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Bycatch mitigation from the sky: using helicopter communication for mobulid conservation in tropical tuna fisheries

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The incidental capture of non-target species (bycatch) in tuna fisheries impacts some marine vertebrates, particularly species with vulnerable life histories such as manta and devil rays (mobulids). There is broad interest in reducing mobulid bycatch in tuna purse seine fisheries, with existing efforts mainly focusing on reducing post-capture mortality rates. We explore a novel potential pre-capture mobulid bycatch avoidance strategy for the tuna purse seine fishery using communication between fishing vessels and associated spotter helicopters. We conducted a survey of tuna purse seine helicopter pilots, spotters, and fishers operating in the eastern Pacific Ocean (n = 33) to ascertain the ability of helicopter crew to detect mobulids prior to capture and communicate bycatch avoidance with vessel crew. Results indicate over half of the helicopter crew report being "always" or "sometimes" able to sight and identify mobulids and that helicopter crew regularly communicate mobulid sightings to the vessel already. Given that an average of 63% of class-6 vessel trips between 2017 to 2022 carried onboard helicopters, our results suggest that helicopter-vessel communication could be feasible and scalable for mobulid bycatch detection, enabling potential bycatch avoidance and early alerts for proper handling protocols. We also identify the potential use of helicopter detection to improve research efforts for mobulid conservation (e.g., data collection of population and habitat observations). This study is the first to investigate the utility of helicopter-vessel communication as a bycatch mitigation strategy for elasmobranchs and identifies research and management directions that could be further investigated to avoid bycatch of mobulids.

KEYWORDS
purse seine, management, eastern Pacific Ocean, stakeholder knowledge, elasmobranch, conservation technology

1 Introduction

The incidental capture of non-target species (bycatch) is one of the main drivers of population declines for several large marine vertebrate species (Myers and Worm, 2003; Lewison et al., 2004; Eddy et al., 2016). Sharks and rays (elasmobranchs), sea turtles, marine mammals, and seabirds are particularly at risk from bycatch due to vulnerable life history traits including slow growth, delayed maturity, and low fecundity (Gilman, 2011; Duffy et al., 2019).

Manta and devil rays (together referred to as mobulids) are filter-feeding species distributed globally in tropical and subtropical waters (Couturier et al., 2012; Stewart et al., 2018). Mobulids' geographic ranges overlap with commercial tuna fisheries across multiple gears, creating the potential for incidental bycatch (Croll et al., 2012; Croll et al., 2016; Lezama-Ochoa et al., 2019b). Additionally, declines in mobulid populations have been observed globally (Couturier et al., 2012; Ward-Paige et al., 2013; Lezama-Ochoa et al., 2019b; Fernando and Stewart, 2021). As a result, all nine mobulid species are considered Vulnerable or Endangered on the International Union for Conservation of Nature Red List (IUCN, 2023). All mobulid species were also added to Appendices I and II of the Convention of Migratory Species (2015), which indicates conservation obligations for the protection of migratory species (Lezama-Ochoa et al., 2019b; Griffiths and Lezama-Ochoa, 2021) and to Appendix II of the Convention on International Trade in Endangered Species, which restricts international trade of listed species (Lyster, 1989; CITES, 2016). Despite these efforts, mobulid vulnerability to fisheries impacts persists (Croll et al., 2016; Fernando and Stewart, 2021; Griffiths and Lezama-Ochoa, 2021).

Some of the highest reports of mobulid catch and bycatch occur in the eastern Pacific Ocean (EPO), an important habitat for mobulids due to its favorable environmental conditions including seasonal upwelling and high productivity (Croll et al., 2016; Alfaro-Cordova et al., 2017; Lezama-Ochoa et al., 2019a). A total of 58,609 mobulids were caught by tuna fisheries operating in the EPO between 1993 and 2014, including all five species found in the EPO: oceanic manta ray (*Mobula birostris*), spinetail devil ray (*M. mobular*), sicklefin devil ray (*M. tarapacana*), bentfin devil ray (*M. thurstoni*), and pygmy devil ray (*M. munkiana*) (Lezama-Ochoa et al., 2019a). Further, captures of large mobulid aggregations have been recorded in this region, with reports of up to 220 individuals being caught in a single purse seine net (Lezama-Ochoa et al., 2019b; Palacios et al., 2023). EPO tuna purse seiners use three types of fishing strategies: nets deployed around schools of tuna associated with dolphins (dolphin sets), nets deployed around free-swimming schools of tuna (unassociated sets or school sets), and nets deployed around tunas aggregating near floating objects (natural log objects or fishing aggregating devices (FADs)) (Duffy et al., 2019; Lezama-Ochoa et al., 2019a). While tuna fishing sets and catches in the EPO increased from 2010-2019 and have generally remained steady in the EPO in recent years (IATTC, 2022), capture rates of the most frequently caught mobulid species (*M. mobular*) have decreased, suggesting populations in the region may be experiencing declines (White et al., 2015) given the species' substantial increase in vulnerability status despite fishery closure periods in recent years (Griffiths and Lezama-Ochoa, 2021). In response, efforts to develop conservation and management measures have increased, including the employment and evaluation of best handling and release practices (Hutchinson et al., 2017; Hutchinson et al., 2023).

