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By-catch of sea turtles in Pacific artisanal fishery: Two points of view: From observer and fishers

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Fisheries bycatch is a primary driver of population declines in marine megafauna. These captures not only have environmental impacts, they also have economic consequences for fishers such as direct losses when repairing fishing gear. Therefore, evaluating the fishers' perception of bycatch and comparing it with data from scientific fisheries observers might provide a broader view of the current situation these species face. To do this, we obtained data concerning the bycatch of 1,838 sea turtles between 2008-2018 in the Eastern Pacific Ocean as well as informative surveys from 421 artisanal fishers surveyed in 2020. There is a discrepancy between the bycatch observed and the fishers' perceptions of it. The observers' results identified that high rates of incidental capture of sea turtles are associated with the mahi mahi fishery that occurs during winter and is a shallow set fishery using fish as bait. The olive ridley turtle was the main species affected by bycatch. According to the fishers' perception, bycatch was higher with the use of J-hooks and a longline (compared to circle hooks and to gill nets and trawl nets) and when the target species are pelagic fish during the winter season. In addition, the fishers' perception showed that 39.4% considered incidental fishing as an environmental problem and 28.5% considered it as a nuisance, while 32.1% do not consider sea turtle bycatch as a problem. These findings suggest that 60% of fishers do not consider it a need to protect sea turtles. Given the different responses between fisheries observers and fishers' perception, it is clear that more dialogue is necessary to raise awareness about the effects of bycatch on worldwide sea turtle populations. Thus, there is an enormous potential to recruit/increase fishers' active participation for turtle protection. In this context, the idea of including the fishers' perception into any management strategy or conservation measure should be reinforced in order to effectively reduce the bycatch of these iconic species.

KEYWORDS
fishing gear, fishing nets, longlines, marine turtles, surveys

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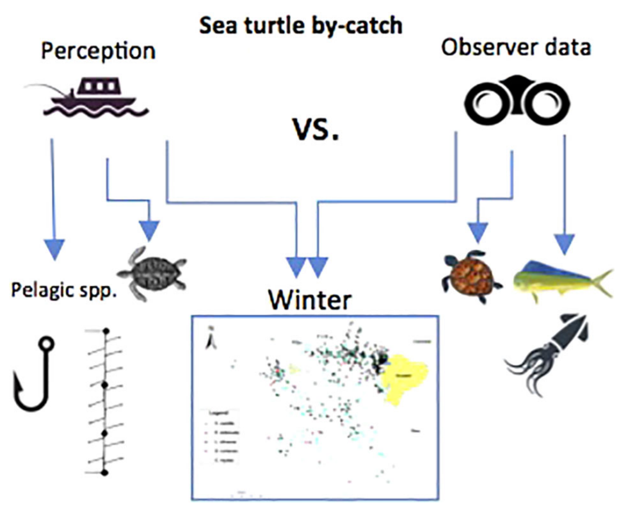

GRAPHICAL ABSTRACT

Introduction

Bycatch resulting from fishing gear (in particular longlines and gillnets) is one of the most serious threats to marine megafauna such as seabirds, sea turtles, marine mammals, and elasmobranchs (Lewison et al., 2004; Žydelis et al., 2009; Fiedler et al., 2012; López-Barrera et al., 2012; Wallace et al., 2013; Gilman and Huang, 2017). This is particularly concerning in long-lived animals with low reproductive rates, such as is the case of sea turtles (Parga et al., 2015), cetaceans, pinnipeds and sirenians (Reeves et al., 2013) or elasmobranchs (Gallagher et al., 2014). Pelagic longline gear is commonly used throughout the world to catch large pelagic fish such as tuna, billfish, and sharks (Myers and Worm, 2003; Watson and Kerstetter, 2006; Martínez-Ortiz et al., 2015; Gilman et al., 2017; Gilman et al., 2020). Although this gear is often considered to be more selective when compared with gillnetting and trawling (Lewison et al., 2004; Berninsone et al., 2020), it continues to catch large numbers of sea turtles and other non-target species (Deflorio et al., 2005; Carranza et al., 2006; Ovetz, 2007; Garrison and Stokes, 2017).

A conservative estimate of fisheries data suggest that bycatch represents 40.4% of global marine catches (Davies et al., 2009). Many studies have focused almost exclusively on industrial fishing in industrialized countries (Casale et al., 2017; Tagliolatto et al., 2020; Swimmer et al., 2020), given that in most countries there is little data on the artisanal fishing effort, catch, or bycatch of sea turtles, seabirds and marine mammals (Moore et al., 2010; Shester and Micheli, 2011). However, recent evidence has highlighted the potential for artisanal fishing to have significant negative impacts on sea turtles (e.g., the Caribbean: Blades et al., 2019; Rojas-Cañizales et al., 2020; Peru: Alfaro-Shigueto et al., 2011; Ayala et al., 2019; Kenya: Kakai, 2019 or Ecuador: Darquea et al., 2020), cetaceans (e.g., Ecuador: Alava et al., 2019; Peru: Mangel et al., 2010; Bielli et al., 2020), sharks or mobulids (Indonesia: Mustika et al., 2021) or seabirds (Western Mediterranean: Cortés and González-Solís, 2018). With artisanal fisheries comprising >95% of the world's fishers, this knowledge gap needs to be evaluated (Shester and Micheli, 2011). Previous assessments of sea turtle bycatch due to industrial longline fishing indicate significantly higher catch rates with narrower J and tuna hooks and with squid bait compared to wider and large circle hooks (18/0) equivalent to ≈4.9 cm and fish as bait (Gilman and Huang, 2017; Swimmer et al., 2017; Gilman et al., 2020). However, the target species for most artisanal fishing are medium and small-sized fish which are usually caught in medium-sized hooks (Alfaro-Shigueto et al., 2010; Gilman et al., 2018).

