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Pingers Reduce Small Cetacean Bycatch in a Peruvian Small-Scale Driftnet Fishery, but Humpback Whale (*Megaptera novaeangliae*) Interactions Abound

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Abstract

Fishery interactions pose the most significant direct anthropogenic threat to marine mammals. In this study, we tested the effectiveness of acoustic alarms at reducing the bycatch of cetaceans by small-scale gillnet vessels operating from the northern Peru port of Mancora. We equipped nets with 10 kHz pingers for vessels targeting sharks, tuna, dolphinfish, and rays. We monitored a total of 313 sets in 60 trips. We found that small cetacean bycatch per unit effort (BPUE) was reduced by 83% in experimental nets compared to control nets, with no observed reduction in whale BPUE. The study also found that pingers did not negatively affect catch rates of target species such as rays and bony fishes. However, sets with pingers had a reduction in shark catch per unit effort (CPUE) of 32.9%. Given the high number of humpback whale (*Megaptera novaeangliae*) entanglements we observed, we recommend testing of lower frequency "whale" pingers. We also encourage larger scale implementation of pingers for small cetaceans given the potential shown here to reduce gillnet bycatch mortality by thousands of animals annually.

Key Words: acoustic deterrent, dolphins, marine mammal, conservation, artisanal

Introduction

Incidental catch, or bycatch, refers to unwanted, unmanaged, or discarded catch (Davies et al., 2009) during fishing operations. Bycatch is one of the largest and most common threats for marine mammals, affecting at least 112 species and estimated to kill 650,000 individuals annually (Read et al., 2006; Ávila et al., 2018). Particularly for species like marine mammals that have delayed sexual maturity and low reproductive rates, bycatch mortality can lead to rapid population declines when bycatch rates exceed population growth (Read, 2008). Gillnet fisheries, in particular, are considered the main cause of mortality for cetaceans (Alava et al., 2012; Reeves et al., 2013). These synthetic gillnets are difficult for cetaceans to detect and are often set overnight, causing dolphins and whales to become entangled and drown. They are also highly abundant off the coast of Peru, with an annual total length of 100,000 km (Alfaro-Shigueto et al., 2010).

Reports of fishery interactions, bycatch, or direct captures of cetaceans in Peru date back to at least the 1960s (Clarke, 1962) when the use of dolphins as wild meat was recorded for the first time. Since then, more systematic studies have calculated that annual small cetacean (i.e., dusky dolphin [*Lagenorhynchus obscurus*], bottlenose dolphin [*Tursiops truncatus*], common dolphin [*Delphinus* spp.], and Burmeister's porpoise [*Phocoena spinipinnis*]) landings by gillnet fisheries reached up to 15,000 to 20,000 individuals annually from 1990 to 1994 (Van Waerebeek & Reyes, 1994). Mangel et al. (2010), based upon onboard observations of bycatch, suggested that this level of captures continued despite a ban on the fishing and commerce of marine mammals established in 1996 (Law No. 26585). These captures are used as wild meat or as bait in shark fisheries, or they are discarded (Mangel et al., 2010; Campbell et al., 2020).

Bycatch of large cetaceans in Peruvian fisheries is not as well documented; however, observations of strandings along the northern Peru coast have revealed entanglements of humpback whales in fishing nets (Campbell et al., 2017; Chauca et al., 2021). García-Godos et al. (2013) found that gillnets in Peru were responsible for 80% of the entanglements of large cetaceans found in their study.

The Southeast Pacific humpback whale (*Megaptera novaeangliae*) stock inhabits the northern coast of Peru seasonally from July to November (Pacheco et al., 2009; García-Godos et al., 2013; Guidino et al., 2014). During migration, humpback whales tend to travel along the continental shelf where there is a greater threat for entanglements as their migratory routes overlap with Peruvian small-scale fishery operations (SSF) (Félix & Botero-Acosta, 2011; Félix & Guzmán, 2014; Guidino et al., 2014; Acevedo et al., 2017). As the Southern Hemisphere humpback whale population is increasing and continues to congregate in breeding grounds (Clapham & Zerbini, 2015; Pacheco et al., 2021), it will increasingly come into conflict with the also growing small-scale fishing fleets along the coast of Peru (De la Puente et al., 2020).

