A PILOT STUDY USING EM IN THE HAWAIIAN LONGLINE FISHERY

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ABSTRACT

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This pilot study explored the use of electronic monitoring (EM) in the shallow and deep set components of the Hawaiian pelagic longline fishery. EM systems, consisting of closed circuit television cameras, sensors (e.g., GPS, hydraulic pressure and winch rotation) and a system control box, were deployed on three vessels, simultaneously monitored with observers, for a collective total of about 320 sea days, 13 fishing trips and 182 fishing events. Overall, the equipment performed well, recording data for 99.2% of the time vessels were at sea. A key strength of EM is the continuous sensor data record providing very accurate temporal and spatial information on gear setting and retrieval activities. EM image reviewers were also able to reliably detect hooks deployed and retained catch. About 40% of the discard catch was not detected by EM image reviewers, because discard releases occurred outside the camera view. Overall, EM species identifications were more general than by observers and most common species were identified from EM imagery. Detection of protected species by EM and observers was similar, with both detecting all sea turtles encountered and each missing one of three caught. The shortcomings of EM for discard detection could be addressed by improvements to camera placements and harmonizing crew activities with the technology.

Key Words: Hawaii, pelagic longline fishery, observer, electronic monitoring, EM

EXECUTIVE SUMMARY

The pelagic longline fishery in Hawaii is composed of a shallow-set fishery targeting swordfish and a deep-set fishery targeting tuna. There is a strong need for at-sea catch data for management purposes, especially as it relates to sea turtle interactions and seabirds. The Western Pacific Fishery Management Council (WPFMC) has been interested in the use of technology based monitoring to compliment the existing observer program. Over the past decade, Archipelago Marine Research Ltd. (Archipelago) has pioneered the development of electronic monitoring (EM) technology and a number of completed studies have shown that EM has a number of advantages over observers including suitability across a broad range of vessels, creation of a permanent data record, lower cost, higher scalability, and the ability to engage industry in self-reporting processes (i.e. using EM to audit fishing logbooks).

The primary goal of the study was to evaluate the feasibility of using video monitoring in the Hawaii longline fleet, which could be used to augment observer programs, increase the accuracy of data collected by observers and fishers, and replace some observers. The project was intended to address the following questions:

- Can electronic monitoring image data provide images of sufficient resolution and clarity to allow an EM image reviewer to accurately record the number of hooks and counts of target and non-target species?

- Can electronic monitoring image data provide images of sufficient resolution and clarity to allow an EM image reviewer to identify interactions with various species of sea turtles, marine mammals, and seabirds as well as detect hooking location and release condition?

- Are results from video monitoring similar to those obtained from on-board observers?

The EM system used for this project, custom manufactured by Archipelago, consists of up to four closed circuit television cameras, a GPS receiver, a hydraulic pressure sensor, winch sensor, a satellite modem, and a system control box. The system was to be powered continuously to record sensor data (e.g. location, time, speed, hydraulic and winch activity, system events, etc.) at a 10-second frequency and image data recording was set to record when hydraulic pressure or winch rotations exceeded a preset threshold, indicating activation of fishing gear. All data were recorded onto a 500GB hard drive which was estimated to last four to five weeks of normal pelagic longline operations. The satellite modem was used to transmit an hourly synoptic report consisting of vessel speed and location, sensor activity, video triggers and EM system performance data.

EM systems were installed on two shallow-set and one deep-set vessel. All vessels ranged in length from 70 to 80 feet and were designed for making extended fishing trips of three to five weeks. EM systems were serviced by a local electronics firm for the data collection period (January to July 2009) and forwarding data to Archipelago at regular intervals. All fishing trips were also monitored by observers performing their normal duties on this fishery.

EM data were processed Archipelago staff in Victoria, BC. Sensor data were assessed for completeness, data quality, then specific details of the fishing trip (e.g., trip start and end, and the location and time for all fishing events). Image data were examined for all fishing events of interest, performing either a full catch assessment or quicker review for just protected species. Observer data were supplied to Archipelago after all EM image interpretation work had been completed to ensure independence between the two data sets.

The data collection period spanned six-months involving three vessels, each completing between three and six fishing trips for a combined total of 320 days at sea with observer data available for all trips. EM systems collected a total of over 7,600 hours of sensor data at sea and over 3,000 hours of imagery associated with 182 fishing events. Overall, the equipment performed well, recording data for 99.2% of the time vessels were at sea. The number of fishing events with imagery usable for comparison with observer data was 159, or 86% of total events, with the major source of data loss being a hard drive damaged in shipment after removal from the vessel.

Sensor performance was high across all vessels with image data recording having always been properly triggered and fishing activity was distinguishable from sensor signature at all times. Image quality was rated as high for 90% of the hauls reviewed and the rest were rated as medium quality.

A key strength of EM is the continuous sensor data record providing very accurate temporal and spatial information on gear setting and retrieval activities. Among the set and haul start times, most (93% and 84%, respectively) were within 10 minutes. Similarly, among the set and haul locations, most (70%, and 68%) were within 0.5km and we believe EM to be more accurate than observer results.

Among the 159 hauling events examined, a total of 116,739 hooks (hooks empty and with catch) were recorded in the observer data versus 117,587 reported by EM image reviewers for a total difference of -0.7%. These comparisons agreed very well on a set by set basis, except in once instance where camera views made hook counting difficult, and another where the observer appeared to estimate (three hooks per float) rather than count hooks.

Among the 159 hauling events examined there were three instances of leatherback turtle captures, all of which were detected by both EM and observers. All three turtles appeared vigorous and swam away once released. Among seabirds, there were three capture events recorded, one detected by both EM and the observer and two seen by one but not the other. A black footed albatross was detected by both and recorded as dead. One injured black footed albatross was reported by the observer and not detected in the EM image data set. Imagery was examined a second time after noting the observer record and the encounter was still not evident and we concluded that the capture event either occurred outside the camera view or at a different time. In another instance, on the same vessel but different set, EM image reviewers detected a Laysan's albatross for which there was no record in the observer catch record.

Observer catch data consisted of a total of 36 catch categories including 30 species, 2 genera, a tribe, and 3 families. EM data categorized catch in 33 categories including 25 species, 4 genera, a tribe, 3 families and an unknown fish category. The slightly lower number of categories and greater use of more general categories correspond to a lower ability to identify catch as compared with observers.

The two shallow set vessels principally targeted billfish with broadbill swordfish being the most common, followed by striped marlin. Other significant catch species were blue shark, lancetfish, escolar and dolphinfish. The deep set vessel primarily caught bigeye and skipjack tuna. Catch diversity in general was higher than shallow set vessels with a significant proportion of the catch made up with species such as sharks, billfish, and other species including lancetfish, escolar, dolphinfish, pomfret and snake mackerel. Overall, about 60% of the total catch was retained, blue shark and longnose lancet fish were the most common species discarded.

Among the three vessels combined, EM image reviewers estimated less total catch than the observer estimate by about 16%. This trend was consistent across all three vessels, with the range -26.1 to +7.5%. This catch accounting difference was primarily with discarded species where EM image reviewers detected 40% less catch than observers (range -13.4 to -61.2%), while among retained catch the difference was -0.4% (range -0.2, and 3.3%). The total piece count difference was seven for all three vessels (range 1 to 12). These results indicate that EM was very reliable at accounting of retained catch but not for discarded catch. The consistently poor level of agreement and underestimate by EM image reviewers suggests that a significant portion of the discarded catch was not evident in the imagery.

On the basis of individual retained catch identifications there was high agreement between EM and observers for broadbill swordfish and total billfishes, but identifications for species of marlin, sailfish and spearfish were inconsistent. Among tunas, EM and observer retained catch estimates were within 2% for bigeye tuna and 10% for all tunas, but counts by individual species varied. Among other species, the total count was within 2% but individual species identifications varied.

Improvements are needed for detection of discarded catch species could be overcome by working with industry to develop more structured catch handling procedures. We suggest a control point approach be taken, making sure that all catch and discard items are brought to a single place (e.g., seaward of sea door) that is clearly in view of a camera. Industry input is needed to design this process that minimally impact fishing operations.

Improvements to species identification from EM imagery could be addressed in two ways: use Hawaii-based image reviewing staff and improve image resolution as the control point (see above).

A difficult challenge for both EM and observers is to ensure that all branch line retrievals are monitored. Vessel operators can easily avert detection by unclipping and releasing the branch line before the catch item comes into view. The occurrence (or perception of occurrence) of undetected dropped clips will impede confidence in bycatch estimates and therefore monitoring needs to account for all gear deployed of whether it contains catch or not.

In conclusion, the results from this pilot study show differences between EM and observer. With issues such as fishing time and location, and counts of gear used, EM provided more accurate assessments than observers. For issues including counting and identification of catch and bycatch, observers provided clearly superior assessments. The suggested improvements to camera placements and more structured catch handling procedures would significantly improve the ability of EM for catch and bycatch assessments, although we would expect that observer assessments are likely to be more detailed, particularly with species identification. In terms of protected species takes, EM and observer results were very comparable although we would expect observers to have greater ability to identify to species and make more detailed assessments of animal condition.

From a broad perspective, Hawaiian pelagic longline fisheries are under scrutiny and there is presently strong political will to improve visibility into the fishery through an observer program. The existing monitoring program is expensive to maintain which puts the fishery at risk if funding priorities change. A technology based monitoring alternative comes into consideration because of the potential to significantly low monitoring costs and improve efficiencies. In our view the pelagic longline fishery could be monitored using a combination of EM and observers, the former being widely used for key issues such as catch and effort, and protected species takes, while the latter to support more detailed data collection needs such as fine scale species resolution and biological sampling. A key dependency for EM to be successful is the level of industry support. We understand that some of the captains involved in the pilot study liked EM because it provided multiple camera views from which they could oversee operations from the bridge. Additional required support would include vessel personnel taking responsibility to ensure the EM system is performing properly (powered on, cameras clean, etc.) and ensuring that catch handling activities always occur within camera view.

