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The role of electronic monitoring in assessing post-release mortality of protected species in pelagic longline fisheries

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The Pacific Islands Fisheries Science Center of NOAA's National Marine Fisheries Service uses the NOAA Technical Memorandum NMFS-PIFSC series to disseminate scientific and technical information that has been scientifically reviewed and edited. Documents within this series reflect sound professional work and may be referenced in the formal scientific and technical literature.

This report includes results from a study reviewing protected species interactions from electronic monitoring (EM) video collected from the Hawai'i longline fisheries (deep-set and shallow-set fisheries), and was funded by the Fisheries Information System Program (FIS). The intent of the study was to determine if data could be collected from EM video to assess the likely post-release condition of protected species following fishing interactions, and to provide recommendations for improving data collection for the assessment of the likely post-release condition.

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Executive Summary

Protected species bycatch occurs in longline fisheries worldwide with accurate documentation limited to trips with a fishery observer onboard. Electronic monitoring (EM) provides an additional data stream to detect these protected species interactions and to assess the likelihood of an animal's survival after their incidental capture and release from fishing gear. In this study, protected species interactions were reviewed from EM video collected from the Hawaii longline fisheries to evaluate if determinations of mortality or injury severity (serious or non-serious) could be made for cetaceans, and if the percent likelihood of post-interaction mortality could be assigned for sea turtles. Cetacean injury determinations were made based on criteria developed by the National Marine Fisheries Service (NMFS 2012; NMFS 2023), with our study focusing on the location and amount of attached fishing gear at capture and at release and on the health condition of the animal. The percent likelihood of mortality for sea turtles was assigned based on criteria such as: 1) whether the sea turtle was a leatherback (*Dermochelys coriacea*) or hardshell, 2) its injury category derived from its hooking/entanglement location, and 3) the amount of fishing gear remaining at release, per Ryder et al. (2006, Table 1). When uncertainty existed in protected species data, then in some cases an injury determination could not be made for cetacean interactions or a potentially higher percent likelihood of mortality was assigned for sea turtles.

During this study, we reviewed video footage of eight small cetaceans and 37 sea turtle interactions incidentally captured on Hawaii-based longline fishing trips. Our study demonstrated that injury determinations could be made for most cetacean interactions, with the reviewer able to see the general location of the attached fishing gear, if the animal was alive or dead at release, and if the amount of fishing line at release was enough to result in a serious injury. However, in two cases where cameras were dirty or had poor views (e.g., limited view of the water out from the vessel), no determination could be made as the amount of trailing line at release was unknown. For sea turtles, EM video could be used to estimate the percent likelihood of mortality (per Ryder et al. 2006) with high certainty for most sea turtles caught. Improvements during the study to camera resolution allowed reviewers to generally discern the hooking/entanglement location and to determine the release condition, which was based on the amount of trailing gear at release (per Ryder et al. 2006). However, some uncertainty occurred in cases where the sea turtle was hooked around the mouth or released with attached fishing gear.

We provide recommendations and specifications for EM cameras and handling requirements that will enable reviewers to assess the likely post release mortality. EM cameras should have a resolution of at least 4 megapixels and, at a minimum one camera per vessel should have a view that extends out from the vessel over the water while a separate camera view should cover the entire deck. In addition, recording at a higher frame rate of 30 frames per second (fps) may increase the probability of seeing a hook to discern the specific attachment location and to distinguish dark-colored protected species, such as leatherback sea turtles and false killer whales, (*Pseudorca crassidens*) from the dark-colored ocean at night. Fisher handling guidelines are needed to remove fishing gear and to coil remaining fishing line after removal from the animal within the view of the EM cameras to improve estimation of the amount of fishing line that remains attached after protected species are released. Implementation of EM technology can provide a better understanding of the impacts of longline fisheries on protected species stocks worldwide and can lead to better management of fisheries.

Introduction

Protected species such as sea turtles, marine mammals, and seabirds are incidentally captured in many fisheries worldwide. Few of these interactions are documented when a fisheries observer is not present, and most fisheries have a low proportion of observers present on fishing trips. Consequently, there is a high degree of uncertainty in estimates of sea turtles (Lewison et al. 2004), cetaceans (Carretta et al. 2022), sharks (Mucientes et al. 2022), and seabirds (Zhou and Liao 2022) incidentally taken by fisheries, and an even greater uncertainty in whether an animal will survive the interaction if they are returned to sea. Thus, information regarding protected species for the use of population and stock assessments is limited.

Marine turtles and mammals are protected under the Endangered Species Act (ESA, 1973) and the Marine Mammal Protection Act (MMPA, 1972); thus, it is critical to quantify interactions and develop mitigation measures. Previous research conducted in the Pacific Islands Region (PIR) confirms electronic monitoring (EM) is a viable method to document catch of both target and bycatch, including protected species, from video footage in the Hawaii longline fisheries (Carnes et al. 2019; Stahl and Carnes 2020).

Protected species detections are crucial in the PIR longline fisheries as interactions can result in management actions (e.g., leatherback sea turtle annual fleet interaction limit may close the Hawai‘i shallow-set fishery, sea turtle bycatch trip limits may require a vessel to return to port, and false killer whale interactions may close an area to deep-set fishing). However, to inform some of these management actions and stock assessments, it is necessary to not only detect the protected species events but also to predict the likelihood that an animal will survive post-interaction. These data are crucial as the National Marine Fisheries Service (NMFS) is required to estimate annual rates of human caused mortality for cetacean stocks and sea turtle populations occurring during federal permitted activities in U.S. and high seas waters. In addition, these data are used to assess population level impacts on protected species from incidental fishery interactions (i.e., the maximum number of cetaceans which may be removed from a stock while allowing the stock to reach its optimum sustainable population size).

The uncertainty of whether an animal will survive a fishery interaction has been quantified for some species through various injuries or attached fishing gear at release. In some cases, satellite tags have demonstrated whether an animal will survive a fishery interaction for a specified time period after its release (e.g., sea turtles in Swimmer et al. 2013). In other cases, necropsies or re-sightings of animals after a fishery interaction have provided data on survival (e.g., small cetaceans in Wells et al. 2008). As these types of data are limited, expert advice from researchers and veterinarians combined with the verified survivability data have been used to develop criteria for cetaceans (NMFS 2023) and sea turtles (Ryder et al. 2023) to assess the likelihood of an animal surviving a longline fishery interaction based on information that is observable from a fishing vessel (e.g., condition of the animal at the vessel, hook or entanglement location, and fishing gear remaining at release). In the PIR, these data (i.e., notes and imagery) are collected by at-sea observers and reviewed by protected species experts that make determinations of the likelihood of post-interaction mortality (typically referred to as mortality or serious or non-serious injury for cetaceans and post-interaction mortality for sea turtles). The ability for EM to collect these data on protected species interactions in the PIR longline fisheries is critical to effectively supplement the at-sea observer program.

Currently, data on protected species interactions in the PIR longline fisheries (Hawaiʻi and California-based deep- and shallow-set fisheries, and American Samoa-based longline fishery) are collected by human observers. However, the costs for observer coverage continue to rise, and observer coverage is limited in the Hawaiʻi and California-based deep-set and American Samoa-based longline fisheries. For each observed trip, the work is time intensive and tedious with observers monitoring gear retrieval to enumerate catch and protected species: an average of 12 sets with an average of 1,295 hooks per set in the Hawaiʻi and California based shallow-set fishery, 13 sets with an average of 2,896 hooks per set in the Hawaii and California based deep-set fishery (FRMD 2022a), and 38 sets with an average of 2,882 hooks per set in the American Samoa fishery (FRMD 2022b). Each longline set consists of a heavy monofilament mainline with lighter monofilament branchlines that include a weighted swivel typically located approximately 0.5 m from a circle hook.

As of 2023, 17% of these Hawaiʻi and California based deep-set trips and 20% of American Samoa-based trips are monitored by observers, while shallow-set trips have 100% observer coverage. Consequently, continued development of EM with movement towards implementation in the region has been encouraged in the 2021–2025 Pacific Islands Regional Electronic Technology Implementation Plan (NMFS 2021). EM research in PIR has been conducted on protected species interactions in the Hawaiʻi based deep- and shallow-set fisheries; however, this research will have broader implications on the other longline fisheries in PIR (American Samoa and California-based) and inform other developing EM programs for both domestic and international fisheries that incidentally interact with protected species. Many international pelagic longline fisheries have very limited or no observer coverage, and as a result, there has been recent movement towards developing EM in the broader Pacific. The Regional Fishery Management Organizations (RFMOs) of the Western and Central Pacific Fisheries Commission (WCPFC) and Inter-American Tropical Tuna Commission (IATTC) have established electronic technologies working groups and are developing minimum standards to operationalize EM.