Several tuna Regional Fisheries Management Organizations (tRFMOs) have implemented conservation and management measures for mobulids across oceans (Duffy et al., 2019; Griffiths and Lezama-Ochoa, 2021). In 2015, the Inter-American Tropical Tuna Commission (IATTC), which manages tuna fisheries operating in the EPO, adopted Resolution C-15-04 which prohibits the "retention, transshipment, landing, storing, sale, or offering for sale of any part or whole carcass of mobulid rays by any commercial vessel" to encourage more sustainable tuna fishing operations (IATTC, 2015). The resolution also prohibits specific mobulid ray handling and manipulation methods (e.g., use of gaffs, hooks, or damage to the body or gills) and encourages proper handling and release methods for smaller individuals and new release handling techniques recommended by Poisson et al. (2014) (e.g., the use of a waste chute from the lower deck). Implementing appropriate best handling and release practices can reduce post-capture mortality rates by as little as 20%, as simulated for EPO tuna fisheries in 2018 (IATTC, 2023a).

Even with these fishery modifications, mobulids likely remain vulnerable to post-capture bycatch mortality (Stewart et al., 2018). Mobulids are obligate ram ventilators and require constant movement of water over their gills to breathe (Carlson et al., 2004). Further, mobulids lack a rigid skeleton to protect their internal organs, putting them at risk of internal injuries and crushing during handling (Poisson et al., 2014; Stewart et al., 2018). These traits emphasize the importance of developing effective bycatch avoidance or early release strategies to prevent or reduce mortality pre-capture, in addition to recent post-capture handling and releasing modifications.

The behavior and distribution of mobulids make developing pre-capture avoidance strategies challenging. First, mobulids share habitats with fishery target species (skipjack, yellowfin, and bigeye tuna), with co-occurrence mainly observed in free-swimming tuna school sets and dolphin-associated fishing sets (Lezama-Ochoa et al., 2019b). Second, some mobulid species (e.g., *M. birostris* and *M. mobular*) are highly migratory, traveling between productive regions to access oceanographic features with ephemeral prey availability, exposing them to bycatch across a broad geographic range; other species (e.g., *M. munkiana*) aggregate in specific coastal areas during different seasons for feeding or mating, exposing them to bycatch during vulnerable life history stages (Couturier et al., 2012; Croll et al., 2012; Lezama-Ochoa et al., 2019b; Andrzeiaczek et al., 2021; Palacios et al., 2021, 2023). Due to these broad distributions, inter-specific differences in movement patterns, and aggregative behaviour, it has been difficult to implement effective early avoidance and mitigation methods for all species.

Many bycatch mitigation programs have identified stakeholder collaboration and cooperation as key components to their success, as the application of bycatch mitigation measures is both a sociopolitical and an ecological endeavor (Moreno et al., 2007; Lewison et al., 2015; Hazen et al., 2018). Fishers have first-hand experience with vessel operations and bycatch protocols and are uniquely positioned to identify feasible mitigation methods (Matsushita et al., 2002; Cronin et al., 2023). The inclusion of fishers and fishery stakeholders in the development of novel bycatch mitigation can guide the implementation of more effective and adaptive bycatch mitigation (Hind, 2015; Stephenson et al., 2016; Watson et al., 2018; Cronin et al., 2023; Pol and Maravelias, 2023).

One way the involvement of fishers has helped address bycatch in dynamic environments is through the implementation of fleet-wide communication programs (Bethoney et al., 2017). Fleet communication programs prompt fishers of several vessels to act together sharing fishery information in real-time (Gilman et al., 2006; O'Keefe et al., 2014). Although fleet communication programs can be effective at reducing bycatch (Gilman et al., 2006), they often add additional costs and require voluntary uptake and communication from most vessels in a fleet (O'Keefe et al., 2014). Considering both these programs' success and potential costs, a similarly modeled but smaller-scale approach to bycatch communication in the EPO using existing technology may be the first step to exploring the potential of communication programs.

