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A collaborative approach to collecting species-specific manta and devil ray catch data and assessing handling effects on post release survival

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A Comprehensive Approach to Collecting Species-Specific Data and Assessing Post-release Survival on Mobulid Rays in the Hawaii Longline Fisheries

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Executive Summary

Conservation of mobulid rays (manta and devil rays) is constrained by the limited availability of species-specific data on interactions with pelagic longline fisheries, including bycatch rates and post-release survival (PRS). To address these critical data gaps, a collaborative research program amongst scientists-fishers-policy makers and other industry personnel was implemented within U.S. Hawai'i-based longline fisheries. This multi-faceted effort integrated genetic sampling, development of a regional species identification guide, satellite tagging, and the use of electronic monitoring (EM) to document bycatch events.

Genetic sampling in combination with improved observer program identification capabilities confirmed the presence of four mobulid species in the fishery—*Mobula birostris*, *M. tarapacana*, *M. mobular*, and *M. thurstoni*. EM analysis provided high-resolution documentation of mobulid interactions, including species identification, at-vessel condition, hook and entanglement location, gear configuration, and handling and release practices.

Satellite tagging revealed that mobulid rays, when released from fishing gear using best handling and release practices (BHRP), exhibit high rates of post-release survival. Combining EM data with tagging outcomes further enables linkage between interaction conditions and survival rates for improved population assessments.

The presence of *M. birostris*, a U.S. Endangered Species Act (ESA)-listed species, highlights the importance of continued investment in accurate identification and monitoring tools. These data directly support ESA recovery objectives by improving catch composition estimates and informing post-release survival metrics.

Key recommendations include:

- Improved data collection capacities for observers and fishers by updating and expanding

species data codes to data and reporting sheets.

- Improved ID training for observers and EM reviewers using the identification guide.

- Ongoing genetic sampling for validation, particularly for difficult-to-distinguish species or life stages.

- Expansion of tagging studies to generate PRS estimates, the development of BHRP and to inform species-specific risk assessments and dynamic conservation management strategies.

This collaborative project emphasizes the crucial role of partnerships in addressing complex conservation challenges. By integrating technology, field science, and stakeholder knowledge, this work strengthens our capacity to monitor, assess, and mitigate fishery impacts on vulnerable mobulid species.

Introduction

Mobulid rays (comprising manta and devil rays) are found in tropical and temperate oceans worldwide (Couturier et al., 2012). Mobulids are slow-growing and have very low reproductive rates, usually producing a single pup after a long gestation, every three to seven years (Dulvy et al. 2014; Pardo et al., 2016; Stewart et al., 2018). Some species undertake long-distance migrations, often gathering in offshore aggregations for foraging and reproduction. These traits, taken together, make them extremely vulnerable to overfishing (Dulvy et al. 2014; Croll et al. 2016; Stewart et al. 2018). Data are limited in many fisheries and regions, but where available, relative abundance trends suggest severe declines (White et al., 2015; Fernando and Stewart, 2021; Pacoureau et al., 2021; Carpenter et al., 2023). All mobula ray species have been listed under the International Union for the Conservation of Nature (IUCN) Red list as either Endangered (*M birostris, M. tarapacana, M. mobular, M. thurstoni, M. kuhlii, M. eregoodoo, M. hypostoma*) or Vulnerable (*M. alfredi, M. munkiana*) to extinction mostly due to overfishing (IUCN, 2018 & 2019).

In the last decade several protective mechanisms have been enacted to address overfishing of mobulids. In 2013, both manta ray species (*Mobula birostris and M. alfredi*) were listed under Appendix II in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). In 2016, the listing was expanded to include all mobulid species (Mobula spp. and Manta spp.). Similarly, all *Mobula* ray species are listed under Appendix I and II of the Convention on the Conservation of Migratory Species of Wild Animals. In 2018, the United States listed the giant manta ray (*Mobula birostris*) as threatened throughout its range under the US Endangered Species Act (ESA, 83 FR 2916), eliciting a recovery plan requirement to reduce mortality (NMFS, 2024a). Further international protective measures have been enacted in all four tuna Regional Fisheries Management Organizations (RFMOs)—Inter-American Tropical Tuna

Commission (IATTC, 2015), Indian Ocean Tuna Commission (IOTC, 2019), Western Central Pacific Fisheries Commission (WCPFC, 2019), and the International Commission for the Conservation of Atlantic Tunas (ICCAT, 2024). These tuna RFMOs have adopted conservation measures to protect mobulid rays, primarily through prohibitions on retention, transshipment, landing, and sale. These measures are complemented by requirements or recommendations for the safe live release of incidentally caught rays and, in most cases, promote the use of best handling and release practices. Several RFMOs, including the IOTC and WCPFC, have also encouraged improved monitoring, observer reporting, and research on post-release survival and habitat use to better understand the impacts of fisheries on mobulid populations. ICCAT's most recent recommendation aligns its protections with those of the other RFMOs, underscoring a growing international consensus on mobulid ray conservation.

Mobulid rays are captured in both small- and large-scale fisheries across a variety of gear types, including gillnets, purse seines, longlines, and trawls. In some regions mobulids are commonly targeted and or retained for their meat, skin, cartilage and gill plates (White et al., 2006; Croll et al. 2016; Fernando and Stewart, 2021; Rojas-Perea et al., 2025). In the Indo-Pacific tuna fisheries mobula are captured as bycatch and must be released in a manner that minimizes harm. In the western and central Pacific Ocean (WCPO) purse seine fishery, mobulids comprise approximately 5% of the total elasmobranch catch (Peatman et al., 2023). In the eastern Pacific Ocean (EPO), large-scale purse seine fisheries mobula ray catches are regionally and seasonally aggregated, with most interactions reported in free-school sets rather than those associated with fish aggregating devices (FADs) (Lezama-Ochoa et al., 2019). In longline fisheries, despite widespread overlap between mobulid distribution and fishing effort, observed catch rates of mobula in both the EPO and WCPO longline fisheries are far lower than in purse seine fisheries (Lezama-Ochoa et al., 2019; Tremblay-Boyer & Berkenbusch, 2020).

