spatial distribution of 15 species of

deep-sea elasmobranchs (12 sharks and 3 rays) captured frequently in the Exclusive Economic Zone of the Azores Archipelago (Mid-Atlantic Ridge) to explore spatial management to reduce unwanted catches of these species. We applied Generalised Additive Models to predict the probability of presence of 15 species, as well as the abundance of 6 of those species, within the Azores EEZ and neighbouring seamounts (up to 2000 m depth), using environmental and operational variables as predictors. Our results identified that depth is most influential in determining the distribution of these sharks and rays, in addition to seafloor topography. Distinctive bathymetric features such as seamounts and ridges were highlighted as areas where the probability of presence of the greatest number of species overlapped. Although not related to habitat, gear type influenced the capture probability of certain species, with the artisanal handline, gorazeira, having lower captures than bottom longline. Our results support using depth-based, area-based, and gear-based tactics to design management measures to reduce elasmobranch bycatch, for more sustainable deep-sea fisheries.

Domingo, A., Pons, M., Jimenez, S., Miller, P., Barcelo, C., & Swimmer, Y. (2012). Circle Hook Performance In The Uruguayan Pelagic Longline Fishery. *Bulletin of Marine Science,* 88(3), 499-511. https://doi.org/10.5343/bms.2011.1069

Circle hooks have been promoted as an alternative to traditional J-hooks in pelagic longline fisheries to minimize bycatch mortality and injury to sea turtles and other marine wildlife. We evaluated the effect of hook type (circle hook vs J-hook) on the catch and length composition of target and non-target species in the Uruguayan pelagic longline fishery, for both American- and Spanish-style longlines. The sample unit used for comparing catches was two consecutive sections of the longline, each with a different hook type. For the American-style longline 39,822 hooks were deployed in 108 paired sections, and for the Spanish-style 45,142 hooks were deployed in 238 paired sections. The catch of albacore tuna, Thunnus alalunga (Bonnaterre, 1788), was higher with circle hooks with both gears. The catch of shortfin mako shark, Isurus oxyrinchus (Rafinesque, 1810), also increased with the use of circle hooks, but only with the American-style longline. A decrease was observed in the catch of pelagic stingray, Pteroplatytrygon violacea (Bonaparte, 1832), with both gears, though it was significant only with the Spanish-style longline. The performance of circle hooks for other target species, such as swordfish, Xiphias gladius (Linnaeus, 1758), and sharks, and for bycatch species including sea turtles and seabirds remains unclear and requires further research.

Duarte, D. L. V., Broadhurst, M. K., & Dumont, L. F. C. (2019). Challenges in adopting turtle excluder devices (TEDs) in Brazilian penaeid-trawl fisheries. *Marine Policy,* 99, 374-381. https://doi.org/10.1016/j.marpol.2018.10.048

The incidental capture and mortality of endangered, threatened and protected (ETP) marine species remains a global problem. Among the most problematic fishing methods is penaeid trawling, which is responsible for one quarter of the world's discarded bycatch and remains a key threatening process to ETP species (turtles and some elasmobranchs). So-called 'turtle excluder devices' (TEDs) legislated among USA penaeid trawlers and subsequently fleets in other countries during the 1990s alleviated some concerns over impacts to ETP species, but adoption has not been global. One country characterised by resistance to TEDs is Brazil—despite federal legislation mandating usage for almost 25 years. The reasons for this deficit, reiterated here via interviews with 64 southern penaeid-trawler captains, are threefold. First, are perceived issues with mandated designs and minimal third-party expertise, leading to a sustained misconception that TEDs simply do not work in Brazilian penaeid

trawls. Second, is the perpetuated belief of minimum negative impacts to ETP species; exacerbated by few quantitative data. Third, is jurisdictional failure to promote the concept that slight economic loss associated with not catching ETP species (elasmobranchs) is necessary for broader ecological sustainability. We propose TED use among Brazilian penaeid-trawl fisheries might be promoted via a co-management strategy facilitated by sustained education and technical expertise from research providers encouraging fishers to develop fishery-specific solutions. If industries can be encouraged to accept the concept of TEDs, they might then be expected to refine and develop ownership of the most appropriate configurations.

Duarte, D. L. V., Broadhurst, M. K., Ortega, I., Pias, B. S., & Dumont, L. F. C. (2018). Quantifying the morphology of key species caught in the southern Brazilian penaeid-trawl fishery as a precursor to improving selection. *Latin American Journal of Aquatic Research,* 46(4), 799-809. https://doi.org/10.3856/vol46-issue4-fulltext-17

Penaeid trawls are poorly selective fishing gears; contributing towards approximately 27% of global marine fisheries discards. Various options are available for mitigating penaeid-trawl bycatch, including gear modifications such as 'bycatch reduction devices' (BRDs) or codend mesh-size regulations. A precursor to developing modifications is information about the key target and bycatch species in terms of their sizes and morphology. Here we describe the relationships between these characteristics for the southern Brazilian industrial penaeid-trawl fishery within a broader objective of proposing more selective trawl configurations. Catches were sampled during 37 tows. Fifty-two species were caught, including two loggerhead turtles, Caretta caretta, one green turtle, Chelonia mydas, as well as 61 individuals of seven ray species classified as Endangered or Critically Endangered. One penaeid (Pleoticus muelleri) and 11 teleosts were assessed for various morphological relationships. The data demonstrated that both the existing conventionally used 26 mm (stretched mesh opening; SMO) mesh and a legislated size of 30 mm SMO are too small. Using morphological relationships, we propose testing a minimum diamond-shaped mesh size of at least 35 mm and a square-mesh window in the top of the codend comprising at least 48 mm mesh. Such a configuration would probably retain penaeids and larger teleosts, but allow many small teleosts to escape. Anteriorly located grids are also required to reduce the bycatch of charismatic species like turtles and rays. Wide-scale use of such BRDs should considerably reduce bycatches and the ancillary impacts of regional penaeid-trawl fisheries.

Fakioglu, Y. E., Ozbilgin, H., Gokce, G., & Herrmann, B. (2022). Effect of ground gear modification on bycatch of rays in mediterranean bottom trawl fishery. *Ocean & Coastal Management,* 223. https://doi.org/10.1016/j.ocecoaman.2022.106134

Bycatch of rays and skates in towed fishing gears represents one of the major threats to these relatively slow growing marine species. The objective of this study was to modify ground gear in a bottom trawl fishery to increase the escape of these species during towing without associated loss of target catch. Sea trials were carried out with a research vessel in Mersin Bay, North-eastern Mediterranean. Experimental ground gear was modified by cutting the rigging twine between the fishing line and the footrope in the central part of the ground gear. Capture of three unwanted bycatch species were estimated. The probability of capture of guitarfish (Rhinobatos sp.) and common stingray (Dasyatis pastinaca) was significantly reduced to 8% and 20% for guitarfish and stingray, respectively compared to standard ground gear. The results for spiny butterfly ray (Gymnura altavela) were inconclusive due to the wide confidence intervals. Further, the catch comparison results for five out of six target species investigated

did not show significant reduction in catch efficiency when using experimental gear compared to the standard trawl. Only for common sole (Solea solea) the modified trawl had significantly lower catch efficiency than the standard trawl. We believe that this technical measure for reducing unwanted bycatch in bottom trawls has a potential to be adopted by the fishery due to being an efficient, low-cost measure which does not create additional challenges during handling of the gear.

Favaro, B., & Cote, I. M. (2015). Do by-catch reduction devices in longline fisheries reduce capture of sharks and rays? A global meta-analysis. *Fish and Fisheries,* 16(2), 300-309. https://doi.org/10.1111/faf.12055

By-catch in marine fisheries, particularly those using pelagic and demersal longlines, is a major driver of declines in abundance of sharks and rays around the world. A wide variety of by-catch reduction devices (BRDs), that is, modified gears designed to reduce incidental captures of a variety of marine species while maintaining target catch rates, have been proposed, but the extent to which BRDs actually reduce the risk of catching sharks and rays remains unclear. We performed a meta-analysis of 27 publications that reported the capture of sharks and rays and, in some cases, of targeted teleosts in longline gear deployed with and without BRDs. The risk of shark and ray capture differed between types of BRDs, but only one BRD type, longlines raised off the bottom, reduced by-catch significantly. Circle hooks did not reduce the risk of capturing sharks and rays but might improve discard survival and are inexpensive, which might make them effective in reducing the detrimental effects of longlining on these species. In addition to being generally ineffective, some devices, such as electropositive and magnetic repellents, are expensive and have inherent construction drawbacks that are likely to make them unsuitable for commercial use. Overall, most BRDs did not affect the likelihood of catching targeted teleosts, but a substantial number of studies did not adequately assess target catch. We identified two poorly studied classes of BRD gear (i.e. raised demersal longlines, and monofilament nylon leaders), which represent promising directions for future research.

Fennessy, S. T., & Isaksen, B. (2007). Can bycatch reduction devices be implemented successfully on prawn trawlers in the Western Indian Ocean? *African Journal of Marine Science,* 29(3), 453-463. https://doi.org/10.2989/ajms.2007.29.3.12.342

Bycatch reduction devices (BRDs) are increasingly being used in prawn trawl fisheries worldwide. This paper describes an experiment with a Nordmore grid and a square-mesh panel on a prawn trawler off Mocambique. Although numbers of hauls that caught elasmobranchs were low, 75% of hauls with grids caught fewer large rays than those without grids; hauls using grids caught no large sharks at all. In its final configuration, the grid respectively reduced prawn, discard and retained fish catches by 5%, 25% and 32% relative to control hauls; the square-mesh panel increased prawn catches by 3% and respectively reduced discard and retained fish catches by 23% and 18% relative to control hauls. Changes in prawn catches were not statistically significant; however, when the grid and the square-mesh panel were used together, they reduced prawn, discard and retained fish catches by 25%, 47% and 26% respectively relative to control hauls (all significant except for retained fish catches). Overall, the Nordmore grid successfully released large elasmobranchs, and the grid and the square-mesh panel individually reduced bycatch without reducing prawn catches. In combination, the two BRDs also reduced bycatch, but at the cost of substantially reduced prawn catches. The results indicate that there is scope for the wider use of BRDs on prawn trawlers in the Western Indian Ocean region, although this would require increased support from management agencies and industry.

Fernandez-Carvalho, J., Coelho, R., Santos, M. N., & Amorim, S. (2015). Effects of hook and bait in a tropical northeast Atlantic pelagic longline fishery: Part II-Target, bycatch and discard fishes. *Fisheries Research,* 164, 312-321. https://doi.org/10.1016/j.fishres.2014.11.009

The incidental bycatch of sea turtle in tuna and swordfish fisheries is currently recognized as one of the major threats to the populations of these species. Therefore a number of mitigation measures have been tested, particularly for longline fisheries targeting swordfish. As mitigation measures may also affect the fish catches, it is important to quantify these impacts both at the ecological and socio-economic levels. Between August 2008 and December 2011, a total of 202 experimental pelagic longline sets were carried out in the Tropical Northeast Atlantic Ocean. The combination J-hook baited with squid (traditionally used by the fishery) was compared against two circle hooks (one non-offset and one with 100 offset) and mackerel bait. Catches per unit effort (CPUE) were calculated and compared between the different hook style and bait combinations for all target, bycatch and discarded fish species. In addition, a GLM (generalized linear model) was applied for swordfish Xiphias gladius and blue shark Prionace glauca (two main target species) and bigeye thresher Alopias superciliosus (most discarded species). The swordfish catches were negatively affected when changing from the traditional gear (J-style hooks baited with squid) to one of the experimental combinations, with the bait type having a stronger influence than the hook style on this reduction. However, the overall target species CPUE and the value of the retained catch (VPUE, value per unit of effort) were not significantly affected, due to an increase on the blue shark CPUE. Furthermore, the hook style and the bait type did not seem to influence the at-haulback mortality rates of most discarded species, which were highly species-specific. Given the apparent lack of impact on the overall value of the retained catch, the use of circle hooks baited with mackerel on this particular fishery and region would be highly beneficial for sea turtle conservation, without affecting the economic viability of the fishery.

Filmalter, J. D., Bauer, R. K., Forget, F., Cowley, P. D., & Dagorn, L. (2021). Movement behaviour and fishery interaction of silky sharks (Carcharhinus falciformis) in the tropical tuna purse seine fishery in the Western Indian Ocean. *ICES Journal of Marine Science,* 78(7), 2474-2485. https://doi.org/10.1093/icesjms/fsab119

The silky shark Carcharhinus falciformis regularly associates with floating objects in the open ocean, resulting in relatively high levels of bycatch in industrial tuna purse seine fisheries using drifting fish aggregating devices (FADs). This bycatch has contributed to concerns regarding the sustainability of this fishery and its impact on silky shark populations. To investigate fishery interactions, movements of 28 silky sharks (86-235 cm TL, mean = 118 cm) fitted with pop-up and archival tags in the western Indian Ocean, between 2010 and 2012, were examined. Monthly overlap between probability surfaces of sharks and two fishery metrics (FAD-tuna catches and FAD positions) were calculated. Vertical habitat use overlapped almost entirely with operational gear depth. Horizontal movements were extensive (3-5024 km) and covered large areas of the western Indian Ocean. Monthly overlap with FAD distributions was consistently high (64.03-100%) highlighting the need for compliance with FAD design regulations to avoid entanglement. Monthly overlap with tuna catches was more variable (8.43-51.83%). The observed movement patterns suggest static spatial management measures would be have limited conservation impact, however dynamic approaches could be appropriate. Limiting fishery activities directly will likely have the greatest conservation outcomes for silky sharks in the purse seine fishery.

Folkins, M. H., Grant, S. M., & Walsh, P. (2021). A feasibility study to determine the use of baited pots in Greenland halibut (Reinhardtius hippoglossoides) fisheries, supported by the use of underwater video observations. *PeerJ,* 9, e10536. https://doi.org/10.7717/peerj.10536

High incidental catches of Greenland shark (Somniosus microcephalus) in Nunavut's Greenland halibut (Reinhardtius hippoglossoides) fishery has led to studies on the feasibility of capturing Greenland halibut with baited pots. In this study, catch rates among six experimental pots are compared. In addition to this, underwater video observations of Greenland halibut interacting with two of these experimental pot types are quantified in order to help provide recommendations on future pot designs. Catch rates of Greenland halibut differed among pots with different entrance mesh types, and none of the pots produced substantial amounts of bycatch. Strings of pots were deployed within a narrow corridor between baited gillnets targeting Greenland halibut, which may have affected catch results. Video observations revealed Greenland halibut entangled by their teeth significantly more often in entrance funnels constructed with 50 mm than with 19 mm clear monofilament netting and the entrance rate was 45% higher with the 19 mm netting. Greenland halibut that successfully entered a pot repeatedly became entangled by their teeth in 58 mm netting used in the side and end panels and in a horizontal panel used to separate the pot into a lower and upper chamber. The majority (80%) of Greenland halibut were observed to approach a pot against the current. The downstream entrance was aligned with the current in 52% of the observed Greenland halibut approaches. Seventy percent of entry attempts and 67% of successful entries occurred when fish approached against the current and when the entrance was aligned with the current. These observations lead to recommendations that future studies consider developing a four entrance pot to ensure an entrance is always aligned with bottom currents. Based on these observations of entanglements, it is recommended to use 19 mm clear monofilament netting in the entrance funnel, 100 mm polyethylene netting in the exterior panels, and 19 mm polypropylene netting in the horizontal panel when targeting Greenland halibut. Three Greenland sharks were observed interacting with the pots in the video sets, but none were captured or damaged the pots during the potting experiments, providing validity to the use of pots to mitigate the capture of Greenland shark in Nunavut territorial waters.

Foster, D. G., Epperly, S. P., Shah, A. K., & Watson, J. W. (2012). Evaluation Of Hook And Bait Type On The Catch Rates In The Western North Atlantic Ocean Pelagic Longline Fishery. *Bulletin of Marine Science,* 88(3), 529-545. https://doi.org/10.5343/bms.2011.1081

Research was conducted in 2002 and 2003 by NOAA's National Marine Fisheries Service, Southeast Fisheries Science Center, to investigate changes in hook design and bait type to reduce the bycatch of sea turtles on pelagic longlines in the western North Atlantic Ocean. The effectiveness of 18/0-20/0 circle hooks and 10/0 Japanese tuna hooks with squid (Illex spp.) and mackerel bait (Scomber scombrus Linnaeus, 1758) was evaluated against the industry standard 9/0 J-hooks with squid bait with respect to reducing sea turtle and shark interactions while maintaining swordfish (Xiphias gladius Linnaeus, 1758) and tuna (Thunnus spp.) catch rates. In total, 973,734 hooks were deployed during the study. Individually, circle hooks and mackerel bait significantly reduced both loggerhead [Caretta caretta (Linnaeus, 1758)] and leatherback [Dermochelys coriacea (Vandelli, 1761)] sea turtle bycatch. The combination of 18/0 circle hooks with mackerel bait was even more effective for loggerhead sea turtles and had a significant increase in swordfish catch by weight. The combination 18/0 circle hooks with squid bait resulted in a significant decrease in the swordfish catch and a significant increase in the catch rate of blue shark [Prionace glauca (Linnaeus, 1758)], bluefin tuna [Thunnus thynnus (Linnaeus, 1758)1, and albacore tuna [Thunnus alalunga (Bonnaterre, 1788)]. With all hook types, mackerel bait resulted in

a significant decrease in blue shark, bigeye tuna [Thunnus obesus (Lowe, 1839)], and albacore tuna, but significantly increased the catch of porbeagle [Lamna nasus (Bonnaterre, 1788)] and shortfin mako (Isurus oxyrinchus Rafinesque, 1810).

François, P., Sidonie, C., Caroline, C., & Jean-Marc, G. (2019). The effect of hook type and trailing gear on hook shedding and fate of pelagic stingray (Pteroplatytrygon violacea): New insights to develop effective mitigation approaches. *Marine Policy,* 107, 103594. https://doi.org/10.1016/j.marpol.2019.103594

The pelagic stingray (Pteroplatytrygon violacea) in the French Atlantic bluefin tuna makes up almost half of the catch in numbers, ranking first of the five major species caught. Given the high levels of catches, more attention was given to the impact of this fishery in order to avoid future conservation issues. The effects of the hook shape (circle versus J-type hooks) and trailing gear on hook retention has been investigated on 10 individuals kept in captivity during 125 days. Experiments showed that the J-type hook used commonly by fishers had a fast self-shedding rate which will allow for a quick resumption of feeding and minimal injury which means quicker wound healing and better chance for survival. J-type hooks were all expelled within 6 days while circle hook shedding rates were much longer, taking 44.5 ± 54.4 days (mean ± SD). The mechanism of expulsion of the hook has been clearly described and the impact of the trailing line assessed. Appropriate handling practices maximizing the crew safety and the post-release survival were identified. Other effective mitigation approaches for the fishery are proposed and discussed.

Garstin, A., & Oxenford, H. A. (2018). Reducing Elasmobranch Bycatch in the Atlantic Seabob (Xiphopenaeus kroyeri) Trawl Fishery of Guyana. *Gulf and Caribbean Research,* 29(1), GCFI10-GCFI20. https://doi.org/10.18785/gcr.2901.04

The Atlantic seabob (Xiphopenaeus kroyeri) trawl fishery is very important to Guyana, with 88 licensed industrial vessels harvesting about 15,000 mt annually, representing Guyana's most valuable seafood export. All vessels are already using both teleost by—catch reduction devices (BRDs) and turtle excluder devices (TEDs) to satisfy international market standards. However, the key stakeholder, the Guyana Association of Private Trawler Owners and Seafood Processors, is now seeking to access sustainable seafood markets through pursuing Marine Stewardship Council (MSC) certification. To this end, this study documents elasmobranch by—catch in the current fishery and examines the effectiveness of a modified TED (with a reduced bar spacing and the addition of a brace bar) in reducing elasmobranch by—catch. From July—August 2014, 131 tows were made, 80 of which represented simultaneous hauls with control and modified TEDs. One shark and 8 ray species were recorded. A statistically significant 40% decline in the elasmobranch catch rate was observed when using modified TEDs compared with control TEDs (mean by—catch rate dropped from 2.3 to 1.4 individuals per twin—trawl/h). Furthermore, modified TEDs significantly reduced the mean size of rays caught by 6.3%. This also resulted in a virtual elimination of 3 IUCN—designated 'Near Threatened' ray species in the by—catch, although having little effect on the capture of small—sized elasmobranch species, including the 'Critically Endangered' Caribbean Electric Ray (Narcine bancroftii). We conclude that the modified TED was successful in reducing the by—catch of vulnerable elasmobranch species and should advance progress towards attaining by—catch standards required for MSC certification.

Garstin, A., Oxenford, H. A., & Maison, D. (2017). *The effectiveness of a modified turtle excluder device (TED) in reducing the bycatch of elasmobranchs in the Atlantic seabob (Xiphopenaeus kroyeri) industrial trawl fishery of Guyana.* CERMES Technical Report No. 87. Centre for Resource Management and Environmental Studies (CERMES), Retrieved from https://www.cavehill.uwi.edu/cermes/getdoc/d2f2bd90-29c1-4e3e-9aba-c30ad93e5dcf/garstin_et_al_2017_elasmobranch_bycatch_guyana_sea.aspx

The Atlantic seabob (Xiphopenaeus kroyeri) trawl fishery is extremely important to Guyana, with some 88 licensed industrial trawling vessels harvesting around 15,000 mt per year, almost all of which is exported to the US and EU, representing Guyana's most valuable seafood export. The key player in this industry, the Guyana Association of Private Trawler Owners and Seafood Processors (GAPTO&SP) is taking pro-active steps in pursuing Marine Stewardship Council certification for the seabob trawl fishery to ensure top market prices and long-term sustainability of the seabob stock. To this end, all commercial vessels in the fleet are using turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) in their trawl nets. However, the effectiveness of these devices in reducing the bycatch of vulnerable sharks and rays has not yet been examined. This study, requested by GAPTO&SP, represents the first attempt to document the bycatch of these discarded species by the seabob trawl fleet, and to compare the effectiveness of two different TED designs. Over the period July-August 2014, five trips were taken on three different seabob vessels to document the species, sizes and condition of all sharks and rays landed and discarded during the normal 24 hour-day operation of the vessels. Wherever possible, vessels deployed nets fitted with a standard control TED, simultaneously with nets fitted with a modified test TED for comparison of bycatch by the two gears. A total of 131 tows were sampled, 80 of which represented simultaneous tows of both the control and modified test TEDs. Shark and ray bycatch in the nets with control TEDs comprised eight ray species and one shark species including, among the infrequently landed species, three 'Near Threatened' and one 'Critically Endangered' ray species according to the IUCN Red List. The use of the modified TEDs significantly reduced the overall mean size of individuals in the elasmobranch bycatch by 6.3%. Most importantly the mean sizes of the two ray species representing more than 80% by number of elasmobranchs taken as bycatch were reduced by 9.4% and this resulted in a near elimination of mature females in the bycatch. By excluding larger individuals from the cod-end, a statistically significant and substantial decline in the catch rate (by 40%) was observed when using the test TED compared with the control TED (mean elasmobranch bycatch rate dropped from 2.29 to just 1.37 individuals per twin-net hr-1). This also resulted in a virtual elimination of the three 'Near Threatened' ray species in the bycatch, although it had little effect on the capture of the small-sized ray and shark species, including the 'Critically Endangered' Bancroft's numbfish. We conclude that the modified TED was very successful in reducing important elements of the elasmobranch bycatch and should advance the progress towards attaining the bycatch standards required for MSC certification. We further recommend that the impact of this TED on the capture rate of the target seabob, which was beyond the scope of this study, should be examined to inform the decision on mandatory adoption of this gear modification.

Gilman, E., Chaloupka, M., Bach, P., Fennell, H., Hall, M., Musyl, M., . . . Song, L. (2020). Effect of pelagic longline bait type on species selectivity: a global synthesis of evidence. *Reviews in Fish Biology and Fisheries,* 30(3), 535-551. https://doi.org/10.1007/s11160-020-09612-0

Fisheries can profoundly affect bycatch species with 'slow' life history traits. Managing bait type offers one tool to control species selectivity. Different species and sizes of marine predators have different prey, and hence bait, preferences. This preference is a function of a bait's chemical, visual, acoustic and

textural characteristics and size, and for seabirds the effect on hook sink rate is also important. We conducted a global meta-analysis of existing estimates of the relative risk of capture on different pelagic longline baits. We applied a Bayesian random effects meta-analytic regression modelling approach to estimate overall expected bait-specific catch rates. For blue shark and marine turtles, there were 34% (95% HDI: 4-59%) and 60% (95% HDI: 44-76%) significantly lower relative risks of capture on forage fish bait than squid bait, respectively. Overall estimates of bait-specific relative risk were not significantly different for seven other assessed taxa. The lack of a significant overall estimate of relative capture risk for pelagic shark species combined but significant effect for blue sharks suggests there is species-specific variability in bait-specific catch risk within this group. A qualitative literature review suggests that tunas and istiophorid billfishes may have higher catch rates on squid than fish bait, which conflicts with reducing marine turtle and blue shark catch rates. The findings from this synthesis of quantitative and qualitative evidence support identifying economically viable bycatch management measures with acceptable tradeoffs when multispecies conflicts are unavoidable, and highlight research priorities for global pelagic longline fisheries.

Gilman, E., Chaloupka, M., Merrifield, M., Malsol, N. D., & Cook, C. (2016). Standardized catch and survival rates, and effect of a ban on shark retention, Palau pelagic longline fishery. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 26(6), 1031-1062. https://doi.org/10.1002/aqc.2599

1. Pelagic longline fisheries affect both market and vulnerable bycatch species and can have broad effects on community structure and processes. 2. Observer data from the Palau longline fishery were analysed to identify opportunities to mitigate vulnerable species bycatch, determine temporal trends in local abundance, and assess changes following a ban on shark retention and wire leaders. Catch and haulback condition data for bigeye and yellowfin tunas, blue and silky sharks and pelagic stingrays were fitted to standardized catch and survival rate models. 3. The fishery caught silky and blue sharks, olive ridley sea turtles and other species of conservation concern. 4. Changing from shallow sets to deep daytime sets might reduce shark and sea turtle catch rates but increase turtle haulback mortality rates, maintain economically viable tuna catch rates, but increase catch rates of pelagic stingrays, a lower conservation concern than main caught species of sharks and turtles. 5. Focusing fishing effort during the middle of the calendar year would maximize yellowfin tuna and minimize silky shark standardized catch rates, but maximize blue shark catch rates. 6. A large decline in shark fishing mortality rate very likely occurred following a ban on shark retention and wire leaders. This was due to large reductions in the nominal shark catch rate and shark retention, partially offset by decreases in the shark haulback survival rate and pre-catch survival rate. Significantly higher blue shark and lower pelagic stingray nominal catch rates occurred on wire vs. monofilament leaders. Significantly higher blue shark and lower yellowfin tuna nominal catch rates occurred on sets using shallow 'shark lines'. It is a research priority to compare the probability of shark pre-catch survival after escaping from monofilament leaders with an ingested hook and trailing line to the survival probability when captured on wire leaders.

Gilman, E., Chaloupka, M., & Musyl, M. (2018). Effects of pelagic longline hook size on species- and size-selectivity and survival. *Reviews in Fish Biology and Fisheries,* 28(2), 417-433. https://doi.org/10.1007/s11160-017-9509-7

Pelagic fisheries can have profound effects on ecosystem structure and functioning, affecting ecosystem services, including fisheries production, and threaten vulnerable bycatch species. Controlling hook size

could manage the species- and size-selectivity and survival of target and incidental catch. To test this hypothesis, we conducted experimental pelagic longline fishing in the western tropical Pacific testing a control hook and two hooks with wider minimum widths. Data such as catch, length and condition were fit to response-specific Bayesian geo-additive generalized additive and linear mixed regression models. Model fits were assessed using posterior predictive check tests. Catch rates of both retained and discarded species were significantly higher on medium hooks. Target tuna species were significantly larger and had significantly higher at-vessel survival rates on wider hooks. Significantly larger billfishes, also market species, were caught on narrowest hooks. These effects of hook width on length and survival, however, are a much smaller determinant of economic value of the catch than effects on catch rates. If input controls are limiting, then, relative to medium hooks, continued use of narrowest hooks would maintain current economic viability without causing a significant increase in discard catch levels, including of vulnerable sharks. If market species output controls are limiting, because the ratio of retained to discarded catch on medium hooks was greater than on narrowest hooks, medium hooks would generate lower discard levels. Further research assessing single-factor effects of longline hook width is needed to support robust meta-analyses that account for fishery-specific effects.

Gilman, E., Chaloupka, M., Read, A., Dalzell, P., Holetschek, J., & Curtice, C. (2012). Hawaii longline tuna fishery temporal trends in standardized catch rates and length distributions and effects on pelagic and seamount ecosystems. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 22(4), 446-488. https://doi.org/10.1002/aqc.2237

Declines in absolute abundance and altered size distributions from size-selective removals of market species of pelagic apex predators in tuna fisheries alters evolutionary characteristics of populations and ecosystem processes and stability. Pelagic fishing at seamounts, where hyperstability of pelagic predators may occur, can exacerbate declining abundance and have high bycatch of species groups that are highly vulnerable to overexploitation. Generalized additive mixed Poisson regression models (GAMMs) were fitted to Hawaii longline tuna fishery observer data to determine temporal trends in standardized catch rates, an index for local, relative abundance. Temporal trends in expectile length distributions were determined through geoadditive expectile GAMMs. Significant declining trends in relative abundance in this fishery were observed for tunas, sharks and billfish. A decline in seabird standardized catch rate occurred concurrently with the uptake of seabird bycatch mitigation technology. Changed spatial distribution of fishing effort and increased use of wider circle hooks likely contributed to a declining sea turtle standardized catch rate. Tuna and billfish mean lengths significantly increased over the time series due to entire distributions of length classes having shifted towards larger fish. Larger tunas comprised a larger proportion of the catch due to fewer small tunas being caught, and to a lesser extent because mean lengths of larger size classes increased. Conversely, billfish largest length classes experienced the largest increases in average lengths. Changes in spatial and seasonal distributions of fishing effort, increased use of wider circle hooks, and possibly increasing purse seine selective removals of juvenile tunas, may have contributed to increased selectivity for larger fish. Significant differences in standardized catch rates and length distributions at a shallow seamount vs. the open ocean confirms the aggregating effect of seamounts on pelagic predators, including juvenile market species of pelagic fish and species groups relatively vulnerable to overexploitation. Wider circle hooks significantly improved valuable tuna standardized catch rates, but also increased unwanted shark and reduced valuable billfish standardized catch rates.