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1. INTRODUCTION

The pelagic longline fishery in Hawaii is composed of a shallow-set fishery targeting swordfish and a deep-set fishery targeting tuna. There is a strong need for at-sea catch data for management purposes, especially as it relates to sea turtle interactions. The shallow-set fishery has a hard sea turtle interaction limit that, if met, would trigger the closure of the fishery for the calendar year. Sea turtle interactions are currently monitored with at-sea observers; the shallow-set fishery has 100% coverage and the deep-set fishery 20%. The Western Pacific Fishery Management Council (WPFMC) has been interested in the use of technology to compliment the existing observer program. Over the past decade, Archipelago Marine Research Ltd. (Archipelago) has pioneered the development of electronic monitoring (EM) technology and a number of pilot studies have been carried out to test the efficacy of this technology (McElderry, 2008). These studies have shown that, in many instances, EM has a number of advantages over observers including suitability across a broad range of vessels, creation of a permanent data record, lower cost, higher scalability, and the ability to engage industry in self-reporting processes (i.e. using EM to audit fishing logbooks).

While EM has been tested in several different fisheries around the world, tests with pelagic longline fisheries are few. A New Zealand study with two pelagic longline vessels, which monitored about 30 fishing events for a total of 70 days, concluded that further work was needed to determine if the technology could be successfully applied in pelagic longline fishing (McElderry et al., 2008). The report concluded: *In comparison with demersal longline fishing, pelagic longline branch lines are long and catch items are comparatively few and vary considerably in size. Whereas demersal catch simply comes out of the water and over the rail, landing pelagic catch can be more involved, manoeuvring the catch alongside and through the sea door. Certain catch/species may not be brought aboard at all, either released with hook and branch line attached or brought alongside and cleared of as much of the terminal gear as possible. Successful capture of this style of fishing is more demanding as cameras need to monitor the hauling station, the area where catch is boarded, and a fairly large (5–6 m) area around the sea door where catch is manoeuvred.* This study provided the basis for further work on pelagic longline fisheries.

WPFMC contracted with Archipelago to continue testing EM technology on Hawaii's pelagic longline fisheries. The primary goal of the study was to evaluate the feasibility of using video monitoring in the Hawaii longline fleet, which could be used to augment observer programs, increase the accuracy of data collected by observers and fishers, and replace some observers.

Additionally, the data collected from EM technology was compared to the traditional human method of collecting data on fishing activities. The evaluation was based on the following questions:

- Can electronic monitoring image data provide images of sufficient resolution and clarity to allow an EM image reviewer to accurately record the number of hooks and counts of target and non-target species?

- Can electronic monitoring image data provide images of sufficient resolution and clarity to allow an EM image reviewer to identify interactions with various species of sea turtles, marine mammals, and seabirds as well as detect hooking location and release condition?

- Are results from video monitoring similar to those obtained from on-board observers?

2. MATERIALS AND METHODS

2.1 EM TRIALS ON FISHING VESSELS

EM Equipment

The EM system used for this project was custom manufactured by Archipelago. A basic EM system, shown schematically in Figure 1, consists of up to four closed circuit television cameras, a GPS receiver, a hydraulic pressure sensor, winch sensor, and a system control box. Two of the EM systems used for this study also included a satellite modem for ship to shore communication. Technical specifications for the EM system are provided in Figure 2.

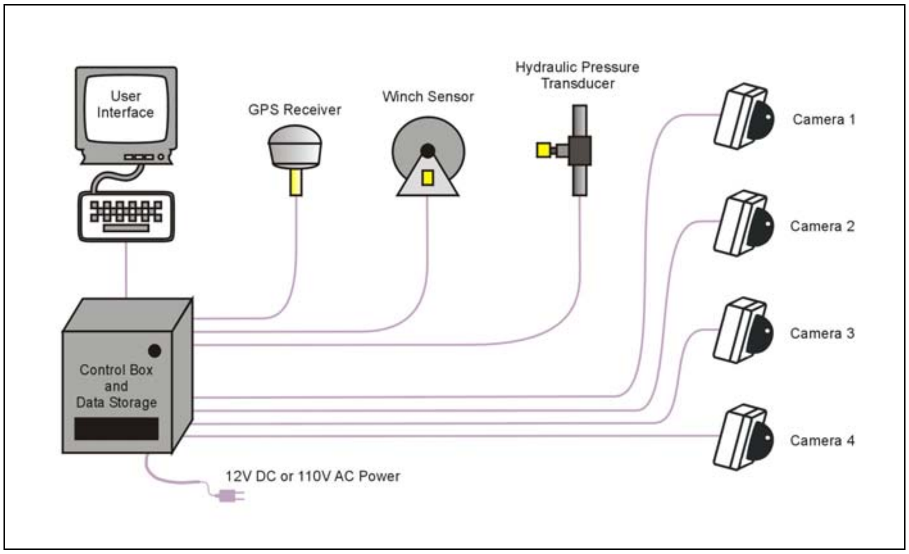

Figure 1. Schematic of standard EM system.

The EM system control software can be set in a variety of ways for data recording. For the purposes of this study, the system was to be powered continuously to record sensor data (e.g. location, time, speed, hydraulic and winch activity, system events, etc.) at a 10-second frequency. Image data recording was set to record when hydraulic pressure or winch rotations exceeded a preset threshold and continued to record for 10 minutes after sensor activity dropped below the threshold. All data were recorded onto a 500GB hard drive which was estimated to last four to five weeks of normal pelagic longline operations. The satellite modem was used to transmit an hourly synoptic report consisting of vessel speed and location, sensor activity, video triggers and EM system performance data. Equipping EM systems with satellite communications systems was relatively new technology and its use was thought to improve real time monitoring for these remotely located systems, aid in troubleshooting technical problems and assist with technology development.

Control Box

Dimensions	8” x 8” x 13” (20 x 20 x 31 cm)
Weight	11 lbs, 5.2 kg
Chassis/Container	Welded Aluminum (splash-proof)
Video Storage	Removable hard disk up to 500 Gigabytes
Recording Time	Configuration dependent, up to 1000 hrs
Recording Channels	4
Video Resolution	VGA (640-480 pixels)
Video Compression	Windows or DivX
Frame Rate (fps)	Up to 30 total
Operating System	Microsoft Windows XP Embedded on Solid State Disk
Operating Software	Autonomous at-sea execution, user configurable recording operations according to sensor input events

Power Specifications

DC Power	12 to 16 VDC
AC Power (adaptor)	90 to 240 VAC
Operating Current	6 Amps
Protection	20 Amp fuse, Battery deep discharge prevention
Protection	Low current (20 mA) Sleep Mode

Available Sensors and Options

GPS, Radio Frequency ID Tag, pressure, rotation, acoustic receiver, contact closure, power supply monitor, Iridium satellite modem (ship to shore).

Standard Camera

Housing	Powder coated cast aluminum, sealed to IP66
Power	12 VDC
Resolution	480 TV lines, analog NTSC signal
Lenses	2.9 (fisheye) to 16 mm (telephoto)
Light rating	1 – Lux
Aiming	Fixed aim, internally adjustable for Pan, Tilt, Rotation.

Figure 2. Technical Specifications of an EM system.

Field Operations

Project planning began in December 2008 with a telephone conference call between WPFMC, Hawaii Longline Association (HLA) and Archipelago representatives. The meeting covered project timelines, vessel requirements, project communications, available resources and observer coverage levels.

The WPFMC and HLA were responsible for selecting participants and scheduling installations from a pool of vessels volunteered by their owners. WPFMC was also responsible for identifying a local partner who could be trained to carry out regular servicing of EM systems during the study. The firm chosen was Commercial Marine Electronics of Hawaii (CME), a Honolulu based firm that has a lot of expertise working with electronics systems on pelagic longline vessels.

During the second week of January 2009 a senior technician from Archipelago and two representatives from CME met in Honolulu to begin EM system installations and service training. EM systems were installed on two shallow-set and one deep-set vessel, hereafter referred to as S1, S2, and D1. Installation was planned for a fourth vessel (D2) but this did not occur as the vessel was unavailable during the dates allocated to the installation effort. Participating vessels either targeted swordfish, S1 and S2, or tuna, D1, and all three used the port of Honolulu as their base of operations. All vessels ranged in length from 70 to 80 feet (Figure 3) and were designed for making extended fishing trips of three to five weeks.

Figure 3. Two project participants in Honolulu, Shallow-set vessel (left) and Deep-set vessel (right).

Each installation began with a discussion between the install team and the vessel's captain regarding EM system component placement, wire routing, fishing deck operations and the vessel's power supply. The EM system configuration and use of components was similar on all vessels; however, D1 was outfitted with four cameras while three were used on the other vessels. The GPS receiver and satellite modem were fixed to existing standing structures on the cabin roof, the hydraulic pressure sensor was installed on a high pressure manifold near hydraulic pumps in the engine room and the drum rotation sensor was applied to the longline drum (Figure 4). The control box, monitor and keyboard were secured in the vessel cabin (Figure 5). Power to EM systems was supplied by each vessel's AC generator. Upon completion of the installation, the EM system was powered up to test all sensors and cameras and the skipper was given an overview of EM system basic operation and taken through the user interface.

Figure 4. Examples of sensor installations on the project vessels: hydraulic pressure sensor (top left), drum rotation sensor (top right), GPS receiver (bottom left) and satellite modem (bottom right).

