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REVIEW

Safe handling practices to increase post-capture survival of cetaceans, sea turtles, seabirds, sharks, and billfish in tuna fisheries

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ABSTRACT: 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.

KEY WORDS: Protected species · Vulnerable · Regional Fishery Management Organization · RFMO · Fisheries · Management · Conservation

1. INTRODUCTION

Capture of non-target species in fishing gear is a global problem (Alverson et al. 1994, Hall et al. 2000). Species that are not retained for sale or personal consumption are often discarded. In fisheries for large pelagic species, such as tunas, non-target catch includes protected and threatened species (e.g. sea turtles, cetaceans, and seabirds), and in some cases, shark and billfish species that are discarded due to regulatory measures or other reasons (Clarke et al. 2013). In certain areas, they are captured and discarded in such high numbers that their capture poses a conservation concern (Lewison et al. 2004, Read et al. 2006).

Capture in fishing gear may cause injury that results in immediate mortality (e.g. dead upon arrival at vessel) or leads to a delayed mortality due to injury or stress after the animal's escape or release from fishing gear (Moyes et al. 2006, Parga 2012). Ideally, avoiding interactions between marine animals and fishing gear is important for the conservation of protected species and the stock management of non-target species. However, in cases where avoidance is not possible, strategies for improving post-capture survival can be vital (Patterson et al. 2014, Swimmer et al.

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2014). When interactions do occur, it is important to work carefully to remove gear when conditions and safety considerations allow, and to document the occurrence for later reporting to fisheries managers.

Identifying practices that allow for gear to be safely removed from marine animals can increase post-capture survival of bycaught animals and can enable fishery managers to create effective management measures (e.g. safe handling protocols or tool requirements on vessels) to improve the outcome of interactions (e.g. alive vs. dead). Improved management through identification and implementation of safe handling practices and protocols would allow tuna Regional Fishery Management Organizations (tRFMOs) to respond to recent mandates (e.g. FAO 1995, 1999a,b, 2011a,b, CBD 2010, Juan-Jordá et al. 2018) to improve governance of fisheries and conservation and management of fishery resources within their jurisdiction, including better management of fish and non-fish bycatch species (Gilman 2011, Gilman et al. 2007, 2014). RFMOs are international organizations, formed by countries with fishing interests in a particular area or ocean basin that oversee management of fisheries in that convention area. They have been integral in fisheries management of stocks that span or occur beyond national boundaries and of highly migratory stocks (Gilman et al. 2014). Due to the wide expanse of tRFMO fisheries and their ability to significantly impact non-targeted species, providing the best and most up-to-date information to address bycatch is critical to reduce mortality associated with incidental catch on a global scale.

To reduce post-capture mortality of bycaught species and to inform tRFMO management measures, we provide a summary of recent literature on safe handling of sea turtles, cetaceans, seabirds, sharks, and billfish after interactions with gillnet, pelagic longline, and purse seine gear, the predominant fishing gears for major tuna and tuna-like species that tRFMOs manage (Miyake et al. 2004). We also review measures in place by the 5 regional tRFMOs, and provide an inventory of those that require safe handling in their fisheries for the gears and taxa included in this study. This inventory helps identify where recommendations on safe handling have been applied or adopted in tuna fisheries management and where gaps remain.

2. METHODS

We conducted a comprehensive literature review and compiled information on safe handling and release practices across select taxa (cetaceans, sea turtles, seabirds, sharks, and billfish) from published and unpublished papers, including workshop and technical reports, journal articles, government reports, and government-issued educational materials. We defined safe handling and release practices as strategies that increase post-capture survival of marine species, such as proper handling, resuscitation, and prompt release of incidentally caught animals. We use the term post-release survival to differentiate survival after an animal has been released from fishing gear.

We summarize gear-specific information for each taxa, where available, for pelagic longlines, purse seines, and gillnets. We also reviewed measures in place by the following tRFMOs: International Commission for the Conservation of Atlantic Tunas (ICCAT), Inter-American Tropical Tuna Commission (IATTC), Western and Central Pacific Fisheries Commission (WCPFC), Indian Ocean Tuna Commission (IOTC), and Commission for the Conservation of Southern Bluefin Tuna (CCSBT). We consulted websites of the tRFMOs, and provide an inventory of tRFMOs and their measures that require safe handling for their fisheries for the gears and taxa included in this study. We used this inventory to highlight gaps in implementation of the safe handling measures identified through the primary literature review. We also included measures that require training in the safe handling release practices.

