NOAA
FISHERIES

Evaluation of Electronic Monitoring Pre-implementation in the Hawai‘i-based Longline Fisheries

Matthew J. Carnes, Jennifer P. Stahl, and Keith A. Bigelow

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Pacific Islands Fisheries Science Center

NOAA Technical Memorandum NMFS-PIFSC-90
https://doi.org/10.25923/82gg-jq77

October 2019

Evaluation of Electronic Monitoring Pre-implementation in the Hawai‘i-based Longline Fisheries

Matthew J. Carnes[1], Jennifer P. Stahl[1], and Keith A. Bigelow[2]

[1] Joint Institute for Marine and Atmospheric Research
University of Hawaii
1000 Pope Road
Honolulu, Hawaii 96822

[2] Pacific Islands Fisheries Science Center
National Marine Fisheries Service
1845 Wasp Boulevard
Honolulu, HI 96818

NOAA Technical Memorandum NMFS-PIFSC-90

October 2019

U.S. Department of Commerce
Wilbur L. Ross, Jr., Secretary

National Oceanic and Atmospheric Administration
Neil A. Jacobs, Ph.D., Acting NOAA Administrator

National Marine Fisheries Service
Chris Oliver, Assistant Administrator for Fisheries

Recommended citation

Carnes MJ, Stahl JP, Bigelow KA. 2019. Evaluation of electronic monitoring pre-implementation in the Hawai‘i-based longline fisheries. NOAA Tech Memo. NMFS-PIFSC -90, 38 p. doi:10.25923/82gg-jq77

Copies of this report are available from

Science Operations Division
Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
1845 Wasp Boulevard, Building #176
Honolulu, Hawaii 96818

Or online at

https://repository.library.noaa.gov/

Table of Contents

List of Tables

List of Figures

List of Acronyms

ETPSG	Electronic Technologies Professional Specialty Group
ETWG	Electronic Technologies Working Group
EM	Electronic Monitoring
ET	Electronic Technologies
FIS	Fisheries Information Systems
JIMAR	Joint Institute for Marine and Atmospheric Research
NFWF	National Fish and Wildlife Foundation
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOP	National Observer Program
PIFSC	Pacific Islands Fisheries Science Center
PIR	Pacific Islands Region
PIRO	Pacific Islands Regional Office
PIROP	Pacific Islands Regional Observer Program
RFMO	Regional Fisheries Management Organization
SWI	Saltwater Inc.
VMS	Vessel Monitoring System
WCPFC	Western and Central Pacific Fisheries Commission
WPRFMC	Western Pacific Regional Fishery Management Council

Executive Summary

The Pacific Islands Fisheries Science Center (PIFSC) is currently evaluating how to effectively use electronic monitoring (EM) systems in Hawai‘i-based pelagic longline fisheries as a data collection tool. These fisheries are comprised of two sectors, a deep-set fishery targeting bigeye tuna (*Thunnus obesus*) and a shallow-set fishery targeting swordfish (*Xiphias gladius*), with fisheries-dependent data collected from three sources: captain logbooks, dealer reports, and at-sea observers. Each data set has limitations. Logbook data consist of industry reported data, which historically underreport bycatch[1] that are discarded, such as sharks (Camhi et al. 2009). Dealers report weights for marketable fish; consequently, average weights calculated from these data do not represent discards. At-sea observer data provide information on both discarded and retained catch, including subsamples of lengths which are limited to estimates for animals not brought aboard. At sea observer data are collected on about 25% of fishing trips (100% of shallow-set trips and 20% of deep-set trips); whereas logbook and dealer data sets provide data from all fishing trips. EM provides a method to supplement these data streams to reduce potential sources of bias and inform management of the Hawai‘i longline fisheries.

To evaluate the efficacy of EM as a monitoring tool, 18 systems were installed on Hawai‘i longline vessels for this pre-implementation study. These EM systems included video cameras to capture footage for fish and protected species (sea turtles, seabirds, and marine mammals) identification, global positioning systems (GPS) for fishing location, and fishing gear sensors that help detect catch events (i.e., reel rotation, hydraulic pressure, and vessel speed generally decline when large fish are brought aboard) and trigger video cameras to record during gear retrieval.

Comparison of data collected by at-sea observers with post-cruise review of EM data indicate EM systems provide an additional means to accurately enumerate fish. A total of 89% of all catch enumerated by at-sea observers (retained and bycatch) were detected in EM data during video review. For retained fish only, EM reviewers located 98% of the fish enumerated by at-sea observers in the shallow-set fishery and 100% in the deep-set fishery. EM data also provided accurate enumeration over broad taxonomic groupings (e.g., tunas, billfishes, sea turtles) and for many economically valuable fish species. However, compared to at-sea observers, EM reviewers were not able to provide identifications to the species level for some species, including those subject to management implications, such as bigeye tuna and hardshell sea turtles. For bigeye tuna, there were significant differences ($p < 0.001$) between EM and at-sea observer enumerations. Sea turtle identifications were limited to the broader categories of hardshell or softshell sea turtle. Specific modifications to the current EM systems and catch handling are recommended in this technical memorandum to improve enumeration and identification to species that can be used for monitoring in the Hawai‘i longline fisheries (e.g., identification of tunas, sharks, and sea turtles to species).

---

[1] Bycatch in this document refers to catch that are discarded. This definition does not include incidental catch that is retained.

Finally, this PIFSC pre-implementation project demonstrated that EM could be a cost-effective method to augment fisheries-dependent data collection. EM data review may be completed with a 76% reduction in the time needed to collect similar data by at-sea observers.

Introduction

The Pacific Islands Region (PIR) manages two commercial pelagic longline fisheries with permits issued by the Pacific Islands Regional Office (PIRO). There is a shallow-set fishery targeting swordfish and a deep-set fishery targeting bigeye tuna. Approximately 95% of the 20,437 hauls in the Hawaiʻi longline fisheries in 2017 were with deep-set gear and only 949 shallow-set hauls retrieved (FRMD 2018). These fisheries operate under a Hawaiʻi Longline Limited Entry Permit. In 2017, 145 permits were actively fished (FRMD 2018). The Pacific Islands Region Observer Program (PIROP) maintains greater than 20% coverage annually in the deep-set fishery (deployments are based on a complex adaptive sample design for at-sea observer placement (McCracken 2019)) and 100% in the shallow-set fishery.

EM provides a means to collect catch and effort data similar to the observer program, which currently supplies the primary source of bycatch and protected species interaction information for stock assessment and management of the Hawaiʻi longline fisheries. Annual at-sea observer coverage in the Hawaiʻi longline fisheries has increased over time, ranging from 3.3% to 5.3% across both longline fisheries in the 1990s to 100% coverage in the shallow-set fishery and 20% or greater in the deep-set fishery after 2004 (NMFS 2004). Observing on Hawaiʻi longline fishing vessels can be demanding physically and mentally with long deep-set trips (2–4 weeks) on relatively small vessels (40–100 ft), resulting in feelings of isolation, as well as possible health and safety concerns. At-sea observer responsibilities have increased since the program was established. Data collection and biological sampling requests have grown, resulting in at-sea observers being requested to assist with a variety of research projects and record gear configuration data. These tasks are in addition to their primary duties, which include watching the first hour of gear setting and the entire gear retrieval to record catches and identify protected species interactions. A deep-set fishing haul is approximately 12 hours; during this time, at-sea observers watch an average of 2,720 hooks (FRMD 2018). However, only about 1% of these hooks contain fish (catch per unit effort of 12.49 fish per 1,000 hooks for deep-set; FRMD 2018). With the ability to increase video speed, EM provides a time-effective method for identification of fish and protected species in the Hawaiʻi longline fisheries.

Due to variations in gear operations between the deep-set and shallow-set fisheries, NMFS imposes differences in observer coverage and regulations to better identify and prevent protected species interactions. Both gear configurations make these fisheries suitable for monitoring with EM systems. The deep-set fishery operates with hooks at depths of 40–350 m with mean hook depth of 248 m (Bigelow et al. 2006). To minimize sea turtle interactions in the deep-set fishery, float lines attached to the mainline must be a minimum length of 20 m and 15 or more branch lines must be attached to the mainline between floats. To reduce mortality of false killer whales (*Pseudorca crassidens*) in the deep-set fishery, a minimum monofilament diameter (2.0 mm) is required for branch lines, as well as mandatory use of circle hooks with maximum diameter specifications (4.5 mm). These regulations are intended to increase the ability of a large animal, such as a whale, to escape hooking. Animals with the strength and mass to pull, bend, and straighten the hook can escape, while the hook is still strong enough to retain the smaller fish that are targeted. The shallow-set fishery operates at depths of 30–90 m with mean hook depth of 60 m (Bigelow et al. 2006). To prevent sea turtle interactions in the shallow-set fishery, size 18/0 or larger circle hooks and mackerel-type bait are required. In 2017, maximum annual catch limits were set at 17 loggerhead (*Caretta caretta*) and 26 leatherback (*Dermochelys coriacea*) sea turtles in the shallow-set fishery with no limits in the deep-set fishery. In both fisheries, compliance of regulations is monitored by dockside inspections from NOAA's Office of Law Enforcement (OLE), at-sea boardings by the United States Coast Guard, and at-sea observers.

