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# Marine megafauna interactions with the Peruvian artisanal purse-seine fleet

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ABSTRACT

Bycatch is a global problem for marine megafauna. Peru is a major fishing nation known in particular for its industrial purse-seine fishery for the Peruvian anchovy (*Engraulis ringens*). However, Peru also has an artisanal purse-seine fishery for this same resource and other species such as Pacific bonito (*Sarda chiliensis),* Pacific chub mackerel (*Scomber japonicus*) and Chilean jack mackerel (*Trachurus murphyi*) used for human consumption. While there is limited documentation of bycatch of megafauna by the industrial purse-seine fishery, there is no similar information for the artisanal purse-seine fishery. Therefore, this study aimed to assess the marine megafauna (small-cetaceans, seabirds, sea turtles, and elasmobranchs) bycatch interactions of the Peruvian artisanal purse-seine fishery for consumption for the year 2019 (before the COVID-19 pandemic) through interviews with artisanal fishers in 5 landing ports (San Jose, Santa Rosa, Callao, Pucusana, and San Andres). We found that these fisheries had bycatch with all taxa groups, with dusky dolphins (*Lagenorhynchus obscurus*), guanay cormorants (*Leucocarbo bougainvilliorum*) and eagle rays (*Myliobatis* spp.) having the highest quantity and most frequently reported bycatch. Multiple correspondence analysis (MCA) indicated an association between the bycatch of 1–3 common dolphins (*Delphinus* spp.) per set from the northern ports (San Jose and Santa Rosa) and vessels of 20–36 MT. Likewise, a relationship was found between smooth hammerhead sharks (*Sphyrna zygaena*) and vessel storage capacity, with a similar result reported for the bycatch of humpback smoothhounds (*Mustelus whitneyi*). In addition, a relationship of eagle ray (*Myliobatis* spp.) bycatch with a landing port was identified, and several respondents mentioned catching more than 1 MT per set. Fifty-three percent of fishers considered bycatch to be a problem, mainly because it wastes their time during fishing operations. This preliminary study is the first research that demonstrates bycatch in artisanal purse-seine in Peru and can serve as a baseline for future research. We also highlight the need to quantify bycatch rates of marine megafauna using additional methodologies, such as monitoring with onboard observers.

## 1. Introduction

Fishing is a fundamental activity contributing to the sustainable development of many countries by generating employment and providing a source of food (FAO, 2021, 2022). However, as the catch of target species intensifies, non-target species of little or no commercial importance are also caught incidentally in events known as “bycatch” (Lewison et al., 2004; National Marine Fisheries Service, 2011; Zimmerhackel et al., 2015). Bycatch is a global problem, putting at risk food security through the catch of non-target species, represents a waste of protein when discarded (Telesetsky, 2017), and threatens long-lived marine megafauna populations (e.g. mammals, birds, turtles, elasmobranchs) (Alfaro-Shigueto et al., 2018; Anderson et al., 2011; Komoroske and Lewison, 2015; Lewison et al., 2004, 2014). Losses of megafauna can lead to ecosystem degradation by altering trophic interactions (Keledjian et al., 2014), causing altered top-down regimes, facilitating the emergence of invasive species, and affecting nutrient cycling (Estes et al., 2011). Coastal and small-scale fisheries pose a

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particular challenge in terms of marine fauna bycatch given their high interaction rates and the general lack of information available about these fisheries (Lewison et al., 2014).

Peru is one of the most important countries in terms of global fisheries, with landings deriving mainly from the industrial purse-seine fishery for Peruvian anchovy (*Engraulis ringens*) for fish meal and fish oil (FAO, 2018). However, it is the artisanal fishery that is the main supplier of marine products to local markets (Christensen et al., 2014). According to national regulations, artisanal (or small-scale) fisheries are defined as vessels with storage capacity up to 32.6 $m^3$, total length up to 15 m and predominantly using manual labor (Decreto Ley Nº 25977, El Peruano, 2001). Artisanal fishers employ a variety of fishing gears including handlines, gillnets, longlines, and purse-seine nets, among others (Guevara-Carrasco and Bertrand, 2017). Purse-seines are among the five most used artisanal fishing gears in the country (Castillo et al., 2018; Guevara-Carrasco and Bertrand, 2017). Within the artisanal purse-seine fishery, there are two variants: the "anchovy purse-seine" (small-scale fleets) that targets mainly Peruvian anchovy for human consumption and the "consumption purse-seine" (artisanal fleets) that targets species such as Chilean jack mackerel (*Trachurus murphyi*), Pacific mackerel (*Scomber japonicus)*, cabinza grunt (*Isacia conceptionis)*, lorna drum (*Sciaena deliciosa)*, etc. (Castillo et al., 2018; Guevara-Carrasco and Bertrand, 2017).

Despite the wide variety of fishing gears employed by the artisanal fishery in the country, bycatch information of marine megafauna remains scarce, with information available mainly for gillnet fisheries (Alfaro-Shigueto et al., 2010, 2018; Bielli et al., 2020; Mangel et al., 2013, 2018; Ortiz et al., 2016; Pajuelo et al., 2018; Pingo et al., 2017) and longlines (Alfaro-Shigueto et al., 2011; Ayala et al., 2018; Ayala and Sanchez-Scaglioni, 2014). In the case of the purse-seine fishery, bycatch has been assessed exclusively for the industrial fleet since 1996 through the onboard observer program "Programa Bitacoras de Pesca (PBP) of the Instituto del Mar del Peru (IMARPE)", which primarily monitors the bycatch of the target species (i.e., undersized or juvenile Peruvian anchovy individuals). As of 2008, marine megafauna bycatch monitoring efforts increased by the Peruvian anchovy industrial purse-seine fishery through private initiatives such as the program "Cuidamar" led by Tecnologica de Alimentos S.A. and later on the "Salvamar" program led by the Sociedad Nacional de Pesqueria (SNP). However, bycatch interactions have also been reported for the artisanal purse-seine fleet due to its low selectivity (De la Puente et al., 2020; Sociedad Peruana de Derecho Ambiental, 2022). Nonetheless, to date, there are no initiatives to systematically monitor bycatch in artisanal purse-seine fisheries.

Using rapid assessment surveys, this study sought to evaluate the interaction between the artisanal purse-seine fishery for consumption (APFC) and megafauna, focusing on small-cetaceans, seabirds, sea turtles and elasmobranchs. This methodology has been used worldwide to assess bycatch in different fisheries (Alfaro-Shigueto et al., 2018; Ayala et al., 2018; Moore et al., 2010; Ortiz-Alvarez et al., 2020) and has been shown to be a cost-effective methodology for assessing bycatch