This report summarizes what data EM can collect from protected species interactions that have occurred in the Hawaiʻi-based deep-set and shallow-set longline fisheries to make determinations on mortality and injury severity for cetaceans and post-interaction mortality for sea turtles. In these fisheries, protected species are captured across genera (e.g., sea turtles, whales, dolphins, birds, and elasmobranchs); however, for this study we only reviewed cetacean and sea turtle interactions. We also provide recommendations for modifications to EM systems, fisher handling, and video review to improve data collection.

Methods

EM systems were installed in two separate deployments on volunteer Hawai‘i longline vessels, which participate in both deep-set and shallow-set trips: 18 systems in 2017 installed by Saltwater, Inc. (phase I), and 20 systems in 2021 installed by Lynker (phase II). Each system consisted of a computer and two cameras as well as sensors for GPS, hydraulic, and magnetic rotation with computer and sensor configuration according to Carnes et al. (2019). In both deployments, dome-shaped security cameras—optimized for low light conditions (minimum illumination at 0.01 lux)—were used. The security cameras were fitted with a waterproof housing that was supplemented with an application of marine sealant on top of the seam. Cameras in the first deployment had 3 megapixels with imagery at a resolution of 720p, while those in the second had 4 megapixels with a resolution of 1080p. Cameras in the first deployment were set to record at 10 frames per second (fps). These settings were selected to minimize data storage while capturing images adequate for fish identification. However, one vessel’s cameras were set at 30 fps during the first deployment. In the second deployment, cameras were initially set at 10 fps and then switched to 30 fps. This change was made to determine if this setting could improve the quality of the video footage and data available for determinations of mortality and injury severity for cetaceans and post-interaction mortality for sea turtles.

All EM systems were equipped with a “rail” and a “deck” camera that were installed on the vessel house. The “deck” camera was mounted downward to capture activities on deck, while the “rail” was used to capture imagery of fish and protected species in the water. The “deck” camera had a field of view that extended to at least 1 ft outside of the rail and included the fish door, where fish are brought on to the deck. The “rail” camera view included the area around the fish door and extended over the water. The “deck” and “rail” cameras have some overlap along the rail of the vessel. During the first deployment of cameras, staff adjusted cameras over time to improve views for data collection. Knowledge gained from the first deployment informed camera placement for the second deployment to ensure the best data collection possible. As a result, “rail” cameras were placed to include views from the fish door all the way to the back rail of the vessel when possible. Booms were installed on some vessels to allow cameras to extend out from the vessel house to achieve this preferred view. However, there was some variation in the camera angle and views between vessels due to the location of the vessel house where cameras were installed and its relationship to the fish door, along with the length and width of the vessel. Consequently, some vessels had “rail” cameras with a larger field of view over the water, while other views appeared more vertical with a smaller field of view.

Recorded EM video was collected from both deep-set and shallow-set longline trips. Protected species interactions from the first deployment of EM systems were detected during comprehensive video review that was performed for all trips and hauls from both observed and unobserved trips. During the second deployment of EM systems, EM footage was only reviewed if a cetacean or sea turtle interaction was reported by an at-sea observer due to limitations in staff time. However, unobserved interactions likely occurred that could have been detected if we had performed a comprehensive review of EM footage as during phase I. Events were located in the video footage with the aid of the capture time recorded on the observer report.

During phase I of this study, EM videos (PIFSC 2023) of protected species interactions were reviewed in their entirety to determine the feasibility of making injury determinations for cetaceans and assigning a percent likelihood of mortality for sea turtles using EM. These interactions were initially reviewed and annotated by EM staff and then evaluated by a protected species expert. The review of protected species interactions from this first EM system deployment indicated potential for making injury determinations for cetaceans and assigning a percent likelihood of mortality for sea turtles using EM. Consequently, we proceeded with phase II of the study to evaluate which data for the determinations could be collected with the EM camera configurations used during the second deployment and to make any recommendations to EM systems and/or handling to improve data collection. More detailed observations are provided in the results section of this document for Phase II interactions, which will demonstrate the capability of the improved EM cameras and views to collect the needed data, as future EM programs would be established with at least these minimum standards.

For all cetacean interactions, EM staff (J. Stahl, J. Tucker, or M. Carnes) reviewed and annotated video and a protected species expert (A. Bradford) reviewed the video to make determinations of mortality, serious injury, or non-serious injury based on criteria defined for small cetaceans (odontocetes except sperm whales) from Table 2 in NMFS 2023 (updated from NMFS 2012). NMFS defines a serious injury as "an injury that is more likely than not to result in mortality". If data were insufficient to determine injury severity, then a determination of "cannot be determined" (CBD) was assigned (NMFS 2023). The primary data examined to make a determination were the species; the location and amount of attached fishing gear at capture and at release; and the condition and behavior of the animal at capture and release. If cetaceans were hooked in the mouth or head, then a serious injury was assigned, unless it could be confirmed that the cetacean was only hooked in the lip in external tissue outside of the teeth and released with no trailing gear (NMFS 2023). However, regardless of the hook (or entanglement) location, the injury was also considered serious if a cetacean was released with trailing gear that had the potential to be constricting, ingested, cause drag, or anchor the animal. Trailing line greater than a cetacean's body length is always considered to have this potential (NMFS 2023). For injuries not categorized as serious (e.g., lip hooking, hook removed), case-specific factors were considered (e.g., potential for capture myopathy, presence of other injuries) for each interaction before a non-serious injury determination was assigned (NMFS 2023).

For both phases of the study, EM footage of sea turtle interactions were examined to determine if the data necessary to assign a percent likelihood of post-interaction mortality could be collected. For phase I, sea turtle interactions were reviewed by EM staff (M. Carnes and J. Stahl) and the protected species expert (L. Hawn), while the phase II review was performed solely by EM staff (J. Stahl and J. Tucker). After video and data review, a percent likelihood of post-interaction mortality was selected from Table 1 in Ryder et al. (2006) based on the assigned injury and release condition and whether the sea turtle was a hardshell or leatherback, with leatherbacks assigned a higher percent (5-10% greater) likelihood of mortality for the same injury and release condition. An injury category was assigned (I-VI) based on the hooking or entanglement location and whether the sea turtle was comatose or resuscitated. The release condition was based on the amount of attached fishing gear at release in relation to the sea turtle's body length.

For both phases of the study, protected species interactions were reviewed using the software ("Review")[1] created by Saltwater. This software allows simultaneous review of video footage and a timeline that displays sensor data and any marked events and to zoom in or slow down video from real-time to examine more closely. For each interaction reviewed, notable events were annotated and marked on the timeline including the capture and release time, the time the animal was brought on deck if it was boarded, times that a hook or entanglement location were visible, and times of fishing gear removal attempts (e.g., removing fishing gear by hand, cutting line, using a dehooker or bolt cutters) and other handling. For each interaction during the second deployment, EM staff summarized the aforementioned notable events as well as answered the following questions: 1) Is the species identifiable?, 2) Is the fishing gear (hook or entanglement) location visible?, 3) Is fisher handling observable (i.e., if fishing gear was removed, how was the animal released)?, and 4) Is the condition of the animal observable at capture or release? The answers to these questions are summarized in this document and inform our discussion on whether determinations of mortality and injury severity for cetaceans and post-interaction mortality for sea turtles can be performed using EM.

[1] Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the NOAA Pacific Islands Fisheries Science Center of the Department of Commerce or any of their employees/contractors.

Results

Phase I

Phase I of the study demonstrated the feasibility of making determinations of mortality and injury severity for cetaceans and assigning a percent likelihood of post-interaction mortality for sea turtles. A total of 29 protected species (six small cetacean and 23 sea turtle) interactions were recorded by EM systems from the first deployment. These interactions were detected, reviewed, and annotated by EM staff and then reviewed by protected species experts.

Cetaceans

Six small cetacean interactions were recorded in EM footage and reviewed for phase I of this study with two from observed and three from unobserved deep-set trips, and one from an observed shallow-set trip (Table 1). Video was recorded during the day for two interactions (#3 and #4) and at night for four interactions (#1, #2, #5, and #6) at a frame rate of 10 fps for five of the interactions while one interaction (#4) was recorded at a rate of 30 fps.

For the six cetacean interactions reviewed during phase I, the reviewer had sufficient data to make a determination of mortality, serious, or non-serious injury for four of the six cetaceans (Table 1). For the two interactions where a determination could not be made (#2 and #3), observations were hindered by the limited field of view and the orientation of the "rail" cameras (i.e., the camera did not allow much view of the water). In addition, the view was further obscured for one interaction (#3) by dirty cameras. For one of these interactions (#2), the species and general location of fishing gear attachment could be identified. However, other critical data, such as the amount of fishing gear at release and the behavior after release, could not be observed. The cetacean was very close to the vessel, which allowed identification of it as a false killer whale and that it was entangled. However, it was difficult to observe the dark-colored body against the dark ocean at night with the very limited field of view and poor camera orientation. As a result, it could not be determined from EM video how the false killer whale was removed from the fishing gear, if any fishing gear was attached at release, or if it was alive or dead and floating at the surface. For the other interaction (#3), the cetacean could only be identified as a dolphin but not to the species. It could not be determined how the dolphin was attached or released from the fishing gear, the amount of trailing line at release, or its behavior at release, only that it was alive.