EM technology has been investigated as a monitoring tool in the Hawai'i longline fisheries since 1991, beginning with VMS for tracking and expanding to the current systems targeted at collecting quality, cost-effective, and timely fisheries-dependent data. A 2009 pilot study was initiated to collect catch information through EM video systems and was facilitated through collaborations among Archipelago Marine Research, the Hawaii Longline Association, and the Western Pacific Regional Fishery Management Council (WPRFMC). Three EM systems were placed on Hawai'i longline vessels, two on shallow-set, and one on a deep-set vessel(s) (McElderry et al. 2010). These EM systems consisted of closed-circuit television cameras, sensors (GPS, hydraulic pressure, and winch rotation) configured to record sensor data for 24 hours a day, and a system controller. To evaluate the efficacy of EM for data collection and monitoring purposes, data collected using EM systems were compared to data from trips where at-sea observers were simultaneously deployed, for a total of 13 trips with 182 fishing sets and 320 days at sea. EM systems successfully recorded data 99.2% of the time vessels were at sea and provided accurate temporal and spatial information on gear setting and retrieval. The EM video reviewers were able to detect hooks deployed, retained catch, and protected species, including sea turtles and albatross. Variable detection rates occurred between at-sea observers and EM reviewers with two albatross identified exclusively through only one of the review methods (i.e., one albatross was only detected with EM and not by the at-sea observer and vice versa) and with 40% of bycatch identified using EM (McElderry et al. 2010). In addition, some misalignment in classifications occurred, and fish identification often could only be performed to species group (i.e., tuna were more likely to be called unidentified tuna rather than bigeye, yellowfin (*T. albacares*), or albacore (*T. alalunga*)) with EM, compared to at-sea observer data. The current pre-implementation project was designed to improve the issues in detection rates and fish identification that occurred in the pilot project, such as with changes in camera placements and utilization of a reviewer with experience in the Hawai'i longline fisheries.

The current pre-implementation project was able to respond to a national interest in the application of EM technologies through the development of software tools. In 2015, each NOAA Fisheries region drafted a plan to address this national interest. The PIR implementation plan identified the need for electronic technologies (ET) in the Hawai'i longline fisheries (PIR 2015). The current pre-implementation project was initiated with the objective of comparing catch accounting between EM and at-sea observer collected data using concurrent fishing trips. Due to this national initiative, the National Fish and Wildlife Foundation (NFWF) awarded grants for the development of open source software for EM data review to Saltwater Inc. (SWI) and for EM system on-board operation to Sea State, Inc. In 2017, EM equipment, including operating systems and review software, was provided to the PIR pre-implementation project by SWI.[2]

---

[2] 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.

Methods

To test EM in the Hawaiʻi longline fleets, EM systems were placed on vessels that typically fish deep-set but also have a history of fishing some shallow-set trips. In 2017, SWI provided and installed EM systems on eighteen different vessels that were voluntarily participating in the program. The systems consisted of two internet protocol (IP) cameras (configured within a closed network aboard each vessel) and sensors for GPS, hydraulic, and magnetic rotation. Systems were controlled by a fanless computer with SWI software installed to trigger recordings based on sensor data and to encrypt collected data stored on up to two, 2.5-in hard drives. Components were wired with waterproof Ethernet to harness Power over Ethernet technology as supplied by the main computer. Cameras were dome-shaped security cameras with 3 megapixel super low-lux sensors, which optimized the camera for low light conditions (minimum illumination at 0.01 lux). In addition, these cameras were built to function in a harsh environment with an IP67 waterproof housing which was supplemented further with an application of marine sealant (3MTM Marine Adhesive Sealant). Cameras were set to record at 10 frames per second and imagery in 720p resolution; these settings minimized data storage while capturing images expected to be adequate for fish identification.

The placement of cameras was changed over time to optimize the field of view to provide a view of all hooked fish, both those landed and those discarded before being brought aboard the vessel. A “deck” camera was mounted downward to capture deck activities. At a minimum, this camera had a field of view that extended from 1 ft outside of the rail, which included the fish door where fish were brought on deck, to the fish hold (Figure 1). If possible, the field of view included the entire deck to capture any bycatch discarded over the side of the vessel opposite of the fish door. A second “rail” camera was mounted to view fishing activity on the side of the vessel with the fish door and included the area from the crewman located at the roller (location where hooks are removed from the mainline) to the aft rail, preferably all the way to the stern (to include catches brought aboard and usually discarded catch in this area). This camera was placed as far out as possible over the rail. The most informative images were derived from cameras mounted on a boom to optimize the view of fish over the side of the vessel (Figure 1).

A variety of sensors collected supplemental data on fishing activities and triggered cameras to record during gear retrieval. Location and vessel average speed data were collected with a GPS sensor mounted in the wheelhouse, independent of the vessel’s GPS system. Hydraulic pressure was obtained from a sensor installed in-line with the vessel’s hydraulic system on the mainline reel, and rotation direction of the mainline reel was collected from a magnetic sensor mounted directly on the reel. Sensor data were collected through the entire trip; while video was only recorded during gear retrieval and was triggered primarily by the hydraulic pressure sensor. As backup, the rotation sensor could trigger cameras to record after a defined amount of rotations of the mainline reel. However, some vessels use two reels, and only one reel was fitted with a sensor. Recording video only during gear retrieval saves costs on storage. A typical trip may accrue 500–700 GB of video, which results in approximately 60–84 TB per year (with current participation). To retrieve these data from hard drives, NMFS project personnel visited vessels upon arrival in the port of Honolulu and coordinated any necessary maintenance of EM systems.

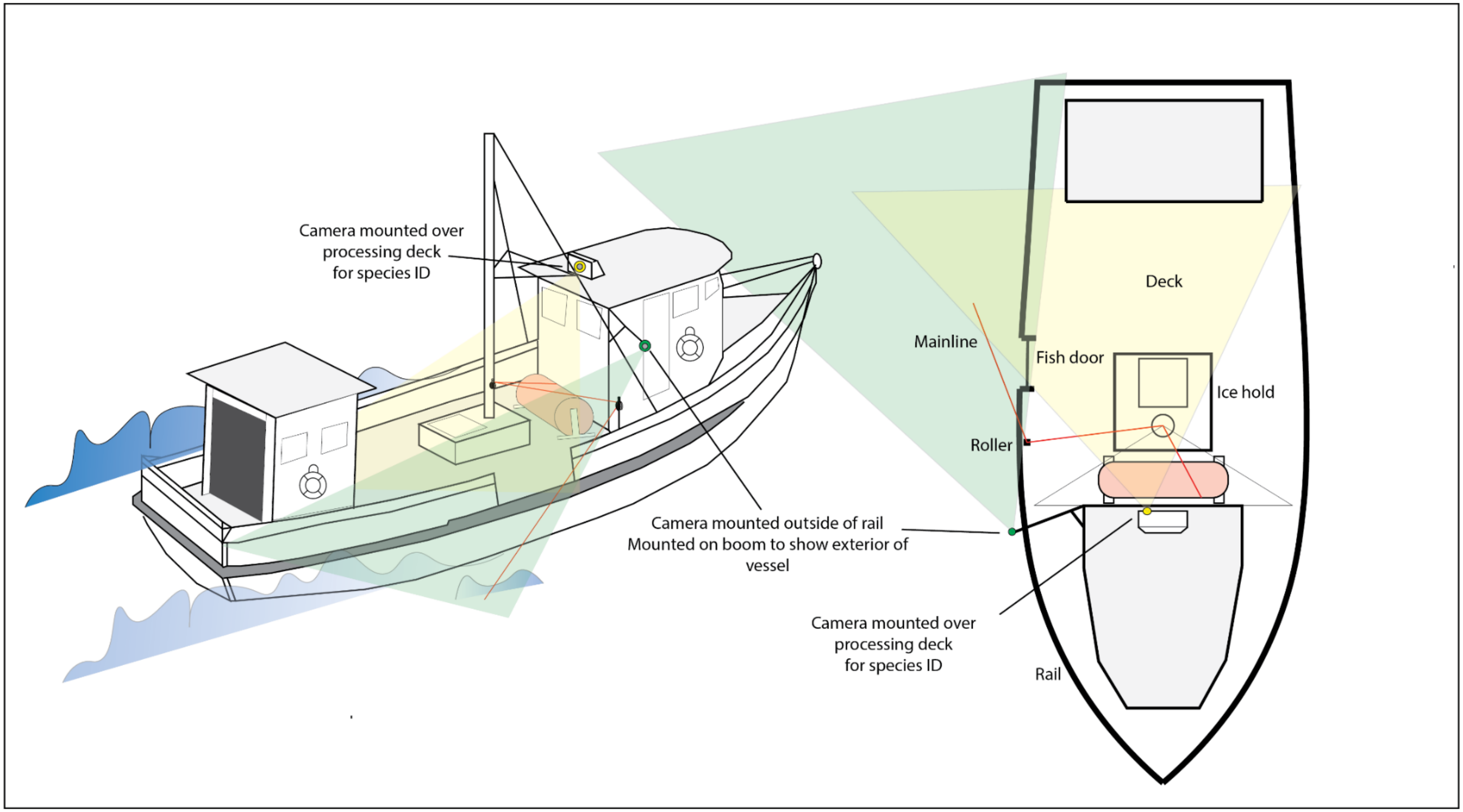

Figure 1. Diagram of recommended electronic monitoring (EM) camera configurations for Hawai‘i longline vessels.