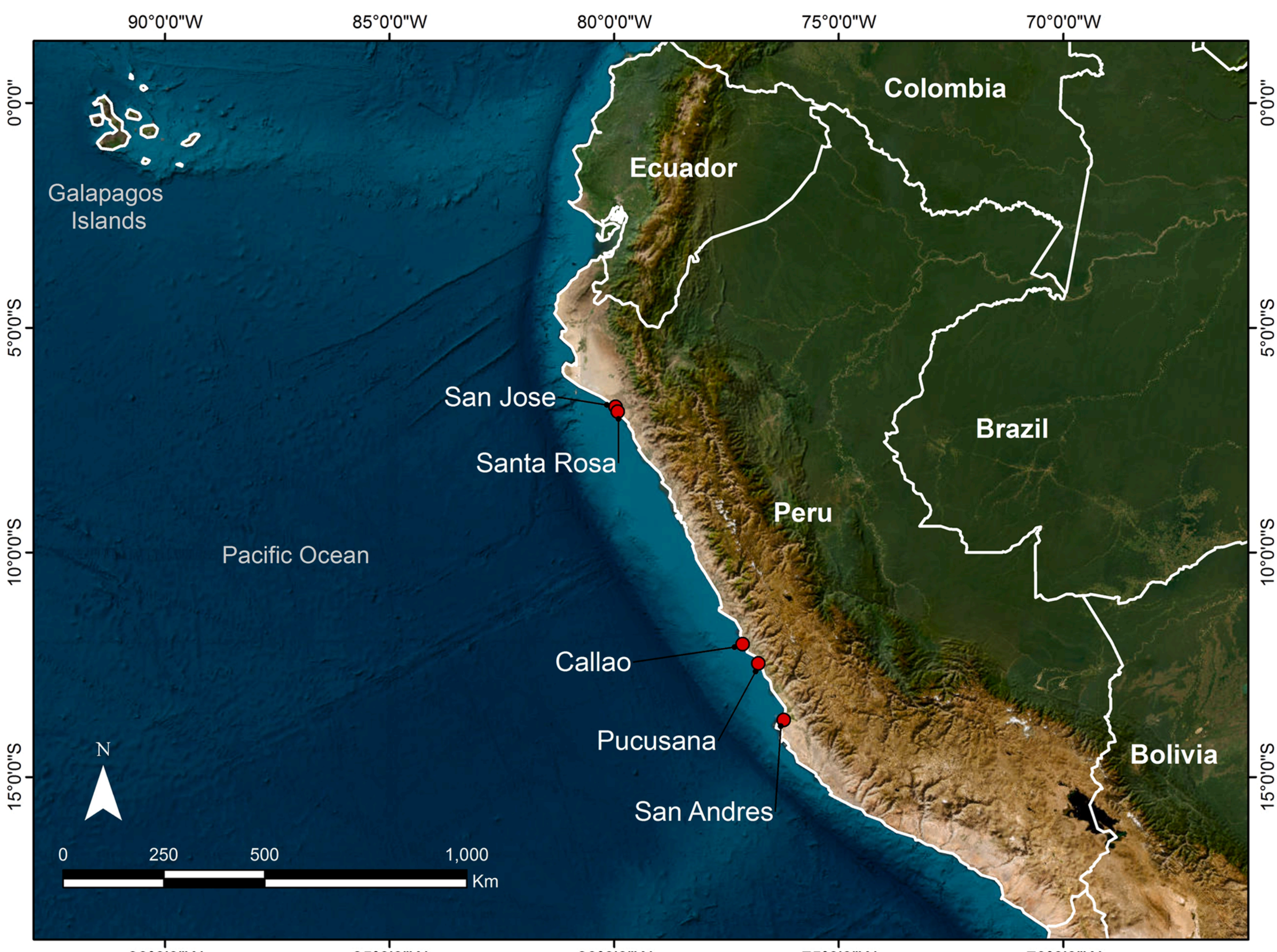


**Fig. 1.** Map of five sampled landing sites, regions in brackets. From north to south: San Jose and Santa Rosa (Lambayeque), Callao (Callao), Pucusana (Lima) and San Andres (Ica).

interactions compared to onboard monitoring programs, allowing for coverage of a wide geographic area, taking into account the local knowledge of fishers, and integrating them into conservation initiatives (Alexandre et al., 2022; Alfaro-Shigueto et al., 2018; Liu et al., 2017).

## 2. Materials and methods

### 2.1. Study area

Interviews to APFC fishers were conducted between January and April 2021 in five ports or landing sites along the Peruvian coast that are among those locations with the largest artisanal purse-seine fleet for consumption (Castillo et al., 2018): San Jose, Santa Rosa, Callao, Pucusana and San Andres (Fig. 1). We note that due to the COVID-19 pandemic, the fishing ports were inactive during the first months of 2020 and gradually returned to normal activity.

### 2.2. Data collection

The interviews were conducted individually and lasted approximately 30 min. Ten percent (10%) of APFC vessels were interviewed per landing site. We note that during 2020 most fishing ports were closed and many fishers stopped fishing (Aroni, 2020; D.U. N°026-2020, 2020), therefore, we focused on collecting information on megafauna bycatch during 2019. At the same time, the Peruvian government put in place regulations such as the circulation at certain times according to the levels of contagion in different areas of the country (D.S N°002-2021-PCM, 2021). Taken together, these factors limited the availability of fishers to participate in the study. Likewise, the number of interviews was established based on the official report ENEPA III conducted by IMARPE in 2015 (Castillo et al., 2018). Before beginning each interview, all fishers were informed of the anonymity and voluntary nature of the interview.

The survey methodology was based on a structured questionnaire of 24 questions, divided into 3 sections: (1) background information, which included characteristics of the fishing activity, fishing gear and fishing vessel, (2) bycatch of marine megafauna, including seabirds, small cetaceans (dolphins and porpoises), seabirds, sea turtles and elasmobranchs (sharks and batoids), condition of the individuals upon capture and post-capture use, and (3) fisher perceptions about the impacts of bycatch. Photos for species identification were also used to enable interviewees to more accurately identify the species with which the fishery interacts.

Information about the characteristics of the artisanal purse-seine fishing fleet included questions on storage capacity, target species, mesh size, fishing season, fishing area and the number of sets per trip. To explore which taxonomic groups of marine megafauna interact with the APFC, the frequency of interaction of dolphins, whales, sea lions, seabirds, sea turtles, sharks and batoids was determined. The options were as follows: very frequent (1), moderately frequent (2), infrequent (3) and no interaction (4). To determine the fate of bycatch species, the following options were given: (A) consumption, (B) sale, (C) released alive/discarded dead, (D) consumption and sale, and (E) released alive/discarded dead and consumption. Fishers were also asked if they consider bycatch to be a problem, for those fishers who answered yes, the following options were given: (A) destruction of fishing nets, (B) loss of time, (C) economic loss, and (D) damage to fish.

### 2.3. Data analysis

#### 2.3.1. Descriptive analysis

Descriptive analyses were conducted to evaluate the frequency of interactions between marine megafauna and APFC, to determine the fate of bycatch species, and to understand fisher perceptions of marine megafauna bycatch. All descriptive graphs were made in Sigma Plot (version 12.0).

#### 2.3.2. Variables description

Marine megafauna overarching taxonomic groups, except sea turtles, were subdivided into two subcategories. Small-cetaceans were subdivided into dolphins and porpoises, seabirds into coastal and oceanic assemblages, and elasmobranchs, into sharks and batoids. Bycatch ranges (i.e. the typical number of animals reported caught per set when bycatch occurs), were established for each species, based on the responses of the fishers. These quantities were grouped into catch ranges (Table 1).

Fishing variables considered were selected based upon Alexandre et al. (2022), who identified a relationship between bycatch, fishing gear (including purse-seine), fishing area and vessel size (related to storage capacity). In turn, the mesh size of the net was taken into account, since interactions with certain groups have been previously reported as a function of this variable. Although we did not observe large differences in mesh size in the nets evaluated, this variable was still included in the analysis. For example, in 6–10 in. nets there was bycatch of small-cetaceans (Mangel et al., 2013; Torres and Sarmiento, 2021) and sea turtles in 4–18 in. nets (Bielli et al., 2020; Darquea et al., 2020). Ports surveyed were grouped into 3 categories based on their latitude: lp1 (San Jose and Santa Rosa, northern ports), lp2 (Callao and Pucusana, central ports), and lp3 (San Andres, southern port) (Table 1). Latitude was taken into account, since in other studies such as from Llapapasca et al. (2018) mentions that common dolphins (*Delphinus delphis*) and dusky dolphins (*Lagenorhynchus obscurus*) have potential habitat overlaps with their prey, including squid, mackerel and Peruvian anchovy, where the latter are found mainly in the north-central zone and have sea temperature preferences (Bouchon et al., 2019). Season variable was separated into 'warm season', 'cold season', 'both seasons' and 'no season'. These were considered only for cetaceans, since studies such as Mangel et al. (2010), Fernández-Contreras et al., (2010) and Liu et al., (2017) show a relationship between the incidental capture of cetaceans and this variable.