For two of the interactions (#1 and #6) determinations were possible from the information collectable, even though some data elements could not be collected (Table 1). A Risso's dolphin (*Grampus griseus*) (#1) was determined to be dead as it was floating close to the vessel. However, it was not possible to see how much trailing line was left on the animal as the line was cut out of the view of the camera towards the stern. In addition, it was difficult to determine where the fishing gear was attached due to observations possibly being hindered at night and the camera switching from recording in color to monochrome. For the other cetacean (#6), it was given a serious injury determination as fishers could be observed cutting the line close to the mainline leaving a considerable amount of trailing line (greater than its body length) on it at release. However, as protected species guidelines were not followed to bring the cetacean towards the vessel, the species and the fishing gear attachment location could not be identified nor its condition at release.

For the other two interactions where determinations could be made (#4 and #5), all of the data elements could be observed from the EM footage (Table 1). For one of these interactions (#4), the field of view was somewhat limited (less than 15 ft out from the vessel). However, data could be collected to make a non-serious injury determination with a favorable rail camera angle, good imagery with a video recorded at a high frame rate (30 fps compared to the other interactions at 10 fps), and the cetacean in view for an extended period of time as it was pulled toward the vessel for handling. In addition, it was daytime, which allowed for better observations of the dark-colored false killer whale against the light ocean surface compared to the dark surface at night. For this interaction, it could be confirmed that the false killer whale was only hooked in the lip as the hook could be seen in a few frames. Handling could also be observed through the crew tying the branchline with the attached cetacean to the vessel following protected species guidelines. It could also be determined that no fishing gear remained at release as the hook dislodged from the false killer whale and was seen still attached to the branchline that the fisherman coiled on deck. In addition, it was observed that the hook did not straighten from the interaction. For the other interaction (#5), data could be collected with a favorable camera orientation and sufficient field of view. It could be observed that the animal was hooked in the mouth and released with a considerable amount of trailing line (greater than its body length) with the branchline seen cut close to the mainline, leading to the serious injury determination. In addition, the animal was observed diving at release. However, as protected species guidelines were not followed to bring the cetacean towards the vessel, the cetacean could not be identified to species but only to one of the dark-colored cetaceans that interact with the Hawaiʻi longline fisheries and are collectively referred to as "blackfish", which include the species: false killer whale, pygmy killer whale (*Feresa attenuata*), short-finned pilot whale (*Globicephala macrorhynchus*), and melon-headed whale (*Peponocephala electra*).

Sea turtles

Twenty-three sea turtle interactions were recorded in EM video footage and reviewed in phase I of this study with twenty from observed trips in the shallow-set fishery and three from unobserved trips in the deep-set fishery. The majority of these interactions occurred during the day and all were recorded at a frame rate of 10 fps. For all of the sea turtle interactions reviewed, the protected species expert was able to assign a percent likelihood of post-interaction mortality based on the injury category and the release condition determined from the EM video. However, a "worse case" injury was often assigned due to uncertainty in the hook or entanglement location, potentially inflating the percent likelihood of post-interaction mortality (Table 2). For 13 (57%) of the 23 sea turtles, the hook and/or entanglement location was uncertain, but it was clear they were released with no fishing gear attached. Consequently, the reviewer assumed a "worse case" Injury category III (defined by "the insertion point of the hook is visible when viewed through the mouth"). It was assumed that the "worst case" Injury category IV (defined by "the insertion point of the hook is not visible when viewed through the mouth") did not occur in the reviewed interactions as removal of fishing gear is not recommended in these cases (Ryder et al. 2006). For two interactions where the hook and/or entanglement location could not be determined, the reviewer was able to deduce that the turtle was not deeply hooked due to the ease at which the fishermen removed the fishing gear. However, a more conservative “worse case” percent likelihood of mortality was still assigned of injury category III.

Fourteen (61%) of the sea turtles could be identified to species and the rest could be identified as a hardshell sea turtle (Table 2). All sea turtles were boarded and observed in both the “deck” and “rail” cameras. The reviewer was able to determine that two were dead and the others were all released alive with six called “lively” and one “moving”. In addition, it was confirmed that every sea turtle was released with all fishing gear removed including hook and line. Identification of the species and hook/entanglement location were sometimes prevented from poor imagery due to water spots on cameras, blurry cameras, washed out footage from sun, and/or too much shade. In addition, the crew or observer sometimes blocked the view of the sea turtle, and in one case, left a dead sea turtle ventral side up making it challenging to identify. In addition, imagery was blurry when zoomed in for cameras in the first deployment

Table 1. Cetacean interactions in the Hawaiʻi shallow-set (SS) and deep-set (DS) longline fisheries captured in electronic monitoring (EM) footage and reviewed by a marine mammal expert to determine if data could be collected to make determinations of mortality, serious injury (SI), or non-serious injury (NSI). These reviews were performed during phase I of our study with our first deployment of cameras. An asterisk (*) next to the fishery type indicates the trip had an at-sea observer aboard the vessel. It is noted when data could not be collected or was uncertain with EM with cells colored gray.

Event number	Species category	Species	Fishery	Hook and/or entanglement location	Fishing gear removal	Fishing gear at release	Condition	Determination
1	Cetacean	Risso's dolphin (*Grampus griseus*)	DS	Not determined	Deduced line cut but couldn't see action	Not determined	Dead	Mortality
2	Cetacean	False killer whale (*Pseudorca crassidens*)	DS*	Entangled around body	Not determined	Not determined	Not determined	Cannot be determined
3	Cetacean	Unidentified dolphin	SS*	Not determined	Not determined	Not determined	Alive, behavior at release not observed	Cannot be determined
4	Cetacean	False killer whale (*Pseudorca crassidens*)	DS*	Mouth	Hook dislodged after animal tied off	None	Alive, behavior at release not observed	NSI
5	Cetacean	"Blackfish"[2]	DS	Mouth	Line cut	Trailing line greater than body length	Alive, dove after release	SI
6	Cetacean	Not determined	DS	Not determined	Line cut	Trailing line greater than body length	Alive, behavior at release not observed	SI

[2] "Blackfish " are small cetaceans that interact with the Hawaiʻi longline fisheries. They are dark in coloration and can be difficult to differentiate from imagery when dorsal fin views are limited. "Blackfish" species include the false killer whale (*Pseudorca crassidens*), pygmy killer whale (*Feresa attenuata*), short-finned pilot whale (*Globicephala macrorhynchus*), and melon-headed whale (*Peponocephala electra*).

Table 2. Sea turtle interactions in the Hawai‘i shallow-set (SS) and deep-set (DS) longline fisheries reviewed from electronic monitoring (EM) footage to determine which data could be collected to assign a percent likelihood of post-interaction mortality based on criteria in Ryder et al. 2006. Review occurred during phase I with cameras from the first deployment. All turtles were boarded, and all turtles that were alive were released with no fishing gear. An asterisk (*) next to the fishery type indicates the trip had an at-sea observer aboard the vessel. It is noted when data could not be collected or was uncertain with EM with cells colored gray.

Event number	Species category	Species	Fishery	Hook and/or entanglement location	Fishing gear at release	Percent likelihood of post-interaction mortality
1	Hardshell	Not determined	DS	Externally hooked, possibly mouth but not ingested	None	25%
2	Hardshell	Olive ridley (*Lepidochelys olivacea*)	DS	Hooked lower jaw	NA	100% (mortality)
3	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Hooked lower beak	None	10%
4	Hardshell	Olive ridley (*Lepidochelys olivacea*)	DS	Externally hooked in mouth	None	10%
5	Hardshell	Not determined	SS*	Not determined	None	25%, worse case
6	Hardshell	Not determined	SS*	Externally hooked, neck area?	None	5%
7	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Hooked right flipper	NA	100% (mortality)
8	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Not determined	None	25%, worse case

Event number	**Species category**	**Species**	**Fishery**	**Hook and/or entanglement location**	**Fishing gear at release**	**Percent likelihood of post-interaction mortality**
9	Hardshell	Not determined	SS*	Not determined	None	25%, worse case
10	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Not determined	None	25%, worse case
11	Hardshell	Not determined	SS*	Not determined	None	25%, worse case
12	Hardshell	Not determined	SS*	Not determined	None	25%, worse case
13	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Hooked, but could not determine location, likely external due to ease of removal.	None	25%, worse case
14	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Not determined	None	25%, worse case
15	Hardshell	Not determined	SS*	Not determined	None	25%, worse case
16	Hardshell	Not determined	SS*	Not determined	None	25%, worse case
17	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Hooked jaw	None	10%
18	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Not determined, possibly entangled	None	25%, worse case
19	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Could not see, but inferred lightly hooked/entangled by handling	None	25%, worse case
20	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Hooked near the head	None	10%

Event number	Species category	Species	Fishery	Hook and/or entanglement location	Fishing gear at release	Percent likelihood of post-interaction mortality
21	Hardshell	Not determined	SS*	Not determined	None	25%, worse case
22	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Hooked externally in flipper	None	5%
23	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Hooked in head/jaw area	None	10%

Phase II

A total of 16 protected species (two cetacean and 14 sea turtle) interactions were reviewed from EM footage during phase II. All interactions were from trips with an at-sea observer.