Gilman, E., Chaloupka, M., Swimmer, Y., & Piovano, S. (2016). A cross-taxa assessment of pelagic longline by-catch mitigation measures: conflicts and mutual benefits to elasmobranchs. *Fish and Fisheries,* 17(3), 748-784. https://doi.org/10.1111/faf.12143

Elasmobranch mortality in pelagic longline fisheries poses a risk to some populations, alters the distribution of abundance between sympatric competitors, changing ecosystem structure, processes and stability. Individual and synergistic effects on elasmobranch catch and survival from pelagic longline gear factors, including methods prescribed to mitigate bycatch of other vulnerable taxa, were determined. Overall relative risk of higher circle vs. J-shaped hook shark catch rates conditioned on potentially informative moderators, from 30 studies, was estimated using an inverse-precision weighted mixed-effects meta-regression modelling approach. Sharks had a 1.20 times (95% CI: 1.03-1.39) significantly higher pooled relative risk of capture on circle hooks, with two significant moderators. The pooled relative risk estimate of ray circle hook catch from 15 studies was not significant (RR=1.22, 95% CI: 0.89-1.66) with no significant moderators. From a literature review, wire leaders had higher shark catch and haulback mortality than monofilament. Interacting effects of hook, bait and leader affect shark catch rates: hook shape and width and bait type determine hooking position and ability to sever monofilament leaders. Circle hooks increased elasmobranch catch, but reduced haulback mortality and deep hooking relative to J-shaped hooks of the same or narrower width. Using fish vs. squid for bait increased shark catch and deep hooking. Pelagic stingray (Pteroplatytrygon violacea) catch and mortality were lower on wider hooks. Using circle instead of J-shaped hooks and fish instead of squid for bait, while benefitting sea turtles, odontocetes and possibly seabirds, exacerbates elasmobranch catch and injury, therefore warranting fishery-specific assessments to determine relative risks.

Gilman, E., Dalzell, P., Goren, M., Werner, T. B., Clarke, S., Alfaro-Shigueto, J., . . . Thomson, N. (2007). *Shark Depredation and Unwanted Bycatch in Pelagic Longline Fisheries: Industry Practices and Attitudes, and Shark Avoidance Strategies.* Western Pacific Regional Fishery Management Council, Retrieved from https://wedocs.unep.org/20.500.11822/13627

Substantial ecological, economic and social problems result from shark interactions in pelagic longline fisheries. Improved understanding of industry attitudes and practices towards shark interactions assists with managing these problems. Information on fisher knowledge and new strategies for shark avoidance may benefit sharks and fishers. A study of 12 pelagic longline fisheries from eight countries shows that incentives to avoid sharks vary along a continuum, based on whether sharks represent an economic disadvantage or advantage. Shark avoidance practices are limited, including avoiding certain areas, moving when shark interaction rates are high, using fish instead of squid for bait and deeper setting. Some conventionally employed fishing gear and methods used to target non-shark species contribute to shark avoidance. Shark repellents hold promise; more research and development is needed. Development of specifically designed equipment to discard sharks could improve shark post release survival prospects, reduce gear loss and improve crew safety. With expanding exploitation of sharks for fins and meat, improved data collection, monitoring and precautionary shark management measures are needed to ensure shark fishing mortality levels are sustainable.

Gilman, E., & Lundin, C. (2010). Minimising bycatch of sensitive species groups in marine capture fisheries: lessons from tuna fisheries. In *Handbook of Marine Fisheries Conservation and Management.* Q. Grafton, R. Hillborn, D. Squires, M. Tait, & M. Williams (Eds.), (pp. 23): Oxford University Press Retrieved from http://ecite.utas.edu.au/58808

Bycatch in marine capture fisheries is the retained catch of nontargeted but commercially viable species (referred to as "incidental catch") plus all discards (Food and Agriculture Organization of the United Nations [FAO] 2005).1 It is an increasingly prominent international issue, raising ecological concerns, as some bycatch species of cetaceans (whales, dolphins, and porpoises), seabirds, sea turtles, elasmobranchs (sharks, skates, and rays), and other fi sh species are particularly vulnerable to overexploitation and slow to recover from large population declines (FAO 1999a, 1999b, in press; Fowler et al. 2005; Gales 1998; Gilman et al. 2005, 2006a, 2006c, 2008; Lutz and Musick 1997). Bycatch can alter biodiversity and ecosystem functions by removing top predators and prey species at unsustainable levels (Myers et al. 2007). It also alters foraging behavior of species that learn to take advantage of discards. Economic effects of bycatch on fi sheries include loss of bait, reduced availability of baited hooks when they are occupied with unwanted bycatch species, and concomitant reduced catch of marketable species; the imposition of a range of restrictions, closed areas, embargos, and possible closures; allocation among fi sheries, where bycatch in one fi shery reduces target catch in another, and bycatch of juvenile and undersized individuals of a commercial species can adversely affect future catch levels (Brothers et al. 1999; Hall et al. 2000). Discarded bycatch raises a social issue over waste: From 1992 to 2001 an average of 7.3 million metric tons of fi sh were annually discarded, representing 8 percent of the world catch (FAO 2005). Prominent bycatch issues include dolphins and porpoises in purse seine fi sheries and driftnets; fi sh discards in shrimp trawl fi sheries; and seabird, sea turtle, marine mammal, and shark bycatch in longline, purse seine, gillnet, and trawl fi sheries (FAO 1999a, 1999b, 2005, in press; Hall et al. 2000). In commercial tuna fi sheries, the incidental bycatch of sensitive species groups (seabirds, sea turtles, marine mammals, and sharks) and bycatch of juvenile and undersized tunas are allocation and conservation issues. In addition to problematic bycatch, overexploitation and illegal, unreported, and unregulated (IUU) fi shing, which complicates bycatch management, are additional conservation issues facing the management of tuna fi sheries. This chapter employs examples of bycatch in commercial tuna fi sheries to describe (1) the range of options to reduce bycatch, (2) principles and approaches to successfully introduce effective bycatch reduction measures, and (3) initiatives taken by intergovernmental organizations, the fi shing industry, and retailers to address bycatch. Changes needed to improve the sustainability of tuna production are recommended.

Godin, A. C., Carlson, J. K., & Burgener, V. (2012). The effect of circle hooks on shark catchability and at-vessel mortality rates in longlines fisheries. *Bulletin of Marine Science,* 88(3), 469-483. https://doi.org/10.5343/bms.2011.1054

Circle hooks have gained recent attention as a cost-effective bycatch mitigation tool in pelagic longline fisheries, particularly for marine turtles. Over the last few years, a growing number of studies have investigated the use of circle hooks and their effects on other species, including elasmobranchs. To elucidate the potential value of circle hook use as a tool for shark conservation and management in pelagic longline fisheries, we conducted a quantitative review of all available studies to date. We compiled 15 published and eight gray literature studies and where possible used random effects meta-analysis and analysis of covariance to test the effects of circle hooks on catchability and at-vessel mortality rates. Overall, results suggest that using circle hooks on pelagic longlines do not have a major

effect on shark catch rates, but do reduce at-vessel mortality compared to J-hooks. Thus circle hooks should be seen as one potential tool to help reduce bycatch mortality of sharks in longline fisheries. However, the high level of heterogeneity found between studies highlights the need for shark-specific controlled experiments to provide more definitive results.

Godin, A. C., Wimmer, T., Wang, J. H., & Worm, B. (2013). No effect from rare-earth metal deterrent on shark bycatch in a commercial pelagic longline trial. *Fisheries Research,* 143, 131-135. https://doi.org/10.1016/j.fishres.2013.01.020

The indiscriminate capture of non-target organisms (bycatch) in commercial fisheries undermines the sustainable development of marine resources. In the Northwest Atlantic, blue sharks (Prionace glauca) account for most of the bycatch in the Canadian pelagic longline swordfish fishery. Minimizing the capture of this species is of interest to conservationists as well as the fishing industry because the high incidence of shark bycatch negatively affects fishing operations through bait loss and increased handling time. Electropositive metals (e.g., lanthanide) oxidize in seawater and create electric fields, which can alter the swimming and feeding behaviors of several species of sharks. Although electropositive metals appear to have the potential to reduce shark bycatch in pelagic longline fisheries, there have not been any controlled trials reported from a commercial fishery. A total of 7 sets (6300 hooks) with 3 hook treatments (standard hooks, hooks with electropositive metals (neodymium/praseodymium), and hooks with lead weights) were deployed in 2011 on the Scotian Shelf in the Northwest Atlantic. The results of this study show that electropositive metals did not reduce the catch of blue sharks or other common shark bycatch species, and hence do not present a practical bycatch mitigation measure for the Canadian longline fishery.

Gorman, D., & Dixon, C. (2015). Reducing discards in a temperate prawn trawl fishery: a collaborative approach to bycatch research in South Australia. *ICES Journal of Marine Science,* 72(9), 2609-2617. https://doi.org/10.1093/icesjms/fsv147

We present the outcomes of a collaborative research programme tasked with reducing bycatch, and thus discards in a temperate Australian prawn trawl fishery. Sea trials in the Gulf of St Vincent, South Australia, assessed the performance of a modified trawlnet that incorporated a rigid polyethylene grid and a T90-mesh codend. Compared with conventional designs, the modified net yielded marked reductions in bycatch (cumulatively >81% by weight), with pronounced decreases in sponge (92%), elasmobranchs (80%), teleost fish (71%), molluscs (61%), and crustaceans (78%). Using commercial logbook data, we estimate that the use of modified nets could reduce discards by similar to 240 tons per year. This outcome was achieved with moderate declines in the catch rate (kg h(-1)) of the target species, Western King Prawn (mean similar to 15%), of which almost all were small adults of low commercial value. Adoption of the modified net by industry was realized in March 2012, because it met environmental objectives (i.e. reducing bycatch and improving public perceptions of sustainability), reduced prawn damage, demonstrated commensurate financial returns, and engaged stakeholders throughout the development process. Overall, the project provides a useful example of bycatch research with demonstrable outcomes of improving the ecological and economic sustainability of prawn harvests.

Grant, S. M., Munden, J. G., & Hedges, K. J. (2020). Effects of monofilament nylon versus braided multifilament nylon gangions on catch rates of Greenland shark (Somniosus microcephalus) in bottom set longlines. *PeerJ,* 8, e10407. https://doi.org/10.7717/peerj.10407

The Greenland shark (Somniosus microcephalus) is the main bycatch species in established and exploratory inshore longline fisheries for Greenland halibut (Reinhardtius hippoglossoides) on the east coast of Baffin Island, Canada. Bycatch and entanglement in longline gear has at times been substantial and post-release survival is questionable when Greenland sharks are released with trailing fishing gear. This study investigated the effect of the type of fishing line used in the gangion and gangion breaking strength on catch rates of Greenland shark and Greenland halibut in bottom set longlines. Circle (size 14/0, 0 degrees offset) hooks were used throughout the study. Behavior of captured sharks, mode of capture (i.e., jaw hook and/or entanglement), level of entanglement in longline gear, time required to disentangle sharks and biological information (sex, body length and health status) were recorded. Catch rates of Greenland shark were independent of monofilament nylon gangion breaking strength and monofilament gangions captured significantly fewer Greenland sharks than the traditional braided multifilament nylon gangion. Catch rates and body size of Greenland halibut did not differ significantly between gangion treatments. Although most (84%) of the Greenland sharks were hooked by the jaw, a high percentage (76%) were entangled in the mainline. The mean length of mainline entangled around the body and/or caudal peduncle and caudal fin was 28.7 m. Greenland sharks exhibited cannibalistic behavior with 15% of captured sharks cannibalized. All remaining sharks were alive and survived the disentanglement process which can be attributed to their lethargic behavior and lack of resistance when hauled to the surface. Thus, as a conservation measure fishers should be encouraged to remove trailing fishing gear prior to release. Our results are used to demonstrate benefits to the fishing industry with regard to an overall reduction in the period of time to disentangle sharks and damage to fishing gear by switching from braided multifilament to monofilament gangions in Greenland halibut longline fisheries.

Grant, S. M., Sullivan, R., & Hedges, K. J. (2018). Greenland shark (Somniosus microcephalus) feeding behavior on static fishing gear, effect of SMART (Selective Magnetic and Repellent-Treated) hook deterrent technology, and factors influencing entanglement in bottom longlines. *PeerJ,* 6, e4751. https://doi.org/10.7717/peerj.4751

The Greenland Shark (Somniosus microcephalus) is the most common bycatch in the Greenland halibut (Reinhardtius hippoglossoides) bottom longline fishery in Cumberland Sound, Canada. Historically, this inshore fishery has been prosecuted through the ice during winter but winter storms and unpredictable landfast ice conditions since the mid-1990s have led to interest in developing a summer fishery during the ice-free season. However, bycatch of Greenland shark was found to increase substantially with 570 sharks captured during an experimental Greenland halibut summer fishery (i.e., mean of 6.3 sharks per 1,000 hooks set) and mortality was reported to be about 50% due in part to fishers killing sharks that were severely entangled in longline gear. This study investigated whether the SMART (Selective Magnetic and Repellent-Treated) hook technology is a practical deterrent to Greenland shark predation and subsequent bycatch on bottom longlines. Greenland shark feeding behavior, feeding kinematics, and variables affecting entanglement/ disentanglement and release are also described. The SMART hook failed to deter Greenland shark predation, i.e., all sharks were captured on SMART hooks, some with more than one SMART hook in their jaw. Moreover, recently captured Greenland sharks did not exhibit a behavioral response to SMART hooks. In situ observations of Greenland shark feeding show that this species uses a powerful inertial suction mode of feeding and was able to draw bait into the mouth from a distance of 25-35 cm. This method of feeding is suggested to negate the potential deterrent effects of

electropositive metal and magnetic alloy substitutions to the SMART hook technology. The number of hooks entangled by a Greenland shark and time to disentangle and live-release a shark was found to increase with body length.

Gulak, S. J. B., & Carlson, J. K. (2021). Less Soak Time Saves Those upon the Line: Capture Times and Hooking Mortality of Sharks Caught on Bottom Longlines. *North American Journal of Fisheries Management,* 41(3), 791-808. https://doi.org/10.1002/nafm.10592

The National Marine Fisheries Service is mandated by the Magnuson-Stevens Fishery Conservation and Management Act to implement effective annual catch limits and accountability measures to prevent overfishing. These requirements compel further research into alternative fishing practices that could reduce mortality of sharks (class Chondrichthyes) and allow fishers to release unwanted sharks to the water alive, while still effectively catching targeted species. We used hook timers and temperature-depth recorders aboard contracted vessels and participants in the National Marine Fisheries Service's Shark Research Fishery to collect hooking time and time-on-the-line data for 10 species of sharks that were commonly encountered in the fishery. A subset of standardized fishing sets compared the most popular circle hook and J-hook models. Over 60% of sharks were hooked within 4 h of hook soak time. The fastest to bite the hook was the Atlantic Sharpnose Shark Rhizoprionodon terraenovae and the slowest was the Dusky Shark Carcharhinus obscurus. Shark resilience to time on the longline varied among species, with Sandbar Shark C. plumbeus exhibiting the most resilience and Atlantic Sharpnose Shark the least. Shorter set soak times, approximately 2 h, would still maximize catch, while minimizing at-vessel mortality. The most frequently used circle hook model did not significantly reduce at-vessel mortality over large J-style hooks. The recent circle hook requirement will have little effect for fishers that previously used 12/0 J-hooks, but it may be beneficial by preventing the use of smaller J-hooks that are more likely to cause at-vessel mortality.

Gupta, T., Booth, H., Arlidge, W., Rao, C., Manoharakrishnan, M., Namboothri, N., . . . Milner-Gulland, E. J. (2020). Mitigation of Elasmobranch Bycatch in Trawlers: A Case Study in Indian Fisheries. *Frontiers in Marine Science,* 7. https://doi.org/10.3389/fmars.2020.00571

Bycatch poses a significant threat to marine megafauna, such as elasmobranchs. India has one of the highest elasmobranch landings globally, through both targeted catch and bycatch. As elasmobranchs contribute to food and livelihood security, there is a need for holistic approaches to bycatch mitigation. We adopt an interdisciplinary approach to critically assess a range of hypothetical measures for reducing elasmobranch capture in a trawler fishery on India's west coast, using a risk-based mitigation hierarchy framework. Data were collected through landing surveys, interviews and a literature review, to assess the following potential management options for their technical effectiveness and socio-economic feasibility: (1) spatio-temporal closures; (2) net restrictions; (3) bycatch reduction devices (BRDs); and (4) live onboard release. Our study provides the first evidence-based and nuanced understanding of elasmobranch bycatch management for this fishery, and suggestions for future conservation and research efforts. Onboard release may be viable for species like guitarfish, with moderate chances of survival, and was the favored option among interview respondents due to minimal impact on earnings. While closures, net restrictions and BRDs may reduce elasmobranch capture, implementation will be challenging under present circumstances due to the potentially high impact on fisher income. Interventions for live release can therefore be used as a step toward ameliorating bycatch, while initiating longer-term engagement with the fishing community. Participatory monitoring can help

address critical knowledge gaps in elasmobranch ecology. Spatio-temporal closures and gear restriction measures may then be developed through a bottom-up approach in the long term. Overall, the framework facilitated a holistic assessment of bycatch management to guide decision-making. Scaling-up and integrating such case studies across different species, fisheries and sites would support the formulation of a meaningful management plan for elasmobranch fisheries in India.

Howard, S. (2015). *Mitigation options for shark bycatch in longline fisheries*.(New Zealand Aquatic Environment and Biodiversity Report No. 148). Ministry for Primary Industries, New Zealand Retrieved from https://www.bmis-bycatch.org/references/sw9bq7hj

A systematic review of literature addressing methods of reducing shark catch rates on longline fishing gear was conducted using academic publication databases and the Ministry for Primary Industries' publications database. Gear technology as well as operational and environmental variables were evaluated as potential elasmobranch bycatch reduction methods for use in New Zealand commercial longline fisheries. Twenty candidate shark bycatch reduction methods were identified. The criteria used to assess these methods were weighted toward approaches currently ready for deployment in commercial fisheries. The methods of mitigating shark bycatch that ranked highest in this assessment are already used extensively in New Zealand longline fisheries. These are nylon leaders, large hooks and squid bait. Nylon leaders enable sharks to escape by biting off from fishing gear after capture. The 16/0 hooks commonly used in New Zealand surface longline fisheries have been associated with reduced blue shark (Prionace glauca) and pelagic stingray (Pteroplatytrygon violacea) catch rates, compared to 14/0 circle hooks and J-hooks respectively. Circle hooks are more often associated with increased shark catch rates, which may be due to increased retention on the line rather than increased total catches. Circle hooks complement the use of nylon leaders by reducing the incidence of gut hooking, which improves the odds of survival for animals that bite off the leader. 17/0 and 18/0 circle hooks are common in surface longline fisheries internationally and it is possible that a shift to these larger hooks could further reduce elasmobranch bycatch by making gear less available to smaller individuals. Other shark bycatch reduction methods that scored highly in this assessment include a shift in setting depth, the use of weak hooks, eliminating lightsticks, and developing artificial bait. A shift in setting depth holds more promise in bottom longline fisheries than in surface longline fisheries, but the research that lead to this conclusion was conducted outside of New Zealand and addressed species not found in New Zealand waters. Understanding the effect of altering setting depth on local elasmobranch species, target catches and vessel operations would require further investigation. Weak hooks scored highly because they could be very straightforward to implement, but little peer reviewed information was available regarding their impact on shark catch rates, post release survival, or target catch rates, particularly those of large tuna. Likewise, eliminating lightsticks scored highly largely due to ease of implementation. Despite the significant relationships between shark catches and lightstick use reported in the literature, it is probable that the practical significance of such a measure is not great. Unlike weak hooks or eliminating lightsticks, artificial baits manufactured from fish processing waste scored highly in this assessment because they have the potential to strongly reduce shark catch rates. However, this approach would require extensive development, including creating new formulae from locally available waste products, conducting field trials, and establishing manufacturing capability. By condensing and summarising available data on how shark and target species' catch rates are influenced by different operational and environmental parameters, this review makes a large amount of information about shark bycatch mitigation options accessible. The scoring system used to assess those options illustrates how the conclusions presented here were reached. This evidence together with a transparent assessment

framework is intended to encourage discussion about future directions for shark bycatch mitigation in New Zealand's longline fisheries.

Howard, S. (2018). *Applying a multidisciplinary framework for developing a shark bycatch reduction device.* (Ph.D.), University of Otago, Retrieved from http://hdl.handle.net/10523/7824

The overarching aim of this multidisciplinary thesis was to contribute to the development of a novel shark bycatch reduction device (BRD) that both meets fishing operators' needs and is economically feasible. Following the multidisciplinary approach evident in existing frameworks developed for addressing bycatch problems, each chapter employed a different methodology drawn from a research discipline that provided a suitable set of tools for investigating a specific problem related to the overall goal.First, a literature review identified and evaluated global options available for mitigating elasmobranch bycatch on longline fishing gear. The aim of this review was to determine whether a shark bycatch reduction method currently exists that New Zealand longline fisheries could use to reduce their shark bycatch rates, and if not, identify promising emergent bycatch reduction methods as candidates for further development. The review found that no effective shark bycatch reduction methods or devices were commercially available to longline fishing operators, and identified electrosensory shark deterrents as an approach that showed potential for further development.Qualitative social research methods were then used to explore New Zealand longline fishing operators' perspectives on shark bycatch. Most interviews occurred in 2014 during a national campaign to legislate against shark finning in New Zealand waters. At this time, widespread popular opinion held that finning made sharks an economically valuable bycatch or even target species in many longline fisheries. If sharks were valued by fishermen for their fins or otherwise targeted then it was unlikely that they would consider a shark BRD useful. Interviews with ling (Genypterus blacodes) and tuna (Thunnus spp.) longline fishermen showed that they viewed spiny dogfish (Squalus acanthias) and blue shark (Prionace glauca) bycatch in their respective fisheries as a significant operational and economic challenge that they were motivated to mitigate but lacked effective tools to do so. Interviews also revealed that fishermen viewed the issue of shark bycatch in the context of maximising target species catch rates rather than minimising shark bycatch rates.Following interviews with skippers, laboratory animal behaviour experiments tested the hypothesis that weak electric stimulus generated by a prototype BRD would deter spiny dogfish or sandbar sharks (Carcharhinus plumbeus) from eating bait. Sandbar sharks were used as a carcharhinid model for an important longline bycatch species, blue sharks. The primary function of the elasmobranch electric sense is to guide predatory strikes during the final stage of prey capture, so electrosensory stimulus could disrupt their close range feeding responses. Weak electric stimulus produced by a microcontroller attached to an array of carbon electrodes and powered by a 9 V battery was used to deter groups of sharks from eating bait. Electric stimulus significantly reduced bait consumption by each species in a laboratory setting. Bait consumption by groups of juvenile sandbar shark median declined by 85 % when bait was located 10 cm from active electrodes compared to when it was 2 m away. Bait consumption by groups of adult spiny dogfish declined by 50 % when bait was located 10 cm from active electrodes compared to when it was located 10 cm from inactive electrodes. Results from laboratory studies of electrosensory shark deterrents tend to produce larger effect sizes than similar stimuli applied in field studies. If these results translated to the field the effect size produced in the sandbar shark experiment could be adequate to meet fishermen's expectations of a successful BRD. Conversely, the smaller effect size and wide interquartile range in spiny dogfish bait consumption means that for this species, improvements in both effectiveness and consistency would be required for the prototype electrosensory BRD to meet fishing industry needs.Following the bait choice experiments, a spatial utilisation experiment tested the hypothesis th t individual sandbar sharks avoided the location of

carbon electrodes emitting weak electric stimulus. Sharks were not deterred from the location of either 4 Hz, 33 mA direct current or alternating current stimuli nor did their swimming speed change relative to a non-electric control. The absence of an avoidance response suggests that an electrosensory shark BRD based on this concept may not be applicable to non-baited fishing gears such as purse seine and trawl nets. The finding electrosensory stimuli that reduced bait consumption in the previous experiments did not also elicit spatial avoidance supports the premise that electrosensory deterrents interrupt shark feeding behaviours rather than eliciting an aversive response.Finally, the economic impact of spiny dogfish in the inshore ling longline fishery was analysed quantitatively. Spiny dogfish and ling catch rates and export markets were assessed, then New Zealand government fisheries observer data were used to investigate a hypothesis that arose during skipper interviews, that spiny dogfish incur costs to inshore ling longline vessels by reducing ling catch rates. Overall, there was a significant weak positive relationship between spiny dogfish catch per unit effort (CPUE) and ling CPUE, which probably reflects these two species' spatial and temporal co-occurrence. On fishing lines in the upper quartile of spiny dogfish CPUE, there was a significant moderate negative relationship between spiny dogfish and ling CPUE. Median total hook occupancy in this fishery was 21 % but spiny dogfish alone could occasionally take up to 90 % of hooks. When spiny dogfish catch rates were high, the negative impact of spiny dogfish on ling CPUE could have been the result of hook occupation by spiny dogfish reducing the number of hooks available to ling. To reduce the highest spiny dogfish catches to a level below that likely to incur an opportunity cost in this fishery, the BRD would need to have an approximately 80 % effect size in the field. Based on the ratio of spiny dogfish to ling, an opportunity cost of high spiny dogfish catches in terms of 'lost' ling was estimated and valued at 34 cents per hook. The novel BRD under development produced weak electrosensory stimulus which was only perceptible to sharks at close range, which meant that every hook would require an individual BRD. Therefore, our estimates suggest a price ceiling of 34 cents per unit, above which the cost of a BRD outweighs its benefit in terms of increased ling catch. Increased durability could allow for the use of a more expensive device. However, based on the views of the three interviewed skippers, willingness to pay for a BRD is very low. Skipper access to better information, including our estimates of spiny dogfish bycatch-associated costs of ling catch, may provide increased incentives for BRD adoption.This thesis shows that an electronic BRD that produces electrosensory stimulus is a promising approach for mitigating carcharhinid shark bycatch, although it would require further development to become effective and reliable enough to be cost effective as a method of mitigating spiny dogfish bycatch in the ling longline fishery. This thesis also provides insight into an improved framework for developing bycatch reduction methods aimed at meeting fishing industry needs. Such a framework should involve initiating bycatch reduction research by conducting social research aimed at understanding fishing industry needs and perspectives on the bycatch problem. This can highlight the potential economic impacts, species of concern and key outcomes that industry would require for BRD uptake to occur. Proceeding to conduct an economic assessment of a bycatch problem's cost in a specific fishery can contribute to BRD cost-per-unit and minimum acceptable effect size estimates, which can then guide subsequent device development.

Howard, S., Brill, R., Hepburn, C., & Rock, J. (2018). Microprocessor-based prototype bycatch reduction device reduces bait consumption by spiny dogfish and sandbar shark. *ICES Journal of Marine Science,* 75(6), 2235-2244. https://doi.org/10.1093/icesjms/fsy098

Elasmobranchs contribute heavily to bycatch in longline fisheries globally, and an effective method of deterring them from baited fishing gear is needed. Electrosensory stimulus holds promise as a method of disrupting elasmobranch close-range feeding responses as their electric sense guides their final strike during prey capture. We used laboratory experiments to test the hypothesis that weak electric stimuli

generated by a prototype electronic bycatch reduction device (BRD) could deter sandbar shark (Carcharhinus plumbeus) and spiny dogfish (Squalus acanthias) from eating bait. Voltage gradients <1mVcm(-1) at the location of bait were produced by an Arduino microcontroller powered by a 9 V battery and attached to carbon electrodes. Median bait consumption by groups of juvenile sandbar shark declined by 74% when bait was located 10 cm vs. 2m from active electrodes. Spiny dogfish median bait consumption halved when bait was located 10 cm from active vs. inactive electrodes. Although laboratory studies often produce a larger effect for electrosensory shark deterrents than can be demonstrated during field trials, if the effects seen in our laboratory studies produced similar effects in the field, it could meet fishermen's requirements for a BRD.

Huang, H.-W., Swimmer, Y., Bigelow, K., Gutierrez, A., & Foster, D. G. (2016). Influence of hook type on catch of commercial and bycatch species in an Atlantic tuna fishery. *Marine Policy,* 65, 68-75. https://doi.org/10.1016/j.marpol.2015.12.016

Experimental sets were conducted on a Taiwanese deep set longline fishing vessel operating in the tropical Atlantic Ocean to evaluate the effects of relatively wide circle hooks vs. Japanese tuna hooks with respect to catch rates of both target and incidental species. On circle hooks there were significantly higher catch rates of bigeye tuna (Thunnus obesus), yellowfin tuna (T. albacares), swordfish (Xiphias gladius) and blue sharks (Prionace glauca) as compared to tuna hooks. Significantly higher rates of albacore (T. alalunga) and longbill spearfish (Tetrapterus pfluegeri) were caught on Japanese tuna hooks as compared to circle hooks. Overall, 55 sea turtles were incidentally captured, most (n=47) of which were leatherback turtles (Dermochelys coriacea), and capture rates were similar between hook type. Immediate survival rates (percentage alive) when landed were statistically similar for all major target fish species and sea turtles independent of hook type. Most (64%) sea turtles were hooked on the first and second branchlines closest to the float, which are the shallowest hooks deployed on a longline. Lengths of six retained species were compared between hook types. Of these, swordfish was the only species to show a significant difference in length by hook type, which were significantly larger on circle hooks compared to tuna hooks. Additional incentives to use circle hooks would be the increased catch rate in targeted bigeye tuna over traditional Japanese tuna hooks. This international collaboration was initiated in direct response to regional fisheries management organization recommendations that encourage member countries to conduct experiments aimed to identify means to reduce bycatch in longline fishing gear. Information presented may be useful for managers in developing international fisheries policies that aim to balance increases in commercial fishery revenue and endangered species protection.