3. RESULTS

Safe handling and other practices that increase post-capture survival varied by species and by gear type. Factors such as sea conditions and access of fishermen to training and appropriate tools also contributed to variable post-capture survival. However, we found certain general principles consistently throughout our review that can be applied to either all or multiple taxa (Table 1). Recommended practices varied by taxa, in some cases, due to size of animals or if animals require air to breathe. For all taxa and gear types, disentanglement decisions should be based on crew safety.

Other safe handling practices differed by gear and taxa; details are provided for each in the taxa-specific sections below. Taxa- and gear-specific safe handling and release practices were found for less than half of the gear and taxa combinations (Table 2). For the others, general principles apply (Table 2). Where taxa-specific handling practices have been identi-

Table 1. General principles for all or multiple taxa to increase post-capture survival of bycatch

All taxa
The crew should scan the gear before and/or during hauling (depending on gear type) for bycaught animals. A sighted animal should be approached slowly, and once the animal is alongside the vessel, the engine(s) should be placed in neutral (NMFS SEFSC 2008).
Methods for disentangling or de-hooking should be based on the animal's condition, size, and hook and/or line location.
The crew should not use disentangling devices (e.g. tether, ninja sticks, or de-hooking devices) to control the animal (NOAA 2009).
The crew should remove as much gear as safely possible. For animals hooked on longline gear, de-hooking tools should be used when possible and when appropriate to remove hooks. For animals with deeply ingested (swallowed) hooks, or those where the insertion point of the barb is not visible, the hooks should not be removed from any species. For all species with deeply ingested hooks, the line should be cut as close as possible to the hook (NMFS SEFSC 2008, Parga 2012).
To reduce likelihood of recapture, animals should be released, when possible, away from fishing gear, when the engine is in neutral.
Multiple taxa
For air-breathing species, including cetaceans, sea turtles, and seabirds, crew should attempt to ensure the animal can access the surface to breathe.
Use of circle hooks can lead to shallow hooking of sea turtles, sharks, and billfish, which can make hook removal easier and result in fewer severe injuries.
Small hard-shelled turtles (<1 m) and seabirds with attached fishing gear can be brought on board with a dipnet for gear removal when feasible. Other animals (e.g. cetaceans, large sea turtles, sharks, sawfish, and billfish) should have gear removed in the water with the animal brought gently alongside the vessel.
For animals that can be safely brought on board, the fishing crew should minimize tension and avoid pulling on gear that entangled or hooked on the animal while bringing it on board.
Other fishing vessels operating in the same area should be alerted to the presence of or interactions with cetaceans, sea turtles, or with certain shark species (NOAA 2009, 2017b) to reduce the likelihood of another interaction occurring.

Table 2. Gear and taxa combinations with either general principles or specific safe handling and release practices

General principles only	Gear- and taxa-specific practices
Gillnet + cetacean	Longline + cetacean
Gillnet + sea turtle	Longline + sea turtle
Gillnet + seabird	Longline + seabird
Gillnet + shark	Longline + billfish
Gillnet + billfish	Purse seine + cetacean
Purse seine + seabird	Purse seine + sea turtle
Purse seine + billfish	Purse seine + shark
Longline + shark	

fied, they are included in the sections below. In general, no taxa had explicit safe handling and release practices characterized for gillnet gear. For longline gear, however, consulted resources included explicit practices for all taxa, with the exception of sharks.

Some of the safe handling practices included in this paper are suggested or required by the tRFMOs. Table 3 provides an inventory of the relevant and adopted tRFMO safe handling practices by taxa, and notes to which gear type the practices apply, where relevant. Only sharks and sea turtles have measures indicating safe handling and release across all 5 tRFMOs. In some instances, such as for sea turtles, the safe handling measures are detailed and accompanied by manuals or specific how-to guidance. In other cases, the measure just references the need for safe handling and/or release of the specific taxa but does not give explicit guidance (e.g. billfish). Very few of the measures specifically required training for the captain and crew; rather, they require the implementation of the FAO Guidelines to Reduce Sea Turtle Mortality in Fishing Operations (FAO 2009) or the International and/or National Plans of Action for Seabirds (e.g. FAO 1999a, NOAA 2001), which specifically state the need for training of captain and crew.

