Fisheries Research 271 (2024) 106928

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Full length article

Toothed whale and shark depredation and bycatch in the longline fishery of French Polynesia

Juliette Aminian Biquet [a,b,c,*,1], Paul Tixier [d], Gaëtan Richard [e], Marie Soehnlen [f], Thibaut Thellier [f], Pamela Carzon [a,b], Eric Clua [a,b], Christophe Guinet [c]

[a] EPHE, PSL Research University, CRIOBE USR3278 EPHE-CNRS-UPVD, Université de Perpignan, 58 avenue Paul Alduy, Bât. R, 66860 Perpignan, France
[b] Labex Corail, CRIOBE, 98729 Moorea, French Polynesia
[c] Centre d'Études Biologiques de Chizé-Centre National de la Recherche Scientifique (CEBC-CNRS), Equipe Prédateurs marins, UMR 7372 CNRS/Université de La Rochelle, 79360 Villiers-en-Bois, France
[d] MARBEC, Univ Montpellier, CNRS, Ifremer, IRD, 87 avenue Jean Monnet, 34200 Sète, France
[e] Société d'Observation Multi-Modale de l'Environnement, 38 rue Jim Sevellec, 29200 Brest, France
[f] Direction des ressources marines, Fare Ute - Immeuble Le caill, 2ème étage - BP 20, 98713 Papeete, Tahiti, French Polynesia

ARTICLE INFO

Handled by A.E. Punt

Keywords:
Fisheries
Elasmobranch and cetacean conservation
Depredation
Bycatch
Pacific

ABSTRACT

Marine megafauna feeding on fishery catches (depredation) or being incidentally caught on fishing gear (bycatch) have become important issues. Their socioeconomic and conservation stakes have been increasingly studied across the world fisheries. They remain understudied in the Pacific Ocean, where longline tuna fisheries reported such interactions. In this study, we provide the first assessment of bycatch and depredation by sharks and odontocetes on longlines in French Polynesia between 2000 and 2018, using data from observers reporting, captains' logbooks, questionnaires and additional monitoring by authors during three fishing trip. We found that less than 2% of the catch had been depredated, and that shark depredation was more common than odontocete depredation. Shark bycatch was important (20,000 sharks annually, 0.5 shark every 1000 hooks) and odontocete bycatch seemed low (13 occurrences in 18 years), though we identified clear reporting flaws. We discuss the range of uncertainty associated with our assessment, based on the current reporting systems, and the potential consequences of depredation and bycatch on tuna fisheries, as well as on shark and odontocete populations in French Polynesia.

1. Introduction

Marine megafauna feeding on fishery catch (depredation) or being incidentally caught on fishing gear (bycatch) have become two major environmental issues, with high socio-economic and conservation stakes across the world fisheries (Clarke et al., 2014; Komoroske and Lewison, 2015; Read, 2008; Tixier et al., 2021). Depredation and bycatch are frequently reported in longlining, a fishing technique using lines with a series of baited hooks. It primarily involves both sharks (Gilman et al., 2008; Mitchell et al., 2018) and toothed whales (Clarke et al., 2014; Gilman et al., 2006; Lewison et al., 2014; Werner et al., 2015). Depredation is often a causal factor of bycatch, i.e., predators become hooked or entangled when attempting to feed on catch or bait, potentially leading to death or injury of depredating individuals (Gilman and Clarke, 2007; Hamer et al., 2012). The life history traits of sharks and odontocetes (slow growing, late maturing and long-lived) can make

Abbreviations: CPUE, Catch per unit of effort; GDR, Gross depredation rate, DPUE, Depredation per unit of effort; IR, interaction rate; BPUE, Bycatch per unit of effort.

* Corresponding author at: EPHE, PSL Research University, CRIOBE USR3278 EPHE-CNRS-UPVD, Université de Perpignan, 58 avenue Paul Alduy, Bât. R, 66860 Perpignan, France.

E-mail addresses: juliette.biquet@lilo.org (J. Aminian Biquet), paul.tixier@ird.fr (P. Tixier), richard.somme@orange.fr (G. Richard), marie.soehnlen@administration.gov.pf (M. Soehnlen), thibaut.thellier@administration.gov.pf (T. Thellier), carzonpamela@gmail.com (P. Carzon), eric.clua@gmail.com (E. Clua), christophe.guinet@cebc.cnrs.fr (C. Guinet).

[1] Present address: CCMAR – Centre of Marine Sciences, University of Algarve, 8005-139 Faro, Portugal; Agroécologie, INRAE, Institut Agro, Université de Bourgogne Franche-Comté, 21000 Dijon, France; EPHE, PSL Research University, CRIOBE USR3278 EPHE-CNRS-UPVD, Université de Perpignan, 58 avenue Paul Alduy, Bât. R, 66860 Perpignan, France.

https://doi.org/10.1016/j.fishres.2023.106928
Received 2 August 2023; Received in revised form 20 December 2023; Accepted 20 December 2023
Available online 4 January 2024
0165-7836/

them especially vulnerable to the impacts of such interactions (Heppell et al., 2005; Lewison et al., 2004). Indeed, bycatch has been identified as the main threat to the conservation of endangered shark species (Dulvy et al., 2021), and is currently a major driver of extinction for several small odontocete species (Avila et al., 2018).

Depredation and bycatch can have a broad range of ecological and social impacts (Tixier et al., 2021). Typically, depredation can result in socio-economic costs for fishers, mainly associated with additional efforts to recoup catch losses (Peterson et al., 2014). It can also generate uncertainty in fish stock assessments due to the difficulty in estimating catch losses (Clavareau et al., 2020), and alter trophic interactions, through changes in the predators' behavior, diet and population dynamics (Schakner et al., 2014; Tixier et al., 2015). Shark and odontocete bycatch can cause gear loss or damage and can increase the work load of fishers (Hall et al., 2017; Werner et al., 2015). Overall, bycatch and depredation often lead to severe human-wildlife conflicts that can affect the sustainability of marine socio-ecosystems as a whole and, therefore, require mitigation measures (Guerra, 2019; Snape et al., 2018).

Bycatch and depredation remain difficult to mitigate in many fisheries. This is often due to a lack of data and knowledge, either because the fisheries involved are poorly monitored or because the occurrence of such interactions are difficult to detect. Pelagic longline fisheries targeting tuna (*Thunnus* spp.) are highly exposed to bycatch and depredation (Clarke et al., 2014; Lewison et al., 2014; Oliver et al., 2015). Yet the (increasing) monitoring effort remains insufficient: fishery observers coverage is often low (Ewell et al., 2020; Peatman, 2018) and the logbook data collected by captains lacks accurate and reliable information on the extent of bycatch and depredated fish and on the shark and odontocete species involved (Brown et al., 2021; Molony, 2006). In an effort to fill these gaps of information, additional approaches have been used to quantify bycatch and depredation. This includes fieldworkers actively collecting data during selected fishing trips, or surveys conducted across fishers, including questionnaires, interviews, and participant observation, where scholars get immerged in the ways of living of the studied social group (NOAA, 2009; Wang et al., 2021). Asking fishers for their perceptions of the frequency of depredation and bycatch and the species involved allows for a rapid overview of these interactions' costs on their yields (Mitchell et al., 2023), that can be compared with captains' logbooks and observer data (Bearzi et al., 2011). Such information also helps planning future management measures, by understanding and accounting for local fishers' responses to depredation and bycatch events (e.g., travelling away from depredation, loosing gear in mitigation measures, handling methods of bycaught animals), which impact their fishing yields and the survival of released bycatch (Zollett and Swimmer, 2019).

In the tropical waters of the central Pacific Ocean, both depredation and bycatch of sharks and odontocetes have been reported across pelagic longline fisheries targeting albacore (*Thunnus alalunga*), bigeye (*T. obesus*) and yellowfin (*T. albacares*) tunas. These interactions remain understudied compared to other regions, like the Atlantic Ocean (Aylesworth, 2009; Clarke et al., 2014; Juan-Jordá et al., 2018; Lawson, 2001; Lewison et al., 2014; Peatman, 2018; Peatman et al., 2023). This is especially the case for the tuna longline fishery operating in the French Polynesian Exclusive Economic Zone (EEZ). This fishery started in the 1990 s and has become a major economic activity in French Polynesia. There were 72 longliners in 2020, for a production of 6000 tons per year of tuna and other commercial catches, equivalent to USD 25 million (IEOM, 2021; Gillett, 2016). It is required by the Western and Central Pacific Fishery Regional Convention (WCPFC) to implement an observer program and conservation measures for the monitoring and release of shark species (WCPFC, 2019a). Fishing activities have been monitored by logbook reports by captains since 2000, supposedly covering all fishing sets. A national observer program was initiated in 2002 (covering 2 to 6% of days spent at sea, Fig. S1, Table S1). While longline tuna fisheries can occur throughout the French Polynesian territory, the entire EEZ was first designated as a sanctuary for marine mammals in 2002 and for sharks in 2006 which forbids their retention and commercial use (in 2012 for mako sharks; Lallemant-Moe, 2015). In 2018, it was designated as a Marine Managed Area, with a management plan including a monitoring and mitigation program of depredation and bycatch (DIREN et al., 2023). The extent of shark and odontocete bycatch and depredation, the species involved and the consequences of these interactions have not yet been examined, though some data from observers and captains have been collected. Annual reports to the WCPFC included five bycatch of false killer whales *Pseudorca crassidens* and short-finned pilot whales *Globicephala macrorhynchus*, (Delphinidae) caught and released alive (DRM, 2019). Shark bycatch makes about 7% of the total longliners catch (27,000 bycaught individuals in 2019, 81% of which were released alive) and involves vulnerable species such as the critically endangered oceanic whitetip shark *Carcharhinus longimanus* (Carcharhinidae, Tremblay-Boyer et al., 2019). Though depredation was not studied yet, the same shark and odontocete species recorded as the most bycaught are likely involved in depredation in the French Polynesia fishery, as shown in other Pacific tuna longline fisheries (Clarke et al., 2014; Mitchell et al., 2018).

