RESEARCH ARTICLE

Exploring odontocete depredation rates in a pelagic longline fishery

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Abstract

Several odontocete species depredate catch and bait from fishing gear, resulting in their bycatch and causing substantial economic costs. There are no known mitigation methods for odontocete depredation in pelagic longline fisheries that are effective, do not harm odontocetes and are commercially viable. Understanding odontocetes' depredation strategies can contribute to mitigating this human-wildlife conflict. Using observer data from the Hawaii-based tuna longline fishery, this study summarized teleost and elasmobranch species-specific mean posterior odontocete depredation rates using a simple Bayesian binomial likelihood estimator with a Bayes-Laplace prior. Depredation rates of species with sufficient sample sizes ranged from a high of 1.2% (1.1 to 1.3 95% highest posterior density interval or HDI) for shortbill spearfish to a low of 0.002% (0.001 to 0.003 95% HDI) for blue shark. Depredation of catch is a rare event in this fishery, occurring in about 6% of sets. When depredation did occur, most frequently odontocetes depredated a small proportion of the catch, however, there was large variability in depredation rates between teleost species. For example, bigeye tuna was two times more likely to be depredated than yellowfin tuna (odds ratio = 2.03, 95% CI: 1.8–2.3, P<0.0001). For sets with depredation, 10% and 2% of sets had depredation of over half of the captured bigeye tuna and combined teleosts, respectively. All elasmobranch species had relatively low depredation rates, where only 7 of almost 0.5M captured elasmobranchs were depredated. Odontocetes selectively depredate a subset of the teleost species captured within sets, possibly based on net energy value, chemical, visual, acoustic and textural characteristics and body size, but not median length, which was found to be unrelated to depredation rate (Pearson's r = 0.14, 95% CI: -0.26 to 0.50, p = 0.49). Study findings provide evidence to support the identification and innovation of effective and commercially viable methods to mitigate odontocete depredation and bycatch.

1. Introduction

Marine mammals occupy a range of trophic levels and some species have important roles in regulating the structure, function, dynamics and state of marine communities and ecosystems [1–6]. Large changes in their abundance can therefore cause profound community- and

ecosystem-level consequences that are protracted or irreversible. Some marine mammals, including sirenians and most toothed whales, are extremely sensitive to anthropogenic mortality due to having relatively low rates of potential population growth and other intrinsic life history characteristics, small population sizes, and extrinsic environmental variables such as narrow habitat requirements for foraging and breeding [7–9].

Fisheries bycatch in both in-use and derelict (abandoned, lost and discarded) fishing gear is the largest threat to many populations of marine megafauna, including marine mammals, and is an obstacle to sustainable seafood production [9–12]. Of the range of anthropogenic hazards faced by marine mammals, bycatch affects the greatest number of species, contributed to the presumed extinction of the baiji (Yangtze River dolphin, *Lipotes vexillifer*), and has contributed to reducing the abundance of several populations and species of cetaceans and pinnipeds to critical levels [9, 13, 14]. Furthermore, marine mammal depredation (removal and damage of catch and bait from fishing gear) causes substantial direct and indirect socioeconomic costs [15, 16]. Depredation can also result in fishers deliberately injuring and killing marine mammals, and alters marine mammals' foraging behavior, distribution, diet and demographics [7, 15–19].

Several species of odontocetes (Odontoceti, toothed whales), including the false killer whale (*Pseudorca crassidens*), short-finned pilot whale (*Globicephala macrorhynchus*) and killer whale (*Orcinus orca*), depredate catch and bait in pelagic longline fisheries, which can result in their bycatch by becoming hooked or entangled in line [20, 21]. A U.S. central north Pacific Ocean tuna longline fishery with vessels based primarily from Hawaii experiences odontocete depredation and bycatch primarily by false killer whales [22]. Under the U.S. Marine Mammal Protection Act, a Take Reduction Team was established in 2010 because the five-year running average of the estimated annual false killer whale mortalities and series injuries (M&SI) exceeded a threshold Potential Biological Removal (PBR) level. The team was tasked with reducing M&SI to below PBR within six months and to a level approaching zero, defined as <10% of PBR, within five years, and was further tasked with having no increase in M&SIs for a high seas false killer whale stock [23]. To date, existing measures recommended by the team and adopted by the US fisheries management authority ('weak' circle hooks, permanent static closed area, fleetwide bycatch cap that triggers an area closure, prescribed handling and release practices [23]) have not achieved <10% of PBR, and M&SIs on the high seas have increased [22]. More effective false killer whale depredation and bycatch mitigation methods are needed.