Review

Fishing trips conducted by deep-set Hawai‘i longline vessels were selected for review if they had fully functioning EM systems, unobstructed imagery (i.e., not fully blocked by water or objects being placed in front of the cameras), and had an at-sea observer, which allowed for comparison with EM-collected data. Data were limited for review of shallow-set trips due to the early fishery closures in 2017 and 2018; consequently, an additional criterion was implemented: only the most recent trip was reviewed for each vessel. Camera optimization was ongoing throughout the project, so review of the most recent trip provided the best camera views and imagery.

For each fishing trip that was selected for review, data collected during gear retrieval were reviewed afterwards onshore by the primary author to detect kept and discarded fish catch and gear interactions with protected species. The primary EM reviewer and author was an at-sea observer with 707 sea days collecting data across the Alaska, Hawai‘i, and the Inter-American Tropical Tuna Commission observer programs. For each haul of gear retrieved, the reviewer scanned video for catch and interaction events using a speed that reduced viewing time but minimized missing encounters (4× to 16× real-time). Once an animal was encountered, the video was slowed down or paused to identify the catch to the lowest taxonomic level possible. For sea turtles, EM review followed the guidelines of the observer manual (PIROP 2017) with five key characteristics needed for identification to the species level. If these five characteristics were not observable in the EM video, sea turtles were recorded as either a hardshell or softshell (leatherback) sea turtle. In addition, the condition of the species at capture was recorded and whether it was kept or discarded: alive, dead, or injured. The reviewer also recorded any damage at the time of capture using the categories from the PIROP: “No Damage,” “Marine Mammal Damage,” “Depredation Damage,” and “Undetermined Damage” (PIROP 2017). Any crew behavior typical of a catch event was enumerated even if no animal was observed on the camera. These events were categorized as “Unidentified Bony Fish” if the crew was able to pull the animal to the vessel with relative ease or jerked the line to pull a hook out, but the animal could not be identified on the camera. “Unknown Catch Event” was used when the crew was observed pulling in a tight line that was then either cut or broke, indicating a large animal (such as a shark) was captured.

All review of EM data was conducted using SWI's "Electronic Monitoring Data Review" software[2], which allowed for data collected by video and sensors to be reviewed together for a complete picture of fishing activities. This software was designed by work conducted through a NFWF grant and was easily configurable to meet project needs. The two EM camera views (“deck” and “rail”) were examined side-by-side simultaneously along with a Timeline window that contained sensor data (vessel speed, rotation, and pressure) and demarcations of when video was recorded. While examining video, the reviewer could glance at the Timeline to identify possible catch events, which could occur with changes in the reel rotation and declines in hydraulic pressure and speed. When an animal was encountered, it was enumerated, and the time at which it was encountered was marked in the Timeline. After an entire haul was examined, the reviewer scanned the Timeline for changes in sensor data that had no matching marks indicating an encounter. If these conditions were met, the video was reexamined for possible encounters. The reviewer also demarcated the time frame at which the gear setting and retrieval occurred. Review time was limited to six hours per day to reduce eye-strain and to maintain reviewer engagement.

Analysis

Validation of EM-collected data was attempted by comparison with at-sea observer data. Data were subdivided into the following datasets for comparisons:

1. deep-set kept catch
2. deep-set bycatch
3. deep-set all catches
4. shallow-set kept catch
5. shallow-set bycatch
6. shallow-set all catches
7. protected species

For each dataset, comparisons were performed by species and by groupings of tunas[3], billfishes[4], sharks[5], non-marketable pelagic fishes[6], marketable pelagic fishes[7], other consumable bony fishes[8], or protected species[9].

For each dataset, the percent difference between at-sea observer and EM data was calculated by fish species and group by summing across hauls:
percent difference = (number recorded by EM reviewer − number recorded by at-sea observer) ∕ number recorded by at-sea observer × 100.

The null hypothesis of no difference between at-sea observer and EM-collected data was examined using a randomization test with paired observations in R (version 3.4.2). The test statistic of mean difference between the number of fish of a species (or number of fish in a broader group) recorded by the at-sea observer and the corresponding number recorded by the EM reviewer within each longline haul was calculated for the actual data and for resampled data by first randomizing and then resampling 10,000 times. The dataset was then scored based on whether or not the resample test statistic was equal to or greater than the actual data test statistic. Differences were considered significant if P values were less than 0.05. The difference between

---

[3] Tunas include: bigeye, yellowfin, skipjack (*Katsuwonus pelamis*), albacore tuna, and other or unidentified tuna.

[4] Billfishes include: blue (*Makaira mazara*), striped (*Kajikia audax*), and black (*Istiompax indica*) marlin, swordfish, sailfish (*Istiophorus platypterus*), shortbill spearfish (*Tetrapturus angustirostris*), and unidentified billfish.

[5] Sharks include: blue (*Prionace glauca*), oceanic whitetip (*Carcharhinus longimanus*), silky (*Carcharhinus falciformis*), crocodile (*Pseudocarcharias kamoharai*), mako (*Isurus* spp.), thresher (*Alopias pelagicus*), and hammerhead sharks (*Sphyrna* spp.) and velvet dogfish (*Zameus squamulosus*)

[6] Non-marketable pelagic fishes include: longnose lancetfish (*Alepisaurus ferox*), swallower (Chiasmodontidae spp.), snake mackerel (*Gempylus serpens*), oceanic puffer (*Lagocephalus lagocephalus*), razorback scabbardfish (*Assurger anzac*), hammerjaw (*Omosudis lowii*), tapertail ribbonfish *(Trachipterus fukuzakii*), pelagic stingray (*Pteroplatytrygon violacea*), crestfish (*Lophotus* spp.), giant manta ray (*Manta birostris*), common mola (*Mola mola*), Mobula (*Mobula* spp.), slender mola (*Ranzania laevis*), longfin escolar (*Scombrolabrax heterolepis*), black gemfish (*Nesiarchus nasutus*), remora (Echeneidae spp.), Roudi escolar (*Promethichthys prometheus*).

[7] Marketable pelagic fishes include: pomfret unidentified (Family Bramidae), sickle pomfret (*Taractichthys steindachneri*), lustrous Pomfret (*Eumegistus illustris*), dagger pomfret (*Taractes rubescens*), rough pomfret (*Taractes asper*), brama pomfret (*Brama* spp.), escolar (*Taractichthys steindachneri*), oilfish (*Ruvettus pretiosus*), mahimahi (*Coryphaena hippurus*), pompano dolphinfish (C*oryphaena equiselis*), opah (*Lampris guttatus*), wahoo (*Acanthocybium solandri*), great barracuda (*Sphyraena barracuda*)

[8] Other consumable bony fishes include: pomfret unidentified, lustrous pomfret, dagger pomfret, rough pomfret, brama pomfret, oilfish, pompano dolphinfish, great barracuda

[9] Protected species includes any marine mammal, sea turtle, or seabird.

the EM and at-sea observer data was calculated for each haul and then averaged across all hauls for each species or species grouping. Some species or species groups had small effective sample sizes due to low catches; hypothesis testing was only conducted if the sample size was 20 or more individuals.

Results

For the 238 hauls reviewed, EM video review and quality control were completed in 621 hours compared to 2,585 hours of fishing activity. EM analysis was thus performed in 24% of the time necessary for at-sea observers to monitor the same fishing hauls.

In 2017, EM systems provided coverage for 7% (116 trips) of the total 1,563 Hawaiʻi-based trips (FRMD 2018). The EM systems fully functioned on 88% of trips in which they were deployed and powered on. Fourteen trips encountered problems; one system was lost at sea, two systems experienced hardware failures that resulted in incompletely recorded trips, and corrupted hard drives on 11 systems at sea led to lost data. Staff discovered corrupted hard drives were due to heat, and remediated the issue by using heat-resistant drives rated to operate up to 70 degrees Celsius. In addition, problems occurred with obtaining quality imagery. Initially, a few cameras were installed without proper focus; however, this issue was fixed once identified. In addition, some cameras regularly became unusable from obscurity by water and/or salt residue. In 2018, EM coverage increased, and system functionality improved with coverage for approximately 10% (189 EM trips) of the over 1,500 Hawaiʻi-based trips with EM systems fully functioning 95% of the time. Eight trips still had problems with hard drive corruption due to heat; however, all problem hard drives were replaced by April 2018. One trip did not record video due to a control unit shut-off from an unknown issue. Some cameras slipped out of focus during trips due to age which caused cracks in the housing and wear of securing screws for the focus ring.

Data collected by EM systems were similar to those collected by at-sea observers with 89% of catch (in numbers) enumerated by EM ($n = 15,180$) compared to at-sea observer data ($n = 17,052$) for all retained and discarded fish for the shallow-set and deep-set fisheries. A data gap was identified in detecting sharks and the non-marketable bycatch of longnose lancetfish and snake mackerel. If these species, as well as unknown catch events are removed from both data streams, EM was able to detect 9,089 catches compared to the observer's detecting 9,400 catches, representing a 97% match between the data streams.