Whether bycatch and depredation represent an increasing socio-economic concern for the industry remains uncertain, in a context where French Polynesian longliners already face a steady decrease in tuna Catch Per Unit Effort (CPUE) since 2005 (DRM, 2021). Firstly, the extent of depredation has yet to be assessed in this fishery. Secondly, comparing the different reporting sources (logbooks, observers' reports, captains' perceptions) is needed to assess the degree of confidence of the reported data and to quantify both the level and consequences of bycatch. This is especially important because the reported data are then used for policy making by national and international fisheries management bodies. Finally, the crews' responses to bycatch and depredation remain to be investigated to understand the consequences of these interactions (including economic costs and potential survival of bycaught animals). It can help the national marine resources department (DRM) to monitor current and plan future management measures to be put in place. Together, the high conservation and the socio-economic stakes associated with the French Polynesian tuna longline fishery raise the study of shark and odontocete bycatch and depredation as a priority for its sustainable management in the EEZ.

In this study, we combined long-term fishing data collected by captains and observers between 2000 and 2018 with questionnaires with fishermen and onboard observations on three fishing trips by one of the author to investigate the nature, extent, patterns and consequences of sharks and odontocetes bycatch and depredation in the industrial tuna longline fishery of French Polynesia. Specifically, we aimed at i) quantifying bycatch and depredation through standardized metrics, ii) assessing the potential discrepancies in depredation and bycatch levels and species involved across the various sources of data, including between reported, observed levels and levels perceived by the fishermen; and iii) examining the attitudes of fishermen towards mitigating bycatch and depredation.

2. Material and methods

2.1. Data used to assess bycatch and depredation

We used fishing data collected within the EEZ of French Polynesia. The EEZ spans over 5 million km^2 between 5–31°S and 132–158°W. French Polynesia is composed of approximately 120 islands grouped into five archipelagos. Between 50 and 65 longliners of less than 30 m in length were active in the EEZ every year between 2000 and 2018 (no foreign fleet has been allowed since 2000). The mean duration of fishing trips was 20 days, with a mean of 9 sets per trip and a mean of 30 marketable fish per set. Effort and practices were highly heterogenous (Toromona and CRMMR 2018) and poorly documented. Longines vary in length from 9 to 180 km, equipped with 1500 to 2500 hooks. Longlines were set early in the morning, left to soak for 5 to 7 h, and hauled in the afternoon and night. The three crews observed for this study targeted a maximum depth of 400 m.

We used data reported by captains in their logbooks between 2000 and 2018 (hereafter referred to as the "LOG" data, mandatory reporting), and collected by observers between 2002 and 2018 ("NOP" hereafter; see Supplementary material 1 for information on fishing effort, catch, and observer coverage). Both the LOG and NOP data included information on the date, time, location, and effort (number of hooks) for each longline set (Table 1); no photograph of any of the bycatch was available. Observers were trained in identifying shark and odontocete species (PIRFO observer certification). They recorded catches (number and size) for all species, including bycatches of sharks and odontocetes (per species), their condition (alive, injured, dead; there were no additional information about the release, e.g. hooks or line removal) and their fate (retained or discarded). The NOP dataset included data from 4384 sets hauled between September 2002 and January 2018 (3.9% of the total number of sets for this period) by 80 vessels during 455 fishing trips (Table 2, Supplementary Material 1). Observers also had a notebook to record additional onboard observations, which were not formatted into the database and therefore not used in this analysis (although a few were consulted). Captains were required to report their catch per set in logbooks, including the number of fish (commercial species; list in Table S2), sharks and odontocetes bycaught per set, and their fate (retained or discarded; Table 1). Captains were provided with an identification book describing the main species potentially encountered (birds, reptiles, mammals, fishes and sharks). The LOG dataset included data from 120,173 sets hauled between January 2000 and August 2018 by 138 vessels during 14,073 fishing trips.

The species and number of fishes depredated were only recorded in the NOP dataset (Table 1). Observers established that depredation had occurred on a longline set from the presence of partially eaten fish on hooks. They could determine whether it had been depredated by a shark or an odontocete from the type of bite and shape of the teeth marks on the fish (Gilman et al., 2006). In the LOG dataset, observations of odontocetes (with no indication of species, number, or description of the interactions) made from the vessel have been collected since 2016, but since they did not solely refer to observations of depredating individuals, it could not be used to assess depredation in this study (Fig. S4).

In addition to the LOG and NOP datasets, data on shark and odontocete depredation and bycatch were dedicatedly collected by J. Biquet between May and August, during three fishing trips on two vessels (with partly-changing crews, 33 sets observed). This data included the number of catches per species (including all species, pictures were taken to confirm species identification), the occurrence of depredation, the number of depredated fish per species and species depredating, the presence of sharks and/or odontocetes around the vessel, and the captains' responses to this presence or to the occurrence of shark and odontocete bycatch.

Finally, we designed a written questionnaire with both open and closed questions on depredation and bycatch (Supplementary material 6). Pilot questionnaires were run with one captain, one DRM officer and the fishery observer program coordinator. We collected answers from 10 captains (17% of all captains working in 2018).

Table 1
Summary of data sources and available information from captains' logbook dataset (LOG), observers dataset (NOP), observations during three fishing trips (OBS), captains' answers to the questionnaire (CAP).

	Depredation		Bycatch	
Quantitative indices	*IR, GDR, DR*	NOP	*BPUE*	NOP, LOG
	Fishing trip IR, Set DR	NOP, LOG, OBS, CAP	*Species involved*	NOP, LOG, OBS, CAP
Spatial distribution	*Spatial distribution*	NOP	*Spatial distribution*	NOP, LOG
Consequences	*Impact perception*	CAP	*Release condition (alive, injured, dead)*	NOP
	Fate of depredated catch (retained, discarded)	NOP	*Fate of bycaught animals (retained, discarded)*	NOP, LOG
Responses	*Response to depredation*	OBS, CAP	*Response to bycatch*	CAP, OBS

2.2. Indices used to quantify depredation and bycatch levels

We used the NOP dataset to quantify depredation based on three of the indices defined by Rabearisoa et al. (2018): the interaction rate (IR), the depredation rate at the set scale (DR), the gross depredation rate at the global and annual scales (GDR) and the depredation per unit effort (DPUE). We only considered marketable species to calculate these indices and excluded depredated catch of non-marketable species (n = 79 catches excluded, Table S2).

The IR was used to assess how often depredation occurred. It was calculated as the proportion (%) of sets on which fish were depredated (at least one depredated fish) out of all sets, as follows:

$$\mathrm{IR} = \frac{\text{depredated } sets}{\text{total number of } sets} \mathrm{x}100 \quad (1)$$

The DR (set scale) and GDR (global scale) were used to assess the amplitude of fish damaged by depredation. It was calculated as the proportion (%) of fish depredated out of the total number of fishes caught (whether depredated or not), as follows:

$$\mathrm{GDR}\ ;\ \mathrm{DR} = \frac{\text{depredated } catch}{\text{total number of } catch} \mathrm{x}100 \quad (2)$$

When depredation occurred on a given set, the DPUE indicated the amount of fish depredated as a function of the fishing effort expressed as the number of hooks deployed. For each depredated set *i*, it was calculated as the number of fishes depredated for every 1000 hooks deployed, as follows:

$$\mathrm{DPUE_i} = \frac{\text{depredated } catch_\mathrm{i}}{\mathrm{hooks_i}} \times 1,000 \quad (3)$$

We separately calculated each index considering shark depredation (IR_{shark}, GDR_{shark}, DR_{shark}, $DPUE_{shark}$) and odontocete depredation ($IR_{odontocete}$, $GDR_{odontocete}$, $DR_{odontocete}$, $DPUE_{odontocete}$), and depredation by any of these two taxa (IR, GDR, DR, DPUE). For each case, we calculated all three indices per set (except for GDR), year and overall (i.e. over the whole period using all data).

To assess if fishermen could, on average, still benefit from depredated catch, we determined the percentage of tuna depredated out of the total depredated catch and the percentage of discarded or retained for sale of depredated fish.

We used both the NOP and the LOG datasets to quantify bycatch per unit of effort (BPUE). The BPUE was calculated as the number of sharks ($BPUE_{shark}$) or odontocetes ($BPUE_{odontocete}$) bycaught for each 1000 hooks deployed. It was calculated globally (using the total number of hooks of all sets) and at the scale of each set *i*:

$$\mathrm{BPUE_i} = \frac{\text{number of bycaught sharks or } odontocetes_\mathrm{i}}{\text{number of } hooks_\mathrm{i}} \times 1,000 \quad (4)$$

We conducted generalized linear models to assess the spatial and temporal trends in depredation and bycatch (together with linear regressions for the temporal trend presented in Fig. 1). The presence/absence of depredation was modelled using a Binomial distribution (using a logit link, Zuur et al., 2009):

$$\mathrm{logit(pi)} = \alpha + \beta 1\mathrm{yeari} + \beta 2\mathrm{regioni} + \varepsilon \mathrm{i} \quad (5)$$

Where pi is the probability of depredation on a set *i* is explained by the year (as a numeric variable, only complete years included, i.e.,

Table 2

Summary of the LOG and NOP databases and of depredation and bycatch indices based on both NOP and LOG datasets. The total number of vessels is given for each dataset with the minimum and maximum annual numbers of vessels in brackets. Each rate is given for sharks, odontocetes and when one or the other occurred (or both). Depredation and bycatch indices are given at the global scale and as the mean of annual scales (± SD, IR and GDR are calculated excluding incompletely monitored years). IR and GDR are given in percentages; BPUE and DPUE in individuals per 1000 hooks.