Cetaceans

Two small cetacean interactions that occurred in the deep-set fishery at night were captured and reviewed in EM video during phase II of this study (Table 3). The cetaceans were identified to species including a bottlenose dolphin (*Tursiops truncatus*) interaction recorded for approximately seven minutes with clear imagery and ample surface time, and a false killer whale interaction of just over a minute with four surfaces during that time. The false killer whale and the ocean were both dark in coloration making it difficult to distinguish the cetacean at certain times in the video. However, there was footage collected that allowed for identification of the cetacean as its head, dorsal fin, and pectoral fins were all visible as it surfaced close to the vessel in the open area by the fish door, which allowed footage to be recorded in the deck camera at close range. In contrast, the bottlenose dolphin was light compared to the ocean and easily distinguishable.

For both interactions reviewed during phase II, a determination of serious injury could be made from the EM video. For the bottlenose dolphin interaction (#1), the cameras were clear with a good field of view (i.e., greater than 15 ft along the rail of the vessel and greater than 20 ft out from the vessel) and an overhead (i.e., "bird's eye view") camera angle to allow observation of the fishing gear attachment location and to approximate the amount of line at release based on the location where the line was cut. It could be determined from the EM footage that the dolphin was hooked in the mouth and that the hook was ingested as there was video with the dolphin's mouth open with the line coming from the middle. In addition, the location of the weight on the branchline could be seen, this also suggested ingestion as it was closer to the mouth than would be expected if not ingested. This hook location resulted in assigning a serious injury determination for this interaction (NMFS 2023). In addition, it could be observed that the dolphin was entangled loosely with monofilament around the fluke and body, but it was free from the entanglement at release.

For the false killer whale interaction (#2), the cameras were also clear with a good field of view and camera angle. The location of the attached fishing gear could be seen on the right side of the false killer whale's mouth and the weight could be seen at a distance from the mouth, suggesting the hook was not ingested. The actual hook could not be observed to determine if the cetacean was hooked in the lip, so a serious injury was assigned as is the case for mouth-hooked cetaceans where a lip-hooking cannot be confirmed (NMFS 2023). Although the fishing gear removal was not observed, the remaining line after release could be observed as it was coiled by a fisherman. The coiled line had no weight or hook, which indicated that the remaining line attached to the false killer whale was at least the length of the branchline leader and long enough to be ingested by this mouth-hooked cetacean and potentially wrap around its goosebeak.

For the cetacean interactions, some of the crew handling was visible while some actions were blocked or not in the view of the camera. In the video for the bottlenose dolphin interaction, all crew handling can be observed in the video from initially pulling in the branchline with the captured animal to its release. For this vessel, the "rail" camera has a field of view that includes the entire stern for the side of the vessel where the fish door is located, and the deck, rail, and area adjacent to the vessel on the water side are all visible. The mounting location allows for this view as the “rail” camera sits on a small boom on top of a house, which is a bit higher compared to other vessels. The captain can be seen attempting to remove the hook by leaning over the rail and using a long-handled dehooker. However, after his attempts were unsuccessful, he pulls on the line by hand and then switches tools to a long-handled cutter and is able to cut the branchline close to the mouth below the weight to release the dolphin, which suggests the hook and a small amount (less than 0.5 m) of monofilament remain. Some of the false killer whale handling can be observed, while some of the action is not visible at the stern of the vessel as the handling is out of the view of the camera or blocked by crew. For this vessel, the “rail” camera is mounted on a pole on top of the vessel house and does not include a view of the rail at the back of the stern. The “deck” camera view extends down the rail further toward the stern; however, it does not include the area of the water at the side of the rail. The crew can be observed pulling the branchline in by hand to bring the animal close to the vessel and then moving to the stern of the vessel as they continue to pull the line. When at the stern, the crew holding the branchline becomes blocked by other crew or go out of the camera view. Thus, it is not possible to observe whether the crew tied off the line to allow the whale a chance to straighten the hook—as recommended by handling procedures—or how the animal becomes separated from the fishing gear (i.e., was the line cut or did the line break?). After the animal is released, the fisher holding the line can be seen coiling monofilament with no hook or weight visible. This suggests that this fishing gear is still attached to the cetacean and is confirmed by the observer report, which indicates the full branchline leader is still attached.

Some data on the condition of the two cetaceans at capture and release could be gathered while other information was uncertain. The EM footage of the bottlenose dolphin allows for data to be collected on the animal’s condition at capture. The bottlenose dolphin is very active as it tries to free itself from the monofilament entangled around its fluke and body with multiple surfaces and dives. An assessment of the body can be made with it appearing to be of normal girth and having only minor injuries visible: some blood by its mouth near the monofilament branchline and some scars on the body including cookie cutter shark wounds. Once released, the animal descends underwater and disappears. For the false killer whale, we could observe that the animal was somewhat active, with multiple surfacings that included it bringing its head out of the water, and that it swam away. The body condition of the animal appeared to be normal girth with no injuries.

Sea turtles

Fourteen sea turtle interactions, 13 in the shallow-set and one in the deep-set fishery, were captured in EM footage during phase II of this study (Table 4). One video of a leatherback sea turtle (#13) was recorded at a frame rate of 30 fps, while all other footage of sea turtles in this study were recorded at 10 fps. All but one of the capture events (#11) occurred during the daytime. For eleven of the interactions, cameras recorded during the time the sea turtles were released with nine of these occurring during the day and two at night (#7 and #11). However, the release event was sometimes out of frame or blocked from view. The cameras did not record during the time one sea turtle (#10) was released as the sea turtle was released after the haul and the cameras were no longer recording. For the sea turtles that were not boarded, the interaction time (from first observation in EM camera to release) ranged from 1 minute to 8 minutes in duration; whereas, the interaction time for sea turtles brought on board the vessel ranged from 47 minutes to 412 minutes. While sea turtles were on deck, observers applied flipper or satellite tags, measured, and/or took genetic samples; satellite tags were applied with glue, which required time for drying. Sea turtles were also given time to recover from the capture before being released. Often, they were released after hauling to prevent disruption of fishing or to prevent entanglement with fishing gear.

Eleven of the sea turtle interactions were of hardshell sea turtles (one green, *Chelonia mydas*; three olive ridley, *Lepidochelys olivacea;* seven loggerhead, *Caretta caretta*) and three were of leatherback sea turtles; all sea turtles identifiable to species. The sea turtles were generally easy to distinguish from the ocean surface that varied in color from bright blue to a dark gray. The dorsal side of the hardshell sea turtles were dark-colored and were sometimes similar to the coloration of the ocean during the day in cloudy weather, and at night dependent on lighting. However, the ventral side of sea turtles are yellow in coloration which makes them easier to distinguish. As leatherback sea turtles are very dark on both their dorsal and ventral surfaces, they blended in more with the water when it was dark blue or gray. Also, the leatherback sea turtles had a tendency to dive more frequently making observations more challenging. However, these animals tended to flap their elongated front flippers which made them easy to spot and identify.

For all of the sea turtle interactions reviewed during phase II, a percent likelihood of post-interaction mortality could be assigned based on the injury category and the release condition determined from the EM video. Only for two interactions, a “worse or worst case” injury was assigned due to uncertainty in the hook location and/or the amount of trailing line at release, potentially inflating the percent likelihood of post-interaction mortality (Table 4).

For one of the “worse or worst case” interactions (#9), it could be determined that the sea turtle was hooked in the mouth with part of the hook visible, but it could not be determined if the hook was embedded in the jaw, beak, or another area such as the soft tissue. However, it was clear all gear was removed before release, which lead to the assumption that the “worst case” injury of Category IV (defined by “the insertion point of the hook is not visible when viewed through the mouth”) did not occur as fishing gear removal is not recommended for this category (Ryder et al. 2006). Consequently, the reviewer assumed a “worse case” Injury Category III (defined by “the insertion point of the hook is visible when viewed through the mouth”). For the other “worse or worst case” interaction (#12), a fisher was seen using a long-handled line cutter to cut the branchline to release the leatherback sea turtle. However, it was uncertain from the video where it was hooked and if the trailing line was greater than or equal to half of the length of its carapace. Consequently, the “worst case” injury was assigned for both the injury and release categories, which potentially inflated the percent likelihood of post-interaction mortality.