Deep-set Catch Comparisons for Kept Catch

EM and at-sea observer collected data were similar for retained fish in the deep-set Hawaiʻi longline fishery. During 193 deep-sets, 6,666 retained fish were detected by EM review and 6,647 retained fish by at-sea observers with an overall percent difference of 0.3% for the total of all retained catch events, which included bigeye and yellowfin tuna, blue and striped marlin, swordfish, wahoo, mahimahi, escolar, opah, sickle pomfret, and other and unidentified species. Randomization tests for mean differences on these species and taxonomic groups indicated that there were no significant differences ($p > 0.05$) for nine of the ten retained species, or for the three species groups (tunas[3], billfishes[4], and sharks[5]). However, there was a significant difference for bigeye tuna ($p < 0.001$) with a mean difference of −1.09 fish per haul between the at-sea observer and EM datasets and a percent difference of −8.5%. There was an overall mean difference for all catch events of 0.1 fish per haul ($p = 0.540$) between EM and at-sea observer data (Table 1). There was not a significant difference in mean difference for striped marlin or blue marlin; however, a −9.7 % difference occurred for striped marlin and an 11.4 % difference for blue marlin between the at-sea observer and the EM datasets.

Table 1. Deep-set longline comparisons between electronic monitoring (EM) and at-sea observer data for kept (retained) catches.

Species/group	Scientific name	Observer	EM	Percent difference	Mean difference per haul	P-value
Bigeye tuna	*Thunnus obesus*	2,460	2,251	−8.5%	−1.09	<0.001
Yellowfin tuna	*Thunnus albacares*	1,079	1,094	1.4%	0.08	0.585
Other & unidentified tunas		256	470	83.6%	1.10	N/A[13]
Blue marlin	*Makaira mazara*	44	49	11.4%	0.03	0.405
Striped marlin	*Kajikia audax*	144	130	−9.7%	−0.07	0.102
Swordfish	*Xiphias gladius*	61	66	8.2%	0.03	0.308
Other & unidentified billfishes		218	237	8.7%	0.09	N/A[13]
Wahoo	*Acanthocybium solandri*	229	228	−0.4%	−0.01	1.000
Mahimahi	*Coryphaena hippurus*	1,092	1,089	−0.3%	−0.02	0.891
Escolar	*Lepidocybium flavobrunneum*	210	198	−5.7%	−0.06	0.088
Opah	*Lampris* spp.	228	229	0.4%	0.01	1.000
Sickle pomfret	*Taractichthys steindachneri*	567	583	2.8%	0.08	0.199
Other consumable bony fishes		56	38	−32.1%	−0.09	N/A[13]
Unidentified retained catches		0	1	N/A[10]	0.01	N/A[13]
Tunas[3]		3,795	3,815	0.5%	0.11	0.281
Billfishes[4]		467	482	3.2%	0.08	0.035
Sharks[5]		3	3	0.0%	0.00	N/A[11]
Marketable pelagic fishes[7]		2,373	2,358	0.7%	−0.08	N/A[13]
Non-marketable pelagic fishes[6]		9	8	−11.1%	−0.01	N/A[13]
Total catch events		6,647	6,666	0.3%	0.10	0.540

---

[10] The unknown catch event field was not used by the at-sea observers.

[11] P-value was not calculated for catch with n<20 and catch that was broadly categorized or unidentified.

Deep-set Catch Comparisons for Bycatch (Discarded Catches)

EM and at-sea observer collected data comparisons for bycatch in the deep-set fishery indicated gear interactions with some encountered species were commonly missed during EM review. Detections from 193 deep-sets showed that the EM reviewer recorded 6,735 discard events while the at-sea observer enumerated 8,464 discard events (−8.96% difference, $p < 0.001$). Randomization tests performed to compare detections by species or taxonomic groups ($n \geq 20$ animals) indicated no significant differences in mean difference per haul ($p > 0.05$) for any of the species groups and two of five species (mahimahi and sickle pomfret). Significant differences in mean difference per haul occurred for discards of bigeye and yellowfin tunas, swordfish, and escolar, as well as fishes grouped by tunas[3], billfishes[4], and sharks[5] (Table 2). Another difference between EM and at-sea observer detections occurred with the enumeration of unknown catch events. EM reviewers detected 737 unknown catch events while at-sea observers only enumerated 11 unknown catch events (Table 2).

Table 2. Deep-set longline comparisons between electronic monitoring (EM) and at-sea observer data for bycatch (discarded catches).

Species/group	Scientific name	Observer	EM	Percent difference	Mean difference per haul	P-value
Bigeye tuna	*Thunnus obesus*	260	99	−61.9%	−0.83	<0.001
Yellowfin tuna	*Thunnus albacares*	118	55	−53.4%	−0.33	0.008
Other & unidentified tunas		103	276	168.0%	0.90	N/A[13]
Blue marlin	*Makaira mazara*	1	0	−100.0%	−0.01	N/A[13]
Striped marlin	*Kajikia audax*	11	3	−72.7%	−0.04	N/A[13]
Swordfish	*Xiphias* gladius	80	70	−12.5%	−0.05	0.041
Other & unidentified billfishes		28	26	−7.1%	−0.01	N/A[13]
Wahoo	*Acanthocybium solandri*	5	3	−40.0%	−0.01	N/A[13]
Mahimahi	*Coryphaena hippurus*	81	84	3.7%	0.02	0.830
Escolar	*Lepidocybium flavobrunneum*	289	199	−31.1%	−0.47	<0.001
Opah	*Lampris* spp.	16	10	−37.5%	−0.03	N/A[13]
Sickle pomfret	*Taractichthys steindachneri*	36	26	−27.8%	−0.05	0.099
Other consumable bony fishes		157	129	−17.8%	−0.15	N/A[13]
Unidentified catch events		9	737	80.9%	3.77	N/A[13]
Tunas[3]		481	430	−10.6%	−0.26	0.006
Billfishes[4]		120	99	−17.5%	−0.11	0.002
Sharks[5]		1,657	696	−58.0%	−4.98	<0.001
Marketable pelagic fishes[7]		584	451	−22.8%	−0.69	N/A[13]
Non-marketable pelagic fishes[6]		5,609	5,047	−10.0%	−2.91	N/A[13]
Protected Species[9]		13	12	−7.7%	−0.01	1.00
Total catch events		8,464	6,735	−20.4%	−8.96	<0.001

Deep-set Catch Comparisons for All Catches

During 193 deep-sets, 13,401 retained and bycatch events were recorded by EM review and 15,111 retained and bycatch catches were recorded by at-sea observers with an overall percent difference of −11.3% for all catch events including the non-marketable fishes[6], and there was an overall mean difference of −8.86 fish per haul ($p < 0.001$) between EM and at-sea observer data (Table 3). Randomization tests indicated that there were no significant differences ($p > 0.05$) in mean difference by haul for seven of the ten tested species (yellowfin tuna, blue marlin, swordfish, wahoo, mahimahi, opah, and sickle pomfret) and two of the species groups (tunas[3] and billfishes[4]). However, there were significant differences in mean difference by haul for striped marlin, escolar, and bigeye tuna, as well as for the species groups of non-marketable fish[6] and sharks[5].

Table 3. Deep-set longline comparisons between electronic monitoring (EM) and at-sea observer data for all catches.

Species/group	Scientific name	Observer	EM	Percent difference	Mean difference per haul	P-value
Bigeye tuna	*Thunnus obesus*	2,720	2,350	−13.6%	−1.92	<0.001
Yellowfin tuna	*Thunnus albacares*	1,197	1,149	−4.0%	−0.25	0.245
Other & unidentified tunas		359	746	107.8%	2.01	N/A[13]
Blue marlin	*Makaira mazara*	45	49	8.9%	0.02	0.548
Striped marlin	*Kajikia audax*	155	133	−14.2%	−0.11	0.008
Swordfish	*Xiphias gladius*	141	136	−3.5%	−0.03	0.369
Other & unidentified billfishes		246	263	6.9%	0.09	N/A[13]
Wahoo	*Acanthocybium solandri*	234	231	−1.3%	−0.02	0.549
Mahimahi	*Coryphaena hippurus*	1,173	1,173	0.0%	0.00	1.000
Escolar	*Lepidocybium flavobrunneum*	499	397	−20.4%	−0.53	<0.001
Opah	*Lampris* spp.	244	239	−2.0%	−0.03	0.376
Sickle pomfret	*Taractichthys steindachneri*	603	609	1.0%	0.03	0.683
Other consumable bony fishes		204	159	−22.1%	−0.23	N/A[13]
Unidentified catch events		9	738	81.0%	3.78	N/A[13]
Tunas[3]		4,276	4,245	−0.7%	−0.16	0.291
Billfishes[4]		587	581	−1.0%	−0.03	0.474
Sharks[5]		1,660	699	−57.9%	−4.98	<0.001
Marketable pelagic fishes[7]		2,957	2,808	−5.0%	−0.77	N/A[13]
Non-marketable pelagic fishes[6]		5,618	5,056	−10.0%	−2.91	N/A[13]
Protected Species[9]		13	12	−7.7%	−0.01	N/A[13]
Total catch events		15,111	13,401	−11.3%	−8.86	<0.001

Shallow-set Catch Comparisons for Kept Catch

EM and at-sea observer collected data were similar for retained fish in the shallow-set Hawai‘i longline fishery. During 45 shallow-sets, 1,117 retained fish were detected by EM review and 1,133 retained fish by at-sea observers with an overall percent difference of −0.4% for the total of all retained catch events, which included bigeye tuna, yellowfin tuna, blue marlin, striped marlin, swordfish, wahoo, mahimahi, escolar, sickle pomfret, and the other and unidentified species. Randomization tests for mean difference on these species and taxonomic groups indicated that there were no significant differences ($p > 0.05$) in mean difference by haul for six of the six tested retained species or for the three species groups (tunas[3], billfishes[4], and sharks[5]). There was an overall mean difference for all catch events of −0.36 fish per haul ($p = 0.402$) between EM and at-sea observer data (Table 4).