3.1. Cetaceans

In general, we found relatively few robust studies to guide safe release practices for cetaceans. In gillnet gear, bycaught cetaceans often experience high mortality, since they cannot reach the surface to

Table 3. Tuna Regional Fishery Management Organizations (tRFMO) safe handling and release practices by organization and taxa. ICCAT: International Commission for the Conservation of Atlantic Tunas; IATTC: Inter-American Tropical Tuna Commission; WCPFC: Western and Central Pacific Fisheries Commission; IOTC: Indian Ocean Tuna Commission; CCSBT: Commission for the Conservation of Southern Bluefin Tuna; Rec: Recommendation; Res: Resolution; CMM: Conservation and management measure

Safe handling and release requirements	ICCAT	IATTC	WCPFC	IOTC	CCSBT
Sea turtle	Rec 10-09 (longline and purse seine)	Res-C-O7-03 (longline and purse seine)	CMM-2008-03 (longline and purse seine)	Res 12/04 (longline and purse seine)	Rec-11-10 (longline only)
	Rec 13-11 (longline and purse seine)	Res C-04-05 (longline and purse seine)			
	Res 05-08 (longline only)	Res C-04-07 (longline and purse seine)			
		Res C-16-01 (purse seine only)			
Seabird		Res C-11-02 (longline only)	CMM 2015-03 (longline only)		Rec-11-10 (longline only)
Cetacean			CMM-2011-03 (purse seine only)	Res 13/04 (purse seine only)	
Billfish	Rec 15-05 (marlins)			Res 15/05 (marlins)	
Shark	Rec 04-10	Res C-16-06 (silky sharks *Carcharhinus falciformis*)	CMM-2011-04 (oceanic whitetip sharks *Carcharhinus longimanus*; longline and purse seine)	Res 12/09 (thresher sharks)	Rec-11-10 (longline only)
	Rec 09-07 (thresher sharks *Alopias* spp.)	Res C-16-04	CMM-2010-07	Res 13/06	
	Rec 10-06 (shortfin mako sharks *Isurus oxyrinchus*)	Res-C-16-01 (purse seine only)	CMM-2013-08 (silky sharks; longline only)	Res 17/05	
	Rec 10-07 (oceanic whitetip sharks)	Res C-04-05	CMM-2012-04 (whale sharks *Rhincodon typus;* purse seine only)	Res 13-05 (whale sharks; purse seine only)	
	Rec 10-08 (hammerhead sharks *Sphyrna* spp.)	Res C-05-03			
	Rec 11-08 (silky sharks)	Res C-11-10 (oceanic whitetip sharks)			
	Rec 15-06 (porbeagle sharks *Lamna nasus*)	Res C-15-04 (mobulid rays)			
	Rec 16-12 (Atlantic blue sharks *Prionace glauca*)	Res C-16-05			
	Rec 16-13				
	Res 03-10				
	Res 05-08 (longline only)				

breathe. As a result, we found little focus on safe handling of cetaceans caught in gillnet gear; however, if an animal is encountered alive, the general principles described above and for other gear types apply.

For longline gear, practices to increase post-capture survivability of the cetaceans vary by animal size. For small entangled or hooked cetaceans (odontocetes or toothed whales, excluding sperm whales *Physeter macrocephalus* and killer whales *Orcinus orca*), recommended measures were consistent with the general principles of removing gear wrapped around the animals with identified gear removal equipment (e.g. gaff and longline cutter) and removing hook barbs or straightening the hook (e.g. with long-handled bolt cutters or other de-hooking devices) when safe to do so (NOAA 2009). Large whale (mysticetes or baleen whales, killer whales, and sperm whales) entanglements in longline gear were identified as being more difficult to address and required assistance of disentanglement trained experts, when available (NMFS SEFSC 2008). Consistent with the general principles, safe handling guidelines recommended removing as much gear as possible, particularly if it could impede movement or feeding, and cutting as close to the animal as can be done safely (NMFS SEFSC 2008). For line that had been embedded into the animal long enough for the wound to begin to heal over the gear, guidelines recommend that the lines should be cut as short as possible on either side of the animal, and the embedded line should be left alone (NMFS SEFSC 2008).