**Table 1**
Variables related to bycatch (number of individuals per set by species) and fishery-related variables were used for the MCA analysis.

| Bycatch variables | | | |
|---|---|---|---|
| Species | Catch range | | Group |
| *Lagenorhynchus obscurus, Delphinus* spp., *Tursiops truncatus* | 0, 1 a 3, 4 a 10, > 10 | | Dolphins |
| *Phocoena spinipinnis* | 0, 1 a 3 | | Porpoise |
| *Phoebastria irrorata, Procellaria aequinoctialis* | 0, 1 a 3, 4 a 10, > 10 | | Oceanic birds |
| *Pelecanus thagus, Sula variegata,Leucocarbo bougainvilliorum* | 0, 1 a 3, 4 a 10, > 10 | | Coastal birds |
| *Chelonia mydas, Lepidochelys olivacea, Caretta caretta, Eretmochelys imbricata* | 0, 1 a 3 | | Sea turtles |
| *Prionace glauca, Sphyrna zygaena, Mustelus whitneyi* | 0, 1 a 3, 4 a 10, > 10 | | Sharks |
| *Myliobatis* spp., *Mobula* spp. | 0, 1 a 3, 4 a 10, > 10, > 1 MT | | Batoids |
| Fishing variables | | | |
| Variable | Variable type | Symbol | Category |
| Storage (MT) | Active | s | 1 (<10), 2 (10–19), 3 (20–36) |
| Latitude of port | Active | lp | 1 ( San Jose, Santa Rosa), 2 (Callao, Pucusana), 3 (Pisco) |
| Mesh size (inch) | Active | ms | 1 (<1), 2 (1 ≤) |
| Season (only for cetaceans) | Supplementary | t | t_warm (warm), t_cold (cold), t_both (warm and cold), N/S (no season) |

#### 2.3.3. Multiple Correspondence Analysis (MCA)

We note that, given the limited number of interviews and the type of bycatch data (by ranges), Generalized Linear Model (GLM) and Generalized Additive Models (GAM) were not applied, as have been used in several other studies (e.g. Coelho et al., 2020; Mannocci et al., 2020; Yan Yuan et al., 2021; Shirk Philip et al., 2023) to predict marine fauna bycatch. In this case, we applied the MCA to visualize associations between marine megafauna bycatch ranges per set variables and purse-seine fishing activity variables (Table 1), with the objective of generating graphical representations that facilitate data interpretation.

All the variables mentioned were considered active variables, except for season, which is a supplementary variable. MCA analyses were performed using the "FactoMineR" package (Husson et al., 2020) of the R software version 4.1.2 (R Core Team, 2021). We note that the rationale of MCA starts from the existing asymmetry between multivariate data, since it is understood that such data among themselves are conditional (Hoffman and De Leeuw, 1992). However, a principal inertia value is first obtained which is expressed as a percentage of the total inertia, where the principal inertia is decomposed into components that provide numerical contributions. These are used to understand the visualization of points in space (Ayala and Sanchez-Scaglioni, 2014). Therefore, it is necessary that these points are related to the degree of contribution of each dimension (Hoffman and De Leeuw, 1992), since if the points of certain variables are close graphically, but do not contribute to a certain dimension, this relationship is not valid.

## 3. Results

### 3.1. Fleet characteristics

We interviewed 38 APFC fishers in 5 Peruvian fishing ports (Fig. 1). All respondents were male with a mean age of 43 ± 13 years (range 20–68 years). In all ports evaluated, 61% of the fishers used purse-seine nets throughout the year, while the remainder used them mainly during the austral summer months. The largest vessels (average storage: 22.8 ± 7 MT) were reported in the port of Santa Rosa, while the smallest were in San Andres (average storage: 10.6 ± 3.2 MT) (Table 2). The main target species reported by fishers were Eastern Pacific bonito (*Sarda chiliensis*) (93%), Pacific chub mackerel (*Scomber japonicus*) (73%) and Chilean jack mackerel (*Trachurus murphyi*) (55%). Other target species reported included flathead mullet (*Mugil cephalus)*, Peruvian weakfish (*Cynoscion analis*), Peruvian banded croaker (*Paralonchurus peruanus)*, lorna drum (*Sciaena deliciosa)*, cabinza grunt (*Isacia conceptionis)*, Choicy ruff (*Seriolella porosa)*, Pacific menhaden (*Ethmidium maculatum)*, dolphinfish (*Coryphaena hippurus*), Humboldt squid (*Dosidicus gigas)* and tuna (*Thunnus albacares*, *Thunnus obesus*, *Katsuwonus pelamis*). All fishers surveyed (100%) reported selling their catch fresh for human consumption.

**Table 2**
Fleet characteristics of artisanal purse-seine in five ports of Peru during 2019. Values are shown as "mean ± standard deviation (range)" or as range only, and "n" is the number of fishers surveyed.

| | San Jose | Santa Rosa | Callao | Pucusana | San Andres |
|---|---|---|---|---|---|
| Characteristics | n = 5 | n = 9 | n = 9 | n = 5 | n = 10 |
| Storage (MT) | 19.8 ± 5.5 (12–25) | 22.8 ± 7 (12–30) | 14 ± 4.5 (8–22) | 11.6 ± 3.2 (8–15) | 10.6 ± 3.2 (6–15) |
| Target species | SC, SJ, CA, PP | SC, SJ, TM, CA, MC, PP | SC, SJ, TM, SD, MC, CA, CH | SC, SJ, TM, IC, MC, SD, SP, EM | SC, SJ, TM, SP, DG, T |
| Mesh size (in) | 1.4 ± 0.3 (1–1.75) | 1.6 ± 0.4 (0.75–2) | 1.8 ± 0.9 (1.25–4) | 1.8 ± 0.3 (1.5–2) | 1.3 ± 0.3 (1–2) |
| # Fishing months/ year | 8.6 ± 4.7 (3–12) | 7.2 ± 4.6 (2–12) | All year | 6 ± 3.74 (3–12) | 9.2 ± 3.7 (3–12) |
| # Fishing trip/ months | 3–12 | 3 – 18 | 9–25 | 2–15 | 4–12 |
| # Sets/ trip | 1–10 | 1–6 | 1–8 | 1–10 | 1–10 |

Note. Abbreviation of target species indicates SC: S. chiliensis, SJ: S. japonicus, TM: T. murphyi, CA: C. analis, MC: M. cephalus, PP: P. peruanus, SD: S. deliciosa, CH: C. hippurus, IC: I. conceptionis, SP: S. porosa, EM: E. maculatum, DG: D. gigas, T: tuna.

### 3.2. Interactions with megafauna

Interactions with sea lions showed the highest frequency in the all 5 ports (Fig. 2); however, these were not included in the evaluation because there is a tense and complex relationship between these sea lions and fishers. Therefore, to avoid biasing results, it was not considered further in the analyses and we believe it needs to be evaluated in future, more focused research (Oliveira et al., 2020; Sepúlveda et al., 2007).

#### 3.2.1. Small cetaceans

The following small cetaceans species were reported by fishers as bycatch: dusky dolphins (*L. obscurus*) (n = 19), common dolphins (*Delphinus* spp.) (n = 15), bottlenose dolphins (*Tursiops truncatus*) (n = 5) and Burmeister's porpoises (*Phocoena spinipinnis*) (n = 3). Our results showed that the first two dimensions of the MCA explained 35.8% of the inertia. Dimension 1 (Dim1) contributed 19.6% of the inertia, while dimension 2 (Dim2) contributed 16.2%. The MCA biplot (Fig. 3, Supplementary Material S1) suggests that bycatch of *Delphinus* spp., which ranged from 1 to 3 individuals per set, was associated with vessels with higher storage capacity (s3) and with ports located in northern Peru (lp1). Regarding porpoise bycatch, our results suggest that there is no association between porpoise bycatch and the fishing variables used in this study.