Acoustic alarms, also referred to as pingers, are a bycatch reduction technology used to deter small cetaceans from fishing nets (Omeyer et al., 2020). Pingers emit intermittent sounds of low intensity, usually at frequencies between 10 and 140 kHz. They can be installed in fishing nets to reduce the probability of entanglement (Dawson et al., 2013). Studies have shown that pingers can reduce bycatch of small cetaceans in different types of fisheries (e.g., Bordino et al., 2002; Barlow & Cameron, 2003; Carretta et al., 2008; Carretta & Barlow, 2011; Omeyer et al., 2020). In Peru, 10 to 12 kHz pingers were tested in Salaverry port by Mangel et al. (2013) where they were shown to reduce small cetacean bycatch in a small-scale s(hark gillnet fishery by 37% with no significant effect on the composition and amount of the fishery's target catch. Similarly, these were recommended as a possible solution for the high rates of interactions in Ecuadorian small-scale fisheries (Alava et al., 2019).

The hearing range of humpback whales and other baleen whale species differs from that of dolphins (Helweg et al., 2000), therefore trials to reduce whale bycatch have been done using acoustic alarms with a lower frequency (3 kHz; Harcourt et al., 2014; How et al., 2015; Basran et al., 2020), usually called *whale pingers*. There are, however, contrasting results on the effect of whale pingers on humpback whales. For example, Lien et al. (1992) found a change in humpback behaviour when whale pingers were used, and Basran et al. (2020) found that pingers could be a useful entanglement mitigation tool as they reduced feeding around nets. On the other hand, Harcourt et al. (2014) concluded that pingers with lower frequencies were unlikely to effectively deter humpback whales from approaching potential hazards. Pirotta et al. (2016) installed a fixed mooring device projecting whale alarm sounds of 2 to 2.1 kHz and 5.3 kHz and found no detectable surface response or change of swimming direction of humpback whales to pingers.

Given the impact of the small-scale Peruvian fishery on both small and large cetaceans, it is essential to find a solution able to mitigate bycatch of both taxa. Building upon the success of previous pinger trials with small cetaceans, this study aimed to expand 8 to 12 kHz pinger trials to the fleet operating from Mancora in northern Peru. Furthermore, given the expected severity of the impact of the Mancora fishery on the humpback whale population, our study monitored small cetacean bycatch and humpback whale entanglements for the first time to explore the possibility of using 8 to 12 kHz pingers as a multi-taxa bycatch reduction technology. More specifically, our study investigated the effect of pingers on bycatch of (1) small cetaceans, (2) large cetaceans, and (3) the target catch of the Mancora small-scale gillnet fishery.

Methods

The Fishery

The study area was located along the coast of Mancora (04° 05' S, 81° 04' W), northern Peru. The port of Mancora is located at the convergence of the Northern Humboldt Current System (NHCS) and the Pacific Equatorial System (PES), which generates high biodiversity, as well as high fishing productivity (Strub et al., 1998; Chavez et al., 2008). Mancora was chosen for this study because it has an active gillnet fishery with known bycatch of small cetaceans and humpback whales given its location at the southern limit of the winter breeding grounds (Pacheco et al., 2009, 2021; García-Godos et al., 2013; Guidino et al., 2014).

The study was conducted between September 2018 and January 2020 using three small-scale vessels that departed from the port of Mancora. This period encompasses the dry and wet seasons of 2019 as well as the humpback whale migratory and breeding seasons (June to November 2019). The vessels in this fishery set multifilament nets that are composed of multiple net panes that measure ~66 m in length by 11 m in height, with a stretched mesh of ~18 cm. These are surface driftnets that are deployed in the late afternoon, soaked overnight, and retrieved the following morning. The primary target catch in this fishery is elasmobranchs, including smooth hammerhead sharks (*Sphyrna zygaena*), thresher sharks (*Alopias vulpinus*), blue sharks (*Prionace glauca*), and rays (*Mobula* sp.). However, this fishery also catches other species, including dolphinfish (*Coryphaena hippurus*) and tuna (*Thunnus* spp.).

Experimental Design

Gillnet vessels were equipped with "Netguard" Porpoise & Dolphin Pingers (Future Oceans, Queensland, Australia). They have a modulating frequency of 8 to 12 kHz and a sound pressure level of 132 dB re 1 µPa at 1 m with emission presented every 4 seconds. These pingers incorporate a saltwater sensor which activates the pinger upon placement in the water. Pingers were placed every 100 m along the float line of the net in experimental sets. Net length was different in each set, thus the number of pingers used per vessel varied (min.: 10; max.: 25). Vessels alternated in a consecutive manner between control and experimental sets throughout the course of a fishing trip whenever possible.