For cetaceans caught in purse seine gear, fishermen should avoid encircling animals. However, in circumstances where cetaceans become unintentionally captured during purse seine operations, safe handling and release procedures have been identified beyond the general principles and specific to these interactions in order to increase the likelihood of survival.

Cetacean bycatch in a tuna purse seine fishery is best documented in the Eastern Pacific Ocean (EPO), largely due to IATTC regulations. A number of required procedures have been identified by the Agreement on the International Dolphin Conservation Program (AIDCP), which is a legally binding multilateral agreement for the EPO. The AIDCP requires vessels with a carrying capacity of more than 363 metric tons (400 short tons) operating in the Agreement Area to follow certain guidelines on safe handling and release, including performing a backdown procedure when dolphins are captured until all live dolphins are released, completing the backdown at least 30 min prior to sunset, deploying crew to aid in dolphin release, and properly using and testing net alignment of the dolphin safety panel (also known as Medina panel) during the backdown procedure (adapted from AIDCP 2009). Additional actions are prohibited, including night sets, brailing or sacking-up live dolphins, using explosive devices during fishing operations, and setting on dolphins if a vessel does not have a dolphin mortality limit (DML). For vessels with a DML, fishing must stop when it has been reached. The AIDCP specifies that the crew should not be placed in unsafe conditions to meet these requirements.

3.2. Sea turtles

Instructions differ for handling bycaught sea turtles depending upon whether they are brought on board the fishing vessel (dependent upon turtle's size) and the type of injury. Safe handling and release practices recommend that only smaller turtles (<~1 m in length) should be brought on board, with the use of a dipnet, when conditions and availability of equipment permit (Parga 2012). For larger turtles or in conditions where an animal cannot be safely boarded, gear should be removed while an animal is in the water (e.g. with use of a line cutter).

Other identified practices focused on the importance of reducing stress for sea turtles, particularly for those that are brought on deck and may be agitated. Recommended measures included keeping a turtle moist by covering its head with a wet towel or by periodically spraying it with water and by keeping it out of the sun (Poisson et al. 2012). These measures can keep a turtle calm and prevent it from overheating. Other measures relate to positioning to avoid injury, including placing a turtle in a right side up position (i.e. not on their carapace) when possible, raising its back flippers 20 cm off the deck, and positioning it on a support device (e.g. a car tire) to safely isolate and immobilize the animal (Poisson et al. 2012). Sea turtles should never be placed upside down as they cannot breathe in this position. Also, to improve a turtle's chance of recovery after gear is removed, the turtle should be released in waters of a similar temperature to where it was captured. A cold-stunned animal or one that was caught in waters too cold for its survival would need to be released in warmer waters.

Other identified measures that minimize injury and increase post-capture survival include gently releasing turtles from the lowest point on the vessel. A tur-

tle should be given as long as possible, or at least 24 h, to show signs of life after being on deck, before being considered dead. Ideally, the turtle should show signs of decomposition or rigor mortis before attempts at survival are discontinued. The general principles can be applied to turtles for removing gear, including the use of line cutters to remove nets or lines from a turtle. If necessary, long-handled line cutters can be used to cut gear off turtles that remain in the water (NMFS SEFSC 2008, Parga 2012). For hook removal of small turtles brought on board a boat, longline hooks should only be removed if it is possible to see the point of the hook (Parga 2012). A de-hooker can be used for hooks where the insertion point is visible either through the jaw or mouth, while other gear removal devices (e.g. bolt cutters or pliers) can be useful for hooks in other body parts, such as a flipper. For turtles in the water, when the seas are calm and the hook is visible from afar, a lightly embedded hook (e.g. in a flipper) can be removed; however, if the crew is uncertain about removing the hook, it should not be removed, and line should be cut as close to the eye of the hook as possible (Parga 2012). The recommended measures reduce the likelihood of injury that could lead to mortality. Attempts to remove swallowed hooks could cause damage and are not recommended.