Figure 5. Example of monitor, keyboard, and EM control box installation in vessel wheelhouse

Cameras were installed on each vessel with the objective of capturing image data of catch, catch handling, gear handling and catch disposition. A deployable outboard camera mount was fabricated and attached to the cabin top roof. Two cameras were fixed to this mount on the shallow-set vessels, one with a close-up view of the waterside of the sea door and the other with a wide-angle view of the activity along both sides of the rail (Figures 6, 7). On the deep-set vessel, only the camera with a view of the waterside of the sea door was fixed to the fabricated mount while two cameras providing views of gear handling and rail activity were fixed to an already existing deployable outboard support for flood lights (Figure 8). A third camera on each shallow-set vessel and a fourth camera on the deep-set vessel were aimed at the deck inside the sea door where retained catch was brought aboard and dressed.

EM systems were serviced by CME staff for the duration of the data collection period (January to July 2009). They were responsible for retrieving data from participating vessels after every fishing trip, delivering data to Archipelago and WPFMC staff, performing operational checks, replenishing media and configuring the EM system for the vessel's next trip. As well, under the direction of Archipelago, CME staff made adjustments to camera angles based on imagery collected during fishing activity, updated software as part of the satellite modem beta test and removed and shipped EM systems once the field effort was completed. After each data retrieval, CME staff emailed sensor data directly to Archipelago and delivered the imagery data to WPFMC in Honolulu where it was checked and packaged for shipping to Archipelago's head office in Victoria, BC. All data collected during the project were treated as confidential and handled in the same protected status as observer or logbook data.

As one of the objectives of the project was to compare EM and observer methodologies, all fishing trips with EM systems aboard were targeted for at-sea observer coverage. The duties of the observers were the same as they would be if they were on vessels without EM systems.

Figure 6. A. Camera installations on the shallow-set vessel S1, two on the fabricated outboard mount, one giving a close-up view of the waterside of the sea door and the other giving a wide angle view of both sides of the rail (left). A third camera is mounted on a rail support and covers the deck inside the sea door (right). B. Example images from the corresponding camera views.

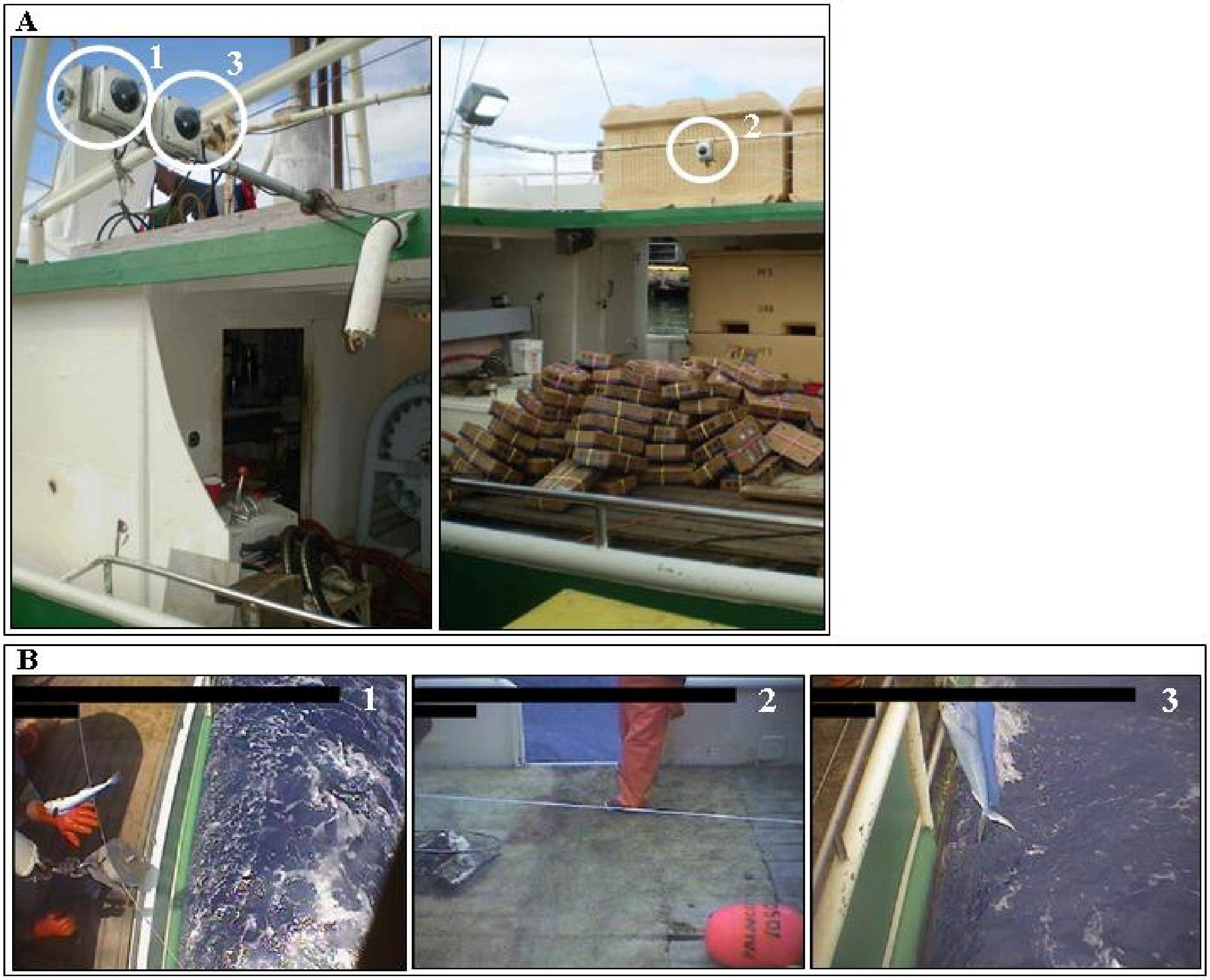

Figure 7. A. Camera installations on the shallow-set vessel S2, two on the fabricated outboard mount, one giving a close-up view of the waterside of the sea door and the other giving a wide angle view of both sides of the rail (left). A third camera is mounted on a rail support and covers the deck inside the sea door (right). B. Example images from the corresponding camera views.

Figure 8. A. Camera installations on the deep-set vessel (D1), one on the fabricated outboard mount giving a close-up view of the waterside of the sea door and two on an existing light support covering both sides of the rail and gear handling (left). A fourth camera is on a mast support covering the deck inside the sea door (right). B. Example images from the corresponding camera views.

2.2 EM DATA INTERPRETATION

EM data were delivered to Archipelago staff in Victoria, BC from Hawaii in batches and were processed as quickly as possible using staff designated for this project. Data interpretation protocols were designed and communicated to the data analysts before any of the data processing began. The protocols were based on the project objectives and experience with similar studies carried out in the past.

EM data interpretation began with an overall inventory of the data set and an assessment of its quality. Through this process a determination was made of missing data and whether the EM system and sensors performed properly. Once this was completed, the sensor data set was interpreted to determine details of the fishing trip such as trip start and end, and the location and time for all fishing events. This fishing activity information was then used by the image data viewer who could then directly access fishing events of interest. Complete image data were reviewed using one of two methods: a detailed assessment of all catch items or an assessment of only protected species interactions. The latter method was much less time consuming than a full catch assessment.

Observer data were supplied to Archipelago after all EM image interpretation work had been completed. This was primarily to ensure independence between the two data sets.

EM Data Inventory

Sensor data (GPS, hydraulic pressure winch rotation, etc.) were first imported to an MS SQL database and analysed to determine the completeness of each data set. As the sensor data are recorded on a 10-second frequency, time breaks in the data record are easily identified as time intervals of greater than 10 seconds between adjacent records. As well, the EM system log reports all instances of power interruption or system reboot. Time breaks were recorded in terms of the number of breaks and the total time missing.

An evaluation of the performance of EM system sensors and cameras was also carried out. The signals from the GPS, electronic pressure transducer and winch sensor were evaluated for completeness throughout each trip while the signal from each camera was evaluated for each haul. The ratings used were defined as follows:

- Complete - The sensor or camera provided data as expected.
- Incomplete - The sensor or camera experienced intermittent failures where it did not report a signal when expected.
- No data - The sensor or camera did not operate during the trip or set.

Image data were further assessed for quality as an average of all cameras for each haul event viewed, according to the rank scale defined as follows:

- High - The imagery was very clear and the viewer had a good view of fishing activities. Focus was sharp, light levels were high and activity was easily seen.

- Medium - The view was acceptable, but there may have been difficulty assessing certain activities (e.g., discards). Focus slightly blurred or dark imagery but image analysis still possible.

- Low - The imagery was difficult to work with because some camera views were not available, blurry imagery, or poor lighting.

- Unusable - Imagery was poorly resolved or obstructed such that interpretations could not be reliably made.

Fishing Activity Interpretation

All of the sensor data collected during the project was interpreted to distinguish key vessel activities including transit, gear setting, and gear retrieval. This was achieved through presentation of EM sensor data in time series and spatial plots, which are illustrated in Figure 9. Vessel speed, hydraulic pressure and winch rotations often correlate uniquely to various activities such as transit, setting and hauling. The spatial plot provided a geographic perspective on the various activities in relation to one another. When displayed in this manner, the data analyst reviewed the trip, interpreted vessel activity and made annotations in the sensor record for haul and setting events.

Catch Interpretation

Image data were interpreted using a custom software product that provided synchronised playback of all camera imagery and a data entry form for recording catch observations in a sequential manner. This application outputted catch data in XML files that were then loaded into a relational database for catch comparison analysis. Image playback speeds during interpretation varied from about 1.5 to 4 times real time according to monitoring objective, catch density and image quality.

Image data were recorded for both gear setting and hauling activity events all hauling activity image data were examined. A random sample of about 100 haul events was selected for a detailed assessment of all catch items, including protected species and fish. The sample was stratified by fishing method with 75% from shallow-set and 25% from deep-set fishing events. For these events, the EM image reviewer counted and identified target and non-target catch to the highest taxonomical grouping possible, kept track of catch disposition, counted blank hooks (i.e. hooks with no catch) and counted floats. Possible EM catch disposition data included: retained, released and drop-off (catch that fell off the gear before the fisherman had control over it). The balance of hauling events was examined for protected species interactions, without counts of hooks, floats or catch other than protected species.

