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EXPLORING HELICOPTER-VESSEL COMMUNICATION FOR MOBULID BYCATCH AVOIDANCE IN TROPICAL TUNA FISHERIES

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ABSTRACT

The incidental capture of non-target species (bycatch) in tuna fisheries is a threat to some marine vertebrates, including manta and devil rays (Mobulids). There is broad interest in reducing Mobulid bycatch in tuna fisheries; however, existing efforts mainly focus on reducing post-capture mortality rates. To explore a potentially novel pre-capture Mobulid bycatch avoidance and mitigation strategy, we conducted a small survey of tuna purse seine vessels' helicopter pilots, spotters, and fishers operating in the eastern Pacific Ocean. We surveyed respondents on their ability to detect Mobulids prior to capture and their communication protocols with vessel crew. Results indicate that over half of the fishing crew searching for tuna from helicopters report being "always" or "sometimes" able to sight and identify Mobulids, and that helicopter crew regularly communicate Mobulid sightings to the vessel already. These results suggest that

helicopter-vessel communication could be feasible for Mobulid bycatch detection, data collection, and potential avoidance, along with the associated potential improvements for science (e.g., data collection of 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.

INTRODUCTION

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

Manta and devil rays (together referred to as Mobulids) are filter-feeding species distributed globally in tropical and subtropical waters (Stewart et al., 2018). Mobulids' geographic ranges overlap with commercial tuna fisheries across multiple gears, creating the opportunity for bycatch (Croll et al., 2016). Additionally, declines in Mobulid populations have been observed globally (Couturier et al., 2012; Lezama-Ochoa et al., 1/2019b; Ward-Paige et al., 2013). As a result, all nine Mobulid species are considered Vulnerable or Endangered on the IUCN Red List (IUCN 2023). All Mobulid species were also added to Appendices I and II of the Convention of Migratory Species (2015), which imposes conservation obligations for the protection of migratory species (Griffiths & Lezama-Ochoa, 2021; Lezama-Ochoa et al., 1/2019b) and to Appendix II of the Convention on International Trade in Endangered Species (CITES), which controls commercial trade and exports (CITES 2016; Lyster, 1989). Despite these efforts, these policies have not resulted in reduced Mobulid vulnerability (Griffiths & Lezama-Ochoa, 2021).

Some of the highest reports of Mobulid 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 (Alfaro-Cordova et al., 2017; Lezama-Ochoa et al., 2019b). 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., 2019b). 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 more vulnerable to declines given the historical vulnerability status of the species (Griffiths & Lezama-Ochoa, 2021).

In an effort to reduce Mobulids mortalities, several tuna Regional Fisheries Management Organizations (tRFMOs) have implemented conservation and management measures for Mobulids across oceans (Duffy et al., 2019; Griffiths & 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, among other provisions, 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 sustainable fishing operations. The Resolution also prohibits specific Mobulid ray manipulation methods (e.g., use of gaffs, hooks, or damage to the body or gills) and recommended new release handling techniques, such as the use of the waste chute for individuals that get to the lower deck and proper handling and release methods for smaller rays.

Mobulids and other elasmobranchs are especially vulnerable to post-capture mortality being handled out of the water, therefore pre-capture bycatch avoidance strategies may be particularly beneficial (Stewart et al., 2018). Mobulids are obligate ram ventilators and need the constant movement of water over their gills to breathe (Carlson et al., 2004). Furthermore, 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.

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); the overlaps are mainly observed in School sets and Dolphin sets (Lezama-Ochoa et al., 2019b). Second, some Mobulid species (e.g., *M. mobular*) are highly migratory and exhibit extensive movements, traveling between productive regions to access oceanographic features with ephemeral prey availability; other species (e.g., *M. munkiana*) aggregate in specific coastal areas during different seasons for feeding or mating (Couturier et al., 2012; Lezama-Ochoa et al., 2019b; Palacios et al., 2021, 2023). It is thus 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 (Hazen et al., 2018; Lewison et al., 2015; Moreno et al., 2007). Fishers have first-hand experience with vessel operations and bycatch protocols and are uniquely positioned to identify feasible mitigation methods (Matsushita et al., 2002). As a result, the inclusion of fishers and fishery stakeholders in the development of novel bycatch mitigation can help guide the implementation of more effective and adaptive bycatch mitigation (Hind, 2015; Stephenson et al., 2016; Pol & Maravelias, 2023; Watson et al., 2018).