Table 4. Shallow-set longline comparisons between electronic monitoring (EM) and at-sea observer data for retained (kept) catches.

Species/group	Scientific name	Observer	EM	Percent difference	Mean difference per haul	P-value
Bigeye tuna	*Thunnus obesus*	98	103	5.1%	0.11	0.179
Yellowfin tuna	*Thunnus albacares*	117	107	−8.5%	−0.22	0.062
Other & unidentified tunas		3	4	33.3%	0.02	N/A[13]
Blue marlin	*Makaira mazara*	6	9	50.0%	0.07	N/A[13]
Striped marlin	*Kajikia audax*	23	23	0.0%	0.00	0.499
Swordfish	*Xiphias gladius*	542	547	0.9%	0.11	0.486
Other & unidentified billfishes		19	18	−5.3%	−0.02	N/A[13]
Wahoo	*Acanthocybium solandri*	5	3	−40.0%	−0.04	N/A[13]
Sickle pomfret	*Taractichthys steindachneri*	1	1	0.0%	0.00	N/A[13]
Mahimahi	*Coryphaena hippurus*	252	237	−6.0%	−0.33	0.156
Escolar	*Lepidocybium flavobrunneum*	51	50	−2.0%	−0.02	1.000
Tunas[3]		218	214	−1.8%	−0.09	0.874
Billfishes[4]		590	597	1.2%	0.16	0.578
Sharks[5]		14	15	7.1%	0.02	1.000
Marketable pelagic fishes[7]		309	291	−5.8%	−0.40	N/A[13]
Non-marketable pelagic fishes[6]		2	0	−100.0%	−0.04	N/A[13]
Total catch events		1,133	1,117	−1.4%	−0.36	0.402

Shallow-set Catch Comparisons for Bycatch (Discarded Catches)

EM and at-sea observer collected data comparisons for bycatch in the shallow-set fishery indicated gear interactions with some encountered species were commonly missed during EM review. Detections from 45 shallow-sets showed that the EM reviewer recorded 662 discard events while the at-sea observer enumerated 808 discard events (−3.24% difference, $p < 0.001$). Randomization tests performed to compare detections by species or taxonomic groups ($n \geq 20$ animals) indicated no significant differences in mean difference per haul ($p > 0.05$) for one of the two species tested (escolar). Significant differences in mean difference per haul occurred for discards of swordfish, as well as fishes grouped by billfishes[4] and sharks[5] (Table 5). Another difference between EM and at-sea observer detections occurred with the enumeration of unknown catch events. EM reviewers detected 181 unknown catch events while at-sea observers only enumerated 11 unknown catch events (Table 2).

Table 5. Shallow-set longline comparisons between electronic monitoring (EM) and at-sea observer data for bycatch (discarded catches).

Species/group	Scientific name	Observer	EM	Percent difference	Mean difference per haul	P-value
Bigeye tuna	*Thunnus obesus*	3	0	−100.0%	−0.07	N/A[13]
Yellowfin tuna	*Thunnus albacares*	7	1	−85.7%	−0.13	N/A[13]
Other & unidentified tunas		4	4	0.0%	0.00	N/A[13]
Striped marlin	*Kajikia audax*	2	1	−50.0%	−0.02	N/A[13]
Swordfish	*Xiphias gladius*	165	142	−13.9%	−0.51	0.005
Other & unidentified billfishes		0	1	N/A[12]	0.02	N/A[13]
Mahimahi	*Coryphaena hippurus*	11	4	−63.6%	−0.16	N/A[13]
Escolar	*Lepidocybium flavobrunneum*	32	27	−15.6%	−0.11	0.433
Other consumable bony fishes		1	0	−100.0%	−0.02	N/A[13]
Unidentified catches		2	181	99.9%	3.98	N/A[13]
Tunas[3]		14	5	−64.3%	−0.20	N/A[13]
Billfishes[4]		167	144	−13.8%	−0.51	0.003
Sharks[5]		354	161	−54.5%	−4.29	<0.001
Marketable pelagic fishes[7]		44	31	−29.5%	−0.29	N/A[13]
Non-marketable fishes[6]		196	333	69.9%	3.04	N/A[13]
Protected Species[9]		8	3	−62.5%	−0.11	N/A[13]
Total catch events		808	662	−18.1%	−3.24	<0.001

Shallow-set Catch Comparisons for All Catches

During 45 shallow-sets, 1,779 retained and bycatch events were recorded by EM review and 1,941 retained and bycatch catches were recorded by at-sea observers with an overall percent difference of −11.3% for all catch events including the non-marketable fishes[6] with an overall mean difference of -8.86 fish per haul ($p < 0.001$) between EM and at-sea observer data (Table 6). Randomization tests performed on species or taxonomic groups indicated no significant differences ($p > 0.05$) in mean difference per haul for five of the six tested species (bigeye tuna, striped marlin, swordfish, mahimahi, and escolar) and one of the species groups (billfishes[4]). However, there were significant differences for yellowfin tuna, striped marlin, escolar, and bigeye tuna, as well as for the species groups of non-marketable fish[6] and sharks[5].

Table 6. Shallow-set longline comparisons between electronic monitoring (EM) and at-sea observer data for all catches.

Species/group	Scientific name	Observer	EM	Percent difference	Mean difference per haul	P-value
Bigeye tuna	*Thunnus obesus*	101	103	2.0%	0.04	0.507
Yellowfin tuna	*Thunnus albacares*	124	108	−12.9%	−0.36	0.002
Other & unidentified tunas		7	8	14.3%	0.02	N/A[10]
Blue marlin	*Makaira mazara*	6	9	50.0%	0.07	N/A[15]
Striped marlin	*Kajikia audax*	25	24	−4.0%	−0.02	0.657
Swordfish	*Xiphias gladius*	707	689	−2.5%	−0.40	0.062
Other & unidentified billfishes		19	19	0.0%	0.00	N/A[10]
Wahoo	*Acanthocybium solandri*	5	3	−40.0%	−0.04	N/A[13]
Sickle pomfret	*Taractichthys steindachneri*	1	1	0.0%	0.00	N/A[10]
Mahimahi	*Coryphaena hippurus*	263	241	−8.4%	−0.49	0.054
Escolar	*Lepidocybium flavobrunneum*	83	77	−7.2%	−0.13	0.267
Other consumable bony fishes		1	0	−100.0%	−0.02	
Unidentified catches		2	181	99.9%	3.98	N/A[13]
Tunas[3]		232	219	−5.6%	−0.29	0.008
Billfishes[4]		757	741	−2.1%	−0.36	0.169
Sharks[5]		393	161	−59.0%	−5.16	<0.001
Marketable pelagic fishes[7]		353	322	−8.8%	−0.69	N/A[10]
Non-marketable fishes[6]		198	333	68.2%	3.00	N/A[10]
Protected Species[9]		8	3	−62.5%	−0.11	N/A[10]
Total catch events		1,941	1,779	−8.3%	−3.60	<0.001

Protected Species Comparisons

For both deep-set and shallow-set fisheries, protected species interactions were detected similarly using EM and by at-sea observers. During deep-set review, all false killer whales and sea turtles that were identified by at-sea observers were also documented with EM video review. However, one albatross was missed during EM review, likely due to the location of capture at the stern, out of the view of the camera (Table 7). During the shallow-set fishery review, both sea turtles that were identified by at-sea observers were also documented during EM review. However, five out of six albatross reported by the at-sea observer were missed during EM review. Reexamination of EM and at-sea observer data indicated these missing albatross were brought aboard the vessel over the stern rail after capture on a branchline detached from the mainline and pulled in by crew (Table 8). This occurred in an area of the deck which is recorded but not focused on by the reviewer unless crew actions indicate further careful review is warranted. Hypothesis testing to determine differences between at-sea observer and EM data with the parameter of mean difference by haul was not conducted for protected species comparisons because interactions with protected species in both Hawai‘i longline fisheries were rare events with small sample sizes.

Table 7. Deep-set longline comparisons between electronic monitoring (EM) and at-sea observer data for protected species.