Many large vessels in the EPO use spotter helicopters that fly miles ahead of the vessel in search of schools of fish and/or dolphins that tuna may be associated with (Lennert-Cody et al., 2016). Helicopters are usually single-rotor two-seater designs, operated by special crew members and include cockpits that allow a spotter to search for dolphins and tuna (Lennert-Cody et al., 2016; Trygg Mat Tracking and IMCS Network, 2021). Data from class-6 tuna purse seine vessels (i.e., vessels larger than 362 tons of carrying capacity) indicate that 69% of trips in 2022 carried an onboard helicopter (IATTC, unpublished data). In detail, aerial assistance was used for 99.7% of dolphin sets, 75.4% of unassociated sets, and 35.7% of floating object sets. Class-6 vessels account for roughly 75% of the purse seine fleet in the IATTC Convention Area and produce nearly 90% of the catch, demonstrating the potential for the use of helicopter-generated information to mitigate mobulid bycatch.

The ability of helicopter crew to sight dolphin pods and tuna from the air suggests they may also be able to sight other non-target near-surface swimming species in the area. Previous research on elasmobranchs conducted through aerial surveys at altitudes ranging 150m – 579m provide evidence that they are visible by plane when at the water's surface (Figure 1; Notarbartolo-di-Sciara and Hillyer, 1989; Mullican et al., 2013; Kajiura and Tellman, 2016; Nykänen et al., 2018; Trujillo-Córdova et al., 2020). In a previous survey of tuna fishers from the EPO, a small number of helicopter pilot respondents reported being "sometimes" aware of mobulid presence before deploying the purse seine net in the water (Cronin et al., 2023). Mobulids may be recognizable from air because of their distinctive shape, large body size, prominent cephalic fins, dark coloration, tendency to swim and jump at the ocean's surface, and tendency to aggregate in large schools (Notarbartolo-di-Sciara and Hillyer, 1989; Croll et al., 2012; Notarbartolo-di-Sciara et al., 2015; Francis and Jones, 2017; Palacios et al., 2023; S. Velazquez Hernandez, pers. comm., 22 December 2021). Communication between tuna helicopter pilots and their associated vessels about where mobulids are located could inform potential bycatch avoidance strategies in tuna purse seiners. This study investigates 1) the ability of tuna purse seine fishery helicopter crew to identify mobulids before the net is set, and 2) the potential feasibility of implementing bycatch communication protocols between helicopter and vessel crew. Given previous conservation gains from fleet communication programs, we hypothesize that within-vessel communication could be similarly feasible, particularly with vessels in a high-capacity fishery using spotting helicopters to facilitate fish-finding.

2 Methods

We conducted structured surveys with helicopter pilots, spotters, and fishers with experience working in the EPO tropical tuna purse-seine fishery to understand 1) visual awareness of mobulids while on the helicopter, 2) differences between visual awareness of helicopter and vessel crew, and 3) existing habits of communicating with vessel crew and potential improvements to communicating mobulid presence.

2.1 Survey design and distribution

Surveys were administered in Spanish and English via the survey platform Qualtrics from February to July 2022 (UCSC IRB #HS-FY2022-156). Survey results were translated into English using a translation service before analysis. All respondents read and agreed to a consent form before participating which instructed that all survey questions were voluntary and confidential. Survey questions were grouped into four categories: 1) experience as helicopter crew, 2) indicators used to sight species, 3) visual identification of species, and 4) communication with the vessel (Table 1).

2.2 Data analysis

Participants were split into two groups based on whether they had experience as a pilot or spotter on a tuna vessel helicopter ("helicopter crew") or not ("vessel crew"). Survey results were sorted and analyzed using the *dplyr* package in R version 4.0.4 (Wickham et al., 2023). Responses to multiple-choice questions about participants' ability to sight bycatch species were placed on a four-point scale and analyzed using the *likert* package in R (Bryer and Speershneider, 2016). To understand mobulids' likelihood of being sighted relative to other large vertebrates, these questions were asked separately for four species groups commonly bycaught in the EPO: mobulids, dolphins, sea turtles, and sharks. The IATTC has specific requirements for purse seine vessels to release these species of interest (IATTC, 2006; IATTC, 2011; IATTC, 2019; IATTC, 2023b), therefore the crew needs to be aware of the species' presence to comply with the commission's requirements.