One way in which the involvement of fishers has helped address bycatch in a dynamic environment is through the implementation of fleet-wide communication programs (Bethoney et al., 2017). Fleet communication programs prompt fishers of several vessels to act together as "one fleet" to share fishery information in real-time, such as reporting observations of bycatch hotspots and interactions so vessels of the same fleet can actively avoid fishing in those areas (Gilman et al., 2006; O'Keefe et al., 2014). These programs have been used in multiple fishery settings to successfully reduce the capture of non-target species. For instance, during a period in which a fleet-communication protocol was enacted in the U.S. North Atlantic longline swordfish fishery, endangered sea turtle bycatch was reduced by 50% (Gilman et al., 2006). Similarly, in the U.S. Alaska demersal longline fishery, average bycatch rates of halibut were higher for non-participating vessels than for participating vessels during a seven-year period (Gilman et al., 2006). Although fleet communication programs can be effective at reducing bycatch, they often add additional costs and require voluntary uptake and communication from a majority of vessels in a fleet (O'Keefe et al., 2014). Considering both the success of these programs and their 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 vessels in the EPO use helicopters that fly out miles ahead, often 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 a special crew member and include cockpits to allow a spotter to search for dolphins and tuna (Lennert-Cody et al., 2016; Trygg Mat Tracking & IMCS Network, 2021). The ability of pilots and spotters to sight dolphin pods and tuna from the helicopter suggests that they may be able to sight other non-target species in the area. Previous research on elasmobranchs conducted through aerial surveys provide evidence that they are visible by plane when at the water's surface (Mullican et al., 2013; Notarbartolo-di-Sciara & Hillyer, 1989; Nykänen et al., 2018; Pate & Marshall, 2020; 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., 2022). Mobulids may be recognizable from the air because of their 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 (D. Croll et al., 2012; Francis & Jones, 2017; Notarbartolo-di-Sciara & Hillyer, 1989; 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 pilots and spotters 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, particularly with vessels in a high-capacity fishery using spotting helicopters to facilitate fish-finding, could be similarly feasible.

METHODS

We surveyed 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 bycatch.

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 prior to analysis. All participants read and agreed to a consent form prior to participating and were instructed that all survey questions were completely voluntary and responses were anonymous. 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).

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

Participant stratification

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").

Data analysis

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' likelihood of being able to sight a bycatch species were placed on a four-point scale and analyzed using the *likert* package in R (Bryer & Speershneider, 2016). To understand Mobulids' likelihood of being sighted relative to other large vertebrates, these questions were asked separately for four bycatch species groups: Mobulids, dolphins, sea turtles, and sharks.

We performed a Shapiro test for normality, which indicated that the data did not follow a normal distribution. Kruskal-Wallis tests were used to find significant 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 identify paired answers that differed. 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.

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 have experience as helicopter crew. Survey sample size was limited and constrained by the number of eligible accessible participants, particularly for helicopter crew.

Visual identification of species

When asked about their ability to sight and identify Mobulids, helicopter crew were significantly 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; Fig. 1a), 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; Fig. 1c). Respondents' ability to "always" or "sometimes" sight Mobulid schools was higher for helicopter crew (40%; n = 4) than vessel crew (10%; n = 2; Fig. 1b) and overall, 85% of respondents (n = 23) said less than 10 individuals are needed to sight a school of Mobulids.