Across longline fleets, observer data indicate that most mobulids are brought to the vessel alive but are frequently injured during handling and release from the fishing gear (Mas et al., 2015; Tremblay-Boyer & Brouwer, 2016). An analysis of WCPFC observer records shows that many mobulids initially classified as "alive" or "healthy" are ultimately released in weakened or moribund states—classified as "alive injured," "alive but dying," or "dead" at the point of discard (Tremblay-Boyer & Brouwer, 2016). This degradation in condition underscores the importance of fisher behavior on reducing mortality to discarded mobulids. In tuna fisheries governed by RFMOs, mobulids are subject to no-retention policies; thus, individuals must be released alive whenever possible. However, the effectiveness of these measures in reducing mortality hinges on fisher behavior and concerted effort to minimize injuries and stress during removal from the fishing gear. In tuna purse seine fisheries emerging research shows that post release survival (PRS) rates for mobulids vary widely by species and handling method (Stewart et al., 2024). These studies have documented PRS rates ranging from ~20% to 74%, with higher survival associated with direct release from the net (i.e., without being brought onboard) and with handling times on deck under three minutes (Francis and Jones 2017; Hutchinson et al.

2019; Stewart et al. 2024). In longline fisheries, although mobulids are typically released alive, little is known about their fate after release, nor is there any data on how handling and release methods or trailing gear may impact survival rates.

Across survival studies of elasmobranch bycatch in tuna purse seine and longline fisheries, species has consistently emerged as a key predictor of post-release fate (reviewed in Hutchinson et al., 2023). Accurate, species-specific interaction and survival data are critical for assessing the impact of fisheries on vulnerable populations. However, monitoring efforts remain insufficient across fleets and regions, and taxonomic resolution of mobula bycatch is often low. In many cases, observer and logbook records aggregate mobulid captures under generic categories such as "manta ray," "devil ray," or simply "ray," which hinders evaluation of interaction rates and the effectiveness of no-retention conservation measures (Tremblay-Boyer & Berkenbusch, 2020). To address these limitations, this study aimed to fill critical knowledge gaps related to mobulid interactions in the U.S. Pacific longline fisheries by improving species-level identification and estimating post-release survival (PRS) across taxa and handling conditions.

Fishing effort in the U.S. Pacific longline fisheries overlaps with the known distributions of at least five mobula species found in the Pacific Ocean, including *Mobula birostris*, *M. alfredi*, *M. tarapacana*, *M. mobular*, and *M. thurstoni*. Despite this, the Pacific Islands Regional Observer Program (PIROP) has historically lacked species-level reporting codes for most mobulids—apart from *M. birostris*, which is assigned a unique code due to its listing under the U.S. Endangered Species Act. Observers have been limited to reporting other mobulids under broad categories (i.e. "other ray", "manta/mobula", or "devil ray"), while fisher logbooks only contain a code for 'giant manta ray' interactions, reducing the resolution and usefulness of these data and perhaps artificially inflating reports of *M. birostris* interactions. To improve our understanding of species composition captured in these fleets, this study employed a multi-pronged approach involving genetic sampling, video review from both electronic monitoring (EM) systems and observed trips and a telemetry component to reveal post release fates of discarded mobulids. These efforts aim to generate data on species composition, interaction rates, and post-release outcomes, thereby informing future monitoring and management strategies for mobula rays in the Pacific Islands region. Furthermore, the study assesses the potential of EM for species detection and fate assessment and provides recommendations for best handling and release practices for mobula bycatch in longline fisheries.

Methods

To address the data gaps preventing assessment of fishing impacts for mobula rays incidentally captured in the US Pacific pelagic longline fisheries, we collected species specific catch data through enhanced monitoring (observer and EM) and identification efforts (genetic analysis of tissue samples and visual identification using a new identification guide) and used electronic tags to verify post-release fate and to develop condition and handling protocols in a collaborative effort among scientists, managers and Hawaii-based longline fishery personnel.

Research was conducted in the U.S. Hawaii-permitted longline fishery operating across the western and central regions of the north Pacific Ocean and eastern tropical Pacific Ocean (Figure 1). This fishery consists of two sectors: a deep-set fishery (DSLL) targeting bigeye tuna (*Thunnus obesus*) and a shallow-set fishery (SSLL) targeting swordfish (*Xiphias gladius*). Of the two sectors the DSLL has ~146 active permit holders and comprises 96-99% of the total trips (NMFS, 2023a). Both fisheries use monofilament mainlines with branchlines baited with mackerel type fish and suspended in the water column by floats. In the DSLL fishery, gear is deployed during the day, and haulback typically starts at night. Circle hooks (15/0-16/0) are set to target depths ranging from 150-270 m (Scott et al. 2022; Siders et al. 2020), with 45-gram weighted swivels placed within 1 m from the hook (NMFS, 2024b). In the SSLL fishery, the target depth for circle hooks (18/0) is 30–90 m, and gear is deployed at night with haulback beginning during daylight (NMFS, 2024c).

Improving taxonomic resolution of catch data

Improvements to the identification of mobula rays incidentally caught in the Hawaii longline fisheries was achieved through the development and publication of a taxonomic key and field guide to identify mobulids captured or landed in Pacific Ocean fisheries (Stevens et. al 2023). The ID guide includes species spatial distribution in a dichotomous key using characteristics that are easy to observe and discern in fishery scenarios. The ID guide was used to identify incidental mobula rays to species, when possible, that were captured in video and imagery collected by observers, fishers, and in electronic monitoring (EM) systems. A genetics study was also conducted to help resolve species composition of mobula ray interactions.

Observer Data Collections

The Pacific Regional Observer Program (PIROP) observers record information for all catch events including mobulid interactions. These data include; condition ("alive", "alive good", "alive lethargic", "injured", "unknown", or "dead" - see Hutchinson et al. 2021 for condition definitions); sex, when possible (based on presence of claspers); and disc width (every third fish). Beginning in April 2022, a new biological data form for elasmobranchs was implemented into the normal PIROP data collections. The form (https://www.fisheries.noaa.gov/s3/2023-01/obs_as_eb_jan_2023.pdf) allowed observers to record additional details during shark and ray interactions to help illustrate the level of injury for protected and other management unit elasmobranchs. The form included fields for: hooking location, handling and release practices, including the amount of gear remaining on an animal at release (trailing gear).

Beginning in 2023 PIROP staff—including observers, trainers, and reviewers—received enhanced training to improve mobula ray identification and data quality in the field and during trip debriefing. Observers were trained on species identification using the taxonomic key in the ID guide and encouraged to collect video or photos, and record distinguishing features for ID validation during debrief. Prior to this training species-specific identifications were lacking and the only available classifications for observers to record were, “Manta/mobula”, “Mobula Nei (Devil ray)”, “Manta”, or “Giant Manta Ray”.