Each analysis was conducted using a two-tailed test and P-values below 0.05 were considered significant. We performed a Shapiro test for normality using the *stats* package in base R (R Core Team, 2023), which indicated data did not follow a normal

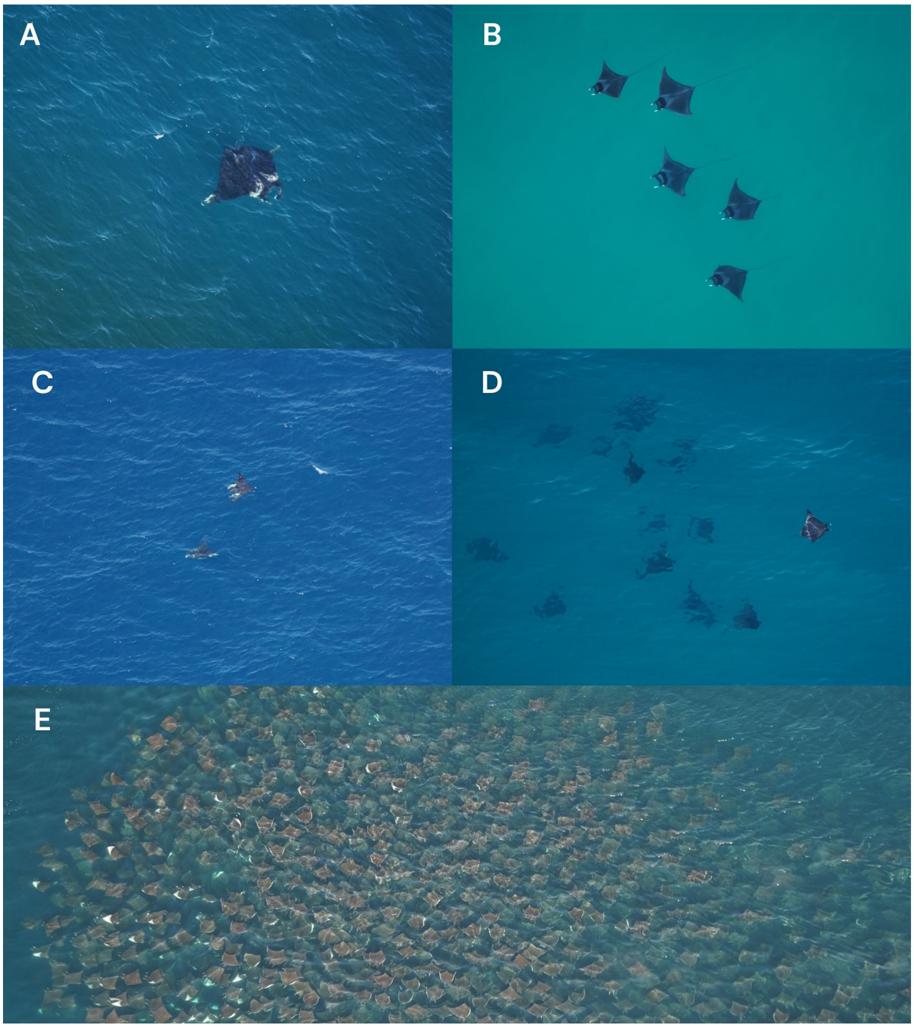

FIGURE 1
Aerial photos taken from a research seaplane of the following five Mobulid species found in the EPO: **(A)** *M. birostris*, **(B)** *M. mobular*, **(C)** *M. tarapacana*, **(D)** *M. thurstoni*, **(E)** *M. munkiana*. Photo credits: © Siddharta Velázquez Hernández, Ocean Life Flights.

distribution. Kruskal-Wallis tests were used to test for differences between independent responses. For data comparing more than two independent variables, such as between responses comparing the four bycatch species groups, *post hoc* Wilcoxon signed-rank tests were used to test for differences between paired answers. Effect sizes were calculated to measure the strength of the relationship (Kruskal-Wallis test: small effect = 0.01–0.06, moderate effect = 0.06–0.14, large effect = >0.14; Wilcoxon signed-rank test: small effect = 0.10–0.30, moderate effect = 0.30–0.50, large effect = >0.50). Participants who did not respond to a given question were excluded from the analysis of that question, therefore questions differ in their number of respondents.

3 Results

A total of 33 tuna purse seine fishers operating in the EPO were surveyed. 30% of the respondents (n = 10) had experience as helicopter crew, while 70% (n = 23) of respondents did not. The survey sample size was limited and constrained by the number of eligible accessible participants, particularly for helicopter crew.