A sea turtle drowning in purse seine gear is rare but occurs if an animal is entangled for a prolonged period of time and/or is unable to reach the surface to breathe. It is possible that a turtle lifted out of the water while entangled can fall and be injured or could be killed by passing through the power block. More often, a turtle found alive in purse seine gear can be gently released over the side of a vessel (FAO 2009). Efforts to minimize stress and injury should be taken to decrease potential for delayed mortality. Such measures have been identified in the FAO Guidelines to Reduce Sea Turtle Mortality in Fishing Operations for purse seine fisheries and include: (1) avoid encirclement of sea turtles to the extent practical; (2) if encircled or entangled, take all possible measures to safely release sea turtles; (3) for fish aggregating devices (FADs) that may entangle sea turtles, take necessary measures to monitor FADs and release entangled sea turtles, and recover these FADs when not in use; (4) conduct research and development of modified FADs to reduce and eliminate entanglement; and (5) implement successful methodologies developed as a result of (4).

The following specific measures are recommended in cases when a sea turtle is caught (FAO 2009): (1) whenever a sea turtle is sighted in the purse seine, all reasonable efforts should be made to rescue the turtle before it becomes entangled in the net, including, if necessary, the deployment of a speedboat; (2) If a turtle is entangled in the net, hauling should stop as soon as the turtle comes out of the water and should not start again until the turtle has been disentangled and released; and (3) if a turtle is brought aboard the vessel, all appropriate efforts to assist in the recovery of the turtle should be made before returning it to the water.

3.3. Seabirds

Seabirds are particularly vulnerable to mortality after an interaction with fishing gear due to a number of physiological and anatomical factors. Safe handling guidelines for seabirds have been developed for longline gear by several institutions, including the American Bird Conservancy, International Bird Rescue Research Center (IBRRC), and the National Audubon Society; however, the same principles can be applied to other gear types (Elliott & Gilman 2002). Many of these fact sheets and practical information on seabird mitigation measures are contained in the Agreement on the Conservation of Albatrosses and Petrels (ACAP) bycatch mitigation fact sheets.[1]

Similar to sea turtles, much of the reviewed research recommended handling practices to keep the seabirds safe while on board a vessel and while gear is being removed from an entangled or hooked animals. Specific guidelines provide recommendations for how to hold a bycaught seabird to protect their soft necks and delicate wings, to keep them calm, and to ensure they can breathe (see Elliott & Gilman 2002). A bird that is lightly hooked in the beak, wing, or foot, or has a hook visibly sticking out of its body can have the hook removed with bolt cutters. When this is not feasible, similar to other taxa, the line should be cut close to the hook.

If possible, birds that are injured (e.g. wounds or broken bones) or with swallowed hooks should be brought ashore for treatment. When this is not feasible, the bird's likelihood of survival is improved if it is given a quiet, dry, and shaded area to recover, while being checked on regularly (Elliott & Gilman 2002). The bird can be lowered and released once it is dry and energetic, holds its head erect, and stands with its wings in a normal, folded position (Elliott & Gilman 2002).

[1]https://www.acap.aq/en/bycatch-mitigation/bycatch-mitigation-fact-sheets

3.4. Sharks

Mortality rates of captured sharks are highly variable and related to species-specific physiological sensitivities and to handling practices (Skomal 2007, Gallagher et al. 2014b, Hutchinson et al. 2015). Ideally, sharks should remain in the water to improve post-capture survival as they are physiologically vulnerable and stressed once out of the water (AFMA 2014, Poisson et al. 2014). Research indicates that proper handling and quick release improve a shark's chance of survival once released from fishing gear. Reducing fight time and soak time has also been linked with less stress and lower mortality of some shark species (Heberer et al. 2010, Gallagher et al. 2014b). Using heavier tackle can reduce fight time and thus reduce how stressed the animal becomes.

Given that human safety is a primary concern, sharks should always be left in the water. If a shark is incidentally landed, the length of time it spends out of the water should be minimized to reduce potential injury and stress (Patterson et al. 2014, Fowler 2016). Safe handling guidelines indicate that a shark should never be lifted by its tail or head, carried or dragged by the gill slits, exposed to the sun or to physical trauma (e.g. throwing or pushing), or squeezed around the belly as this can damage internal organs. Instead, a shark can be guided alongside a vessel while gear is removed. For longline gear, hooks should only be removed if this can be done safely for fishermen and shark. De-hooking devices are considered by some fishermen to be impractical and/or potentially dangerous for use with sharks (Gilman et al. 2008). Consistent with the general principles, if a hook cannot be removed safely, the line should be cut as close to it as safely possible.