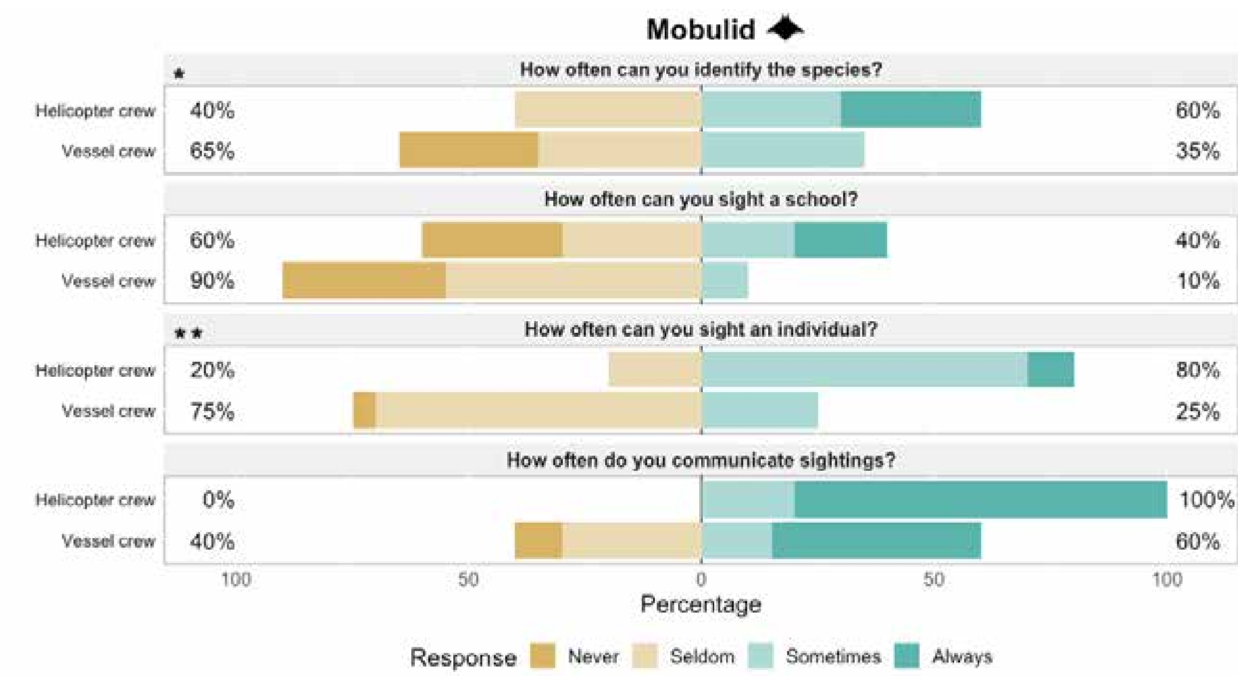

FIGURE. 1 Fishers' ability to identify the species of Mobulid, sight schools of Mobulids, sight individual Mobulids, and frequency of communicating Mobulid sightings. Grouped by experience as tuna purse seine helicopter crew (n = 10) or no experience as helicopter crew (n = 20).

When comparing answers overall between the four taxonomic groups, more respondents reported they are "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; Fig. S1 & S2). Respondents were also more likely to say they are "always" or "sometimes" able to identify the species of dolphin compared to the species of Mobulid (Wilcoxon signed-rank test: $p < 0.05$; effect size = moderate; Fig. S2). When asked what the easiest marine animals are to sight, Mobulids were the third most reported species (18%; n = 6), following dolphins (76%; n = 25) and whales (55%; n = 18).

Communication with the vessel

All helicopter crew respondents said that they "always" or "sometimes" communicate Mobulid sightings. This was significantly more frequent than vessel crew, of whom 60% reported they "always" or "sometimes" communicate Mobulid sightings (Kruskal-Wallis test: $p < 0.05$; effect size = moderate; Fig. 1). In comparison, all but one respondent said they "always" or "sometimes" communicate dolphin sightings to the vessel (Fig. S1).