For the other 12 sea turtles, the EM footage allowed the reviewer to confidently assign a percent likelihood of post-interaction mortality based on the determined injury and release condition (Table 4). One sea turtle was dead (#3), which the reviewer was able to determine while the animal was in the water prior to boarding as its fins were stiff and not moving. One of the sea turtles (#14) was determined to be hooked in the roof of the mouth and was consequently assigned Injury Category III based on Ryder et al. (2006). The remaining sea turtles were all determined to be hooked or entangled externally from EM footage, allowing assignment of an Injury Category I based on Ryder et al. (2006). For the ten that were hooked, the hook was visible for seven of the interactions even while the sea turtles were in the water. For the other three sea turtles, it could be determined they were hooked in the front flipper as the branchline could be seen. In addition, a hook was visible for one of the sea turtles (#8) that was reported by the observer to be only entangled. When the sea turtle was on deck and rotated, the point of the hook could be seen to verify the hook did not penetrate the skin.

From EM footage, the release condition of the sea turtles could be determined, which is needed to assign a percent likelihood of post-release mortality, as it could be resolved that either all fishing gear was removed before the sea turtle's release or the amount of trailing line (in relationship to the turtle's body size) could be deduced. For all sea turtles that were boarded and released alive (eight sea turtles), it was verified in EM footage that they were released with no remaining fishing gear as the gear removal was seen and/or the sea turtle release was seen in EM footage. For two of the sea turtles that were not boarded, EM footage revealed they were released with no fishing gear: one loggerhead (#9) escaped while the fishers tried to board it, and one leatherback (#13) was released with a long-handled dehooker. For the three sea turtles that were released by cutting the line, the amount of trailing line could be estimated from observations from EM footage. Fishers were seen cutting the line below the weight with scissors for one turtle (#1) and with a long-handled cutter for another (#12). However, one sea turtle (#2) was removed from the fishing gear at the stern and out of view of the cameras. But the amount of trailing line in relation to the sea turtle's body could be approximated, as the fishers were seen coiling the remaining line with no weight. For all three sea turtles, the "worse case" release condition was assigned as there was either uncertainty or it was certain that the amount of trailing line was equal to or greater than half the length of the sea turtle's carapace.

From EM footage, sea turtles that were entangled in fishing gear at capture (with or without hooking) could be seen for four of the five entangled sea turtles reported by the at-sea observer with all five sea turtles seen without any entangled fishing line attached at release. However, the specifics of the entanglement were difficult to discern (e.g., how many times the monofilament was wrapped). The clear monofilament of the branchline was challenging to see against the body; however, in some cases, an entanglement could be inferred if the sea turtle had restricted movements while swimming (#4 and #6) or by how it was hanging from the attached fishing gear (#7). For one sea turtle (#5), a wrap of monofilament could be seen, but the turtle had no restricted movements while swimming as the wraps were at the base of the flipper. For one of the sea turtles (#4), the bait could be seen hanging next to the attached branchline, which was another clue it was entangled and not hooked. Once on deck, the entanglement was sometimes easier to see (#4 and #8) with closer views than in the water.

For the five sea turtles (three leatherbacks, one green, and one loggerhead) that were not boarded, the fisher handling could be seen for four of the interactions. For the three leatherback sea turtles (#2, #12, #13), the fisher handling and fishing gear removal was visible for two (#12, #13) of the interactions where fishing gear removal occurred at the side of the vessel. However, fishing gear removal was not seen for one (#2) of the interactions as the sea turtle was pulled to the stern of the vessel and out of the view of the cameras. For the leatherback out of view, the crew could be seen pulling hard on the branchline to bring the animal close to the vessel and then seen loosening tension and letting go of the line as the sea turtle is likely released from the fishing gear. The observer report indicates the line was cut; however, from the camera view it is not possible to tell whether the line was cut or the animal broke the line. For the two leatherback interactions (#12, #13) that fishing gear removal was visible, a long-handled dehooker was seen removing all fishing gear, including the hook, for one interaction (#13), and a long-handled cutter was seen cutting the line for the other interaction (#12). In addition, all handling was visible for a green (#1) and loggerhead (#9) sea turtle that were not boarded. In the case of the green sea turtle (#1), hook removal was attempted with a long-handled dehooker, after multiple unsuccessful attempts, the line was cut with scissors to release the sea turtle. For the loggerhead sea turtle (#9), we can see it swim away after the crew attempted to bring it on board, so we can assume it escaped after falling off the hook.

For the nine sea turtles that were boarded alive with a net, the majority of handling and fishing gear removal could be seen in the EM video. For the two sea turtles (#4, #8) that were entangled but not hooked, we were able to see the line cut but we could not see the fishing gear actually removed as the captain was blocking one of the sea turtles and the other was processed out of the camera view. For three (#5, #10, #11) of the hooked sea turtles that were boarded, the hook and any entangled line were shown in EM video to easily be removed by hand. While for one sea turtle (#6), it was deduced from EM footage that the fishing gear falls off as it is seen boarded with no gear remaining after it is removed from the net. For another sea turtle (#7) a hook was shown to be successfully removed using bolt cutters. While for another sea turtle (#14) that was hooked in the roof of its mouth, failed attempts to remove the hook were shown in the EM video (e.g., long-handled dehooker while in water and by hand and bolt cutter on deck). However, the final hook removal was performed out of view of the cameras by the observer while the sea turtle was in the bait shed.

We were able to see the sea turtle's condition at both capture and release for four of the five sea turtles that were not boarded but released from fishing gear while still in the water. For one leatherback sea turtle, we could only infer that its condition was good from its left flipper flapping up and down during the interaction; however, the release is not in the video as it occurs out of view behind the vessel. For the other four sea turtles (two leatherbacks, a green, and a loggerhead sea turtle), they all were seen in EM footage to be lively during capture and release with flippers flapping and seen quickly swimming and/or diving at release.

Observations could be made about the capture condition for all eight sea turtles that were boarded alive and release conditions for seven of these turtles. While on deck, we assessed all the sea turtles to be in good condition as they can be seen flapping flippers, turning, crawling, and/or moving their head. For one of the sea turtles, the camera stopped recording prior to its release as it was released after the fishing set; however, we did see that the turtle's condition was lively after fishing gear was removed. For the other sea turtles, the release condition could be observed on deck immediately prior to its release and/or once it was released into the water. Once in the water, the sea turtles moved quickly out of view of the camera as they swam off or dove. In one case, the "rail" camera was broken, so the view was even more limited when the sea turtle was in the water at release. All the sea turtles appeared to be in good condition at release as they were flapping their flippers and holding their heads up. One turtle had its head covered prior to release and its flippers hung down motionless until its head was uncovered. Then it flapped its flippers slowly and raised its head and could be seen moving its flippers once in the water.

From EM footage, we were able to see specific injuries or blood that resulted from fishing gear for two of the four sea turtles reported by the observer. For an olive ridley sea turtle (#6) that was brought on deck, we were unable to see a puncture wound from a hook on the ventral side of a front flipper likely due to the clarity of the imagery recorded at 10 fps or potentially due to limited views of the ventral side of the flipper with the crew blocking many views. And for a leatherback sea turtle (#13), we were unable to see the torn tissue at the mid-dorsal anterior portion of the carapace that resulted from removing the hook with a long-handled dehooker while it was in the water, even though this interaction was recorded at 30 fps. There were also limited views of the fishing gear removal location as it was on the side of the turtle facing away from the camera when fishing gear was being removed, the dehooker tended to push its body underwater, and the sea turtle swam away quickly. For a loggerhead (#7) that was brought on deck for fishing gear removal, we were able to see a laceration that penetrated the skin from a cinched hook that was located on the dorsal side of a front flipper. However, a cookie cutter shark injury on the ventral side of this same sea turtle's back flipper was not visible nor was the blood mentioned by the observer associated with both injuries. The blood was likely minimal as it was reported by the observer "that neither injury was bleeding very much". In contrast, we were able to see blood during fishing gear removal of another loggerhead sea turtle (#14) that was brought on board. The observer reports the loggerhead sea turtle as having "a good deal of blood" after wedging its beak open to remove the hook from the roof of its mouth. We were unable to see the hook removal or the associated blood during that specific time as the sea turtle was brought to the back deck out of view. However, we did see blood on the deck when the observer first attempted to remove the hook with bolt cutters.

Table 3. Cetacean interactions in the Hawaii longline deep-set (DS) fishery captured in electronic monitoring (EM) footage and reviewed by EM staff to determine if data could be collected to make determinations of mortality, serious injury (SI), or non-serious injury (NSI). This review was performed during phase II of our study with the second deployment of cameras. An asterisk (*) next to the fishery type indicates the trip had an at-sea observer aboard the vessel. It is noted when data could not be collected or was uncertain with EM with cells colored gray.