Data Collection

Over the 16 months of the study, we observed 124 control sets over 44 trips and 189 experimental sets over 56 trips for a total of 313 sets in 60 trips (six trips were control sets only, while 16 trips were experimental sets only). The total fishing effort of the study was 202.85 (km*day) for control trips and 327.36 (km*day) for experimental trips, and mean fishing effort was 1.64 (km*day) for control sets and 1.73 (km*day) for experimental sets.

Onboard observers monitored all control and experimental sets. Observers were trained in the deployment of pingers, species identification, and data collection. Data recorded included gear characteristics (e.g., net size and the number of panes) and information for each set (e.g., date, GPS location, time of set, and haul). Observers monitored whether entangled cetaceans were alive or dead in the gillnet and, if possible, identified the species of bycaught individuals. Observers also recorded target catch quantities and species. Bycaught cetaceans were rarely hauled onboard the vessels and, thus, identification was mainly possible only to the family level.

Data Analysis

We first computed the fishing effort of each fishing set, calculated as (net length/ 1,000 m)*(soak time/24 h). We then computed catch and bycatch per unit effort (CPUE and BPUE, respectively) as the number of individuals captured in a set divided by the fishing effort of the set. Because our data distribution was skewed and sample sizes were unequal, we compared cetacean bycatch per unit effort between the control and experimental sets using a Wilcoxon rank-sum test for dolphins and whales separately (Mann & Whitney, 1947). The same analysis was carried out separately for three target species groups to account for differences in target species catches: sharks (Selachimorpha), rays (Batoidea), and bony fish (Osteichthyes). The 'wilcox.test' function in the 'stats' package was used to run the tests. We excluded 31 sets for sharks and rays and 37 sets for bony fish due to a lack of detailed catch data. Therefore, the number of sets considered for the analysis of target catch was smaller than the sets considered for the bycatch analysis. Statistical analysis was run in the statistical modelling programme *R*, Version 4.0.2 (R Core Team, 2019).

Results

Bycatch

A total of 30 cetaceans were caught, with 7.3% of fishing sets having cetacean interactions. Eight humpback whales were bycaught in control sets and eight in experimental sets, as well as five long-beaked common dolphins (*Delphinus delphis bairdii*: four in control sets and one in experimental sets) and one short-finned pilot whale (*Globicephala macrorhynchus*) that was released alive from an experimental net (Figure 1; Table 1). The remaining eight unidentified dolphins were caught during control sets.

All humpback whales, except for one, were observed entangled and were released. Fishers would cut parts of the net to let the animals pass through. In one case only, an observer found a hole in the net and presumed it was caused by a whale interaction. This event was excluded from the analysis as we were not able to identify the animal.

The Wilcoxon sum-rank test showed that dolphin BPUE was significantly different ($p < 0.05$) between control sets (0.06 ± 0.03 km.day^{-1}) and experimental sets (0.01 ± 0.004 km.day^{-1}), with an 83.3% reduction in BPUE when pingers were used (Table 2). According to the results of the Wilcoxon sum-rank test, humpback whale BPUE was not significantly different ($p = 0.38$) between control sets (0.05 ± 0.02 km.day^{-1}) and experimental sets (0.03 ± 0.01 km.day^{-1}; Table 2; Figure 2).

Target Catch

The total target catch consisted of 5,602 bony fishes, 3,606 sharks, and 267 rays. We identified 17 bony fish species, eight shark species, and three ray species, while 25 ray specimens could not be identified to species level (Supplemental Table 1; this supplemental table is available in the "Supplemental Material" section of the *Aquatic Mammals* website: https://www.aquaticmammalsjournal.org/index.php?option=com_content&view=article&id=10&Itemid=147).