The largest small-scale artisanal fishing fleets of the Eastern Pacific Ocean (EPO) are in Ecuador (Alava et al., 2015), with an estimated annual sea turtle bycatch of 40,480 individuals, which represents approximately 5.3 sea turtles per 1,000 hooks (Maunder et al., 2021); and account for 87% of the total bycatch from Chile to Ecuador (Alfaro-Shigueto et al., 2018). These fleets mainly use longlines and gillnets to catch several species (tuna, billfish, sharks and mahi-mahi; *Coryphaena hippurus*) (Martínez-Ortiz et al., 2015). Even in the Galapagos, where marine megafauna is protected since 1998, these protected species are still being caught (Cerutti-Pereyra et al., 2020). In addition to the ecological impact, this incurs an economic cost for the fishers due to the damage or repair of the fishing gear (repaired by themselves) and loss of hooks (between 10-20$ per year/own data) due to the interaction with the turtles (Hall et al., 2000).

To gain insights into the impact of bycatch and the other financial, behavioral and environmental challenges faced by small-scale fishers, we initiated a questionnaire survey to assess fishers' perception of the problem (Gaibor, 2016; Panagopoulou et al., 2017; Mustika et al., 2021). Most previous studies have been based on observers obtaining large-scale data on bycatch and then evaluating fishing gears separately and not in an integrated way by considering all the fishing gears affecting sea turtle populations individually (Marco et al., 2020). In this context, knowledge about the difference of perceptions of bycatch is essential to reach a global overview of this current threat in order to reduce its impact (Wallace et al., 2011). In addition, both approaches (the fishers' replies to questionnaires and the data from observers) should provide a more accurate assessment than the current limited sea turtle bycatch estimates (Carreras et al., 2004; Barrios-Garrido et al., 2020).

There are many socio-cultural constraints related to the culture of fishing, such as values of conservation, family relationships and hierarchies, fishing knowledge and beliefs (Teh et al., 2015), all of which hamper effective knowledge transfer or implementation, thereby necessitating a multidisciplinary conservation approach (Komoroske and Lewison, 2015). Alexander et al. (2017) found that sea turtle conservation strategies succeed when the cultural and social traditions of local communities are integrated with management activities. Therefore, it is essential to evaluate whether there is a difference or discrepancy between the fishers' perception of the phenomenon and the observers' data concerning the incidental catch of turtles, since each stakeholder group may have an unique perspective towards these conflicts (Barrios-Garrido et al., 2019). Understanding how fishers perceive the problem has significant implications for management and policies (Moore et al., 2010; Mason et al., 2020; Awabdi et al., 2021). Although, perceptions and attitudes are difficult to change (de Carvalho et al., 2016), raising awareness robustly should help this conceptual change and, consequently, lead to a change in behaviors (Fu et al., 2020). There is a necessity to assess both approaches (fishers' perception and observer data) at global and regional scales simultaneously, such as in the EPO fisheries, as it might determine the future of these populations (Gaibor, 2016; Alfaro-Shigueto et al., 2018; Darquea et al., 2020). Using the largest small-scale fleets in the EPO as a case study will highlight the differences between the fishers' perception of the problem and the data provided by on-board observers.

In this paper, we aim to: i) estimate and characterize the bycatch of sea turtles in the EPO according to the fisheries observer data; ii) identify the fishers' perceptions concerning bycatch; iii) compare the results obtained from both approaches, and iv) propose concrete recommendations for conservation management to reduce this worldwide phenomenon and at a local level.

Material and methods

Observer data

A monitoring programme using fisheries observers was implemented from August 2008 to June 2018 regarding small-scale longline fishing (a "mother ship" fleet) from the fishing ports of Manta (Ecuador). This programme represents a small percentage of the Ecuadorian fishing fleet (10% for 2022; ACUERDO Nro. MPCEIP-SRP-2021-0208-A https://vlex.ec/vid/mpceip-srp-2021-0208-876693938). The observer data were provided by PAT – Ec, which is part of the National Plan for the Fisheries Control of Ecuador (PNCP – Ec). Observers were trained in biological and fishing data collection by the undersecretary of Fishery Resources (SRP); using the "Programa Nacional de Observadores Pesqueros de Ecuador" (PROBECUADOR). The information recorded in 160 boats included: target fish, hook type, number and size, type of bait, number and species of turtle caught, coordinates and date (Manual para el observador a bordo, Ministerio de acuacultura y pesca). These 160 boats each made between 1 and 29 fishing trips per year (mean ± SE = 5.5 ± 5), and between 1 to 20 sets (the action and result of releasing the longline) per trip (mean 4.3 ± 3). Therefore, we analyzed 1,363 sets, representing 17,965 of fishing hours. The soaking time (number of hours of the set in the water)

TABLE 1 Percentage of catches of the target species according to the type of hook, type of bait and season.