Genetic assessment of species composition

Tissue samples were opportunistically collected by PIROP fisheries observers to determine which species of mobula rays are captured in the Hawaii longline fisheries. Observers collected a small plug of muscle tissue from the dorsal surface of incidentally caught mobulids using a pole with a specialized sampling tip, while the animal remained in the water alongside the vessel. Samples were stored in ethanol in a collection tube or in a plastic bag, either frozen or on ice. Genomic DNA was extracted from mobulid tissue samples and quantified using the Qubit High Sensitivity (HS) Assay to ensure accurate input for PCR. Species-specific mitochondrial gene regions were amplified using custom-designed oligonucleotide primers, followed by Sanger sequencing employing chain-termination PCR with fluorescently labeled dideoxynucleotides. Resulting fragments were separated by capillary electrophoresis, and sequences were compared against reference databases for species-level identification.

Electronic monitoring (EM) data collections

EM video footage generated during a research and development program through NOAA‘s Pacific Islands Fishery Science Center (PIFSC) using EM systems installed on volunteer longline vessels in 2017 (n = 18 vessels) and in 2021 (n = 20 vessels, PIFSC 2023) was reviewed to assess the feasibility of using EM to detect mobula rays, identify them to species level, and to collect condition and handling data for PRS predictability. See Carnes et al. (2019) for details on EM systems and Stahl et al. (2024) for a comprehensive overview of the program and data collections (NMFS 2023b).

EM sets were flagged for video review if an observer onboard an EM vessel recorded a mobula interaction between the implementation of the EM program in 2017 and the present (n=19 interactions) or if mobula were reported by fishers (n = 5, i.e. during tagging trips or other interactions). A comprehensive review of all EM footage was not performed due to limited resources.

Electronic tagging for fate determination

To assess the fate of mobula post release, survivorship pop-off archival tags (sPAT; Wildlife Computers Inc., Redmond WA) were attached to incidental mobulids captured in the DSLL fishery. Because mobula interactions are such rare events and observer coverage is less than 20% in this sector, fishers were trained to conduct the tagging. Vessels were selected for this study if they had had previous mobula interactions, had participated in the shark tagging study (Hutchinson et al. 2021) and were amenable to the study protocols and conducting research on their vessels. Thirteen different vessels were identified and the captains and crews of these vessels were trained in the tagging protocols and data collections. A waterproof one-page data form was provided with each tagging kit (Appendix 1). Vessels were given one tag, instructions, the data sheet and the mobula ID guide and also asked to record information that would support later species identification. Video of the interaction—showing hook/entanglement location, tagging, tag placement and release from the gear—was also requested and required for a monetary reward pending a successful tag deployment.

Fishers were instructed to leave the animals in the water and tag them over the rail of the vessel prior to releasing them however they normally handle and release mobulids. Tags were applied to the dorsal side of the inner pectoral fin using a pole with a specialized anchor, avoiding the body cavity to prevent injury and wingtips to reduce drag and early tag shedding. When a tag was deployed, data forms and imagery were collected when the vessel returned to port. Researchers reviewed the datasheets and footage with the fishers. Videos were also later reviewed to verify species identification, estimate size and sex, hooking location, at vessel and release condition, tagging location, handling and release methods, trailing gear, and any other relevant details that may have impacted the fate of each individual post release.

Tags were programmed for 60-day deployments, recording depth, temperature and light level changes for fate determination. The sPATs initiate release from the animal and report the release reasons through a data portal for later interpretation of the fate of the animal. A tag will initiate release when: 1) it reaches the end of the programmed deployment period (Interval), indicating the animal survived the interaction and was still swimming when the tag initiated release; 2) if the tag detects that it is sinking to its maximum depth threshold (>1500 m; Too Deep), indicating the animal was either diving to a depth that is too deep for the tag or it was a mortality that was sinking through the water column (for these tags the sink rate must be reviewed in the depth time series data for fate determination); and 3) if the tag detects that it is at a constant depth for more than one day (Floater). If the tag was a Floater and was 'dry' for most of the period this indicates an attachment failure and the tag is floating at the surface. In these cases the depth data are reviewed to determine whether the animal was swimming or sitting at a constant depth when the tag came off. If the animal was over 'shallow water' (<1500m) this would indicate a mortality, if the animal was still swimming when the tag detached, the animal was determined to be a 'survivor' and the data was censored to reflect the actual deployment period.

Results

Species Identification

Observer Data

PIROP observer coverage rates in the SSLL sector is 100% and was ~20% through 2022, 17% in 2023 and 13% in 2024 in the DSLL sector. This component of the study is ongoing and catch data are continuously being collected through the PIROP in both the DSLL and SSLL fisheries.

At present mobula ray interactions are still being recorded at low taxonomic resolution as the PIROP's data sheets dictate, with species identification and field ID validation occurring during the trip debriefing process. Low resolution catch data is available for both sectors from 2019-2023 and provided in the Appendix for reference (Appendix Table 1; WPRFMC, 2025). A desirable outcome of this study will be the development of mobulid species level codes so observers and fishers can more accurately report mobula interactions to species level. With the development of the Mobula ID guide and improved identification training, species-level identifications can confidently be performed in the field and validated during review of observer-collected imagery.

Our next step is to analyze archived PIROP footage of mobulid catches to obtain species-specific interaction data and perform extrapolations of bycatch estimates for the Hawaii-based longline fisheries.

Genetic identification

A total of 37 tissue samples were collected in both the DSLL (n = 35) and the SSLL (n = 2) fisheries during incidental mobulid ray interactions between 2022 and the present. One of the samples failed genetic analysis. Of the remaining 36 successfully analyzed samples, three devil ray species were identified: *M. thurstoni* (n = 21), *M. mobular* (n = 7), and *M. tarapacana* (n = 7). One of the samples taken in the SSLL was identified as a manta ray (*M. birostris* or *M. alfredi*) but could not be further resolved to the species level (Table 1). The other sample from the SSLL was identified as *M. thurstoni.* An additional five samples have been collected and submitted to the NOAA Northwest Fisheries Science Center (NWFSC) for analysis but have not yet been processed.

A blind review (i.e., without prior knowledge of genetic results) of the videos taken by PIROP for 34 of the 37 sampling events was also conducted to verify accuracy of both the genetic results and our competence in identifying mobula from imagery. In all cases where species level identification was possible, visual identifications were consistent with genetic results. Video for the one manta ray that could not be resolved using genetic identification techniques was visually identified as *M. birostris*. Of the 33 devil rays with both tissue samples and corresponding video, 30 were visually matched to the same species determined through the genetic analysis. The remaining three could not be confidently identified to species from the PIROP footage due to limited or poor-quality footage. However, for one of these individuals, additional video provided by fishers enabled species-level identification, which was consistent with the genetic result.

Table 1. Mobula identified to species by genetic analysis of tissue samples collected by PIROP observers in the DSLL and SSLL fisheries.