		NOP				LOG
Sets		4384 (3454 that could be compared with LOG)				120,173
Vessels		80 vessels, 6 to 28 annually				138 vessels, 50 to 65 annually
Indices		IR (%)	GDR (%)	DPUE	BPUE	BPUE
Sharks	Global	23.0	1.0	0.8 ± 0.8	0.1	0.5
	Annual	30.0 ± 10.1	1 ± 0.5	0.7 ± 0.2	0.6 ± 0.3	0.5 ± 0.3
Odontocetes	Global	6.7	0.5	1.4 ± 1.2	0.001	0
	Annual	8.7 ± 6.1	0.4 ± 0.5	1.1 ± 0.7	0.003 ± 0.01	0
Sharks or Odontocetes	Global	27.7	1.5	1 ± 1.4	-	-
	Annual	35.2 ± 12.0	1.4 ± 0.8	0.9 ± 0.4	-	-

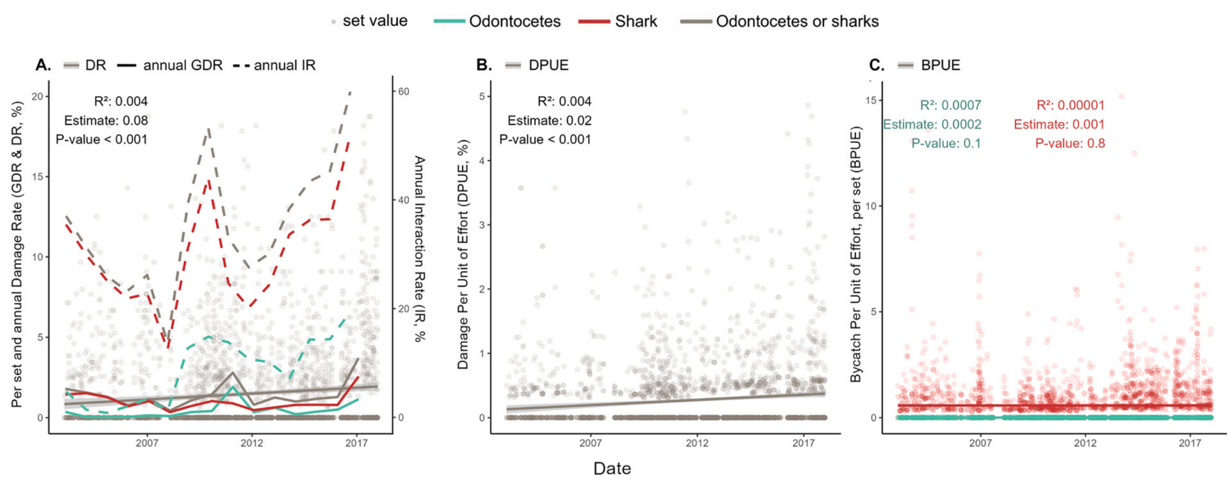

Fig. 1. Temporal variation in depredation (A. DR, GDR and IR, B. DPUE), and bycatch (C. BPUE) for odontocetes and sharks, based on observers' reports (NOP) between 2003 and 2017. For each plot, the dots indicate the indices (DR, DPUE, BPUE) at the set scale and the results of the linear regression (e.g., DR ~ α + β * year) is shown as a solid line (with the confidence interval displayed) and the results of the test are written. In A., the annual IRs are shown using dashed lines, and the annual GDRs are shown as thinner solid lines. For readability issues, outliers were removed from the plot (DR >20, n = 35; DPUE >5, n = 29; BPUE >16, n = 39); the complete dataset was used to conduct the linear regressions.

2003–2017), and region (among the five expanded archipelago polygon, there were no sets located in the Gambier region; Fig. 3); α is the intercept, β1, β2 are the coefficients of the predictive variables and εi the residuals (species depredating are not included as this variable is highly correlated with the presence of depredation).

Following the same modelling approach, bycatch and depredation rates (BPUE, DPUE, DR at set scales) were modelled using Gaussian distributions, and also included the species depredating (no species, sharks, odontocetes or both on the same set) as an explanatory variable:

$$DRi;\ DPUEi;\ BPUEi = \alpha + \beta 1 yeari + \beta 2 regioni + \beta 3 speciesi + \varepsilon i \quad (6)$$

We also conducted Wilcoxon pairwise comparison tests (Fig. S3) to quantify the difference in damages between shark and odontocetes depredation.

2.3. Comparisons of bycatch and depredation levels between datasets

We compared bycatch and depredation levels from the NOP dataset, the LOG dataset, the dataset from the dedicated trips on fishing vessels, and the fishermen questionnaires (Table 1). We used information available simultaneously in both the NOP and LOG datasets for 372 trips totaling 3454 sets to assess potential discrepancies in odontocete and shark bycatch frequencies between the two datasets (Supplementary material 2). To identify species, captain could use the black and white shark species drawing in the logbook or the odontocete and shark species guide they were previously given (Chapman et al., 2006). It was not known whether captains used these identification tools to distinguish shark and odontocete species. They did not provide pictures of bycaught animals in their reporting. The consistency of species bycaught could be compared between the NOP and LOG datasets as well as with captains' questionnaires (captains were asked to score 10 shark species from never caught to the most commonly caught, and to indicate other species they caught). Captains have not been trained to identify odontocetes, thus they were asked in the questionnaire if they knew of the false killer whale that should be widespread in the EEZ (Laran et al., 2012). As there is no depredation information in the LOG dataset, NOP information about depredation was further compared to answers given by fishermen in the questionnaire on the frequency of depredation (mean numbers of sets with depredation per fishing trip) and on the amount of fish depredated by either sharks or odontocetes (mean numbers of fish depredated per set). Captains were asked what species depredated the most (several choices possible among sharks, birds, turtles, mysticetes and odontocetes, and the possibility to specify other species). During the three onboard trips, J. Biquet reported all bycatch at the species level to qualitatively compare with the NOP and LOG datasets, as well as the frequency and species depredated to compare with the NOP dataset and captains' answers to the questionnaire.

2.4. Fishermen's perceptions and attitudes towards bycatch and depredation

We used the questionnaire to investigate the attitudes of fishermen towards the mitigation of depredation and bycatch (Supplementary material 6). Except for questions about quantifying depredation, captains could select multiple answers. Captains were asked to choose among a set of actions describing what they would do with a bycaught shark, depending on whether the individual was dead or alive (multiple choices between picking up the hook, cutting the line, hauling the shark in, recording the catch, checking the species). In an open question, captains were asked to describe the techniques they use to avoid depredation. These answers were then compared to the onboard observations. Closed questions were used to ask them how urgent it was to mitigate depredation, the consequences of depredation (choosing among bad yields, damaged gear, bycatch of sharks or odontocetes, changes in fishing zones or in the fishing trip duration), their strategy when facing a depredation event (e.g., keeping on fishing, retrieving the line; at hauling or setting), their will to contribute to scientific studies and the way they would do so, their will to be trained and on what aspects of to improve their practice and mitigation efforts.

We performed all analyses using R (R Core Team 2016, RStudio version 1.2). All mean values were provided with their standard deviation (SD). All maps were produced with QGIS using spatial cells of 55 km^2 (QGIS Development team 2014, versions 3.8). EEZ delineations were extracted from the database provided by the Flanders Marine Institute (2018). Regions used in the models were created as expanded polygons of the archipelago polygons extracted from the Te Fenua geoportal (accessed in December 2023).

3. Results

3.1. Depredation levels

In the NOP dataset, between 2002 and 2018, 1216 sets out of the 4384 sets monitored were affected by depredation, corresponding to an overall IR of 27.7% (Table 2). The mean annual IR was 35.2% (SD = 12%) of the sets (n = 15 years; ranging from 13.7% in 2008 to 59.9% in 2017) and it has been slightly increasing (Table 3), especially since 2014 (Fig. 1). Observers' reports included 923 sets with shark depredation only, 210 sets with odontocete depredation only, and 83 with depredation by both taxa. Together, IR_{shark} was 23% and $IR_{odontocetes}$ was 6.7% of all sets (Fig. S3). The mean number of depredated sets per fishing trip was 2.7 (SD = 2.4, n = 455 trips). The levels of depredation (described below) were higher in the Marquises compared to other regions (Fig. 3, Table 3).

With a total of 2373 fish depredated by either sharks or odontocetes out of 163,604 marketable fish, the GDR was 1.5% of the total marketable fish caught over the study period (Table 2). Sharks depredated a total of 1580 fish (GDR_{shark} = 1%) with a mean of 106.3 (SD = 77.5) fish per year. Odontocetes depredated 793 fish ($GDR_{odontocete}$ = 0.5%) with a mean of 53.7 (SD = 55.4) fish per year (Fig. S3). At the set scale, the mean DR was 1.5% of the marketable fish per set (SD = 4.4) and it slightly increased through time (Fig. 1, Table 3). $DR_{odontocete}$ were higher than DR_{shark} (Fig. S3).

The mean DPUE was 1 (SD = 1.4) fish per 1000 hooks (n = 1216 sets) and it showed a slight increase over the study period (Fig. 1,

Table 3
Results of the models (Eqs. 5 and 6; regions are presented in Fig. 3). The DPUE model does not include the level "No depredation" because they are calculated for sets with depredation.

			Estimate	Statistic	P-value
Presence of depredation					
Presence of depredation (similar to IR, modelled as a binomial) n = 4384 sets	Intercept		-64.6 SD = 17.3	-3.8	< 0.001
	Year		0.03 SD = 0.01	3.8	< 0.001
	Region (comparison to the Marquises archipelago)	Australes	-0.8 SD = 0.2	-4.6	< 0.001
		Société	-0.9 SD = 0.1	-8.1	< 0.001
		Tuamotu	-0.8 SD = 0.1	-7.3	< 0.001
Level of depredation					
DR (modelled as a gaussian) n = 4384 sets	Intercept		-48.1 SD = 27.2	-1.8	0.08
	Year		0.03 SD = 0.01	2.0	0.05
	Region (comparison to the Marquises archipelago)	Australes	-1.0 SD = 0.3	-3.3	< 0.001
		Société	-1.1 SD = 0.2	-5.8	< 0.001
		Tuamotu	-1.2 SD = 0.2	-6.3	< 0.001
	Species depredating (comparison to sharks only)	Odontocetes only	4.1 SD = 0.3	15.0	< 0.001
		Odontocetes & sharks	6.2 SD = 0.4	15.1	< 0.001
		No depredation	-4.2 SD = 0.1	-31.2	< 0.001
DPUE (modelled as a gaussian) n = 1216 sets	Intercept		-19.5 SD = 16.5	-1.2	0.3
	Year		0.01 SD = 0.01	1.3	0.2
	Region (comparison to the Marquises region)	Australes	-1.2 SD = 0.2	-6.4	< 0.001
		Société	-1.1 SD = 0.1	-9.8	< 0.001
		Tuamotu	-1.3 SD = 0.1	-11.9	< 0.001
	Species depredating (comparison to sharks only)	Odontocetes only	0.3 SD = 0.1	3.7	< 0.001
		Odontocetes & sharks	2.0 SD = 0.1	13.9	< 0.001
Bycatch					
$BPUE_{odontocete}$ (modelled as a gaussian) n = 4384 sets	Intercept		-0.3 SD = 0.2	-1.9	0.06
	Year		0.0002 SD < 0.001	1.9	0.06
	Region (comparison to the Marquises archipelago)	Australes	-0.002 SD = 0.002	-1.1	0.3
		Société	-0.002 SD = 0.001	-1.4	0.2
		Tuamotu	-0.001 SD = 0.001	-0.9	0.4
$BPUE_{shark}$ (modelled as a gaussian) n = 4384 sets	Intercept		5.1 SD = 10.0	-0.5	0.6
	Year		0.003 SD = 0.01	0.7	0.5
	Region (comparison to the Marquises archipelago)	Australes	-0.7 SD = 0.1	-7.3	< 0.001
		Société	-1.1 SD = 0.1	-14.6	< 0.001
		Tuamotu	-1.0 SD = 0.1	-14.0	< 0.001

Table 3). Regardless of the number of hooks, in 67% of the sets, only one catch had been depredated by either sharks or odontocetes (Table S4), with a mean of 2 (SD = 2.5) fish depredated per set (n = 1216 sets). The mean $DPUE_{odontocete}$ (1.4, SD = 1.2 per 1000 hooks, n = 293 sets) was higher than the mean $DPUE_{shark}$ (0.8, SD = 0.8 per 1000 hooks, n = 1006 sets; Table 3, Fig. S3). DPUE indices were positively correlated with CPUEs (Fig. S5).