Species	Scientific name	Observer	EM	Percent difference
False killer whale	*Pseudorca crassidens*	1	1	0.0%
Hard shell sea turtle	*Lepidochelys olivacea, Caretta caretta*	2	2	0.0%
Albatross	*Phoebastria nigripes, Phoebastria immutabilis*	11	10	−9.1%

Table 8. Shallow-set longline comparisons between electronic monitoring (EM) and at-sea observer data for protected species.

Species	Scientific name	Observer	EM	Percent difference
Hard shell sea turtle	*Lepidochelys olivacea, Caretta caretta*	2	2	0.0%
Albatross	*Phoebastria nigripes, Phoebastria immutabilis*	6	1	−83.3%

Detection of Damage Due to Depredation

Most types of depredation damage were difficult to identify from EM video compared to an at-sea observer with a percent difference of 41% (Table 9). However, marine mammal depredation damage was identified with only an 8% percent difference between EM review and at-sea observer data (Table 9).

Table 9. Percent difference between depredation damage detections by electronic monitoring (EM) and by at-sea observers for the deep-set and shallow-set longline fisheries.

	Marine mammal damage			All damage types		
Species	**Observer**	**EM**	**Percent difference**	**Observer**	**EM**	**Percent difference**
Tuna[3]	53	52	−1.9%	177	152	−14.1%
Billfish[4]	24	21	−12.5%	104	66	−36.5%
Pomfrets[12]	0	0	0.0%	7	3	−57.1%
Marketable pelagic fishes[13]	10	2	−80.0%	101	61	−39.6%
Non-marketable pelagic fishes[6]	1	0	−100.0%	354	136	−61.6%
All depredated species	89	82	−7.9%	746	443	−40.6%

---

[12] Pomfrets includes: Sickle pomfret, Lustrous pomfret (*Eumegistus illustris*), Dagger pomfret (*Taractes rubescens*), Rough pomfret (*Taractes asper*), and Brama pomfret (*Brama* spp.)

[13] Marketable pelagic fishes include: Escolar, Great barracuda (*Sphyraena barracuda*), Oilfish (*Ruvettus pretiosus*), Opah, Mahimahi, Pompano (*Coryphaena hippurus*), and Wahoo.

Discussion

EM systems can provide necessary data to improve and supplement data streams that inform management decisions for the Hawaiʻi longline fisheries and Regional Fisheries Management Organizations (RFMO). As a member of the Western and Central Pacific Fisheries Commission (WCPFC), the PIR is required to report all retained fish caught by species. Currently, the best data on total retained catch by species come from the nearly complete coverage of the fisheries by logbook and dealer data. For discarded species, the EM data stream can supplement at-sea observer data to improve extrapolation of catch. In addition, at-sea observer and EM data may provide verification for both retained and discarded species (e.g., sharks) reported on logbooks, similar to previous studies using observer data (Walsh et al. 2005).

EM may also perform well for the detection of protected species interactions, a key objective of the mandatory PIROP established in 1994 (NMFS 2004). Although fishermen logbooks provide information for most retained fish species, logbooks are not considered a good source of estimating interactions of sea turtles and other protected species (NMFS 2004). PIRO closes the Hawaiʻi longline fisheries according to limits on marine mammal and sea turtle interactions estimated at the species level. During EM review, all sea turtles and the only whale reported by the at-sea observer were detected. Additional EM research is necessary with regard to protected species given the small sample sizes and limited species identifications in this study. Accurate identification of sea turtles to the species level may allow for tracking interaction limits of loggerhead and leatherback sea turtles. During this study, the reviewer only identified sea turtles to the broader taxonomic group of hardshell sea turtles because they were unable to observe the necessary number of characteristic from the video footage for identification to the species level. The protocols in this study followed the observer manual guidelines for sea turtle identification, which requires recording at least five identifying characteristics and was developed to ensure at-sea observers provided enough positive evidence for sea turtle identification that could be verified by an expert without a picture. However, it is possible that sea turtles could have been identified to the species level in this study if these determinations were performed by a sea turtle expert using the video and/or photo documentation that EM provides. In the future, we will collaborate with the PIR Protected Resources Division to clarify if the current EM systems have the capability to identify sea turtles to the species level or if more research is needed to improve these EM systems (e.g., higher megapixel cameras).

Hawaiʻi-based fisheries are highly suitable for EM. In some fisheries, it is estimated that EM-technology may be twice as expensive as at-sea observers. However, these estimates were for fisheries where fishing occurred over a short interval, such as day-trip fisheries (GARFO and NEFSC 2015). In contrast, deployments in the Hawaiʻi deep-set fishery are, on average, 22 days including 13 fishing days with at-sea observers compensated for every day regardless of fishing activity. Therefore, trips from the PIR are likely more economical when data are collected using EM technology. The majority of landings in the deep-set and shallow-set fisheries are landed in the port of Honolulu (95% of 2017 trips[14]), which allows vessels to be easily accessed for collection of hard drives and maintenance of EM systems. Additionally, video storage costs may

---

[14] Based on unpublished logbook database query to find the port of landing for every trip in 2017.

be reduced because lower resolution and cameras with a smaller megapixel rating are needed, comparatively to other fisheries, to detect the relatively large, distinguishable pelagic species encountered along the longline. In addition, fishing occurs at a slow enough rate (2,720 hooks per 12 hours; FRMD 2018) that the reviewer is able to increase the speed of the video for review (4× to 16×) and still encounter most species captured or interacting with the gear. At the fastest effective playback speed of 16×, a hook would only be encountered about every second.

SWI's review software increased the efficiency and reduced the cost for the EM analysis of fishing trips. An open source version of the review software is available at Bitbucket.org/fisherieselectronicmonitoring. This software is adaptable to changes in program needs; for instance, data fields may be configured by staff without the need of technical support. In addition, this software provides an excellent platform for reviewing fishing activities with the ability to view video and sensor data simultaneously.

EM systems are an efficient, cost-effective method to collect quality data for the Hawaiʻi longline fisheries for monitoring. EM enables a census of the catch from a fishing trip in a week compared to approximately a three-week time commitment for an at-sea observer. Deep-set fishing trips are typically 22 days with about 13 of those days containing fishing activities; at-sea observers need to spend an additional 1 to 3 days in a debriefing process once at port. EM review, including video analysis and quality control, was completed in 24% of the time that at-sea observers spent on deck during gear retrieval and in 7.5%[15] of the total at-sea observer time aboard the fishing vessel (all fishing activity and transit time to the fishing grounds) for the 238 hauls reviewed. There is a small additional time component with EM to retrieve hard drives from vessels and to download and archive video files.

EM provides an alternative fisheries-dependent data stream from the Hawaiʻi longline fisheries to collect data on catch events, protected species interactions, and catalog fishing activities. In the absence of an at-sea observer, most fields are collectable directly from the EM-gathered video and sensors. From video, retained species, bycatch, and protected species interactions may be identified. In addition, information may be collected on gear type and configuration and whether or not the mainline parted during gear retrieval. From sensors, data may be recorded on date and time of gear setting, gear retrieval, and transit; vessel location; and direction gear is hauled (same or opposite from direction set). Currently, weather may be noted from video. However, sea state and wind information are not collected, but sensors could be added for these data in the future. Species measurements and gender are not currently collected; however, camera and system modifications may allow collection of these data for some species. Although EM systems do not currently record video during gear setting, this could be added to provide information on bird mitigation and interactions. EM has the capacity to collect most, but not all of the same data as at-sea observers. For example, at-sea observers perform activities, such as measure gear, conduct fishermen interviews on economic data, determine whether fishermen are high-grading (i.e., selecting specific fish based on economic worth), and watch for compliance to

---

[15] Based on unpublished PIROP database query to find number of at-sea observer deployment days minus number of observed sets in 2017.

requirements on strategic discarding of bait and offal. A complete comparison between information collected by at-sea observers and EM can be found in Appendix A.

With improvements in technology and fishery-specific reviewer knowledge, EM has shown improvement in capabilities since this work began in 2009. During the 2009 pilot project, EM data showed a 16% difference from at-sea observer data in all catch events (enumerated catch kept plus discards); comparatively, this statistic improved to 11% difference for the pre-implementation project.

The largest discrepancies in identifications between the pre-implementation EM and at-sea observer catch data likely occurred due to crew handing practices for discarded species. Species such as lancetfish, snake mackerels, or escolar (when discarded) may be discarded over the rail (Table 2; Table 3; Table 5; Table 6; Table 10), and sharks may be cut from the fishing line. These fish were likely enumerated as "unidentified bony fish" (lancetfish and snake mackerels) and "unknown catch" (sharks) by the EM reviewers. These taxonomic groups make up the majority of the missing detections. Removing these groups and comparing all other retained and discarded species shows a 97% match between data (Table 11). Review of at-sea observer data demonstrates that the majority of discarded bony fish were snake mackerel and lancetfish (Table 10).

Table 10. Percent difference for commonly missed species in the deep-set and shallow-set longline fisheries during electronic monitoring (EM) review.