Hutchinson, M., Wang, J. H., Swimmer, Y., Holland, K., Kohin, S., Dewar, H., . . . Martinez, J. (2012). The effects of a lanthanide metal alloy on shark catch rates. *Fisheries Research,* 131, 45-51. https://doi.org/10.1016/j.fishres.2012.07.006

Bycatch of sharks in longline fisheries has contributed to declines in shark populations and prompted the need for exploring novel technologies to reduce the incidental capture of sharks. One potential strategy is to exploit the unique electrosensory system of sharks, used to detect weak electric fields. Metals from the lanthanide series, made up of neodymium (Nd) and praseodymium (Pr), produce strong electric fields in water. In this study, we tested the effects of an Nd/Pr alloy on shark catch rates. Using longline fishing gear, we compared the catch rates of baited hooks affixed with either a block of the metal alloy (experimental) or a lead weight (control). Four experiments were conducted in different regions of the

Pacific Ocean. Two bottom longline experiments were conducted inside and offshore of Kaneohe Bay, Hawaii. One of these experiments targeted young of the year scalloped hammerhead sharks (Sphyrna lewini), while the other targeted sandbar (Carcharhinus plumbeus) and tiger sharks (Galeocerdo cuvier). In the Southern California Bight (SCB), pelagic longlines were deployed to target mako (Isurus oxyrinchus) and blue sharks (Prionace glauca) and longlines targeting pelagic sharks were set in the Eastern Tropical Pacific (ETP) off Ecuador. There was a significant reduction in juvenile hammerhead sharks caught on hooks with the lanthanide metal compared to the controls. In contrast, there was no difference in the catch rates for experiments targeting sandbar sharks in Hawaii or those conducted in the SCB and Ecuador. These results suggest that there are inter-specific differences regarding the effects of lanthanide metals on catch rates. This may reflect the diverse feeding strategies and sensory modalities used by shark species for detecting and attacking prey.

Hyatt, M. W., Anderson, P. A., & O'Donnell, P. M. (2018). Influence of Temperature, Salinity, and Dissolved Oxygen on the Stress Response of Bull (Carcharhinus leucas) and Bonnethead (Sphyrna tiburo) Sharks after Capture and Handling. *Journal of Coastal Research,* 34(4), 818-827. https://doi.org/10.2112/jcoastres-d-17-00118.1

Capture and handling stress can induce acidosis in sharks. This response, endured during commercial bycatch and in catch-and-release recreational fisheries, could be exacerbated in certain environmental conditions. To assess environmental influence on stress response, changes in acid-base, blood gas, and metabolite analytes (pH, pCO(2), and lactate) measured with the i-STAT portable clinical analyzer were evaluated immediately after capture and removal from gillnets among wild bull (Carcharhinus leucas) and bonnethead (Sphyrna tiburo) sharks caught in waters of differing temperature (T), salinity (Sal), and dissolved oxygen (DO). Time from capture to blood collection (C-BD) was also recorded. Effects of T, Sal, DO, and C-BD on acid-base physiology were evaluated by modeling their ability to predict pH, pCO(2), and lactate concentrations using ordinal logistic regression (OLR). The OLR models suggest that C. leucas sharks experienced a mixed metabolic and respiratory acidosis in warmer waters and at the low end of their salinity tolerance, and that S. tiburo sharks experienced a metabolic acidosis in warmer waters with a potential for respiratory acidosis at the high end of their salinity tolerance. In S. tiburo, capture and handling time exacerbated acidosis. Based on these findings, it is recommended that commercial and catch-and-release fisheries conduct operations cautiously during times of the year when water temperatures are high and salinities are at either extreme, by decreasing soak times, using the strongest proper tackle gear to reduce fight times, and releasing sharks as soon as possible after capture and detection.

International Seafood Sustainability Foundation. (2019). *Non-Entangling and Biodegradable FADs Guide.* Retrieved from https://www.iss-foundation.org/research-advocacy-recommendations/our-scientific-program/scientific-reports/download-info/non-entangling-and-biodegradable-fads-guide-english/

This guide is an August 2019 update of the ISSF Guide for Non-entangling FADs, first published in 2012 and last updated in 2015.We have created this version of the guide for tuna fishers, Regional Fisheries Management Organizations (RFMOs), governments and vessel owners. It shows best practices in Fish Aggregating Device (FAD) design, both to avoid bycatch — especially of sharks and sea turtles — and to reduce marine pollution.New to this version of the guide is a focus on constructing FADs that are not only non-entangling to bycatch species but also biodegradable. Illustrations (p. 6) show how to design

and build non-entangling biodegradable FADs without netting using natural materials. Those guidelines are contrasted with other FAD designs fishers have used that pose some degree of entanglement risk (low to high) to marine species.The four tuna RFMOs already require fleets that fish with FADs to use only non-entangling designs. Some RFMOs also encourage fleets to use biodegradable materials in those non-entangling FADs.The guide, which reflects the latest scientific research, was produced with input from ISSF's Scientific Advisory Committee and Bycatch Steering Committee.

Itano, D., Muir, J., Hutchinson, M., & Leroy, B. (2012). *Development and testing of a release panel for sharks and non-target finfish in purse seine gear.* WCPFC-SC8-2012/EB-WP-14 Western and Central Pacific Fisheries Commission, Retrieved from https://meetings.wcpfc.int/node/7833

An experimental release panel was installed in purse seine nets to determine their ability to release both silky sharks and non-target finfish. The release panels (5.5 m wide, extending down from the corkline for 11 m) were installed in a portion of the net that forms a "pocket" toward the end of net retrieval. Dive surveys previously reported that silky sharks tend to segregate and collect in this section of the net. The release panel was tested during seven purse seine sets, but only two silky sharks (out of 105) exited through this panel. In net observations indicated that sharks and other non-target finfish did not appear to recognize the opening as an escape route out of the net. Despite this initial failure of the release panel, the authors feel refinement of the panel and additional testing is still warranted.

Jaiteh, V. F., Allen, S. J., Meeuwig, J. J., & Loneragan, N. R. (2014). Combining in-trawl video with observer coverage improves understanding of protected and vulnerable species by-catch in trawl fisheries. *Marine and Freshwater Research,* 65(9), 830-837. https://doi.org/10.1071/mf13130

Assessments of incidental wildlife mortality resulting from fishing rarely account for unobserved by-catch. We assessed by-catch of protected and vulnerable wildlife species in an Australian trawl fishery by comparing in-trawl video footage with data collected by an on-board observer. Data were obtained from 44 commercial trawls with two different by-catch reduction devices (BRDs). Eighty-six individuals from six major taxa (dolphins, sharks, rays, sea snakes, turtles and sygnathids) were documented from video analysis, including the endangered scalloped hammerhead shark (Sphyrna lewini) and the critically endangered green sawfish (Pristis zijsron). On the basis of the 2008–2009 fishing effort of 4149 trawls and scaling from these results, we estimated the annual catch of protected and vulnerable species (± 1 s.e.) at 8109 ± 910 individuals. Only 34% of by-catch was expelled through the BRDs. Independent observer data for the 44 trawls showed that 77% of the landed by-catch from these taxa were dead when discarded. The results indicate that unaccounted by-catch in trawl fisheries can be substantial, and that current methods of recording by-catch on-board vessels are likely to underestimate total fishing mortality. We recommend gear modifications and their validation through dedicated observer coverage, combined with in-trawl video camera deployments to improve current approaches to by-catch mitigation.

Jimenez, S., Forselledo, R., & Domingo, A. (2019). Effects of best practices to reduce seabird bycatch in pelagic longline fisheries on other threatened, protected and bycaught megafauna species. *Biodiversity and Conservation,* 28(13), 3657-3667. https://doi.org/10.1007/s10531-019-01842-4

Fisheries bycatch is one of main conservation problems for many threatened seabirds. Currently, it is unknown whether existing best practices to mitigate seabird bycatch in pelagic longline fisheries influence the capture of other vulnerable taxa. We assessed the effect of two seabird mitigation measures for pelagic longline fisheries on 13 threatened, protected and/or bycaught species, including elasmobranchs, teleosts, sea turtles and fur seals. Analyses were from two experimental studies in Uruguay assessing the effect of a bird scaring line (BSL) and branch lines with weights close to the hooks (weighted branch lines) on these taxa. One hundred longline sets with randomized use of a BSL were deployed. In turn, 224 paired longline sections, with control branch lines versus weighted branch lines, were deployed. BSL use did not increase the capture of any of the species addressed. No detectable differences in capture rate were recorded in our branch line weighting study. However, the effect of branch line weighting in the capture of Porbeagle shark (Lamna nasus) remains unclear and requires further research. Our study suggests that effective measures to reduce seabird bycatch in pelagic longline have no negative connotations for other vulnerable species. Caution should be exercised when interpreting our results as analyses were underpowered to detect small and subtle differences in the catch rates. We strongly encourage researchers to conduct similar studies to elucidate potential regional and across fisheries differences in the effect of seabird mitigation measures in other vulnerable taxa, as well as the effect that mitigation measures for other taxa may have on seabirds.

Kaimmer, S., & Stoner, A. W. (2008). Field investigation of rare-earth metal as a deterrent to spiny dogfish in the Pacific halibut fishery. *Fisheries Research,* 94(1), 43-47. https://doi.org/10.1016/j.fishres.2008.06.015

Spiny dogfish (Squalus acanthias) comprise a Significant unwanted bycatch on demersal longlines set for halibut, sablefish (Anoplopoma fimbria), and Pacific cod (Gadus macrocephalus) in shelf waters of the east and west coasts of North America. Recently. rare-earth magnets and metals have been shown to have deterrent effects on sharks. These effects are likely the result of magnetic or electric fields created by these materials in seawater, which are sensed and avoided by sharks. Our earlier laboratory studies showed that attack rates by spiny dogfish on baits protected with cerium mischmetal (a rare-earth alloy) were reduced and Suggested that this metal might reduce unwanted bycatch of spiny dogfish in setline fishing for Pacific halibut (Hippoglossus stenolepis). We conducted a field study near Homer, Alaska in September 2007 with three hook treatments interspersed on 36 longline sets. These included standard circle hooks used in the halibut fishery, hooks with small pieces of cerium mischmetal attached above the hook. and hooks with a similar (but inert) mild steel piece above the hook. Fewer dogfish were caught on hooks with mischmetal than on either of the two other treatments. Reductions in catch of longnose skate (Raja rhina) also occurred on hooks protected with mischmetal. However, halibut catch did not increase with protected hooks. Limitations in using mischmetal in commercial operations are expense, hazardous nature, and relatively rapid hydrolysis in seawater.

Kaplan, I. C., Cox, S. P., & Kitchell, J. F. (2007). Circle hooks for Pacific longliners: Not a panacea for marlin and shark bycatch, but part of the solution. *Transactions of the American Fisheries Society,* 136(2), 392-401. https://doi.org/10.1577/t05-301.1

Blue marlin Makaira nigricans, striped marlin Tetrapturus audax, and pelagic sharks (e.g., blue shark Prionace glauca) are commonly caught as bycatch by longline fisheries in the central North Pacific Ocean. Recently, concern has increased about depletion of these species. Modifications in longline gear may offer one solution. Here. we test the use of circle hooks, rather than the conventional tuna-style hooks, on longlines using an ecosystem model of the central North Pacific Ocean. The simulations considered span a range of reasonable circle hook catchability and Survival rates for released fish. The results suggest that if circle hooks have higher catchability than the Currently used tuna-style hooks, switching to circle hooks depletes marlin biomass by 25-40% and shark biomass by 15-35% over 30 years. However. these depletions do not occur if circle hook catchability is equal to or lower than that of tuna-style hooks. When the effects of catch-and-release requirements for marlins and sharks were also considered. we found that regardless of assumptions about circle hook catchability and survival rates, a combined policy of using circle hooks and releasing sharks and marlins leads to net increases in marlin and shark abundance. The simulations show a trade-off between the abundance of marlins and sharks and their prey items, yellowfin tuna Thunnus albacares and small blue sharks. There is also evidence of trophic trade-offs between yellowfin tuna and small blue sharks and their prey, small scombrids (Auxis spp.) and mahi mahi Coryphaena hippurus. The results illustrate the importance of understanding catchability and survival rates for circle hooks compared with those for tuna-style hooks and encourage further research in this area.

Keller, B. A., Swimmer, Y., & Brown, C. A. (2020). *Review on the effect of hook type on the catchability, hooking location, and post-capture mortality of the shortfin mako, Isurus oxyrinchus*.(PIFSC working paper WP-20-003). Pacific Islands Fishery Science Center Retrieved from https://repository.library.noaa.gov/view/noaa/25889

Due to the assessed vulnerability for the North Atlantic shortfin mako, Isurus oxyrinchus, ICCAT has identified the need to better understand the use of circle hooks as a potential mitigation measure in longline fisheries. We conducted a literature review related to the effect of hook type on the catchability, anatomical hooking location, and post-capture mortality of this species. We found twenty eight papers related to these topics, yet many were limited in interpretation due to small sample sizes and lack of statistical analysis. In regards to catchability, our results were inconclusive, suggesting no clear trend in catch rates by hook type. The use of circle hooks was shown to either decrease or have no effect on at-haulback mortality. Three papers documented post-release mortality, ranging from 23-31%. The use of circle hooks significantly increased the likelihood of mouth hooking, which is associated with lower rates of post-release mortality. Overall, our review suggests minimal differences in catchability of shortfin mako between hook types, but suggests that use of circle hooks likely results in higher post-release survival that may assist population recovery efforts.

Kennelly, S. J., Melli, V., & Broadhurst, M. K. (2018). *Reducing bycatch using modifications to sweeps and lines anterior to the trawl mouth - collaboration with the Technical University of Denmark.* FRDC Project No. 2017/097 Retrieved from https://www.frdc.com.au/project/2017-097

Prawn trawling is among the world's least selective fishing methods and there has been a great deal of work done over the past few decades to develop modifications that reduce unwanted bycatches. Much of this work has focussed on modifications at, or near, the codend (at the aft section) of trawls, but more recent efforts have examined ways to stop fish entering the trawl at all—via modifications to their anterior components (or forward section).New South Wales (NSW) Department of Primary Industries (DPI) Fisheries Conservation Technology Unit (FCTU) has led such work with prawn trawls in Australia. Another group based in Denmark (the Danish Technical University's team in Hirtshals – DTU Aqua) has grown to be among the European leaders with similar work directed at Nephrops and fish trawls and is a major centre for work being done to underpin the European 'landings obligation' (often termed the 'discard ban'). The current project took advantage of a travel grant for a PhD student at DTU Aqua to: (i) establish a link and exchange of ideas between the Australian and the Danish teams; whilst (ii) exploring ways of refining anterior-trawl modifications to reduce bycatch in our prawn fisheries.

Kerstetter, D. W., & Graves, J. E. (2006). Effects of circle versus J-style hooks on target and non-target species in a pelagic longline fishery. *Fisheries Research,* 80(2-3), 239-250. https://doi.org/10.1016/j.fishres.2006.03.032

The U.S. Atlantic coastal pelagic longline fishery that targets tunas and swordfish also interacts with a wide range of non-target species including billfishes and sea turtles. Preliminary studies indicate that a change in terminal gear from J-style hooks to circle hooks may reduce bycatch mortality, but the effects of this change on catch rates of target species are unclear. To evaluate this, we monitored catch composition, catch rates, hooking location, and number of fish alive at haulback during 85 sets in the fall and spring seasonal fisheries from a commercial vessel operating in the western North Atlantic. Circle (size 16/0, 0 degrees offset) and J-style (size 9/0, 10 degrees offset) hooks were deployed in an alternating fashion. Hook-time recorders were used to assess time at hooking and temperature-depth recorders to measure gear behavior. Catch rates for most species categories were not significantly different between hook types (P < 0.05), although circle hooks generally had higher tuna catch rates in the fall and lower swordfish catch rates in the spring. In :he fall, both total catches and catches of pelagic rays were significantly higher on J-style hooks. Yellowfin tuna in the fall and dolphinfish in the spring caught on circle hooks were significantly larger than those caught on J-style hooks. In both seasonal fisheries, circle hooks caught fishes in the mouth more frequently than J-style hooks, which hooked more often in the throat or gut, although these differences between hook types were not statistically significant. Yellowfin tuna in the fall fishery were over four times more likely to be hooked in the mouth with circle hooks than with J-style hooks. Several target and bycatch species showed higher rates of survival at haulback with circle hooks, although only for dolphinfish in the fall fishery was this difference statistically significant. Our results suggest that the use of 0 degrees offset circle hooks in the coastal pelagic longline fishery will increase the survival of bycatch species at haulback with minimal effects on the catches of target species.

Kim, S.-S., Moon, D.-Y., Boggs, C., Koh, J.-R., & An, D.-H. (2006). Comparison of circle hook and J hook catch rate for target and bycatch species taken in the Korean tuna longline fishery. *Journal of the Korean society of Fisheries Technology,* 42(4), 210-216. https://doi.org/10.3796/ksft.2006.42.4.210

The circle hook experiments were conducted to compare the catch rates of target and bycatch species between J hook and circle hooks in the tuna longline fishery of the eastern Pacific Ocean between from July 15 to August 12, 2005. In the target species group no significant differences among 3 types hook, between size 4.0 traditional tuna hooks(J-4) and size 15 circle hooks(C15), and between C15 and size 18 circle hooks(C18) were revealed, but significant differences were found between J-4 and C18. In the bycatch species group significant differences were found among 3 types hook, between J 4 and C15, and between J-4 and C18, but no significant differences were revealed between C15 and C18. Large circle hook(C18) had the lowest catch rate for tunas and for other fishes, and the small circle hook(C15) had lowest rate for billfishes and sharks. The length distributions for bigeye tuna are very similar for the 3 hook types. There were very slight differences in length size between hook types in the bycatch species.

Kumar, K. V. A., Khanolkar, P. S., Pravin, P., Madhu, V. R., & Meenakumari, B. (2013). Effect of hook design on longline catches in Lakshadweep Sea, India. *Indian Journal of Fisheries,* 60(1), 21-27. Retrieved from https://agris.fao.org/agris-search/search.do?recordID=IN2022010629

Tuna longlining is considered as an ecofriendly, economical, species-selective and size-selective fishing technique suitable for harvesting sparsely distributed large predatory fishes. Many non-targeted and protected species like marine turtles, seabirds, cetaceans and sharks are also caught as bycatch in the pelagic longline gear. Investigations were undertaken to evaluate the effect of hook design on the longline catches in Lakshadweep Sea by comparing the species selection efficiency, bait holding efficiency and hooking pattern of the Japanese and circle hook designs. The results indicated that hook design has no effect on the catching efficiency, species selectivity and bait holding ability in pelagic longline fisheries in Lakshadweep Sea. The hooking pattern was found to be significantly different, indicating favorable hooking locations in the case of circle hooks. The results of the present study, indicated the positive effects of circle hooks in minimising the impact of bycatch by hooking on the fish favouring post-release survival of the species.

Kumar, K. V. A., Pravin, P., & Meenakumari, B. (2016). Bait, Bait Loss, and Depredation in Pelagic Longline Fisheries-A Review. *Reviews in Fisheries Science & Aquaculture,* 24(4), 295-304. https://doi.org/10.1080/23308249.2016.1162134

This article reviews the importance of bait, bait loss, and depredation in longline fishery operations worldwide. In general, fish bait is preferred over squid due to reduced sea turtle and elasmobranch bycatch. However, there are many reports which have indicated high shark catch and deep hooking when using fish as bait. High and low hooking rates for blue shark have been reported from different fishing areas when using mackerel as bait, indicating the need for further studies on selection of appropriate baits. Conflicting results from many part of the world on the catching efficiency of different bait species on target and nontarget species indicate the need to consider area, species specific and cross taxa effect of various combinations of baits and hooks, before their adoption in commercial fishing. Baiting pattern has also been reported to affect the catch rates significantly. The review has revealed that bait loss and depredation on the hooked fish cause considerable damage to the fishery

and significant economic loss. Loss rates can be significantly minimized using squids as bait while it may also incur a high catch rate of bycatch. The review has confirmed the superiority of natural baits over alternative and artificial baits during the longline fishing operations. Though an effective substitute for the natural bait has not been developed, so far, such alternatives which make use of the food and foraging behavior and the olfactory response of the fish are necessary for future development of longline fisheries.

Kynoch, R. J., Fryer, R. J., & Neat, F. C. (2015). A simple technical measure to reduce bycatch and discard of skates and sharks in mixed-species bottom-trawl fisheries. *ICES Journal of Marine Science,* 72(6), 1861-1868. https://doi.org/10.1093/icesjms/fsv037

Due to global declines, skates and sharks have become a focus of marine conservation in recent years. Despite protective measures, they remain vulnerable to bycatch by fisheries, especially bottom-trawls and pose a problem for fisheries management measures that aim to eliminate discards in the future. In the mixed-species bottom-trawl fisheries of the North Atlantic catches can be increased by fitting a length of chain known as a "tickler" in front of the groundgear of the trawl. It was hypothesized that the tickler is especially effective at catching skates and rays that may otherwise escape beneath the net. A trial was undertaken with paired tows with and without the tickler chain. The trial demonstrated that the catch rate of skates and sharks can be significantly lowered by removing the tickler. A set of secondary nets (groundgear bags) attached behind the groundgear of the main net allowed the number of fish escaping under the net to be estimated and showed that the reduction of skates and sharks in the main net was accompanied by an increase in number in the groundgear bags. This suggests that prohibition of the use of tickler chains in areas that are known to be especially important to skates and sharks could have conservation benefits. The removal of the tickler chain had little effect on catch rates of haddock, whiting, and flatfish, but caused a marked decrease in the catch rate of commercially valuable anglerfish.

Li, J., Song, L., & Li, D. (2013). *The capture depth of the dominant bycatch species and the relationship between their catch rates and the sea surface temperature.* Indian Ocean Tuna Commission, Retrieved from https://www.fao.org/3/bh060e/bh060e.pdf

On the basis of the data collected on a pelagic longline vessel from November 18, 2012 through March 31, 2013 in the fishing area of the Indian Ocean (2°47'N~8°13'S,62°18'E~ 67°49'E), the capture depth of the dominant bycatch species and the relationship between their catch rates and the sea surface temperature were analyzed. The results showed that (1) blue shark (Prionace glauca) mainly inhabited the water layer of 80~160m, the water layer with the highest catch rate was 120~160m, followed by 80~120m, the catch rate of remaining water layers was low; (2) swordfish (Xiphias gladius) mainly inhabited the water layer of 80~200m, the catch rate of this water layer increased at first then decreased, the catch rate in the water layer of 120~160m was the highest and much higher than that of other water layers; (3) blue marlin (Makaira nigricans) was mainly caught in the water layer of 80~200m, the catch rate of this water layer was high, and the catch rate peaked in the water layer of 160~200m. The catch rate in the water layer of 200~280m was low, and decreased with depth; (4)striped marlin (Tetrapturus audax) was caught in the water layer of 80~200m, no striped marlin was caught in other water layer, the catch rates decreased with depth; (5) crocodile shark was caught in the water layer of 200~320m, no crocodile shark was caught in other water layer, the catch rates increased with depth; (6)the catch rates of blue shark increased with the increasing of the sea surface temperature, peaked at

30.1~30.5°C; the catch rates of swordfish and blue marlin peaked at 29.6~30°C; the catch rates of striped marlin were high at 29.6~31°C and peaked at 30.1~30.5°C; the catch rates of crocodile shark peaked at 30.6~31°C. This study suggested that the depth of the pelagic longline hook should be deployed deeper than 160m and shallower than 280m or avoid operation in the area where the sea surface temperature is higher than 29.6°C to reduce the bycatch of blue shark, swordfish, blue marlin and striped marlin.

Massey, Y., Sabarros, P. S., & Bach, P. (2022). Drivers of at-vessel mortality of the blue shark (Prionace glauca) and oceanic whitetip shark (Carcharhinus longimanus) assessed from monitored pelagic longline experiments. *Canadian Journal of Fisheries and Aquatic Sciences,* 79(9), 1407-1419. https://doi.org/10.1139/cjfas-2021-0273

Elasmobranchs make up a significant part of bycatch in pelagic longline fisheries, whose induced mortality can be a major threat to endangered species. It is therefore crucial to understand the drivers of at-vessel mortality (AVM) for this fishing gear to enhance postrelease survival. To this end, we analysed scientific data collected during monitored longline fishing experiments conducted in French Polynesia to (i) estimate AVM for each species based on bootstrapped samples and (ii) to assess AVM drivers using multivariate logistic regression models for the blue shark (Prionace glauca) and oceanic whitetip shark (Carcharhinus longimanus). We found that AVM varies widely between species. Oceanic whitetip sharks are more likely to die when caught in waters outside their comfort temperature range, and their odds of survival increase with body length. For the blue shark, the only driver related to AVM is hooking duration. These results indicate that to reduce the AVM of these two species, the vertical distribution of hooks and soak duration should be considered as mitigation measures related to pelagic longlining.

McCutcheon, S. M. (2012). *Lanthanide metals as potential shark deterrents.* Florida Atlantic University, Master of Science. Retrieved from https://www.bmis-bycatch.org/references/sa8sgprh

Sharks comprise a large portion of bycatch in pelagic longline fisheries worldwide. Lanthanide metals have been proposed as shark repellents. This study quantified the normalized voltage of lanthanide metals in seawater and found that there was no difference in normalized voltage among the six tested metals. Temperature and salinity had a significant effect on lanthanide normalized voltage. The output at 18C was significantly greater than at both 12 and 24C. The normalized voltage was significantly greater in freshwater than brackish or seawater. The dissolution rate for the lanthanides varied from -1.6 to -0.2g/h. As the metals dissolved the voltage remained constant. In a behavioral assay, neodymium was ineffective at repelling bonnethead sharks (Sphyrna tiburo) tested individually and in groups, and lemon sharks (Negaprion brevirostris) in groups. Due to high cost, fast dissolution rates, and lack of deterrent effects, lanthanide metals are not recommended for use in mitigating shark bycatch.

McCutcheon, S. M., & Kajiura, S. M. (2013). Electrochemical properties of lanthanide metals in relation to their application as shark repellents. *Fisheries Research,* 147, 47-54. https://doi.org/10.1016/j.fishres.2013.04.014

Sharks comprise a large portion of unwanted bycatch in longline fisheries worldwide and various technologies have been proposed to reduce elasmobranch bycatch without impacting the catch of

target species. Recently, the naturally electrogenic lanthanide metals have been introduced as an elasmobranch-specific repellent. We quantified the voltage produced by six lanthanide metals in seawater, compared their dissolution rates, and performed a behavioral assay to determine their efficacy against two coastal shark species. We found that there was no difference in the voltage produced by the six tested metals and the voltage decayed as a power function (approximately x(-1.5)) with distance from the metal sample. We calculated that sharks should detect a sample of neodymium from a distance of 65-85 cm in seawater. Voltage was greatest in freshwater and decreased logarithmically with increasing salinity but did not differ above salinities greater than 10 ppt. The dissolution rate for the lanthanides varied from -1.6 to -0.2 g h(-1) and as the metals dissolved, the voltage remained constant. In a behavioral assay, neodymium was ineffective at repelling bonnethead sharks (Sphyrna tiburo) tested individually and in groups, and juvenile lemon sharks (Negaprion brevirostris) in groups.

Miller, K. I., Nadheeh, I., Jauharee, A. R., Anderson, R. C., & Adam, M. S. (2017). Bycatch in the Maldivian pole-and-line tuna fishery. *Plos One,* 12(5), e0177391. https://doi.org/10.1371/journal.pone.0177391

Tropical tuna fisheries are among the largest worldwide, with some having significant bycatch issues. However, pole-and-line tuna fisheries are widely believed to have low bycatch rates, although these have rarely been quantified. The Maldives has an important pole-and-line fishery, targeting skipjack tuna (Katsuwonus pelamis). In the Maldives, 106 pole-and-line tuna fishing days were observed between August 2014 and November 2015. During 161 fishing events, tuna catches amounted to 147 t: 72% by weight was skipjack, 25% yellowfin tuna (Thunnus albacares) and 3% other tunas. Bycatch (all non-tuna species caught plus all tuna discards) amounted to 951 kg (0.65% of total tuna catch). Most of the bycatch (95%) was utilized, and some bycatch was released alive, so dead discards were particularly low (0.02% of total tuna catch, or 22 kg per 100 t). Rainbow runner (Elagatis bipinnulata) and dolphinfish (Coryphaena hippurus) together constituted 93% of the bycatch. Live releases included small numbers of silky sharks (Carcharhinus falciformis) and seabirds (noddies, Anous tenuirostris and A. stolidus). Pole-and-line tuna fishing was conducted on free schools and schools associated with various objects (Maldivian anchored fish aggregating devices [aFADs], drifting FADs from western Indian Ocean purse seine fisheries, other drifting objects and seamounts). Free school catches typically included a high proportion of large skipjack and significantly less bycatch. Associated schools produced more variable tuna catches and higher bycatch rates. Fishing trips in the south had significantly lower bycatch rates than those in the north. This study is the first to quantify bycatch rates in the Maldives pole-and-line tuna fishery and the influence of school association on catch composition. Ratio estimator methods suggest roughly 552.6 t of bycatch and 27.9 t of discards are caught annually in the fishery (based on 2015 national catch), much less than other Indian Ocean tuna fisheries, e.g. gillnet, purse-seine, and longline.

Munden, J. G. (2013). *Reducing negative ecological impacts of capture fisheries through gear modification.* (Master of Science), Memorial University of Newfoundland, Retrieved from http://research.library.mun.ca/id/eprint/11100

Capture fisheries provide the world with a healthy source of protein than can have minimal environmental impacts if harvested sustainably. Negative environmental impacts of capture fisheries include; overexploitation, modification of food webs, mortality of nontarget species, habitat alteration

and biodiversity loss. A mitigation technique often used to reduce ecological impacts of fishing without compromising commercial catches is gear modification. This thesis explores modification of two gear types; shrimp trawl and turbot longline. Modifications were made to shrimp trawl footgear to reduce habitat alteration and to turbot longline gear to reduce Greenland shark bycatch. Testing of modified with traditional gears demonstrated that the modified gears with reduced ecological impacts did not negatively affect commercial catches. The 200 lb monofilament gangion is recommended for commercial testing by turbot longline fishers in Cumberland Sound; however the aligned shrimp trawl requires further modifications due to unexpected increases in turbot bycatch compared to the traditional trawl.