The Wilcoxon sum-rank test showed that bony fish CPUE did not differ significantly ($p = 0.46$) between control sets (10.99 ± 2.08 km.day^{-1}) and experimental sets (24.01 ± 8.62 km.day^{-1}). Likewise, the test showed no significant difference in ray CPUE ($p = 0.33$) between control sets (0.71 ± 0.22 km.day^{-1}) and experimental sets (1.08

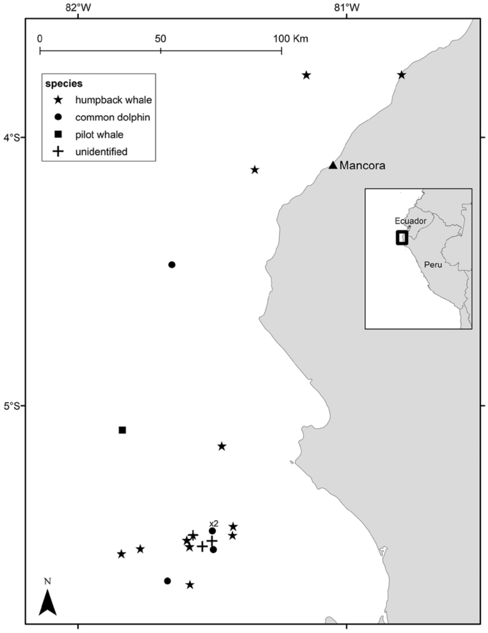

Figure 1. Locations of marine mammal bycatch events. "x^2" indicates two bycatch events with the same location (one of humpback whales [*Megaptera novaeangliae*] and the other of common dolphins [*Delphinus delphis*]). Other positions could not be reported.

Table 1. The number of cetaceans observed captured in control (no pinger) and experimental (pinger) sets

	Treatment	
Species	Control	Experimental
Long-beaked common dolphin	4	1
Short-finned pilot whale	0	1
Humpback whale	8	8
Unidentified dolphin	8	0
Total	20	10

± 0.29 km.day^{-1}). However, the test showed a statistically significant 32.9% decline ($p < 0.01$) in shark CPUE in experimental sets (8.91 ± 1.46 km. day^{-1}) compared to control sets (13.27 ± 1.81 km. day^{-1}) (Figure 3).

Discussion

Cetacean bycatch rates by small-scale net fisheries in Peru are some of the highest reported globally, affecting small cetaceans and large whales (Read et al., 2006). Herein, we report an encouraging 83.3% reduction in the small cetacean bycatch rate when pingers were used; this bycatch was of common dolphins and pilot whales (*Globicephala* sp.). This finding is similar to Van Waerebeek & Reyes (1994) who, through interviews with gillnet fishers in Mancora, reported bycatch of mainly common dolphins and pilot whales but also of Burmeister's porpoises. Our pinger results differ somewhat from Mangel et al. (2013) who reported a 37% decrease in small cetacean bycatch using pingers from the central Peru port of Salaverry. In that study, pingers were spaced every 200 m; while in our study, we used a 100 m spacing. This tighter spacing may have yielded a higher reduction in observed bycatch. This effect was shown by Kindt-Larsen et al. (2018) who found a significant pinger affect with less distance between pingers with porpoises (*Phocoena phocoena*). Our results are more in line with studies showing 50 to 90% reductions in bycatch rates such as Kraus et al. (1997) who tested acoustic alarms with porpoises on the coasts of New Hampshire and southern Maine, Bordino et al. (2002) who tested acoustic alarms with Franciscana dolphin (*Pontoporia blainvillei*) in Argentina, Barlow & Cameron (2003) who tested acoustic alarms for short-beaked common dolphins in California, and Carretta et al. (2008) who reported no entanglements of beaked whales (i.e., Baird's beaked whale [*Berardius bairdii*], Hubbs' beaked whale [*Mesoplodon carlhubbsi*], Stejneger's beaked

Table 2. Mean and sum of total fishing effort (km*day) for control and experimental sets. Observed mean bycatch per unit effort (BPUE; individuals/fishing effort [km*day]) by treatment for dolphins and whales and catch per unit effort (CPUE) of bony fishes, sharks, and rays. A negative value for % change indicates a reduction of BPUE/CPUE in experimental sets compared to control sets. * indicates that Wilcoxon test *p* value was < 0.05.