Common name	*Scientific name*	Number of samples	Proportion of samples
Reef manta ray/ Giant oceanic manta ray*	*Mobula alfredi/ Mobula birostris*	1	3%
Spinetail devil ray	*Mobula mobular*	7	19%
Sicklefin devil ray	*Mobula tarapacana*	7	19%
Bentfin devil ray	*Mobula thurstoni*	21	58%

*This individual was visually identified as *M. birostris* through video analysis

Identification using EM

EM video footage from the Hawai ‘i longline fishery enabled species-level identification of one giant manta ray (*M. birostris*) and three devil ray species (*M. thurstoni*, *M. mobular*, and *M. tarapacana*) from 24 reviewed interactions. One individual, recorded by the observer as a mobula, could not be identified due to limited camera coverage; the animal approached from the front of the vessel, outside the field of view of the fixed camera (non-boom mounted). Among the remaining mobulas, 75% were identifiable to species level, 4% to the broader devil ray group, and 21% could only be classified at the genus level as *Mobula* spp..

Post-Release Fate

Electronic Tagging

A total of 15 sPATs were provided to fishers from 13 different vessels in the DSLL fishery. Only four of these vessels actually deployed tags, so tags were often swapped amongst vessels. Between January 2023 and the present, one of the tags was misplaced, one was lost at sea during a failed deployment, one tag failed to report and the remaining 12 sPATs were successfully deployed and transmitted data and fate information (Table 2). Only one of the 12 tags that reported, revealed a post release mortality (*M. mobular;* tag 813) after a deployment period of 10 days. One other tag initiated release at a depth of 1338 m on day 58 post-release (*M. tarapacana;* tag 823). Normally this would indicate an animal that had died and was sinking out of the water column. However, *M. tarapacana* have been demonstrated to rapidly dive to very deep depths of over 2000 m at 0.6 m^{-s} in other regions (Thorrold et al. 2014). Comparison of the descent profile with the only mortality documented in this study (tag 813) shows a sink rate of 0.144m^{-s} compared to a rapid descent rate of 0.56 m^{-s} (tag 823), suggesting the animal was actively diving and thus swimming when the tag severed its attachment before it reached its crushing depth of ~1400 m.

Eleven of the tagged mobula survived to the point of tag detachment, nine tags completed the 60-day deployments and two tags were shed early, after 58 (tag 823 described above) and 51 days (*M. mobular;* tag 811). Encouragingly, survival was higher than expected for individuals with visible injuries—of the five animals that were released 'Injured' only one of these perished (tag 813). Videos of this interaction revealed serious injuries from entanglement that indicated the animal was likely moribund. Two of the other injured animals were actually injured by the tagging itself and exhibited heavy bleeding at the tagging site (tags 811 and 814) but survived to at least 51 days. One of the *M. thurstoni* (tag 820) that was injured when brought to the vessel and bleeding from the mouth and gills, also survived the interaction. The fifth injured animal was an *M. birostris* (tag 810) but this tag was a failed deployment and the fate of the animal could not be determined. The majority of mobula were released in good condition with the fishers cutting the line while the mobula rays remained in the water. All individuals were released with less than 1.3 m of trailing gear (Table 2).

Most rays (n = 9) were foul-hooked in the head, while two animals were hooked in the mouth and another two were merely entangled in the gear; one *M. birostris* was both entangled and hooked in multiple locations. Fisher collected-video proved invaluable for verification as imagery revealed that many rays recorded by fishers as hooked in the mouth were actually foul-hooked in the head.

For three of the tagging events, observers were onboard and provided additional documentation, including imagery from handheld cameras. For the tagged individual that later died (tag 813), an observer collected a tissue sample verifying the *M. mobular* identification made from the fisher's video.

Two successful tag events and one attempted event were captured on EM video. EM footage provided complete, start-to-finish coverage of the whole event—including gear preparation, handling, tagging, and the release of mobula from fishing gear—offering valuable context when fisher videos were incomplete. For one tagged mobula (tag 814) that experienced heavy bleeding, EM footage revealed the bleeding began immediately after the tag was attached and showed the tag embedded near the gill crease, suggesting the injury was due to tag placement. On another occasion, EM footage captured a failed tagging attempt on a *M. birostris* (tag 810), showing the tag falling off the animal and into the water after two failed tag attempts. Without this footage, the transmitted tag data would have remained unclear (i.e. did the tag detach early from user error or was it a hardware malfunction), as the fishers reported a successful deployment and their footage of the tagging did not include the event in its entirety.

Table 2. Interaction data and post release outcomes for tagged mobula rays.

Species	Tag ID	Hook / entanglement location	Release condition	Trailing gear	Tag & (animal) fate	Deploy period (days)
M. birostris	812	Entangled and hooked multiple locations	Good	NR	Full deployment (survivor)	60
	810	Entangled in mainline around right wing	Injured-bleeding around cephalic fin, animal missing tail	0	Bad attachment-tag fell off animal (Unknown)	NA
M. tarapacana	814	Hooked head	Injured-heavy bleeding from tagging	~ 1.2 m	Full deployment (survivor)	60
	823	Hooked head	Good	~ 0.9 m	Too deep[‡] (survivor)	58
M. mobular	813	Entangled around body	Injured-entangled line cut tissue	0	Too deep (mortality)	10
	811	Hooked head	Injured-bleeding at tag site	~ 0.6 m	Detached early (survivor)	51
	815	Hooked head	Good-tear in skin at hook location	~ 0.6 m	Full deployment (survivor)	60
	819	Hooked head	Lethargic	~ 0.3 m	Non-reporter (Unknown)	Unknown
M. thurstoni	821	Hooked head, base cephalic fin	Good	~ 0.9 m	Full deployment (survivor)	60
	820	Hooked mouth	Injured-bleeding from gills and mouth	~ 0.9 m	Full deployment (survivor)	60
	701	Hooked head	Good	~ 0.6 m	Full deployment (survivor)	60
	816	Hooked head	Good	~ 1.2 m	Full deployment (survivor)	60
	818	Hooked mouth	Alive	~ 1.1 m	Full deployment (survivor)	60
	817	Hooked head	Good	~ 0.2 m	Full deployment (survivor)	60

*NR = not recorded, ‡This animal was deep-diving and actively swimming when the tag initiated release.

EM

In addition to aiding in the species-level identification of incidentally captured mobulid rays, EM systems also provided valuable data relevant to PRS assessment. For trips with and without PIROP observers coverage, EM footage captured key interaction details when the animals were brought to the vessel and within the field of view of the EM systems and we were able to record catch and release condition, hook and/or entanglement location, injury status, handling and release methods used and the type and amount of trailing gear left on animals at release (Table 3). Body size estimates from EM footage are also possible, but further validation is required.