Target species	Hook Type	Bait type	Season	Average hook per set (n°)	Average hour set in water
Tuna (*Thunnus*)	J38 78% J36 10% C16 9%	Squid 46% Auxis 33% Fish 21%	Summer 59% Winter 41%	248 ± 182	14 ± 7.1
Billfish (Istiophoridae and Xiphiidae)	J38 79% J36 10% C16 9%	Squid 49% Auxis 34% Fish 17%	Summer 75% Winter 25%	295 ± 336	13.7 ± 6.9
Mahi mahi (*Coryphaena hippurus*)	J4 66% J5 13% J3 11%	Squid 45% Auxis 43% Fish 12%	Winter 62%, Summer 38%	480 ± 272	11.2 ± 6.1

(between 5 and 45; mean ± SE= 13.2 ± 7) and the number of hooks per set (between 8 and 1,680; mean ± SE= 322 ± 263) were used to estimate the Catch Per Unit of Effort (CPUE) = (number of catches/hour/1,000 hooks).

Observers recorded the catch composition (target and bycatch species) per set. The fish species were categorized for the statistical analysis, such as: tunas (*Thunus obesus*, *T. albacaren* or *T. alalunga*), billfish *(Xiphias gladius, Makaira nigricans* or *Istiophorus platypterus*) and mahi-mahi (*Coryphaena hippurus*) (this clustering is similar to Parga et al., 2015). The hooks were grouped into two categories, circle (C14, C15 and C16) and J (J1, 2, 3, 4, 5, 7, 8, 34, 36, 38 and 40) (see Mituhasi and Hall, 2011 for more details). The baits were grouped into: fish, squid and small scombrids (Auxis spp.). The seasons of the year were grouped into: winter (from December to May) and summer (from June to November) (Table 1). The setting depth depends on the season and varies between 12-16 meters in winter (mahi-mahi) and between 20 and 30 meters in summer (tuna and billfish). The characterization of the study longline fishing is detailed in Table S1.

Fishers' survey

The total population of artisanal fishers is made up from 63,972 Ecuadorian fishers (Alava et al., 2015). Therefore, the minimum number of fishermen required to survey for the sample to be representative according to the population was 382 (Singh and Masuku, 2014). In total, 421 fishers participated in the survey: 51 answered the online version of the questionnaire and 370 the in-person questionnaire (Table S2). Age and years of experience were also registered since previous studies have showed that the fishers' perception may change according to these variables (Bender et al., 2014).

Fishers' perceptions

The questionnaire was divided into two parts (i) the fishers' experience, type of fishing gear, bait and boat used, and sociodemographic variables (Annex 1), and (ii) the fishers' perceptions about the problem of sea turtle bycatch. In the first part, questions were included about: whether they had experienced the bycatch of sea turtles and its frequency; their perceptions of trends in sea turtle bycatch in the last ten years; what gear, types of baits, season, or hooks they think cause the most bycatch. In the second part of the questionnaire, we asked questions such us: Is such bycatch a nuisance? Do they have a major environmental impact? Or, are they not relevant?

The development of the questionnaire follows three differentiated steps that provide it with precision and reliability (Gracia et al., 2021):

1. **Selection and formulation of the items**. Firstly, a review of the literature was carried out in order to identify the different variables that may influence sea turtle bycatch.
2. **Content validation** by the panel of scientific experts. Secondly, a panel of experts judged the instrument's clarity, pertinence and relevance using a Likert-scale (Annex 2). Then, the validation of the items in terms of content led to include some adaptations.
3. **Comprehension validation.** Thirdly, after modifying the instrument considering the experts' suggestions, it was carried out on to 30 fishers (face-to-face) following the recommendation of Beaton et al. (2000) and Serrano et al. (2020) to analyse its comprehension.

After these validation processes (content and comprehension), the questionnaire was composed of 16 sociodemographic questions and 13 closed questions about bycatch. The average time taken to fill in the questionnaire was 15 minutes per fisher. The results of the content validation are shown in Annex 2.

Questionnaire implementation

The sampling technique applied was convenience sampling (Emerson, 2015) as fishers were selected based on availability and willingness to take part. Fishers were previously informed about the purpose of the present study and research ethical principles were applied to protect their anonymity, dignity, rights and welfare throughout the whole research project. Collecting the information from the fishers took place from June 2020 to November 2020 in ports of the province of Manabí and Esmeraldas. Two strategies were used to recruit participants for the study. First, in-person surveys were conducted in the ports of P. Lopez, P. Cayo, Machalilla, Jaramijó, Salango, S. Lorenzo, Pampanal, Tambillo and Manta (see Annex 3). These ports include the main points of artisanal and industrial fishing catches in Manabí and Esmeraldas (Ecuador). The questionnaires were completed in the presence of the fishers (n=370), by the interviewer. Simultaneously, we conducted an online questionnaire during the same period using the Google Forms tool (n=51). The online questionnaire was also promoted by the fishers' cooperatives and guilds of Manabí and Esmeraldas.