#### 3.2.2. Seabirds

Seven seabird species were reported as bycatch by fishers (n = 29) including the Peruvian pelican (*Pelecanus thagus*) (n = 21), Peruvian booby (*Sula variegata*) (n = 19), guanay cormorant *(Leucocarbo bougainvilliorum)* (n = 19), blue-footed booby (*Sula nebouxii)* (n = 3), Humboldt penguin *(Spheniscus humboldti)* (n = 2), waved albatross (*Phoebastria irrorata*) (n = 7), and white-chinned petrel (*Procellaria aequinoctialis*) (n = 6). Guano birds (*L. bougainvilliorum, S. variegata*, and *P. thagus*) were the most frequently reported species caught and the species with the highest numbers of bycatch, exceeding 10 individuals per set in the case of the first two. In relation to coastal birds, the first two dimensions explained 35% of the inertia, Dim1 explained 20.2% of variance, while Dim2 explained 14.8%. According to the MCA, there were no associations between the variables related to fishing and coastal birds species bycatch; however, associations between *L. bougainvilliorum, S. variegata*, and *P. thagus* were observed. For oceanic birds, the first two dimensions explained 39.7% of the inertia, Dim1 explained 24.3% of the variance and Dim2 explained 15.4%. The results of the MCA did not show associations between the variables related to fishing and any of the oceanic bird species evaluated.

#### 3.2.3. Sea turtles

The five species of sea turtles that inhabit Peruvian waters were reported by fishers as bycatch (n = 18): green turtles (*Chelonia mydas*) (n = 14), olive-ridley turtles (*Lepidochelys olivacea*) (n = 6), loggerhead turtles (*Caretta caretta*) (n = 5), hawksbill turtles (*Eretmochelys imbricata*) (n = 2), and leatherback turtles (*Dermochelys coriacea*) (n = 2). However, sea turtles were the group with the lowest frequency of reported interactions (Fig. 2). According to the MCA, the first two dimensions explained 41.1% of the inertia. Dim1 explained 22.5% of the variance and Dim2 18.6%. The results of the MCA did not show associations between the fishing variables and bycatch of any of the sea

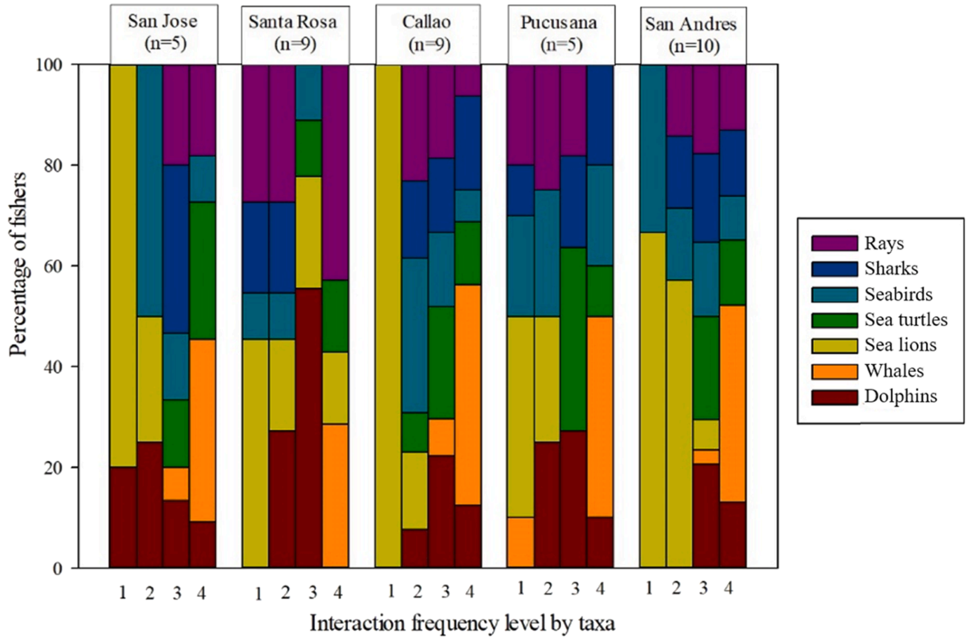


**Fig. 2.** Percentage of fishers from five ports reporting the frequencies of interactions with marine megafauna in artisanal purse-seines, where interaction frequency is (1) very frequent, (2) moderately frequent, (3) infrequent and (4) no interaction.

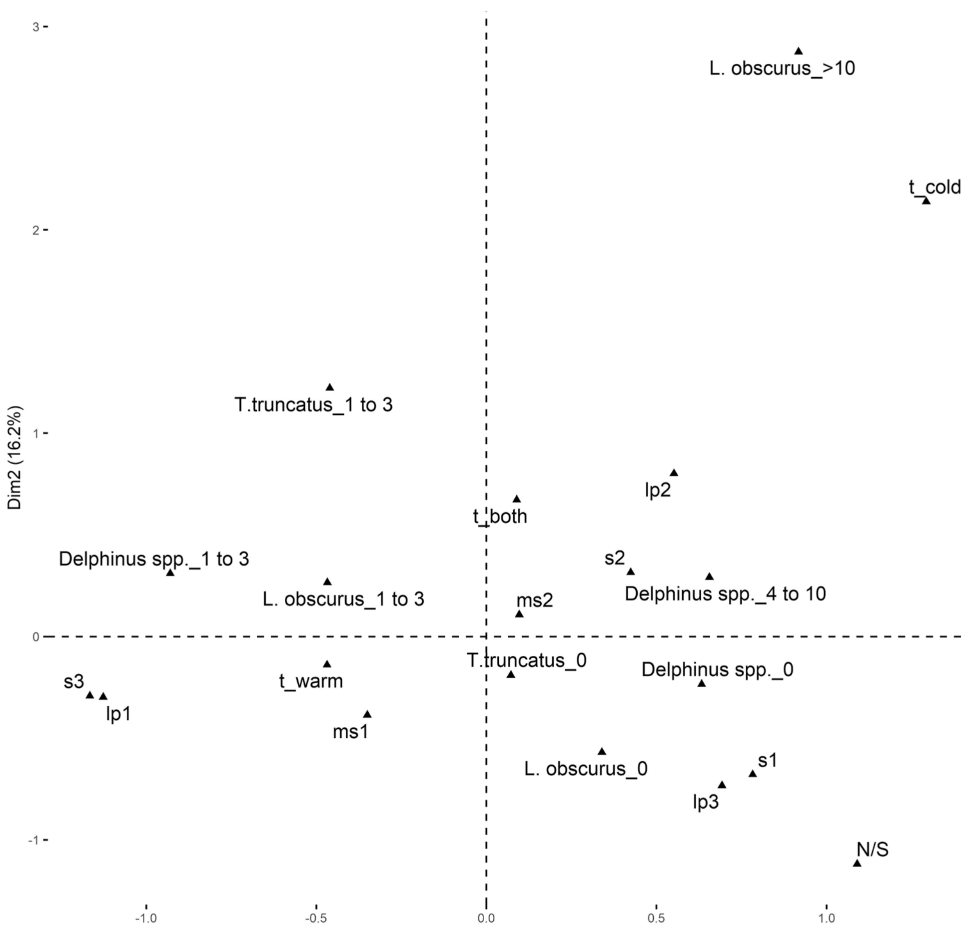


**Fig. 3.** Multivariate Correspondence Analysis (MCA) for dolphins. Where the variables related to fishing are: Mesh size = ms1 and ms2; Port latitude = lp1, lp2, lp3; Storage = s1, s2, s3 and Season = t_warm, t_cold, t_both and N/S. Variables related to interaction of artisanal purse-seine with *Delphinus* spp. = Delphinus sp_0, Delphinus sp_1 to 3, Delphinus sp_4 to 10, and Delphinus sp_> 10; *L. obscurus*= L.obscurus_0, L.obscurus_1 to 3, L.obscurus_4 to 10, L.obscurus_> 10; *T. truncatus* = T. truncatus_0, T. truncatus_1 to 3, and T. Truncatus_4 to 10, and T. truncatus_> 10.

turtle species evaluated.