EM image reviewers had extensive experience with the identification of Northeast Pacific fish fauna but no experience identifying fish species from the central Pacific or previous knowledge of the catch diversity in the Hawaii longline fishery involved in this study. Chapman et al., 2006 was the primary reference material used to aid in the identification of fish catch items.

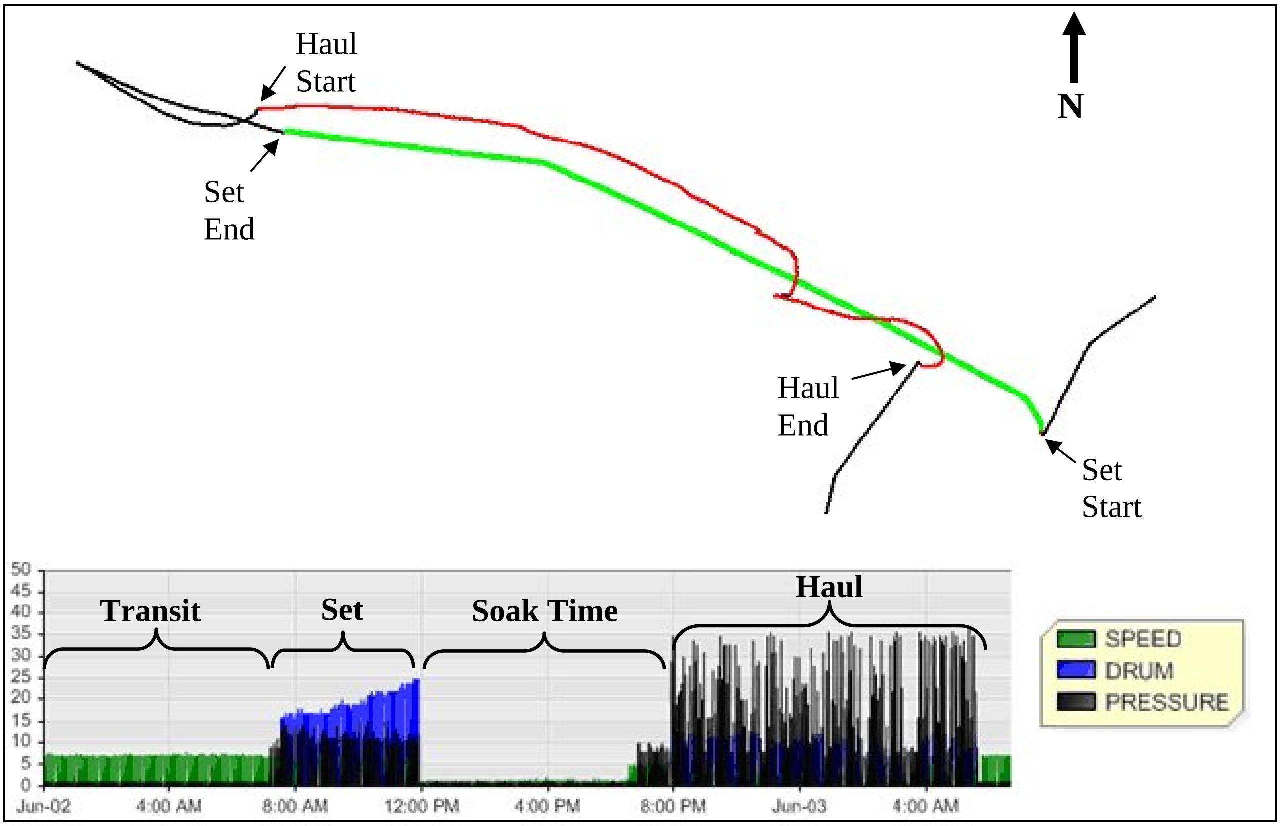

Figure 9. Example of sensor data from one of the project vessels showing sensor data representation for a set and its associated haul. The time series graphs (lower) show vessel speed (knots), hydraulic pressure (psi), and winch rotation (average counts per minute). Setting activity is associated to high drum rotation counts, low hydraulic pressure, and constant speed. Hauling is associated with high hydraulic pressure, and relatively low winch counts and speed. The spatial plot (upper) shows the vessel's cruise track for the same period, with setting highlighted in green and hauling in red.

Data Analysis

Data checks were in place throughout the data interpretation steps and mainly involved the use of validation rules with minimal ad-hoc double-checking of some data. The data analysis took place as EM and observer data became available for each trip, the bulk of it occurring after the field data collection phase was complete. After comparing observer and EM data, a second review of selected portions of the imagery was done by a second EM image reviewer only to gain further insight on possible reasons surrounding specific catch discrepancies between observer and EM data. Data from these secondary reviews helped guide the discussion for this report and was not used to modify the EM catch data set.

The data outputs from all sources (sensor, image and observer data) were available in a relational databases allowing all the data analysis to be carried out using an MS Access database. The data tracking and management were also done using an MS Access application.

As one of the main goals of the study was to compare EM and observer estimates of catch species, it was important to appropriately match the two data sets. Fishing event matching was done using the set start and haul end date and time as determined by each data source. Pairing each catch item between the two data sets required an additional alignment process since the observer and EM data sets almost never matched up catch-by-catch due to the fact that a single catch item missed on either data set compared to the other throws the rest of the alignment off. Without alignments, the two data sets almost never matched up, resulting in very few true-paired observer-EM observations. Alignment was forced by copying each data set into the same spreadsheet where row adjustments could be made on each data sets to account for catch items missing in one data set as compared to the other. Alignment was not an arbitrary process and no catch records were added, deleted or modified. Invertebrate, algae, and debris caught were ignored for this analysis.

3. RESULTS

2.1 EM TRIALS ON FISHING VESSELS

EM System Deployments and Data Capture

An inventory of EM data collected during the pilot study is presented in Table 1. The data collection period spanned six-months involving three vessels, each completing between three and six fishing trips for a combined total of 320 days at sea with observer data available for all trips. EM systems collected a total of over 7,600 hours of sensor data at sea and over 3,000 hours of imagery associated with 182 fishing events.

The three vessels had very high levels of sensor data completeness with most trips having over 99% and an overall average of 99.2%, indicating that the data set was virtually complete for the entire study period. Gaps in the sensor data record were caused by the system not operating for a portion of the trip, most likely due to the system not being powered before leaving port, manual power down of the system or brief generator shut down during the trip. Among the three vessels there were a total of 68 time gaps, half of which were less than 30 minutes in duration and the balance ranging from 1 to 11 hours.

Table 1. Inventory of fishing trips monitored by EM for the three participating vessels.

Vessel ID	Trip Number	Trip Start Date	Trip length (days)	Sensor Data Collected (hours)	Sensor Data Completeness (%)	Image Data Collected (hours)	Fishing Events Captured
S1	1	21-Mar-09	28.6	683.6	99.4%	442.5	19
	2	24-Apr-09	33.3	763.0	95.5%	356.9	26
	3	03-May-09	26.6	637.5	100.0%	233.6	14
	Vessel Totals		**88.5**	**2,084.1**	**98.1%**	**1,033.0**	**59**
S2	1	25-Jan-09	35.7	856.1	100.0%	224.7	14
	2	08-Mar-09	25.0	584.0	97.4%	246.5	18
	3	18-Apr-09	30.5	732.5	100.0%	225.5	15
	4	30-May-09	13.1	315.5	100.0%	88.1	5
	Vessel Totals		**104.3**	**2,488.1**	**99.4%**	**784.8**	**52**
D1	1	17-Jan-09	19.6	469.7	100.0%	234.9	14
	2	14-Feb-09	24.9	598.4	100.0%	224.24 *	14 *
	3	14-Mar-09	19.7	471.0	99.5%	186.1	11
	4	08-Apr-09	23.0	550.4	99.9%	203.6	12
	5	05-May-09	17.5	419.5	100.0%	87.6	6
	6	27-May-09	25.9	622.1	100.0%	248.5	14
	Vessel Totals		**130.6**	**3,131.2**	**99.9%**	**1,185.0**	**71**
Overall Totals	**13**		**323.4**	**7,703.4**	**99.2%**	**3,002.8**	**182**

** Although image data was captured for this trip, it was lost post-retrieval.*

As image recording was triggered just during setting and hauling events, the total number of hours of image data was about 40% of the sensor data. Image data from the second trip on vessel D1 was lost due to physical damage to the hard drive beyond repair during shipping to Victoria.

Because of this, no image data interpretation was possible and this trip is not included in the catch analysis.

Sensor performance was high across all vessels with image data recording having always been properly triggered and fishing activity was distinguishable from sensor signature at all times (Table 2). The only sensor problem occurred with the winch rotation sensor on the last trip of vessel D1. This failure did not affect image recording as hydraulic pressure continued to trigger image recording.

Table 2. Summary of sensor performance for all trips throughout the pilot study.

Sensor Performance	GPS Receiver	Hydraulic Pressure Transducer	Winch Rotation Sensor
Complete	13	13	12
Incomplete	0	0	1
No Data	0	0	0
Total number of trips	**13**	**13**	**13**

The two vessels equipped with satellite modems and configured to provide hourly reports of system health status. Both vessels generated hourly report packets for the entire time the EM systems were operating. Transmission of these reports occurred with varying success. The level of successful transmissions for S1 ranged from 41% to 51% per trip with a gradual increase over the course of the study. The first trip for vessel D1transmitted only 6% of the reports successfully and all remaining had 95% or higher rates of successful transmissions. The failed transmissions were related to a software issue in how the EM control box interacted with the satellite modem.