To account for any uncertainty and potential bias in this convenient sampling method, we took some precautions and applied controls before the data analyses (Maas et al., 2021), for example: (i) distributing the survey online and on paper; (ii) distributing the survey at 9 ports to achieve higher levels of diversity and sample size in our survey (Annex 3); (iii) controlling demographic representativeness by comparing our survey sample to census data concerning the fishers, showing a

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high level of representativeness for age and a higher representation of artisanal groups compared to the overall fishing populations. In addition, sampling bias was avoided through; (iv) the participants' self-identification with the type of fishing that the fishers practice, type of boat, and type of fishing gear used, (v) reliability analyses of scale (Cronbach's Alpha for internal validity). Cronbach's Alpha was above 0.70 for our scale, representing a good level of fit (e.g., Cortina, 1993).

Data analysis

With respect to observer logbook data, one GLM (observer model)was carried out where the Catch Per Unit of Effort (CPUE) was included as response variable. In the case of fishers' perception one GLMM (fishers' model) was performed where number of turtles bycatch by fishers was included as response variable (frequency of the fishers' perception of bycatch). In the observer model, the target species (3 levels), hook type (2 levels, circle vs J-hook), bait type (3 levels), turtle species (5 levels), and season (2 levels) were included as factors. The year was included as a random factor (ten levels). In the fishers' model, the target species (2 levels), fishing gear (3 levels), hook type (2 levels), bait type (3 levels), turtle species (4 levels), and time of year (2 levels) were included as factors. The port was included as a random factor (six levels). For the observer model, a normal distribution with an identity link function was used, while for the fisher's survey model, Poisson distribution with a log link function was used. Fisher's Least Significant Difference (LSD) *post-hoc* test was also applied to check for response differences among different levels of categorical variables. The most plausible models were selected by comparing Akaike's information criterion (AIC) (Burnham and Anderson, 2002) following a backward procedure (Zuur et al., 2009). The statistical analyses were performed using InfoStats software.

Results

Survey respondents

There were more men (n = 417) than women (n = 4) among the respondents, as well as a predominance of the intermediate age-class (30-45). The participation of older people and artisanal fishers was lower for the online questionnaire than the in-person questionnaire. The specialized fishing gear most commonly used were the gillnet (51%), followed by the longline (44%) and trawl net (5%). Artisanal fishers represented 94% of the responders, while professional fishers (working for a company for a salary) represented only 6% of the questionnaire's respondents.

Sea turtle bycatch data from observers

According to the observers' data, 1,838 sea turtles were captured incidentally during the study period (Figure 1), of which 72.3% were olive ridley (*Lepidochelys olivacea*), 23.7% green (*Chelonia mydas*), 1.5% leatherback (*Dermochelys coriacea*), 1.3% hawksbill (*Eretmochelys imbricata*), 0.8%

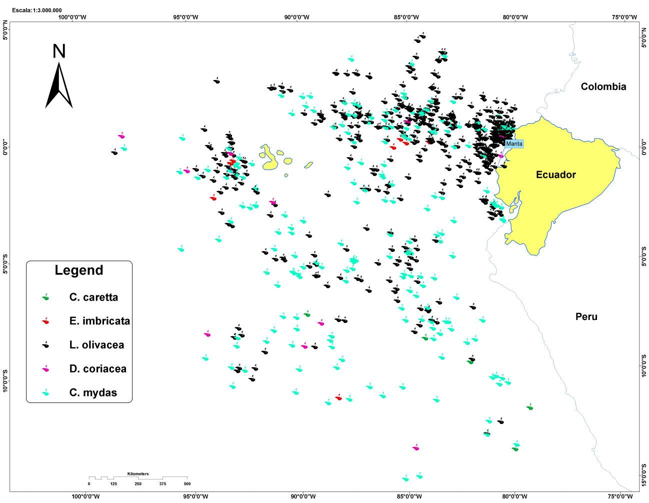

FIGURE 1
Location of sea turtles captured incidentally on longlines.

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TABLE 2 *F, p*-values and coefficients of the variables included in the mixed linear model to explain the by-catch of sea turtles according to the observers' data (Model 1) and fishers' perception (Model 2).