Of the 24 total interactions that were flagged for EM review at vessel condition indices were possible where 83% (n = 20) were confirmed alive, 54% were categorized as alive and in good condition, and 8% were determined to be injured with bleeding. One mobula was confirmed dead at the vessel based on EM footage, and three had undetermined conditions. In one case, an observer onboard recorded the animal as injured with an ingested hook—details that were not visible in the EM review due to camera angle limitations.

EM footage also allowed for the evaluation of hooking and entanglement location. In 63% of cases (n = 15 interactions), mobulids were clearly hooked - primarily foul hooked in the head (n = 13), with several involving multiple hook locations (Table 3). In three interactions, the mobulas were clearly entangled. In two of these cases, it was difficult to determine if the animals had also been hooked. One interaction showed multiple lines wrapped around the animal's wing, mouth, and shoulder, with a hook visible within the entanglement but not embedded. For six interactions, it was not possible to determine if the mobula was hooked or entangled; however, some information about hooking or entanglement location could be inferred based on observations of fisher behavior and the gear brought back on board after release (e.g., amount of line remaining after it was cut, hook visible in a coiled line, Table 3).

EM data also provided valuable information on fisher handling practices. For all interactions where mobula were alive at the vessel, fishers followed the NOAA Protected Species best handling and release practices by leaving the mobula in the water and cutting the entangled lines away from the animals prior to release. It was also possible to determine when a line broke and a mobula escaped (n = 3) or the hook dislodged (n = 1). When fishers were observed cutting or coiling the fishing line, we were often able to estimate the amount of trailing gear remaining attached to the mobula after release, including whether or not the line was cut above or below the weight. The amount of fishing gear remaining on the animals varied significantly, ranging from no fishing gear to as much as 10.5 meters of trailing gear (Table 3).

Discussion

This ongoing study underscores the value of cross-sector partnerships—among fishers, scientists, and managers—in addressing complex conservation challenges. Through this collaboration, we significantly improved our understanding of mobulid ray interactions in the Hawaiʻi longline fishery, laying the groundwork for more effective, science-based conservation strategies for these vulnerable species. Integrating observer data, genetic sampling, EM, tagging, and fisher collaboration enabled high-confidence species identifications and provided critical insight into mobulid post-release survival and the challenges fishers face while safely removing large individuals from the fishing gear. While EM proved to be an effective technology for collecting species specific mobula interaction data for injury level determination and showing potential for post release fate prediction.

Species Composition and Identification Accuracy

Genetic sampling and analyses, combined with observations from EM video, fishers, and observers, have conclusively determined that Hawaiʻi-based longline fisheries interact with at least four mobulid ray species: the ESA listed giant manta ray (*M. birostris*) and three devil rays (*M. mobular, M. tarapacana and M. thurstoni*).

The development and publication of the *Field Guide to Manta and Devil Rays in Pacific Ocean Fisheries* (Stevens et al., 2023) for this project was instrumental in our ability to accurately identify mobula ray species using imagery collected by observers, electronic monitoring, and fishers by highlighting diagnostic external features visible from vessels—minimizing the need for physical samples or close-up imagery. While the genetic component of our study validated the effectiveness of applying this ID guide to image-based identifications, the majority of genetically sampled individuals also had corresponding imagery, allowing us to use genetic data to ground-truth our visual assessments.

While this work is ongoing and data collections are continuous, the next steps for the historic interaction data that has been collected, archived and accompanied by either video (observer, fisher or EM) or genetic samples, is to update the observer database with identification to species or the highest possible level to enable species specific bycatch estimation across all sectors of the US Pacific longline fisheries. One complicating factor remains, in that at present, observers still only have low resolution taxonomic codes to document mobulid interactions (i.e. "other ray", "giant manta ray", "manta/mobula", or "devil ray") and fisher logbooks only contain the code "giant manta ray". This lack of capacity for collecting species-level data cannot support reliable analysis of population impacts, highlighting the need for improved species codes and data reporting capabilities for both observers and fishers. Thus, one of the major recommendations stemming from this project are a programmatic update to data collections and databases for the region.

Accurate assessment of the impacts that any fishery is having on vulnerable species is a critical conservation requirement. For the Mobula, where all species have very low intrinsic rates of growth, and are particularly susceptible to overfishing, species level catch data is crucial for effective management and conservation.

Post-Release Survival

Tagging and at-vessel observations of mobula rays captured in the Hawai‘i longline fishery have provided new insights into post-release survival and factors that influence survivorship. This study demonstrated that key at-vessel indicators of post-release survival, such as species, condition, handling and trailing gear length, can be effectively documented by at-sea observers and through imagery collected by EM systems.

At-vessel mortality rates of mobulid rays captured in longline fisheries appears to be low (1–5 %; Coelho et al., 2012; Mas et al., 2015; NMFS, 2023); however, limited research prior to this study was available to determine the fate of mobula ray after longline interactions. Existing research on other taxa in longline fisheries–such as sharks (e.g. Hutchinson et al. 2021; Francis et al. 2023), sea turtles (Swimmer et al., 2014; Ryder et al., 2023), and cetaceans (Wells et al., 2008; NMFS, 2023)—has shown that post-release survival (PRS) is strongly influenced by the underlying physiology of some species, release condition, handling methods, and the amount of trailing gear.

For mobulid rays, most available PRS data comes from tuna purse seine fisheries, which differ substantially from longline operations in gear configuration, encounter conditions, and handling and release procedures (Francis and Jones, 2017; Stewart et al., 2024). These purse seine studies demonstrated strong species-specific effects on survival as well as the importance of handling and minimizing the amount of time required to return mobulids to the sea. However, longline-specific data on mobula PRS remain sparse. Despite lower mobula catch rates in longline gear compared to purse seines, the cumulative impact on some Mobula species may still be significant, especially if survival after release is low (Griffiths and Lezama-Ochoa, 2021). This underscores the potential conservation value of improving PRS outcomes through evidence-based handling and release practices.

In tuna fisheries, international management bodies such as the IATTC (Resolution C-15-04) and WCPFC (CMM 2019-05) have prohibited retention and mandated prompt release of mobulid rays with minimal harm. However, only the WCPFC provides detailed best handling and release practice (BHRP) guidelines specific to longline fisheries. These recommend that small rays be brought aboard to facilitate safe gear removal, while large rays (>30 kg) be left in the water and released using dehookers or long-handled cutters, and that less than 0.5 m of trailing line remain on discarded animals.

This study showed that when best practices were used—leaving large animals in the water, carefully disentangling them, and minimizing trailing gear—PRS rates were high, even for the mobula that were injured. All tagged individuals were released with less than 1.2 m of trailing gear. However, EM analysis revealed substantial variability in gear left on released rays, ranging from none to more than 10 m of line, weights, and hooks. Given the strong evidence linking trailing gear to delayed mortality (Hutchinson et al., 2021; Francis et al. 2023), removing gear at or below the weights—when safe and feasible—is strongly recommended.