To understand current communication protocols, we asked participants about the type of information they communicate regarding species sightings. Respondents said they routinely communicate the species ("type") of tuna (97%; n = 28), the location of tuna (79%; n = 25), and the amount of tuna (69%; n = 20; Fig. 2). 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; Fig. 2).

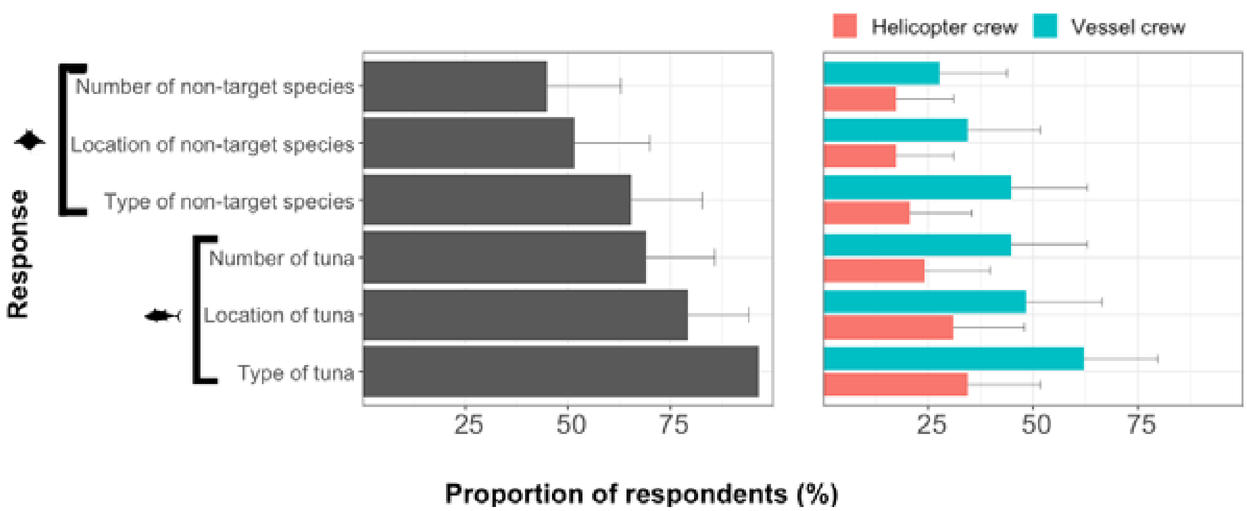

FIGURE. 2 Information fishers routinely communicate to vessel crew. (N = 29).

When asked how much additional time it would take to communicate information about the presence of bycatch species, 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 about how to improve 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 the bycatch and target species before setting or removing bycatch from the net).

Indicators used to sight species

When asked what indicators are used to sight bycatch species, most fishers reported using the color of the species as an indicator of its presence (47%; n = 14), but other reported indicators include 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 (52%; n = 15), followed by their color (10%; n = 3), shape (10%; n = 3), movements (7%; n = 2), number of individuals (3%; n = 1), the light conditions (3%; n = 1), and the presence of birds (3%; n = 1).

In addition, fishers 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 (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 it is cloudy and the color of the species is not visible.

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. Though there are some limitations associated with the sample size of this study due to a limited number of vessels currently using helicopters, our analysis suggests pilots and spotters aboard helicopters may be more successful in sighting Mobulids compared to vessel crew and are 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 the presence of Mobulids to the vessel.

Participants with experience on a helicopter were more likely to report ability to sight an individual Mobulid and to identify the species of Mobulid compared to other vessel crew, suggesting that helicopter pilots and spotters may be more useful in locating the presence of Mobulids. 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 & Francis, 2012).

Mobulids were the third most reported marine animal for ease of sighting, with dolphins being the first, and respondents were more likely to be able to sight a dolphin school compared to a Mobulid school. These results are unsurprising, given the frequent use of dolphin school sightings as an indicator of tuna presence in the EPO (Lennert-Cody et al., 2016; Lewison et al., 2004; Polacheck, 1989; Ward et al., 2018). However, 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 sighting Mobulids and other bycatch species.