Unlike for some other threatened taxonomic groups exposed to bycatch in pelagic longline fisheries, there are no known odontocete methods across the tiers of a sequential bycatch mitigation hierarchy (avoid, minimize, remediate and offset) that are: (1) effective, (2) do not harm odontocetes, and (3) have acceptable costs to commercial viability (economic viability, practicality and crew safety) [15, 21, 24, 25]. There is low strength of evidence of the efficacy and commercial viability of bycatch and depredation mitigation approaches for odontocetes in pelagic longline gear. This includes mitigation approaches such as spatiotemporal fisheries management, including quasi-real time dynamic (fleet communication, move-on rules, habitat suitability modelling, real-time acoustic tracking) and static approaches [9, 15, 22, 24, 26, 27], input controls such as limits on soak and haul duration [24, 28], and output controls such as bycatch thresholds [29]. The same applies to gear technology approaches such as:

- Catch encasement to physically protect catch from depredation, and visual and acoustic camouflage of target catch such as by using bubble screens or knots [24, 30, 31];

- Mainline length limits, hookless sections of mainline, hookless sets, and set geometry [32];

- Active acoustic deterrents and decoys, including pingers, acoustic harassment devices, decoy vessels, broadcasts of decoy fishing vessel acoustic cues, broadcasts of killer whale and other predator sounds, masked or disrupted odontocete returning echolocation [21, 24, 33–36];

- Passive acoustic decoys and deterrents such as the incorporation of objects into gear that: simulate the acoustic target strength of odontocete-depredated catch, simulate the target strength of species that odontocetes avoid depredating, are perceived as unusual prey, or interfere with echolocation [24, 37];

- Acoustic masking, including quieter vessels; bubble screen to reduce the dissemination of vessel sounds; broadcast of sounds to conceal the sounds of the vessel gear, setting and hauling; not remaining near the gear after it is set; and minimizing shifting in and out of gear [20];

- Artificial bait [38];

- Weak hooks. While there is no evidence of weak hooks causing reduced odontocete bycatch rates, mechanistic studies found that wire diameter was an informative predictor of the force required to straighten hooks [39–41] and during at-sea experiments weak hooks were observed to straightened more often than control hooks with a wider hook wire diameter [39, 40]; and

- Chemical deterrents [20, 24, 42].

There is also weak evidence of the effect of prescribed pelagic longline handling and release practices on cetacean post-release mortality rates. For instance, estimates of survival probability made by the US Government are based largely on expert opinion [22, 43]. Therefore, evidence is needed to support the identification and development of effective and commercially viable approaches to mitigate odontocete depredation and bycatch rates in pelagic longline fisheries.

Understanding the depredation strategies of odontocetes that are susceptible to fisheries bycatch can contribute to mitigating this human-wildlife conflict. Knowledge of species-specific odontocete depredation rates might contribute to the development of promising, new mitigation methods, such as geospatial, depth and temporal separation of predictable catch rate hotspots of species with both low commercial value and high odontocete depredation rates and hotspots of catch rates of principal market species, and passive acoustic decoys, deterrents and echolocation disruptors. This study analyzed observer data from the Hawaii tuna longline fishery to estimate teleost and elasmobranch species-specific mean posterior marine mammal depredation rates using a Bayesian binomial likelihood estimator with a Bayes-Laplace prior, expanding upon previous assessments [44, 45]. The study also assessed the correlation between species-specific depredation rates and length. Study findings provide evidence to support the innovation of effective and commercially viable methods to reduce the risk of odontocete depredation and bycatch in pelagic longline fisheries.

2. Methods

Data on species-specific catch, presence/absence of marine mammal depredation and length were obtained from the U.S. government observer program database for the Hawaii pelagic longline fishery. Observer data fields and data collection protocols are defined in NMFS [46]. The study period was from 15 August 2003, the date when observers began to record damage to the catch, through 26 August 2023, the most recent available record. The study sample included 179,853,812 hooks deployed in 73,217 sets within 5,445 trips by 194 vessels. Records were included in the study sample to estimate species-specific odontocete depredation rates

for fish species, both teleosts and elasmobranchs, that were identified to the species level, and had >100 capture records where the observer determined whether the catch had been depredated by a marine mammal, Thus, the study sample excludes catch records where either the observer was unable to determine whether there was damage to the catch or observed damage but could not determine the source. Length measurement methods of eye-to-fork was used for billfishes and fork length for all other species, as these produced the largest sample sizes for species within these groups.