3.1 Visual identification of species

When asked about their ability to sight and identify mobulids, helicopter crew were more likely to report "always" or "sometimes" being able to identify the species of mobulid than vessel crew (Kruskal-Wallis test: $p < 0.05$; effect size = moderate; Figure 2A), and were more likely to "always" or "sometimes" be able to sight an individual mobulid compared to vessel crew (Kruskal-Wallis test: $p < 0.01$; effect size = large; Figure 2C). Respondents' ability to "always" or "sometimes" sight mobulid schools was higher for helicopter crew (40%; n = 4) than vessel crew (10%; n = 2; Figure 2B) and overall, 85% of respondents (n = 23) said less than 10 individuals are needed to sight a mobulid school.

TABLE 1 Survey questions included in this study.

Category	Question	Answer Type
Helicopter experience	Are you currently or do you have experience as a helicopter pilot/spotter on a tuna vessel?	Yes/No
Sighting indicators	What are the easiest species to sight from the helicopter/vessel?	Open-ended
	What indicators/ characteristics do you use to sight non-target species? (e.g., color, behavior, etc.)	Open-ended
	What observational signals do you use to sight **mobulids**?	Open-ended
	How do environmental conditions affect your ability to sight non-target species from the helicopter/vessel? (e.g., weather, time of day, sea-state conditions, light conditions, etc.)	Open-ended
Species sightings ('X' suggests that each question was asked separately for mobulids, dolphins, sea turtles, and sharks)	How often are you able to sight an **individual (X)** from the helicopter/vessel?	Likert scale: Always, sometimes, seldom, never
	How often are you able to **identify the species of (X)** from the helicopter/vessel?	Likert scale: Always, sometimes, seldom, never
	How often are you able to sight a **large school of (X)** (more than 50 individuals) from the helicopter/vessel?	Likert scale: Always, sometimes, seldom, never
	Generally, what is the **minimum number of individuals** needed for you to identify a **school of (X)**?	Numeric
Communication with the ship	How often do you report **(X) sightings** to the vessel?	Likert scale: Always, sometimes, seldom, never
	What kind of information do you report to the vessel? (Select all that apply)	Multiple choice: -Type of tuna (species) sighted -Number (amount) of tuna sighted -Location of tuna schools -Type of non-target species sighted -Number of non-target species sighted -Location of non-target species -Other:
	How much additional time would it take for you to include non-target species identification (such as sea turtles, sharks, manta rays, etc.) in your routine vessel communication?	Multiple choice: -Less than 5 minutes -5-10 minutes -10-15 minutes -More than 15 minutes
	How could you imagine communication with the vessel could be improved to avoid incidental catches of non-target species (such as sea turtles, sharks, manta rays, etc.)?	Open-ended

Comparing the four taxonomic groups, more respondents reported being "always" or "sometimes" able to sight a dolphin school than a mobulid school (Kruskal-Wallis test: $p < 0.001$; Wilcoxon signed-rank test: $p < 0.001$; effect size = large; Supplementary Figures S1, S2). Respondents were also more likely to "always" or "sometimes" be able to identify the species of dolphin compared to the species of mobulid (Wilcoxon signed-rank test: $p < 0.05$; effect size = moderate; Supplementary Figure S2). When asked what the easiest marine animals are to sight, mobulids were the third most frequently reported species (18%; n = 6), following dolphins (76%; n = 25) and whales (55%; n = 18).

3.2 Communication with the vessel

All helicopter crew respondents said they "always" or "sometimes" communicate mobulid sightings. This was significantly more frequent than vessel crew, of whom 60% reported "always" or "sometimes" communicating mobulid sightings (Kruskal-Wallis test: $p < 0.05$; effect size = moderate; Figure 2D). In comparison, all but one respondent said they "always" or "sometimes" communicate dolphin sightings to the vessel (Supplementary Figure S1).

For the type of information communicated regarding species sightings, respondents said they routinely communicate the type of tuna (97%; n = 28), the location of tuna (79%; n = 25), and the number of tuna (69%; n = 20; Figure 3A). More than half of respondents said they communicate the type of bycatch species (66%; n = 19), followed by the location of that species (52%; n = 15) and the number of individuals of that species (45%; n = 13; Figure 3A). Vessel crew were slightly more likely to report specific information about bycatch species sightings while helicopter crew were slightly more likely to report specific information about tuna sightings (Figure 3B).

When asked how much additional time it would take to communicate information about bycatch species presence, 60% of helicopter crew respondents (n = 6) said it would add less than five minutes to routine communication, 30% (n = 3) said five to ten minutes, and 10% (n = 1) said ten to fifteen minutes.