All of the helicopter crew respondents in this study reported that they ‘always’ or ‘sometimes’ communicate Mobulid sightings, suggesting that communication about Mobulid sightings is already informally occurring, at least in these cases. Further, a majority of helicopter crew respondents reported that communicating information about the presence of bycatch species would add five minutes or less to routine communication, implying that implementing bycatch communication could be a simple addition to existing vessel communication protocols.

Given the ability of helicopter crew to see Mobulids while searching for tuna and the reported ease of communicating bycatch species 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. This communication should include in-depth information about the species, number, and location of Mobulid presence. Communication could also include if Mobulids are observed alone or associated with tunas or other species. In addition, we suggest that improving the helicopter crew’s ability to sight bycatch species presence 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., 2019). Compared to vessel crew, our results suggest that helicopter crew are more likely to ‘always’ or ‘sometimes’ identify the species compared to vessel crew. Understanding how the helicopter crew is able to distinguish between species is an area of further exploration that could provide valuable identification information.

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. One way this could be done is by providing helicopter crew with a species identification guidebook to use while searching 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 & Secretariat of the Pacific Community, 2006; Fukofuka & Itano, 2006; Park, 2019; Stevens, 2011), and could be adapted for aerial perspective. In fact, 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 more rudimentary approaches like the development of Mobulid species identification guides for observers and fishers (for example, see SAC-13-01). Educational posters on Mobulid identification have also been distributed for tuna fishers in each ocean (Cronin et al., 2022), which could be refashioned for the helicopter. Another way the crew’s identification skills could be improved is through training workshops. Skipper workshops have previously been conducted to teach crew about the latest advances in bycatch mitigation methods and regulation (Murua et al., 2019, 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 also be implemented specifically with the helicopter crew for species identification from an aerial view.

Although almost all the effect sizes for significant results were found to be large, the 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 bycatch avoidance if helicopter-vessel communication is further considered as an option and measuring the vessel response time to helicopter-vessel communication. Additionally, as this sample only encompasses vessels with onboard helicopters operating in the EPO, future research should explore similar methods for identifying the presence of Mobulids and taking preventive measures, including avoiding their capture, that could apply to vessels without helicopters, including dynamic management applications based on remote sensing information and distribution changes of the species, the use of drones, sonar, and other emerging technologies (Cronin et al., 2022; Hazen et al., 2018; Howell et al., 2008; Moreno et al., 2016).

More explicitly, the difficulty in managing the ecosystem impacts of fisheries in a highly dynamic environment has brought attention to dynamic fisheries management (Dunn et al., 2016; Hazen et al., 2018; Lewison et al., 2015; Maxwell et al., 2015). The majority of existing pre-capture bycatch avoidance strategies used in industrial tuna fishing, such as time-area closures, are static and restricted to specific areas (Leape et al., 2020; Lewison et al., 2015). Static management approaches may not always encompass the core habitat of species of concern (Hazen et al., 2018; Lewison et al., 2015; Maxwell et al., 2015). More dynamic and real-time strategies for monitoring and communicating ocean conditions can enable managers and fishers to respond quickly to changing conditions and bycatch risk (Leape et al., 2020). A more dynamic approach to bycatch management could offer a potential "win-win" outcome for protected species and fisheries by supporting effective bycatch reduction while maintaining fisheries yield (Hazen et al., 2018; Lewison et al., 2015; Pons et al., 2022). However, dynamic strategies have not been widely adopted for Mobulids due to the difficulties of good data collection, species identification, and other technical and management challenges. Implementing an adaptive strategy that makes use of existing technology, such as helicopter-vessel communication, may be the first step in exploring the feasibility of adaptive bycatch management. Further, helicopter-vessel communication may have potentially broader applications to fleet-wide vessel-to-vessel communication programs. The use of helicopter-vessel communication as an approach to dynamic fleet-wide bycatch communication should be additionally explored.