Murua, J., Ferarios, J. M., Grande, M., Onandia, L., & Santiago, J. (2021). *Improving on deck best handling and release practices for sharks in tuna purse seiners using hopper with ramp devices.* Scientific Committee Seventeenth Regular Session WCPFC-SC17-2021/EB-IP-13. Western and Central Pacific Fisheries Commission, Retrieved from https://meetings.wcpfc.int/node/12489

A possible bycatch reduction device (BRD) that tuna purse seiners could employ to promote safer and faster release of vulnerable bycatch, such as sharks, are hoppers with ramps. These selective hopper trays can take many shapes and sizes depending on the vessels' top deck configuration. Not all hoppers are equally valuable for bycatch release as some are either too small to access the bycatch or act as funnels with no stop mechanism to allow for time to detect and take out nontarget species. In this study four class A purse seiners operating in the Pacific Ocean and fitted with mobile hoppers were examined for shark release efficiency. Observer data results indicated that when hoppers were used on the vessels between 92% and 98% of the sharks were released from the top deck, against 21% to 46% with no hopper. Hoppers can increase shark survival because their mortality greatly increases once they reach the lower deck, where release times are delayed if there is no release exit from this area, resulting in sharks having to be carried manually upstairs. In addition, release ramps were built and trialled with the hoppers, which acted as wet slides to facilitate faster and safer release of sharks and other bycatches with minimal handling. While designs of hopper and ramps for bycatch release can still be improved, they offer a promising tool for fleets to implement best release practices of vulnerable species. Future trials will employ satellite pop-up tags to properly assess survival rates with and without hoppers. We recommend that tuna RFMOs concerned with best bycatch mitigation and crew safety practices consider the implementation of hoppers with ramps as an efficient BRD in tropical tuna purse seiners which would be in line with shark protection recommendations in CMM-2019-04 paragraph 17.

Murua, J., Moreno, G., Hall, M., Dagorn, L., Itano, D., & Restrepo, V. R. (2017). *ISSF 2017-07: Towards Global Non-Entangling Fish Aggregating Device (FAD) Use in Tropical Tuna Purse Seine Fisheries Through a Participatory Approach.* International Seafood Sustainability Foundation, Retrieved from https://www.iss-foundation.org/research-advocacy-recommendations/our-scientific-program/scientific-reports/download-info/issf-2017-07-towards-global-non-entangling-fish-aggregating-device-fad-use-in-tropical-tuna-purse-seine-fisheries-through-a-participatory-approach/

The impact of bycatch caused by cryptic fishing, including ghost fishing by gear lost at sea, is poorly understood. Since the 1980s, purse seine fishers have deployed floating objects at sea, with ten to a hundred meters deep large mesh net panels hanging beneath a floating structure, to aggregate tuna schools. Known as drifting fish aggregating devices (dFADs) their numbers have rapidly increased

globally. Unexpectedly high shark entanglement levels in dFAD netting were first identified in the Indian Ocean in 2012, when all dFADs had loosely hanging large mesh size net panels with potential for higher entanglement risk of dFAD associated species (HERFADs).Many fleets since have adopted lower entanglement risk FADs (LERFADs) and non-entangling FADs (NEFADs), which were initially designed by fishers in collaboration with scientists to minimize entanglement. The move to more sustainable FAD designs has not affected target tuna catches in any of the oceans. These advances have been supported by FAD entanglement-mitigating management measures adopted by regional fisheries management organizations (RFMOs) in the Indian, Atlantic and Eastern Pacific Oceans. Only the Western and Central Pacific region has no FAD entanglement preventive recommendations put forth by its RFMO at present.Information gathered in workshops held in all RFMO regions with skippers and vessel visits at key tuna ports indicate that LERFAD and NEFAD implementation is almost one hundred percent in the Indian and Atlantic Oceans, and very high in the Eastern Pacific Ocean. On the other hand, in the Western and Central Pacific Ocean, except for anchored FADs (aFADs), most are HERFADs. Ocean-specific studies examining shark ghost fishing rates by different FAD types are currently lacking.In addition, harmonization of NEFAD definitions and observer data collection methods across RFMOs would be useful to scientists and industry. Given the increasing number of dFADs and the vulnerable life history and poor population status of sharks, the replacement of HERFADS in the Western and Central Pacific Ocean, the largest tuna fishery in the world, for entanglement reducing designs should be promoted.

Mustika, P. L. K., Wonneberger, E., Erzini, K., & Pasisingi, N. (2021). Marine megafauna bycatch in artisanal fisheries in Gorontalo, northern Sulawesi (Indonesia): An assessment based on fisher interviews. *Ocean & Coastal Management,* 208. https://doi.org/10.1016/j.ocecoaman.2021.105606

While bycatch, the unintentional catch of untargeted species, is one of the main threats to large marine species such as cetaceans, reef sharks and turtles, also known as megafauna, fishers can also be negatively impacted by bycatch. Understanding local fisheries profiles, fishers' demography and their opinion is thus a necessary part of the strategy to mitigate marine megafauna bycatch in artisanal fisheries. Interviews with fishers were conducted in order to assess the magnitude of marine megafauna bycatch, the dependency of fishers on the fishery and the potential for implementation of bycatch mitigation measures in the artisanal fisheries in Gorontalo, northern Sulawesi (Indonesia). Quantitative and qualitative methods were used to analyse the data. Regression trees showed that cetacean and turtle bycatch were mainly influenced by the fishing location, while bycatch of reef sharks, whale sharks (Rhincodon typus) and mobulids was mainly influenced by the gear type. Cetaceans mostly escaped after being caught or were released. Reef sharks, which were often sold for their meat, were caught in the highest numbers followed by sea turtles. Interviewed fishers had large households, typically averaging more than five people, and mostly were dependent on the fishery, often with few other sources of income. Fishers were generally in favour of reducing bycatch as bycatch often posed a financial threat, due to lost catch and damaged gear. When implementing bycatch reduction measures, it is important to involve fishers in design and implementation of mitigation measures. As awareness on bycatch management and mitigation is growing in Indonesia, measures including recordings (official and self-reporting), capacity building on bycatch specimen handling and release and bycatch mitigation techniques (e.g. gear modifications) are some of the most important bycatch reduction strategies for the country.

Nunes, D. M., Hazin, F. H. V., Branco-Nunes, I. S. L., Hazin, H., Pacheco, J. C., Afonso, A. S., . . . Carvalho, F. C. (2019). Survivorship of species caught in a longline tuna fishery in the western equatorial Atlantic Ocean. *Latin American Journal of Aquatic Research,* 47(5), 798-807. https://doi.org/10.3856/vol47-issue5-fulltext-9

Longlines bearing "hook timers" (HTs) and alternating circle (15/0 and 17/0) and "J" (10/0) hooks were employed off the coast of Brazil to measure differences in fishing mortality associated with hook type and on-hook time between capture and boarding. A total of 431 HTs were activated, revealing a clear pattern of the increased mortality rate of fishes associated with increased on-hook time. Swordfish had high mortality rates, unlike blue sharks, which had low mortality rates regardless of hook type and the location in which the hook was transfixed. The six species of tunas and billfishes examined in this study showed a strong association between hooking location and the animal's release condition, with reduced mortality associated with individuals hooked externally. Results suggest that knowledge of factors affecting the survival of pelagic fishes caught in longline fisheries may enable the development and adoption of fishing methods to reduce mortality of longline bycatch.

O'Connell, C. P., Abel, D. C., Stroud, E. M., & Rice, P. H. (2011). Analysis of permanent magnets as elasmobranch bycatch reduction devices in hook-and-line and longline trials. *Fishery Bulletin,* 109(4), 394-401. Retrieved from https://spo.nmfs.noaa.gov/content/analysis-permanent-magnets-elasmobranch-bycatch-reduction-devices-hook-and-line-and

Previous studies indicate that elasmobranch fishes (sharks, skates and rays) detect the Earth's geomagnetic field by indirect magnetoreception through electromagnetic induction, using their ampullae of Lorenzini. Applying this concept, we evaluated the capture of elasmobranchs in the presence of permanent magnets in hook-and-line and inshore longline fishing experiments. Hooks with neodymium-iron-boron magnets significantly reduced the capture of elasmobranchs overall in comparison with control and procedural control hooks in the hook-and-line experiment. Catches of Atlantic sharpnose shark (Rhizoprionodon terraenovae) and smooth dogfish (Mustelus canis) were significantly reduced with magnetic hook-and-line treatments, whereas catches of spiny dogfish (Squalus acanthias) and clearnose skate (Raja eglanteria) were not. Longline hooks with barium-ferrite magnets significantly reduced total elasmobranch capture when compared with control hooks. In the longline study, capture of blacktip sharks (Carcharhinus limbatus) and southern stingrays (Dasyatis americana) was reduced on magnetic hooks, whereas capture of sandbar shark (Carcharhinus plumbeus) was not affected. Teleosts, such as red drum (Sciaenops ocellatus), Atlantic croaker (Micropogonias undulatus), oyster toadfish (Opsanus tau), black sea bass (Centropristis striata), and the bluefish (Pomatomas saltatrix), showed no hook preference in either hook-and-line or longline studies. These results indicate that permanent magnets, although eliciting species-specific capture trends, warrant further investigation in commercial longline and recreational fisheries, where bycatch mortality is a leading contributor to declines in elasmobranch populations.

Ochi, D., Okamoto, K., & Ueno, S. (2022). Multifaceted effects of bycatch mitigation measures on target/non-target species for pelagic longline fisheries and consideration for bycatch management. *bioRxiv*. https://doi.org/10.1101/2022.07.14.500149

The pelagic longline fishery, in an effort to reduce bycatch of sea turtles, have developed and deployed fisheries bycatch mitigation techniques such as replacing J/tuna hooks and squid bait with circle hooks

and whole fish bait. However, little emphasis has been placed on the side effects of bycatch mitigation measures on endangered species other than target bycatch species. Several previous studies of the side effects have been marred by lack of control for the covariates. Here, based on long-term data obtained from research cruises by a pelagic longline vessel, we examined the effects of using circle hooks and whole fish bait to replace squid bait on the fishing mortality of target and non-target fishes, and also bycatch species. A quantitative evaluation analysis of our results, based on a Bayesian approach, showed the use of circle hooks to increase mouth hooking in target and bycatch species, and their size to be proportional to the magnitude of the effect. Although deploying circle hooks increased catch per unit effort (CPUE) and fishing mortality per unit effort (MPUE), changing the bait species from squid to fish clearly had a far greater impact on shark mortality than the use of circle hooks. Because the impact of the introduction of bycatch mitigation measures on species other than the focused bycatch species is non-negligible, a quantitative assessment of bycatch mitigation-related fishing mortality is critical before introducing such measures.

Ochi, D., Ueno, S., & Okamoto, K. (2021). Assessment of the Effect of Hook Shape on Fishing Mortality of Multi-Taxa Fish Species Using Experimental Longline Operation Data. *Collective volume of scientific papers,* 78(4), 105-117. Retrieved from https://www.iccat.int/Documents/CVSP/CV078_2021/n_4/CV078040105.pdf

To evaluate the effect of circle hooks (C-hooks) on fishing mortality of fish species (blue shark, shortfin mako, striped marlin and swordfish) other than sea turtles in experimental longline operations, Bayesian estimation using statistical models was used to examine whether there were differences in haulback mortality rate, CPUE, mortality per unit effort (MPUE), and hooking position between 3.8 sun tuna hooks and size-different C-hooks. The results showed that the haulback mortality rate, CPUE, and MPUE did not improve with either size of C-hook, but rather tended to worsen. In addition, the use of the C-hook did not reduce the hook swallowing which can lead to post-release mortality. In addition, the mortality rate may be greatly influenced by environmental factors such as soak time and water temperature. These results suggest that it is necessary to consider the trade-off between the effects on sea turtles and on multi-taxa fish species when discussing the use of C-hooks.

Pacheco, J. C., Kerstetter, D. W., Hazin, F. H., Hazin, H., Segundo, R. S. S. L., Graves, J. E., . . . Travassos, P. E. (2011). A comparison of circle hook and J hook performance in a western equatorial Atlantic Ocean pelagic longline fishery. *Fisheries Research,* 107(1), 39-45. https://doi.org/10.1016/j.fishres.2010.10.003

Catch composition, catch rates, hooking location, and status at release at haulback were monitored during 81 experimental sets (launches and hauling fishing per day) in a commercial pelagic longline fishery targeting tuna in the equatorial South Atlantic Ocean. Circle hooks (size 18/0, 0° offset) and J-style hooks (size 9/0, 10° offset) with squid baits were deployed in an alternating fashion. The catch composition was not significantly different for most species between the two types of hooks, except for bigeye tuna, which showed a significantly higher proportion of catches on the circle hook ($p \gg 0.001$) and for sailfish, pelagic stingray, and leatherback sea turtle, which had higher catch rates on the J-style hook ($p=0.018$, $p \gg 0.001$, and $p=0.044$, respectively). Bigeye and yellowfin tuna showed significantly higher rates of survival at the time of gear retrieval with circle hooks, and circle hooks hooked bigeye tuna, yellowfin tuna, swordfish, and sailfish significantly more often externally than internally. Our results suggest that the use of size 18/0, 0° offset circle hooks in the equatorial pelagic longline fishery may

increase the survival of bycatch species at the time of gear retrieval with minimal effects on the catches of target species.

Patterson, H., Hansen, S. W., & Larcombe, J. (2014). *A review of shark bycatch mitigation in tuna longline fisheries.* Western and Central Pacific Fisheries Commission, Retrieved from https://purl.org/spc/digilib/doc/z22ec

A review of the most studied mitigation methods (generally defined as measures that reduce the incidence of sharks being caught on the gear) is undertaken here and is extended to include measures that reduce mortality once the shark is captured and brought to the boat.

Piovano, S., Clo, S., & Giacoma, C. (2010). Reducing longline bycatch: The larger the hook, the fewer the stingrays. *Biological Conservation,* 143(1), 261-264. https://doi.org/10.1016/j.biocon.2009.10.001

Chondrichthyan populations in the Mediterranean Sea have been heavily affected by the impact of fishing activities. In the last two decades, even fishing gears that were traditionally considered highly selective, such as pelagic longlines, have been revealed to be responsible for the capture of many unwanted species. The pelagic stingray (Pteroplatytrygon violacea) is not an endangered nor a charismatic species, but it largely dominates longlines bycatch fractions. The aim of our study was to investigate the importance of three main variables, bait size, presence and type of light attractors, and hook size and shape, in the capture rate of pelagic stingrays. Ninety-seven longline experimental sets were run. Trials took place on nine vessels in the Strait of Sicily, central Mediterranean Sea, over a period of 3 years from 2005 to 2007. Results showed that the larger the J hook, the lower the stingray capture rate. Moreover, 16/0 circle hooks had a significantly lower number of stingrays captured per 1000 hooks than J hooks, up to approximate to 80%. Bait size, within the range of sizes assessed, and use of light attractors did not have significant effects on stingray catch rate. These results suggest that the adoption of large circle hooks by commercial and artisanal swordfish longlining may be a measure to reduce their environmental footprint.

Piovano, S., & Gilman, E. (2017). Elasmobranch captures in the Fijian pelagic longline fishery. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 27(2), 381-393. https://doi.org/10.1002/aqc.2666

Pelagic longline fisheries for relatively fecund tuna and tuna-like species can have large adverse effects on incidentally caught species with low-fecundity, including elasmobranchs. Analyses of observer programme data from the Fiji longline fishery from 2011 to 2014 were conducted to characterize the shark and ray catch composition and identify factors that significantly explained standardized catch rates. Catch data were fitted to generalized linear models to identify potentially significant explanatory variables. With a nominal catch rate of 0.610 elasmobranchs per 1000 hooks, a total of 27 species of elasmobranchs were captured, 48% of which are categorized as Threatened under the IUCN Red List. Sharks and rays made up 2.4% and 1.4%, respectively, of total fish catch. Blue sharks and pelagic stingrays accounted for 51% and 99% of caught sharks and rays, respectively. There was near elimination of ?shark lines?, branchlines set at or near the sea surface via attachment directly to floats, after 2011. Of caught elasmobranchs, 35% were finned, 11% had the entire carcass retained, and the

remainder was released alive or discarded dead. Finning of elasmobranchs listed in CITES Appendix II was not observed in 2014. There were significantly higher standardized shark and ray catch rates on narrower J-shaped hooks than on wider circle hooks. Based on findings from previous studies on single factor effects of hook width and shape, the smaller minimum width of the J-shaped hooks may have caused the higher shark and ray catch rates. For sharks, the effect of hook width may have exceeded the effect of hook shape, where small increases in shark catch rates have been observed on circle vs J-shaped hooks. Shark and ray standardized catch rates were lowest in the latter half of the year. Focusing effort during the second half of the year could reduce elasmobranch catch rates. Copyright ? 2016 John Wiley & Sons, Ltd.

Piovano, S., & Swimmer, Y. (2017). Effects of a hook ring on catch and bycatch in a Mediterranean swordfish longline fishery: small addition with potentially large consequences. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 27(2), 372-380. https://doi.org/10.1002/aqc.2689

1. The purpose of this study was to investigate the effects of a circle hook ring on catch rates of target fish species and bycatch rates of sea turtles, elasmobranchs, and non- commercial fish in a shallow- set Italian swordfish longline fishery. 2. Results were compared from 65 sets from six commercial fishing vessels totalling 50 800 hooks in which ringed and non- ringed 16/ 0 circle hooks with a 10 degrees offset were alternated along the length of the longline. In total, 464 individuals were caught in the 4 years of experiment, with swordfish (Xiphias gladius) comprising 83% of the total number of animals captured. Catch rates of targeted swordfish were significantly higher on ringed hooks (CPUEringed hooks = 8.465, CPUEnon- ringed hooks = 6.654). 3. Results indicate that ringed circle hooks captured significantly more small- sized swordfish than non- ringed circle hooks (27.7% vs. 19.5%, respectively). 4. For species with sufficient sample sizes, the odds ratio (OR) of a capture was in favour of ringed hooks; significantly for swordfish (OR = 1.27 95% CI 1.04- 1.57), and not significantly for bluefin tuna (Thunnus thynnus) (OR = 1.50, 95% CI 0.68- 3.42) nor for pelagic stingray (Pteroplatytrigon violacea) (OR = 1.13, 95% CI 0.54- 2.36). All six loggerhead turtles (Caretta caretta) and three of the four blue sharks (Prionace glauca) were captured on ringed hooks, however, the small sample sizes prevented meaningful statistical analysis. 5. In summary, results from this study suggest that the addition of a ring to 16/ 0 circle hooks confers higher catchability for small- sized commercial swordfish, and does not significantly reduce catch rate of bycatch species and protected species in a Mediterranean shallow pelagic longline fishery. 6. These findings should motivate fisheries managers to consider factors in addition to hook shape when aiming to promote sustainable fishing practices. The presence of a ring has the potential to negate some conservation benefits.

Poisson, F. (2009). *Fate of the fish caught on longline gears and potential mitigation measures.* IOTC-2009-WPEB-15. Indian Ocean Tuna Commission, Retrieved from https://archimer.ifremer.fr/doc/00129/24056/22023.pdf

This document summarises some major results obtained during experiments conducted in collaboration with the Reunion Island (France) (20°-22°N and 53°-57°N) fishing industry. These studies may aid fishermen in modifying fishing operations and selecting a fishing strategy to increase economic benefits and also to reduce the impact on bycatch mortality. Firstly, we investigated the behaviour of the fishes when caught on the longline gear and the survivorship of fish hooked, using longline gears instrumented with hook time recorders (HT) and temperature depth recorders (TDR). We showed that the

percentages of fish recovered alive at hauling varied among species. The percentages of fish recovered alive up to 8 h after capture provides a rough idea of the resistance of each species to the capture process; these rates were recorded for the blue shark (Prionace glauca), the oceanic whitetip shark (Carcharhinus longimanus) and for the bigeye tuna (Thunnus obesus) and were respectively 29%, 23 % and 27% while this rate was lower for the swordfish (8%). Moreover, we demonstrated that shortening the soaking time during the fishing operation could be beneficial in many ways for fishermen. A second study on the reproduction dynamic of the swordfish in the vicinity of Reunion Island showed that the Big Old Fat Fecund Female Fish (BOFFFF) hypothesis could effectively apply to this species. Consequently, the removal of the larger, older individuals could be detrimental for the stock and the current results may be used, in the future, to support new policies preserving population age structure. One management method available to conserve older fish would be to institute slot size limits for retention (minimum and maximum size) but this potential measure to be successful need the individuals to survive their release back to the water. The last study aimed at investigating the possibility of developing a method to reduce the stress of the fishes caught with hooks. Prototypes of “sleeping hook” were developed and tested, using rod and reel, around moored fish aggregating devices (FAD’s). During the fishing experiments a total of 162 fish comprising 3 main species were caught including: yellowfin tuna (Thunnus albacares), skipjack tuna (Katsuwonus pelamis) and dolphinfish (Coryphaena hippurus). Analyses of blood chemistry stress indicators revealed the “sleeping hook” method to be successful in reducing the fish stress. Additional research should be conducted to evaluate the feasibility of reducing the soaking period in the current fishing strategy. However, the “sleeping hook” could contribute to the development of alternative fishing technology enabling also to reduce the side effect of protracted soaking times e.g. by reducing post hooking mortality and increasing the post release survivorship of species of conservation concern and unwanted sized target species.

Poisson, F., Abascal Crespo, F., Ellis, J. R., Chavance, P., Pascal, B., Santos, M. N., . . . Murua, H. (2016). Technical mitigation measures for sharks and rays in fisheries for tuna and tuna-like species: turning possibility into reality. *Aquatic Living Resources,* 29(4). https://doi.org/10.1051/alr/2016030

Tuna fisheries have been identified as one of the major threats to populations of other marine vertebrates, including sea turtles, sharks, seabirds and marine mammals. The development of technical mitigation measures (MM) in fisheries is part of the code of conduct for responsible fisheries. An in-depth analysis of the available literature regarding bycatch mitigation in tuna fisheries with special reference to elasmobranchs was undertaken. Studies highlighting promising MMs were reviewed for four tuna fisheries (longline, purse seine, driftnets and gillnet, and rod and line - including recreational fisheries). The advantages and disadvantages of different MMs are discussed and assessed based on current scientific knowledge. Current management measures for sharks and rays in tuna Regional Fishery Management Organizations (t-RFMOs) are presented. A review of relevant studies examining at-vessel and postrelease mortality of elasmobranch bycatch is provided. This review aims to help fisheries managers identify pragmatic solutions to reduce mortality on pelagic elasmobranchs (and other higher vertebrates) whilst minimizing impacts on catches of target tuna species. Recent research efforts have identified several effective MMs that, if endorsed by t-RFMOs, could reduce elasmobranchs mortality rate in international tropical purse seine tuna fisheries. In the case of longline fisheries, the number of operational effective MMs is very limited. Fisheries deploying driftnets in pelagic ecosystems are suspected to have a high elasmobranchs bycatch and their discard survival is uncertain, but no effective MMs have been field validated for these fisheries. The precautionary bans of such gear by the EU and by some t-RFMOs seem therefore appropriate. Recreational tuna fisheries should be accompanied by

science-based support to reduce potential negative impacts on shark populations. Priorities for research and management are identified and discussed.

Porsmoguer, S. B., Bănaru, D., Boudouresque, C. F., Dekeyser, I., & Almarcha, C. (2015). Hooks equipped with magnets can increase catches of blue shark (Prionace glauca) by longline fishery. *Fisheries Research,* 172, 345-351. https://doi.org/10.1016/j.fishres.2015.07.016

Blue shark (Prionace glauca) populations are decreasing worldwide and the species is currently classified as near threatened. However, it is the main species caught by the Spanish and Portuguese longline fisheries; and blue shark is specifically targeted by a part of these fleets in the northeastern Atlantic Ocean. Sharks are well known to be able to detect electric fields in the microvolt range and this sense has been proposed to provide a mechanism to detect the earth's magnetic field. As a result, the use of magnets has been proposed as a method to reduce shark interactions with fishing gear. We therefore tested two models of high field strength neodymium magnets to effect shark catch rates during commercial longline fishing operations. Our results show that magnets do not reduce blue shark catch rates and can even have an attractive effect. This effect was significantly higher for the larger magnet model tested (26mm×11mm×12mm, 0.885T) compared to the smaller one (20mm×13mm×15mm, 0.464T). We also noted that hooks remain magnetized after removal of the magnets and are even slightly magnetized without any previous contact with a magnet.

Promjinda, S., Siriraksophon, S., Darumas, N., & Chaidee, P. (2008). Efficiency of the circle hook in comparison with J-hook in longline fishery. In *The Ecosystem-Based Management Fishery in the Bay of Bengal.* (pp. 167-181): Ministry of Agriculture and Cooperatives, Thailand Retrieved from http://map.seafdec.org/downloads/BIMSTEC/015-Efficiency-Sayan.pdf

Tests were conducted aboard pelagic longline vessels in the Bay of Bengal to determine if there were differences in the catch composition, catch rate, hooking position or length frequency of target and bycatch species caught with circle and J-hooks. Circle hooks caught similar percentages of both target (46.7%) and bycatch (53.3%) species, while J-hooks caught a higher percentage of bycatch (74.5%) species. Catch rates for the target species were higher for circle hooks (2.2 individuals/1,000 hooks) compared to J-hooks (1.9 individuals/1,000 hooks). In contrast, catch rates for the bycatch species were higher on J-hooks (5.6 individuals/1,000 hooks) than circle hooks (2.6 individuals/1,000 hooks). For the target species, swordfish had the higest catch rates for both hook types but catch rates were slightly higher on circle hooks. Close to three quarters (73.3%) of fish were hooked in the mouth when circle hooks were used while only half (53%) were hooked in the mouth, and 38% in the digestive system, when J-hooks were used. Swordfish caught with J-hooks were slightly larger (mode of 250-269 cm) than those caught with circle hooks (mode 210-229 cm).

Raborn, S. W., Gallaway, B. J., Cole, J. G., Gazey, W. J., & Andrews, K. I. (2012). Effects of Turtle Excluder Devices (TEDs) on the Bycatch of Three Small Coastal Sharks in the Gulf of Mexico Penaeid Shrimp Fishery. *North American Journal of Fisheries Management,* 32(2), 333-345. https://doi.org/10.1080/02755947.2012.678962

The stock of blacknose sharks Carcharhinus acronotus in the U.S. South Atlantic and the Gulf of Mexico is overfished, and according to the 2007 stock assessment conducted by the National Marine Fisheries

Service overfishing continues to occur. Penaeid shrimp trawl bycatch rates in the Gulf of Mexico were modeled for this species as well as for the Atlantic sharpnose shark Rhizoprionodon terraenovae and bonnethead shark Sphyrna tiburo using a combination of research trawl and observer data. Research trawls have never used turtle excluder devices (TEDs), which are expected to exclude larger specimens of blacknose sharks. Most of the observer data that contain blacknose shark occurrences were collected during the pre-TED era when the two data sets tracked one another. Minimum observer data were available for the post-TED period (1990-present). As a consequence, the pre-TED (1972-1989) relationship between observer and research trawl catch per unit effort (CPUE) is driving the observer CPUE estimates from 1990 to the present, a period characterized by increased blacknose shark abundance. We suspected that the increase in predicted observer CPUE in the post-TED era is an artifact of application of the pre-TED observer and research trawl relationship to the post-TED era. This suspicion led us to question whether the bycatch of these species was altered due to the use of TEDs. We used negative binomial regression in a before-after-control-impact setting to test the effects of TEDs on the bycatch rates of these small coastal sharks. The TED effect was found to substantially reduce the bycatch of blacknose sharks (by 94%) and to do so moderately for bonnethead sharks (31%); the results were inconclusive for Atlantic sharpnose sharks. The management implication of our findings is that the existing small coastal shark-penaeid shrimp fishery bycatch model needs to be modified or replaced with a model that explicitly incorporates the potential for a TED effect.

Ramirez-Amaro, S., & Galvan-Magana, F. (2019). Effect of gillnet selectivity on elasmobranchs off the northwestern coast of Mexico. *Ocean & Coastal Management,* 172, 105-116. https://doi.org/10.1016/j.ocecoaman.2019.02.001

The regulation of mesh size is important for the effective and sustainable management of fisheries using gillnets, which are the main fishing gear used in artisanal elasmobranch fisheries throughout northwestern Mexico. Gillnet selectivity studies focusing on elasmobranchs have generally evaluated the impact on target species, and information on bycatches remains scarce. This study assessed the impact of gillnet selectivity on both target elasmobranch species and bycatches, by varying the mesh size of gillnets. Sampling was performed from 2009 to 2015 in five artisanal fishing grounds located along the northwestern coast of Mexico. The species composition and ecological parameters of the elasmobranch communities that were caught, as well as the size structure and estimated selectivity models for the main species caught, were compared between four mesh sizes: 10.16, 15.24, 20.32 and 25.4 cm (stretched opening). Overall, 32 elasmobranch species were caught, nine of which were common to all mesh sizes. Our results indicate that the species composition of the catch varied with mesh size. While the small-sized sharks Mustelus californicus and M. henlei were the main species caught by gillnets with the smaller mesh sizes, the guitarfish Pseudobatos productus and Zapteryx exasperata, and the Pacific angel shark Squatina californica were the main species caught gillnets with the largest mesh sizes. Gillnet selectivity was estimated for these latter four species as well as for the horn shark Heterodontus francisci. Optimum length for these species varied widely, increasing proportionally to mesh size. These findings emphasize the difficulty of determining an optimal minimum mesh size for multi-species fishery in this area. Finally, recommendations for future directions according to the species' vulnerability to fishing are discussed, focusing on the development of effective strategies to initiate or strengthen the recovery of elasmobranchs of the northwestern coast of Mexico.