Model 1: Observed data

Variables	F-value	p-value	Estimate ± SE
Target species	11.03	<0.001	Mahi-mahi = 0.29 ± 0.08 Billfish = -0.16 ± 0.07
Turtle species	5.17	<0.01	Olive ridley = 0.56 ± 0.29 Hawksbill = 0.47 ± 0.33 Green = 0.25 ± 0.17 Leatherback = 0.12 ± 0.25
Season	10.44	<0.001	Summer = -0.17 ± 0.09
Bait type	7.46	<0.01	Squid = 0.09 ± 0.07 Fish = -0.12 ± 0.07
Model 2: Fishers' perception			
Hook type	12.2	<0.001	J-hook = 0.4 ± 0.21
Season	4.43	<0.01	Summer = -0.21 ± 0.10
Target species	4.05	<0.01	Pelagic = 0.36 ± 0.07
Turtle species	3.33	<0.05	Hawksbill = 0.42 ± 0.14 Green = 0.33 ± 0.24 Olive ridley = 0.29 ± 0.27
Fishing gear	2.64	<0.05	Longline = 0.28 ± 0.07 Trawl net = 0.05 ± 0.02

The coefficients for the level of fixed factors were calculated according to the reference value of 'tuna' (in model 1) and 'groundfish' (in model 2) for the variable 'target species', 'loggerhead' for the variable 'sea turtle', 'winter for the variable 'season', 'Auxis spp' for the variable 'bait type' (model 1) and 'gillnet' for the variable 'fishing gear' (model 2).

loggerhead (*Caretta caretta*) and 0.4% undetermined sea turtles. In contrast, fishers identified that the green turtle was the most frequently caught species (46%), whereas they stated the olive ridley and hawksbill turtles to be caught at a lower rate, 27% and 24.7% respectively (Table S3). The mean number of turtles caught incidentally per set was 1.3 ± 1 (range between 1 and 13), with an average of 4.2 sea turtles caught incidentally per 1,000 hooks.

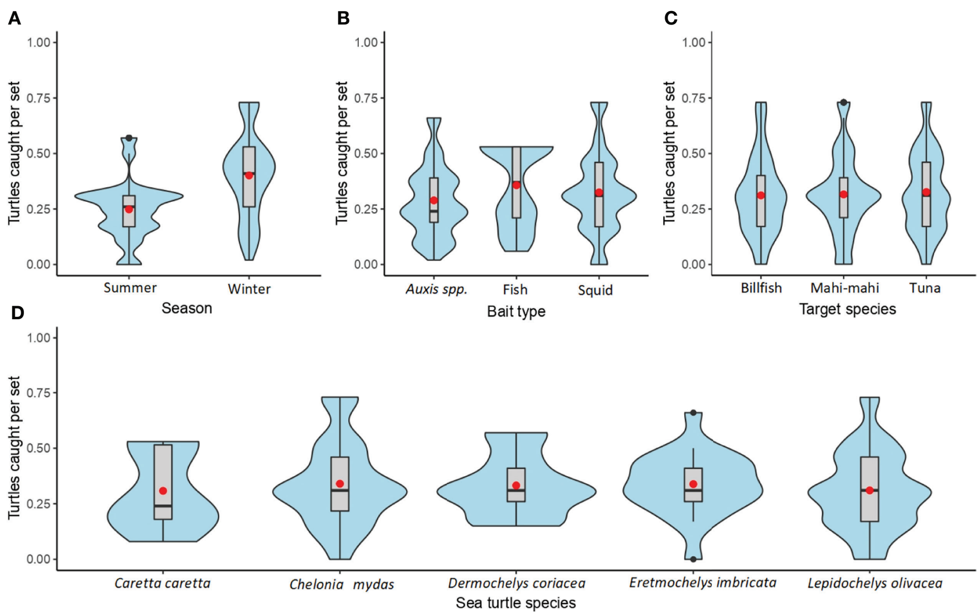

FIGURE 2
Violin plots of predicted values of the catch per unit effort according to: **(A)** season **(B)** bait type **(C)** target species and **(D)** sea turtle species, according to the observers' data (model 1). The thick grey bar in the center represents the interquartile range and the width of the violin represents the sample size. Red point and horizontal black line represent mean and median respectively.

Observers' model

Regarding the factors that influence the incidental catch of sea turtles, according to the observers' data (model 1), the results show the effect of the target species, the season, the type of bait and the turtle species (Table 2). The results show significantly more bycatch in winter (Figure 2A) and when squid is used as bait (Figure 2B). As for the target species, results show significant differences between when the intended catch was mahi-mahi and when it was other species (tuna or billfish), with a higher bycatch percentage of sea turtles when mahi-mahi was the target species (Figure 2C). Finally, there are significant differences between the proportions of turtles captured, with a particular predominance of the olive ridley turtle (Figure 2D).

Fishers' model

Regarding the factors that, according to the fishers, influence bycatch (model 2), the results show the effect of the type of hook, the season, the target species, the turtle species and the fishing gear (Figure 3). The highest incidental catch rates occur with the J-hook (Figure 3A), in winter (Figure 3B) and on a longline (Figure 3C). The results also show that the highest rates of bycatch occur when the target species are pelagic fish

TABLE 3 Comparison of the variables studied between the fishers and observers.

Variable	Fishers	Observers
Target species	Pelagic	Mahi-Mahi
Fishing gear	Long line	No data
Hook type	J-hook	J-hook (n.s.)
Sea turtle	Hawksbill turtle	Olive ridley turtle
Bait type	Squid (n.s)	Squid
Season	Winter	Winter

n.s. (no differences according to Table 2).