This study also 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 (Lezama-Ochoa et al., 2019), but investigating these species in the open ocean is often difficult and costly. Helicopter crew might currently see Mobulids during flights but not report these sightings because they are not accompanied by tunas. 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 species and should be further considered in the EPO.

Though avoiding capture would be a principal strategy for alleviating Mobulid bycatch, additionally developing safe handling practices to increase post-capture survival is useful when a species is caught despite attempts to avoid it (Swimmer et al., 2020). Bycatch avoidance programs have been most effective when integrated with existing or impending regulations

(Bethoney et al., 2017), therefore we suggest combining pre-capture avoidance strategies, such as helicopter-vessel communication, with improved post-capture handling and release methods could potentially support effective Mobulid bycatch mitigation. Helicopter-vessel communication can be used as an early alert system to the vessel that a Mobulid will be in the set, 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 as a way to develop innovative strategies that include fishers' knowledge and help meet fisheries management goals.

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SUPPLEMENTARY MATERIALS

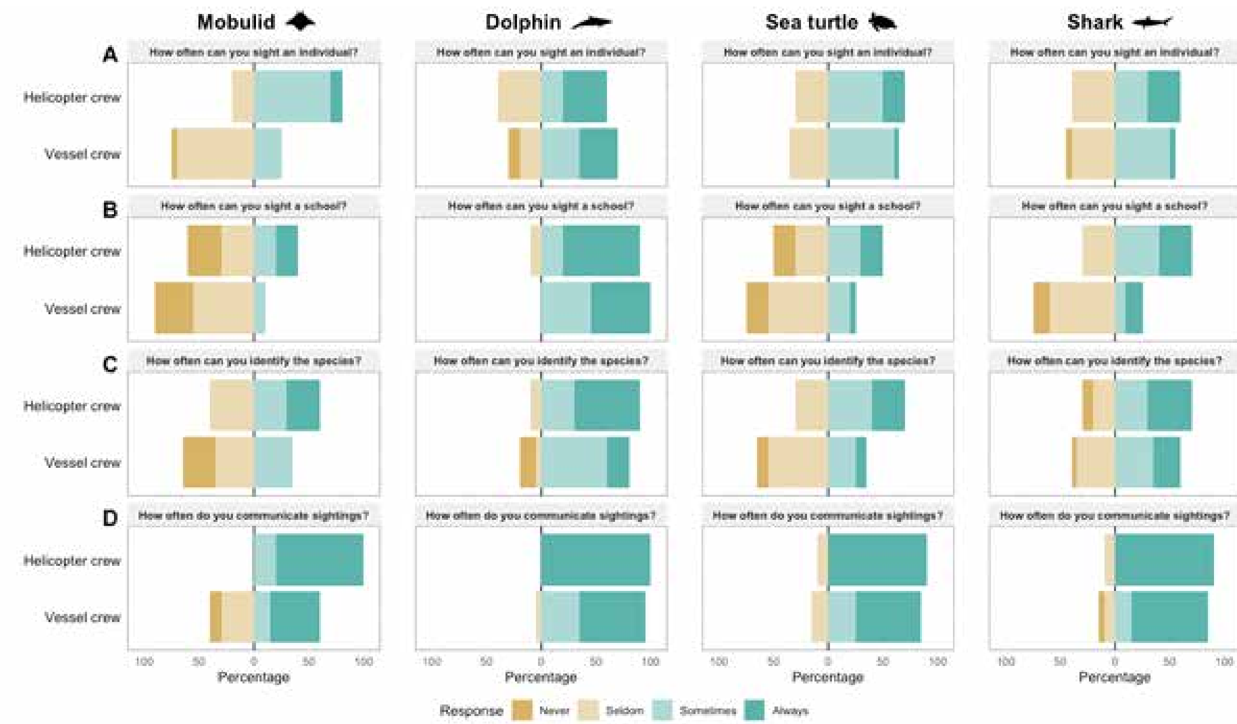

FIGURE. S1 Respondents' reported ability to A) sight individuals, B) sight schools, C) identify species, and D) frequency of communicating sightings of the species. Grouped by experience as helicopter crew (N = 10) or no experience as helicopter crew (N = 20).