The majority (84.5%) of the depredated fish was discarded, i.e., 99.7% of the 793 odontocete-depredated fish and 76.8% of the 1580 shark-depredated fish were discarded. Most depredated fish were tunas (81.4% of all depredated fish), including 35.6% of yellowfin, 30.8% of albacore, 10.4% of bigeye, and 4.6% of skipjack tuna (*Katsuwonus pelamis*, Scombridae), followed by wahoo (*Acanthocybium solandri*, Scombridae, 7.3%) and mahi-mahi (*Coryphaena hippurus*, Coryphaenidae, 4.3%).

3.2. Bycatch levels

A total of nine odontocetes were documented as bycatch in the NOP dataset over the 2002–2018 period (n = 4384 sets; $BPUE_{odontocete}$ = 0.001 per 1000 hooks, mean $BPUE_{odontocete}$ over all sets = 0.0001, SD = 0.02), showing no time trend (Table 3, Fig. 1). These all occurred in the northern part of the EEZ (Fig. S9): three short-finned pilot whales, one false killer whale, and five small undetailed species (two small Delphinidae including one *Stenella sp.*, and three animals recorded as Dall's porpoises, *Phocoenoides dalli*). Only one of these individuals was caught dead. The three pilot whales and the false killer whale were released and the crews kept the other five odontocetes (no explanation was provided in the dataset).

In total, the bycatch of 4947 sharks was recorded in the NOP dataset. The mean number of sharks bycaught per set was 1.1 (SD = 2, n = 4384 sets, Fig. 2), and the $BPUE_{shark}$ of 0.1 shark per 1000 hooks (mean $BPUE_{shark}$ over all sets = 0.6, SD =1.4; Table 2). Annual shark bycatch reported by observers varied over time, from 162 individuals in 2002 to 609 in 2017, but there is no time trend in $BPUE_{shark}$, i.e., when standardizing bycatch by fishing effort (Figs. 1 and 2B, Table 3). Sharks were caught throughout the EEZ but in greater numbers in the Marquises region compared to the others (Fig. 3B, Table 3). $BPUE_{shark}$ indices were positively correlated with CPUEs (but with a large variability, Fig. S11).

Twenty-nine shark species were reported in the NOP dataset as subjects to bycatch, including rarely observed species such as the velvet dogfish (*Zameus squamulasus*¸ Somniosidae). Four species were most frequently caught, representing 79.5% of all sharks bycaught (Fig. 2A, Table S6). They were blue sharks (*Prionace glauca,* 42.3%), oceanic whitetip sharks (16.2%), silky sharks (*Carcharhinus falciformis*, Carcharhinidae, 11.2%) and shortfin mako sharks (*Isurus oxyrinchus*, Lamnidae, 9.9%). Observers reported captures of one great white shark (*Carcharodon carcharias*, Lamnidae), one bigeye sand tiger *Odontaspis noronhai* (Odontaspididae), and several kitefin sharks *Dalatias licha* (Dalatiidae, n = 6) and bignose sharks *Carcharhinus altimus*

Fig. 2. A. Most commonly bycaught species as reported by captains in their logbooks (LOG), by observers (NOP, see Table 1), as observed during three fishing trips (OBS, 33 sets), and from captains' answers in the questionnaires (CAP, mean score for each species). B. Annual reports of shark bycatch by captains (LOG, 19 species reported, rarely caught species are indicated as "other species") and observers (ROP, 31 species reported). C. Fate of sharks bycaught observed in the LOG (above) and NOP (below) datasets (retained or discarded) and their condition when discarded (NOP dataset; see Appendix 3 for species details).

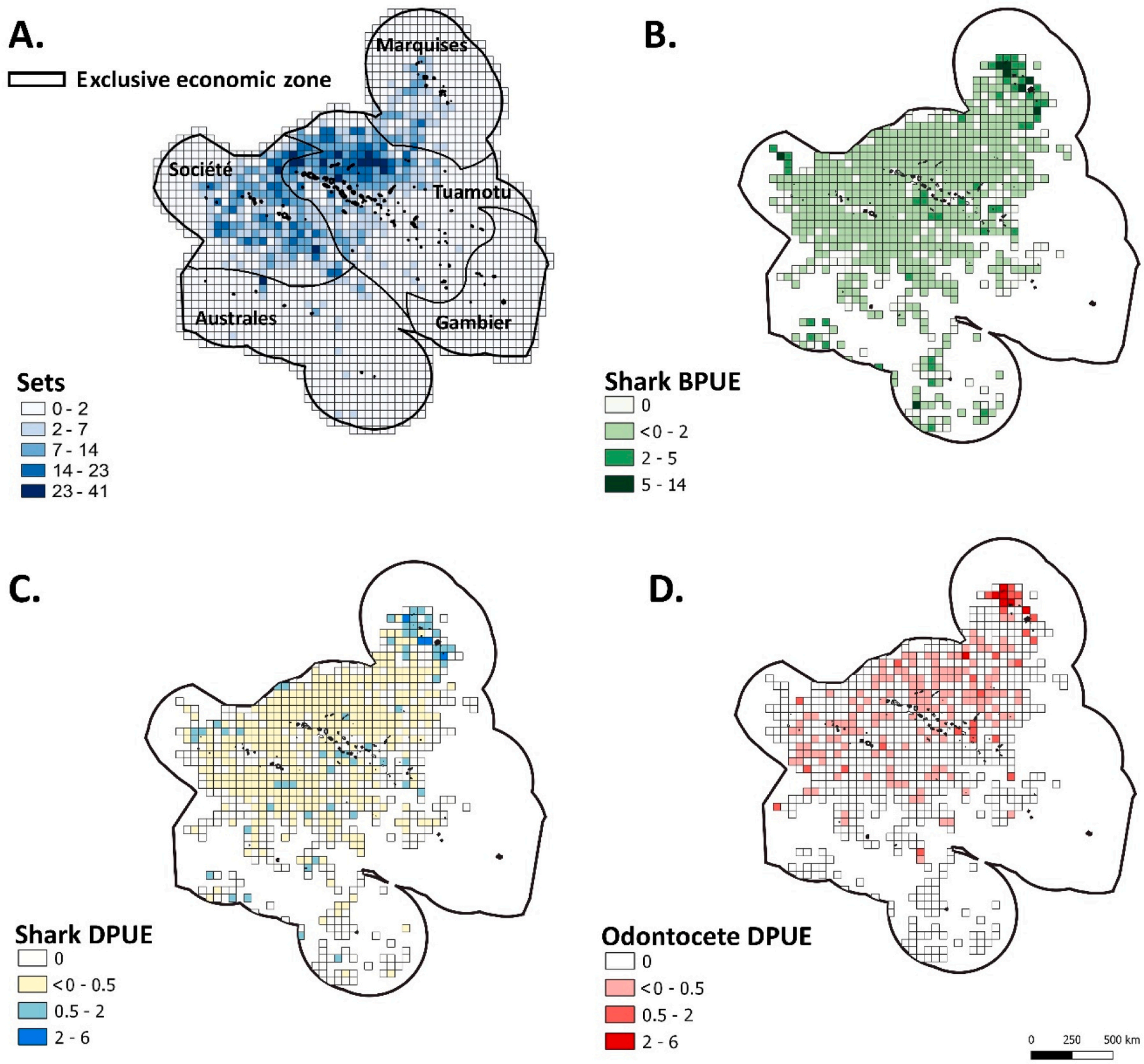

Fig. 3. A. Spatial distribution of sets (cells of 55 km^2), of B. mean $BPUE_{shark}$ per spatial unit based on observers' reports (see Fig. S13 for captains' data), of C. $DPUE_{shark}$ and D. mean $DPUE_{odontocete}$ per spatial unit.

(Carcharhinidae, n = 35).

Out of the 98.7% of bycaught sharks with known fate in the NOP dataset, 3.6% were retained; the annual number of sharks retained decreased from 7.5% in 2002 (reaching 11.8% in 2006) to 0.7% in 2017 (Fig. 2C and S5). Every year, a mean of 15.3% (SD = 20.2) of bycaught sharks were released in unknown condition. Out of sharks released in known condition, the mean percentage of sharks released annually as alive and in good condition was 64.6% (SD = 18.8), 11.6% (SD = 13.6) were alive but injured, 23.8% (SD = 7.4) were dead (Fig. 2C, S7, and S8).

3.3. Comparisons of information on bycatch and depredation across datasets

During the three trips observed by one of the author for the study, 2.1 (SD =1.4) depredated fish per set with depredation were recorded (mean = 1, SD = 0.7 depredated fish per 1000). By comparison, in the NOP dataset, for sets with depredation, a mean of 2 (SD = 2.5) fish were depredated (mean = 1, SD = 1.4 depredated fish per 1000 hooks), and a mean of 2.7 (SD = 2.4) sets were depredated per fishing trip. From the questionnaire, 67% of the captains indicated that shark and/or odontocete depredation occurred on two to five sets per fishing trip and 33% indicated that depredation occurred on all sets of a trip (Fig. 4 for responses and sample size for each question of the questionnaire). When depredation occurred, 70% of the captains indicated that less than five fish were depredated per set and 20% indicated that more than 20 fish were depredated per set.