Sharks that are caught in purse seine nets or gillnets may appear healthy when released, but depending on species, there can be relatively high post-capture mortality due to injury from fishing gear or handling practices (Poisson et al. 2012). Previous studies indicate that sharks that have been encircled by purse seine nets are more likely to survive if they can be released from the net before being brailed on board the vessel (Fowler 2016). A quick release to sea using careful methods, such as cutting nets during hauling if a shark is spotted, will ensure higher rates of post-release survival (Poisson et al. 2012, Fowler 2016). Specific protocols were developed for purse seine nets but can apply to other fishing gear, including gillnets, for which specific guidelines have not been developed (see Poisson et al. 2012, 2014, IATTC 2016, Restrepo et al. 2016).

Whale sharks, due to their size and physiological sensitivity, require additional care. A number of additional actions have been identified to avoid injury to sensitive whale sharks, including pulling sharks by a loop hooked around the animal's gills or holes bored into a fin, gaffing an animal, leaving towing ropes attached, brailing sharks >2 m, or brailing whale sharks on board (WCPFC 2015). Non-lethal techniques for releasing whale sharks have been developed by experienced skippers, including cutting the net in front of a shark to release it or taking steps to roll the shark out of the net (Poisson et al. 2012, Fowler 2016, Lopez et al. 2017). For all sharks, to allow time for recovery from a stressful interaction, fishermen can slowly tow them in the water while ensuring that their head is still in the water (NOAA 2017a). Sharks will start to swim more actively once they have had a chance to recover.

3.5. Billfish

Billfishes (sailfishes and marlins) are a diverse group; however, safe handling practices remain consistent for most species and are consistent with the general principles outlined throughout this paper. Caught billfish should not be removed from the water, even for a picture, and efforts should be made to cut the line (e.g. using long-handled line cutters and de-hooking devices). Animals should be released as soon as possible, and hooks removed if feasible (Prince et al. 2002). Use of circle hooks increases the chances of hooking the fish in the jaw or corner of the mouth, which makes hook removal easier.

Research has shown that when a fish is too weak to swim away from a vessel, mortality is likely to occur unless the fish is allowed time to recover. Fishermen can enable recovery by bringing the fish alongside the vessel and allowing water to pass over its gills (see Prince et al. 2002).

4. DISCUSSION

4.1. Review of safe handling practices

Increasing post-capture survival of marine animals incidentally caught in fishing gear is very important to reduce the widespread impacts of bycatch on marine populations. In this paper, we summarize the general safe handling and release principles as well as gear- and taxa-specific recommendations, based on best available science and outreach materials.

As a disclaimer, this paper does not seek to cover all gear- and taxa-specific requirements of fishery regulations in different regions of the United States. Furthermore, in some cases, US regulations may require methods that differ from those recommended here. In such cases, this paper does not intend to imply that the requirements of US regulations in those specific circumstances are not the best available practice. Instead, the paper intends to identify safe handling and release practices that can increase post-capture survival of bycaught species in tRFMO fisheries in an attempt to reduce mortality in these fisheries through improved management measures where gaps currently exist, and these identified practices may differ from US regulations.

The reviewed safe handling practices fall into 3 primary categories: reducing stress that can lead to death, minimizing injury that results in death, and reducing immediate mortality. The practices should be taken into consideration by fishermen and fishery managers when determining the best measures for reducing bycatch mortality in fisheries.

4.1.1. Reducing stress

Safe handling and release practices described throughout this paper differ slightly by taxa; however, the importance of reducing physiological stress is consistent across taxa. For the purposes of this review, stress is considered the physiological alterations in an animal, aside from physical injury or trauma, which occur as a consequence of interactions with fishing gear. Some practices to reduce stress in bycaught animals are consistent across taxa (e.g. minimizing time in gear, reducing fight time or struggle, and gentle handling), while others may vary by taxa (e.g. maintaining preferred temperature, covering an animal's head, using proper positioning, and keeping them moist [or dry for seabirds]).