Details on the hauling events for the thirteen observed trips are shown in Table 3, showing the total number of hauls recorded by the observer for each trip and the EM capture success for them. Hauls were considered to be complete when EM data (sensor and imagery) were available for review for the entire haul, incomplete when any portion of the haul was not available for review, and missed when observer data showed that a haul occurred during a gap in the EM data record.

Observer and EM data records aligned to show the same number of hauling events by vessel per trip with an overall total of 168 fishing events (excluding the data from the damaged drive from the second trip of vessel D2). There were 159 (95%) fishing events fully captured which could be used to compare with observer data. The right two columns show that about 65% of the fishing events were analyzed for a full catch assessment while the remainder were examined only for protected species captures. Among the nine unusable fishing events three were incomplete due to EM system power interruptions during the hauling event where 56% of the fishing event imagery was recorded. Image data for the remaining six missed fishing events occurred with the second trip of vessel S1 where about 50 hours of haul time was lost because the hard drive became too full. As image files are written to the hard drive as large (~2GB) files, when the drive became too full for image files, there was still sufficient capacity for the much smaller sensor data files. Hence, for this vessel sensor data collection was complete while image data were incomplete.

Table 3. Summary of trips and hauls by vessel, an assessment of imagery completeness for haul events, and a breakdown of image analysis method for hauls with complete image data.

Vessel ID	Trips	Hauls	Image Data Complete	Image Data Incomplete	No Image Data Captured	Full Catch Assessment	Protected Species Only
S1	3	59	52	1	6	37	15
S2	4	52	51	1	0	38	13
Shallow-Set Totals	**7**	**111**	**103**	**2**	**6**	**75**	**28**
D1	6	57	56	1	0	26	30
Overall Totals	**13**	**168**	**159**	**3**	**6**	**101**	**58**

Among the 159 fishing events that were used for image analysis the performance of individual cameras was assessed separately (Table 4). There were 32 instances when imagery was intermittent from one of the cameras during a hauling event and 36 instances no imagery was recorded from one of the cameras. Intermittent camera failure was caused by loose wiring connections, which affected all vessels and about half of the trips. The problem was identified by image analysis staff, but CME technicians had difficulty troubleshooting because of its intermittent nature. Although loss of imagery from certain cameras increased the difficulty of assessing catch, the multiple camera views often provided enough coverage to interpret hauling events. For example, the sea door camera provided a view of the water adjacent to the vessel, and was intended for identifying catch items breaking the surface and determining catch utilization. On vessel D1, a wide-angle camera (Figure 8, #1) also showed the sea door but at a lower resolution.

Table 4. Summary of performance by camera for haul events considered as complete. Camera numbers correspond with designations in Figures 6, 7 and 8.

Vessel	Camera	Complete	Incomplete	No Video	Total Hauls
S1	1	28	0	24	52
	2	52	0	0	52
	3	50	2	0	52
S2	1	51	0	0	51
	2	50	0	1	51
	3	48	0	3	51
D1	1	55	1	0	56
	2	44	9	3	56
	3	43	11	2	56
	4	44	9	3	56

Image quality ratings for all hauls reviewed are shown in Table 5. Image quality was rated as high for 90% of the hauls reviewed and the rest were rated as medium. No hauls were rated as low or unusable. The main issue surrounding medium-rated hauls was from a dirty camera lens (Figure 10). Although all of the hauls for vessel D1 were carried out at night, lighting was adequate for image interpretation.

Table 5. Summary of EM imagery data quality assessments.

Vessel	High	Medium	Low	Unusable	Total Hauls Reviewed
S1	51	1	0	0	**52**
S2	51	0	0	0	**51**
D1	41	15	0	0	**56**
Total Hauls	**143**	**16**	**0**	**0**	**159**

Figure 10. Example image quality assessments: high (top row) and medium (bottom row).

3.2 EM DATA INTERPRETATION AND ANALYSIS

Fishing Activity Interpretation

Distinguishing fishing activity through sensor data interpretation was easily achieved for all vessels, although the multiple longline drums for vessel S1 (one with a sensor, one without) created some difficulty identifying set start and needed to be verified with imagery. Results from EM sensor data interpretation were compared with set and haul information recorded by observers and the differences are shown in Table 6. On average, observer set start data were 0.1 minutes ahead of the EM set starts while observer haul start data were 30 minutes ahead of EM.

The use of two drums by vessel S2 caused confusion in identifying haul starts for some sets. Among the set and haul start times, most (93% and 84%, respectively) were within 10 minutes. Similarly, among the set and haul locations, most (70%, and 68%) were within 0.5km. Large differences over an hour and more 10 kilometres are most likely data entry errors by observer or EM sources.

Table 6. Absolute differences between EM and Observer set and haul starting times and locations.

Difference	Set Start	Haul Start
Time (min):		
0-10	157	134
10-60	9	11
60-120	2	3
> 120		11
Total	**168**	**159**
Distance (km):		
0-0.5	118	109
0.5-1	12	8
1-10	33	20
10-100	5	20
> 100	0	2
Total	**168**	**159**

For all fishing events recorded, the daily fishing pattern was consistent with only one string of gear soaking at any one point in time. Shallow-set vessels always began setting in the evening and hauled their gear in the mid morning while the deep-set vessel began setting mid-day and began hauling in the evening. Average set, haul, and soak times varied between vessels (Table 7).

Table 7. Average duration of sets, hauls, and soak times per vessel as detected by EM. Soak time was defined as the time between the end of the set and the beginning of the haul.

Vessel ID	Average Set Duration (hours)	Average Haul Duration (hours)	Average Soak Duration (hours)
S1	6.7	8.8	4.1
S2	5.0	7.0	6.8
D1	4.4	10.0	7.1

A total of 116,739 hooks (hooks empty and with catch) were recorded in the observer data versus 117,587 reported by EM image reviewers for a total difference of -0.7%. It is evident from

Figure 11 that for most fishing events, EM and observer hook counts closely agreed. The deep-set vessel averaged about 2,300 hooks per fishing event while shallow-set vessels averaged about 1,000 hooks. Most of the outliers are associated to vessel S1 and there were two factors that likely explain the differences observed. Firstly, it was difficult for EM image reviewers to count hooks for this vessel as the hauling station camera view did not provide a clear view of the clips being removed and counts relied mostly on crew behaviour around handling the leaders. Secondly, for one trip the observer seemed to have estimated total hooks using an average of three hooks per float rather than making an actual hook count.

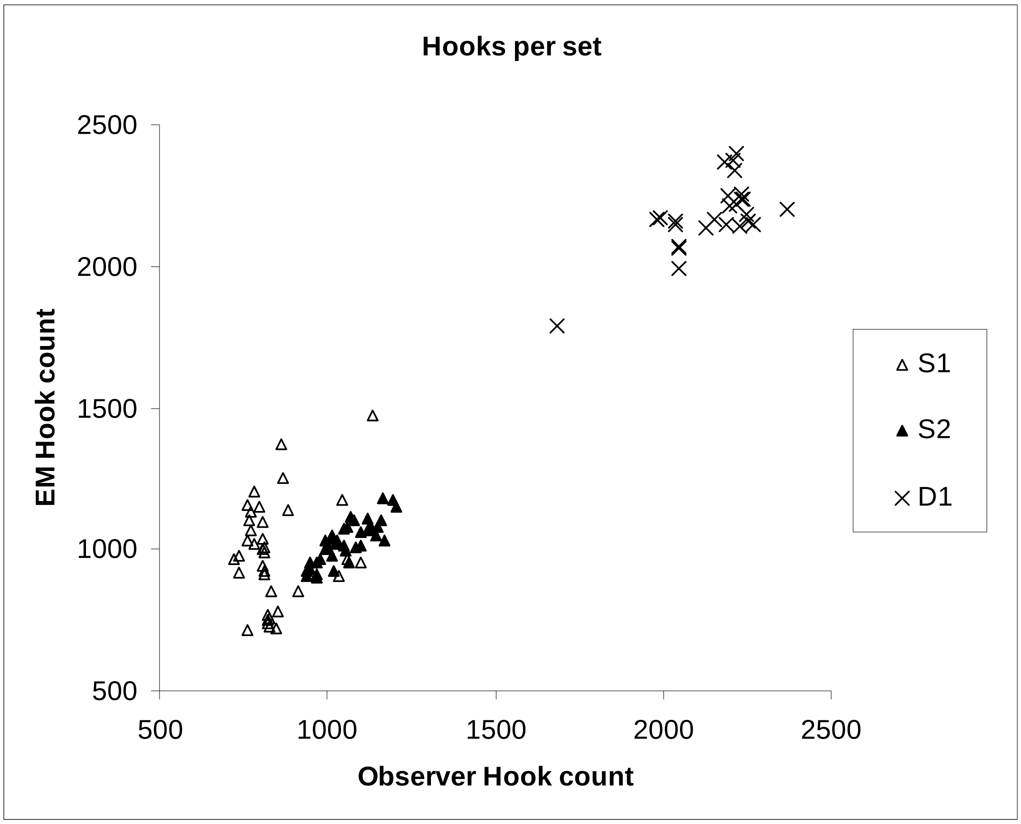

Figure 11. Scatter plot of total hook counts by observer and EM methods per haul.

Comparison of EM and Observer Protected Species Interactions

Among the 159 hauling events examined and compared with observer data there were very few incidents of protected species (Table 8, Figure 12). There were three instances of leatherback turtle captures, all of which occurred with a single shallow-set vessel. EM and observer data sets both recorded these leatherback turtle captures and both were recorded as released injured. One of the turtles was entangled in the main line and the two others were hooked (Figure 12A). The extent of injury to the sea turtles was hard to directly assess using EM although all three turtles appeared vigorous and swam away once released and no bleeding was observed.