Event number	Species category	Species	Fishery	Hook/entanglement location	Fishing gear removal	Fishing gear at release	Condition	Determination
1	Cetacean	Bottlenose dolphin (*Tursiops truncatus*)	DS*	Mouth (ingested)	Line cut	Small amount of trailing line as cut below weight.	Alive, active trying to free itself from fishing gear. Descends after release and disappears underwater.	SI
2	Cetacean	False killer whale (*Pseudorca crassidens*)	DS*	Mouth	Not determined	Trailing line, at least the length of the leader (about 0.5 m) and weight.	Alive, swims off after release.	SI

Table 4. Sea turtle interactions in the Hawaii longline shallow-set (SS) and deep-set (DS) fisheries reviewed from electronic monitoring (EM) footage to determine which data could be collected to assign a percent likelihood of post-interaction mortality based on criteria in Ryder et al. 2006. This review was performed during phase II with EM cameras from the second deployment. An asterisk (*) next to the fishery type indicates the trip had an at-sea observer aboard the vessel. It is noted when data could not be collected or was uncertain with EM with cells colored gray; in these cases, data is from the observer report.

Event number	**Species category**	**Species**	**Fishery**	**Boarded**	**Hooked/ entanglement location**	**Fishing gear removal**	**Fishing gear at release**	**Hook visible with EM**	**Percent likelihood post-interaction mortality**
1	Hardshell	Green (*Chelonia mydas)*	SS*	No	Hooked front flipper	Line cut below weight.	1.5 ft (Estimated with EM)	No	20%
2	Leatherback	Leatherback (*Dermochelys coriacea*)	SS*	No	Hooked front flipper	Line cut (Can't determine with EM.)	2.5 ft (Estimated with EM)	No	30%
3	Hardshell	Olive ridley (*Lepidochelys olivacea*)	DS*	Yes	Hooked front flipper	Line cut	NA, dead	No	100% (mortality)
4	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Yes	Entangled front flipper	Entangled line cut (Can't determine with EM.)	None	NA	1%
5	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Yes	Hooked and entangled front flipper	Hook removed by hand	None	Yes	5%
6	Hardshell	Olive ridley (*Lepidochelys olivacea*)	SS*	Yes	Hooked and entangled front flipper	Falls off as brought on board	None	Yes	5%
7	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Yes	Hooked and entangled front flipper (Can't see entanglement with EM)	Bolt cutter to remove hook, entangled gear falls off	None	Yes	5%

Event number	Species category	Species	Fishery	Boarded	Hooked/ entanglement location	Fishing gear removal	Fishing gear at release	Hook visible with EM	Percent likelihood post-interaction mortality
8	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Yes	Entangled front flipper	Line cut (Can't determine with EM.)	None	Yes, not embedded	1%
9	Hardshell	Loggerhead (*Caretta caretta*)	SS*	No	Hooked upper beak (Can't determine where the mouth is hooked)	Falls off	None	Yes	25% (worse case)
10	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Yes	Hooked front flipper	Hook removed by hand	None	Yes	5%
11	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Yes	Hooked front flipper	Hook removed by hand	None	Yes	5%
12	Leatherback	Leatherback (*Dermochelys coriacea*)	SS*	No	Hooked front flipper (Can't determine with EM)	Line cut	2 ft (Estimated with EM)	No	70% (worst case)
13	Leatherback	Leatherback (*Dermochelys coriacea*)	SS*	No	Hooked body/shell	Long-handled dehooker	None	Yes	10%
14	Hardshell	Loggerhead (*Caretta caretta*)	SS*	Yes	Hooked roof of mouth	Removed hook by hand. (Can't determine with EM)	None	Yes	25%

Discussion

EM can provide an additional data stream to assess protected species interactions that can inform sustainable fisheries management. Although logbooks are required for all longline fishing trips in the PIR, protected species interaction rates from logbooks are considered unreliable due to under-reporting (McCracken 2000). As a result, data on protected species interactions are collected through the at-sea observer program; however, increasing costs of the observer program creates challenges to monitor at current levels (100% in the shallow-set fishery, 17% in the Hawaii and California based deep-set fisheries, and 20% in the American Samoa based longline fishery). Further, when observer coverage is less than 100%, protected species handling is assumed to be the same on unobserved trips as it is on observed trips when estimating the total number of annual interactions that result in cetaceans that are dead or released with a serious injury based on determinations made from historical observer data (McCracken 2000; McCracken 2011; McCracken 2019).

EM provides a means to view fisher handling when an observer is not aboard the vessel to not only test these assumptions but also to increase adherence to handling guidelines that improve post-release outcomes for protected species. In addition, this research has broader implications as it can inform other developing EM programs both domestically and internationally for other fisheries that unintentionally interact with protected species. This is particularly important as many international pelagic longline fisheries have very limited observer coverage, and there has been recent movement towards developing EM in the Pacific Ocean.

Although our study was limited in the number of protected species interactions reviewed, we were still able to draw key insights on which data can be collected using EM to make determinations of mortality and injury severity for cetaceans, and to assign a percent likelihood of mortality for sea turtles. Our recommendations and conclusions are provided with an understanding that the study was limited in the number of interactions, especially for cetaceans, and the majority of sea turtle interactions occurred on observed trips in the shallow-set fishery that hauls fishing gear during the day. We recognize that fishers may behave differently on unobserved trips and data may be more difficult to collect from nighttime video. In addition, we only had two interactions that were recorded at the higher frame rate of 30 fps for comparison to the other interactions recorded at 10 fps.

Cetaceans

EM footage may allow mortality, serious, and non-serious injury determinations to be made that are comparable to those of the at-sea observer when camera views and imagery are optimized and fisher handling is performed within the camera views. Both serious injury determinations that were made for the phase II interactions by the protected species expert using the video collected by the observers' handheld cameras matched the determinations made using EM video. In addition, the protected species expert noted the view from EM for the bottlenose dolphin interaction (#1) had a better perspective for providing a sense of the cetacean's struggle during the interaction than the observer collected video. While for phase I, EM data was comparable to the at-sea observer data for a false killer whale interaction (#4) and allowed the same determination of a non-serious injury to be made. For the other two interactions in phase I that had an at-sea observer (#2 and #3), no determination could be made with the EM footage. In both these cases, the poor camera angle and orientation hindered observations and even prevented determining if a false killer whale was alive or dead. Dirty cameras also prevented data collection for a dolphin interaction (#3). However, careful camera placement will prevent issues with camera angle and orientation for future EM systems, and dirty cameras can be prevented with crew education. We suspect that in most cases the data collected using the recommended camera resolution and views will allow data comparable to that collected by at-sea observers. In addition, EM may allow more information to be collected than the observer data on fisher handling with views of the deck and water during the entire interaction.

The essential data needed to make cetacean injury determinations—location of attached fishing gear, trailing gear, and condition of animal—are collectable from EM footage. Moreover, cetacean determinations are sometimes possible with EM when not all of these data elements are known if one or more of the data elements suggests a mortality or a serious injury determination. For instance, a serious injury determination can be made if, from the video, it could be seen or inferred that the cetacean was 1) hooked anywhere in the head or mouth other than the lip or had ingested the hook, or 2) released with trailing gear with the potential to become constricting, ingested, accumulate drag, or become snagged on something in the environment (with remaining line that was greater than the body length of the animal always considered to have this potential). These scenarios are assigned as serious injuries based on criteria in the NMFS policy directive (NMFS 2023) that were developed based on 1) studies that showed hooks embedded in the throat, esophagus, or goosebeak, or ingested line that wrap around the goosebeak lead to death in bottlenose dolphins (Wells et al. 2008); and 2) consultation with experts, who agreed on the risks posed to small cetaceans by trailing gear (Angliss and DeMaster 1998, Andersen et al. 2008).

This study indicates if fisher handling is performed in the view of the cameras, then the amount of the trailing line attached to a cetacean at release may be deduced and inform injury determination, even if the cetaceans are not brought close to the vessel following protected species guidelines. For phase I, all handling for a false killer whale (#4) was done in the view of the cameras—including tying off the line attached to the animal and coiling the line—which allowed us to see the animal was released with no fishing gear as we could locate the hook in the coiled line. Whereas for two of the cetacean interactions in phase I (#5 and #6), the line was cut in the view of the cameras while the cetaceans were observed at a distance, indicating they were released with greater than a body's length of line, which would result in a serious injury regardless of the hook or entanglement location. While in phase II, all handling of the bottlenose dolphin occurred within the "rail" camera view, which allowed the reviewer to observe the fisher cut the line below the weight and close to the mouth, resulting in only a few inches of line attached at release. For the false killer whale in phase II, it could not be observed how it was released from the gear as it was out of view of the cameras. However, the amount of trailing line could be deduced to include the hook, weight, and greater than a few inches of line as the fisher was observed coiling the remaining line which had no weight or hook visible.