(Figure 3D). Finally, there are significant differences between the proportions of turtles captured, with a particular predominance of the hawksbill turtle (Figure 3E).

Data from observers vs the fishers' perception

The fishers' perception of bycatch was heterogeneous throughout the participants sampled, highlighting that age and years of experience influence the perception of bycatch (Annex 4). According to our results, 39% of the fishers answered that bycatch is an important environmental problem, while 32% and 29% answered that it is not relevant or is a nuisance, respectively.

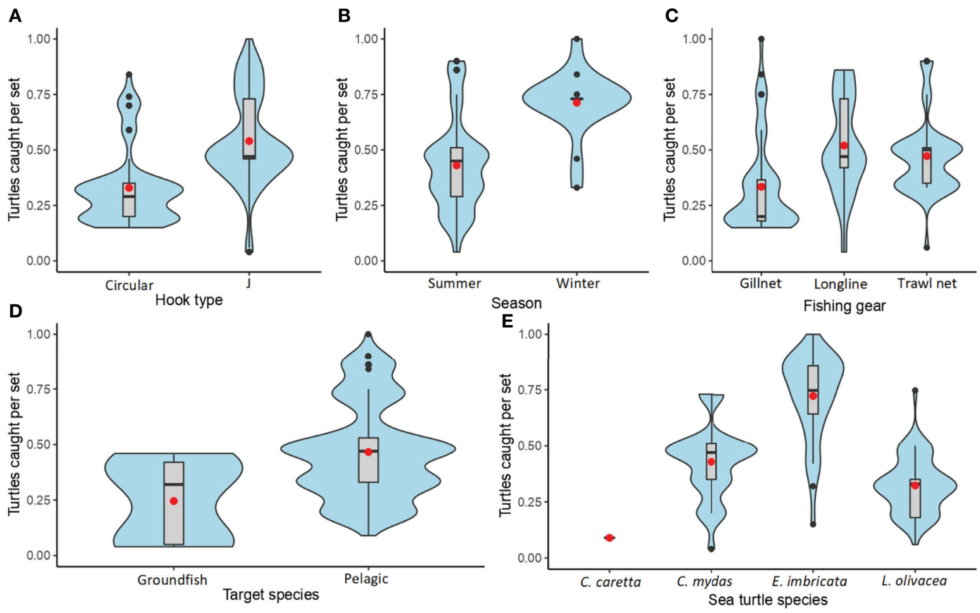

FIGURE 3
Violin plots of the predicted values of the number of sea turtle by-catch according to: **(A)** hook type **(B)** season **(C)** fishing gear **(D)** target species and **(E)** sea turtle species, according to the fishers' data (model 2). The thick grey bar in the center represents the interquartile range and the width of the violin represents the sample size. Red point and horizontal black line represent mean and median respectively.

Their perception of the temporal trends in the last ten years of bycatch is that it remains constant, which is similar to data reported by the observers. Concerning the question of what fishing gear was associated with more accidental catches of turtles, 43% point to the longline; followed by the gillnet 31% and the trawl net 26%. With respect to the bait, squid was the bait most indicated by the observers as responsible for bycatch (60%), followed by fish (35%), which coincides with what is reported by fishers (Table 3), where squid represented 57% and fish 40%. Both the data from the observers and the perception of the fishers show that winter is the season with the most bycatch. For the target species, 78% of fishers highlight that bycatch occurs when pelagic species (included mahi-mahi, tuna or billfish) are selected, while in the case of observers, mahi mahi was involved in 53% of the captures. As for the moment at which the bycatch occurs, 60% of the respondents stated that it occurs when the fishing gear is already set versus 14% hauling or 26% setting fishing gear (Annex 4). In addition, 70% indicated that the bycatch was due to entanglement with fishing gear. Finally, 63% said the J-hook was responsible for the bycatch.

Discussion

This study found that sea turtle bycatch is associated with factors such as hook type, bait type, fishing gear, season, fishing effort and target species. However, we also found differences between observer data and fishers' perceptions. It is noteworthy that 61% of fishers perceive incidental fishing as a nuisance (economic loss or damage to fishing gear) or not relevant and only 39% as an environmental problem, which represents that 61% of fishers are not aware of the conservation needs for the protection of sea turtles.