The expected depredation rate (or proportion) for each of the 50 species was estimated using a Bayesian binomial likelihood estimator that here accounts for the zero recorded depredation events [47]. A simple binomial estimator is the most appropriate likelihood for these data that comprise the number of depredated observations and the number of not-depredated observations per set (or "successes" and "failures")—see Lin and Chu [48] for further discussion. Moreover, 40% of the 35 species-specific records had zero depredations per set and hence the use of a Bayes-Laplace prior to account for those zero observations explicitly when using a binomial estimator ([47]; and see Gilman et al. [49] for an example for shark at-vessel mortality rates). The mean posterior rate and a 95% highest posterior density interval (HDI) was summarized by sampling from a binomial likelihood with a Bayes-Laplace prior [47] using the `binom` package for R [50] as proposed elsewhere by Roda et al. [51] and Gilman et al. [49]—rather than just using the raw study-specific summaries.

The relationship between predicted mean depredation rates and median lengths was assessed for teleosts with > 1,000 capture records by calculating the Pearson product-moment correlation coefficient [52] using the corr() and cor.mtest () functions in the `corrplot` R package [53]. There were insufficient sample sizes available to estimate expected marine mammal depredation rates by length class within species (of 1,038,586 species-level catch records with length values, only 44 were identified as having marine mammal depredation)–observers are typically unable to make common length measurements (total length, eye-to-fork length, fork length) of catch depredated by marine mammals because the depredated catch tends to be retrieved with only the fish head up to the gills, or just the lips and upper jaw of the fish remaining [15, 16]. In other words, we were able to conduct analyses to determine whether catch with larger median lengths had different expected mean odontocete depredation rates than species with smaller median lengths, but not on whether larger individuals within a species had a different odontocete depredation rate than smaller individuals of that species.

The proportion of total sets with odontocete depredation of ≥1 fish was determined. The proportion of the total catch of bigeye tunas (*Thunnus obesus*), yellowfin tunas (*T. albacares*) and combined teleosts that had odontocete depredation was determined for (1) sets with observed odontocete depredation of ≥ 1 fish, and (2) sets with observed odontocete depredation of ≥ 1 bigeye tuna, yellowfin tuna or teleost. We then also compared the depredation rate for bigeye and yellowfin tunas, the principal target species of this fishery, using the odds ratio [54] calculated by conditional maximum likelihood or Fishers exact procedure using the epitools R package [55].

3. Results

Table 1 presents the mean posterior depredation rates (percent of the catch that was depredated by marine mammals) with 95% HDIs and median and mean lengths. For species with >1,000 capture records, depredation rates ranged from a high of ca. 1.2% (1.1 to 1.3 95% HDI) for shortbill spearfish to a low of 0.002% (0.001 to 0.003 95% HDI) for blue shark. Bigeye tuna was at least two times more likely to be depredated than yellowfin tuna (odds ratio = 2.03, 95% CI: 1.8–2.3, P<0.0001). Elasmobranchs had extremely low marine mammal depredation rates,

Table 1. Study sample sizes, mean posterior depredation rates and 95% highest posterior density intervals (HDIs), and length summaries for fish species with >100 catch records for which an observer determined whether there was marine mammal depredation in the Hawaii longline tuna fishery (2003–2023). There were 179,853,812 observed hooks in 73,217 sets. Lengths are eye-to-fork for billfishes and fork length for all other species. Sorted from high to low mean depredation rate within 5 taxonomic groups.