Raudzens, E. (2007). *At sea testing of the Popeye Fishbox bycatch reduction device onboard the FV Adelaide Pearl for approval in Australia's northern prawn fishery*. Australian Fisheries Management Authority Retrieved from https://www.fish.gov.au/Archived-Reports/2014/Documents/Raudzens_2007.pdf

Tests were conducted to determine if twin trawl nets containing a Turtle Excluder Device (TED) and a Popeye Fishbox caught less bycatch then nets fitted only with a TED. Nets that had the Popeye Fishbox located 70 meshes from the codend draw strings had a 48% reduction in the weight of small bycatch, an 87% reduction in number of sea snakes and a 35% reduction in the number of sharks and rays caught. When the Popeye Fishbox was placed 100 meshes from the codend draw strings, the weight of small bycatch was reduced by 28% and the number of sharks and rays was reduced by 27%. No analysis of sea snake bycatch at this distance was carried out. There was no significant difference in the catch of targeted prawns between nets with and without the Popeye Fishbox.

Reinhardt, J. F., Weaver, J., Latham, P. J., Dell'Apa, A., Serafy, J. E., Browder, J. A., . . . Blankinship, D. R. (2018). Catch rate and at-vessel mortality of circle hooks versus J-hooks in pelagic longline fisheries: A global meta-analysis. *Fish and Fisheries,* 19(3), 413-430. https://doi.org/10.1111/faf.12260

We conducted a meta-analysis of literature reporting on the use of circle hooks and J-hooks in pelagic longline fisheries. Our study included more data than previous meta-analyses of the effects of hook type, due to both a larger number of relevant studies available in recent years and a more general modelling approach. Data from 42 empirical studies were analysed using a random effects model to compare the effects of circle hooks and J-hooks on catch rate (43 species) and at-vessel mortality (31 species) of target and bycatch species. Catch rates with circle hooks were greater for 11 species, including four tuna species, six shark species and one Istiophorid billfish. Catch rates on circle hooks were lower for seven species, including two Istiophorid billfishes and two species of sea turtle. At-vessel mortality was significantly lower with circle hooks in 12 species, including three tuna species, three Istiophorid billfishes, swordfish (Xiphias gladius) and three shark species. No species had significantly greater at-vessel mortality when captured with a circle hook rather than a J-hook. While our general approach increased model variability compared to more detailed studies, results were consistent with trends identified in previous studies that compared the catch rates and at-vessel mortality (between hook types) for a number of species. Our results suggest that circle hooks can be a promising tool to reduce mortality of some bycatch species in pelagic longline fisheries, although the effects depend on the species and the metric (catch rate or at-vessel mortality), emphasizing the need for fishery-specific data in conservation and management decisions.

Rice, P. H., Goodyear, C. P., Prince, E. D., Serafy, J. E., & Snodgrass, D. (2006). Hook Time At Depths For Experimental Longline Sets In The Windward Passage In 2003. *Collective volume of scientific papers,* 59(1), 170-181. Retrieved from https://www.iccat.int/Documents/CVSP/CV059_2006/n_1/CV059010170.pdf

We monitored hook time at depth for experimental longlines set in the Windward Passage in 2003 using time depth recorders (TDRs) attached at regular intervals along the mainline. The TDRs were placed on every 13 th hook (~43 TDRs per set) resulting in a 7-9% coverage at the deepest point in the corresponding basket and once in every section of the set, an additional TDR was placed on the

shallowest hook in a specific predetermined basket. The experiment monitored ten pelagic longline sets with an average distance of 46.9 + 2.8 kilometers (25.3 + 1.5 nautical miles). Thirteen taxa of fish were caught by the longline fishing gear. The target species were swordfish (46% total catch) and tuna (24% total catch). Marlin dominated the bycatch (15% of the total catch) and sharks comprised the remainder of the fish by-catch (7% total catch). Time at depth for individual instruments was a poor predictor of time at depth for the other TDRs at the same hook position on the same set, and an even worse predictor of the depths fished on other sets.

Rice, P. H., Serafy, J. E., Snodgrass, D., & Prince, E. D. (2012). Performance Of Non-Offset And 10 Degrees Offset 18/0 Circle Hooks In The United States Pelagic Longline Fishery. *Bulletin of Marine Science,* 88(3), 571-587. https://doi.org/10.5343/bms.2011.1095

Industry standard fishing hooks used prior to 2004 during US commercial pelagic longline (PLL) fishing were the 8/0-10/0 J-hooks with a 20 degrees-25 degrees offset-a lateral deviation of the hook point relative to the hook shaft. However, federal regulations enacted in 2004 require the US PLL industry to employ circle hooks allowing up to 10 degrees offset during fishing operations. Until recently, there have been no studies directly comparing the performance of non-offset and 10 degrees offset circle hooks in commercial PLL applications. Our study alternated non-offset and 10 degrees offset circle hooks along the gear length on individual PLL deployments in the western North Atlantic, Gulf of Mexico, and Windward Passage in the Caribbean Sea. The study compared the relative performance of both hook types in terms of: (1) catch rates, (2) percent mortality, and (3) the percentage of deep-hooked target and bycatch species. For swordfish, Xiphias gladius (Linnaeus, 1758), several experiments indicate: (1) marginally higher catch rates, (2) significantly lower mortality, and (3) significantly less deep hooking on non-offset than 100 offset circle hooks. Most of the performance differences for blue marlin, Makaira nigricans Lacepede, 1802, were insignificant; however, one study produced significantly higher mortality on 10 degrees offset than non-offset circle hooks. The present study suggests that, relative to non-offset circle hooks, 10 degrees offset circle hooks may reduce fishing efficiency and can counteract the conservation benefits commonly associated with circle hooks (e.g., lower mortality). However, additional research is required to assess the effects of offset hooks on tunas, billfishes, and elasmobranchs.

Richards, R. J., Raoult, V., Powter, D. M., & Gaston, T. F. (2018). Permanent magnets reduce bycatch of benthic sharks in an ocean trap fishery. *Fisheries Research,* 208, 16-21. https://doi.org/10.1016/j.fishres.2018.07.006

Sharks and rays are often caught as bycatch by commercial fisheries, and high incidences of bycatch are partially to blame for the declines in many populations of elasmobranchs. In an effort to reduce rates of bycatch, researchers have tested various deterrents that could benefit fisheries. Permanent magnets are one promising form of bycatch reduction device, yet their efficacy has only been tested for hook-and-line fisheries with variable results. Here, we examined the potential benefits of permanent magnets on an ocean fish trap fishery targeting snapper (Pagrus auratus) where more than 10% of the total catch is comprised of unwanted elasmobranchs and the presence of elasmobranchs reduces the catch of target species. Over 1000 fish traps were deployed in a fishery-dependent survey in New South Wales, Australia. Standardised catch rates indicate that the incorporation of magnets into fish traps significantly reduced incidences of elasmobranch bycatch (mainly Brachaelurus waddi) by over a third, while increasing the amount of target fish caught by an equivalent amount. Together these results suggest

that magnets can be used as an effective bycatch reduction device that reduces incidences of elasmobranch bycatch while increasing the profitability of fish traps for fishermen. Future studies should aim to replicate these results in areas where different species of elasmobranchs occur.

Rosa, D., Santos, C. C., & Coelho, R. (2020). Assessing the effects of hook, bait and leader type as potential mitigation measures to reduce bycatch and mortality rates of shortfin mako: a meta-analysis with comparisons for target, bycatch and vulnerable fauna interactions. *Collective Volume Of Scientific Papers,* 76, 247-278. Retrieved from http://www.iccat.es/en/pubs_CVSP.htm

A meta-analysis of 24 publications was conducted to assess effects of hook, bait and leader type on retention rates of target, bycatch and vulnerable species of the pelagic longline fishery. Retention rate and at-haulback mortality rate analyses considered hook type, bait type, the combination of both variables and leader type. Turtles and swordfish had a lower retention rate with circle hooks. In contrast, retention rates of 3 sharks and 2 tuna species were greater with circle hooks. Bait type alone did not seem to significantly influence the retention rates of most of the species examined. Results were mixed when considering the combined effects of hook and bait type. Wire leader led to a decrease in retention rates of bony fishes and a mix for elasmobranchs. For at-haulback mortality, hook type was the most influential, while bait type only influenced blue shark at-haulback mortality. Leader type did not have a significant effect. The results presented here should be considered preliminary. Future work will consider information on at-haulback mortality rates for bony fishes and sea turtle and expanded information on fishery characteristics.

Sacchi, J. (2019). *Mitigation Measures for Protected Species.* Paper presented at the Seventh Meeting of the Parties to ACCOBAMS. Retrieved from https://accobams.org/wp-content/uploads/2019/04/MOP7.Doc30_Mitigation-measures-for-protected-species.pdf

Highly migratory for the most part, occupying a wide distribution across the oceans, the marine megafauna undergo all possible forms of human pressure. Among them, bycatch fishery has increased exponentially in recent years and is now considered the most serious threat to these highly vulnerable species. Minimizing bycatch, is therefore a key component of sustainable fisheries management to maintain marine biodiversity and consequently to reduce negative effects on the resources (see Hall, 1996; Hall et al., 2000). The aim of this document is to present various experimented approaches and strategies that could also serve as an example for fisheries facing the same problems. This review of the different mitigation measures draws on the analysis of the available literature, comprising scientific journal articles together with reports from international organisations and documents available on the internet. The presentation adopted here is guided by the principle that it is not species that should be managed but fishing activities (metiers)1 that should be the target of the technical or management measures that are required to reduce the negative impacts of interactions with fisheries. Consequently, for each of the main fishing gear groups (gill and trammel nets, longlines and lines, trawls, purse seines, trapnets and pots) the various solutions found in the documents consulted are classified by the four main groups of protected species (Cetaceans, Birds, Sharks and Sea turtles).

Saidi, B., Echwikhi, K., Enajjar, S., Karaa, S., Jribi, I., & Bradai, M. N. (2020). Are circle hooks effective management measures in the pelagic longline fishery for sharks in the Gulf of Gabès? *Aquatic Conservation: Marine and Freshwater Ecosystems,* 30(6), 1172-1181. https://doi.org/10.1002/aqc.3315

This study evaluated the circle hook use as a tool for shark management in the pelagic longline fishery in the Gulf of Gabès. The usual J-hook No. 2 with 10° offset, which has been traditionally used by the fishery, was compared to the 18/0 non-offset circle hook in an alternating fashion along the main line. In total, 22 experimental longline sets were deployed through the shark fishing seasons of 2016 and 2017 to examine the effects of hook types on the catch composition, the catch rates, the hooking location, and the status at haulback. The catch composition differed significantly among hook types. Moreover, an overall increase in catch rates for the main species, the sandbar shark Carcharhinus plumbeus, and the shortfin mako shark Isurus oxyrinchus, was observed when using circle hooks. There was no size-selective effect of circle hooks for the common species. The circle hooks were not effective at reducing at-haulback mortality of sandbar shark. Conversely, shortfin mako and smooth-hound shark Mustelus mustelus showed significantly lower relative mortality at haulback with circle hooks than with J-hooks. Furthermore, circle hooks were more frequently hooked externally than the J-hooks for the three shark species. Results demonstrated that the use of 18/0 non-offset circle hooks in the pelagic shark longline fishery can reduce mortality at haulback for some species without any benefit for the dominant species, the sandbar shark. Overall, it is difficult to promote the adoption of the use of circle hooks as a management measure in this specialized fishery. Management measures focusing on fishing effort controls, fishing closures in critical habitats, and size limits could have significant benefits for the conservation of shark species and may help to improve the sustainability of the shark fishery in the Gulf of Gabès.

Sancristobal, I., Martinez, U., Boyra, G., Muir, J., Moreno, G., & Restrepo, V. R. (2017). ISSF Bycatch Reduction Research Cruise On The F/V Mar De Sergio In 2016. *Collective volume of scientific papers,* 73(9), 3152-3162. Retrieved from https://www.iccat.int/Documents/CVSP/CV073_2017/n_9/CV073093152.pdf

A research cruise in support of the International Seafood Sustainability Foundation (ISSF) bycatch reduction project was conducted on the tuna purse seine vessel MAR DE SERGIO, during March-April 2016 in the eastern tropical Atlantic Ocean. During a 4-week period a group of three scientists joined the fishing trip with the following objectives: (1) Improving pre-set estimation of species composition, sizes, and quantities of tunas associated with FADs using acoustics: Attaching fishers´ echo-sounder buoys from four different brands to the FADs to compare signals; (2) Use of three scientific echo-sounders with frequencies of 38, 120 and 200 kHz and an EK80 wideband echo-sounder for the frequency band from 85 kHz to 170 kHz onboard a work boat, followed by intensive spill sampling to compare acoustic data and species composition; (3) Study of fish behavior inside the net; (4) shark fish and release from the net; (5) Making other observations that could lead to further tests of mitigation techniques. Preliminary results of these studies are presented.

Scott, M., Cardona, E., Scidmore-Rossing, K., Royer, M., Stahl, J., & Hutchinson, M. (2022). What's the catch? Examining optimal longline fishing gear configurations to minimize negative impacts on non-target species. *Marine Policy,* 143, 105186. https://doi.org/10.1016/j.marpol.2022.105186

Changes to fishing gear configurations have great potential to decrease fishing interactions, minimize injury and reduce mortality for non-target species in commercial fisheries. In this two-part study, we investigate potential options to optimize fishing gear configurations for United States Pacific pelagic longline vessels to maintain target catch rates whilst reducing bycatch mortality, injury, and harm. In part one, a paired-gear trial was conducted on a deep-set tuna longline vessel to compare catch rates and catch condition of target and non-target species between wire and monofilament leader materials. Temperature-depth recorders were also deployed on hooks to determine sinking rates and fishing depth between the two leader materials. In part two, hooks of different configurations (size, diameter, shape, metal type, and leader material) were soaked in a seawater flume for 360 days to obtain quantitative estimates of breaking strength, as well as the time taken for gear to break apart. We found that switching from wire to monofilament leaders reduced the catch rate of sharks by approximately 41 %, whilst maintaining catch rates of target species (Bigeye tuna, Thunnus obesus). However, trailing gear composed of monofilament did not break apart even after 360 days. In contrast, branchlines with wire leaders began to break at the crimps after approximately 60 days. Additionally, the breaking strength of soaked fishing hooks was greater for larger, forged hooks composed of stainless steel typically used in United States Pacific longline fisheries. These results have direct implications for fisheries management and the operational effectiveness of bycatch mitigation strategies for longline fisheries worldwide.

Senko, J. F., Peckham, S. H., Aguilar-Ramirez, D., & Wang, J. H. (2022). Net illumination reduces fisheries bycatch, maintains catch value, and increases operational efficiency. *Current Biology,* 32(4), 911-918 e912. https://doi.org/10.1016/j.cub.2021.12.050

Small-scale fisheries are vital for food security, nutrition, and livelihoods in coastal areas throughout the world's oceans.(1-9) As intricately linked social-ecological systems, small-scale fisheries require management approaches that help ensure both ecological and socioeconomic sustainability.(7,)(10-14) Given their ease of use and lucrative nature, coastal gillnet fisheries are globally ubiquitous.(10,15) However, these fisheries often result in high discarded capture of non-target organisms (bycatch) that can lead to significant cascading effects throughout trophic chains(16-18) and costly fisheries restrictions that result in important revenue losses in coastal communities with scarce economic alternatives.(19,)(20) Despite these challenges, few solutions have been developed and broadly adopted to decrease bycatch in coastal gillnet fisheries, particularly in developing nations.(5,21) Here we used controlled experiments along Mexico's Baja California peninsula to show that illuminating gillnets with green LED lights-an emerging technology originally developed to mitigate sea turtle bycatch-significantly reduced mean rates of total discarded bycatch biomass by 63%, which included significant decreases in elasmobranch (95%), Humboldt squid (81%), and unwanted finfish (48%). Moreover, illuminated nets significantly reduced the mean time required to retrieve and disentangle nets by 57%. In contrast, there were no significant differences in target fish catch or value. These findings advance our understanding of how artificial illumination affects operational efficiency and changes in catch rates in coastal gillnet fisheries, while illustrating the value of assessing broad-scale ecological and socioeconomic effects of species-specific conservation strategies.

Serafy, J. E., Orbesen, E. S., Snodgrass, D. J. G., Beerkircher, L. R., & Walter, J. F. (2012). Hooking Survival Of Fishes Captured By The United States Atlantic Pelagic Longline Fishery: Impact Of The 2004 Circle Hook Rule. *Bulletin of Marine Science,* 88(3), 605-621. https://doi.org/10.5343/bms.2011.1080

We examine the impact on pelagic fish hooking survival rates (defined as the proportion of fish alive upon gear retrieval) of the rapid switch from J-hooks to circle hooks that was required of the US pelagic longline fishery operating in the Atlantic Ocean and Gulf of Mexico after August 2004. Our focus was on 12 fish taxa that are commonly caught as bycatch or retained for the market, and for which individual disposition (live or dead) information was available from 1992 to 2010. To test the hypothesis of no change in survival before vs after the circle hook rule went into effect, we utilized a repeated measures logistic regression approach which accounted for variation in several operational, environmental, and biological covariates, including bait, fishery target, fishing zone, soak duration, water temperature, maximum fishing depth, and fish size (length). For white marlin and albacore, results were mixed, with both increases and decreases in hooking survival varying by fishing zone. For blue shark and lancetfish, no significant differences in hooking survival were detected between the pre- and post-circle hook rule time periods. However, for the remaining eight taxa (swordfish, yellowfin tuna, dolphinfish, bigeye tuna, escolar, silky shark, blue marlin, and sailfish), significant increases in survival were evident. Our results are generally consistent with previous experimental and fishery observer longline studies which suggested circle hook use has the potential to increase hooking survival. Results imply that the 2004 circle hook rule has provided increased opportunities for: (1) live release for several bycatch species; and (2) improved quality (and perhaps prices) of targeted and incidentally-caught taxa that are retained for the market.

Smith, L. E., & O'Connell, C. P. (2014). The effects of neodymium-iron-boron permanent magnets on the behaviour of the small spotted catshark (Scyliorhinus canicula) and the thornback skate (Raja clavata). *Ocean & Coastal Management,* 97, 44-49. https://doi.org/10.1016/j.ocecoaman.2013.05.010

Elasmobranchs (sharks, skates, and rays) are frequently captured as bycatch on a wide variety of fishing gears, such as pelagic longlines and hook-and-line fisheries, and therefore many species have experienced severe population declines. To reduce elasmobranch bycatch, scientists have begun exploring the effectiveness and potential application of elasmobranch-specific repellents, such as permanent magnets and electropositive metals. For the present study, the behavioural responses of captive small spotted catsharks (Scyliorhinus canicula) and thornback skates (Raja clavata) were observed in response to neodymium-iron-boron (Nd2Fe14B) permanent magnets. Results demonstrate that both R. clavata and S. canicula; (1) significantly avoided the Nd2Fe14B magnets more often in comparison to the control and procedural control and (2) significantly fed from the control and procedural control more often in comparison to the Nd2Fe14B magnets. Data also suggests a relationship between water temperature and the avoidance distance by R. clavata, with closer approaches prior to avoidance occurring in association with water temperatures of <= 12 degrees C. Additionally, the tail beat frequency associated with the avoidance behaviour of S. canicula was significantly slower (<= 9 beats/10 s) in water temperatures of <= 12 degrees C. The findings from this study agree with previous electrosensory repellent studies, in that elasmobranchs detect and are deterred by permanent magnets however, the present study also demonstrated that there is a correlation between avoidance speed and distance with water temperature. These findings suggest that

water temperature may be correlated to magnetic repellent effectiveness and thus warrants further experimentation.

Song, K. S., Moon, D.-Y., Boggs, C., Koh, J.-R., & An, D.-H. (2006). Comparison of circle hook and J hook catch rate for target bycatch species taken in the Korean tuna longline fisher. *Journal of the Korean Society of Fisheries and Ocean Technology,* 42(4), 210-216. https://doi.org/10.3796/KSFT.2006.42.4.210

The circle hook experiments were conducted to compare the catch rates of target and bycatch species between J hook and circle hooks in the tuna longline fishery of the eastern Pacific Ocean between 1Â°48'S-7Â°00'S and 142Â°00' -149Â°13'W from July 15 to August 12, 2005. In the target species group no significant differences among 3 types hook, between size 4.0 traditional tuna hooks(J-4) and size 15 circle hooks(C15), and between C15 and size 18 circle hooks(C18) were revealed, but significant differences were found between J-4 and C18. In the bycatch species group significant differences were found among 3 types hook, between J 4 and C15, and between J-4 and C18, but no significant differences were revealed between C15 and C18. Large circle hook(C18) had the lowest catch rate for tunas and for other fishes, and the small circle hook(C15) had lowest rate for billfishes and sharks. The length distributions for bigeye tuna are very similar for the 3 hook types. There were very slight differences in length size between hook types in the bycatch species.

Song, L. (2015). Effects of environmental factors and fishing gear on catch rates of silky shark (Carcharhinus falciformis) in waters near Gilbert Islands. *Journal Of Fisheries Of China,* 39(1), 147-159. https://doi.org/10.3724/SP.J.1231.2015.59354

At present, many scientists pay more attention to the incidental catch of top predator of food chain in longline fisheries, such as sharks, sea turtles and sea birds. Given the long life span and relatively low reproductive capacity of many shark species ,reducing the incidental catch of sharks during commercial fishing operations is thus critical in the conservation of shark species. In 1999, FAO promulgated the International Plan of Action for the Conservation and Management of Sharks. In order to protect the marine environment and conserve the shark species,many countries and regions declared a law prohibiting commercial shark fishing in its national waters. Shark's habitat environment is complex with respect to both spatial and temporal variations. Mechanisms of their migration are not fully understood even though many studies suggested that they might be related to the behavior and dynamics of zooplankton. The effective fishing gears and methods to mitigate the incidental catch rate of Carcharhinusfalciformis and the effects of 16/0 and 18/0 circle hooks to the incidental catch rate of C. falciformis should be studied further. Based on these studies, the robust results could be obtained and could be used to reduce the incidental catch rate of C. falciformis effectively. On the other hand, there were many studies about the biological characteristics of C. falciformis, but the studies about the impacts of marine environment on the incidental catch rate of C. falciformis were rare. The aim of this study is to reduce the incidental catch rate of C. falciformis in longline fisheries. In this study, the mean nominal catch rates of C. falciformis and environmental variables were obtained from two longlining surveys in waters near Gilbert Islands from 4 October 2009 through 25 December 2009 and from 20 November 2010 through 20 January 2011. Data included: hook depth data ,temperature, salinity,dissolved oxygen concentration and chlorophyll concentration vertical profile data, operating parameters, catch statistics. Stepwise regression was used to develop the hook depth calculation model. Wilcoxon-test was used to test if there were significant differences among C.falciformis incidental catch

rates of four kinds of fishing gear or hook types. Statistics and clustering analysis were used to analyze environmental effects on the C. falciformis catch rate. Results showed that: (1)C.falciformis incidental catch rate can be significantly reduced by using the experimental gear or 18/0 circle hook; (2) the depth, temperature, salinity, chlorophyll concentration and dissolved oxygen (DO) range with the high incidental catch rate for C.falciformis was 40.0-79.9m,24.0-24.9 degree C and 29.0-29.9 not equal to , 35.40-35.99,0.120-0.199 mu g/L, and 4.50-4.99 mg/L, respectively. This study suggests that: (1) the numbers of 18/0 circle hook or hook deeper than 120 m should be increased; (2)the numbers of hook should be reduced in the higher incidental catch rate ranges of hook depth, temperature, salinity, dissolved oxygen concentration and chlorophyll concentration.

Stephenson, P. C., Wells, S., & King, J. A. (2008). *Evaluation of exclusion grids to reduce the bycatch of dolphins, turtles, sharks and rays in the Pilbara trawl fishery DBIF funded Project.* Fisheries Research Report 171. Department of Fisheries of Western Australia, Retrieved from https://www.bycatch.org/articles/evaluation-exclusion-grids-reduce-bycatch-dolphins-turtles-sharks-and-rays-pilbara-trawl-fi

A semi-flexible exclusion grid with a bar spacing of 15.5 cm reduced dolphin bycatch in the Pilbara trawl fishery by close to 50% and reduced the bycatch of sea turtles, large sharks and rays. However, the fate of the dolphins that encountered the grid and escaped is unknown.

Stoner, A. W., & Kaimmer, S. M. (2008). Reducing elasmobranch bycatch: Laboratory investigation of rare earth metal and magnetic deterrents with spiny dogfish and Pacific halibut. *Fisheries Research,* 92(2-3), 162-168. https://doi.org/10.1016/j.fishres.2008.01.004

Spiny dogfish (Squalus acanthius) comprises a significant unwanted bycatch on demersal longlines set for halibut and cod in shelf waters of the east and west coasts of North America. In this laboratory study, attacks on baits were tested in the presence of two different rare earth materials (neodymium-iron-boride magnets and cerium mischmetal) believed to deter elasmobranch catch. Experiments were made with spiny dogfish and with Pacific halibut (Hippoglossus stenolepis) in pairwise tests of the rare earth materials and inert metal controls. Dogfish attacked and consumed baits tested with cerium mischmetal at a lower frequency than controls. Times to attack the baits were significantly higher in the presence of mischmetal, as were numbers of approaches before first attack. The time differential between mischmetal and control treatments and the number of baits consumed converged with increasing food deprivation (1 h, 2 d, and 4 d), but treatment differences were always significant. Cerium mischmetal appeared to be irritating to dogfish and may disrupt their bait detection and orientation abilities. Magnets also appeared to irritate dogfish but provided no protection for baits in feeding trials. Pacific halibut showed no reaction whatsoever to the rare earth magnets or cerium mischmetal. Mischmetal, therefore, may be useful in reducing spiny dogfish bycatch in the halibut fishery. Disadvantages in using mischmetal in commercial operations are expense, hazardous nature, and relatively rapid hydrolysis in seawater.

Swimmer, Y., & Barcelo, C. (2018). *Blue shark and swordfish catch rates in Hawaii's shallow-set longline fishery: before and after regulations aimed to reduce sea turtle bycatch (DRAFT).* 14th Regular Session of the Scientific Committee WCPFC-SC14-2018/EB-IP-06. Western and Central Pacific Fisheries Commission, Retrieved from https://meetings.wcpfc.int/node/10741

To reduce capture and mortality of endangered and threatened sea turtles, United States longline vessels targeting swordfish in the Pacific Ocean have operated under extensive fisheries regulations since 2004. We analyzed longline observer data from the Pacific Ocean to assess the impact of these regulations on targeted swordfish (Xiphias gladius) and bycatch of blue sharks (Prionace glauca). Using generalized additive mixed models (GAMMs), we investigated relationships between the nominal catch-per unit effort (CPUE) of blue sharks and swordfish and using operational components such as fishing location, hook type, bait type, hooks between floats, use of light sticks, and sea surface temperature. For blue sharks, GAMMs identified a significantly higher catch on J hooks with squid or fish bait relative to circle hooks with fish bait. For swordfish, J hooks with squid bait caught significantly more relative to circle hooks with fish bait, however there was no significant difference of catch when comparing J hooks with fish bait to circle hooks with fish bait. Confounding variables such as year and terminal gear components (hook type, bait) are discussed. Single factor analysis identified that catch rates of blue sharks and swordfish were significantly lower after the regulations, which were lower by over 2.4 times for blue sharks, yet by only ~8% for swordfish. These results indicate that the use of mitigation measures to reduce sea turtle bycatch, specifically large circle hooks and fish bait, can provide a significant conservation value by reducing blue shark bycatch, yet may also result in a slight reduction in targeted swordfish catch rates.

Swimmer, Y., Suter, J., Arauz, R., Bigelow, K., Lopez, A., Zanela, I., . . . Boggs, C. (2011). Sustainable fishing gear: the case of modified circle hooks in a Costa Rican longline fishery. *Marine Biology,* 158(4), 757-767. https://doi.org/10.1007/s00227-010-1604-4

Our research aims to identify longline fishing gear modifications that can improve fishing selectivity and reduce incidental capture of non-target species. Catch rates and anatomical hook locations (AHL) were compared when using a 14/0 standard "control" circle hook with a 00 offset and an experimental "appendage" hook in a Costa Rican longline fishery. With the appendage, the maximum dimension of the appendage hook was increased by 10% and the minimum dimension of the hook by 19%. A total of 1,811 marine animals were captured during five fishing trips. By taxonomic groups, sea turtles represented the largest total catch (27%), followed by sharks (26%), rays (25%), mahimahi (Coryphaenu hippurus) (12%), and tunas and billfish (10%). Non-target and discard species, such as rays and sea turtles, accounted for over half of the total catch. Catch per unit effort (CPUE; number of individuals per 1,000 hooks) was higher with control hooks compared to appendage hooks for all species' categories except rays; appendage hooks caught 52% fewer sea turtles and 23% fewer tunas and billfish than standard hooks, which represents a significant reduction in bycatch of endangered and other species. No differences were found in the AHL for sea turtles, suggesting use of the appendage may not incur additional advantages regarding turtles' post-release survivorship. Despite lower catch rates for marketable species, such as sharks and mahimahi, use of the appendage resulted in dramatic reductions in catch rates of sea turtles. The results suggest that large scale adoption of hooks with a significantly wider hook dimension could be an effective conservation measure to maintain marine biodiversity while allowing for continued fishing.

Swimmer, Y., Wang, J. H., & McNaughton, L. (2008). *Shark Deterrent and Incidental Capture Workshop, April 10-11, 2008*.(NOAA technical memorandum NMFS-PIFSC 16). Pacific Islands Fisheries Science Center Retrieved from https://repository.library.noaa.gov/view/noaa/3615

This report summarizes findings reported by scientists at a Shark Deterrent and Incidental Capture Workshop cosponsored by the Consortium for Wildlife Bycatch Reduction, the New England Aquarium, and NOAA PIFSC. The meeting was held at the New England Aquarium in Boston, Massachusetts during April 10-11, 2008. Participants of this workshop included NOAA fisheries biologists, researchers from U.S. and foreign universities, and consultants from private companies. A list of participants and their affiliations is included at the end of this report.