Participants made several recommendations for improving within-vessel communication about bycatch. Respondents suggested implementing: 1) more detailed coordination between the helicopter and the vessel (e.g., reporting the specific species and its location), and 2) improving maneuvering (e.g., separating

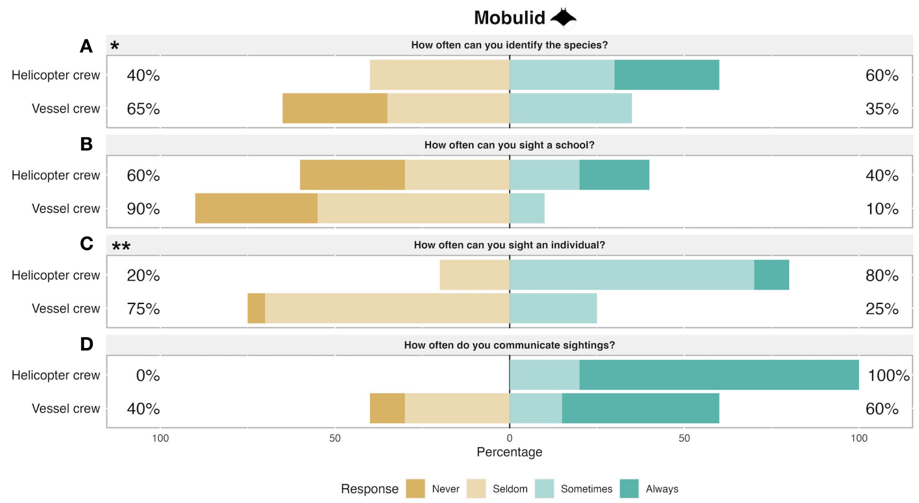

FIGURE 2
Fishers' ability to identify the species of mobulid, sight schools of mobulids, sight individual mobulids, and frequency of communicating mobulid sightings. Grouped by experience as tuna purse seine helicopter crew (n = 10) or no experience as helicopter crew (n = 20). * = p < .05 ** = p < .01.

bycatch and target species before setting or removing bycatch from the net).

3.3 Indicators used to sight species

For the indicators used to sight bycatch species, most fishers reported using the color of the species as an indicator of its presence (47%; n = 14), but others included the species' behavior, shape, jumps, fins, size, schooling behavior, and the presence of birds. For mobulids specifically, their behavior to jump was the highest given response (56%; n = 15), followed by their color (11%; n = 3), shape (11%; n = 3), movements (7%; n = 2), number of individuals (4%; n = 1), and the presence of birds (4%; n = 1).

In addition, respondents were asked what environmental conditions affect their ability to sight bycatch species. Weather (48%; n = 15) was the most reported answer, followed by sea state (i.e., wind, waves, and swell of the ocean's surface) (35%; n = 11), time of day (23%; n = 7), and light conditions (19%; n = 6). These factors can prevent the visibility of species in the water, as one respondent wrote that light conditions and weather are especially obstructive when the weather is cloudy, and the color of the species is not visible.

4 Discussion

This is the first study to investigate communication between helicopter and vessel crew about mobulid sightings as a potential pre-capture avoidance strategy for mobulid bycatch. There are limitations associated with the small sample size of this study due to a limited number of vessels currently using helicopters and limited access to this specific crew – generally, only class-6 vessels carry helicopters, and aerial assistance on these vessels may come

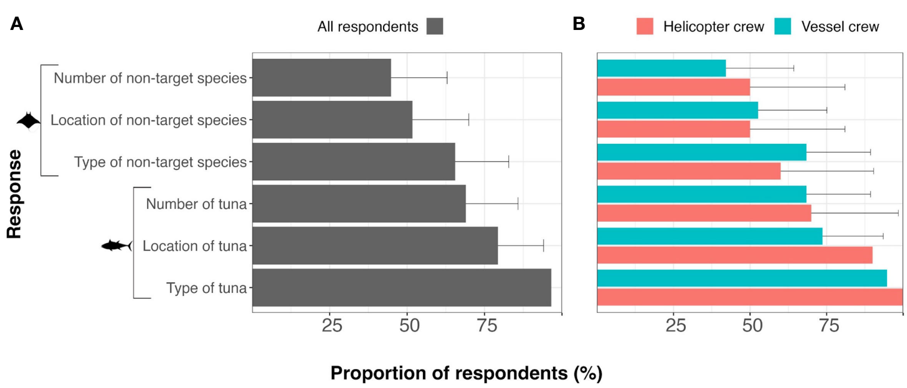

FIGURE 3
(A) Information EPO tuna purse seine fishers routinely communicate to vessel crew (N = 29). **(B)** Responses separated by the proportions of helicopter crew (N = 10; in red) and the proportions of vessel crew (N = 19; in blue). Data are expressed as the proportion ± margin of error.