This study offers new insights into mobula ray survival after release from the Hawaii longline fishery but is limited by only 12 tag deployments across four species. Additional tagging is required to elucidate the effects of species, hooking and entanglement, at vessel condition, handling and release methods and trailing gear on survival. We are currently seeking support to continue the tagging efforts initiated with this study and to develop species specific post-release survival parameters to enhance population assessment capabilities.

EM and Observer Monitoring Capabilities

Trained human observers have long been the gold standard for monitoring bycatch in longline fisheries, including interactions with vulnerable species such as mobulid rays. However, the high cost and limited coverage of observer programs have spurred the development of electronic monitoring (EM) as a complementary tool. Building on previous research and pilot work by NOAA's Pacific Islands Fisheries Science Center (e.g., Carnes et al., 2019; Stahl & Carnes, 2020; Stahl et al., 2023, 2024), this study demonstrates EM's utility for detecting and documenting mobulid ray interactions. EM footage enabled species-level identification in most cases (79%), captured critical handling and gear interaction details, and allowed for estimation of trailing gear length—all of which are important for understanding post-release survival potential.

EM also provided comprehensive visual coverage of the full capture and release process, documenting entanglement and hook locations, fisher handling practices, and gear removal efforts. Camera placements overlooking the deck and rail enabled detailed assessments, especially when handling occurred within view and cameras remained clean and unobstructed. EM further complemented and validated other data sources, such as fisher-recorded videos, which often provided higher-resolution imagery useful for verifying tagging events and assessing condition. Together, EM and observer data offer a powerful, cost-effective strategy for improving species-specific monitoring, informing mitigation efforts, monitoring handling and release practices and potentially estimated post release outcomes.

Ecological considerations

All mobulid rays are planktivorous filter feeders that use their cephalic fins to funnel prey into their mouths, straining plankton and small fishes through specialized gill plates (Couturier et al., 2012; Stevens et al., 2018). The high incidence of foul hooking and entanglement observed in EM footage, observer data, and tagging records in this study suggests that these species are interacting with longline gear not by actively targeting bait, but due to spatial and temporal overlap with fishing effort.

Reducing mobulid interactions in the Hawaiʻi-based longline fishery may therefore be best achieved by minimizing spatiotemporal overlap between fishing activity and mobulid aggregations. In tuna purse seine fisheries, where *M. birostris*, *M. mobular*, *M. tarapacana*, and *M. thurstoni* are also captured, habitat modeling across the Atlantic and Pacific Oceans has consistently shown that mobulid presence is strongly associated with productivity-driven oceanographic features (Lezama-Ochoa et al., 2019; Lezama-Ochoa et al., 2020; Siders et al., 2020).

Specifically, *Mobula mobular* demonstrates increased catch vulnerability in regions influenced by seasonal upwelling, mesoscale eddies, and elevated chlorophyll-a concentrations—features that support high primary productivity and prey availability (Lezama-Ochoa et al., 2019). These environmental conditions create persistent ecological "hotspots" that increase the likelihood of interaction between mobulid rays and pelagic fishing gear (Lezama-Ochoa et al., 2020).

Improving species-specific catch data and through electronic tagging for mobulid rays captured in the U.S. longline fishery will enhance our ability to develop habitat use models and identify spatial indicators. These tools can inform fishers of high-risk areas and times to avoid, helping to reduce unintentional interactions with mobulid aggregations.

Special considerations regarding *Mobula birostris*

A key motivation for this research was concern over the accuracy of reported interactions with *Mobula birostris*, a species listed under the U.S. Endangered Species Act (ESA). Although interactions with mobulids—especially *M. birostris*—are rare in U.S. longline fisheries (Siders et al., 2020), there remains uncertainty about the true frequency of these events. Misidentification may lead to overreporting, where all large mobulids are incorrectly classified as *M. birostris*, or underreporting, where individuals are simply labeled as "manta/mobula ray," obscuring the species-specific impacts of the fishery.

One of the top research priorities identified in the ESA Draft Recovery Plan for *M. birostris* (89 FR 82991) is to improve resolution of fishing impacts on the species. This study confirms *M. birostris* as a bycatch species in the Hawaii longline fishery and demonstrates that improved data collection capacities—particularly through enhanced identification training and improvements to data coding and collections—can enhance species-level identification. These advances will help determine the actual proportion of bycaught mobulids that are *M. birostris*, a key step toward meeting ESA recovery objectives.

The recovery plan also highlights the importance of estimating post-release survival (PRS) rates and developing best handling and release practices (BHRP). This study requires additional tag data to generate PRS rates for this species.

Conclusions

This study addressed key research priorities for mobulid ray conservation in pelagic longline fisheries, providing new insights into species-specific interactions, handling practices, and post-release outcomes. Although interactions remain rare, our findings confirm that *Mobula birostris* and three other devil ray species (*M. mobular, M. tarapacana and M. thurstoni*) are caught as bycatch in the Hawaii longline fishery. Accurate species identification is critical for evaluating bycatch risk, understanding population-level impacts, and informing ESA recovery objectives. The development and use of a Pacific-wide field guide greatly improved species-level identification by both observers and electronic monitoring (EM) reviewers, with high agreement across visual and genetic methods.

However, identification challenges persist, to improve data quality and support species-specific management, the following steps are recommended: (1) improve data collection capacities for observers and fishers by adding species specific data codes to data and reporting sheets, (2) incorporate targeted visual ID training for observers and EM analysts, (3) continue genetic ID validation research.

To support the development of post-release survival (PRS) rates and bycatch mitigation effectiveness, continued satellite tagging remains essential—particularly across a range of species, size classes, gear configurations, and handling practices. Future efforts should combine EM and tagging data to link observed conditions at release to actual survival outcomes, and to identify environmental and fishery characteristics that influence vulnerability. Ultimately, this work provides a strong foundation for improving bycatch monitoring and supporting effective conservation strategies for mobulid rays across industrial tuna fisheries.

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Table 3. Mobula interactions in the Hawaii longline fishery reviewed from EM video for species and at-vessel data to assess likely fate after release from fishing gear. For instances when EM review did not provide complete information for a data field, the cell is shaded gray. Species and species category were derived from EM review. For other data fields comparisons are made to the data collected by the PIROP (obs) or fisher reports (fisher) in the cells when available. Observers were instructed to record additional information on hook/entanglement location, handling and release method, trailing gear, and more refined condition information after April 2022 (double border between event 14 and 15 delineates the time before and after the adoption and implementation of the Elasmobranch Biological Data Form).