None of the odontocete bycatch reported in the NOP dataset (nine odontocetes) were found in the LOG dataset. However, the bycatch of five other odontocetes ($BPUE_{odontocete}$ = 0) were reported in the LOG dataset (all in the eastern part of the EEZ; Fig. S10) with no observer on board. One vessel reported four spectacled porpoises in 2017 (*Phocoena dioptrica*, Phocoenidae), another reported a Pacific white-sided dolphin (*Lagenorhynchus obliquidens*, Delphinidae) in 2018. In the questionnaires, all surveyed captains but one did not know what false killer whales were (Fig. 4).

For the same sets, the LOG and NOP datasets showed different numbers of bycaught sharks reported. We found that 8.3% of sets reported in LOG and NOP showed at least three more sharks reported by observers compared to captains and 3.9% with at least three more reported by captains (n = 3454, Fig. S2). Over-reporting of blue and silky shark bycatch by one of the captains was documented by J. Biquet (difference of 17 sharks over 33 sets, Table S3). Captains reported a mean of one shark per set and observers reported 1.12 sharks per set. In the LOG dataset, a total of 122,610 sharks were recorded as bycaught between 2000 and 2018, with a global BPUE of 0.5 for 1000 hooks (n = 120,173 sets). The spatial distribution of bycatch closely resembled

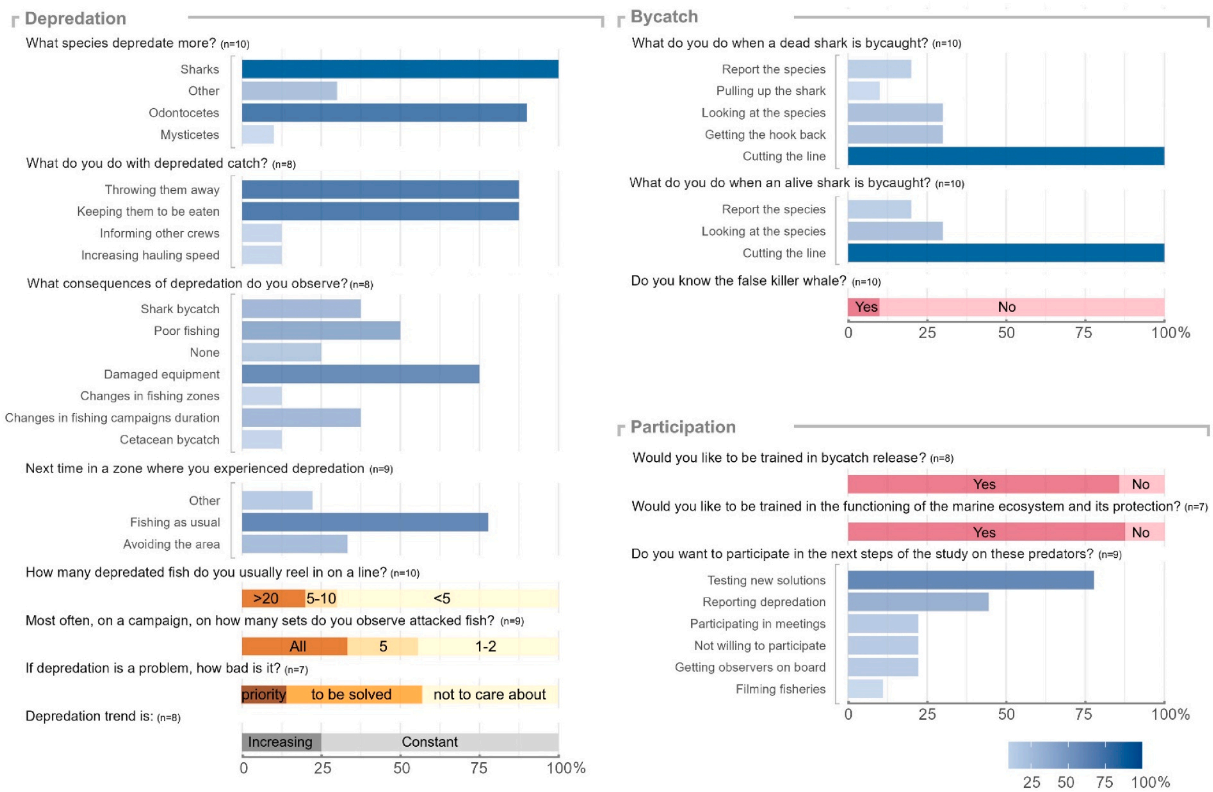

Fig. 4. Questionnaire responses from captains, given in percentage of respondents (additional questions on depredation in Fig. S14). The number of respondents is given for each question. Captains could give multiple answers for questions displayed with multiple bars. The answer "Other" to the question "Next time in a zone where you experienced depredation" includes "warning others" and "look around the boat at setting".

the patterns observed in the NOP dataset (Fig. S10). The number of shark bycatch reported annually in the LOG dataset increased from 6590 in 2002 to 19,186 in 2017 (Fig. 2B). Among this bycatch, data from the LOG dataset indicated that the proportion of sharks retained onboard decreased from 100% between 2002 and 2005 to 0.01% in 2017 (Fig. S5). As in the NOP dataset, blue and oceanic whitetip sharks were the most commonly caught species reported in the LOG dataset, in the questionnaires and for the sets with dedicated observers (Fig. 2A, Fig. S12, Tables S3 and S5). However, the diversity of shark species reported as bycaught in the LOG dataset (18 species) was lower than that reported in the NOP dataset (29 species). Before 2014, 84.4% of the sharks bycatch reported in the LOG dataset were missing information on the species and 15% were identified as makos, *Isurus* sp. (Fig. 2B, Table S6).

3.4. Fishermen's perceptions and attitudes towards bycatch and depredation

When a shark was caught on the line, whether it was dead or alive when landed on the vessel, all responding captains indicated that they would cut the line (n = 10 respondents, none stated that they would remove the hook, Fig. 4). Among these captains, 30% indicated that they would pay attention to the species of shark caught and 20% stated that they would record that information in their logbook. When a shark was caught dead, 30% of the respondents indicated that they would remove the hook from the animal.

When odontocetes were sighted while setting the line, captains all indicated that stopping the setting process, retrieving the part of the line already deployed and moving to another fishing area were practices they had already implemented (n = 8 respondents). Half of the responding captains (3 out of 6) indicated that they would not do anything when sharks were sighted during setting. However, when odontocetes or sharks were sighted at hauling the line, all respondents indicated that nothing could be done and did not change their practice (n = 5 respondents, Fig. S12). In the fishing areas where depredation was likely to occur, 78% of the respondents stated that they would fish as usual, but 45% said they would avoid these areas (n = 9 respondents, they could chose multiple answers; Fig. 4). Sixty-seven percent felt that depredation had been rather constant over the years, 22% felt that it had been increasing, and 11% felt that it had been both constant and increasing (n = 9 respondents). Shark and odontocete depredation was considered as an issue impacting the fishing yield by 50% of the respondents and the fishing equipment by 63% of them (n = 8 respondents, Fig. 4). Forty-three percent stated that it was not important to address this issue, and 15% saw it as a priority (n = 7 respondents).

Eighty-eight percent of the respondents expressed their will to learn more about this marine ecosystem and ways of protecting it (n = 8 respondents) and 88% expressed their will to be trained on improving bycatch release practices (n = 7 respondents). Seventy-eight percent of the respondents indicated that they were eager to get involved in efforts to mitigate bycatch and depredation, through the testing of new solutions for 78% of them and a better reporting of these interactions for 34% of them (n = 9 respondents, Fig. 4).

4. Discussion

In this study, we compared bycatch and depredation as reported in captains and observers databases, that proved incomplete (low observer coverage, lack of reporting of depredation in logbooks, species misidentification), and a high uncertainty therefore remains. We found that while shark or odontocete depredation has frequently occurred (about 1/3 of the sets deployed) in the pelagic longline fishery targeting tuna in the EEZ of French Polynesia between 2002 and 2018, a low proportion of fish were damaged during these interactions, rendering them unsellable (less than 2% of the total catch). As shown in other fisheries through differences in DPUEs between the two taxa, sharks damaged less fish than odontocetes when depredating on a given set (e.g., Rabearisoa et al., 2018). We found no clear trend in depredation, though both GDR and IR indices were increasing in the last years, the annual DPUEs vary strongly. It was not clear from the captains' questionnaires whether depredation was increasing (though damage rates seemed to increase in the recent years) or was an urgent issue to tackle.

The mean DPUE (1 per 1000 hooks) described in our study was lower than previously described in the Western Central Pacific (often by a factor of 10; Lawson, 2001, Mitchell et al., 2018). Depredation rates are likely underestimated due to the low observer coverage and because fish completely removed from the hook cannot be accounted for (similar biases likely occur in most studies). It was also half of the DPUEs described by the Chinese fleet over the Pacific (Wang et al., 2021), or in the similar socio-ecosystem of Hawai'i (Gilman et al., 2008). Given the results from the NOP dataset, the mean observer coverage, and the mean weight of tuna caught by the fishery, approximately 1000 tons of tuna may have been depredated by sharks and odontocetes on longlines over this period (considering a mean weight of 22 kg, based on lengths reported in the NOP dataset and the weight/length relationship from Bertrand, 1999). Based on the market price of tuna in French Polynesia, which ranges between USD 4 and USD 12 per kg, this could represent up to USD 6400,000 for the fleet between 2002 and 2018, and USD 384,000 per year (DRM, 2018; ISPF, 2022). This would be much lower than the last assessment in the Hawai'i tuna longline fishery, estimated to one million USD annually (Fader et al., 2023).