Scientific name	Common name	% depredated			No. caught	No. depredated	Length (cm)		
		mean	lower HDI	upper HDI			N	Median	Mean
Tunas									
Katsuwonus pelamis	Skipjack tuna	0.469	0.433	0.505	136,931	641	51,940	71	70
Thunnus obesus	Bigeye tuna	0.292	0.280	0.305	735,284	2,148	288,006	113	112
Thunnus alalunga	Albacore tuna	0.167	0.134	0.202	55,066	91	22,272	101	100
Thunnus albacares	Yellowfin tuna	0.144	0.127	0.162	177,441	255	68,398	117	110
Billfishes									
Tetrapturus angustirostris	Shortbill spearfish	1.172	1.088	1.256	62,722	734	24,320	134	134
Xiphias gladius	Swordfish	0.466	0.389	0.545	29,386	136	10,643	93	109
Kajikia audax	Striped marlin	0.387	0.338	0.436	61,259	236	26,001	137	134
Istiophorus platypterus	Indo-Pacific sailfish	0.263	0.077	0.475	2,283	5	800	145	141
Makaira nigricans	Blue marlin	0.229	0.165	0.297	20,055	45	7,646	161	166
Other teleosts									
Elagatis bipinnulata	Rainbow runner	1.775	0.185	3.764	167	2	34	73	75
Acanthocybium solandri	Wahoo	1.060	0.992	1.128	87,450	926	24,876	127	126
Uraspis secunda	Cottonmouth jack	0.952	0	2.839	103	0	28	32	31
Brama japonica	Pacific pomfret	0.877	0	2.616	112	0	74	33	35
Lampris megalopsis	Bigeye Pacific opah	0.579	0.524	0.635	71,311	412	27,415	101	100
Assurger anzac	Razorback scabbardfish	0.386	0	1.154	257	0	77	224	218
Coryphaena hippurus	Dolphinfish	0.332	0.310	0.353	278,395	922	77,893	85	86
Masturus lanceolatus	Sharptail mola	0.331	0	0.990	300	0	16	94	93
Trachipterus fukuzakii	Tapertail ribbonfish	0.253	0.005	0.601	790	1	187	194	190
Nesiarchus nasutus	Black gemfish	0.250	0	0.748	398	0	144	70	67
Ranzania laevis	Slender mola	0.218	0.099	0.349	5,037	10	1,196	50	51
Mola mola	Common mola	0.211	0	0.630	473	0	4	98	113
Promethichthys prometheus	Roudi's escolar	0.112	0	0.336	889	0	253	64	65
Sphyraena barracuda	Great barracuda	0.105	0.045	0.172	9,488	9	2,762	99	101
Scombrolabrax heterolepis	Longfin escolar	0.105	0.039	0.179	7,595	7	1,889	24	24
Omosudis lowii	Hammerjaw	0.103	0	0.309	968	0	236	27	28
Eumegistus illustris	Lustrous pomfret	0.095	0	0.284	1,054	0	439	49	51
Taractichthys steindachneri	Sickle pomfret	0.085	0.074	0.097	230,917	196	96,573	60	58
Lepidocybium flavobrunneum	Escolar	0.079	0.067	0.093	179,932	142	47,235	76	76
Lagocephalus lagocephalus	Pelagic puffer	0.066	0	0.198	1,510	0	369	46	45
Gempylus serpens	Snake mackerel	0.062	0.052	0.071	256,820	157	63,820	99	101
Taractes asper	Rough pomfret	0.055	0	0.165	1,815	0	611	50	53
Coryphaena equiselis	Pompano dolphinfish	0.049	0	0.146	2,051	0	666	57	58
Alepisaurus ferox	Longnose lancetfish	0.032	0.028	0.035	855,920	270	179,579	113	105
Ruvettus pretiosus	Oilfish	0.032	0.001	0.076	6,228	1	1,686	72	86
Taractes rubescens	Dagger pomfret	0.012	0	0.028	17,135	1	5,676	67	64
Rays									
Mobula mobular	Devil ray	0.261	0	0.781	381	0	0	NA	NA
Pteroplatytrygon violacea	Pelagic stingray	0.004	0	0.012	24,375	0	27	52	59
Sharks									
Carcharhinus galapagensis	Galapagos shark	0.926	0	2.761	106	0	1	115	115
Carcharhinus plumbeus	Sandbar shark	0.595	0	1.778	166	0	5	109	121

(Continued)

Table 1. (Continued)