Among seabirds, there were three capture events recorded, one detected by both EM and the observer and two seen by one but not the other. A black footed albatross was detected by both and recorded as dead (Figure 12B). One injured black footed albatross was reported by the observer and not detected in the EM image data set. Imagery was examined a second time after noting the observer record and the encounter was still not evident and we concluded that the capture event either occurred outside the camera view or at a different time. In a second incident, on the same vessel but different set, EM image reviewers detected a Laysan's albatross (Figure 12C). There was no record in the observer catch record for this incident.

Table 8. Summary of protected species interactions by species and condition as determined by Observer and EM methods.

Protected Species	Condition	Observer Recorded	EM Recorded
Leatherback Turtle	Injured	3	3
Blackfooted Albatross	Dead	1	1
Blackfooted Albatross	Injured	1	0
Unidentified bird	Dead	0	1

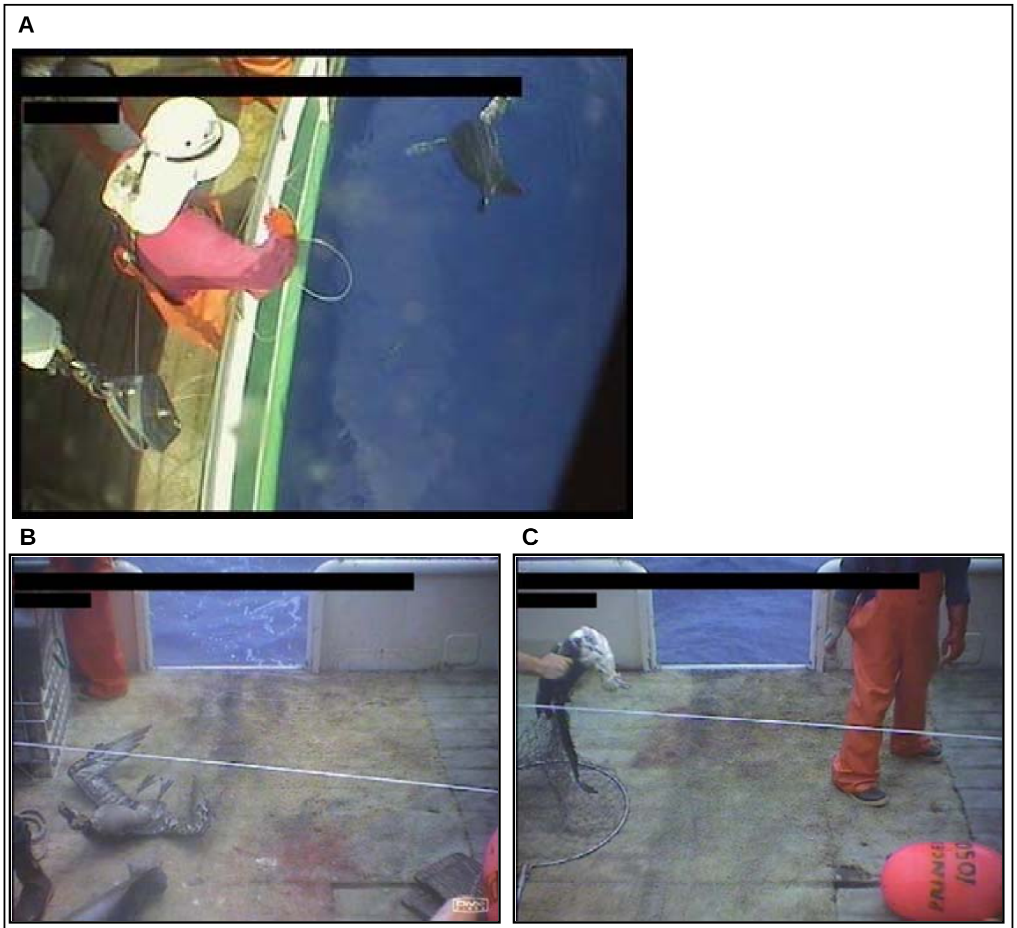

Figure 12. Protected species interactions captured by EM. A. Leatherback turtle. B. Blackfooted albatross. C. Laysan's albatross.

Comparison of EM and Observer Full Catch Observations

Observer catch data consisted of a total of 36 catch categories including 30 species, 2 genera, a tribe, and 3 families. EM data categorized catch in 33 categories including 25 species, 4 genera, a tribe, 3 families and an unknown fish category. The slightly lower number of categories and greater use of more general categories correspond to a lower ability to identify catch as compared with observers. Table 9 presents two indices of abundance for the three vessels combined based on observer data: percent occurrence reflects the percentage of analyzed hauls where the species was detected in the observer data and the average pieces per haul illustrate how many pieces on average are found in the hauls where the species were detected.

Table 9. Percent occurrence and average pieces per set present by species and species group.

Species and Species Groups by Common Name	Percent Occurrence	Average Pieces Per Set
Swordfish, Broadbill	82.2	9.0
Marlin, Striped	41.6	1.6
Marlin, Blue	14.9	1.3
Spearfish, Shortbill	8.9	1.4
Billfish, Unidentified	1.0	1.0
Sailfish	1.0	1.0
Marlin, Black	0.0	0.0
Billfishes Total	**92.1**	**9.2**
Tuna, Bigeye	38.6	4.1
Tuna, Skipjack	16.8	2.8
Tuna, Yellowfin	14.9	1.3
Tuna, Albacore	6.9	3.9
Tuna, Unidentified	1.0	2.0
Tunas Total	**48.5**	**5.3**
Shark, Blue	93.1	3.7
Shark, Bigeye Thresher	18.8	3.4
All other sharks	30.7	1.7
Sharks Total	**96.0**	**4.8**
Lancetfish, Longnose	74.3	5.0
All Escolars	69.3	3.5
All Dolphinfish	64.4	3.7
All Pomfrets	20.8	10.9
Snake Mackerel	36.6	2.5
Other Species Total	35.6	2.3
Unidentified Fish	0.0	0.0
Others Total	**96.0**	**13.0**
Overall Total		**28.1**

The combined results bias toward the shallow set fishery where billfish were targeted. The most common species observed were blue shark, followed by swordfish, lancetfish, escolars and dolphinfish. In terms of catch for all fishing events, the overall average was 28 fish per set, with the top six catch species being pomfret, swordfish, longnose lancetfish, bigeye tuna, blue shark and dolphin fish.

An overall comparison between the observer and EM image reviewer catch data is presented in Table 10, for vessels S1, S2 and D1 combined. The Table shows EM and observer catch numbers by species (or species categories). Where catch numbers exceed 60 pieces, a percent difference was calculated. Only the most common fish species are listed in the table, and all others are shown as species group totals for general comparison purposes. Complete tables with all the species and their corresponding scientific names can be found in Appendix I.

While Table 10 provides catch for the three vessels combined, differences in catch patterns were observed between shallow and deep set vessels. The two shallow set vessels principally targeted billfish with broadbill swordfish being the most common, followed by striped marlin. Other significant catch species were blue shark, lancetfish, escolar and dolphinfish. The deep set vessel primarily caught bigeye and skipjack tuna. Catch diversity in general was higher than shallow set vessels with a significant proportion of the catch made up with species such as sharks, billfish, and other species including lancetfish, escolar, dolphinfish, pomfret and snake mackerel. Overall, about 60% of the total catch was retained, blue shark and longnose lancet fish were the most common species discarded.

Overall, EM image reviewers estimated less total catch than the observer estimate by about 16%. This trend was consistent across all three vessels, with the range -26.1 to +7.5%. This catch accounting difference was primarily with discarded species where EM image reviewers detected 40% less catch than observers (range -13.4 to -61.2%), while among retained catch the difference was -0.4% (range -0.2, and 3.3%). The total piece count difference was seven for all three vessels (range 1 to 12). These results indicate that EM was very reliable at accounting of retained catch but not for discarded catch.

On the basis of individual species identifications for retained catch there was high agreement between EM imagery reviewers and observers for broadbill swordfish and total billfishes, but identifications for species of marlin, sailfish and spearfish were inconsistent. Among tunas, EM and observer retained catch estimates were within 2% for bigeye tuna and 10% for all tunas, but counts by individual species varied. Among other species, the total count was within 2% but individual species identifications varied. Overall, species identification patterns were similar among the three vessels although variable results between vessels for some species including tunas and dolphinfish suggested vessel or viewer specific differences. The species identification results for retained catch indicated that EM identifications closely match observer identifications for conspicuous species but not for less distinctive species.

Among the discarded catch species for all three vessels, estimates by EM and observers were consistently quite different, with values greater than 40% for many species categories. The consistently poor level of agreement and underestimate by EM image reviewers suggests that a significant portion of the discarded catch was not evident in the imagery.

Table 10. Summary of total catch for all vessels by species and species group.