### 3.2.4. Elasmobranchs

Shark species reported by fishers as bycatch were blue sharks (*Prionace glauca*) (n = 19), smooth hammerheads (*Sphyrna zygaena*) (n = 23), shortfin makos (*Isurus oxyrinchus*) (n = 15), threshers (*Alopias* spp.) (n = 7), and humpback smoothhounds (*Mustelus whitneyi*) (n = 12). The first two MCA dimensions explained 37.9% of the inertia. Dim1 explained 23.9% of the variance, while Dim2 explained 14%. In the MCA biplot (Fig. 4, Supplementary Material S2), our results suggest that *M. whitneyi* bycatch in the ranges from 1 to 3 and 4–10 individuals was associated with vessels with higher storage capacity (s3) and with northern ports (lp1). Likewise, the bycatch of *S. zygaena* in a range from 4 to 10 individuals was associated with vessels with lower storage capacity (s1).

The batoids reported by fishers as bycatch were eagle rays (*Myliobatis* spp.) (n = 33) and mobulid rays (*Mobula* spp.) (n = 17). In relation to the rays, our results showed that the first two dimensions explained 38.8% of the inertia. Dim1 21.7%, while Dim2 17.1%. The results in the MCA biplot (Fig. 5, Supplementary Material S3) suggest that the bycatch of *Myliobatis* spp. in the range from 4–10 individuals was associated with s3 vessels and lp1.

### 3.3. Final fate of bycatch

Fishers from all ports reported more than one fate for bycaught animals. Fate and fate combinations reported were: 1) consumption, 2) sale, 3) released alive/discarded dead, 4) consumption and sale, and 5) released/discarded and consumption (Fig. 6). Main fates of dolphins, porpoises, seabirds, and sea turtles reported by fishers in the five ports evaluated was the release of live specimens or the discarding of dead specimens at sea. However, in San Jose, Callao and San Andres consumption of seabirds was also reported, with the Guanay cormorant, also known as "patillo" as the most consumed species. In the case of dolphins and porpoises, consumption was also reported in all ports except Callao, and sales were mentioned in Pucusana to a lesser degree. Sea turtles were also reported as consumed in the ports of Santa Rosa, Pucusana and San Andres. Finally, for sharks and batoids, consumption and sale were predominant in all ports, and only in San Jose and Santa Rosa did fishers report releases and discards to a lesser degree.

### 3.4. Fisher perceptions

General aspects of fisher perceptions towards bycatch of marine megafauna in the APFC were evaluated. Fifty-three percent (53%) of the respondents perceived it negatively, considering it a problem. Four types of problems were identified: destruction of fishing nets, waste of time, economic losses, and damage to the target fish. "Loss of time" refers to the interruption of fishing operations, while "economic loss" refers to the reduction in the quantity and/or quality of catches and the costs of repairing fishing gear. The other 47% did not consider it a problem, having a neutral perception towards bycatch of marine megafauna,

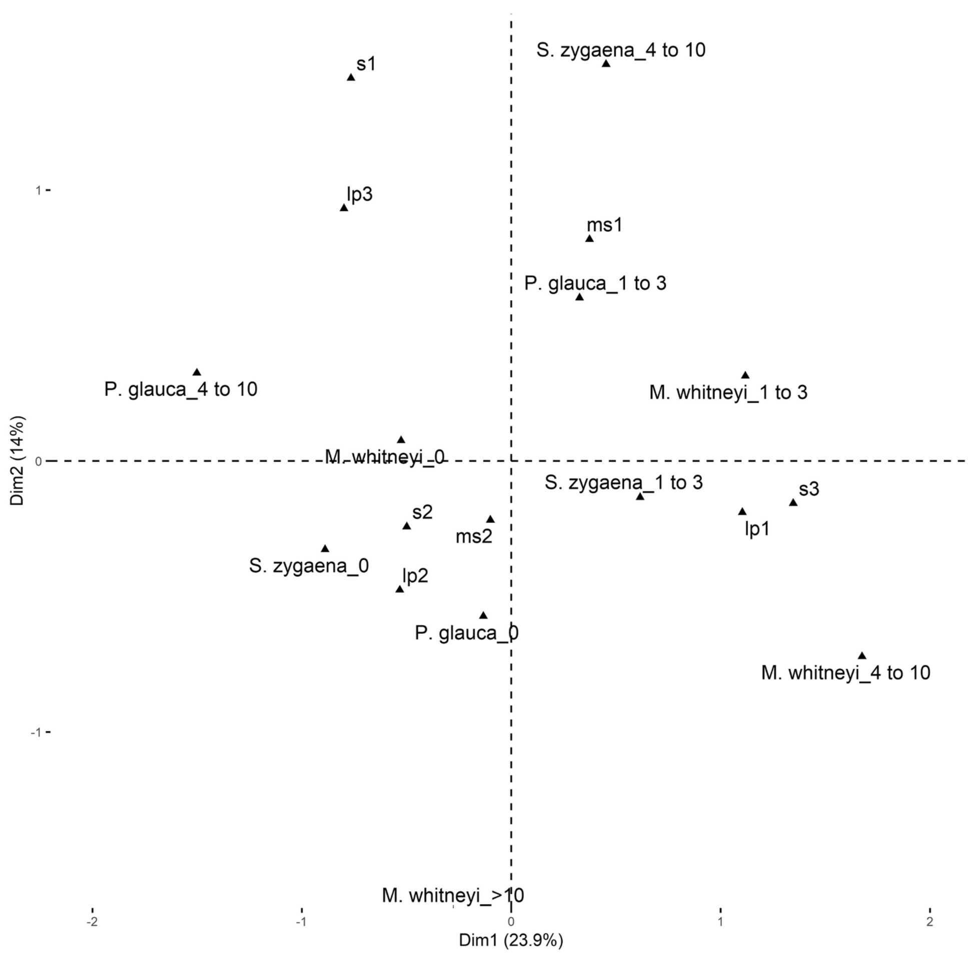


**Fig. 4.** Multivariate Correspondence Analysis (MCA) for sharks. Where the variables related to fishing are: Mesh size=ms1 and ms2; Port latitude = lp1, lp2, lp3; Storage = s1, s2, s3 and Season = t_warm, t_cold, t_both, and N/S. Variables related to interaction of artisanal purse-seine with *M. whitneyi*= M.whitneyi_0, M. whitneyi_1 to 3, M.whitneyi_4 to 10, and M.whitneyi_> 10; *P. glauca*= P.glauca_0, P.glauca_1 to 3, P. glauca_4 to 10, and P.glauca_> 10; *S. zygaena* = S.zygaena_0, S. zygaena_1–3, S.zygaena_4 to 10, and S.zygaena_> 10.