Species/Group	Scientific name	Observer	EM	Percent difference
Lancetfish	*Alepisaurus ferox*	4,218	3,279	−22.3%
Snake mackerel	*Gempylus serpens*	1,370	1,033	−24.6%
Unidentified bony fish		11	280	2445.5%
Blue shark	*Prionace glauca*	1,762	388	−78.0%
Oceanic whitetip shark	*Carcharhinus longimanus*	12	6	−50.0%
Silky shark	*Carcharhinus falciformis*	6	5	−16.7%
Alive shortfin mako shark	*Isurus oxyrinchus*	91	56	−38.5%
Dead shortfin mako shark	*Isurus oxyrinchus*	18	21	16.7%
Crocodile shark	*Pseudocarcharias kamoharai*	60	57	−5.0%
Bigeye thresher shark	*Alopias superciliosus*	46	39	−15.2%
Velvet dogfish shark	*Zameus squamulosus*	17	16	−5.9%
Unidentified shark		9	248	2655.6%
Total sharks		2,021	836	−58.6%
Unknown catch events[16]		0	639	N/A[17]

---

[16] Unknown catch event was used when the crew was observed pulling in a tight line that was either cut or broke, indicating a large animal was captured.

[17] The unknown catch event field was not used by the at-sea observers.

Table 11. Total comparison of detection when sharks, lancetfish, snake mackerel, and anything unidentified are removed from comparison categories

Detection category	Observer	EM	Percent difference	Mean difference per haul
Total detection	17,052	15,180	−11.0%	−7.87
No sharks, lancetfish, snake mackerel, unidentified catch included	9,400	9,089	−3.3%	−1.31

The majority of “unknown catch events" recorded during EM review were most likely blue shark interactions. Crew behavior during blue shark catch events differs from other high-tension catch events. For example, turtles, marine mammals, oceanic whitetip, and silky sharks have specific handling requirements that dictate fishers to bring them closer to the vessel for at-sea observer identification and removal of trailing gear, and retained fish are carefully landed. Whereas, blue sharks are generally cut from the line due to safety concerns (the weight at the end of the branchline can recoil if the line snaps from a shark biting through the leader) as soon as these sharks are identified; the distinct blue color often allows identification before sharks enter the view of the video cameras. The at-sea observer data confirm the majority of these "unknown catch events" in the EM data were likely blue sharks (Table 10).

Shark detection with EM differs by species (Table 10) and depends on crew handling practices. Like blue sharks, live mako sharks may also be undetected with EM because they may fight gear or breach out of the view of the camera before crew cuts the line. However, dead mako sharks and bigeye thresher sharks may be detected because they usually surface closer to the vessel before the line is cut (Table 10). Bigeye thresher shark behavior on the fishing gear is similar to large tuna that swim down and may cause gear tangles; consequently, fishermen slow down to determine if these fish are of value and to manage gear issues. Dead mako sharks will likely be detected. These sharks often cause tangled gear that shortens the branchline, which results in sharks surfacing within the view of the camera and fishing activities slowing down to address gear issues.

Although EM reviewers performed well at tuna and billfish identification to family level for kept species, there was some difficulty with identification to the species level. Bigeye and yellowfin tuna are easy to distinguish when key characteristics are visible, such as long, thin pectoral fins for small bigeye tuna or large extended anal and dorsal fins for yellowfin tuna. However, mid-sized tuna lack distinguishing characteristics visible with the pre-implementation camera configurations. In addition, some large yellowfin may lack the extended second anal and second dorsal fins that, when present, easily distinguish these fish from bigeye tuna. Other morphometric features, such as body shape, orbit diameter, and head length to body length ratios can distinguish bigeye tuna; however, these characteristics may appear skewed due to camera angles (e.g., a bigeye tuna may appear more elongated like a yellowfin tuna). Improvements could be made with tuna identification to species by adding an additional camera that is zoomed in to the processing area or by upgrading existing cameras to a higher megapixel configuration that would allow visibility of distinguishing characteristics, such as the color of finlets, the pattern of vertical bars, or the shape of the caudal fin margin (Itano 2005). Species identification between striped and blue marlins could be improved with changes in fishermen handling. For example, fishermen could briefly extend the dorsal fin of billfish, which would easily allow the reviewer to distinguish between species (i.e., the striped marlin dorsal fin extends greater than the body depth and the blue marlin less than the body depth).

Depredation damage was likely missed during EM review because damage may occur on only one side of the fish. If fish are landed on the side of the body with unilateral depredation, then the damage may be missed. However, EM performed well with identification of marine mammal damage (Table 9), which is bilateral and is more likely to be captured on video.

Recommendations

To create an EM program that produces a timely and robust data stream, we suggest modifications to improve species identification, programmatic guidelines for review, and utilizing reviewers that have previous experience within the fisheries. Improvements to species identification will be explored through modifications in EM system cameras, such as an additional camera that is zoomed in or using a higher megapixel camera. Reviewers with experience in the Hawai‘i longline fisheries, such as previous at-sea observers from PIROP, will ensure familiarity with the nuances of fisher and fish behavior at sea, which will lead to improved data quality with accurate species identifications and detections. Programmatic guidelines for review will require a prescribed number of hauls per week to be reviewed to ensure the annual target of hauls reviewed is completed on schedule. In addition, the amount of review per workday will be limited to six hours to prevent fatigue.

PIFSC is completing a project to determine the recommended speed for video review. Reviewers reviewed EM footage at 4×, 8×, and 16× speeds. Preliminary data suggest that 8× speed will produce the most accurate and precise detections.

If an EM program is adopted to augment monitoring in longline fisheries, then the recommended number of reviewers would depend on the selected review speed, as well as the coverage needed. Estimates of the number of reviewers required for the Hawai‘i longline fisheries are presented based on these variables in Table 12. For example, three reviewers would be required to review 10% of the fishing effort at a review speed of 8× for the Hawai‘i deep-set longline fishery.

Table 12. Recommended number of electronic monitoring (EM) reviewers needed in a calendar year to review video from the Hawai‘i longline fisheries for fish and protected species at different review speeds and fishery coverage rates. Estimates are based on 19,000 fishing hauls and 240 workdays.

	Number of reviewers		
Percent coverage	**4× speed (2 hauls per day)**	**8× speed (3 hauls per day)**	**16× speed (4 hauls per day)**
100%	40	27	20
25%	10	7	5
10%	4	3	2

The time and costs of EM programs could be reduced by implementing an audit-based review process. Instead of reviewing all trips with vessels carrying EM systems, a subset of trips would be selected based on a systematic random sampling scheme. Results from the NOAA Fisheries Northeast Region EM Pilot project suggest that an audit model is effective. The variability between datasets may not be reduced significantly when performing review at rates higher than 50% when EM is used to validate other data streams (i.e., logbook data) (Kennelly and Borges 2018). The Hawai‘i longline fisheries could adopt an audit model after establishing a baseline using a 100% review rate.

We recommend camera placements that optimize imagery and detections based on EM system setups that produced the best data during this pre-implementation project. The best imagery and ability for detections were obtained with cameras that were mounted on a boom that extended over the rail and showed the area outside the rail. This placement allows for minimal interference from crew (i.e., accidently hitting with gaffs) and sea spray. A moveable boom also allows the cameras to be moved out of the way during transit and mooring.

The PIR can consider incorporating EM data into longline bycatch estimation methods for fish, marine mammals, sea turtles, and seabirds. For the deep-set longline fisheries with less than 100% at-sea observer coverage, NMFS extrapolates the observed bycatch interactions using a rigorous statistical methodology to estimate total interactions (Benaka et al. 2019). Instead, EM allows the supplementation of at-sea observer coverage and could be used to estimate bycatch for species that EM detects well (i.e., escolar, mahimahi, pomfrets, and opah). In the future, EM will develop methods to improve detection for species that have been more difficult to identify. For example, handling methods will be explored to place sharks within the camera views.

Future

Automation of fish detection and identification in the Hawai‘i longline fisheries using computer vision technology would improve efficiency of review and accuracy of fish identification. A joint effort between the University of Washington and the Alaska Fisheries Science Center has been highly productive in using machine learning to automate many aspects of the EM data review process. In 2017, systems indicated that automation could be performed for catch event detection, length measurement, and species identification (NMFS 2017). The software and algorithms developed during this effort will be available to other NMFS regions in the near future. These algorithms could be trained using images of fishing activities and fish species annotated from EM-collected data from the Hawai‘i longline fisheries. After the algorithm is trained, EM video footage could be automatically processed to provide species identifications along with a confidence rating. Events with a low confidence rating would be reevaluated by a human to positively identify species. In addition to species identification, computer vision technology could be used to record fishing activities, such as counting hooks. By leveraging this technology, reviewers will be able to reduce the time necessary to complete a trip, as well as increase the coverage of the fishery. Beginning in January 2019, PIFSC started building an image library to feed into these algorithms that will be used to test the viability of automation for the Hawai‘i longline fisheries. PIFSC will also contribute these images to a national photo library for computer vision by providing labeled images of fishing activities and fish that could be used by other regions.

Due to the discrepancies in detection and identification observed for bycatch species, we plan to begin a catch handling study in 2020. This study will be a collaboration between PIFSC and fishermen to determine the most efficient catch handling and lighting configurations for speciation of sharks and other species that are released without landing. Implementing catch handling protocols with EM review in mind could also provide the opportunity to collect reliable and calibrated measurements using EM on animals brought alongside of the vessel, including sharks and protected species.