It may be more challenging with EM compared to at-sea observer data to discern if a cetacean is lip-hooked or hooked in the mouth; this uncertainty may lead to more cases assigned as serious. Cetaceans that interact with Hawaiʻi-based longline fishing gear are usually depredating the fish or bait (Fader et al. 2021), which could result in a lip-hooking or hooking in another area of the mouth or even ingestion. If only lip-hooked, a non-serious injury is more likely to result if the cetacean is released with no trailing gear (NMFS 2012). If it cannot be confirmed that the hook is in the lip, then a mouth-hooking is considered a serious injury (NMFS 2023). If the hook is not visible on the animal, it is possible that it is attached inside the mouth or ingested or that we cannot see the hook due to the image resolution, camera clarity, or view of the cameras. However, the hook may be visible when the crew coils the branchline if all the fishing gear is removed using a dehooker or if the hook becomes dislodged. In our study, we were able to see hooks when the line was coiled in the view of the "deck" camera for one false killer whale interaction recorded at 30 fps after the hook dislodged from its mouth and several sea turtle interactions recorded at 10 fps. We were also able to observe that a false killer whale (phase I, #4) in phase I was only lip-hooked. However, this interaction had very good imagery as it was filmed in the day at 30 fps. We were unable to observe a hook for any of the other cetacean interactions likely due to the interactions recorded at night with the only other interaction filmed during the day having dirty cameras and a cetacean that was far from the vessel. In addition, all the other cetacean interactions were recorded at 10 fps; nevertheless, we were able to see hooks on sea turtles even when in the water that were filmed during the day at only 10 fps. It may be more likely that the hook could be detected for nighttime interactions if the video was recorded at 30 fps. In addition, EM footage may allow a reviewer to deduce if a cetacean is not only hooked in the mouth but has likely ingested the hook. During phase II, we were able to discern that the bottlenose dolphin had ingested the hook as imagery showed that the line coming from the middle of its open mouth. In addition, we could infer from the distance of the weight on the branchline to the mouth that the dolphin had likely ingested the hook, while the false killer whale in phase II had likely not ingested the hook. However, the amount of line from the weight to the hook (i.e., leader length) may vary between vessels, trips, and sets.

Although it is possible that more injury determinations would be assigned as "cannot be determined" for cetacean interactions from EM trips compared to those with an at-sea observer, EM footage would allow for determinations on unobserved trips. In addition, it is possible that fishers may bring cetaceans to the vessel following protected species guidelines knowing that cameras are on board and recording fishing operations, which would allow for data to be collected more easily to make injury determinations. If injury determinations cannot be made, then these interactions would still be included in the estimation of the total number of annual interactions that are used to estimate the number of serious or non-serious injuries based on historic observer data (McCracken 2019; McCracken 2011).

The condition of a cetacean during an interaction and after its release from the fishing gear may be assessed with EM, which is important for informing injury determinations. Condition was more readily observed with the improved "rail" camera views used during phase II. However, even with a good field of view and "rail" camera orientation, it may be difficult to observe the condition if a cetacean is far from the camera, the interaction is short, there is limited surface time, or the cetacean disappears quickly after release. For interactions where there is sufficient EM footage and the animal is not far from the camera, it may be possible to assess whether an animal is showing signs of stress that could lead to capture myopathy (e.g., arching, erratic swimming). However, capture myopathy is challenging to infer (Spraker 1993), and EM cannot provide information on how long a cetacean has been struggling on the line prior to it coming into the views of the cameras. Nevertheless, the cetacean's degree of struggle during the interaction, and especially if it is exhibiting signs of fatigue, can be assessed.

In some cases, EM video may provide a better perspective to observe the cetacean's struggle than observer video and allow for more of the struggle to be videoed. In addition, general health could also be assessed, such as body girth and if there are major or minor injuries, such as blood, scars, wounds, etc. Yet, it is likely small injuries may be difficult to observe with the resolution of the cameras or if they occur on a dark-colored animal at night. It is also possible even large injuries could be missed if they are on the side of the animal that is not presented to the cameras or on parts of the body that remain underwater.

EM video should allow for cetaceans to be identified to species or to the species group "blackfish" in cases where cetaceans are brought towards the vessel within the guidance of protected species handling protocols, cameras are kept clean by fishermen, and cameras have good resolution. For "blackfish", it may be challenging to identify the species if there is not a close view of distinguishing characteristics, such as the dorsal fin, a pectoral fin, or the head, as their dark coloration can be difficult to differentiate against the dark-colored sea at night. However, if these views are available as we observed with the false killer whale interaction reviewed during phase II, then identification can be performed. If a "blackfish" interaction occurs during the day with clear weather, then the cetaceans should be easy to distinguish from the lighter-colored ocean as was the case with one of the false killer whales observed during phase I. In our study, two cetaceans could not be identified to species or as a "blackfish". One cetacean (phase I, #3), identified as a Risso's dolphin by the observer, was close to the vessel in some instances; however, it could only be determined to be an unidentified dolphin as the video in this phase I imagery had poor resolution and the cameras were dirty. In another case (phase I, #6), the cetacean was only in view at a distance as fishers did not follow protected species handling guidelines, but instead cut the line while the animal was at a distance. It is possible that fishers may be more likely to follow protected species handling requirements if they are aware that EM footage may be potentially reviewed.

It may be challenging to draw conclusions about a particular cetacean interaction from information outside of the EM footage that may be available on observed trips. For instance, it will be more difficult to determine from EM compared to at-sea observer data if the cetacean is part of a larger group, as the human observer is able to observe all around the vessel and at a further distance from the cameras. This assessment is especially important for dependent animals who are considered seriously injured if released alone (NMFS 2023). In addition, it may be difficult to assess whether the captured cetacean may have been depredating the catch or bait. From EM footage, we may be able to determine if catch is depredated, but it would likely be challenging to determine if hooks are free of bait as a result of depredation. There has been some initial artificial intelligence (AI) work to build a model to detect hooks and bait. However, more research is needed to determine the feasibility of using AI to assess cetacean depredation, including creating many more annotations of hooks and bait. In addition, video would likely need to be recorded at 30 fps for an AI model to discern hooks, and for some vessels an additional camera may be needed to capture all hooks or bait within the camera views as the lines are brought in and coiled on board the vessel.

Sea turtles

Our study demonstrates that the percent likelihood of post-interaction mortality can be assigned with certainty from EM video for most sea turtles that are caught in the Hawai‘i longline fisheries. However, for sea turtles that are released with trailing line or released from fishing gear while still in the water, there may be uncertainty in the injury or release condition resulting in a more conservative determination that potentially inflates the percent likelihood of mortality. With camera settings and resolution similar to those used in phase II, an injury category can likely be assigned as we were able to assign an injury category with certainty for 86% of the sea turtle interactions examined during phase II compared to only 43% in phase I. In addition, the resolution was clear enough during phase II that the actual hook was visible for 62% of the interactions that involved a hook, and it could even be discerned that a hook was not embedded for an entangled sea turtle.

When sea turtles are hooked externally in the flippers, as was generally observed in phase II of this study, then an injury category can likely be assigned with certainty as this type of hooking or entanglement location was usually visible from EM video for sea turtles both in the water and on deck. However, when sea turtles are hooked in the mouth area (mouth, tongue, glottis, beak, jaw, or ingested), it may be more difficult to ascertain the exact hooking location and assign an injury category as we observed in this study. This could result in more uncertainty and a higher percent likelihood of mortality than necessary to be assigned for about half of the sea turtles as about 46% of all sea turtles were reported by the observers to be hooked around the mouth area in 2021. For one recorded interaction (phase II, #12), we were unable to determine where a leatherback was hooked and/or entangled as it was hard to discern due to the leatherback diving, the rough water, some water spots on the camera, and the dark-colored sea turtle against the dark blue water. A different leatherback sea turtle (phase II, #13) was recorded at 30 fps and had much better imagery. It is possible that the higher frame rate may improve our ability to observe the hooking location for these tough cases and especially for leatherback sea turtles.

For trips where fishers follow protected species guidelines, the release condition could be assigned with a higher degree of certainty for most small to medium-sized sea turtles if fishers board them and remove all attached fishing gear. However, for sea turtles that are not boarded a more conservative "worse case" scenario may need to be assigned if they are released with trailing line and it is not clear if the amount of trailing line is less than half of the carapace length. This may inflate the percent likelihood of post-interaction mortality for leatherback and other large hardshell sea turtles or for sea turtles captured on unobserved trips if fishers do not follow handling guidelines.