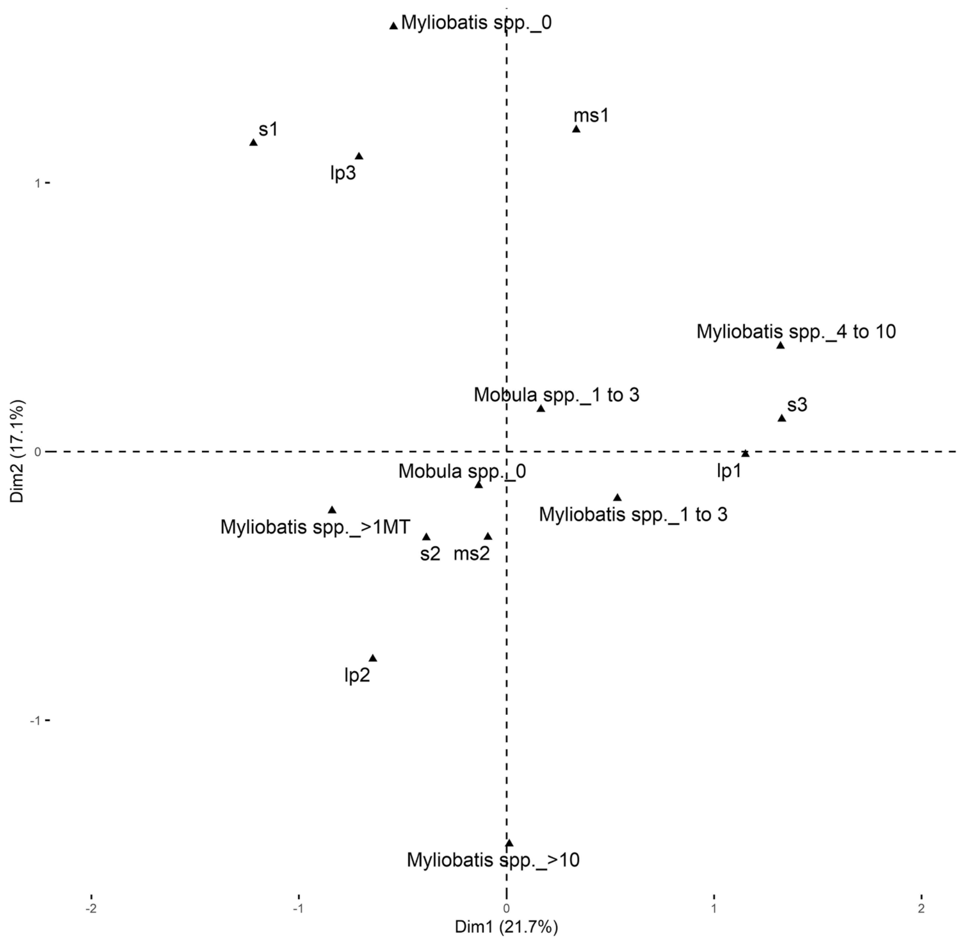


**Fig. 5.** Multivariate Correspondence Analysis (MCA) for batoids. Where the variables related to fishing are: Mesh size= ms1 and ms2; Port latitude = lp1, lp2, lp3; Storage = s1, s2, s3. Variables related to interaction of artisanal purse-seine with Mobula spp. = Mobula spp._0, Mobula spp._1 to 3, Mobula spp._4 to 10, and Mobula spp._> 10; Myliobatis spp. = Myliobatis spp._0, Myliobatis spp._1 to 3, Myliobatis spp._4 to 10, Myliobatis spp._> 10, and Myliobatis spp._> 1MT.

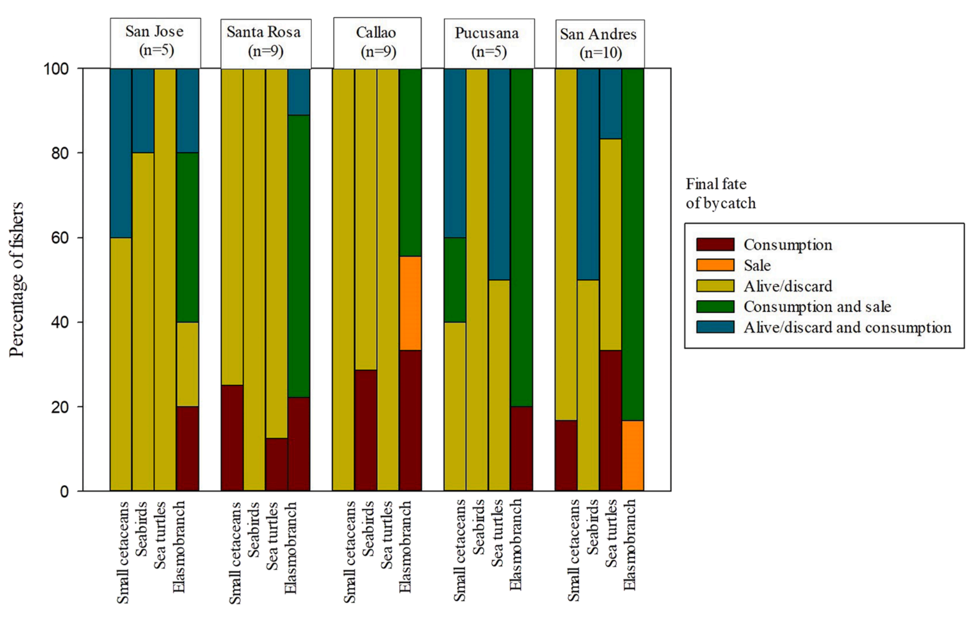


**Fig. 6.** Final fate of bycatch of marine megafauna reported as percentage of fishers.

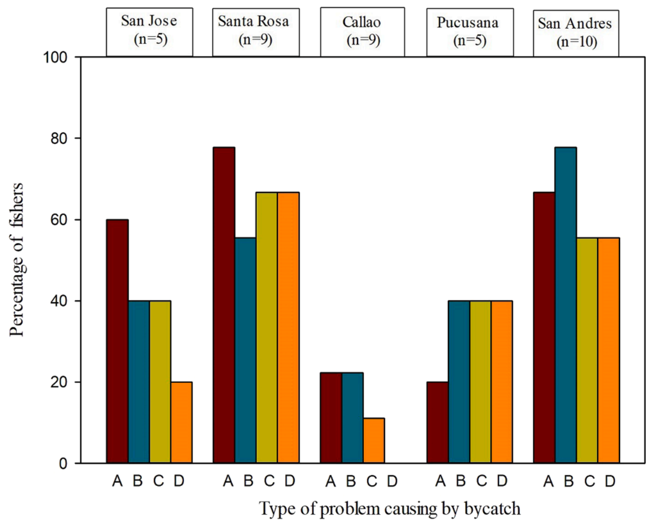


**Fig. 7.** Type of problem caused by bycatch where (A) destroy fishing nets, (B) waste of time, (C) economic losses, and (D) fish damage, reported as percentage of fishers.

considering it as a natural and unpredictable process.

The frequency of these identified problems varied by port (Fig. 7), with 'waste of time' being the main problem reported in the ports of Pucusana and San Andres. San Jose had the lowest percentage of fishers who considered bycatch a problem. In addition, two fishers also mentioned other problems associated with bycatch such as "penalties" and "scaring off the target fish" (e.g. dolphins). On the other hand, 76% of respondents indicated that sea lions are "highly detrimental" to their fishing.

## 4. Discussion

The paper provides a first overview of the marine megafauna bycatch characteristics of the artisanal purse-seine fishery along the Peru coast. Apart from improving our understanding of the scale of bycatch interactions, it also addressed how it is associated with characteristics of the fishery and how it overlaps with the species distribution. Using interviews as a methodology allowed us to obtain fishing information as well as interesting information likefisher perceptions regarding bycatch.

### 4.1. Interactions with megafauna

#### 4.1.1. Small cetaceans

Bycatch of *D. delphis* has been associated with artisanal purse-seine fisheries among other fishing gears and particularly correlated with vessel size (Alexandre et al., 2022). Similarly, our study showed an association between of 1–3 *Delphinus* spp. per set and larger vessels (s3) in the ports of San Jose and Santa Rosa. Both ports are located in Lambayeque region, where high numbers of interactions with common dolphins with surface and bottom multifilament gillnets have also been reported (Bielli et al., 2020; Torres and Sarmiento, 2021).

In Peru, there are two species of common dolphins: short-beaked common dolphin (*D. delphis*) and long-beaked common dolphin (*D. capensis*) according to Heyning and Perrin (1994), although a global analysis indicated that they are one species genetically (Cunha et al., 2015). Northern fishers mentioned that their fishing grounds were generally located near "Lobos de Tierra" and "Lobos de Afuera" islands. Therefore, it is possible that they may have had bycatch of both more neritic common dolphins (formerly long-beaked common dolphin) (Llapapasca et al., 2018; Sanino and Waerebeek, 2007), as well as more oceanic common dolphins (formerly short-beaked common dolphin) (Llapapasca et al., 2018; Sanino and Waerebeek, 2007). On the other hand, there have been observations of productive centers of upwelling between 5° and 7° S (Part of Piura and Lambayeque) (Zuta et al., 1978; Morón, 2000), 4°– 12°S (Piura and Pisco), and 17°– 18°S (Part of Arequipa and Tacna) (Llapapasca et al., 2018), so the relationship between bycatch and fishing area is possible given the distribution of these species along the Peruvian coast.