Factors that determine the bycatch of sea turtles

According to the observers' reports, the main factors associated with turtle bycatch detected in this study were bait type, target species and season. However, the hook type was not found to be a significant factor, possibly because most J-hooks used in the EPO are slightly smaller than circle hooks, which possibly cause the same probability of being swallowed (Parga et al., 2015) but J-hooks cause much more damage and deaths (Parga, 2012). Previous studies such as Foster et al. (2012) in North Atlantic Ocean, Yokota et al. (2009) in Western North Pacific or Coelho et al. (2015) in Tropical Northeast Atlantic Ocean have already shown that squid increases bycatch as it is difficult to separate from the hook and it is swallowed whole (Stokes et al., 2011; Serafy et al., 2012). In the case of the target species, mahi-mahi is the main species linked to the capture of sea turtles, especially for the olive ridley turtle (Whoriskey et al., 2011, Costa Rica's Pacific; Bugoni et al., 2008, Southern Brazil). The results also showed winter as the maximum catch period, which coincides with the peak of mahi-mahi catches as well as when fishing occurs (Whoriskey et al., 2011; Andraka et al., 2013). However, this may be related to the depth of the set, since the mahi-mahi fishing terminal gear is set at between 12-16m deep in winter, while in summer tuna and billfish are deeper, at 20-30m. Previous studies in Madeiran Waters (Dellinger and Ferreira, 2005), Mediterranean Sea (Alessandro and Antonello, 2010) or Atlantic and North Pacific (Swimmer et al., 2017) have shown that the main interaction depth with longlines is in the upper 20 m of the water column, especially when hooks are set between 10 and 15m deep, which coincides with the mahi-mahi relatively shallow fishing strategy.

Data from the observers vs. fishers

Data from fishers were collected in 2020 and from fishery observers from 2008 to 2018. Data from observers and fishers coincide in that winter is the period of most bycatch and that pelagic species are the target catch when the bycatch occurs but differ in those fishers highlight the role of longlines as the most harmful fishing gear for turtles compared to trawl nets and gill nets (Annex 4). This was also identified at other locations such as in the Equatorial Eastern Atlantic (Carranza et al., 2006) or US North Atlantic (Watson et al., 2005). With this gear, the turtle ingests the hook with the bait, up to 40% deep in the throat with the highest probability of mortality (Stokes et al., 2011; Parga, 2012; Stokes et al., 2012; Swimmer et al., 2014). According to the fishers' perception, nets rank second in the causes of bycatch and the mortality of sea turtles, as in Pacific or Atlantic fisheries, especially at the highest levels by gillnets and trawl nets (Wallace et al., 2010; Wallace et al., 2013; Pingo et al., 2017; Awabdi et al., 2021). Regarding the type of hook, fishers do indicate that the J-hook is responsible for a higher bycatch rate compared to circle hook (Annex 4), up to 19.3 turtles per 1,000 hooks for longlines (eastern Pacific Ocean) (Wallace et al., 2010), with the dimensions (length) of between 41 to 60 mm and 20 to 30 mm having the greatest rates of turtle bycatch (Caracappa et al., 2018).

The bycatch rates obtained in this study (4.3 turtles per 1,000 hooks) are comparable to those extrapolated from the results of Barragán et al. (2009) in Machalilla National Parks (Ecuador), which are approximately 4.8 turtles per 1,000 hooks, or those reported by Whoriskey et al. (2011) in Costa Rica's Pacific, where bycatch rates were 9.05 per 1000 hooks for olive ridley turtle and 0.35 per 1000 hooks for green turtles. On the other

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hand, they are relatively higher than those reported by Wang et al. (2021) in the Pacific Ocean, Gilman et al. (2007) in Hawaii longline fleet or Jaiteh et al. (2021) in the western Pacific Ocean (Caroline Islands) with sea turtle bycatch rates ranging from 0 to 0.024/1,000 hooks, 0.094/1,000 hooks and 0.29/1,000 hooks, respectively.

In this study, the observer data indicated higher frequency of catch of green and olive ridley turtles, while the fishers' data identified hawksbill turtles to be most frequently captured In this sense, it is important to train fishers in species identification to improve accuracy of fisheries data collection (Fulton et al., 2019). Awabdi et al. (2021) in southeastern Brazil also found that green turtle was the most-captured species with all fishing gear (gillnet, trawl net and longline) according to the fishers' perception, and Huang and Liu (2010) highlighted the capture of the olive ridley turtle by tuna longline fleets in the Indian Ocean.

Quantitative inclusion of the human element can increase our understanding of marine conservation issues (Awabdi et al., 2021; Primack et al., 2021). Our results highlight the fact that age and years of experience modify the perception of bycatch, as Bender et al. (2014) observed. Additionally, other parameters such as educational or socioeconomic level also have an effect on perception (Pont et al., 2016). For instance, a more negative perception towards South American sea lions was found among less educated fishers who had no other source of income besides fishing. Sanguinetti et al. (2021) found that older fishers with less formal education have a high focus on maximizing fishing yield, while younger fishers have a more sustainable and conservationist view of fishing. Similarly, Liu et al. (2019), found that artisanal fishers' perceptions of marine mammals were predicted by fishing experience and education level. Therefore, it is relevant to include these parameters in studies of this type.

This study has showed that only 39% of fishers perceive incidental catch as an environmental problem, 60.6% consider it as a nuisance or not relevant. This coincides with the results of Aguilar-González et al. (2014) in the Gulf of California, where individual fishers do not see themselves as part of the problem. Although data concerning perception could be biased, since fishers may consider bycatch to be a larger problem than they indicated in the questionnaires because of concerns regarding their livelihoods or negative previous experiences such as damaging nets, spoiling catch, removing bait, or the endangered status of the species (Godley et al., 1998). However, validating the fishers' answers with data collected directly by observers on the fishing vessels could help to minimize this bias (Carreras et al., 2004). Finally, understanding how worldwide fishers perceive and use resources has significant management and policy implications (Awabdi et al., 2021), which would allow the development of robust management models for sustainable fishing, as pointed out by Karnad et al. (2014).