In the future, EM staff will collaborate with PIFSC Protected Species Division to determine if injuries of protected species due to capture and handling can be identified with current EM systems. If current systems lack the ability to collect the necessary information needed for serious injury determinations for marine mammals, then research will be performed to address that question. New fields could be added to the review software to properly illustrate and document these interactions.

Acknowledgements

We thank the NOAA Fisheries Information Systems (FIS) and the National Observer Program (NOP) for financial support and guidance for this project, as well as PIROP, particularly John Kelly, for support and encouragement of technology that can be used to allow observers to become more effective data collectors by role augmentation or coverage supplementation. We would also like to extend our deepest gratitude to the original 18 Hawai‘i-based longline vessels that volunteered to carry EM systems. Thanks to the support from SWI for installation and maintenance of EM systems and providing review software and recommendations for hardware. In addition, we appreciate the continued collaborative effort by the members of the ETWG and the ETPSG to work in partnership across the NMFS regions. Thanks to Josh Lee for creating an infographic of our camera configurations aboard the Hawai‘i longline vessels. And finally, we would like to thank the WPRFMC for establishing the first EM pilot project and facilitating data review for the current project.

Literature Cited

Benaka LR, Bullock D, Hoover AL, Olsen NA, editors. 2019. U.S. National Bycatch Report First Edition Update 3. U.S. Dept. of Commerce, NOAA. NOAA Technical Memorandum NMFS-F/SPO-190, 95 p.

Bigelow K, Musyl MK, Poisson F, Kleiber P. 2006. Pelagic longline gear depths and shoaling. Fish Res. 77:173–183. http://imina.soest.hawaii.edu/PFRP/reprints/Fish_Res_77_Bigelow_et_al.pdf

Camhi MD, Valenti SV, Fordham SV, Fowler SL, Gibson C. 2009. The conservation status of pelagic sharks and rays: report of the IUCN shark specialist group pelagic shark red list workshop. Newbury (UK): IUCN Survival Commission Shark Specialist Group.

Fisheries Research and Monitoring Division [FRMD], Pacific Islands Fisheries Science Center, NOAA Fisheries. 2018. The Hawaii limited access longline logbook summary report, January to December 2017. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-18-007, 10 p. doi:V5/DR-PIFSC-18-007.

Greater Atlantic Regional Fisheries Office [GARFO], Northeast Fisheries Science Center [NEFSC]. 2015. A preliminary cost comparison of at sea monitoring and electronic monitoring for a hypothetical groundfish sector. 43 p.

Itano D. 2005. A handbook for the identification of yellowfin and bigeye tunas in fresh condition. Pelagic Fisheries Research Program, Honolulu, Hawaii, USA. Ver 2. 1–27. http://mexfish.com/fish/beyetuna/ItanoBigeyeTunaID.pdf

Kennelly SJ, Borges L, editors. 2018. Proceedings of the 9th International Fisheries Observer and Monitoring Conference, Vigo, Spain. 397 p. https://ifomcvigo.com/wp-content/uploads/2018/08/proceedings-9th-ifomc1.pdf

McCracken ML. 2019. Hawaii permitted deep-set longline fishery estimated anticipated take levels for Endangered Species Act listed species and estimated anticipated dead or serious injury levels for the listed marine mammals. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-19-011, 26 p. doi:10.25923/brkr-c471

McElderry H, Pria MJ, Dyas M, McVeigh R. 2010. A pilot study using EM in the Hawaiian longline fishery. Unpublished report prepared for the Western Pacific Fishery Management Council by Archipelago Marine Research Ltd., Victoria British Columbia, Canada. 47 p. http://www.wpcouncil.org/library/docs/Archipelago_EM_Pilot_Study_Final.pdf

National Marine Fisheries Service [NMFS]. 2004. Biological opinion on proposed regulatory amendments to the fisheries management plan for the Pelagic Fisheries of the Western Pacific Region. February 23, 2004. 263 p.

NMFS. 2017. Analysis to integrate electronic monitoring into the North Pacific observer program. National Marine Fisheries Service, Alaska Region. 169 p.

Pacific Islands Region. 2015. NMFS Pacific Islands Region Electronic Reporting and Electronic Monitoring Implementation plan January 2015. 33 p. https://www.fpir.noaa.gov/SFD/pdfs/2015_PIR_Electronic_Reporting_Monitoring_Plan.pdf

Pacific Islands Regional Office Observer Program [PIROP]. 2017. Hawaii Longline Observer Program Field Manual; Version LM.17.02. 190 p. https://www.fpir.noaa.gov/Library/PUBDOCs/observer_manual_forms/obs_hawaii/obs_hi_manual_feb_2017.pdf

Walsh WA, Ito RY, Kawamoto KE, McCracken M. 2005. Analysis of logbook accuracy for blue marlin (*Makaira nigricans*) in the Hawaii-based longline fishery with a generalized additive model and commercial sales data. Fish Res. 75(1-3). doi:10.1016/j.fisheries.2004.11.007

Appendix A: Electronic monitoring (EM) capability to collect data currently recorded by the at-sea observer program.

Header/field	Collectable using EM	Collected during EM pre-implementation project
Trip specifications		
Observer identification number	Yes	Yes
Observer trip number	Yes	Yes
Declared trip type (shallow- or deep-set)	Yes	Yes
Vessel documentation number	Yes	Yes
Vessel name	Yes	Yes
Operator name	Yes	Yes
Any high-grading during trip?	No	No
Trip dates/times and port stops		
Departure date/time	Yes	Yes
Departure port	Yes	Yes
Arrival date/time	Yes	Yes
Intermediate port stops		
Stop number	Yes	No
Stopped date/time	Yes	No
Resumed date/time	Yes	No
Stop port	Yes	No
Set and haul information		
Fishing logbook page number	No	No
Begin set, end set, begin haul, or end haul information		
Date/time	Yes	Yes
Latitude/longitude	Yes	Yes
Weather code	Yes	No
Beaufort scale	No	No
Sea surface temperature	No	No
Set/haul events		
Haul back direction	Yes	Yes
Mainline parted?	Yes	Yes
Number sections of mainline retrieved	Yes	Yes
Protected species interactions?	Yes	Yes
Seabird mitigation		
Set at night?	Yes	No
Towed buoy?	Yes	No
Tori line?	Yes	No
Line shooter?	Yes	No
Water sprayed on sea?	Yes	No
Bird curtain?	Yes	No
Gear set from side?	Yes	No
Bait blue-dyed?	Yes	No

Header/field	**Collectable using EM**	**Collected during EM pre-implementation project**
Branch line weighted?	Yes	No
Strategic offal discard?	No	No
Strategic bait discard?	No	No
Bait thawed?	No	No
Bait cast outside wake?	Yes	No
Other mitigation techniques?	Yes	No
Birds present?	Yes	No
Gear configuration		
Hooks/floats		
Number of floats	Yes	No
Hooks per float	Yes	No
Number of floats	Yes	No
Hook characteristics		
Hook type code	No	No
Hook sizes	No	No
Hook diameter	No	No
Hook percentage by type	No	No
Fishing techniques		
Target species code	Yes	No
Bait code	Yes	No
Light devices		
Type code	Yes	No
Number devices	Yes	No
Color code	Yes	No
Mainline		
Material code	Yes	No
Diameter	No	No
Color code	Yes	No
Float line		
Material code	Yes	No
Diameter	No	No
Measured length	No	No
Branch line		
Material code	Yes	No
Diameter	No	No
Measured length	No	No
Color code	Yes	No
Leader		
Material code	Yes	No
Diameter	No	No
Measured length	No	No
Size of leader weight	No	No

Header/field	Collectable using EM	Collected during EM pre-implementation project
Protected species event log		
Event date/time	Yes	Yes
Event type code (gear contact, behavior, scan, event ended)	Yes	Yes
Vessel activity code (gear set, gear retrieval, gear soak/drift, or other)	Yes	Yes
Sighting method (naked eye, binoculars, or other)	Yes	Yes
Latitude/longitude	Yes	Yes
Species code	Yes	Yes
Behavior code	Yes	Yes
Species count	Yes	Yes
Sketch drawn?	No	No
Photo taken?	Yes	Yes
Catch Event Log		
Species common name	Yes	Yes
Species code	Yes	Yes
Float number	Yes	No
Hook number	Yes	No
Caught condition code	Yes	Yes
Kept/return code	Yes	Yes
Damaged code	Yes	Yes
Gender code	Yes	No
Measurement	Yes	No
Marine debris encounter report		
Latitude/longitude	Yes	Yes
Time	Yes	Yes
Incident type	Yes	Yes
Debris type	Yes	Yes
Biota types associated with marine debris	Yes	Yes
Estimated total weight	Yes	Yes
Debris brought on board?	Yes	Yes
Length of time to recover marine debris	Yes	Yes
Operator surveys		
Operator economic information survey	No	No
Operator survey on crew and vessel information for the Western and Central Pacific Fisheries Commission (WCPFC)	No	No