We found no association between bycatch of *L. obscurus* and *T. truncatus* with fishing variables. Bycatch in the Peruvian industrial purse-seine fishery has been previously documented (CeDePesca, n.d.), therefore, we would believe that dusky dolphins and coastal bottlenose dolphins are not taken as bycatch in the consumption purse-seine fishery because they feed primarily on Peruvian anchovies (Garcia-Godos et al., 2007). However, common dolphins also feed on them (Garcia-Godos et al., 2007; Reyes, 2009) but our study does demonstrate an association of bycatch with fishing variables. In addition, 50% and 13.2% of the fishers surveyed indicated that there is bycatch of dusky dolphins and bottlenose dolphins, respectively. This is possible because they feed on mackerel and jack mackerel, although in smaller proportions compared to Peruvian anchovies (Garcia-Godos et al., 2007).

Unlike dolphins, which are more tolerant and sociable (Clay et al., 2018), Burmeister's porpoises are shy with elusive swimming patterns (Brownell and Praderi, 1984; Reyes, 2009), and are therefore more likely to avoid interactions with active fishing vessels such as purse-seines (Guevara-Carrasco and Bertrand, 2017). The opposite is true for drift gillnets, which is a passive fishing gear (Guevara-Carrasco and Bertrand, 2017) and thus potentially more prone to porpoise bycatch. For example, incidental catches of Burmeister's porpoises have been recorded in Peru (Majluf et al., 2002; Mangel et al., 2013; Read et al., 1988; Torres and Sarmiento, 2021; Van Waerebeek and Reyes, 1990, 1994). Nevertheless, 7.9% of surveyed fishers mentioned having had porpoise entanglements so we consider it important to further quantify and characterize these interactions, particularly given the endemic and Near Threatened status of the species.

#### 4.1.2. Seabirds

The association between bycatch of the coastal seabird species, known as guano birds, *P. thagus, S. variegata, L. bougainvilli*, could be explained by their distribution along the Peruvian coastline, including inshore and offshore islands, and restricted to the Humboldt Current (Romero et al., 2021). This area provides foraging, resting, and breeding grounds for all three species (Schulenberg et al., 2010) We note that 63% of the fishers surveyed indicated fishing around islands and islets (e.g. fishers from the northern sites, San Jose and Santa Rosa, fishing in Isla Lobos de Tierra and Isla Lobos de Afuera) where reproductive colonies of these species are located (Aguilar et al., 2020; Figueroa et al., 2016), likely increasing bycatch events. This coincides with what has been reported for the Peruvian industrial anchovy purse-seine fishery, where species of the order Pelecaniformes, mainly guano birds, are those with higher interaction rates (Rivadeneyra-Villafuerte and Román-Amancio, 2021).

Moreover, in San Andres (southern port), 30% of fishers reported having bycatch of Peruvian diving-petrels (*Pelecanoides garnotii*), mainly while fishing for Pacific bonito. The two major Peruvian breeding sites for this petrel species are located on San Gallan island and La Vieja island, both of which are also used as fishing grounds by fishers from San Andres port (Jahncke and Goya, 1998; Zavalaga and Alfaro-Shigueto, 2009).

#### 4.1.3. Sea turtles

Forty-seven percent (47%) of all fishers surveyed reported bycatch of sea turtles during their fishing operations. The most commonly reported species at all ports was *C. mydas,* while *D.coriacea* and *E. imbricata* were the least reported. The prevalences of sea turtles species bycaught reported by artisanal purse-seine fishers was similar in other studies such as Ayala and Sanchez-Scaglioni (2014) and Alfaro-Shigueto et al., (2011) for the longline fishery and Pingo et al. (2017) for the gillnet fishery. Green turtle aggregations have been registered for several areas along the coast of Peru (Velez-Zuazo et al., 2014). Our study did not find associations between fishing variables and sea turtles, however, 80% of the bycatch of loggerhead turtles reported in this study was by fishers from the port of Callao (central Peru). This could be related to its spatial distribution in Peru; indeed, many of the loggerhead turtle capture sites were in the central and southern part of the country (Alfaro-Shigueto et al., 2008), being feeding grounds within the southeast Pacific (Boyle et al., 2009).

Previous studies have reported sea turtle bycatch in Peruvian small-scale fisheries including longlines, trawls, and gillnets (Alfaro-Shigueto et al., 2010, 2011; Ayala et al., 2018; Ayala and Sanchez-Scaglioni, 2014; Kelez, 2011). Peruvian waters are mainly used by sea turtles as a foraging area (Alfaro-Shigueto et al., 2002, 2011; Hays-Brown, 1982) and their bycatch in small-scale fisheries in the southeast Pacific is a major conservation concern (Alfaro-Shigueto et al., 2011). However, bycatch of sea turtles by purse-seine nets is infrequent and relatively low (1–3 specimens per set) compared to other fishing gears (Bourjea et al., 2014).

#### 4.1.4. *Elasmobranchs*

Duffy et al. (2019) conducted an ecological risk assessment (ERA) of the industrial tuna fishery in the Eastern Pacific Ocean (EPO), in which elasmobranchs qualified as a vulnerable group (Duffy et al., 2019). However, the impact of artisanal purse-seine fishing on elasmobranchs has received little attention. Unlike many species of seabirds, sea turtles, and small cetaceans, which are protected species, most sharks and rays are considered commercial species with economic value. We found a relationship between the bycatch of *M. whitneyi* bycatch of 1–3 and 4–10 individuals per set with large storage capacity (s3) and with the northern ports. This species is usually associated with the seabed, since it is a demersal species (Samame et al., 1989) distributed at depths of 16–211 m (Ebert et al., 2013). Purse-seine nets can reach a depth of 54 m (Sociedad Peruana de Derecho Ambiental, 2020) , increasing, therefore, the likelihood of bycatch of this species. In addition, this species is concentrated from Punta La Cruz (4°24’12" S y 81°15’32" W) to Salaverry (8°13′42″S 78°58′50″W), northern Peru (Samame et al., 1989) which also may explain the high frequency of bycatch reported by fishers from northern ports. Incidental catch of this species has also been reported in the Peruvian hake trawl fishery (Céspedes, 2014). These bycatch interactions are concerning given the species’s classification as Critically Endangered on the IUCN Red List (Dulvy et al., 2020). Currently, the species is primarily captured by artisanal fisheries (longline and gillnets) in Peru (Gonzalez-Pestana et al., 2014).

Smooth hammerhead bycatch of 4–10 individuals per set was associated with low storage capacity vessels which based on fishers responses tend to fish near the coast. based on Callao, Pucusana and Pisco fishers reported fishing ground areas including islands and islet located between 2.25 and 10 nm offshore (e.g. Pachacamac, Asia, Chincha and San Gallan) and offshore areas up to 15 nm. These coastal areas have been described as the habitat of juveniles of *S. zygaena* which during this life stage show preference for islands as feeding grounds and areas with lower predation pressure (Clarke et al., 2015; Afonso et al., 2022). Therefore, this overlap between nearshore fishing practices with the distribution of *S. zygaena* early stages may increase the likelihood of bycatch interactions.

Other studies indicate that bycatch of *S. zygaena* by the industrial tuna purse-seine fishery in the Eastern Pacific occurs with high frequency off the Peruvian coast (Díaz-Delgado et al., 2021). This could indicate that vessels with greater storage capacity would have greater bycatch of *S. zygaena*. This could be the case for the 16 industrial tuna purse-seine vessels (IATTC, 2023) allowed in Peru, which exceed the 182 tons of storage capacity established (R.M. N° 00258-2022-PRODUCE). Díaz-Delgado et al. (2021) mention that bycatch of *S. zygaena* is related to its preference for temperate waters of 20–25 °C and Mason et al. (2019) state that there is a temperature preference of 20–23 °C by juvenile individuals and also by chlorophyll-a concentrations, thus demonstrating that these environmental variables are determinant for its capture. Therefore, they should be considered for further studies, since it is a species that can be found both on continental and insular shelves as well as the high seas, depending on its sexual maturity stage (Compagno, 1984). It is also important to note that this species is widely exploited in Peru and is the only shark that has a catch limit and closed season (R.M N° 000132-2023-PRODUCE). It is important, therefore, to understand and consider all the threats to *S. zygaena* given its conservation status and as a commercially fished species.