Scientific name	Common name	% depredated			No. caught	No. depredated	Length (cm)		
		mean	lower HDI	upper HDI			N	Median	Mean
Sphyrna zygaena	Smooth hammerhead shark	0.301	0	0.901	330	0	13	197	191
Isurus paucus	Longfin mako shark	0.112	0	0.334	894	0	95	156	158
Alopias pelagicus	Pelagic thresher shark	0.099	0	0.297	1,006	0	87	125	122
Zameus squamulosus	Velvet dogfish	0.020	0	0.059	5,106	0	1,013	69	68
Carcharhinus falciformis	Silky shark	0.019	0	0.058	5,153	0	270	108	114
Pseudocarcharias kamoharai	Crocodile shark	0.018	0	0.053	5,618	0	642	85	84
Carcharhinus longimanus	Oceanic whitetip shark	0.015	0	0.046	6,475	0	363	106	107
Alopias superciliosus	Bigeye thresher shark	0.009	0.001	0.018	34,728	2	596	156	157
Isurus oxyrinchus	Shortfin mako shark	0.006	0	0.018	17,072	0	1,012	185	186
Prionace glauca	Blue shark	0.002	0.001	0.003	340,967	5	566	175	176

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where of a total of 442,377 captured elasmobranchs identified to the species level and for which the observer determined whether marine mammal depredation occurred, 7 were depredated (2 bigeye thresher sharks and 5 blue sharks) (Table 1).

Fig 1 presents the predicted mean depredation rate (proportion of the catch with marine mammal depredation) and 95% HDIs for the four species of tunas included in Table 1, the five species of billfishes included in Table 1, and the six species of other teleosts with the highest predicted mean depredation rates and with sufficient sample sizes of >1,000 capture records. Species are sorted from lowest to highest depredation rate within each of the three taxonomic groups.

Consistent with this species-selective depredation, there was high variability in the species-specific set-level marine mammal depredation rates. For example, of sets with ≥ 1 depredated bigeye tuna, the main target species of this fishery, 94% had depredation of over half of the captured bigeye tuna. This rate was 42% for yellowfin tuna (i.e., of sets with ≥ 1 depredated yellowfin tuna, 42% had depredation of over half of the captured yellowfin tuna), and 2% for combined teleost species. Similarly, for sets with depredation of ≥ 1 fish of any species, 10%, 4% and 2% of these sets had depredation of over half of the captured bigeye tuna, yellowfin tuna and combined teleosts, respectively. For sets with depredation of ≥ 1 fish of any species, 4%, 2% and 0.1% of these sets had odontocete depredation of all the captured bigeye tuna, yellowfin tuna and combined teleosts, respectively. Of the sets in the study sample, 6.2% had observed odontocete depredation of ≥ 1 fish.

There was no significant relationship between median length and mean depredation rate: Pearson's r = 0.14 (95% CI: -0.26 to 0.50), p = 0.49. The species-specific median length of the catch was not an informative predictor of odontocete depredation rate of teleosts.

4. Discussion and conclusions

Marine mammal depredation is a rare event in this fishery, occurring in about 6% of sets. When depredation did occur, most frequently a small proportion of the total catch was depredated. However, there was large variability in odontocete depredation rates between teleost species, while all species of captured elasmobranchs had negligible odontocete depredation. This is consistent with previous studies of the observer program database for the Hawaii tuna longline fishery [44, 45]. Findings suggest that odontocetes selectively depredate a subset of the teleost species captured within sets. Odontocetes are not indiscriminately depredating the catch down the line, but are selectively depredating certain teleost species.