from either their onboard helicopter, the helicopter of another vessel, or a spotter plane. Nevertheless, our analysis suggests helicopter crew may be more successful in sighting mobulids and are more likely to communicate information about mobulid sightings, creating new opportunities to reduce mobulid bycatch. These results provide guidance on factors influencing mobulid sightings and information that is currently routinely communicated, which could aid in developing protocols for reporting mobulid presence to the vessel.

Participants with helicopter experience were more likely to report an ability to sight an individual mobulid and identify the species of mobulid compared to other vessel crew, suggesting that helicopter crew may be more useful in locating mobulid presence. It should be noted that participants may have interpreted the species identification question as referencing the identification of mobulid rays, rather than the specific species of mobulid. Even so, these results are consistent with a previous study investigating mobulid bycatch mitigation methods in New Zealand, in which two interviewed spotter plane pilots said that mobulids were visible from the air and they felt capable of distinguishing between different mobulid species (Jones and Francis, 2012). Previous studies using spotter planes to identify aggregation sites of *M. mobular* in the Mediterranean and *M. birostris* in the Caribbean Seas additionally demonstrate the ability to spot and differentiate between mobulids from the air (Notarbartolo-di-Sciara and Hillyer, 1989; Duffy and Abbott, 2003; Notarbartolo-di-Sciara et al., 2015). Pilots aboard these spotter planes were likely well-trained to identify mobulids but highlight the potential for training helicopter crew on species identification to differentiate between mobulid species.

Dolphins were the easiest species to sight and dolphin schools were more likely to be sighted compared to mobulid schools. These results are unsurprising, given the size of the aggregation of dolphin schools. In fact, dolphin schools are used as an indicator of tuna presence in the EPO (Polacheck, 1989; Lewison et al., 2004; Lennert-Cody et al., 2016; Ward et al., 2018). If fishers are already looking for dolphin schools and already know what indicators to look for to do so, it is conceivable that dolphins could be a model and the use of similar visual indicators could be explored as a way of improving the sighting of mobulids and other bycatch species of similar size and characteristics.

Given the ability of helicopter crew to see mobulids while searching for tuna and the reported ease of communicating this information, helicopter-vessel communication could be a feasible bycatch mitigation strategy for mobulids, on the condition that communication and coordination between helicopter and vessel crew are improved by including more information on the presence of bycatch species that can be factored into purse seine sets. This communication should include in-depth information about the species, number, and location of mobulid presence. Information could be shared within vessels and between vessels, particularly for vessels cooperatively fishing in groups (Lennert-Cody et al., 2020). Communication could also include whether mobulids are observed alone or in large schools. Though mobulids are more frequently caught in low numbers per set (Lezama-Ochoa et al., 2019b), all mobulid species are documented to undergo aggregation behavior (Palacios et al., 2023) and large aggregations (more than 50 individuals) of some species in the EPO have been observed and captured by sets (Lezama-Ochoa et al., 2019b). To scale the helicopter information and to provide alternative solutions for vessels that do not carry a helicopter, there may be potential to establish a comprehensive onshore open reporting system – like a fleet-wide communication program. If supported by the Regional Fisheries Management Organizations, the system could collect and report real-time information to all registered fleets operating in the area. One example of where a similar helicopter reporting system has been applied in the conservation context is in the heli-ski industry, whereby one company has their guides report caribou sightings via a proprietary tool; the tool alerts other guides in the company when there's a high chance of seeing a caribou in a specific area for them to avoid (Williamson, 2024).