Event number	Species category	Species	Leader material	Hook/entanglement location	Condition	Handling and release method	Trailing gear
1[1]	Devil ray	*M. tarapacana*	mono	**EM:** Hooked in head and right wing from 2 branchlines spun together.	**EM**: Alive **Obs**: Alive	**EM**: line cut **Obs**: line cut	**EM**: ≤ 2.4 m **Obs**: 4 m
2	Devil ray	*M. thurstoni*	wire	**EM**: Hooked in head	**EM**: Alive, Good **Obs**: Alive	**EM**: Wire leader cut	**EM**: ≤ 0.6 m
3	Mobula	Unknown	wire	**EM**: Entangled in float line and hooked or entangled in branchline, location unknown	**EM**: Unknown **Obs**: Alive	**EM**: Fishers retrieve float and float line; cut entangled or hooked line.	**EM**: ≤ 4.6 m branchline. No float line
4	Devil ray	*M. tarapacana*	wire	Hooked in head. Can see hook	**EM**: Alive, Good **Obs**: Alive	**EM**: Line cut	**EM**: ≤ 3.7 m
5	Mobula	Unknown	wire	**EM**: Unknown	**EM**: Unknown **Obs**: Alive	**EM**: Hook pops out	**EM**: None
6	Devil ray	*M. tarapacana*	wire	**EM**: Entangled in branchline and mainline. Hooked, location unknown.	**EM**: Dead **Obs**: Dead	**EM**: Entangled line cut to remove dead animal	NA - Dead
7	Devil ray	*M. tarapacana*	wire	**EM**: Unknown	**EM**: Alive, Good **Obs**: Alive	**EM**: Line cut	**EM**: ≤ 4.6 m

[1] Interaction in the Hawaii shallow-set fishery (swordfish target). All other interactions occurred in the Hawaii deep-set fishery (bigeye tuna target).

8	Manta ray	*M. birostris*	mono	**EM:** Unknown; mainline twisted with branchline	**EM**: Alive, Good **Obs**: Alive	**EM**: Line breaks	**EM**: ≤ 7.6 m branchline & mainline twisted together
9	Devil ray	Unknown	mono	**EM**: Unknown	**EM**: Alive **Obs**: Alive	**EM**: Line likely cut but out of view; fisher makes cutting motion with hand to other fisher	**EM**: 3.0–10.7 m
10	Devil ray	*M. thurstoni*	mono	**EM**: Hooked in head **Obs**: hooked, head	**EM**: Alive, Good **Obs**: Alive, Good	**EM**: Line cut below weight **Obs**: line cut below weight	**EM**: ≤ 0.30 **Obs**: 1 m
11	Devil ray	*M. mobular*	mono	**EM**: Hooked in head **Obs**: hooked, head	**EM**: Alive, Good **Obs**: Alive, Good	**EM**: Line cut **Obs**: cut below weight	**EM**: ≤ 0.30 **Obs**: 0 m
12	Devil ray	*M. thurstoni*	mono	**EM**: Hooked, head **Obs**: hooked, head	**EM**: Alive, Good **Obs**: Alive Good	**EM**: Line cut below weight **Obs**: cut below weight	**EM**: Hook only **Obs**: 0 m
13	Mobula	Unknown	mono	**EM**: Hooked, head from two wrapped branchlines; after release gets hooked in a third unknown location.	**EM**: Alive, Good **Obs**: Alive	**EM**: Line cut	**EM**: Two wrapped branchlines ≤ 0.9 m; third branchline ≤ 10.7 m
14	Devil ray	*M. thurstoni*	mono	**EM**: Hooked in head **Fisher**: hooked, mouth	**EM**: Alive, Good **Fisher**: Alive, Good	**EM**: Line cut **Fisher**: line cut	**EM:** ≤ 0.9 m **Fisher**: 0.9 m
15	Devil ray	*M. mobular*	mono	**EM**: Hooked in head. Can see hook **Obs**: hooked, head	**EM**: Alive, Good **Obs**: Alive, Good	**EM**: Line cut below weight **Obs**: cut below weight	**EM**: ≤ 0.3 m **Obs**: 1 m
16	Unknown	Unknown	mono	**EM**: Unknown **Obs**: hooked, head	**EM**: Unknown **Obs**: Alive, Good	**EM**: Line breaks below weight **Obs**: crimp fails below weight	**EM**: ≤ 0.3 m **Obs**: 1 m
17	Devil ray	*M. tarapacana*	mono	**EM**: Hooked in head **Obs**: hooked, head	**EM**: Alive, Good **Obs**: Alive, Good	**EM**: Line breaks **Obs**: line cut above weight	**EM**: ≤ 0.3 m **Obs**: 2 m

18	Devil ray	*M. thurstoni*	mono	**EM**: Hooked in head, mouth, or gills **Obs**: hooked, mouth	**EM**: Alive, Good **Obs**: Alive, Good	**EM**: Line cut **Obs**: line cut above weight	**EM**: ≤ 1.5 m **Obs**: 2 m
19	Devil ray	*M. tarapacana*	mono	**EM**: Hooked in head **Fisher**: hooked, mouth	**EM**: Alive, Injured - bleeding **Fisher**: Injured	**EM**: Line cut **Fisher**: line cut	**EM**: ≤ 1.5 m **Fisher**: 0.3 m
20	Devil ray	*M. thurstoni*	mono	**EM**: Hooked in head	**EM**: Alive	**EM**: Line cut	**EM**: ≤ 0.9 m
21	Devil ray	*M. thurstoni*	mono	**EM**: Hooked in head, cephalic fins, mouth, or gills **Obs**: hooked, mouth	**EM**: Alive **Obs**: Alive, Good	**EM**: Line cut **Obs**: line cut below weight	**EM**: ≤ 0.9 m **Obs**: 1 m
22	Devil ray	*M. tarapacana*	mono	**EM**: Hooked in head	**EM**: Alive, Good	**EM**: Line cut below weight	**EM**: ≤ 0.6 m
23	Manta ray	*M. birostris*	mono	**EM**: Entangled in mainline with multiple wraps around wing, mouth, shoulder, but can still move wings **Fisher**: mouth, entangled in mainline	**EM:** Alive, Injured - bloody cephalic fin. **Fisher:** Good	**EM:** Line removed **Fisher:** entangled line cut	**EM**: 0 **Fisher**: 0 ft
24	Mobula	Unknown	mono	**EM:** Unknown **Obs**: ingested	**EM:** Alive **Obs:** Alive, Injured	**EM:** Line cut **Obs:** line cut	**EM**: ≤ 1.5 m **Obs:** 1 m