For certain taxa, such as sharks and billfish, 'fight time' on fishing gear has been demonstrated to influence the degree of physiological disturbance. Increased fight time has been linked to increased stress and post-release mortality of bycaught animals (Heberer et al. 2010, Schlenker et al. 2016). Animals that fight capture and release efforts may also be more likely to become further entangled in fishing gear or to become further injured from the gear that is hooking or entangling them, thereby reducing their probability of post-release survival. This should be minimized for all species.

4.1.2. Minimizing injury

Using a variety of techniques, injury to bycaught animals can be minimized through use of proper and gentle safe handling techniques, such as leaving animals in the water when possible, using long-handled line cutters and de-hooking devices, avoiding use of sharp or pointed objects when removing gear, removing as much line and net as possible, and leaving deeply ingested hooks in an animal. Removing a deep hook from an animal is more likely to be lethal than removal from externally or mouth-hooked animals (Parga et al. 2015). Removing a deep hook is also more likely to injure or kill an animal than leaving an ingested hook in an animal.

4.1.3. Reducing immediate mortality

Our findings indicate that many factors influence an animal's likelihood of surviving an interaction with fishing gear, including operational and environmental factors associated with a fishing operation. For instance, the depth and duration of gear soak is directly related to the probability of survival for many species, most critically for air-breathing marine animals such as sea turtles, seabirds, and cetaceans, given their potential to drown. Since many animals die in gillnet gear before retrieval, few safe handling and release guidelines have been identified for this gear type. For sharks, mortality may be directly related to water temperature (Diaz & Serafy 2005, Campana et al. 2009, 2016, Braccini et al. 2012, Gallagher et al. 2014a,b), given the role of temperature in numerous physiological processes. Operational changes such as minimizing soak time or monitoring fishing gear to reduce the time caught animals are entrapped in or on gear below the surface can also increase the proportion of caught animals that survive gear interactions (Gearhart 2003, Watson et al. 2005, Gilman et al. 2010, Gallagher et al. 2014b).

4.2. Gap analysis and implementation of safe handling practices

Because post-capture survival rates of bycaught species largely depend on the ability of the crew to appropriately apply safe handling techniques, it is important that fishermen receive training on a regular basis. As noted above, very few of the tRFMO measures on bycatch reduction specifically require regular training, thus limiting the effectiveness of these measures.

Given that the effectiveness of safe handling is dependent on training, this omission is a significant weakness in the bycatch mitigation strategies of many tRFMOs. Thus, national government requirements for crew and captain training in safe handling and release techniques are very important. Where those requirements do not exist, skipper workshops held by non-governmental organizations, such the International Seafood Sustainability Foundation, are important to fill this gap. Training should be conducted on a semi-annual basis to accommodate incorporation of new information and techniques. Without regular training, the success of safe handling and release measures to reduce the likelihood of post-interaction morality likely decreases.

In a review of RFMO implementation of ecosystem-based fisheries management, Juan-Jordá et al. (2018) found that RFMOs have made only moderate progress in assessing and addressing the impacts of tuna fisheries on bycaught species, with improvement greatly encouraged. Currently, no tRFMO provides safe handling requirements or suggestions for any of the taxa reviewed (Table 2). While the preferred technique for addressing bycatch is to avoid the interaction in the first place, it can be difficult to avoid bycatch completely. When bycatch does occur, the strategies to increase post-release survival become key for protecting vulnerable species. This inventory of tRFMO requirements and suggestions highlights a need by the tRFMOs to provide guidance and training on safe handling practices to increase post-release survival.

The present paper also identifies areas where safe handling practices have yet to be identified, likely due to the nature of the interactions and threat of mortality before hauling occurs. In some cases, only the general principles can be applied to safe handling and release of certain taxa, whereas for others, taxa-specific practices may be identified for a certain gear type and may be applicable overall or in part to other gear types (Table 2). Regular reviews of the effectiveness of the existing techniques should be conducted. While these techniques have been developed by researchers and fishermen, the degree to which they have been assessed for effectiveness is unclear. Additionally, the degree to which they are used by fishermen should be regularly considered. Fishermen should be consulted to identify feasible solutions and encourage their wider use. Safe handling and release techniques are only effective if they are used correctly and routinely by fishermen.

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