Thiam, N., Sow, F. N., Fall, M., Plourde, Y., Thiaw, M., Dème, M., . . . Faye, B. (2018). Nordmøre Grid Trial in Large Prawn Senegalese Fishery: Interest to Reduce By-catch not Evidenced. *Universal Journal of Agricultural Research,* 6(6), 181-193. https://doi.org/10.13189/ujar.2018.060601

Demersal shrimp fisheries, which are not very selective, generate significant discards and / or bycatch, generally composed of crustaceans, fish and molluscs of different size classes. As part of the implementation of the management plan for the deepwater shrimp Parapenaeus longirostris in Senegal, selectivity tests of the Nordmore device were conducted. Thus, three Nordmore grids characterized by different spacings between the bars (24, 28 and 30 mm) were tested on the experimental trawl in the Senegalese Economic Zone. Regardless of spacing, the Nordmore Grid completely removed large individuals from several species of commercial interest (John dory and Bearded brotula) or not (rays, sharks, etc.). Gamba shrimp loss analyzes indicate a significant difference (α <0.05) between the three spacer grids 24, 28 and 30 mm. Regardless of the type of grid, the amount of shrimp sorted per minute is larger for the experimental trawl; and this quantity increases with the spacing of the grid. The 30mm grid stands out with percentages of gamba shrimp losses ranging from 3 to 20% with an average of 8%; and a ratio of bycatch / gamba shrimp catch around 2.2 / 1, below the world average for this type of fishery (5/1).

Thorpe, T., & Frierson, D. (2009). Bycatch mitigation assessment for sharks caught in coastal anchored gillnets. *Fisheries Research,* 98(1-3), 102-112. https://doi.org/10.1016/j.fishres.2009.04.003

Fishing with modified gillnets was conducted to elucidate their potential for reducing shark bycatch. Experimental fishing focused on two commercial fisheries, Spanish mackerel (Scomberomorus maculatus) and spot (Leiostomus xanthurus). The modification took the form of increasing the gillnet tension using larger floats on the head-rope and increasing the lead-core lead-line weight. Gillnet mesh sizes were 7.2 cm (spot fishery) and 7.6 and 10.2 cm (Spanish mackerel fishery). Gillnet selectivity of the four most commonly encountered shark species were fitted to fork-length distribution data using the SELECT method. There was no significant difference in the catch rate of the target species between control and modified gillnets for all mesh sizes used. Catch rates of some shark species were significantly reduced in modified gillnets. Model deviance values indicated good fits to the data for blacknose (Carcharhinus acronotus), blacktip (Carcharhinus limbatus) and bonnethead (Sphyrna tiburo) sharks with lowest deviance values (i.e., best fit) generally associated with the normal scale (spread proportional to mesh size) form. The selectivity results demonstrated that all life stages of Atlantic sharpnose (Rhizoprionodon terraenovae) and blacknose sharks were available to the gillnets. The mesh selectivity of bonnethead sharks was largely uniform due to their exaggerated cepholaphoil that resulted in the

majority being hammer-wrapped. Further, capture data indicated a dominance of large juveniles and adult bonnethead sharks resulting in poor model fits. The capture mortality rate for all shark species was high (78.6%) with higher mortality rates associated with heightened locomotor performance and wrapping as an entanglement mode. These results demonstrated that modified gillnets have the potential to reduce shark bycatch, particularly for those species for which wrapping was the primary entanglement mode.

Tolotti, M. T., Bach, P., Hazin, F., Travassos, P., & Dagorn, L. (2015). Vulnerability of the Oceanic Whitetip Shark to Pelagic Longline Fisheries. *Plos One,* 10(10), e0141396. https://doi.org/10.1371/journal.pone.0141396

A combination of fisheries dependent and independent data was used to assess the vulnerability of the oceanic whitetip shark to pelagic longline fisheries. The Brazilian tuna longline fleet, operating in the equatorial and southwestern Atlantic, is used as a case study. Fisheries dependent data include information from logbooks (from 1999 to 2011) and on-board observers (2004 to 2010), totaling 65,277 pelagic longline sets. Fisheries independent data were obtained from 8 oceanic whitetip sharks tagged with pop-up satellite archival tags in the area where longline fleet operated. Deployment periods varied from 60 to 178 days between 2010 and 2012. Tagging and pop-up sites were relatively close to each other, although individuals tended to travel long distances before returning to the tagging area. Some degree of site fidelity was observed. High utilization hotspots of tagged sharks fell inside the area under strongest fishing pressure. Despite the small sample size, a positive correlation between tag recorded information and catch data was detected. All sharks exhibited a strong preference for the warm and shallow waters of the mixed layer, spending on average more than 70% of the time above the thermocline and 95% above 120 m. Results indicate that the removal of shallow hooks on longline gear might be an efficient mitigation measure to reduce the bycatch of this pelagic shark species. The work also highlights the potential of tagging experiments to provide essential information for the development of spatio-temporal management measures.

Tolotti, M. T., Travassos, P., Fredou, F. L., Wor, C., Andrade, H. A., & Hazin, F. (2013). Size, distribution and catch rates of the oceanic whitetip shark caught by the Brazilian tuna longline fleet. *Fisheries Research,* 143, 136-142. https://doi.org/10.1016/j.fishres.2013.01.014

Catch and effort data from 14,835 longline sets conducted by foreign tuna longline vessels chartered by Brazil, from 2004 to 2010, were analyzed aiming at assessing the size, distribution and the relative abundance of the oceanic whitetip shark (Carcharhinus longimanus) in the southwestern and equatorial Atlantic Ocean. The nominal catch per unit of effort (CPUE) exhibited a gradual increase, from 0.04 sharks/1000 hooks, in 2004, the first year of the time series, up to 0.13, in 2007. In 2008, however, the CPUE increased sharply, reaching 0.43, dropping, then, back to 0.15, in 2010. A CPUE standardization was performed using a delta-GLM approach, but the standardized index of abundance did not differ significantly from the nominal CPUE. The models indicated that the catches of oceanic whitetip sharks are higher for the Spanish fishing strategy, which is characterized by the deployment of hooks at shallower depths. These results indicate that the use of deep longline hooks (>100 m) may help to mitigate the bycatch of this species.

Wakefield, C. B., Blight, S., Dorman, S. R., Denham, A., Newman, S. J., Wakeford, J., . . . O'Donoghue, S. (2014). *Independent observations of catches and subsurface mitigation efficiencies of modified trawl nets for endangered, threatened and protected megafauna bycatch in the Pilbara Fish Trawl Fishery*.(Fisheries Research Report No. 244). Department of Fisheries, Western Australia Retrieved from https://researchrepository.murdoch.edu.au/id/eprint/21296/

Mitigation of endangered, threatened and protected (ETP) species is a challenge in many commercial fisheries globally and independent observer programs are often implemented to determine accurate estimates of interaction rates. However, interactions with ETP species may be extremely rare requiring very high and therefore costly levels of observer coverage to provide adequate statistical rigor for such programs. The Pilbara Fish Trawl (Interim Managed) Fishery (PFTF) has a long history of developing and adopting mitigation measures that have resulted in very low capture rates of ETP megafauna, i.e. dolphins, turtles, sea snakes and sawfish. However, there has been uncertainty over the potential for unaccounted mortality of ETP megafauna from subsurface expulsion in poor condition through escape hatches in the PFTF trawl nets (particularly air breathing species). To examine this issue, all trawl vessels in the PFTF (n = 3) were fitted with dual-lens above water and subsurface within-net camera systems from June to December 2012. Above water cameras recorded continuously (except during malfunctions) and all video files were stored in read only folders and encrypted with passwords to prevent tampering. At the end of each trip these secure folders containing the video files were transferred onto external hard drives by Department of Fisheries staff for later analysis. The observer coverage rates of 85.2% of trawl catches above water (n = 1,916 trawls observed), and 71.7% of day-trawls (n = 774 trawls observed) and 53.9% of day-trawl hours (n = 1,013 h observed) below water, far exceeded that stipulated in the Bycatch Action Plan (22%) and levels achieved from previous studies from the PFTF. Captures of ETP megafauna were rare, despite very high levels of attendance in and around trawl nets by bottlenose dolphins (> 75% of trawls). All observed catches of ETP species were reported in statutory logbooks and these catches were consistent with previous data since exclusion grids were mandated in March 2006. Therefore, there was no evidence to suggest that captures of ETP species were being unreported by commercial fishers. About two thirds of all megafauna, including chondrichthyans, were expelled from escape hatches during trawling, with the majority of megafauna expelled relatively quickly (< 10 min). This resulted in more than half of the trawl catches containing no megafauna (51.4%). A total of 705 megafauna individuals were observed to exit the nets through an escape hatch during trawling. Of these megafauna, only one bottlenose dolphin was observed to exit these trawls in poor condition. A large turtle was observed to persist in a trawl for an extended period (60.1 min). However, despite its condition being inconclusive upon exiting, its duration in the net was well within the breath holding capabilities for marine turtles. Thus, the subsurface expulsion of megafauna in poor condition was extremely rare. No megafauna were observed to exit through the top opening escape slit. However, an upward excluding grid with a top opening escape hatch resulted in a higher proportion of escapement for most chondrichthyans. The loss of targeted scalefish through escape hatches occurred during less than 3% of trawls. Extensive subsurface observations determined that current mitigation strategies are highly effective for sea snakes, turtles and chondrichthyans (except sawfish), and that further investigation in the forward sections of trawl nets may provide useful information to improve mitigation strategies for dolphins and sawfish. The very low rates of mortalities of these ETP megafauna by the PFTF were considered to pose a negligible risk to their sustainability based on 1) these rates likely to be less than their natural mortality rates (e.g. at least 371 bottlenose dolphins stranded from 1981-2010), 2) they appear abundant in Western Australian waters despite large scale mortalities from historic foreign fishing (e.g. 13,459 cetacean mortalities from Taiwanese fishing from 1981-86), and 3) they have wide distributions and are h ghly mobile.

Wakefield, C. B., Santana-Garcon, J., Dorman, S. R., Blight, S., Denham, A., Wakeford, J., . . . Newman, S. J. (2017). Performance of bycatch reduction devices varies for chondrichthyan, reptile, and cetacean mitigation in demersal fish trawls: assimilating subsurface interactions and unaccounted mortality. *ICES Journal of Marine Science,* 74(1), 343-358. https://doi.org/10.1093/icesjms/fsw143

To improve bycatch mitigation of chondrichthyans, reptiles and cetaceans for a tropical demersal fish-trawl fishery, species-specific responses to bycatch reduction devices (BRDs) were investigated using both in situ subsurface and onboard observations. There are few, if any, studies that have determined mitigation performances of BRDs from subsurface interactions for these species, as most are rarely encountered and thus require substantial levels of observer coverage for robust assessments. This study combined in-net and onboard (774 day trawls and 1320 day trawl hours of subsurface observer coverage) electronic monitoring on all fish-trawl vessels (n = 3) to compare bycatch mitigation performances among nine megafauna groups, based on escape rates and interaction durations for three BRDs over 6 months (June to December 2012). Overall, 26.9% of day trawls had no megafauna interactions and 38.3% of the 1826 interactions escaped, with most in rapid time (91.4% in <= 5 min). The upward inclined exclusion grid significantly improved the escape proportions for most chondrichthyans by 20-30%. All BRDs were highly effective in reducing reptile (turtles and seasnakes) bycatch, but irrelevant for the few sawfish (n = 13) that readily entangled in the anterior of the net. Cetacean (bottlenose dolphins only) interactions with BRDs were very rare (n = 7) despite high levels of attendance and depredation during trawling. Loss of targeted teleosts through the BRD hatch was rare (1.3% of day trawls). This relatively cost-effective method of electronic monitoring achieved very high levels of subsurface observer coverage (60% of day trawls or 56% of day trawl hours), and provided evidence that the subsurface expulsion of megafauna in poor condition is negligible. Furthermore, this study provides species-specific improvements toward bycatch mitigation strategies for demersal fish trawling.

Walker, N. D., Maxwell, D. L., Le Quesne, W. J. F., & Jennings, S. (2017). Estimating efficiency of survey and commercial trawl gears from comparisons of catch-ratios. *ICES Journal of Marine Science,* 74(5), 1448-1457. https://doi.org/10.1093/icesjms/fsw250

Assumptions about gear efficiency and catchability influence estimates of abundance, mortality, reference points and catch potential. Despite the need to better quantify fishing effects on some target species and on many non-target species taken as bycatch, there are few gear efficiency estimates for some of the most widely deployed towed fishing gears in the northeast Atlantic. Here, we develop a method that applies generalised additive models to catch-at-length data from trawl surveys and a commercial catch and discard monitoring program in the North Sea to estimate catch-ratios. We then rescale these catch-ratios and fit relationships to estimate gear efficiency. When catches of individuals by species were too low to enable species-specific estimates, gear efficiency was estimated for species-groups. Gear efficiency (and associated uncertainty) at length was ultimately estimated for 75 species, seven species-groups and for up to six types of trawl gear per species or species-group. Results are illustrated for dab (Limanda limanda), grey gurnard (Eutrigula gurnardus) and thornback ray (Raja clavata), two common non-target species and a depleted elasmobranch. All estimates of gear efficiency and uncertainty, by length, species, species-group and gear, are made available in a supplementary data file.

Ward, P., Lawrence, E., Darbyshire, R., & Hindmarsh, S. (2008). Large-scale experiment shows that nylon leaders reduce shark bycatch and benefit pelagic longline fishers. *Fisheries Research,* 90(1-3), 100-108. https://doi.org/10.1016/j.fishres.2007.09.034

We assess the performance of wire leaders, which some jurisdictions have banned to reduce shark mortality from pelagic longline fishing. Experiments were conducted off northeastern Australia on commercial vessels that deployed equal numbers of wire and nylon monofilament leaders randomly along their longlines. Catch rates of several species, including sharks, were lower on nylon than on wire leaders, probably because those animals often escape by biting through the nylon leaders. High bite-off rates indicate that as many animals escape from nylon leaders as are caught on nylon leaders. The fate of escaped animals is not known, although large sharks are more likely to survive than are small animals. By contrast, catch rates of valuable bigeye tuna (Thunnus obesus) were higher on nylon than on wire leaders. Bigeye tuna are probably able to see wire leaders and avoid those hooks. The financial benefits of increased bigeye tuna catches outweigh the costs associated with banning wire leaders, such as increased rates of gear loss. Thus, banning wire leaders is an effective way of reducing shark catches that fishers should be keen to adopt.

Watson, J. T., & Bigelow, K. A. (2014). Trade-offs among Catch, Bycatch, and Landed Value in the American Samoa Longline Fishery. *Conservation Biology,* 28(4), 1012-1022. https://doi.org/10.1111/cobi.12268

The interspecific preferences of fishes for different depths and habitats suggest fishers could avoid unwanted catches of some species while still effectively targeting other species. In pelagic longline fisheries, albacore (Thunnus alalunga) are often caught in relatively cooler, deeper water (>100 m) than many species of conservation concern (e. g., sea turtles, billfishes, and some sharks) that are caught in shallower water (<100 m). From 2007 to 2011, we examined the depth distributions of hooks for 1154 longline sets (3,406,946 hooks) and recorded captures by hook position on 2642 sets (7,829,498 hooks) in the American Samoa longline fishery. Twenty-three percent of hooks had a settled depth <100 m. Individuals captured in the 3 shallowest hook positions accounted for 18.3% of all bycatch. We analyzed hypothetical impacts for 25 of the most abundant species caught in the fishery by eliminating the 3 shallowest hook positions under scenarios with and without redistribution of these hooks to deeper depths. Distributions varied by species: 45.5% (n = 10) of green sea turtle (Chelonia mydas), 59.5% (n = 626) of shortbill spearfish (Tetrapturus angustirostris), 37.3% (n = 435) of silky shark (Carcharhinus falciformis), and 42.6% (n = 150) of oceanic whitetip shark (C. longimanus) were caught on the 3 shallowest hooks. Eleven percent (n = 20,435) of all tuna and 8.5% (n = 10,374) of albacore were caught on the 3 shallowest hooks. Hook elimination reduced landed value by 1.6-9.2%, and redistribution of hooks increased average annual landed value relative to the status quo by 5-11.7%. Based on these scenarios, redistribution of hooks to deeper depths may provide an economically feasible modification to longline gear that could substantially reduce bycatch for a suite of vulnerable species. Our results suggest that this method may be applicable to deep-set pelagic longline fisheries worldwide.

White, J., Heupel, M. R., Simpfendorfer, C. A., & Tobin, A. J. (2013). Shark-like batoids in Pacific fisheries: prevalence and conservation concerns. *Endangered Species Research,* 19(3), 277-284. https://doi.org/10.3354/esr00473

Shark-like batoids are a group of elasmobranchs with a body form similar to that of sharks (i.e. elongate body, well developed caudal and dorsal fins, and head, gill and mouth morphology similar to that of skates and sting rays). Despite a poor understanding of their biology, ecology and resilience to fishing, shark-like batoids are known to have been heavily exploited throughout the Indo-Pacific. Between 2007 and 2009, we recorded the occurrence of shark-like batoid species in the inshore gillnet fishery of Queensland (Australia) across 2 habitat types. Glaucostegus typus and Anoxypristis cuspidata were most frequently caught in intertidal habitats, whereas Rhynchobatus spp. dominated the catch in inshore coastal habitats. Comparison of gillnet catches to research longline sampling showed that not all size classes of shark-like batoids are captured by the gillnet fishery. Given that home-range size and habitat use by elasmobanchs can change between ontogenetic stages and species, vulnerability to fisheries may vary depending on overlap of preferred habitats and fishing activity and whether each size class is susceptible to the gear. Gillnets are highly selective for certain sizes classes; therefore, knowledge of which sizes and thus which life-history stages are susceptible is necessary to effectively regulate the use of this type of fishing gear. Understanding the occurrence and availability of shark-like batoid species to fishing activities and their contribution as bycatch/by-products in fisheries is critical to management and conservation of these species.

Whoriskey, S., Arauz, R., & Baum, J. K. (2011). Potential impacts of emerging mahi-mahi fisheries on sea turtle and elasmobranch bycatch species. *Biological Conservation,* 144(6), 1841-1849. https://doi.org/10.1016/j.biocon.2011.03.021

Mahi-mahi (Coryphaena hippurus) is a resilient pelagic species that could provide long-term highly productive fisheries. Using FAO data we document enormous increases (746%) in reported global mahi-mahi landings since 1950. Detailed mahi-mahi fisheries records are limited, but an observer program monitoring Costa Rica's Pacific mahi-mahi pelagic longline fleet between 1999 and 2008 (n = 217 sets) provided a rare opportunity to quantify bycatch in these fisheries. Several sea turtles and sharks of global conservation concern were caught incidentally: olive ridley turtle (Lepidochelys olivacea; n = 1348, mean = 9.05 per 1000 hooks), silky shark (Carcharhinus falciformis; n = 402, mean = 2.96 per 1000 hooks), thresher sharks (Alopias sp.; n = 158, mean = 1.12 per 1000 hooks), green turtle (Chelonia mydas; n = 49, mean = 0.35 per 1000 hooks), and three other threatened sharks in small numbers. Pelagic stingray (Pteroplatytrygon violacea; a ray of low conservation concern) was also a common bycatch (n = 625, mean = 4.77 per 1000 hooks). Generalized linear models (GLMs) of catch rates showed increases in olive ridley turtles and decreases in mahi-mahi and silky sharks over the decade examined. The high hooking survival rates of olive ridley and green turtles in observed sets (95% and 96% respectively) suggest that widespread training of the fleet in careful gear removal and turtle release methods could be one effective bycatch mitigation strategy for these species. GLMs also provide evidence that closing the fishery during peak olive ridley nesting times (at least near nesting beaches), in combination with reduced gear soak times, could help minimize the fishery's impacts on threatened bycatch species while still maintaining a productive fishery.

Willems, T., Depestele, J., De Backer, A., & Hostens, K. (2016). Ray bycatch in a tropical shrimp fishery: Do Bycatch Reduction Devices and Turtle Excluder Devices effectively exclude rays? *Fisheries Research,* 175, 35-42. https://doi.org/10.1016/j.fishres.2015.11.009

Worldwide, many species of elasmobranchs (Chondrichthyes: Elasmobranchii) are currently threatened by marine fisheries activity and are on the Red List of the International Union for Conservation of Nature (IUCN). Although Bycatch Reduction Devices (BRDs) for teleost fish and Turtle Excluder Devices (TEDs) are now widespread in tropical shrimp trawling, information on their ability to mitigate bycatch of elasmobranchs, particularly rays (Batoidea), is scarce and limited to only a few isolated fisheries. The objective of this study was to evaluate the potential of trawls fitted with a square-mesh panel BRD and supershooter TED in reducing ray bycatch. In this study, 65 catch-comparison hauls were conducted in the Atlantic seabob shrimp (Xiphopenaeus kroyeri) fishery off Suriname. Trawls with a BRD and TED combination reduced ray catch rate by 36%. A 21% reduction in mean size indicated the preferential exclusion of large rays. Hence, high escape ratios were observed for Dasyatis geijskesi (77%), a large-sized species, while exclusion of the small species Urotrygon microphthalmum was not significant, although their disc width is small enough to pass through the meshes of the BRD. Furthermore, a size-dependent escape for the two most abundant mid-sized ray species Dasyatis guttata and Gymnura micrura was observed. Exclusion-at-size differed for both species, however, likely related to species-specific morphology or behavior in response to the TED. This study shows that the combination of BRD and TED causes an important reduction in ray bycatch in seabob shrimp fisheries off Suriname. The great reduction in catch of large-sized rays is positive, but the mortality of juvenile rays is likely to have negative consequences for their populations. We therefore recommend gear-based and non-gear adaptations to further reduce the bycatch of small-sized rays.

Wimmer, T. (2014). *The Use of Zinc and Graphite to Reduce Shark Bycatch in Canadian Pelagic Longline Fisheries.* Paper presented at the American Fisheries Society Annual Meeting. Retrieved from https://afs.confex.com/afs/2014/webprogram/Paper15604.html

Blue sharks (Prionace glauca) represent a significant portion of the catch in the Canadian pelagic longline fishery targeting swordfish and tunas. The capture of sharks represents a significant financial loss to industry, therefore, reducing the capture of sharks is a shared interest between conservationists and fishermen. Sharks have the ability to detect minute electric currents and thus, the use of substances that produce electrical currents upon immersion in salt water are being tested to determine their ability to deter sharks from fishing gear. The combination of zinc and graphite (Zn/Gr) has been tested in experimental trials and has shown to deter sharks. We tested the use of these substances to reduce shark bycatch in a commercial fishery in collaboration with a longline captain off Nova Scotia, Canada. In September 2013, we deployed a total of 9 longline sets (~6300 hooks) with three different treatments: standard hooks, hooks with Zn/Gr and hooks with plastic controls. Sharks, primarily blue sharks, represented 29.6% of the total individuals caught while swordfish (Xiphias gladius), comprised 26.2%. The combination of zinc and graphite did not significantly reduce the bycatch of sharks in this fishery nor did it significantly affect the catch of the target species.

Yokota, K., Kiyota, M., & Minami, H. (2006). Shark catch in a pelagic longline fishery: Comparison of circle and tuna hooks. *Fisheries Research,* 81(2), 337-341. https://doi.org/10.1016/j.fishres.2006.08.006

The effects of circle hooks on blue shark Prionace glauca catch in a pelagic longline fishery were assessed in fishing experiments on two research vessels in the western North Pacific off the coast of Japan from May to September 2005. We used conventional tuna hooks (standard Japanese hook size; 3.8sun) and two sizes of circle hooks (4.3sun and 5.2sun) for each fishing operation and compared catch rates, size compositions and mortalities of blue shark between hooks. One vessel used stainless steel wire leaders and the other vessel used nylon-monofilament leaders. Total numbers of blue shark caught were 755 and 2598 for the respective vessels. Mean catch rates (per 1000 hooks) of blue shark for the 3.8sun tuna hook, the 4.3sun circle hook and the 5.2sun circle hook were 40.5, 37.9 and 36.1, respectively, for one vessel, and 81.6, 95.2 and 93.9, respectively, for the other. Catch rates did not differ significantly between the three hook types on either vessel (P=0.48 and 0.43, two-way ANOVA). Proportions of dead individuals for the 3.8sun tuna hook, the 4.3sun circle hook and the 5.2sun circle hook were 0.03, 0.02 and 0.05, respectively, for one vessel, and 0.10, 0.11 and 0.11, respectively, for the other. The proportion of dead individuals was not significantly different between the three hook types on either vessel (P=0.31 and 0.70, χ2-test of independence). Mean estimated pre-caudal lengths of blue shark caught by each hook type were between 133 and 135cm for one vessel and 193 and 194cm for the other. The difference in mean length between hook types was insignificant for one vessel, but significant for the other (P=1.00 and 0.03, ANOVA). These results indicate that the circle hooks used in this study had little impact on catch rate and mortality of blue shark. We also discuss the possible relationships between hook type, leader material, hooking location, and catch rate of sharks.

Yokota, K., Kiyota, M., & Okamura, H. (2009). Effect of bait species and color on sea turtle bycatch and fish catch in a pelagic longline fishery. *Fisheries Research,* 97(1-2), 53-58. https://doi.org/10.1016/j.fishres.2009.01.003

The effects of bait species (mackerel and squid) and color (blue-dyed and non-dyed) on the loggerhead turtle Caretta caretta bycatch in a pelagic longline fishery in the western North Pacific were assessed in shallow-set longline fishing experiments. The loggerhead turtle catches were analyzed using a generalized linear model (GLM) with a Poisson distribution. The potential factors (bait species, bait color, other species catch, and sea surface temperature) affecting loggerhead turtle catch were incorporated as explanatory variables. The model analyses indicated that bait species affected loggerhead turtle catch, while bait color did not. The model predicted that catch rates of loggerhead turtles were 75% less on mackerel bait to squid bait. This study demonstrated that fish bait choice was very effective in reducing loggerhead turtle bycatch in pelagic longline fisheries, but that the use of blue-dyed bait was not. Similar model analyses were also performed on target and by-product fish species, such as swordfish Xiphias gladius, striped marlin Tetrapturus audax, bigeye tuna Thunnus obesus. blue shark Prionace glauca, and shortfin mako shark Isurus oxyrinchus, and other non-target species. The remarkable differences between bait species and color that were found for loggerhead turtles were not found for these species catches.

Young, H. J., Raoult, V., Platell, M. E., Williamson, J. E., & Gaston, T. F. (2019). Within-genus differences in catchability of elasmobranchs during trawling. *Fisheries Research,* 211, 141-147. https://doi.org/10.1016/j.fishres.2018.11.015

Elasmobranchs make a large contribution to bycatch in commercial trawl fisheries, which reduces the efficiency (and thus profitability of those fisheries), results in injury and mortality of those elasmobranchs, and can lead to unsustainable rates of catches. The development of bycatch reduction devices (BRDs) for elasmobranchs has been hindered, among other things, by a lack of knowledge of their avoidance behaviours and thus their vulnerability to capture (catchability). This lack of knowledge potentially affects assessments of the impact of fishing on those bycatch species. Here we examined underwater behaviours, using video analysis, of three species of elasmobranchs (two stingarees, i.e. Urolophus cruciatus and U. paucimaculatus, and one draughtboard shark, Cephalocyllium laticeps) in response to an approaching demersal trawl to quantify behavioural factors that affect their catchability. The morphologically similar U.cruciatus and U. paucimaculatus were similarly abundant, i.e. 290 and 218 individuals, respectively, but displayed different net avoidance behaviours, with U. paucimaculatus being far more likely to enter the trawl. The greater catchability of U. paucimaculatus would falsely suggest this less common species was more abundant than U. cruciatus, which has implications for any assessments of the impacts of trawling on these two elasmobranchs. Collision with trawl gear was relatively common for both Urolophus spp., and this was shown to decrease their likelihood of capture. In contrast, only 1 of the 68 individuals of the morphologically-different C. laticeps collided with gear. These results will help inform future development of BRDs and highlight that understanding the behaviour of elasmobranchs in response to capture methods should form an integral component of assessments of the impacts of trawling on this highly affected group.

Yuwei, L. I. (2011). Numeric modeling of a pelagic longline based on minimum potential energy principle. *Journal Of Fishery Sciences Of China,* 18(5), 1170-1178. https://doi.org/10.3724/SP.J.1118.2011.01170

Fishing parameters(such as the shooting speed of mainline,vessel speed,time interval between two hooks,numbers of hooks between two floats) can be adjusted to deploy the hooks to water layers that are preferred by target species,such as tuna.As a result,the catch rate of the target species can be increased and the catch of bycatch species(e.g.,loggerhead turtles,Caretta caretta;blue sharks,Prionace glauca;silky sharks,Car-charhinus falciformis) can be reduced.Together,these actions improve fishing efficiency and help maintain bio-logical diversity.To better understand the relationship between these factors and the fishing depth of longline gear,we developed a numeric model of the behavior of a pelagic longline.We conducted surveys on board Chinese large scale tuna longliners in the Indian Ocean between September 2008 and January 2009.During the surveys,the vessels targeted bigeye tuna(Thunnus obesus)but also caught yellowfin tuna(Thunnus albacares),swordfish(Xiphias gladius),albacore(Thunnus alalunga) and billfishes(Istiophoridae).The hook depths(188 hooks) were measured using temperature depth recorders(TDRs) and the three dimensional current was measured at a range of depths at 24 sites using an acoustic doppler current profiler(ADCP).We developed a three-dimensional numerical longline model(3DNLM) using finite element analysis and the minimum potential energy principle method.We used Matrix Laboratory(MATLAB) software to program and conduct the numerical calculations.The three di-mensional current data were assigned to seven,50 m depth intervals(e.g.,0–50,50–100,or 300–350 m).The co-ordinates of all the nodes of the longline(including the float lines,mainline,and branch lines) were calculated by inputting three-dimensional current profile data,fishing gear parameters(the diameter of the mainline and branch line,the total weight of the

branch line and the bait in the water,the density of the mainline and branch line,the elastic modulus of the mainline,the length of the branch line,and the length of the float rope),operating parame-ters(vessel speed,line shooter speed,and the time interval between two hooks) into the numerical model.The model then outputs the shape of the longline under water and the depth of each hook.We verified the model output using experimental data.The model was able to accurately depict the three-dimensional shape and hook depths of the pelagic longline.There was no significant difference between the hook depth measured by TDR and the model estimate of hook depth(P=0.220.05).The average difference between two methods was 12.03 m(range: 0.02–40.36 m,S2=100.30,S=10.01,n=188).The underwater shape of the main line was represented by a wave-shaped curve.The shape was related to the force of the branch line.This load was concentrated at the re-spective node of the main line and made the depth of this node deeper.The main line between two nodes may have floated somewhat because of lift generated by sea currents,especially upwelling currents.The model estimates of the three-dimensional shape and the hook depths were influenced by the value of the drag coefficient(CN90).CN90 was defined as the drag coefficient associated with water flow plumb to the cylinder.The value of the drag coeffi-cient(CN90) was determined based on the Reynolds number(Re) of the study object.