Increased risk of bycatch is a main impact of depredation on sharks and odontocetes. With nearly 20,000 sharks bycaught annually and an overall BPUE of 0.5 sharks per 1000 hooks deployed, the level of shark bycatch might affect their populations in French Polynesia, even though it is smaller than bycatch rates of other longline Pacific fisheries (Carvalho, 2019; Gilman et al., 2008; Gilman and Clarke, 2007; Li et al., 2020; Wang et al., 2021). In French Polynesia, shark bycatch was associated with high mortality, as one shark out of five was reported dead when discarded, and a large proportion of sharks discarded alive might not survive (WCPFC, 2019b, the handling practices affecting their survival are largely unknown at the scale of the fleet, but as captains stated, sharks are released without removing the hook). This mortality is a major threat for heavily caught species at global scale (Pacoureau et al., 2021), and in the Western-Central Pacific where at least one million of sharks are estimated to be caught each year (Peatman, 2018; Peatman et al., 2023). This is especially true for species of high conservation concern such as the oceanic whitetip (Tremblay-Boyer et al., 2019) and the silky sharks (Clarke et al., 2018, both species should not be retained under the WCPFC conservation measures, WCPFC, 2022), as well as for the recovering blue shark populations (Neubauer et al., 2021).

We found that the reported levels of odontocete bycatch in the French Polynesian longline fishery were significantly lower than those of sharks, with less than 15 observed occurrences between 2000 and 2018 considering both LOG and NOP datasets. For example, the bycatch rate was similar to the bycatch described by Chinese longlines operating in the Pacific Ocean (Wang et al., 2021) but was lower compared to pilot whale bycatch rates in the US longlines in the Atlantic Ocean (Stepanuk et al., 2018). Given that observers monitored less than 4% of the reported sets and that captains likely underreported this bycatch (none of observers' reports were found in the LOG data), this is likely an underestimation of the potential odontocete bycatch in this fishery. Given the observers' coverage, an estimated 13 odontocetes might have been caught each year, if extrapolating to 100% of the fishing sets (i.e. a total of 195 odontocetes bycaught between 2003 and 2017). The mortality rates are highly uncertain and the risks and reasons for crews to retain odontocetes are unknown. This level of odontocete bycatch would be considered as problematic for false killer whales in the Hawaiian longline fisheries (Fader et al., 2021). However, it is difficult to understand the consequences of this bycatch in French Polynesia, as several bycaught odontocetes were not identified at the species level and the knowledge of odontocete populations throughout the EEZ remains limited (Laran et al., 2012). A comprehensive monitoring of short-finned and false killer whales' populations in French Polynesian waters, the two species mostly involved in depredation events, could allow an estimation of biological references to adapt fisheries management (Gilman et al., 2022).

We also identified major accuracy issues in the data on odontocete and shark depredation and bycatch when comparing observers and captains data. Firstly, the data collected by observers included all information needed to monitor bycatch and depredation, but the coverage was too low for reliable assessments and accurate understanding (4% of the reported sets). This issue is not inherent to French Polynesia but was reported for the majority of pelagic longline fisheries operating throughout the Pacific Ocean (Peatman, 2018). Secondly, information on depredation were not collected by captains, as there were no dedicated fields in the standardized logbooks. Thirdly, despite an apparent improvement in the captains' reporting over the years, our findings suggested that there were still concerns regarding the reliability of the data. Indeed, captains reported less bycatch of sharks and odontocetes than observers per set. While observing only 4% of the sets over a shorter time period, the observers reported almost twice as many odontocetes as the captains. This under-reporting was also illustrated by the fact that only a third of the captains in the questionnaires stated that they would report shark bycatch. The most commonly caught species reported by both observers and captains corresponded to expected species in the EEZ (DIREN and creocean, 2015). However, some species recorded had never been reported in the EEZ, i.e. great white, bigeye sand tiger, kitefin and bignose sharks (Siu et al., 2017), but the observations have not been verified and no photographs (for none of the bycatch) were provided. Lastly, we found that both captains and observers likely misidentified bycaught odontocetes. Indeed, the data included species such as spectacled and Dall's porpoises, and Pacific white-sided dolphins that were never (and unlikely to be) documented in French Polynesia given their ecology and distribution (Perrin et al., 2009; Shirihai and Jarret, 2007). Difficulties to identify odontocete species was made even more apparent from the results of the questionnaire, with most captains indicating that they did not know about false killer whales, one of the species likely involved in depredation in the region (Carzon and Portal, 2012; Hamer et al., 2012; Laran et al., 2012). The monitoring can be easily improved by offering species identification tools and training, and by adding new fields in logbooks for captains to record the bycatch of odontocetes, the occurrence of depredation and the number of fish depredated, as we showed captains would be willing to participate in such monitoring. Photo documentation by captains and the implementation of electronic monitoring (through cameras, as it was trialed on five French Polynesian longliners in 2022) should also be considered (Emery et al., 2019; Gilman et al., 2019; Stahl et al., 2023). Additional formatting of observers' reports (as they report more information in a notebook), supplementary training on species identification, debriefing with observers (notably in case of odontocete bycatch) can quickly improve the quality of bycatch data (species bycaught, handling practices).

Depredation and bycatch could impact the entire trophic chain, including the behaviors and diet of odontocetes and sharks (Mitchell et al., 2018; Tixier et al., 2021). Mitigation recommendations or regulations should be considered for the fishery ecosystem-based management. DRM started working on these issues, notably because of the Marine Stewardship Council certification and WCPFC requirements and guidelines, creating posters and offering training courses on bycatch avoidance and release methods. This could increase the survival of the individuals bycaught (Poisson et al., 2016; Zollett and Swimmer, 2019). For the reporting quality to improve, captains should also be trained to identify species. For bycatch, additional measures could include the temporal or spatial closures of certain fishing areas, increased collaboration between fishermen (e.g. communicating observations of predators), the use of different gears to reduce bycatch rates (Gilman et al., 2006; Hamilton and Barry Baker, 2019; Pons et al., 2022; Swimmer et al., 2020). For depredation, some of these longliners are already trialling an 'interactive dolphin deterrent' (Sieben and Daxboeck, 2020). Its effectiveness should be monitored, because such devices showed limited effectiveness in other regions (Hamilton and Barry Baker, 2019). Other mitigation devices or measures could be investigated through collaborations between fishermen, scientists, and fishery managers with a full assessment of the socio-economic costs and benefits of implementing these measures, such as avoiding areas of high risks of depredation and reducing fish discards or vessel noise (Hart and Collin, 2015; O'Keefe et al., 2014; Richard et al., 2021; Werner et al., 2015).

In conclusion, both monitoring and mitigation of bycatch and depredation of sharks and odontocetes need management actions to be taken in years to come for the French Polynesian longline fishery. These actions are especially urgent for this fishery firstly because bycatch involves large numbers of individuals from species of high conservation concern in the EEZ of French Polynesia. The EEZ is a sanctuary for both sharks and odontocetes and the 2023–2027 management plan of the EEZ-wide Marine Managed Area sets up an action plan to monitor and mitigate depredation and bycatch, notably through the dissemination of good practices and increase of observer coverage (DIREN et al., 2023). The plan to double offshore fisheries production in the EEZ by 2027 also raises environmental concerns, as it involves a substantial increase in fleet size and the spatial expansion of fishing activities (IEOM, 2021), including in areas of higher densities of sharks and odontocetes, like the Marquises Islands (this study, Gannier, 2009, DIREN and creocean, 2015).

CRediT authorship contribution statement

Guinet Christophe: Conceptualization, Funding acquisition, Supervision, Writing – review & editing. **Aminian Biquet Juliette:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Richard Gaëtan:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Tixier Paul:** Writing – original draft, Writing – review & editing. **Thellier Thibaut:** Writing – review & editing. **Soehnlen Marie:** Methodology, Resources. **Clua Eric:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing. **Carzon Pamela:** Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The authors do not have permission to share data.

Acknowledgements

The main author received financial supports from the OrcaDepred project funded by the French National Agency for Research (ANR-17-CE32-0007) and from Air Tahiti Nui to travel to French Polynesia. We are very grateful to Taiana Raoulx and the SPC-OFP team, especially Emmanuel Schneiter, for the access and help with the databases. Importantly, a big thank you to the crews who warmly welcomed the author. We also thank Anais Janc for their advice and Johann Mourier for their help with species identification. We thank the two reviewers for their thoughtful reading and comments to improve the manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2023.106928.

References

Avila, Isabel C., Kaschner, Kristin, Dormann, Carsten F., 2018. Current global risks to marine mammals: taking stock of the threats. Biol. Conserv. 221 (August 2017), 44–58. https://doi.org/10.1016/j.biocon.2018.02.021.

Aylesworth, Lindsay. 2009. Oceania Regional Assessment: Pacific Island Fisheries and Interactions with Marine Mammals, Seabirds and Sea Turtles.

Bearzi, G., Bonizzoni, S., Gonzalvo, J., 2011. Dolphins and coastal fisheries within a marine protected area: mismatch between dolphin occurrence and reported depredation. Aquat. Conserv.: Mar. Freshw. Ecosyst. 21 (3), 261–267. https://doi.org/10.1002/aqc.1179.

Bertrand, Arnaud. 1999. Le Système Thon-Environnement En Polynésie Française: Caractérisation de l'habitat Pélagique, Étude de La Distribution et de La Capturabilité Des Thons, Par Méthodes Acoustiques et Halieutiques. École nationale supérieure agronomique de Rennes.

Brown, Christopher J., Desbiens, Amelia, Campbell, Max D., Game, Edward T., Gilman, Eric, Hamilton, Richard J., Heberer, Craig, Itano, David, Pollock, Kydd, 2021. Electronic monitoring for improved accountability in western pacific tuna longline fisheries. Mar. Policy 132 (June), 104664. https://doi.org/10.1016/j.marpol.2021.104664.

Carvalho, Felipe. 2019. Standardized Catch Rates of Shortfin Mako Shark (Isurus oxyrinchus) Caught by the Hawaii-Based Pelagic Longline Fleet (1995–2019)."

Carzon, Pamela, and Alain Portal. 2012. DÉPRÉDATION HAUTURIÈRE DANS LES EAUX POLYNÉSIENNES et SYSTÈMES DE LUTTE POTENTIELS.

Chapman, Lindsay B., Peter Sharples, Deirdre Brogan, Aymeric Desurmont, Steve Beverly, and William Sokimi. 2006. Marine Species Identification Manual for Horizontal Longline Fishermen.

Clarke, Shelley, Sato, Mayumi, Small, Cleo, Sullivan, Ben, Inoue, Yukiko, Ochi, Daisuke, 2014. Bycatch in longline fisheries for tuna and tuna-like species. A Glob. Rev. Status Mitig. Meas. Vol. 588.

Clarke, Shelley, Adam Langley, Cleridy Lennert-Cody, Alexandre Aires-da-Silva, and Mark Maunder. 2018. Pacific-Wide Silky Shark (Carcharhinus falciformis) Stock Status Assessment. WCPFC 14th SC (SA-WP-08).