National and international interpretation of the results

At the national level, the results showed the high-level impact that the artisanal fleet has on sea turtles, which was similar to previous studies (Alfaro-Shigueto et al., 2011; Alfaro-Shigueto et al., 2018); highlighting that the season (winter) and type of hooks used with mahi-mahi are associated with bycatch of sea turtles (Andraka et al., 2013). Although Ecuador is implementing measures to reduce the bycatch of sea turtles and other megafauna (such as adoption of circle hooks, distribution of tools and training to unhook turtles from hooks or fisheries observer programs (https://www.iattc.org/GetAttachment/), these policies are still insufficient or not implemented by fishers (Alava et al., 2019). For this reason, empowering fishers' governance is crucial to mitigate megafauna bycatch. At an international level, the results coincide with other studies in the EPO region, which highlight that in order to expand the use of circle hooks in the EPO region, governments should guarantee the availability of circle hooks at competitive prices in each country, and fishery authorities should implement regulatory measures in the use of tools to handle and release turtles (Parga et al., 2015). Therefore, the certification of the implementation of sustainable practices should be presented to fishers as a chance to access international, environmentally sensitive markets. Likely, measures at the international level should invest on scientific data collecting, training, support for the role of women, access to new technologies (by-catch reduction technologies) and promote more sustainable fishing practices (similar to https://oceans-and-fisheries.ec.europa.eu/fisheries/rules/small-scale-fisheries_en).

Limitations

Despite the large amount of information generated by the "Ecuador National Fisheries Observer Program", it only represents a small percentage of the Ecuadorian fishing fleet (10% for 2022; ACUERDO Nro. MPCEIP-SRP-2021-0208-A). Onboard observers can only be efficiently placed on one of the two decks, and information is provided by the crew to complement it, underestimating bycatch estimates (Luck et al., 2020), especially when bycatch estimation is of a lower priority (Forget et al., 2021). The longline fleet is the only one monitored by fisheries observers, while other fishing gears (such as gillnets or trawls) are absent. Another limitation is the possible bias of the fishers when answering the questions due to the fact that their perceptions depends on their memory and bycatch numbers could not be accurate (Mustika et al., 2021). To avoid this, it is relevant to include educational or socioeconomic variables in this type of studies (Pont et al., 2016); and to carry out studies with holistic approaches, where research integrates insights from local fisher communities with large-scale, long-term monitoring programs (Vásquez-Carrillo and Peláez-Ossa, 2021). Natural sciences are increasingly recognizing the value of social science methods for conducting conservation research, through interdisciplinary collaboration (Lowe et al., 2009). In this sense, there is also a growing foray by ecologists into social science realms (Lowe et al., 2009; Moore et al., 2010; Awabdi et al., 2021). For this study, we found several obstacles to achieve our research objectives, which were solved by collaboration with social scientists.

Management implications and recommendations to reduce bycatch

In summary, based on our results and previous studies, we propose a series of management measures and recommendations that could contribute to minimizing the current bycatch rates (see Annex Table S4). Firstly, we recommend (i) evaluating and using the knowledge of the fishers as a tool to diagnose the situation in a time efficient manner (Vásquez-Carrillo and Peláez-Ossa, 2021), (ii) implementing the most turtle friendly type and size of hook and/or type of bait (larger, circular hooks and fish as bait) (see Swimmer et al., 2020), (iii) evaluating the fishers' willingness to adopt bycatch reduction technologies (e.g. LEDs; Bielli et al., 2020; Darquea et al., 2020; Allman et al., 2021), (iv) implementing economic compensation, such as ecological labels or subsidies that would provide added value or incentives for fishers carrying out sustainable practices (Leduc and Hussey, 2019). Finally, (v) the implementation of education and awareness campaigns is also essential, since 32% of fishers do not see this situation as a problem. Legislative changes and political measures must include the fishers' perception (hook, bait, fishing bans) and monitoring programmes (both scientific and citizen science) in any management plans since any action without their active participation and cooperation might fail (Mason et al., 2020). This may be of help to researchers and policy makers to achieve a better managed, sustainable fishery (Panagopoulou et al., 2017). In this sense, we recommend addressing the gap between the fishers' perceptions and behavior as part of the development of environmental policies at the local, regional and national level which, in turn, should then contribute to reducing the significant global impact of bycatch on sea turtles and other species caused by artisanal fishing.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding authors.

Author contributions

AC, RS, FT, and YA contributed equally to the conceptualization of this study. MV, YA, and EQ collected the data. AC, RS, and MR conducted the statistical analyses and the data were interpreted by all authors. AC and YA wrote the manuscript; the other authors provided editorial advice. All authors have read and agreed to the version of the manuscript submitted for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.936734/full#supplementary-material

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