Zainudin, I. M., Patria, M. P., Rahardjo, P., Yasman, Y., Gautama, D. A., & Prawira, W. T. (2017). Bycatch of sharks, marine mammals and seabirds in Indonesian Tuna Longline Fishery. *Biodiversitas, Journal of Biological Diversity,* 18(3), 1179-1189. https://doi.org/10.13057/biodiv/d180341

Bycatch of sharks, marine mammals and seabirds in Indonesian Tuna Longline Fishery. Biodiversitas 18: 1179-1189. Bycatch in longline fishery is recorded to be one of the major factors defining the declined populations of endangered marine species worldwide. This research aimed to identify bycatch level of sharks, marine mammals and seabirds as well as to pinpoint the mitigation options in Indonesian tuna longline fishery. In this study, a total of 8,564,858 hooks were observed from 5,622 gear settings in Indonesian tuna longline fishery based in two major fishing ports, namely Bitung Fishing Port-North Sulawesi and Benoa Port-Bali from May 2006 to June 2014. The results suggest that the best hook rate per thousand hooks in Indonesian tuna longline fisheries for shark bycatch was 0.2446, followed by 0.0030 for seabird bycatch, 0.0021 for dolphin bycatch and 0.0009 for whale bycatch. Seabirds largely acquired in the dead condition while the other species were found still alive (sharks and marine mammals). Bycatch of seabirds only occured in the vessels based in Benoa Bali, and the correlation value (R2) of sharks and seabirds caught at night time was low while for marine mammals was very strong. Deep setting system of fishing gears and night setting also proved to be more effective to reduce bycatch of those critical marine species.

Zeeberg, J., Corten, A., & De Graaf, E. (2006). Bycatch and release of pelagic megafauna in industrial trawler fisheries off Northwest Africa. *Fisheries Research,* 78(2-3), 186-195. https://doi.org/10.1016/j.fishres.2006.01.012

The accidental capture of large animals such as sharks, manta rays, sea turtles, and dolphins in pelagic trawler fisheries remains controversial because it threatens biological diversity in many biogeographical regions, including the subtropical eastern North Atlantic. Bycatch rates observed during more than 1400 trawl sets off Mauritania, Northwest Africa, are shown to have been considerable during the past 4 years, with high animal abundance in Summer when the Northwest African shelf is occupied by subtropical water. We demonstrate the urgency for bycatch reduction and evaluate the use of species-selective gear, a conservation method immediately available and immediately effective in waters fished

through international access agreements. A modification tested in commercial trawls during the observer program guides pelagic megafauna deflected by a filter to an escape tunnel along the bottom of the trawl. This "excluder" reduces bycatch mortality of the most vulnerable megafauna species by at least 40-100%.

2.3 Policy or Management Modifications

Ali, K. (2014). *Status of the Shark Fishery Ban in the Maldives and the Implementation of the National Plan of Action on Sharks.* Indian Ocean Tuna Commission, Retrieved from http://www.iotc.org/documents/status-shark-fishery-ban-maldives-and-implementation-national-plan-action-sharks-update

Sharks have always exhibited an economic significance to the Maldives. In the 1970s, a highly targeted artisanal fishery for sharks had developed and at the same time a newly introduced tourism industry was developing in the country. In comparison with the tuna fishery of the country, the shark fishery was a minor fishery with a small community of fisherfolk involved. From the onset of the commercial shark fisheries, the shark fisheries were in conflict with other stakeholders, the dive tourism sector and the pole and line tuna fishery. The contribution of shark fisheries to the economy was miniscule compared with the implications of over-exploitation of sharks on the thriving dive tourism industry. These factors played a major role in the shark fisheries management of the country. The management measures taken were unsuccessful in resolving the conflicts, which culminated in the declaration of the complete shark fishery ban in 2010. After the ban, measures were taken to mitigate the impact of the management decision on the former shark fishermen. In order to assess the bycatch levels of sharks in the tuna longline fishery, a new logbook system accounting for shark bycatch was implemented in 2012. Bycatch assessments for shark species complexes; hammerhead sharks, thresher sharks, oceanic white tip sharks and mako sharks had been carried out. To improve the reporting of bycatch, training on the identification of oceanic sharks was provided to tuna longline fishermen. Further, with the purpose of determining the effectiveness of the shark ban on reef sharks, a citizen-science programme known as the Maldives Sharkwatch programme was commenced after the declaration of the reef shark fishery ban in the 2009. Data collection is done through the dive tourism sector. The programme is ongoing and is into its fifth year. Recently the Maldives has also developed the National Plan of Action on the Conservation and Management of Sharks. The action plan has been presented to the stakeholders and is in the process of being finalized.

Ambrus, S. (2009). Panama accused of undermining marine preserve -- Bogota, Colombia. *EcoAmericas*. Retrieved from https://www.ecoamericas.com/issues/article/2009/1/BFB897CB-01E4-429D-83DC-4D0900CD9C56

Four years after banning commercial fishing in species-rich Coiba National Park, Panamas National Assembly revoked a critical article of the law prohibiting the use of purse-seine nets for tuna fishing in the 1,040- square-mile (2,700-sq-km) marine preserve. Environmentalists say the June 30 repeal of the ban on purse-seine tuna fishing in Coiba, reportedly influenced by Spanish tuna companies, could pose added risks to endangered marine turtles and dozens of species of sharks, whales and dolphins, which can become trapped in the purse seines as bycatch. They also say it undermines Panamas commitments under a 2004 treaty that the country signed with Colombia, Costa Rica and Ecuador to protect migratory marine species in a vast swath of ocean since named the Marine Conservation Corridor of the Eastern Tropical Pacific.

Belcher, C. N., & Jennings, C. A. (2011). Identification and evaluation of shark bycatch in Georgia's commercial shrimp trawl fishery with implications for management. *Fisheries Management and Ecology,* 18(2), 104-112. https://doi.org/10.1111/j.1365-2400.2010.00757.x

Many US states have recreational and commercial fisheries that occur in nursery areas occupied by subadult sharks and can potentially affect their survival. Georgia is one of few US states without a directed commercial shark fishery, but the state has a large, nearshore penaeid shrimp trawl fishery in which small sharks occur as bycatch. During our 1995-1998 investigation of bycatch in fishery-dependent sampling events, 34% of 127 trawls contained sharks. This bycatch totalled 217 individuals from six species, with Atlantic sharpnose shark, Rhizoprionodon terraenovae (Richardson), the most common and finetooth shark, Carcharhinus isodon (Muller & Henle) and spinner shark, Carcharhinus brevipinna (Muller & Henle), the least common. The highest catch rates for sharks occurred during June and July and coincided with the peak months of the pupping season for many species. Trawl tow speed and tow time did not significantly influence catch rates for shark species. Gear configurations [net type, turtle excluder device (TED), bycatch reduction device] affected catch rates for shark species. Results of this study indicate gear restrictions, a delayed season opening, or reduced bar spacing on TEDs may reduce shark bycatch in this fishery.

Bettis, S. (2017). *Shark Bycatch in Commercial Fisheries: A Global Perspective.* (Master of Science), Nova Southeastern University, Retrieved from https://nsuworks.nova.edu/cnso_stucap/331/

Many shark species have global distributions and are caught incidentally in different types of fisheries. Over the last two decades, shark populations have declined tremendously, with one of the leading causes of this decline bycatch in primarily teleost fisheries. Bycatch occurs throughout the world's fisheries, but is not well documented in terms of species composition and numbers of each species captured. Information on shark bycatch is spread through the primary and grey literature, but has not been compiled in summary to date. The goal of my capstone is to present global shark bycatch data and provide a comparative review to determine fishery types that affect shark populations and identify shark species at risk as a result of bycatch. Longline fisheries caught a larger variety of shark species, and the post-release mortality was generally low. In contrast, trawl fisheries caught mostly the same few species, but post-release mortality was extremely high. Blue sharks (Prionace glauca), silky sharks (Carcharhinus falciformis), and spiny dogfish (Squalus acanthias) were caught most often in trawl fisheries, and in large numbers that likely adds to risk of overexploitation of their populations. This literature review revealed a severe lack of standardization in bycatch data reporting by different fishing nations, and in documents prepared by management agencies and scientists, including the definition of bycatch used and the way it was recorded. Establishing a universal definition of bycatch and standardizing its reporting would vastly improve ability to assess the scale and composition of shark bycatch and its impacts on shark populations. Systematic and standardized accounting of shark bycatch would provide information helpful for collaboration among regulatory agencies. Rather than simply document bycatch, a number of fishing gear alterations show promise for bycatch reduction and are worthy of integration into fisheries by managers. Additional important steps that can improve bycatch assessment is increased observer coverage in fisheries, marine protected areas, and making bycatch data public.

Box, S. J., & Bonilla, R. S. (2009). *An Evaluation of Fishing Practices in the Small Scale Fisheries of the Golfo de Fonseca, Honduras. Recommendations for Management.* Retrieved from https://web.archive.org/web/20140712074615/http://www.utilaecology.org/assets/documents/Artes%20de%20Pesca%20en%20el%20Golfo%20de%20Fonseca%202009%20english_1.pdf

The artisanal and small scale fisheries within the Honduran Golfo de Fonseca underpin the local economy and are an essential livelihood within small coastal communities. As a mixed fishery, confined within the shallow waters and mangrove estuary of the Golfo de Fonseca, the fishermen exploit a range of demersal and bentho-pelagic fish species using gill nets, hook and lines and bottom set long lines. In addition to fish, shrimp are an important resource and are targeted with trammel and cast nets. In the absence of official statistics, anecdotal evidence suggests that all sectors of the fishery are in decline. This study aimed to assess whether unselective practices could be an important contributory factor to the purported decline and to identify management options that aim to increase the sustainability of the fishery. The study re-evaluated existing catch and length frequency data sets and collected new information during field work and through interviews with fishermen and other stakeholders. We found that fishing within the Golfo de Fonseca predominantly uses gears with broad selectivity. Over a third of the landed catch by weight is low grade, low value fish. There is currently no market incentive for selectivity with little price premium for fish size compared to total fish volume. Of extreme concern is that large proportions of fish of commercially valuable species were being landed at sizes below the size of maturity. Within the group of the commercially most important fin fish, the “Babosas” (Cynoscion spp) the percentage of individuals within the landed catch that were below the estimated size at maturity ranged from 22 % (Babosa; C. squamipinnis) to 81 % (Corvina; C. reticulates). The majority of the landings of low value species and small sized individuals are mainly from the ubiquitous use of trammel nets that target shrimp. For every one pound of shrimp being landed, over five pounds of fin fish are also being landed. The sustainability of fin fishing is likely directly inhibited by the shrimp fishing. Since it is the same fishermen who are reliant on both resources integrating shrimp management and fish management is recommended. Rather than specifying changes in gear types which are unlikely to occur due to limitations in enforcement, a more feasible option based on current management capacity is to identify and instigate a closed season for shrimp fishing that corresponds to peak abundance of small individuals of commercial fish species that use the area as a nursery ground. This would help to minimise the incidental catch of undersize fish by trammel nets which currently reduces the economic efficiency and ecological sustainability of the fishery. In addition the study found that the extensive use of bottom set long-lining was likely to threaten the most ecologically vulnerable species found in the Golfo de Fonseca including the commercially important catfish Bagre pinnimaculatus and large pelagic species including sharks. Based on the precautionary principle of sustainable fisheries management, long lining within the gulf should be prohibited until their effect on these vulnerable species can be investigated. The lack of fishing selectivity was identified to be a clear problem in the Golfo de Fonseca fishery, however it is considered to be symptomatic of wider problems in the ecosystem and with the socioeconomic structure of the fishery as a whole. Other serious threats exist that are evidently going to affect sustainability, including the loss of critical habitat, water pollution and disruption in trophic webs that support the fish. From the perspective of gear selectivity, the current market structure rewards volume over quality and provides no incentive for using more selective methods of fishing. Addressing this problem first is necessary before any regulation in fishing methods will likely be successful.

Clarke, J., Milligan, R. J., Bailey, D. M., & Neat, F. C. (2015). A Scientific Basis for Regulating Deep-Sea Fishing by Depth. *Current Biology,* 25(18), 2425-2429. https://doi.org/10.1016/j.cub.2015.07.070

The deep sea is the world's largest ecosystem [1], with high levels of biodiversity [2, 3] and many species that exhibit life-history characteristics that make them vulnerable to high levels of exploitation [4]. Many fisheries in the deep sea have a track record of being unsustainable [5, 6]. In the northeast Atlantic, there has been a decline in the abundance of commercial fish species since deep-sea fishing commenced in the 1970s [7, 8]. Current management is by effort restrictions and total allowable catch (TAC), but there remain problems with compliance [9] and high levels of by-catch of vulnerable species such as sharks [10]. The European Union is currently considering new legislation to manage deep-sea fisheries, including the introduction of a depth limit to bottom trawling. However, there is little evidence to suggest an appropriate depth limit. Here we use survey data to show that biodiversity of the demersal fish community, the ratio of discarded to commercial biomass, and the ratio of Elasmobranchii (sharks and rays) to commercial biomass significantly increases between 600 and 800 m depth while commercial value decreases. These results suggest that limiting bottom trawling to a maximum depth of 600 m could be an effective management strategy that would fit the needs of European legislations such as the Common Fisheries Policy (EC no. 1380/2013) [11] and the Marine Strategy Framework Directive (2008/56/EC) [12].

Cosandey-Godin, A., & Morgan, A. (2011). *Fisheries bycatch of sharks: Options for mitigation.* Pew Environment Group, Washington, DC. Retrieved from https://www.sarri.org/storage/app/media/tools_pdfs/PewOSSsharkbycatchreviewpdf.pdf

Bycatch (see definition below) is one of the most significant issues in the management and conservation of global fisheries (Hall et al. 2000, Kelleher 2005, Lewison et al. 2004) and has been identified as one of the leading causes of shark population declines. Sharks are susceptible to high fishing mortality rates because of their life history characteristics, which include slow growth, late ages at maturity, and the production of a limited number of young over a lifetime (Cortes 2002, Heppell et al. 1999, Cortes 1999). In addition, research has shown that several species of sharks have very high rates of mortality associated with the fishing process (Morgan and Burgess 2007, Mandelman et al. 2008), and it has been estimated that species such as sandbar shark (Carcharhinus plumbeus) (Sminkey and Musick 1994, Cortes 1999) and dusky shark (Carcharhinus obscurus) (Simpfendorfer 1999) increase their population sizes so slowly that they are considered particularly vulnerable to mortality from fishing activities (Musick et al. 2000a). For example, Cortes et al. (2006) found that if fishing for dusky shark stopped for 30 years, their population in the Northwest Atlantic would still be depleted. Over the past two decades, serious population declines have been reported for a number of shark species in several regions around the world (Baum et al. 2003, Ferretti et al. 2008, Robbins et al. 2006, Ferretti et al. 2010, Clarke 2011) and are attributed to both targeted and incidental capture. According to the International Union for Conservation of Nature (IUCN) and other sources, bycatch is one of the primary threats facing sharks (Musick et al. 2000b, Lewison et al. 2004). Despite widespread recognition of shark bycatch issues (Food and Agriculture Organization [FAO] 1999; FAO 2010), few mitigation actions have been established, and there are no clear guidelines about which mitigation actions would be most effective. In addition, there are very few management measures requiring actions to mitigate shark bycatch. However, it is clear that managers and fishermen must aim to reduce both bycatch rates and the harmful effects from bycatch (e.g., injuries from capture on fishing gear). Based on the best available information, this review

provides a summary of the current knowledge and understanding of shark bycatch and discusses available management options and technical measures aimed at reducing both the rate at which sharks encounter fishing gear and the associated damaging effects.

Das, D., Gonzalez-Irusta, J. M., Morato, T., Fauconnet, L., Catarino, D., Afonso, P., . . . Giacomello, E. (2022). Distribution models of deep-sea elasmobranchs in the Azores, Mid-Atlantic Ridge, to inform spatial planning. *Deep-Sea Research Part I-Oceanographic Research Papers,* 182. https://doi.org/10.1016/j.dsr.2022.103707

Elasmobranchs inhabiting depths beyond 200 m are extremely susceptible to overexploitation but are extracted by fisheries around the world either as target species or as bycatch. There is little information available to formulate management strategies to reduce elasmobranch-fishery interactions in the deep sea. In European Union waters, prohibiting the catches of deep-sea elasmobranchs has provided the necessary impetus to study bycatch avoidance of these threatened species. We used over 20 years of fisheries-independent and fisheries-dependent data to model the spatial distribution of 15 species of deep-sea elasmobranchs (12 sharks and 3 rays) captured frequently in the Exclusive Economic Zone of the Azores Archipelago (Mid-Atlantic Ridge) to explore spatial management to reduce unwanted catches of these species. We applied Generalised Additive Models to predict the probability of presence of 15 species, as well as the abundance of 6 of those species, within the Azores EEZ and neighbouring seamounts (up to 2000 m depth), using environmental and operational variables as predictors. Our results identified that depth is most influential in determining the distribution of these sharks and rays, in addition to seafloor topography. Distinctive bathymetric features such as seamounts and ridges were highlighted as areas where the probability of presence of the greatest number of species overlapped. Although not related to habitat, gear type influenced the capture probability of certain species, with the artisanal handline, gorazeira, having lower captures than bottom longline. Our results support using depth-based, area-based, and gear-based tactics to design management measures to reduce elasmobranch bycatch, for more sustainable deep-sea fisheries.

Dinkel, T. M., & Sanchez-Lizaso, J. L. (2020). Involving stakeholders in the evaluation of management strategies for shortfin mako (Isurus oxyrinchus) and blue shark (Prionace glauca) in the Spanish longline fisheries operating in the Atlantic Ocean. *Marine Policy,* 120. https://doi.org/10.1016/j.marpol.2020.104124

Shortfin mako (Isurus oxyrinchus) and blue shark (Prionace glauca) are a relevant bycatch in the Spanish surface longline fisheries that operate in the Atlantic Ocean. Concern has been raised after the 2017 and 2019 shortfin mako evaluations for the Northern Atlantic stock. It stated the population being overfished and suffering from overfishing. Also blue shark is subject to high extraction rates in the Atlantic Ocean. Few data and uncertainty in assessment results suggest that further management strategies could be taken into account for both species. This study evaluated different fisheries management strategies for shortfin mako and blue shark in the Atlantic Ocean from the stakeholders' perspective. Personal interviews were conducted with Spanish fishermen and surveys were sent to scientists and non-governmental organizations (NGOs). Local Ecological Knowledge was considered to be useful as fishermen possess unique expertise based on their continued interaction with the species and environment. Interviews allowed understanding the fishermen's perception on variations of stock

abundance, distribution patterns, size of capture and seasonal fluctuations for both species. SWOT (Strength, Weaknesses, Opportunities and Threats)-analysis was used to study the different management measures. Main management strategies proposed by all stakeholders to reduce the bycatch of both species were spatial-temporal closure, minimum size and quotas. The Sole Bank was suggested as a temporarily closed area to protect blue shark juveniles during the summer months. The participation of stakeholders enriched the knowledge available and provided a broader data set now available for decision makers in the corresponding regional fisheries management organization (RFMOs).

Escalle, L., Gaertner, D., Chavance, P., Delgado de Molina, A., Ariz, J., & Merigot, B. (2016). Consequences of fishing moratoria on catch and bycatch: the case of tropical tuna purse-seiners and whale and whale shark associated sets. *Biodiversity and Conservation,* 25(9), 1637-1659. https://doi.org/10.1007/s10531-016-1146-2

Time–area regulations have been introduced to manage stocks of tropical tuna, given the increased use of drifting fish aggregation devices (FADs). However, the consequences in terms of changes in fishing strategies and effort reallocation may not always be as expected. For instance, in the eastern Pacific Ocean, previous studies have highlighted that the increase use of FAD-fishing following the demand for tuna caught without dolphin mortality has raised concerns about the bycatch and the capture of juvenile tuna. In the tropical eastern Atlantic and western Indian Oceans, this study aimed to (1) assess, using before–after analysis, the consequences of previous time–area regulations on FAD sets on the fishing effort allocated to megafauna associated sets, and (2) evaluate through Monte Carlo simulations the potential effect of new regulations banning whale or/and whale shark associated sets. Firstly, we showed that previous time–area regulations, which were mainly implemented during seasons with few whale and whale shark associated sets, generally had thus little effect on the number of megafauna associated sets. Secondly, some simulations, particularly when both whale and whale shark associated sets were banned, predicted consequences of changes in fishing strategy. Indeed, these types of ban could lead to an increase in the number of FAD and free school sets but no change in the tuna catch, as well as a slight decrease in bycatch. These results indicate that an ecosystem approach to fisheries, by taking into account megafauna associated sets and bycatch, should thus be adopted when implementing management or conservation measures.

Filmalter, J. D., Bauer, R. K., Forget, F., Cowley, P. D., & Dagorn, L. (2021). Movement behaviour and fishery interaction of silky sharks (Carcharhinus falciformis) in the tropical tuna purse seine fishery in the Western Indian Ocean. *ICES Journal of Marine Science,* 78(7), 2474-2485. https://doi.org/10.1093/icesjms/fsab119

The silky shark Carcharhinus falciformis regularly associates with floating objects in the open ocean, resulting in relatively high levels of bycatch in industrial tuna purse seine fisheries using drifting fish aggregating devices (FADs). This bycatch has contributed to concerns regarding the sustainability of this fishery and its impact on silky shark populations. To investigate fishery interactions, movements of 28 silky sharks (86-235 cm TL, mean = 118 cm) fitted with pop-up and archival tags in the western Indian Ocean, between 2010 and 2012, were examined. Monthly overlap between probability surfaces of sharks and two fishery metrics (FAD-tuna catches and FAD positions) were calculated. Vertical habitat use overlapped almost entirely with operational gear depth. Horizontal movements were extensive (3-

5024 km) and covered large areas of the western Indian Ocean. Monthly overlap with FAD distributions was consistently high (64.03-100%) highlighting the need for compliance with FAD design regulations to avoid entanglement. Monthly overlap with tuna catches was more variable (8.43-51.83%). The observed movement patterns suggest static spatial management measures would be have limited conservation impact, however dynamic approaches could be appropriate. Limiting fishery activities directly will likely have the greatest conservation outcomes for silky sharks in the purse seine fishery.

Garcia-Rodriguez, E., & Sosa-Nishizaki, O. (2020). Artisanal fishing activities and their documented interactions with juvenile white sharks inside a nursery area. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 30(5), 903-914. https://doi.org/10.1002/aqc.3300

Juvenile white sharks distribute in coastal nursery areas, which are essential for population growth. Bahia Sebastian Vizcaino (BSV), Mexico, is a white shark nursery area in the north-eastern Pacific. Despite existing regulations forbidding the capture of white sharks, incidental catches still occur in some areas. Artisanal fisheries constitute one of the most important economic activities in BSV, yet no formal description of either these fisheries or the incidental catch of juvenile white sharks exists due to the poor data reporting system, thus preventing a clear understanding of the implications of these catches for the white shark population of the north-eastern Pacific. Artisanal fishing activities and their interactions with juvenile white sharks in BSV are described based on fishermen's knowledge. Artisanal fisheries in BSV are multi-specific, targeting mostly bottom-related species (e.g. white seabass and California halibut) that are also common prey for juvenile white sharks. These activities are the only source of income for the majority of fishermen in BSV and are conducted throughout the year, with gillnets being the main fishing gear. White sharks are incidentally caught in bottom gillnets mainly during the summer, although another peak in incidental catch was recorded during winter, possibly related to the presence of juvenile white sharks from California, USA. The most common size of juvenile white sharks incidentally caught was <2 m in the nearshore areas close to the mouth of the Ojo de Liebre Lagoon; larger juveniles (similar to 3 m) were caught in areas near Cedros, Natividad, and San Benito Islands. The multi-specific nature of BSV artisanal fisheries and their socio-economic value, and the high post-release survival of juvenile white sharks suggest that future regulatory actions should focus on the release of incidentally caught live juvenile white sharks and the involvement of the BSV fishing community to increase the effectiveness of management efforts.

Gilman, E., Chaloupka, M., Merrifield, M., Malsol, N. D., & Cook, C. (2016). Standardized catch and survival rates, and effect of a ban on shark retention, Palau pelagic longline fishery. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 26(6), 1031-1062. https://doi.org/10.1002/aqc.2599

1. Pelagic longline fisheries affect both market and vulnerable bycatch species and can have broad effects on community structure and processes. 2. Observer data from the Palau longline fishery were analysed to identify opportunities to mitigate vulnerable species bycatch, determine temporal trends in local abundance, and assess changes following a ban on shark retention and wire leaders. Catch and haulback condition data for bigeye and yellowfin tunas, blue and silky sharks and pelagic stingrays were fitted to standardized catch and survival rate models. 3. The fishery caught silky and blue sharks, olive ridley sea turtles and other species of conservation concern. 4. Changing from shallow sets to deep

daytime sets might reduce shark and sea turtle catch rates but increase turtle haulback mortality rates, maintain economically viable tuna catch rates, but increase catch rates of pelagic stingrays, a lower conservation concern than main caught species of sharks and turtles. 5. Focusing fishing effort during the middle of the calendar year would maximize yellowfin tuna and minimize silky shark standardized catch rates, but maximize blue shark catch rates. 6. A large decline in shark fishing mortality rate very likely occurred following a ban on shark retention and wire leaders. This was due to large reductions in the nominal shark catch rate and shark retention, partially offset by decreases in the shark haulback survival rate and pre-catch survival rate. Significantly higher blue shark and lower pelagic stingray nominal catch rates occurred on wire vs. monofilament leaders. Significantly higher blue shark and lower yellowfin tuna nominal catch rates occurred on sets using shallow 'shark lines'. It is a research priority to compare the probability of shark pre-catch survival after escaping from monofilament leaders with an ingested hook and trailing line to the survival probability when captured on wire leaders.

Gilman, E., Dalzell, P., Goren, M., Werner, T. B., Clarke, S., Alfaro-Shigueto, J., . . . Thomson, N. (2007). *Shark Depredation and Unwanted Bycatch in Pelagic Longline Fisheries: Industry Practices and Attitudes, and Shark Avoidance Strategies.* Western Pacific Regional Fishery Management Council, Retrieved from https://wedocs.unep.org/20.500.11822/13627

Substantial ecological, economic and social problems result from shark interactions in pelagic longline fisheries. Improved understanding of industry attitudes and practices towards shark interactions assists with managing these problems. Information on fisher knowledge and new strategies for shark avoidance may benefit sharks and fishers. A study of 12 pelagic longline fisheries from eight countries shows that incentives to avoid sharks vary along a continuum, based on whether sharks represent an economic disadvantage or advantage. Shark avoidance practices are limited, including avoiding certain areas, moving when shark interaction rates are high, using fish instead of squid for bait and deeper setting. Some conventionally employed fishing gear and methods used to target non-shark species contribute to shark avoidance. Shark repellents hold promise; more research and development is needed. Development of specifically designed equipment to discard sharks could improve shark post release survival prospects, reduce gear loss and improve crew safety. With expanding exploitation of sharks for fins and meat, improved data collection, monitoring and precautionary shark management measures are needed to ensure shark fishing mortality levels are sustainable.

Gilman, E., & Lundin, C. (2010). Minimising bycatch of sensitive species groups in marine capture fisheries: lessons from tuna fisheries. In *Handbook of Marine Fisheries Conservation and Management.* Q. Grafton, R. Hillborn, D. Squires, M. Tait, & M. Williams (Eds.), (pp. 23): Oxford University Press Retrieved from http://ecite.utas.edu.au/58808

Bycatch in marine capture fisheries is the retained catch of nontargeted but commercially viable species (referred to as “incidental catch”) plus all discards (Food and Agriculture Organization of the United Nations [FAO] 2005).1 It is an increasingly prominent international issue, raising ecological concerns, as some bycatch species of cetaceans (whales, dolphins, and porpoises), seabirds, sea turtles, elasmobranchs (sharks, skates, and rays), and other fi sh species are particularly vulnerable to overexploitation and slow to recover from large population declines (FAO 1999a, 1999b, in press; Fowler et al. 2005; Gales 1998; Gilman et al. 2005, 2006a, 2006c, 2008; Lutz and Musick 1997). Bycatch can

alter biodiversity and ecosystem functions by removing top predators and prey species at unsustainable levels (Myers et al. 2007). It also alters foraging behavior of species that learn to take advantage of discards. Economic effects of bycatch on fi sheries include loss of bait, reduced availability of baited hooks when they are occupied with unwanted bycatch species, and concomitant reduced catch of marketable species; the imposition of a range of restrictions, closed areas, embargos, and possible closures; allocation among fi sheries, where bycatch in one fi shery reduces target catch in another, and bycatch of juvenile and undersized individuals of a commercial species can adversely affect future catch levels (Brothers et al. 1999; Hall et al. 2000). Discarded bycatch raises a social issue over waste: From 1992 to 2001 an average of 7.3 million metric tons of fi sh were annually discarded, representing 8 percent of the world catch (FAO 2005). Prominent bycatch issues include dolphins and porpoises in purse seine fi sheries and driftnets; fi sh discards in shrimp trawl fi sheries; and seabird, sea turtle, marine mammal, and shark bycatch in longline, purse seine, gillnet, and trawl fi sheries (FAO 1999a, 1999b, 2005, in press; Hall et al. 2000). In commercial tuna fi sheries, the incidental bycatch of sensitive species groups (seabirds, sea turtles, marine mammals, and sharks) and bycatch of juvenile and undersized tunas are allocation and conservation issues. In addition to problematic bycatch, overexploitation and illegal, unreported, and unregulated (IUU) fi shing, which complicates bycatch management, are additional conservation issues facing the management of tuna fi sheries. This chapter employs examples of bycatch in commercial tuna fi sheries to describe (1) the range of options to reduce bycatch, (2) principles and approaches to successfully introduce effective bycatch reduction measures, and (3) initiatives taken by intergovernmental organizations, the fi shing industry, and retailers to address bycatch. Changes needed to improve the sustainability of tuna production are recommended.