Species and Species Groups	Retained Catch				Discarded Catch				Total Catch			
	Observer Pieces	EM Pieces	Piece Difference	Percent Difference	Observer Pieces	EM Pieces	Piece Difference	Percent Difference	Observer Pieces	EM Pieces	Piece Difference	Percent Difference
Swordfish, Broadbill	660	663	3	0.5%	90	53	-37	-41.1%	750	716	-34	-4.5%
Marlin, Striped	65	23	-42	-64.6%	3	0	-3		68	23	-45	-66.2%
Marlin, Blue	19	50	31		0	0	0		19	50	31	
Spearfish, Shortbill	12	8	-4		1	0	-1		13	8	-5	
Billfish, Unidentified			0		1	1	0		1	1	0	
Sailfish	1		-1		0	0	0		1	0	-1	
Marlin, Black		11	11		0	0	0		0	11	11	
Billfishes Total	**757**	**755**	**-2**	**-0.3%**	**95**	**54**	**-41**	**-43.2%**	**852**	**809**	**-43**	**-5.0%**
Tuna, Bigeye	157	154	-3	-1.9%	4	6	2		161	160	-1	-0.6%
Tuna, Skipjack	45	14	-31		3	0	-3		48	14	-34	
Tuna, Yellowfin	20	13	-7		0	0	0		20	13	-7	
Tuna, Albacore	13	14	1		14	10	-4		27	24	-3	
Tuna, Unidentified		16	16		2	2	0		2	18	16	
Tunas Total	**235**	**211**	**-24**	**-10.2%**	**23**	**18**	**-5**		**258**	**229**	**-29**	**-11.2%**
Shark, Blue	3	2	-1		342	63	-279	-81.6%	345	65	-280	-81.2%
Shark, Bigeye Thresher		2	2		64	16	-48	-75.0%	64	18	-46	-71.9%
All other sharks	9	12	3		43	85	42		52	97	45	
Sharks Total	**12**	**16**	**4**		**449**	**164**	**-285**	**-63.5%**	**461**	**180**	**-281**	**-61.0%**
Lancetfish, Longnose	3	4	1		373	102	-271	-72.7%	376	106	-270	-71.8%
All Escolars	198	189	-9	-4.5%	46	24	-22		244	213	-31	-12.7%
All Dolphinfish	225	234	9	4.0%	17	6	-11		242	240	-2	-0.8%
All Pomfrets	216	205	-11	-5.1%	12	8	-4		228	213	-15	-6.6%
Snake Mackerel	5	5	0		87	281	194	223.0%	92	286	194	210.9%
Other Species Total	51	71	20		31	15	-16		82	86	4	4.9%
Unidentified Fish		5	5		0	13	13		0	18	18	
Others Total	**699**	**713**	14	**2.0%**	**566**	**449**	**-117**	**-20.7%**	**1264**	**1162**	**-102**	**-8.1%**
Overall Total	**1702**	**1695**	**-7**	**-0.4%**	**1133**	**685**	**-448**	**-39.5%**	**2835**	**2380**	**-455**	**-16.0%**

Scatter plots shown in Figure 13 provide a comparison of EM and observer catch totals on a fishing event level. Figure 13 A-B show total pieces per set for retained and discarded catch, again indicating that EM and observer retained catch estimates are very close but discard estimates vary with EM consistently underestimating the number of pieces discarded.

Piece count comparisons per haul between observer and EM for the most common retained species groups are shown in Figure 13 C-F. Species group comparisons for retained pieces at the haul level were similar as was evidenced in the overall catch comparison, with all species groups having less than one piece difference in average. In fact, billfishes, tunas, and dolphin fishes were within one piece in over 89% of the hauls where they occurred, and 76% for escolars. Although all the scatter plots show one or two outliers, these all correspond to different trips and vessels and do not exhibit any discernable pattern.

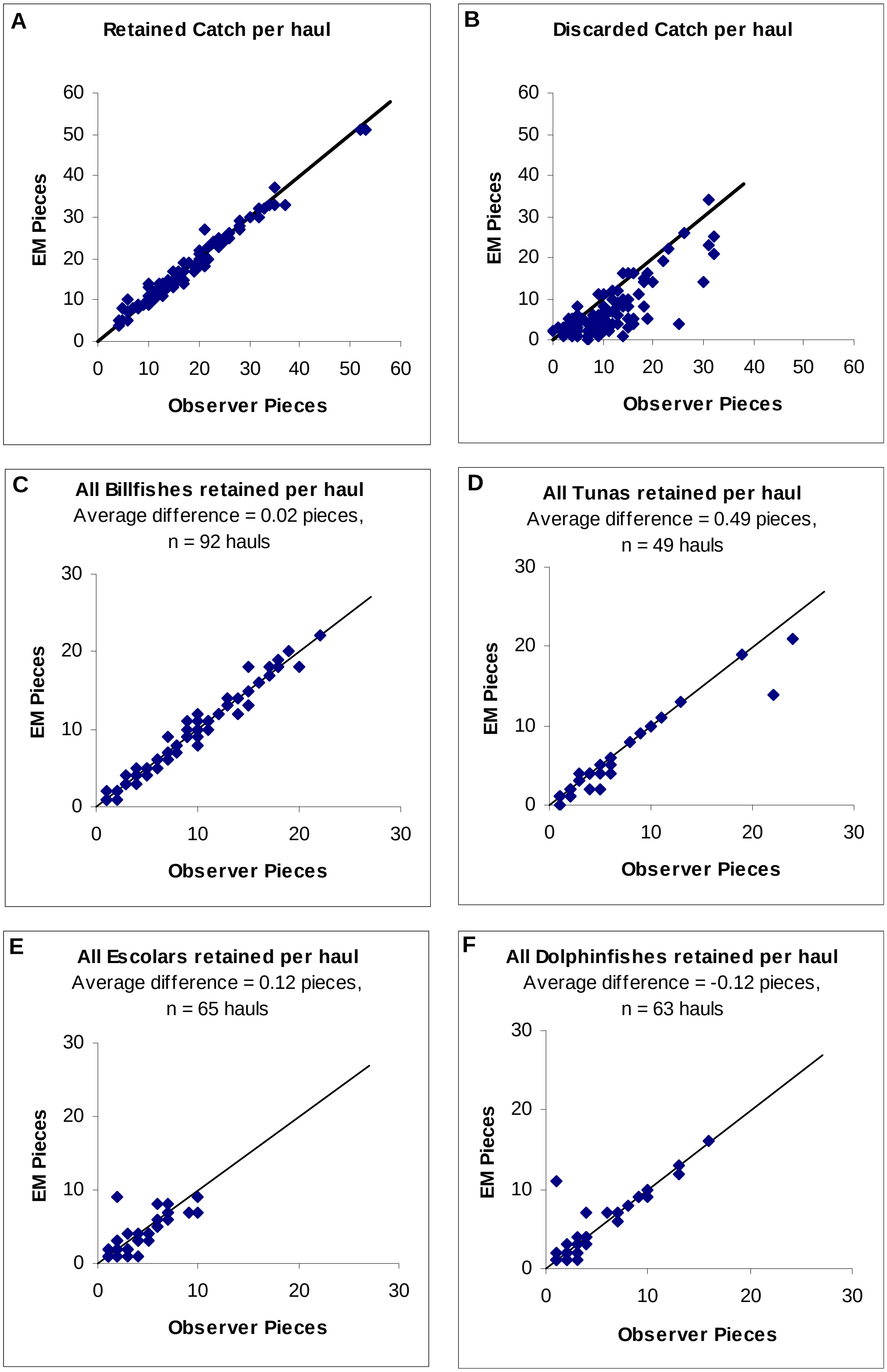

Figure 13. A-B. Scatter plots of observer versus EM retained and discarded catch per haul, respectively. C-F. Observer versus EM retained catch per haul for selected species.

The next level of comparison between EM and observer catch was at the level of individual catch event (hook level). Table 11 provides a summary of catch aligned by hook, with EM and observer identifications compared. The identification comparisons were categorized by outcome, with positive identification where both observer and EM identified the same, misidentified within group refers to the pairings where two catch items were identified differently but both were within the same group (e.g., billfish, tunas, sharks, etc.), misidentified outside of group refers to the pairings where two catch items were identified to different species groups, Obs+ EM- refers to comparisons where a catch item in the observer data could not be paired to a catch item in the EM data, and the opposite outcome is denoted by Obs- EM+. Percentages indicate the portion of matched pairs belonging to each identification success category (i.e. Obs+EM- and Obs-EM+ are excluded).

A total of over 3,000 catch items were examined for comparison of which nearly 30% could not be aligned (Obs+EM-, or Obs-EM+). The high proportion of misaligned is mostly due to the aforementioned underestimate of discarded catch by EM. Among the aligned catch items, 80% were identified correctly, 8% misidentified within a group and 12% misidentified outside the group.

Catch item identification results are shown for the most common species and species groupings in Table 12, taking the observer identification as the correct reference. Consistent with the other catch comparison results, catch item comparison results show that EM identified individual broadbill swordfish and bigeye tuna pieces the same as observers 99.7% and 95.8% of the time respectively. EM also identified dolphinfish, pomfret, escolar and fishes in the "other" category the same as observers in more than 84% of the time. Catch pairs for other tunas and other billfishes resulted in fewer positive identifications but these items were mostly misidentified within their species grouping with such misidentification accounting for 87% of the total other tunas misidentified pairs and 91% for other billfish. For tunas, the biggest source of misidentification was observer skipjack tuna items being called unidentified tuna by the EM image reviewer and for billfishes, observer identifications of stripped marlin were often recorded as blue marlin by the EM image reviewer. Misidentifications outside of species groupings are primarily represented by longnose lancetfish being consistently called snake mackerel by EM. This species alone accounted for 67% of the misidentifications outside species groupings.

Table 11. Summary of catch item comparison results.

Comparison	Number of Comparisons	Percent of Matches
Positive Identification	1,745	81.0%
Misidentified Within Group	162	7.5%
Misidentified Outside Group	248	11.5%
Obs+ EM-	680	
Obs- EM+	225	
Total	**3,060**	

Table 12. Summary of item-by-item catch comparison results.

Observer Identification	Positive ID Species	Misidentification Within Group	Misidentification Outside Group	Positive ID Percentage	Total Items Compared
Swordfish, Broadbill	687	0	2	99.7%	689
All Other Billfishes	36	49	4	40.4%	89
Tuna, Bigeye	138	0	6	95.8%	144
All Other Tunas	45	15	14	60.8%	74
All Dolphinfishes	205	3	1	98.1%	209
All Pomfrets	187	13	2	92.6%	202
All Escolars	162	0	29	84.8%	191
All Sharks	81	81	8	47.6%	170
Others	114	1	16	87.0%	131
Longnose Lancetfish	90	0	166	35.2%	256
Total	**1,745**	**162**	**248**	**81.0%**	**2,155**

4. DISCUSSION

4.1 TECHNICAL ASSESSMENT OF EM SYSTEM

EM systems were deployed on three vessels for a collective total of about 320 sea days, 13 fishing trips and 182 fishing events. Overall, the equipment performed well with very few technical problems. Over the total time these vessels were at sea, EM systems were operating and recording data for 99.2% of the time. The number of fishing events usable for comparison with observer data was 159, or 86% of total events, with data loss from several sources including a hard drive damaged in shipment (14 events), a hard drive becoming full at sea (6 events) and power interruptions during fishing operations resulting in incomplete retrieval imagery (3 events).