In cases where sea turtles are released with trailing line attached, it may be difficult to estimate whether the amount of line is equal to or greater than half of the sea turtle's body length. However, it is possible the amount of trailing line may be deduced if the fisher can be observed cutting the line, or if the remaining line can be observed after it is released from the sea turtle. In phase II, we were able to see the fisherman cut the line below the weight for one sea turtle (phase II, #1), which could provide a fairly accurate estimate of the trailing line. In another case (phase II, #12), we could see the fisherman cut the line with a long-handled cutter, but we could not see a weight for reference so would need to estimate the length of line based on the proximity of the sea turtle to the vessel when the cutting occurred. While for one leatherback sea turtle (Phase II, #2), we were unable to see the fisher handling as the sea turtle was behind the vessel and the fisher that cut the line (as noted on the observer report) was blocked by the bait shed or other fishers. However, we were able to see a fisher coiling the remaining line which did not include a weight, which indicated the trailing line was likely equal to or greater than half of the body length.

This study demonstrates that sea turtles can be identified to species using EM footage if cameras are kept clean and have adequate resolution. With the improved camera settings used in phase II, all sea turtles were identifiable to species compared to only 61% during phase I, likely partly due to the improved camera resolution for phase II cameras. In addition, the video footage from the newer cameras could be zoomed in to focus on identifying characteristics, whereas the video footage from the cameras during phase I were blurry when zoomed in. Also, cleaner cameras may have improved imagery in phase II. Even though the dorsal side of the hardshell and leatherback sea turtles was dark in coloration and sometimes similar to the ocean color during a cloudy day or night, the sea turtles were distinguishable. Leatherback sea turtles were harder to distinguish from the water in some cases; however, their elongated front flippers were easy to identify as they would sometimes extend out from the water's surface.

EM footage allows the condition of sea turtles during an interaction and at release to be assessed as demonstrated by our ability to view different activities while they were on deck and in the water (e. g., on deck sea turtles were observed turning, crawling, moving their head, and/or moving flippers; in the water they were seen swimming, diving, moving their head, and/or flapping their flippers). Leatherback sea turtle condition can be assessed in EM footage by the movements of their elongated front flippers and their diving activity as it is more difficult to observe their head as they appear to frequently dive.

If sea turtles have injuries prior to capture or as a result of an interaction, it may be possible to observe with EM footage if the injury is large enough and within the view of the cameras. We were able to observe a laceration that penetrated the skin from a cinched hook. However, it may have been unnoticed if we did not already know of it from the observer report. Blood on the deck was clearly visible for another sea turtle in an attempt to remove a hook from the roof of its mouth. However, it may be difficult to see blood on a sea turtle that is in the water, as well as any minor bleeding by a sea turtle while on deck. And even if an injury is large but it is on the ventral surface of the sea turtle, submerged underwater, or blocked from the camera view by crew, it would likely be missed. Small injuries like puncture wounds from hooks or rubbings from entangled fishing gear would likely be hard to see at the camera resolution used in this study, especially for animals that are not brought on to the deck. This was demonstrated as we missed the torn tissue on a leatherback sea turtle's (phase II, #13) body where the hook was removed using a long-handled dehooker, which was noted in the at-sea observer report. It is uncertain if the injury was not visible due to the view or the resolution of the camera, but in this particular case, the cameras were recording at the higher frame rate of 30 fps. We do not recommend that fishers flip sea turtles on their back on the deck or in the water to assess for injuries as this could add undo stress on the animals.

Elasmobranchs

EM footage may also allow for determinations of the likelihood of post interaction survival for elasmobranch species. In the past, shark interactions were difficult to detect in EM cameras because hooked sharks were typically cut from the branchline as soon as they were visible by the crew but before they were in view of the cameras. NMFS prohibited the use of wire leaders in the Hawaiʻi deep-set longline fishery effective May 31, 2022, and requires the removal of fishing gear from any oceanic whitetip shark caught in all of the region's domestic longline fisheries. The rule is intended to increase post-hooking survival of threatened oceanic whitetip sharks. Given the rule, it is expected that fishers will bring oceanic whitetip sharks and other shark species closer to the vessel and within the EM camera views to follow regulations, and to potentially retrieve the weights attached to the branchlines as this is more feasible with monofilament leaders. If sharks are visible in EM footage, it may be possible to determine factors (species, condition, handling and release method, hook location, and the amount of trailing gear) shown to affect shark post-release survival in the Hawai‘i longline fisheries (Hutchinson et al. 2021). This study illustrates that while estimation of trailing line after release is challenging for protected species, it can be performed if the line is cut to release the animal or the remaining line is coiled within the view of the cameras.

Recommendations

From this study, we have developed recommendations for EM programs that will improve the ability of reviewers to make determinations on the post-release condition of protected species that interact with longline fisheries.

EM programs should create vessel monitoring plans that outline the requirements for fishers regarding system maintenance and handling. The document should include requirements for fishers to check before each haul that the cameras are clean and without water spots and that EM systems are functioning properly. If the system stops streaming video, then they should contact their EM program when they return to port.

Appropriate fisher handling can allow the ability to collect data from EM video to make injury determinations for cetaceans and assign the likelihood of post-interaction mortality for sea turtles. Consequently, fishers should be reminded to bring protected species to the side of the vessel or aboard the vessel (in the case of small to medium sea turtles) to release them from fishing gear following protected species handling requirements. Also, fishers should be directed to stand within the view of the camera and not behind the bait shed or behind another fisher or observer when administering protected species handling requirements for animals in the water (i.e., cutting the line, tying off a line with a cetacean, using a long-handled dehooker or long-handled cutter).

For sea turtles that are brought on deck, removal of all fishing gear should be in the view of the camera and not in or behind the bait shed. Sea turtles that appear to be dead should be placed on their belly, dorsal-side up, so they can potentially recover if actually comatose and also so the reviewer can perform species identification. Also, sea turtles should be released soon after the haul is finished if they have had enough time to recover from the interaction; this will help ensure that the release is captured on video. In addition, fishers should be mindful not to stand between the sea turtle and the camera at release, so that the condition of the sea turtle at release can be assessed.

After protected species are released from fishing gear, the remaining line should be coiled within the view of the camera. In addition, we suggest that this fishing gear be retained, labeled with the trip and set number, and submitted to NOAA when fishers return to port. Fishers should also be reminded to record protected species interactions in their logbook. This will allow fishing gear to be properly matched to a particular protected species interaction.

We recommend EM systems to have at least the resolution and quality as the cameras used in phase II of our study with 4 megapixels and a resolution of 1080p. In addition, we recommend that they record at a frame rate of at least 10 fps. But it would be preferable to record at 30 fps to improve the ability of the reviewer to see the hook to more accurately discern the hooking location. This higher frame rate may also improve our ability to distinguish dark-colored protected species, such as leatherback sea turtles and false killer whales, from the dark-colored ocean at night and reduce the chance that an injury determination cannot be made for a cetacean or a higher percent likelihood of post-interaction mortality be assigned for a sea turtle. However, only two interactions have been reviewed thus far at this higher frame rate for assessment, and both interactions were recorded during the day.

We recommend setting cameras to record for at least an hour post trigger. This will ensure that sea turtle release events that may occur after a haul are recorded. Sea turtles are often released after a haul to prevent them from getting entangled with other fishing gear and as to not interrupt fishing operations. In addition, observers may affix tags with glue that needs to dry or need to allow the sea turtle time to recover. These settings will also ensure that any protected species interactions that may cause fishing gear tangles will be recorded and cameras do not stop recording if fishers interrupt normal hauling operations (i.e., the reel stops spinning or the hydraulics are not used that normally trigger the cameras to record) to address issues with fishing gear.

We recommend the "rail" and "deck" cameras have fields of view and orientations to optimize data collection for protected species and reduce the chance that handling is performed out of view. The "deck" and "rail" cameras should have views that overlap and include the rail and the fish door. The "deck" cameras should have a field of view that includes the majority of the deck and extends to at least 1 ft outside of the rail and includes the fish door, where fish are brought on to the deck. The "rail" cameras should have a view that includes the fish door and includes the rail all the way to the stern of the vessel with preferably an overhead (i.e., "bird's eye view") that shows a considerable amount of the water's surface (i.e., greater than 15 ft along the rail of the vessel and greater than 20 ft out from the vessel). To achieve this view a boom may need to be installed on top of the vessel house to extend the camera out. It is also preferred that the cameras are not installed on the same poles where lights are attached as this can cause the lights to wash out the video.

We recommend that EM video is not reviewed at a speed faster than 8x real-time as this speed was demonstrated in Stahl and Carnes (2020) to allow for accurate detection of protected species. Once protected species are detected in a video, the video speed should be reduced to real-time to be able to collect data to make determinations of post-release conditions. In addition, the reviewer may need to slow down to 0.5x real-speed and zoom in to see if a hook is visible and get details on hook location.

Artificial intelligence

AI research may more readily allow for the implementation of EM in Hawaiʻi and other longline fisheries as it may reduce costs and time for video review. Currently, research is being conducted in the Hawaiʻi longline fisheries to automatically detect protected species using AI models. If successful, then reviewers would only need to review videos where catch events are detected. This cost savings may allow for more video to be analyzed for protected species and further improve bycatch estimation and stock assessments for protected species.

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