Clavareau, Lyndsay, Martin P. Marzloff, Verena M. Trenkel, Catherine M. Bulman, Sophie Gourguet, Bertrand Le Gallic, Pierre-Yves Hernvann, Clara Péron, Nicolas Gasco, Johanna Faure, and Paul Tixier. 2020. Comparison of Approaches for Incorporating Depredation on Fisheries Catches into Ecopath" edited by S. Northridge. ICES Journal of Marine Science 77(7–8):3153–67. doi: 10.1093/icesjms/fsaa219.

DIREN, and creocean. 2015. L'état de l'environnement En Polynésie Française."

DIREN, D.R.M., OFB, and MCE. 2023. Tainui Atea. L'Aire Marine Gérée de Polynésie Française. Plan de Gestion 2023 – 2037.

DRM. 2018. Politique Sectorielle de La Pêche Hauturière de La Polynésie Française 2018–2022.

DRM. (2019). ANNUAL REPORT TO THE COMMISSION PART 1: INFORMATION ON FISHERIES, RESEARCH, AND STATISTICS. August.

DRM. 2021. Synthèse Des Données de La Pêche Professionnelle, de l'aquaculture et de La Perliculture.

Dulvy, Nicholas K., Pacoureau, Nathan, Rigby, Cassandra L., Pollom, Riley A., Jabado, Rima W., Ebert, David A., Finucci, Brittany, Pollock, Caroline M., Cheok, Jessica, Derrick, Danielle H., Herman, Katelyn B., Sherman, C.Samantha, VanderWright, Wade J., Lawson, Julia M., Walls, Rachel H.L., Carlson, John K., Charvet, Patricia, Bineesh, Kinattumkara K., Fernando, Daniel, Ralph, Gina M., Matsushiba, Jay H., Hilton-Taylor, Craig, Fordham, Sonja V., Simpfendorfer, Colin A., 2021. Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. Curr. Biol. 31 (21), 4773–4787.e8. https://doi.org/10.1016/j.cub.2021.08.062.

Emery, T.J., Noriega, R., Williams, A.J., Larcombe, J., 2019. Changes in logbook reporting by commercial fishers following the implementation of electronic monitoring in Australian Commonwealth fisheries. Mar. Policy 104, 135–145. https://doi.org/10.1016/j.marpol.2019.01.018.

Ewell, Christopher, Hocevar, John, Mitchell, Elizabeth, Snowden, Samantha, Jacquet, Jennifer, 2020. An evaluation of regional fisheries management organization at-sea compliance monitoring and observer programs. Mar. Policy 115 (February), 103842. https://doi.org/10.1016/j.marpol.2020.103842.

Fader, Joseph E., Elliott, Brianna W., Read, Andrew J., 2021. The challenges of managing depredation and bycatch of toothed whales in pelagic longline fisheries: two U.S. case studies. Front. Mar. Sci. 8 https://doi.org/10.3389/fmars.2021.618031.

Fader, Joseph E., Marchetti, Jamie A., Schick, Robert S., Read, Andrew J., 2023. No free lunch: estimating the biomass and ex-vessel value of target catch lost to depredation by odontocetes in the hawai'i longline tuna fishery. Can. J. Fish. Aquat. Sci. 80 (7), 1126–1141. https://doi.org/10.1139/cjfas-2022-0156.

Gannier, Alexandre, 2009. Comparison of odontocete populations of the marquesas and society islands (French Polynesia). J. Mar. Biol. Assoc. U. Kingd. 89 (5), 931–941. https://doi.org/10.1017/S0025315408002713.

Gillett, Robert. 2016. Fisheries in the Economies of the Pacific Island Countries and Territories. Pacific community.

Gilman, E., Legorburu, G., Fedoruk, A., Heberer, C., Zimring, M., Barkai, A., 2019. Increasing the functionalities and accuracy of fisheries electronic monitoring systems. Aquat. Conserv.: Mar. Freshw. Ecosyst. 29 (6), 901–926. https://doi.org/10.1002/aqc.3086.

Gilman, Eric, and Shelley C. Clarke. 2007. Shark Depredation and Unwanted Bycatch in Pelagic Longline Fisheries.

Gilman, Eric, Brothers, Nigel, McPherson, Geof, Dalzell, Paul, 2006. A Review of Cetacean Interactions with Longline Gear. J. Cetacea Res. Manag. 8 (2), 215–223. https://doi.org/10.47536/jcrm.v8i2.717.

Gilman, Eric, Clarke, Shelley, Brothers, Nigel, Alfaro-Shigueto, Joanna, Mandelman, John, Mangel, Jeff, Petersen, Samantha, Piovano, Susanna, Thomson, Nicola, Dalzell, Paul, Donoso, Miguel, Goren, Meidad, Werner, Tim, 2008. Shark interactions in pelagic longline fisheries. Mar. Policy 32 (1), 1–18. https://doi.org/10.1016/j.marpol.2007.05.001.

Gilman, Eric, Hall, Martin, Booth, Hollie, Gupta, Trisha, Chaloupka, Milani, Fennell, Hannah, Kaiser, Michel J., Karnad, Divya, Milner-Gulland, E.J., 2022. A decision support tool for integrated fisheries bycatch management. Rev. Fish. Biol. Fish. 32 (2), 441–472. https://doi.org/10.1007/s11160-021-09693-5.

Guerra, Ana Sofia, 2019. Wolves of the sea: managing human-wildlife conflict in an increasingly tense ocean. Mar. Policy 99 (November 2018), 369–373. https://doi.org/10.1016/j.marpol.2018.11.002.

Hall, Martin, Gilman, Eric, Minami, Hiroshi, Mituhasi, Takahisa, Carruthers, Erin, 2017. Mitigating bycatch in tuna fisheries. Rev. Fish. Biol. Fish. 27 (4), 881–908. https://doi.org/10.1007/s11160-017-9478-x.

Hamer, Derek J., Childerhouse, Simon J., Gales, Nick J., 2012. Odontocete bycatch and depredation in longline fisheries: a review of available literature and of potential solutions. Mar. Mammal. Sci. 28 (4), E345–E374. https://doi.org/10.1111/j.1748-7692.2011.00544.x.

Hamilton, Sheryl, Barry Baker, G., 2019. Technical mitigation to reduce marine mammal bycatch and entanglement in commercial fishing gear: lessons learnt and future directions. Rev. Fish. Biol. Fish. 29 (2), 223–247. https://doi.org/10.1007/s11160-019-09550-6.

Hart, Nathan S., Collin, Shaun P., 2015. Sharks senses and shark repellents. Integr. Zool. 10 (1), 38–64. https://doi.org/10.1111/1749-4877.12095.

Heppell, Selina S., Scott a Heppell, Andrew J. Read, and Larry B. Crowder. 2005. Effects of Fishing on Long-Lived Marine Organisms. Pp. 211–31 in Marine conservation biology: The science of maintaining the sea's biodiversity.

IEOM. 2021. Rapport Annuel Économique Polynésie Française 2020.

ISPF. 2022. Points Etudes et Bilans de La Polynésie Française N°1311 Les Exportations de Produits de La Mer En 2021.

Juan-Jordá, Maria José, Murua, Hilario, Arrizabalaga, Haritz, Dulvy, Nicholas K., Restrepo, Victor, 2018. Report card on ecosystem-based fisheries management in tuna regional fisheries management organizations. Fish Fish 19 (2), 321–339. https://doi.org/10.1111/faf.12256.

Komoroske, Lisa M., Lewison, Rebecca L., 2015. Addressing fisheries bycatch in a changing world. Front. Mar. Sci. 2 (OCT), 1–11. https://doi.org/10.3389/fmars.2015.00083.

Lallemant-Moe, Hervé Raimana. 2015. *Droit de l'environnement En Polynésie Française*.

Laran, Sophie, Olivier Van Canneyt, Ghislain Dorémus, Wendy Massart, Vicent Ridoux, and Pierre Watremez. 2012. Distribution et Abondance de La Mégafaune Marine En Polynésie Française. REMMOA- Polynésie. Rapport Final Pour l'Agence Des Aires Marines Protégées.

Lawson, T. 2001. Predation of Tuna by Whales and Sharks in the Western and Central Pacific Ocean. Working Paper SWG-6 Presented at the Fourteenth Meeting of the Standing Committee on Tunas and Billfish (SCTB14) 8.

Lewison, Rebecca L., Crowder, L., Read, A., Freeman, S., 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol. Evol. 19 (11), 598–604. https://doi.org/10.1016/j.tree.2004.09.004.

Lewison, Rebecca L., Crowder, Larry B., Wallace, Bryan P., Moore, Jeffrey E., Cox, Tara, Zydelis, Ramunas, McDonald, Sara, DiMatteo, Andrew, Dunn, Daniel C., Kot, Connie Y., Bjorkland, Rhema, Kelez, Shaleyla, Soykan, Candan, Stewart, Kelly R., Sims, Michelle, Boustany, Andre, Read, Andrew J., Halpin, Patrick, Nichols, W.J., Safina, Carl, 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proc. Natl. Acad. Sci. 111 (14), 5271–5276. https://doi.org/10.1073/pnas.1318960111.

Li, W.W., Kindong, R., Wu, F., Tian, Q., Dai, X.J., 2020. Catch rate and stock status of blue shark in the pacific ocean inferred from fishery-independent data. Indian J. Geo Mar. Sci. 49 (04), 543–547 doi: 49(4):543-547.

Mitchell, J.D., McLean, D.L., Collin, S.P., Langlois, T.J., 2018. Shark depredation in commercial and recreational fisheries. Rev. Fish. Biol. Fish. 28 (4), 715–748. https://doi.org/10.1007/s11160-018-9528-z.

Mitchell, J.D., Drymon, J.M., Vardon, J., Coulson, P.G., Simpfendorfer, C.A., Scyphers, S. B., Kajiura, S.M., Hoel, K., Williams, S., Ryan, K.L., Barnett, A., Heupel, M.R., Chin, A., Navarro, M., Langlois, T., Ajemian, M.J., Gilman, E., Prasky, E., Jackson, G., 2023. Shark depredation: future directions in research and management. Rev. Fish. Biol. Fish. 33 (2), 475–499. https://doi.org/10.1007/s11160-022-09732-9.