In addition to improved communication, we suggest that improving the helicopter crew's ability to sight bycatch species while searching for tuna may aid in advancing their communication and applying this bycatch avoidance strategy to other vulnerable species, such as sea turtles and sharks. The ability of purse seine fishery crew and observers to accurately identify the mobulid species is low (Lezama-Ochoa et al., 2019b). Training helicopter crew on species identification could additionally help improve their ability to sight mobulids and possibly differentiate between species when reporting sightings to the vessel. Helicopter crew could be provided with a species identification guidebook that includes aerial images of various bycatch species and the indicators they can use to sight them. Similar guidebooks are often distributed to fishery observers and crew in industrial tuna fisheries (Chapman and Secretariat of the Pacific Community, 2006; Fukofuka and Itano, 2006; Stevens, 2011; Park, 2019), and could be adapted for aerial perspective. Significant efforts are currently being conducted to improve species identification in the EPO, such as the development of smart tools based on artificial intelligence or genetic information, or simpler approaches like the development of mobulid species identification guides for observers and fishers (e.g., IATTC SAC-13-01). Educational posters on mobulid identification have also been distributed for tuna fishers in each ocean (Cronin et al., 2023), which could be adapted for use in an aerial setting. Crew's identification skills could also be improved through training workshops. Skipper workshops have previously been conducted to teach crew about advances in bycatch mitigation methods and regulation (Murua et al., 2019; Murua et al., 2023). Adding scientist-led training on species identification during these workshops could improve the crew's ability to identify non-target species; similar workshops can be implemented specifically with the helicopter crew for species identification from an aerial view.

Although almost all effect sizes for significant results were large, the small sample size of this study (n = 33) is a limitation — however, we suggest these results as an indicator of directions for future research. Short-term research directions include: investigating potential incentives for the fleet to improve communication, incentives for bycatch avoidance if helicopter-vessel communication is further considered as an option, and measuring the vessel response time to helicopter-vessel communication. Additionally, we recommend exploring the development of feasible modifications of the net setting process that can effectively translate non-target species information communicated from the helicopter into reduced bycatch in net sets. For instance, several respondents made suggestions of using helicopter information as an alert to maneuver according to the non-target species' location before setting the net. RFMOs should concentrate their efforts on bycatch avoidance strategies, such as this one, considering the vulnerability status of mobulids and other commonly caught species. However, when isolating the species is not possible, information could serve as an early alert for the species' quick release knowing it will be in the set. Finally, as this sample only encompasses vessels with onboard helicopters operating in the EPO, future research should explore similar methods for identifying mobulid presence and taking preventive measures, including avoiding their capture, that could apply to vessels without helicopters, including dynamic management applications based on remote sensing, drones, sonar, and other emerging technologies (Howell et al., 2008; Moreno et al., 2016; Hazen et al., 2018; Cronin et al., 2023). For vessels without helicopters, the crow's nest serves as an observation platform equipped with high-resolution binoculars and viewing ranges of up to 19 miles in good conditions (Green et al., 1971). This view enables fishers to spot tuna – and potentially detect non-target species – much like they do from helicopters, caveating for the reduced visibility of species at depth.

This study highlights the valuable information that helicopter pilots could provide to scientists on the presence of mobulids and other species in specific areas. Increasing knowledge of mobulid populations and their habitats is a research priority (Stewart et al., 2018; Lezama-Ochoa et al., 2019b; Palacios et al., 2023), but investigating these species in the open ocean is often difficult and costly. Helicopter crew might see mobulids during flights but not report these sightings because there is currently no protocol or requirement to do so, other than cases for which fishing operations commence and observers must record any caught mobulids. The use of helicopter crew as observers of the pelagic environment could help fill important knowledge gaps about the spatial and temporal distribution of mobulids and other pelagic species and should be further considered in the EPO.

Bycatch avoidance programs have been most effective when integrated with existing or impending regulations (Bethoney et al., 2017). Despite the small sample size of this study, it could be suggested that combining pre-capture avoidance strategies, such as helicopter-vessel communication, with improved post-capture handling and release methods collectively could significantly mitigate mobulid bycatch and mortality in tuna purse seine fisheries. Helicopter-vessel communication could not only assist avoiding capture but also be an early alert system to the vessel that a mobulid is likely to be in the fishing gear, allowing the vessel crew to prepare for best handling practices for a more efficient release. This study explores a novel application of existing technology for mobulid bycatch avoidance to innovatively include fishers' knowledge and help meet fisheries management goals.

Data availability statement

The data underlying this article cannot be shared publicly to protect the privacy of individuals who participated in the study. The data will be shared on reasonable request to the corresponding author.

Ethics statement

The studies involving humans were approved by University of California Santa Cruz Office of Research Compliance Administration. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JW: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. EA: Data curation, Resources, Writing – review & editing. DC: Supervision, Writing – review & editing. MP: Methodology, Resources, Writing – review & editing. NL: Methodology, Writing – review & editing. JL: Data curation, Resources, Writing – review & editing. GM: Data curation, Methodology, Writing – review & editing. SR: Writing – review & editing. MC: Conceptualization, Data curation, Methodology, Resources, Supervision, Writing – review & editing, Funding acquisition, Investigation, Software.

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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.2024.1303324/full#supplementary-material

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