Gilman, E. L. (2011). Bycatch governance and best practice mitigation technology in global tuna fisheries. *Marine Policy,* 35(5), 590-609. https://doi.org/10.1016/j.marpol.2011.01.021

Overexploitation of bycatch and target species in marine capture fisheries is the most widespread and direct driver of change and loss of global marine biodiversity. Bycatch in purse seine and pelagic longline tuna fisheries, the two primary gear types for catching tunas, is a primary mortality source of some populations of seabirds, sea turtles, marine mammals and sharks. Bycatch of juvenile tunas and unmarketable species and sizes of other fish in purse seine fisheries, and juvenile swordfish in longline fisheries, contributes to the overexploitation of some stocks, and is an allocation issue. There has been substantial progress in identifying gear technology solutions to seabird and sea turtle bycatch on longlines and to direct dolphin mortality in purse seines. Given sufficient investment, gear technology solutions are probably feasible for the remaining bycatch problems. More comprehensive consideration across species groups is needed to identify conflicts as well as mutual benefits from mitigation methods. Fishery-specific bycatch assessments are necessary to determine the efficacy, economic viability, practicality and safety of alternative mitigation methods. While support for gear technology research and development has generally been strong, political will to achieve broad uptake of best practices has been lacking. The five Regional Fisheries Management Organizations have achieved mixed progress mitigating bycatch. Large gaps remain in both knowledge of ecological risks and governance of bycatch. Most binding conservation and management measures fall short of gear technology best practice. A lack of performance standards, in combination with an inadequate observer coverage for all but large Pacific purse seiners, and incomplete data collection, hinders assessing measures' efficacy. Compliance is probably low due to inadequate surveillance and enforcement. Illegal, unreported and unregulated tuna fishing hampers governance efforts. Replacing consensus-based decision-making and eliminating opt-

out provisions would help. Instituting rights-based management measures could elicit improved bycatch mitigation practices. While gradual improvements in an international governance of bycatch can be expected, market-based mechanisms, including retailers and their suppliers working with fisheries to gradually improve practices and governance, promise to be expeditious and effective.

Graf, A. J. (2013). Great White Shark Bycatch Reduction Problems in the California/Oregon Drift Gillnet Fishery. *Golden Gate University Environmental Law Journal,* 6(2), 347. Retrieved from https://digitalcommons.law.ggu.edu/gguelj/vol6/iss2/8/

Part I of this Comment explores the problems of great white shark bycatch by examining the white shark's susceptibility to bycatch and the Fishery responsible for a significant portion of white shark bycatch. Part II discusses the federal statutes and regulations applicable to bycatch and the Fishery. Part III provides recommendations for reducing white shark bycatch in the future by modifying current federal statutes, amending existing regulations, and increasing research efforts.

Graham, J., Kroetz, A. M., Poulakis, G. R., Scharer, R. M., Carlson, J. K., Lowerre-Barbieri, S. K., . . . Grubbs, R. D. (2022). Commercial fishery bycatch risk for large juvenile and adult smalltooth sawfish (Pristis pectinata) in Florida waters. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 32(3), 401-416. https://doi.org/10.1002/aqc.3777

Incidental catch of marine species can create ecological and economic issues, particularly for endangered species. The smalltooth sawfish (Pristis pectinata) is endemic to the Atlantic Ocean and listed as Endangered in the US Endangered Species Act. One of its major threats is bycatch mortality in commercial fisheries. Despite the protection afforded by the US Endangered Species Act, smalltooth sawfish are still captured as bycatch in commercial fisheries. Acoustic and satellite tag data collected on 59 sawfish between 2011 and 2019 were analysed to assess commercial fishery bycatch risk for large juveniles and adults off Florida. This study focused on shrimp trawl, south-east coastal gillnet, and shark bottom longline fisheries, as these were identified in the recovery plan as having the greatest potential threats to recovery. Bycatch risk associated with the shrimp trawl fishery was significantly higher than the other fisheries, indicating that this fishery currently poses the greatest threat to recovery. Bycatch risk was concentrated in all seasons in the Gulf of Mexico adjacent to the lower Florida Keys for the shrimp trawl fishery, off Cape Canaveral in the south-east coastal gillnet fishery, and in the Atlantic Ocean adjacent to the Florida Keys in the shark bottom longline fishery. Tagging location and sex were predictors of bycatch risk. Individuals tagged in Charlotte Harbor had the highest shrimp trawl bycatch risk. Females tagged in south Florida tended to reside in the deepest water, which is where shrimp trawl effort is highest. Therefore, females may be at more risk in these deeper waters. Results from this study indicate a year-round closure of waters off south-west Florida to the shrimp trawl fishery between Charlotte Harbor and the western Florida Keys would reduce sawfish bycatch, and thus mortality, which is in line with recovery plan goals.

Grantham, H. S., Petersen, S. L., & Possingham, H. P. (2008). Reducing bycatch in the South African pelagic longline fishery: the utility of different approaches to fisheries closures. *Endangered Species Research,* 5, 291-299. https://doi.org/10.3354/esr00159

Seabirds, turtles and sharks are often of conservation concern because they are frequently bycatch in fisheries. Fisheries managers shifting from a target species focus to an ecosystem-based approach are being required to consider the impact of fisheries on non-target species. There are a range of complementary management tools that help reduce bycatch, such as gear restrictions, temporal restrictions, and bycatch reduction devices. One management approach that is increasingly being considered is fisheries closures. We tested the utility of 3 closure approaches for the improved protection of bycatch species in the South African pelagic longline fishery. As there was some variation where and when different groups of bycatch species were caught, we found that temporary spatial closures were the most effective strategy for both protecting bycatch and minimizing the cost to fishers. This is logical because having mobile closures in space and time provides more flexibility than permanent spatial closures or seasonal closures. However these benefits need to be traded off against the costs and problems of implementing temporary spatial closures. Of the 2 sub-optimal strategies, we discovered that seasonal closures are significantly less effective than spatial closures.

Gupta, T., Booth, H., Arlidge, W., Rao, C., Manoharakrishnan, M., Namboothri, N., . . . Milner-Gulland, E. J. (2020). Mitigation of Elasmobranch Bycatch in Trawlers: A Case Study in Indian Fisheries. *Frontiers in Marine Science,* 7. https://doi.org/10.3389/fmars.2020.00571

Bycatch poses a significant threat to marine megafauna, such as elasmobranchs. India has one of the highest elasmobranch landings globally, through both targeted catch and bycatch. As elasmobranchs contribute to food and livelihood security, there is a need for holistic approaches to bycatch mitigation. We adopt an interdisciplinary approach to critically assess a range of hypothetical measures for reducing elasmobranch capture in a trawler fishery on India's west coast, using a risk-based mitigation hierarchy framework. Data were collected through landing surveys, interviews and a literature review, to assess the following potential management options for their technical effectiveness and socio-economic feasibility: (1) spatio-temporal closures; (2) net restrictions; (3) bycatch reduction devices (BRDs); and (4) live onboard release. Our study provides the first evidence-based and nuanced understanding of elasmobranch bycatch management for this fishery, and suggestions for future conservation and research efforts. Onboard release may be viable for species like guitarfish, with moderate chances of survival, and was the favored option among interview respondents due to minimal impact on earnings. While closures, net restrictions and BRDs may reduce elasmobranch capture, implementation will be challenging under present circumstances due to the potentially high impact on fisher income. Interventions for live release can therefore be used as a step toward ameliorating bycatch, while initiating longer-term engagement with the fishing community. Participatory monitoring can help address critical knowledge gaps in elasmobranch ecology. Spatio-temporal closures and gear restriction measures may then be developed through a bottom-up approach in the long term. Overall, the framework facilitated a holistic assessment of bycatch management to guide decision-making. Scaling-up and integrating such case studies across different species, fisheries and sites would support the formulation of a meaningful management plan for elasmobranch fisheries in India.

Hutchinson, M., Coffey, D. M., Holland, K., Itano, D., Leroy, B., Kohin, S., . . . Wren, J. (2019). Movements and habitat use of juvenile silky sharks in the Pacific Ocean inform conservation strategies. *Fisheries Research,* 210, 131-142. https://doi.org/10.1016/j.fishres.2018.10.016

Understanding the habitat use and behavior of commercially exploited species throughout ontogeny is useful for devising effective management and conservation strategies. Differences in habitat use can often be exploited to separate target and non-target species, and determinations of home range size can inform the proper scale of conservation actions. In tropical tuna purse seine fisheries in the Pacific Ocean, juvenile silky sharks, Carcharhinus falciformis, comprise a large proportion of the total elasmobranch bycatch. There is now growing recognition of declines in silky shark populations and the need for international collaboration in conservation efforts. Yet, very little is known about the movement behavior or habitat use for this species. In this study, movement behavior of juvenile silky sharks was investigated using pop-up satellite archival tags placed on sharks that were captured during chartered research cruises on a commercial tuna purse seine fishing vessel using drifting Fish Aggregating Devices (FADs) in the western and central Pacific Ocean and on sharks captured using pelagic longlines in the eastern tropical Pacific. Analysis of horizontal and vertical movement behavior revealed silky sharks spend nearly 100% of their time in the shallow, warm waters of the mixed layer. Juvenile silky shark depth and thermal preferences overlapped with the preferred habitat of the primary target tuna species, indicating vulnerability to capture in purse seine and shallow-set longline fisheries throughout the tropical and subtropical regions of the Pacific Ocean where temperatures range between 24 and 29 degrees C. Reconstruction of horizontal movements showed dispersal between adjacent national jurisdictions and international waters, highlighting the need for international collaborations in the implementation of conservation measures.

Iwane, M. A., Leong, K. M., Vaughan, M., & Oleson, K. L. L. (2020). *Engaging Hawai'i small boat fishers to mitigate pelagic shark mortality*. Pacific Islands Fisheries Science Center https://doi.org/10.25923/54tf-kh65

This project examines West Hawai'i small boat fisher perspectives on pelagic shark interactions and fisheries management. A recent listing of the oceanic whitetip shark under the Endangered Species Act (ESA) has stimulated interest in poorly documented fisher-shark interactions of Hawai'i. We conducted semi-structured interviews with West Hawai'i small boat fishers to supplement limited scientific understanding of fisher-shark interactions in Hawai'i, elicit fisher perspectives on shark interactions and local fisheries management more broadly, and shed light on the viability of different approaches to mitigate shark mortality and engage with fishing communities. By partnering with and observing a community-based shark-tagging project based primarily in the West Hawai'i community, we illuminated fishers' relationships with one another, fisheries managers and scientists, and the sharks they encounter.

Li, J., Song, L., & Li, D. (2013). *The capture depth of the dominant bycatch species and the relationship between their catch rates and the sea surface temperature.* Indian Ocean Tuna Commission, Retrieved from https://www.fao.org/3/bh060e/bh060e.pdf

On the basis of the data collected on a pelagic longline vessel from November 18, 2012 through March 31, 2013 in the fishing area of the Indian Ocean (2°47'N~8°13'S,62°18'E~ 67°49'E), the capture depth of

the dominant bycatch species and the relationship between their catch rates and the sea surface temperature were analyzed. The results showed that (1) blue shark (Prionace glauca) mainly inhabited the water layer of 80~160m, the water layer with the highest catch rate was 120~160m, followed by 80~120m, the catch rate of remaining water layers was low; (2) swordfish (Xiphias gladius) mainly inhabited the water layer of 80~200m, the catch rate of this water layer increased at first then decreased, the catch rate in the water layer of 120~160m was the highest and much higher than that of other water layers; (3) blue marlin (Makaira nigricans) was mainly caught in the water layer of 80~200m, the catch rate of this water layer was high, and the catch rate peaked in the water layer of 160~200m. The catch rate in the water layer of 200~280m was low, and decreased with depth; (4)striped marlin (Tetrapturus audax) was caught in the water layer of 80~200m, no striped marlin was caught in other water layer, the catch rates decreased with depth; (5) crocodile shark was caught in the water layer of 200~320m, no crocodile shark was caught in other water layer, the catch rates increased with depth; (6)the catch rates of blue shark increased with the increasing of the sea surface temperature, peaked at 30.1~30.5°C; the catch rates of swordfish and blue marlin peaked at 29.6~30°C; the catch rates of striped marlin were high at 29.6~31°C and peaked at 30.1~30.5°C; the catch rates of crocodile shark peaked at 30.6~31°C. This study suggested that the depth of the pelagic longline hook should be deployed deeper than 160m and shallower than 280m or avoid operation in the area where the sea surface temperature is higher than 29.6°C to reduce the bycatch of blue shark, swordfish, blue marlin and striped marlin.

Mustika, P. L. K., Wonneberger, E., Erzini, K., & Pasisingi, N. (2021). Marine megafauna bycatch in artisanal fisheries in Gorontalo, northern Sulawesi (Indonesia): An assessment based on fisher interviews. *Ocean & Coastal Management,* 208. https://doi.org/10.1016/j.ocecoaman.2021.105606

While bycatch, the unintentional catch of untargeted species, is one of the main threats to large marine species such as cetaceans, reef sharks and turtles, also known as megafauna, fishers can also be negatively impacted by bycatch. Understanding local fisheries profiles, fishers' demography and their opinion is thus a necessary part of the strategy to mitigate marine megafauna bycatch in artisanal fisheries. Interviews with fishers were conducted in order to assess the magnitude of marine megafauna bycatch, the dependency of fishers on the fishery and the potential for implementation of bycatch mitigation measures in the artisanal fisheries in Gorontalo, northern Sulawesi (Indonesia). Quantitative and qualitative methods were used to analyse the data. Regression trees showed that cetacean and turtle bycatch were mainly influenced by the fishing location, while bycatch of reef sharks, whale sharks (Rhincodon typus) and mobulids was mainly influenced by the gear type. Cetaceans mostly escaped after being caught or were released. Reef sharks, which were often sold for their meat, were caught in the highest numbers followed by sea turtles. Interviewed fishers had large households, typically averaging more than five people, and mostly were dependent on the fishery, often with few other sources of income. Fishers were generally in favour of reducing bycatch as bycatch often posed a financial threat, due to lost catch and damaged gear. When implementing bycatch reduction measures, it is important to involve fishers in design and implementation of mitigation measures. As awareness on bycatch management and mitigation is growing in Indonesia, measures including recordings (official and self-reporting), capacity building on bycatch specimen handling and release and bycatch mitigation techniques (e.g. gear modifications) are some of the most important bycatch reduction strategies for the country.

Ortuño-Crespo, G., Griffiths, S. P., & Murua, H. (2022). *Reducing shark bycatch in tuna fisheries: adaptive spatio-temporal management options for the eastern Pacific Ocean.* Working Group on Bycatch Inter-American Tropical Tuna Commission, Retrieved from https://www.bmis-bycatch.org/references/u7srk5zv

Purse-seine tropical tuna fishing in the eastern tropical Pacific Ocean (EPO) results in the bycatch of several sensitive species groups, including elasmobranchs. Effective management of ecosystems balances conservation and resource use, but requires actionable knowledge that accounts for both trade-offs and synergies. Seasonal and adaptive spatial management measures can be effective to reduce the impact of fisheries on non-target species while preserving, or even increasing, target species catch. Exploring the potential distribution and impact of fisheries closures in the open ocean, where highly dynamic environmental conditions drive distributional changes in biological communities throughout the year, requires the identification of persistently high-risk areas, where the likelihood of encountering and catching unwanted bycatch species, relative to the target species, is high. We used fisheries observer data from 1995–2021 to explore the spatio-temporal persistence of areas of high bycatch risk for two species of oceanic sharks, silky shark (Carcharhinus falciformis) and oceanic whitetip shark (Carcharhinus longimanus), and low tuna catch rate areas—defined as areas of high fishing inefficiency (i.e., poor fishing areas). We found that if areas of high fishing inefficiency were closed throughout the study period, and effort reallocated proportionally to reflect historical effort patterns, yearly tuna catch may have increased by 1–11% while the bycatch of silky and oceanic whitetip sharks could have decreased by 10-19% and 9%, respectively. Prior to fishing effort redistribution, bycatch reductions would have accrued to 21–41% and 14% for silky and oceanic whitetip sharks, respectively. Our analysis builds on past evidence and demonstrates the high potential for reducing elasmobranch bycatch in the EPO, while not compromising the catch rates of target tuna species. It also highlights the need to consider new dynamic and adaptive management measures to more efficiently fulfill conservation and sustainability objectives for exploited resources in the EPO.

Poisson, F., Abascal Crespo, F., Ellis, J. R., Chavance, P., Pascal, B., Santos, M. N., . . . Murua, H. (2016). Technical mitigation measures for sharks and rays in fisheries for tuna and tuna-like species: turning possibility into reality. *Aquatic Living Resources,* 29(4). https://doi.org/10.1051/alr/2016030

Tuna fisheries have been identified as one of the major threats to populations of other marine vertebrates, including sea turtles, sharks, seabirds and marine mammals. The development of technical mitigation measures (MM) in fisheries is part of the code of conduct for responsible fisheries. An in-depth analysis of the available literature regarding bycatch mitigation in tuna fisheries with special reference to elasmobranchs was undertaken. Studies highlighting promising MMs were reviewed for four tuna fisheries (longline, purse seine, driftnets and gillnet, and rod and line - including recreational fisheries). The advantages and disadvantages of different MMs are discussed and assessed based on current scientific knowledge. Current management measures for sharks and rays in tuna Regional Fishery Management Organizations (t-RFMOs) are presented. A review of relevant studies examining at-vessel and postrelease mortality of elasmobranch bycatch is provided. This review aims to help fisheries managers identify pragmatic solutions to reduce mortality on pelagic elasmobranchs (and other higher vertebrates) whilst minimizing impacts on catches of target tuna species. Recent research efforts have identified several effective MMs that, if endorsed by t-RFMOs, could reduce elasmobranchs mortality rate in international tropical purse seine tuna fisheries. In the case of longline fisheries, the number of

operational effective MMs is very limited. Fisheries deploying driftnets in pelagic ecosystems are suspected to have a high elasmobranchs bycatch and their discard survival is uncertain, but no effective MMs have been field validated for these fisheries. The precautionary bans of such gear by the EU and by some t-RFMOs seem therefore appropriate. Recreational tuna fisheries should be accompanied by science-based support to reduce potential negative impacts on shark populations. Priorities for research and management are identified and discussed.

Pons, M., Watson, J. T., Ovando, D., Andraka, S., Brodie, S., Domingo, A., . . . Hilborn, R. (2022). Trade-offs between bycatch and target catches in static versus dynamic fishery closures. *Proceedings of the National Academy of Sciences,* 119(4). https://doi.org/10.1073/pnas.2114508119

While there have been recent improvements in reducing bycatch in many fisheries, bycatch remains a threat for numerous species around the globe. Static spatial and temporal closures are used in many places as a tool to reduce bycatch. However, their effectiveness in achieving this goal is uncertain, particularly for highly mobile species. We evaluated evidence for the effects of temporal, static, and dynamic area closures on the bycatch and target catch of 15 fisheries around the world. Assuming perfect knowledge of where the catch and bycatch occurs and a closure of 30% of the fishing area, we found that dynamic area closures could reduce bycatch by an average of 57% without sacrificing catch of target species, compared to 16% reductions in bycatch achievable by static closures. The degree of bycatch reduction achievable for a certain quantity of target catch was related to the correlation in space and time between target and bycatch species. If the correlation was high, it was harder to find an area to reduce bycatch without sacrificing catch of target species. If the goal of spatial closures is to reduce bycatch, our results suggest that dynamic management provides substantially better outcomes than classic static marine area closures. The use of dynamic ocean management might be difficult to implement and enforce in many regions. Nevertheless, dynamic approaches will be increasingly valuable as climate change drives species and fisheries into new habitats or extended ranges, altering species-fishery interactions and underscoring the need for more responsive and flexible regulatory mechanisms.

Prior, J. (2017). *Protection On The Move: Applying Dynamic Ocean Management To Address Shark Bycatch In Atlantic Canada.* (Masters of Marine Management), Dalhousie University, Retrieved from http://hdl.handle.net/10222/73837

The Canadian North Atlantic pelagic longline fishery for swordfish and tuna has unintended bycatch of porbeagle, shortfin mako, and blue sharks. This creates concerns for species-at-risk populations, ecosystem health, harvesters safety and economic security. This study proposes that a Dynamic Ocean Management (DOM) application could mitigate the pelagic shark bycatch associated with this longline fishery. The document reviews published information on the focal shark species, the fishery, current marine spatial management tools used in Canada, and theory and applications of DOM. Following this, the study evaluates the attitudes of 14 primary stakeholders towards DOM through stakeholder group governance analysis and semi-structured interviews. The associated stakeholders who participated in the project include one participant from each of the regional RFMOs; NAFO and ICCAT, three participants from DFO, one participant from the Nova Scotia Swordfish Association, four NGO perspectives, two academic perspectives, and two private third-party interest groups. In the interviews, all individuals discussed their views on the bycatch challenge, the desirability and feasibility of applying

DOM, and the current efforts undertaken by each group. The results of this study show that a DOM application is seen as a desirable potential solution by most and could be feasible depending on project structure and management style. Therefore, based on the considerations of the governance analyses and interview responses, a management plan is proposed and associated requirements, considerations, and concerns are discussed. Specifically, the plan proposes a management tool in the style of a phone app or website interface. This interface would allow harvesters to geo-tag areas where shark bycatch has impacted their catch in near-real time. When overlaid with other data streams, including historical seasonal data, ocean conditions and species tracking, it allows the whole fleet to strategically plan their next location to set their longlines, with an active consideration to avoid sharks.

Silva, P. M., Teixeira, C. M., Pita, C., Cabral, H. N., & Franca, S. (2021). Portuguese Artisanal Fishers' Knowledge About Elasmobranchs-A Case Study. *Frontiers in Marine Science,* 8. https://doi.org/10.3389/fmars.2021.684059

The high economic value of fisheries was historically associated to commercial teleost fishes. Since the 1970s, despite some elasmobranchs becoming an important target or a bycatch, relatively little research has been carried out on this group because of their low economic value. Due to their specific life history characteristics, sharks and rays are particularly vulnerable to overexploitation, taking several decades to recover after reaching an overexploitation status. In Portugal elasmobranch fishery results mainly from targeted longlining and bycatch from different fishing gears. During the last decade, the Total Allowable Catches (TACs) of rays have been decreasing, the European Union (EU) banned the capture of some ray species, the Portuguese government implemented both a closed season and a minimum landing size for some rays, and the EU prohibited target fishing for sharks. All these measures may have been highly responsible for the national and local landings reduction. Official landings from the last decade were analyzed, the landed species conservation status was consulted, and structured interviews using a questionnaire were conducted in the most important fishing port in the Portuguese mainland, the port of Sesimbra. Results led us to conclude that fishers' answers and landings data did not match. It also revealed a lack of awareness by fishers about the state of shark and ray populations, and about some aspects of their biology and ecology, like reproduction season and method. The present study highlights the need to fill in this existing gap in knowledge through the transfer of scientific knowledge and sharing of management responsibilities. Also, we aimed to demonstrate the necessity for awareness and education activities within fishing communities, an essential step to elasmobranch conservation.

Tixier, P., Lea, M. A., Hindell, M. A., Welsford, D., Mazé, C., Gourguet, S., & Arnould, J. P. Y. (2021). When large marine predators feed on fisheries catches: Global patterns of the depredation conflict and directions for coexistence. *Fish and Fisheries,* 22(1), 31-53. https://doi.org/10.1111/faf.12504

The sustainable mitigation of human–wildlife conflicts has become a major societal and environmental challenge globally. Among these conflicts, large marine predators feeding on fisheries catches, a behaviour termed “depredation,” has emerged concomitantly with the expansion of the world’s fisheries. Depredation poses threats to both the socio-economic viability of fisheries and species conservation, stressing the need for mitigation. This review synthesizes the extent and socio-ecological impacts of depredation by sharks and marine mammals across the world, and the various approaches used to minimize it. Depredation was reported in 214 fisheries between 1979 and 2019 (70% post-2000)

and affected fleets from 44 countries, in all sectors (commercial, artisanal and recreational), and in all major fishing techniques (nets, traps and hook-and-lines). A total of 68 predator species were involved in depredation (20 odontocetes, 21 pinnipeds and 27 sharks), and most (73%) were subject to either by-catch and/or retaliatory killing from fishers when interacting with gear. Impacts on fishers were primarily associated with catch losses and gear damage but often lacked assessments. Deterrence was a major mitigation approach but also the least effective. Gear modifications or behavioural adaptation by fishers were more promising. This review highlights the need for improved monitoring, and interdisciplinary and integrated research to quantify the determinants and impacts of depredation in the socio-ecological dimension. More importantly, as the conflict is likely to escalate, efforts directed towards changing perceptions and integrating knowledge through adaptive co-management are raised as key directions towards coexistence between fisheries and large marine predators.

Watson, J. T., Essington, T. E., Lennert-Cody, C. E., & Hall, M. A. (2009). Trade-Offs in the Design of Fishery Closures: Management of Silky Shark Bycatch in the Eastern Pacific Ocean Tuna Fishery. *Conservation Biology,* 23(3), 626-635. https://doi.org/10.1111/j.1523-1739.2008.01121.x

Bycatch-the incidental catch of nontarget species-is a principal concern in marine conservation and fisheries management. In the eastern Pacific Ocean tuna fishery, a large fraction of nonmammal bycatch is captured by purse-seine gear when nets are deployed around floating objects. We examined the spatial distribution of a dominant species in this fishery's bycatch, the apex predator silky shark (Carcharhinus falciformis), from 1994 to 2005 to determine whether spatial closures, areas where fishing is prohibited, might effectively reduce the bycatch of this species. We then identified candidate locations for fishery closures that specifically considered the trade-off between bycatch reduction and the loss of tuna catch and evaluated ancillary conservation benefits to less commonly captured taxa. Smoothed spatial distributions of silky shark bycatch did not indicate persistent small areas of especially high bycatch for any size class of shark over the 12-year period. Nevertheless, bycatch of small silky sharks (< 90 cm total length) was consistently higher north of the equator during all years. On the basis of this distribution, we evaluated nearly 100 candidate closure areas between 5 degrees N and 15 degrees N that could have reduced, by as much as 33%, the total silky shark bycatch while compromising only 12% of the tuna catch. Although silky sharks are the predominant species of elasmobranchs caught as bycatch in this fishery, closures also suggested reductions in the bycatch of other vulnerable taxa, including other shark species and turtles. Our technique provides an effective method with which to balance the costs and benefits of conservation in fisheries management. Spatial closures are a viable management tool, but implementation should be preceded by careful consideration of the consequences of fishing reallocation.

Whitney, N. M., Lear, K. O., Morris, J. J., Hueter, R. E., Carlson, J. K., & Marshall, H. M. (2021). Connecting post-release mortality to the physiological stress response of large coastal sharks in a commercial longline fishery. *Plos One,* 16(9), e0255673. https://doi.org/10.1371/journal.pone.0255673

Bycatch mortality is a major factor contributing to shark population declines. Post-release mortality (PRM) is particularly difficult to quantify, limiting the accuracy of stock assessments. We paired blood-stress physiology with animal-borne accelerometers to quantify PRM rates of sharks caught in a

commercial bottom longline fishery. Blood was sampled from the same individuals that were tagged, providing direct correlation between stress physiology and animal fate for sandbar (Carcharhinus plumbeus, N = 130), blacktip (C. limbatus, N = 105), tiger (Galeocerdo cuvier, N = 52), spinner (C. brevipinna, N = 14), and bull sharks (C. leucas, N = 14). PRM rates ranged from 2% and 3% PRM in tiger and sandbar sharks to 42% and 71% PRM in blacktip and spinner sharks, respectively. Decision trees based on blood values predicted mortality with >67% accuracy in blacktip and spinner sharks, and >99% accuracy in sandbar sharks. Ninety percent of PRM occurred within 5 h after release and 59% within 2 h. Blood physiology indicated that PRM was primarily associated with acidosis and increases in plasma potassium levels. Total fishing mortality reached 62% for blacktip and 89% for spinner sharks, which may be under-estimates given that some soak times were shortened to focus on PRM. Our findings suggest that no-take regulations may be beneficial for sandbar, tiger, and bull sharks, but less effective for more susceptible species such as blacktip and spinner sharks.

Whoriskey, S., Arauz, R., & Baum, J. K. (2011). Potential impacts of emerging mahi-mahi fisheries on sea turtle and elasmobranch bycatch species. *Biological Conservation,* 144(6), 1841-1849. https://doi.org/10.1016/j.biocon.2011.03.021

Mahi-mahi (Coryphaena hippurus) is a resilient pelagic species that could provide long-term highly productive fisheries. Using FAO data we document enormous increases (746%) in reported global mahi-mahi landings since 1950. Detailed mahi-mahi fisheries records are limited, but an observer program monitoring Costa Rica's Pacific mahi-mahi pelagic longline fleet between 1999 and 2008 (n = 217 sets) provided a rare opportunity to quantify bycatch in these fisheries. Several sea turtles and sharks of global conservation concern were caught incidentally: olive ridley turtle (Lepidochelys olivacea; n = 1348, mean = 9.05 per 1000 hooks), silky shark (Carcharhinus falciformis; n = 402, mean = 2.96 per 1000 hooks), thresher sharks (Alopias sp.; n = 158, mean = 1.12 per 1000 hooks), green turtle (Chelonia mydas; n = 49, mean = 0.35 per 1000 hooks), and three other threatened sharks in small numbers. Pelagic stingray (Pteroplatytrygon violacea; a ray of low conservation concern) was also a common bycatch (n = 625, mean = 4.77 per 1000 hooks). Generalized linear models (GLMs) of catch rates showed increases in olive ridley turtles and decreases in mahi-mahi and silky sharks over the decade examined. The high hooking survival rates of olive ridley and green turtles in observed sets (95% and 96% respectively) suggest that widespread training of the fleet in careful gear removal and turtle release methods could be one effective bycatch mitigation strategy for these species. GLMs also provide evidence that closing the fishery during peak olive ridley nesting times (at least near nesting beaches), in combination with reduced gear soak times, could help minimize the fishery's impacts on threatened bycatch species while still maintaining a productive fishery.