					BPUE (*n*/(km*day])		CPUE (*n*/(km*day])		
Treatment	Trips	Sets	Mean effort (km*day)	Total effort (km*day)	Dolphins	Whales	Bony fish	Sharks	Rays
Control	44	124	1.64	202.85	0.06 ± 0.03	0.05 ± 0.02	10.99 ± 2.08	13.27 ± 1.81	0.71 ± 0.22
Experiment	56	189	1.73	327.36	0.01 ± 0.004	0.03 ± 0.01	24.01 ± 8.62	8.91 ± 1.46	1.08 ± 0.29
				% change:	-83.3*	-40.0.0	+118.5	-32.9*	+52.1

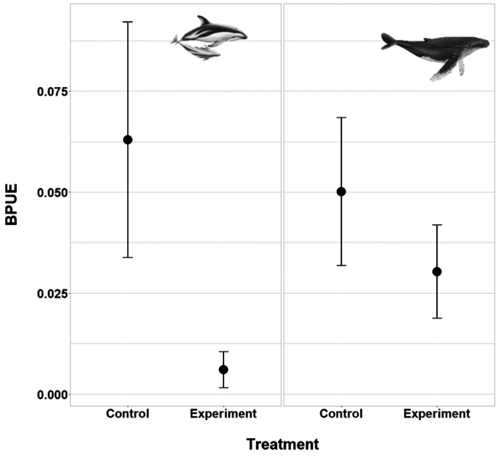

Figure 2. Observed mean BPUE (km.day^{-1}) for dolphins (left) and whales (right) in control and experimental sets. Error bars show standard errors.

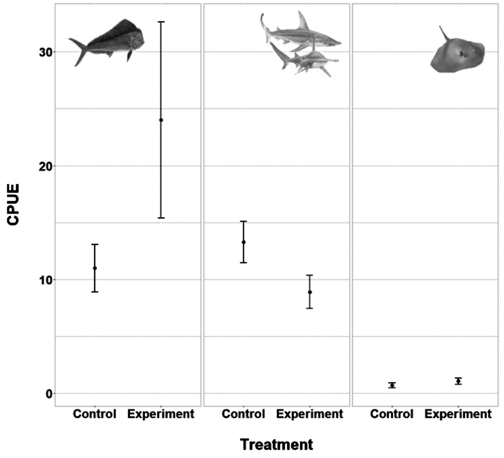

Figure 3. Observed mean CPUE (km.day^{-1}) for bony fish (left), sharks (center), and rays (right) in control and experimental sets. Error bars show standard errors.

whales [*Mesoplodon stejnegeri*], and Cuvier's beaked whale [*Ziphius cavirostris*]) while using pingers in the California current.

We also found that the use of pingers did not negatively affect catch rates of the target catch of rays and bony fishes. Experimental nets had higher CPUEs of rays and bony fishes compared to control nets, but the increases were not statistically significant. We did, however, observe a 32.9% decline in shark CPUE. This may indicate shark avoidance of the ensonified net (Chapuis et al., 2019). On the other hand, Mangel et al. (2013) found that using pingers did not alter the target catch rates of sharks and rays, a result similar to other pinger trials (e.g., Kraus et al., 1997; Bordino et al., 2002; Gönener & Bilgin, 2009; Zaharieva et al., 2019), or trials where sets with pingers had increased target catch (Buscaino et al., 2009). Given the decline we observed, we recommend that further analyses seek to better understand this decline in shark catch rates when pingers are used, particularly given the potential impact on the willingness of fishers to use them.

With 16 observed entanglement events, humpback whales were the most frequently caught mammal species in our study. García-Godos et al. (2013) reported ten strandings of humpback whales that were attributed to having been caught in gillnets along the coast of Peru, but this was over a 17-year period from 1995 to 2012. Our study summarizes results from three fishing vessels operating over 16 months. With the 5.07% annual growth of the Breeding Stock G humpback whale population (Félix et al., 2021) and the massive small-scale net fishing fleet operating in northern Peru—an estimated 6,700 SSF vessels operating in the regions of Piura and Tumbes (Guevara-Carrasco & Bertrand, 2017; Castillo Medonza et al., 2018)—the actual rates of whale and small cetacean bycatch and entanglement occurring in this area are likely to be huge.

Unfortunately, despite a relatively high interaction rate with whales as bycatch, the use of pingers in our study was found to be ineffective at reducing bycatch of humpback whales, excluding the possibility of using 8 to 12 kHz pingers as a multi-taxa bycatch reduction technology. The 8 to 12 kHz pingers used in the experiment are indeed designed more specifically for small cetaceans as humpback whales have been estimated to have a maximum hearing sensibility as low as 2 to 6 kHz (Houser et al., 2001). Although responses of baleen whales to pingers are poorly understood (Basran et al., 2020), studies have shown no effect from pingers or concluded that further research is needed to demonstrate their effectiveness with whales (Erbe & McPherson, 2012; Harcourt et al., 2014; Pirotta et al., 2016).