expected species-specific marine mammal depredation rate
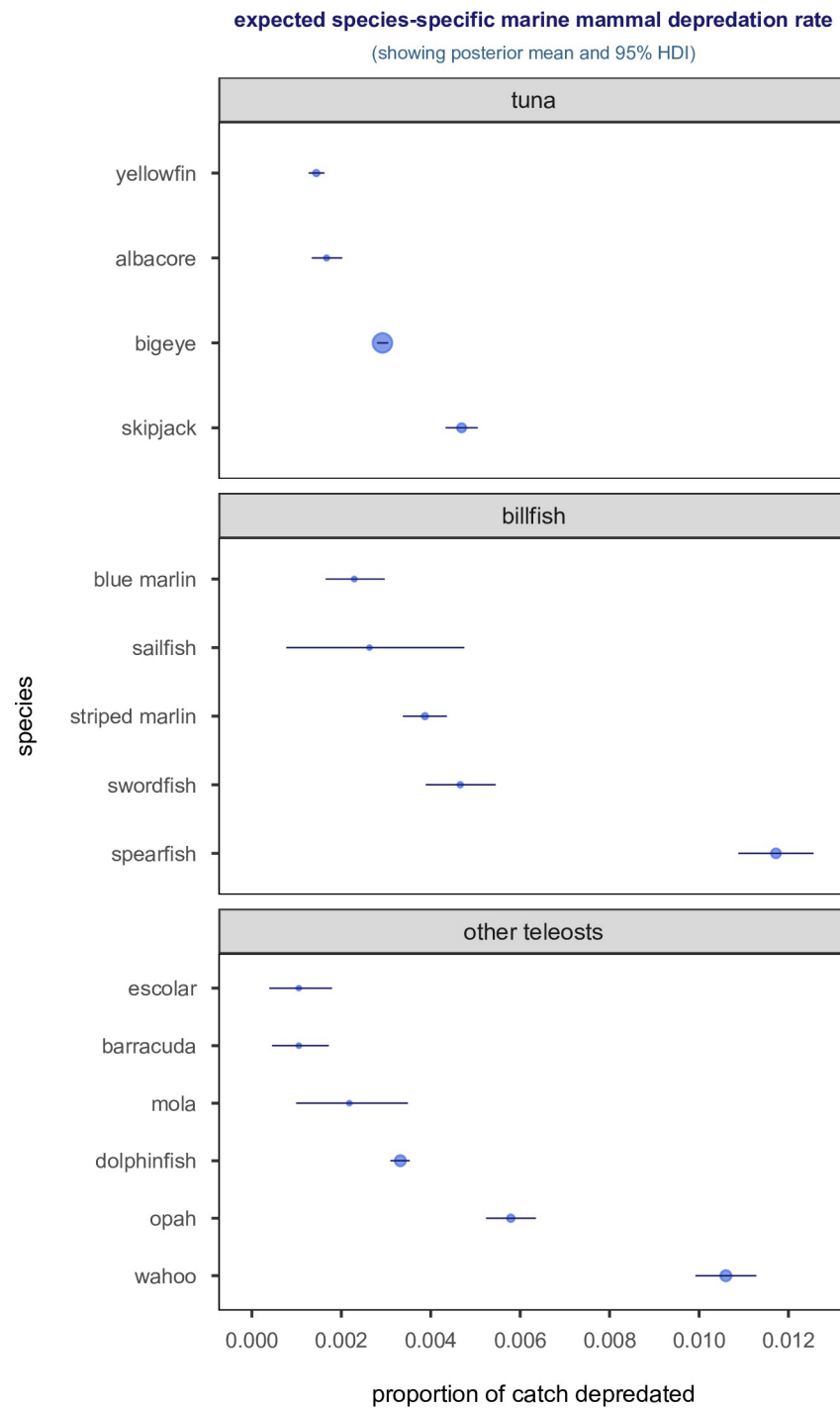(showing posterior mean and 95% HDI)

Fig 1. Mean posterior depredation rates (proportion of the number captured that was depredated by odontocetes) and 95% highest posterior density intervals (HDIs) for tunas, billfishes and six other teleost species with the highest predicted mean depredation rates and with >1,000 capture records in the Hawaii tuna longline fishery (2003–2023). Dot size is proportional to catch for that species relative to the catch for all three taxonomic groupings.

Different species of pelagic marine predators, and sizes within species, have different prey preferences and prey species-specific predation behavior [38], as suggested by the species-selective depredation observed in this study. For some odontocetes, predation and other

behaviors may also vary by sympatric populations (e.g., for killer whales in the northeast
Pacific Ocean, transients feed on marine mammals and residents target fishes, [56]). Pelagic
marine predators' detection, search and attack behavior and preferences for different prey spe-
cies might be a function of prey species' net energy value (i.e., the prey's caloric value com-
pared to the energy required to catch and handle the prey); and chemical, visual (e.g., size,
shape, color and movement), acoustic and textural characteristics [38, 57–62]. However,
median length was found in this study to be unrelated to depredation rate. Globally, false killer
whales have a broad diet that includes coastal and demersal fishes and epipelagic and oceanic-
neritic squids, as well as pelagic fishes that are also captured in pelagic longline fisheries,
including commercial species such as tunas, dolphinfish, wahoo and sickle pomfret (mon-
chong) [44, 63, 64].