Molony, B. 2006. Estimates of Catches and Mortalities of Seabirds, Mammals, Sharks and Turtles in Longline Fisheries of the Western and Central Pacific Ocean, 1990–2004. P. 70 in Hook, Line and Bycatch: Setting the agenda for mitigation of bycatch in longline fisheries Kota Kinabalu, Malaysia, 26–30 September.

Neubauer, Philipp, Kath Large, Stephen Brouwer, Dragonfly Data Science, and Saggitus Consulting. 2021. Stock Assessment of Southwest Pacific Blue Shark. (August).

NOAA. 2009. Cetacean Depredation in the Hawai Longline Fishery: Interviews of Longline Vessel Owners and Captains.

O'Keefe, Catherine E., Cadrin, Steven X., Stokesbury, Kevin D.E., 2014. Evaluating effectiveness of time/area closures, quotas/caps, and fleet communications to reduce fisheries bycatch. ICES J. Mar. Sci. 71 (5), 1286–1297. https://doi.org/10.1093/icesjms/fst063.

Oliver, Shelby, Braccini, Matias, Newman, Stephen J., Harvey, Euan S., 2015. Global patterns in the bycatch of sharks and rays. Mar. Policy 54, 86–97. https://doi.org/10.1016/j.marpol.2014.12.017.

Pacoureau, Nathan, Rigby, Cassandra L., Kyne, Peter M., Sherley, Richard B., Winker, Henning, Carlson, John K., Fordham, Sonja V., Barreto, Rodrigo, Fernando, Daniel, Francis, Malcolm P., Jabado, Rima W., Herman, Katelyn B., Liu, Kwang-Ming, Marshall, Andrea D., Pollom, Riley A., Romanov, Evgeny V., Simpfendorfer, Colin A., Yin, Jamie S., Kindsvater, Holly K., Dulvy, Nicholas K., 2021. Half a century of global decline in oceanic sharks and rays. Nature 589 (7843), 567–571. https://doi.org/10.1038/s41586-020-03173-9.

Peatman. 2018. Summary of Longline Fishery Bycatch at a Regional Scale 2003–2017. Pp. 2003–17 in WCPFC-SC14–2018/ST-WP-03.

Peatman, Tom, Allain, Valerie, Bell, Lui, Muller, Berry, Panizza, Aurélien, Phillip, Naiten B., Pilling, Graham, Nicol, Simon, 2023. Estimating trends and magnitudes of bycatch in the tuna fisheries of the Western and Central Pacific Ocean. Fish Fish. https://doi.org/10.1111/faf.12771.

Perrin, William F., Bernd Wursig, and J.G.M. Thewissen. 2009. Encyclopedia of Marine Mammals.

Peterson, Megan J., Franz Mueter, Keith Criddle, and Alan C. Haynie. 2014. Killer Whale Depredation and Associated Costs to Alaskan Sablefish, Pacific Halibut and Greenland Turbot Longliners" edited by D. E. Duplisea. PLoS ONE 9(2):e88906. doi: 10.1371/journal.pone.0088906.

Poisson, François, Crespo, Francisco Abascal, Ellis, Jim R., Chavance, Pierre, Bach, Pascal, Santos, Miguel N., Séret, Bernard, Korta, Maria, Coelho, Rui, Ariz, Javier, Murua, Hilario, 2016. Technical mitigation measures for sharks and rays in fisheries for tuna and tuna-like species: turning possibility into reality. Aquat. Living Resour. 29 (4), 402. https://doi.org/10.1051/alr/2016030.

Pons, Maite, Watson, Jordan T., Ovando, Daniel, Andraka, Sandra, Brodie, Stephanie, Domingo, Andrés, Fitchett, Mark, Forselledo, Rodrigo, Hall, Martin, Hazen, Elliott L., Jannot, Jason E., Herrera, Miguel, Jiménez, Sebastián, Kaplan, David M., Kerwath, Sven, Lopez, Jon, McVeigh, Jon, Pacheco, Lucas, Rendon, Liliana, Richerson, Kate, Sant'Ana, Rodrigo, Sharma, Rishi, Smith, James A., Somers, Kayleigh, Hilborn, Ray, 2022. Trade-offs between bycatch and target catches in static versus dynamic fishery closures. Proc. Natl. Acad. Sci. 119 (4) https://doi.org/10.1073/pnas.2114508119.

Rabearisoa, Njaratiana, Philippe S. Sabarros, Evgeny V. Romanov, Vincent Lucas, and Pascal Bach. 2018. Toothed Whale and Shark Depredation Indicators: A Case Study from the Reunion Island and Seychelles Pelagic Longline Fisheries" edited by H. M. Patterson. PLOS ONE 13(8):e0202037. doi: 10.1371/journal.pone.0202037.

Read, Andrew J., 2008. The looming crisis: interactions between marine mammals and fisheries. J. Mammal. 89 (3), 541–548. https://doi.org/10.1644/07-MAMM-S-315R1.1.

Richard, Gaëtan, Samaran, Flore, Guinet, Christophe, Bonnel, Julien, 2021. Settings of demersal longlines reveal acoustic cues that can inform toothed whales where and when to depredate. JASA Express Lett. 1 (1), 016004 https://doi.org/10.1121/10.0003191.

Schakner, Zachary A., Chris Lunsford, Janice Straley, Tomoharu Eguchi, and Sarah L. Mesnick. 2014. Using Models of Social Transmission to Examine the Spread of Longline Depredation Behavior among Sperm Whales in the Gulf of Alaska" edited by G. P. Lahvis. PLoS ONE 9(10):e109079. doi: 10.1371/journal.pone.0109079.

Shirihai, Hadoram, and Brett Jarret. 2007. Guide Des Mammifères Marins Du Monde. Delachaux et Niestlé.

Sieben, Authors Chrissie, and Charles Daxboeck. 2020. Marine Stewardship Council (MSC) 1 St Surveillance Audit Report French Polynesia Albacore and Yellowfin Longline Fishery On Behalf of Direction Des Ressources Marines (DRM) Prepared by Control Union Pesca Ltd March 2020.

Siu, Gilles, Bacchet, Philippe, Bernardi, Giacomo, Brooks, Andrew J., Carlot, Jeremy, Causse, Romain, Claudet, Joachim, Clua, Éric, Delrieu-Trottin, Erwan, Espiau, Benoit, Harmelin-Vivien, Mireille, Keith, Philippe, Lecchini, David, Madi-Moussa, Rakamaly, Parravicini, Valeriano, Planes, Serge, Ponsonnet, C.édric, Randall, John E., Sasal, Pierre, Taquet, Marc, Williams, Jeffrey T., Galzin, René, 2017. Shore fishes of french polynesia. Cybium 41 (3), 245–278.

Snape, Robin Thomas Ernest, Broderick, Annette Cameron, Çiçek, Burak Ali, Fuller, Wayne John, Tregenza, Nicholas, Witt, Matthew John, Godley, Brendan John, 2018. Conflict between dolphins and a data-scarce fishery of the European Union. Hum. Ecol. 46 (3), 423–433. https://doi.org/10.1007/s10745-018-9989-7.

Stahl, J.P., Tucker, J.B., Hawn, L.A., & Bradford, A.L. (2023). The role of electronic monitoring in assessing post-release mortality of protected species in pelagic longline fisheries. https://doi.org/10.25923/zxfv-5b50.

Stepanuk, Julia E.F., Read, Andrew J., Baird, Robin W., Webster, Daniel L., Thorne, Lesley H., 2018. Spatiotemporal patterns of overlap between short-finned pilot whales and the u.s. pelagic longline fishery in the mid-atlantic bight: an assessment to inform the management of fisheries bycatch. Fish. Res. 208 (July), 309–320. https://doi.org/10.1016/j.fishres.2018.07.008.

Swimmer, Y., Zollett, E.A., Gutierrez, A., 2020. Bycatch mitigation of protected and threatened species in tuna purse seine and longline fisheries. Endanger. Species Res. 43, 517–542. https://doi.org/10.3354/esr01069.

Tixier, P., Authier, M., Gasco, N., Guinet, C., 2015. Influence of artificial food provisioning from fisheries on killer whale reproductive output. Anim. Conserv. 18 (2), 207–218. https://doi.org/10.1111/acv.12161.

Tixier, Paul, Lea, Mary-Anne, Hindell, Mark A., Welsford, Dirk, Mazé, Camille, Gourguet, Sophie, Arnould, John P.Y., 2021. When large marine predators feed on fisheries catches: global patterns of the depredation conflict and directions for coexistence. Fish Fish 22 (1), 31–53. https://doi.org/10.1111/faf.12504.

Tremblay-Boyer, Laura, Felipe Carvalho, Philipp Neubauer, and Graham Pilling. 2019. Stock Assessment of Oceanic Whitetip Sharks in the Western and Central Pacific Ocean. in Stock Assessment of Oceanic Whitetip Sharks in the Western and Central Pacific Ocean. Vol. 65.

Wang, Jiaqi, Gao, Chunxia, Wu, Feng, Gao, Xiaodi, Chen, Jessica, Dai, Xiaojie, Tian, Siquan, Chen, Yong, 2021. The discards and bycatch of chinese tuna longline fleets in the Pacific Ocean from 2010 to 2018. Biol. Conserv. 255, 109011 https://doi.org/10.1016/j.biocon.2021.109011.

WCPFC. 2019a. Conservation and Management Measures (CMMs) and Resolutions of the Western Central Pacific Fisheries Commission (WCPFC)."

WCPFC. 2019b. Report of the Workshop on Joint Analysis of Shark Post-Release Mortality Tagging Results (SC 15)."

WCPFC. (2022). COMMISSION NINETEENTH REGULAR SESSION CONSERVATION AND MANAGEMENT MEASURE FOR SHARKS. Conservation and Management Measure 2022–04.

Werner, Timothy B., Northridge, Simon, Press, Kate Mc.Clellan, Young, Nina, 2015. Mitigating bycatch and depredation of marine mammals in longline fisheries. ICES J. Mar. Sci. 72 (5), 1576–1586. https://doi.org/10.1093/icesjms/fsv092.

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. Endanger. Species Res. 38, 115–125. https://doi.org/10.3354/esr00940.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., & Smith, G.M. (2009). Mixed Effects Models and Extensions in Ecology with R (Vol. 1). https://doi.org/10.1017/CBO9781107415324.004.