The high rate of humpback whale interactions we observed is alarming not only in terms of its implications for cetacean conservation, but also for the safety and economic consequences for fishers (Buscaino et al., 2009; Alfaro-Shigueto et al., 2010). Northern Peru is part of the breeding area for the Southeast Pacific stock of humpback whales, so they are common in this area from July to November (Guidino et al., 2014; Pacheco et al., 2021). Given the ongoing recovery of the Southern Hemisphere humpback whale population (Clapham & Zerbini, 2015), whale entanglements in northern Peru will likely increase in the coming years. Whale entanglements that cause net damage can result in considerable financial losses for fishers who are already financially vulnerable and whose economic status is likely to worsen (De la Puente et al., 2020). Fishers in Mancora pay ~500 USD per net pane, which means that losing their entire net would represent a loss of ~15,000 to 20,000 USD depending on the number of panes they use (C. Belupu, pers. comm., 23 October 2019). They also spend time disentangling and discarding unwanted catch and then repairing the net on their return to port. To reduce net loss and damage, some fishers also take life-threatening risks while at sea by attempting to disentangle whales from their nets (e.g., climbing onto the whales or diving underwater to cut away net).

As previously mentioned, gillnets have the highest bycatch rates for small cetaceans (Reeves et al., 2013; Brownell et al., 2019; Campbell et al., 2020), and are ubiquitous and increasing in Peru's small-scale fisheries, despite the existence of Law No. 26585 (9 April 1996) that prohibits the capture, use, consumption, and trade of dolphins and porpoises (Mangel et al., 2010, 2013; Campbell et al., 2020). If pingers were found to be similarly effective throughout Peru's small-scale gillnet fleet, their widespread use could potentially translate into thousands of dolphins saved annually. There are some examples of more widespread use of pingers in fisheries that have been largely successful in reducing small cetacean bycatch (Barlow & Cameron, 2003; Dawson et al., 2013; Kyhn et al., 2015). In the California/Oregon swordfish drift gillnet fishery, the use of pingers and a reduction in the depth at which nets are set have been particularly effective in reducing bycatch of different species, including humpback, pilot, and beaked whales (Geijer & Read, 2013).

Pingers cost ~70 USD each and require regular battery replacement (Tulloch et al., 2020), making them a prohibitively expensive bycatch reduction method in developing countries like Peru. However, given the high rate of whale interactions we observed and the high potential costs to fishers resulting from these interactions, trials of whale pingers are recommended and may find support among fishers. Other potential solutions to whale entanglements could also be explored such as alternative fishing gears (e.g., longlines) that can replace gillnets without jeopardizing the lives of fishers, alternative livelihoods during the humpback whale breeding season, fishers taking time off during the breeding season for vessel and gear maintenance, spatial or temporal fishery closures, training of fishers in large cetacean disentanglement techniques, sinking ground lines of gillnets, and close cooperation among scientists, managers, and fishers to develop practical solutions and regulations (Hall et al., 2000; Grantham et al., 2008; Moore, 2019). The growth of whale watch tourism in northern Peru is promising and a particularly relevant example for fishers as an economic alternative during the breeding season of humpback whales (Guidino et al., 2020).

The 2016 enactment of the Fish and Fish Products Import Provisions of the U.S. Marine Mammal Protection Act (MMPA) also provides renewed impetus to reduce marine mammal bycatch in Peru's small-scale fisheries. These changes oblige countries that export fish products to the United States to have similar standards of protection to prevent marine mammal injury or mortality as are required of its domestic fisheries (Roman et al., 2013; Williams et al., 2016). This includes Peru's small-scale net fisheries whose target catch includes tuna and dolphinfish which are exported to the U.S. (OCEANA, 2020). But still, marine mammal bycatch in Peru remains under-regulated and under-reported, and its monitoring is under-funded (Van Waerebeek et al., 1997; Mangel et al., 2010; Bielli et al., 2020; Campbell et al., 2020). However, during our study, fishers showed an interest in reducing their bycatch and in participating in mitigation trials. We believe there are opportunities to advance marine mammal conservation in Peru's small-scale fisheries given this enthusiasm through a wider-scale implementation of pingers. Given the high bycatch of humpback whales in northern Peru, we recommend testing of lower frequency whale pingers along with the exploration of other potential conservation solutions. The regulatory landscape and the likelihood of increasing bycatch in future years may demand it.

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