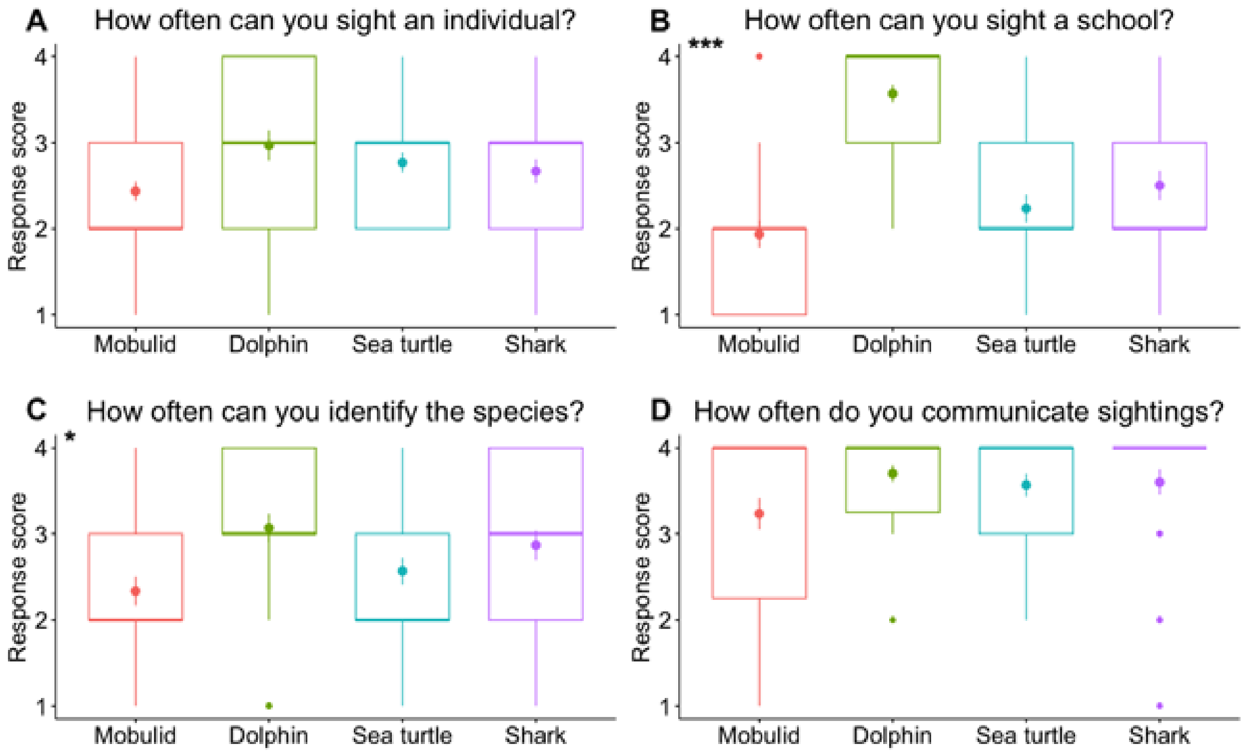

FIGURE. S2 Respondents' reported ability to sight and identify bycatch species and frequency of communicating sightings. Response scores correspond to the numeric Likert score (e.g., 1 = "Never"; 4 = "Always"). Mean responses were significantly different between dolphins and the three other species groups for question B (sighting schools) (Kruskal-Wallis test: $p < 0.001$; Wilcoxon signed-rank test: $p < 0.001$) and question C (identifying species) (Kruskal-Wallis test: $p < 0.05$; Wilcoxon signed-rank test: $p < 0.05$).