Although 86.8% of fishers surveyed reported incidental catches of eagle rays, the catch from 4–10 individuals per fishing set by interviewees from San José and Santa Rosa showed an association with s3. This could indicate that the larger the vessel size, the greater the bycatch of eagle rays because central and southern ports have smaller vessels than those in the north and have incidental catches of 1–3 individuals per fishing set. (Fig. 5., Table 2). Likewise, although 31.6% of the total number of interviewed fishers reported a bycatch of more than 1MT of eagle rays per fishing set, visually in the MCA no association with any port or mesh size was observed, possibly because almost all fishers surveyed mentioned that bycatch of rays is common. In Callao and Pucusana, these large catches were reported by almost all respondents, possibly because the primary fisheries in these areas target Pacific bonito (gillnets and purse-seines), silverside (gillnets), and mahi mahi (gillnets and longlines) (Guevara-Carrasco and Bertrand, 2017). Therefore, batoids may be underexploited in this area, resulting in higher bycatch in purse-seines (which needs further attention). This contrasts with northern Peru (Zorritos, Máncora, San José, Salaverry) where *Myliobatis* spp. are a target species accounting for 20% of landings (Córdova-Zavaleta et al., 2014) and 15.1% in Lambayeque, which includes the ports of San José and Santa Rosa (De la Cruz et al., 2019).

### 4.2. *Final fate of bycatch*

In most cases, fishers reported that they freed animals if they were alive and discarded them if they were dead. However, we also found that consumption as fate of bycatch of small cetaceans, seabirds, and sea turtles still persists in all the ports evaluated. Fishers mentioned that the consumption occurred mainly aboard the vessel during the fishing trip and on certain occasions (i.e., when fishing was scarce) but also that bycatch was sometimes retained for the consumption of their families. It should be noted that in Peru only elasmobranchs are considered hydrobiological resources, while the other groups are prohibited from being caught and commercialized.

Of the fishers that reported bycatch of small cetaceans, 67% indicated that the dolphins were still alive in the fishing gear. This supports previous reports that indicate that in active fishing gear such as a purse-seine, most of the animals are observed alive inside the net (Bourjea et al., 2014; Marcalo et al., 2015). On the contrary, in passive gears and driftnet fisheries there is a high mortality rate (IWC, 1994). The consumption and/or sale of dolphins and porpoises was mainly by fishers from Pucusana, where 60% indicated a use for its meat or as bait. This practice has been documented for many decades despite its prohibition since 1990, with large numbers of small cetaceans having been captured directly and indirectly in gillnets and even purse-seines (Van Waerebeek and Reyes, 1994). It has also been reported that longline fishers from Pucusana purchase dolphins from gillnet fisheries at sea for use as bait (Campbell et al., 2020).

We show here that the post-bycatch consumption of seabirds and sea turtles was present in several ports evaluated. This has been documented previously in other artisanal fisheries such as of waved albatross in longlines (Awkerman et al., 2006; Jahncke et al., 2001) and Humboldt penguins in gillnets (Majluf et al., 2002). In the case of sea turtles, high mortality rates have been recorded with nets (which is further increased by retention for consumption), whereas with longlines mortality and retention is typically lower (Alfaro-Shigueto et al., 2011).

### 4.3. Fishers perception

Regarding fisher perceptions about marine megafauna bycatch in the APFC, 50% of respondents considered bycatch to be a problem for their fishing operations, nonetheless, the remainder commented that it is a natural process considering that the sea is the habitat of these species. The problem most frequently mentioned was the amount of time invested to release animals - to open fishing nets for animals to get out - mainly of large animals such as dolphins, whales, and mobulid ray, as it may cause fishing maneuvers delays or additional operational costs. To avoid these issues, fishers reported choosing not to set the net, moving instead to other fishing areas when observing these animals.

Fishers' perception toward sea lions was negative as has been previously reported (Davis et al., 2021). This complex relationship, in particular with the South American sea lion (*Otaria byronia*), is a consequence of the animals' behaviour. As reported by fishers, they tend to bite their catch, damage their nets and chase away schools of fish. This behaviour is perceived as harmful by fishers surveyed and is accompanied by their perception of an increase of the sea lions population over the last 10 years, an increase that also makes some fishers consider these animals as plague. Given this fraught and complex relationship between fishers and sea lions, we suggest that this be evaluated in future, focused research to avoid biasing the results (Oliveira et al., 2020; Sepúlveda et al., 2007).

On the other hand, only 24% of the fishers evaluated reported having interacted with whales. Interactions have been described, particularly with humpback whales (*Megaptera novaeangliae*) in gillnets in northern Peru (Costanza et al., 2021), an area visited by this species during their breeding and calving season (Guidino et al., 2014). As a result, these fishers avoid setting when whales are sighted to avoid losing their nets or having an accident with their boat.

### 4.4. Bycatch mitigation measures

Numerous strategies and bycatch reduction technologies have been tested or implemented globally in an attempt to mitigate bycatch. Among these strategies are the establishment of individual bycatch limits, fishing gear modifications, time-area closures, and buy-outs (e.g., implemented in rarest species such as vaquita, where immediate action is required) (Senko et al., 2014). Compared to other fisheries, little is known about marine megafauna bycatch in the purse-seine fishery, with what is known limited to the assessment and mitigation of dolphin interactions with the tuna purse-seine fishery. Currently, different tools have been tested to reduce seabird bycatch, including modified purse-seine (MPS) (Suazo et al., 2017a; Suazo et al., 2017b; Suazo et al., 2019).

In the case of Peru, the suitability of these technologies for reducing megafauna bycatch in purse-seines remains to be robustly tested. The development of best practice and safe handling and release guidance for fishers (e.g. Mires-Rojas et al., 2021) along with training workshops with industrial and artisanal purse-seiners could also help reduce or mitigate bycatch interactions. Management tools to address the bycatch problem must consider changing ecological, socioeconomic, and cultural factors (Komoroske and Lewison, 2015) and include fishers in the development of management plans (Senko et al., 2014).

### 4.5. Recommendations and next steps

We recognize that the sample size analyzed is relatively small and therefore interpretations of bycatch in the study groups should be made with caution. Nevertheless, we consider it a useful first step in characterizing the marine megafauna bycatch interactions of Peru's artisanal purse-seine fleet. Although it is true that the mesh size variable shows little variation and is of the multifilament type (visible as opposed to monofilament), it was used to corroborate that it was not an influential variable for the case of the consumer purse seine fishery. In future studies we recommend including a greater number of ports in the northern and southern zone of Peru. Furthermore, including maps identifying bycatch areas would help to further clarify these interactions, since we only collected data from fishing areas, using the port as a reference point. Additionally, artisanal fishers who fish for Peruvian anchovy should also be included since they are also considered part of the artisanal purse-seine fishery. This study has served as a preliminary assessment allowing us to confirm the interactions and bycatch of species of conservation concern in the artisanal purse-seine fishery. We highlight the need to further quantify bycatch rates of marine megafauna in the APFC through different methodologies such as onboard observer monitoring.

## CRediT authorship contribution statement

N. Peña-Cutimbo performed article conceptualization, research, methodology, formal analysis, data curation, as well as writing and revising the manuscript; C. Cordero-Maldonado joined in article conceptualization, research, methodology, data curation, as well as writing and revising the manuscript; C. Ortiz-Alvarez collaborated in methodology writing and revising the manuscript; J. Alfaro-Shigueto and J. Mangel collaborated in manuscript supervision and 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 data that has been used is confidential.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2023.106878.

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