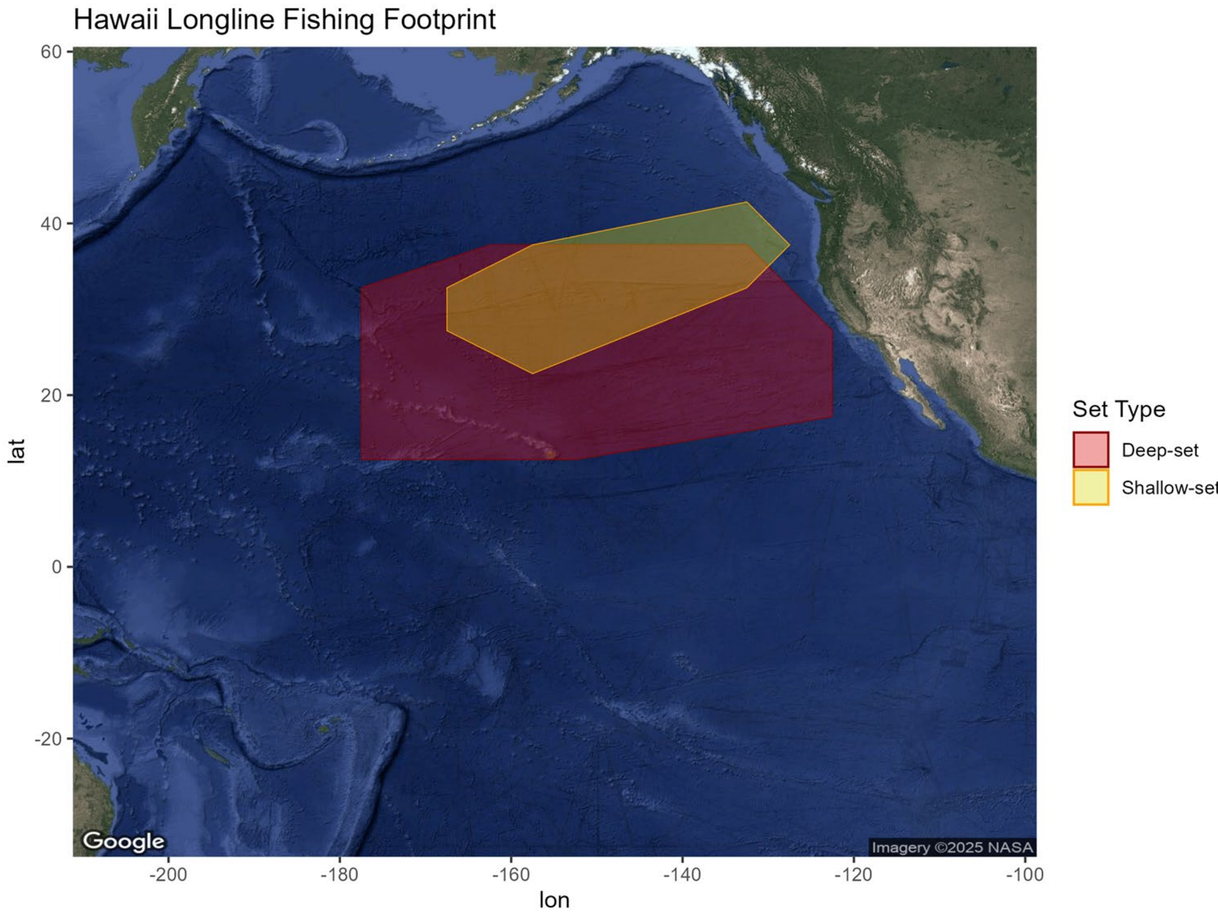


Figure 1. Hawaii longline deep-set longline (magenta) and shallow-set longline (yellow) spatial extent of fishing effort (2022-present).

Appendix

Appendix Figure 1. Data sheet provided to fishers to record key information for each mobula ray tag deployment in the Hawaii longline fishery.

Data required for each tag deployed

The below data fields are requested for each interaction with a mobulid ray. (See identification instructions next page).
Successful tag events with good data and footage will be reimbursed at a rate of $800 USD.

Please take a photo of the data on this sheet and email or text us as soon as you return to port 🙂
Email: pacificsharktagger@gmail.com and/or Text Forest O'Neil: 808.321.9188

Tag serial #: ___________________, **Tag PTT #**:____________**Tag location:** ☐Left wing, ☐Right wing

Trip No._______________________, **Set No.**______________________, **Date**____/____/____, (MM DD YY)

Time____________, **Latitude**_____________________ N / S , **Longitude**______________W / E

Sex: ☐Claspers present (male), ☐Claspers absent (female), ☐Undetermined

Hook/entanglement location: ☐Mouth, ☐Cephalic fin, ☐Wing, ☐Body,
☐Other_________________________________

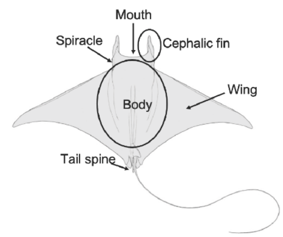
Capture condition: ☐Good, ☐Injured, ☐Lethargic, ☐Dead (Please don't tag dead animals)

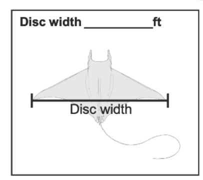
Release condition:☐Good, ☐Injured, ☐Lethargic, ☐Dead

Handling/release method: ☐Line cut, ☐Dehooker, ☐Escaped, ☐Other ______________________

Trailing gear?________________ft, **Comments**:_______________________________________

____





Condition Definitions:
Good - Animal active and energetic, no visible signs of trauma or injury, no bleeding from the vent or gills, fights against the gear, swims away well.
Injured - Clear evidence of injury to any part of the body; bleeding may be seen from the hook, gills or vent.
Lethargic - Animal exhibits signs of life but does not appear very active; still makes efforts to swim.
Dead - Animal does not exhibit signs of life, sinks or sinks upside down.

Appendix Table 1. Total estimated bycatch in number of fish from the Pacific Islands Region Observer Program for the Hawaii deep-set (DSLL) and shallow set (SSLL) longline fisheries (adopted from Appendix Table C-1; WPRFMC, 2025).

Species/Group	Fishery sector	2019	2020	2021	2022	2023
Mobula (Devil ray)	DSLL	218	76	251	298	335
	SSLL	0	0	2	2	1
Manta/Mobula	DSLL	82	43	66	146	106

	SSLL	0	1	4	0	1
Giant Manta Ray	DSLL	0	7	11	0	11
	SSLL	0	0	0	3	0
Unidentified ray	DSLL	0	6	26	9	7
	SSLL	0	0	0	1	0