Observers often cannot determine the species of odontocete depredated catch from the
small portion of the carcass remaining on the gear. The species-specific odontocete depreda-
tion rates for teleosts are conservative underestimates because they do not account for over
half of records of odontocete depredated teleosts for which the observer could not identify the
catch to the species level. A relatively small proportion of total captured tunas, billfishes and
other teleosts lacking odontocete depredation were not identified to the species level. Observ-
ers recorded all seven odontocete depredated sharks (no rays were odontocete depredated) to
the species level while some captured elasmobranchs without odontocete depredation were
not identified to the species level, and therefore the elasmobranch species-specific depredation
rates may be conservative overestimates. The observer program database also lacks records of
pre-catch losses, including when odontocetes and other predators completely remove catch
from the gear prior to gear retrieval, as well as catch that falls from the gear due to mechanical
action, representing an additional data limitation that affects the accuracy of predicted species-
specific odontocete depredation rates.

More robust estimates of species-specific odontocete depredation rates could be derived
through research using observer data from longline fisheries that standardize fishing effort to
account for potentially informative predictors of odontocete depredation. As conduced previ-
ously to explore a response of odontocete depredation of combined species of catch, models
with a response of species-specific depredation rate could include predictors such as unique
vessel, consecutive sets within a trip, season, geospatial location, hooks per set, mainline
length, soak duration, bathymetry and sea surface temperature [26, 32, 37, 45].

While a rare event, odontocete depredation may cause substantial economic and opera-
tional costs in the Hawaii tuna longline fishery. This includes direct costs from lost catch [16,
65]. For example, Fader et al. [16] estimated that in the Hawaii tuna longline fishery, odonto-
cete depredation of bigeye and yellowfin tunas and dolphinfish, the three most frequently
retained species in this fishery, had an annual value of USD 1 million. Other economic costs
result from odontocete depredation of bait, lost and damaged fishing gear and time for crew to
repair and replace it, lost fishing time when vessels move or wait to make another set after
observing depredation, and increased fishing effort to make up for lost catch [15, 16].

Depredation also leads to bycatch fishing mortality and sublethal effects such as altered for-
aging behavior, distributions, diet and demographics [7, 17–19]. The false killer whale is the
main odontocete species captured in the Hawaii fishery. During the study period (2003–2023)
about 70% of captured marine mammals were false killer whales (of 173 odontocetes identified
to the species level or higher taxonomic group that could be differentiated from false killer
whales). The main Hawaiian Islands insular false killer whale population segment is listed as
endangered under the U.S. Endangered Species Act [66], while trends in the abundance of
other false killer whale population segments that are exposed to the Hawaii longline and other
fisheries are highly uncertain [67].

There are no known odontocete depredation and bycatch mitigation methods for pelagic longline fisheries across the tiers of a sequential mitigation hierarchy that are effective, do not harm odontocetes, and are likely to have acceptable costs on economic viability, practicality and crew safety [15, 21, 24, 25, 45]. To date, measures recommended by an advisory team formed under the U.S. Marine Mammal Protection Act and interventions adopted by the national management authority (weak circle hooks, permanent static closed area, fleetwide bycatch cap that triggers an area closure, and prescribed handling and release practices) have been unsuccessful in meeting management objectives [22].

Study findings might provide evidence to support the identification and innovation of effective and commercially viable methods to mitigate odontocete fisheries depredation and bycatch risk. For example, the spatial and temporal distribution of catch rates of species with and without relatively high odontocete depredation rates could be explored. Fishing effort could be conducted in areas and periods with relatively low catch rates of species with low commercial value and with high odontocete depredation rates that maintains economic viability but lowers odontocete depredation and catch rates [68, 69]. Managing the fishing depth and time of day of fishing might similarly enable reducing catch rates of species with high odontocete depredation rates that also have low commercial value [16, 70]. These findings on odontocete depredation strategies might also contribute to the development of passive acoustic decoys and deterrents. Incorporating objects into the fishing gear may act as decoys if they effectively simulate the acoustic target strength (TS) of the main depredated catch species– hence confusing or frustrating depredating whales [24, 37]. Or, if the objects mimic the TS of a species that odontocetes avoid depredating, then the object may effectively deter depredation behavior [37], such as sharks, which lack swimbladders and have a low TS relative to teleosts. For species with swimbladders, the swimbladder accounts for most (>90%) of fishes' acoustic backscatter [71, 72]. Similarly, hollow alloy spheres attached near terminal tackle have been proposed to reduce odontocete-longline depredation where the object might cause odontocetes to perceive the prey as unusual or the sphere might interfere with their echolocation [73]. This expanded evidence of the species-selective depredation strategies of odontocetes that are exposed to fisheries bycatch promises to contribute to mitigating this human-wildlife conflict.

Acknowledgments

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