In our experience with EM pilot studies the rate of data capture success was exceptional given the voluntary participation by vessels, the opportunistic nature of equipment installations, the extended duration of the fishing trips and the use of an independent contractor for field service activities. With field operations based in Honolulu, Hawaii and EM data analysis in Victoria, British Columbia, small, easily correctable problems translated into larger data loss problems because of the time delay from data collection to problem detection and correction. Data loss caused by hard drive damage and a hard drive becoming full at sea is probably more characteristic of pilot studies over a fully functioning EM program as operational procedures were not well established. Data loss from power interruptions were small and should be considered as unavoidable for this type of fleet. The vessels appeared to have reliable power systems and vessel personnel cooperated very well in keeping the EM systems running continuously. Measures to further reduce power loss problems would include dedicated electrical circuits and UPS protection.

Hydraulic, winch and GPS sensors worked reliably during this study. The GPS and hydraulic sensor performed continuously for all trips on all vessels while the winch sensor failed on one trip. The latter sensor is particularly vulnerable to damage because of its exposed location on the working deck. These three sensors are the main tool for distinguishing fishing vessel activity and for triggering image recording during fishing operations. EM control boxes were configured to trigger image recording when either the winch or hydraulic sensors exceeded threshold values. This reduced dependencies on a single sensor but resulted in recording imagery during both setting and hauling, activities which are distinctive from one another but require both sensors in operation. With this configuration the likelihood of image data loss from a damaged sensor was low and the additional data storage cost for setting imagery was not a significant factor.

CCTV camera image recording was also successful in terms or overall completeness and image quality. Among the 159 fishing events, none were considered unusable for interpretation. There was however a persistent problem with intermittent image loss from two of three cameras on S1 and S2 and all four cameras on D1. This problem was caused by a faulty wiring connection and affected data sets from about half the trips. The persistence across so many trips was a function of both the time delay in detection during image analysis and the difficulty in troubleshooting because of the intermittent nature of this problem. Despite this problem, EM image reviewers felt they could still reliably interpret the imagery because fishing operations were monitored with multiple cameras. However, the loss of camera views would impair an EM image reviewer's ability to monitor fishing operations.

Overall, image quality was rated as high for 90% of the fishing events. There was no imagery scored as being low or unusable quality, nor was image quality affected by night time fishing operations of the deep set fishing vessel. The main issue with reduced image quality was associated with the accumulation of salt film on the camera dome. This issue could easily be addressed with periodic cleaning by vessel crew.

The satellite modems worked with moderate success, creating hourly transmission packets throughout the study, but with mixed transmission success. As the use of the technology is new the study provided the opportunity for field testing to identify and correct problems. When data packet transmission was successful the reports provided real time notification of EM system performance as well as vessel location and activity. This information was very useful in monitoring vessel operations from land, scheduling service activities for when vessels come to port, identifying EM system problems and planning repairs during service events. Given the low transmission cost (~$50/month) and quantity of information, this communications device provided very useful information to assist with the operational needs of the EM program. This technology could also be used to serve VMS needs in the fishery.

4.2 EFFICACY OF EM FOR CATCH ACCOUNTING

On the whole, EM systems worked very well and it is likely that similar performance could be expected from other vessels in the fleet. While the equipment operated well, key questions remain whether EM can be effectively used for the specific fishery monitoring objectives. The earlier posed questions outline the monitoring needs of EM:

- Can electronic monitoring image data provide images of sufficient resolution and clarity to allow an imagery viewer to accurately record the number of hooks and counts of target and non-target species?
- Can electronic monitoring image data provide images of sufficient resolution and clarity to allow an imagery viewer to identify interactions with various species of sea turtles, marine mammals, and seabirds as well as detect hooking location and release condition?
- Are results from video monitoring similar to those obtained from on-board observers?

The results from this study provided a sample of 159 fishing events from which to base a comparison between EM and observer catch data. The sample was predominantly from the shallow set component of the pelagic longline fishery but the conclusions are probably common to both shallow and deep set fleets. The basic study design to measure the accuracy of EM data used observer data as a benchmark. The assumption in this design was that observer data are currently the accepted standard in at-sea monitoring so the evaluation consisted of determining how well EM results would match observer data. However, a key problem with this approach is that observer data may also contain errors (Karp and McElderry, 1999). Observer error was not measured in this study and it should be kept in mind that the lack of agreement between observer and EM catch results can be partly attributed to observer error.

Before addressing the catch monitoring aspects is it instructive to compare fishing effort information recorded by EM and observers. A key strength of EM is the continuous data record from GPS, winch and hydraulic pressure sensors. The results provided very good temporal and spatial information on gear setting and hauling activities. Both the EM and observer estimate were very close: over 90% of set start times were within 10 minutes and nearly 80% were within one kilometre. In terms of hook counts, EM and observer estimates also closely agreed, although on one fishing trip (Figure 14, S1), the observer estimate was probably based on float counts rather than a hook count. These results suggest that EM imagery could reliably be used to monitor fishing effort provided that there is a clear camera view of the location where clips are removed from the main line.

In terms of the potential use of EM for catch monitoring, the answer is more complex. Catch, including discards, was examined for a total of 159 fishing events with the two shallow set vessels making up about 65% of the total fishing events examined. Catch from the three vessels combined included nearly 3,000 pieces and 36 catch categories: 30 species, 2 genera, a tribe, and 3 families. Included in the sample were three instances of turtle captures and three of seabirds. The catch results for EM were compared with observer estimates and presented in three ways: overall species (or species group) totals by vessel, fishing event totals by species (or species group), and on the basis of the individual catch event (hook by hook observations). The latter method did not work very well because the high percentage of discarded catch missed by EM made individual catch event alignment more difficult and subjective. None the less, the results from the different comparative approaches suggested similar conclusions.

On the whole, the level of agreement between EM and observer catch estimates was poor because of the large proportion of discarded catch that was missed by EM. Using observer catch estimates the total fraction of catch discarded was about 40% for all three vessels combined. The results showed that EM image reviewers missed about 40% of the total discarded catch reported by observers. The most logical reason for this result was that handling of discarded catch was occurring outside the field of camera view. In terms of retained catch, observer and EM total piece counts were very close, differing by 0.4% for all three vessels combined (range -2.4-3.3%). The higher level of agreement between Observers and EM is due to catch coming aboard in clear view of the cameras.

In terms of species identification, EM image reviewers distinguished fewer catch categories and used more general species groupings than observer records. Among the species categories distinguished, comparison with observer retained catch data suggest that misidentifications were common. EM image reviewers were able to identify common retained species including broadbill swordfish, bigeye tuna, escolar, dolphin fish and pomfret but had difficulty with species of marlin, tuna and some sharks. Misidentifications were generally with species in the same group. The EM species identification capability is likely the result of two factors. As mentioned earlier, EM image reviewing occurred in Canada and misidentifications are partly due to lack of experience with central Pacific fauna. The results were also due to the difficulty for EM image reviewers to resolve key identification features of catch in the imagery. Camera placements were intended to provide broad coverage of areas on and around the vessel where fishing operations occur. These wide angle views lacked the resolution to enable identification of catch, particularly small species.

Among protected species there were only a few incidents encountered in the study. Both EM image reviewers and observers detected the three captures of leatherback turtles. The large size of turtles and the crew activity handling the line and removing the hook would make this a very recognizable event in the EM imagery. The extent of injury for captured sea turtles could be difficult to assess from the imagery. In this study, hook removal and disentangling took place in the camera view, making it possible to determine hooking location. The level of activity during this procedure and upon release also provided an indication of release condition. Among the three seabird captures in this study, the results were mixed with one encounter reported by both EM and the observer, one reported by the observer but not EM, and one reported by EM but not the observer. The seabird takes reported by EM image reviewers were easily detected (See Figure 12) and it is unclear why one of these was missed by the observer. The seabird take reported by the observer as released injured and missed by EM is most likely due to the seabird being handled outside of camera view. Both these events occurred on the same trip but different fishing event raising also the possibility that the two events could be one.

4.3 CONCLUSIONS AND RECOMMENDATIONS

In comparison to the previous trial with EM on a pelagic longline fishery in New Zealand (McElderry et al. 2008), there were considerable improvements in this study. Camera positioning was much better, particularly with the area around the side of the vessel. The ability to synchronously view multiple camera images was a significant technology improvement, making it easier to monitor longline retrieval operations from several viewing points on the vessel. With these improvements, overall catch detection was much improved, as was detection of protected species. However, EM in this study failed to provide equivalent results to an at-sea observer with respect to estimates of discarded catch and with identification of species, except the most common distinctive species. We believe that both of these shortcomings could be addressed and further advancements are less dependent upon developing new technology but rely upon harmonizing crew activities with the technology to ensure that monitoring needs are adequately addressed. This would involve more specific placements of cameras and engaging vessel personnel to conduct their gear and catch handling activities in a fashion that would enable reliable detection by EM.

The main issue with catch detection by EM was with discarded species that were handled outside the camera view. This could be overcome by working with industry to develop more structured catch handling procedures. In this study, retained catch could be reliably detected as it is brought aboard at the sea door which was essentially a control point that was well monitored by cameras. In contrast, discarded catch was handled in a variety of ways with no single control point for identification and counting. We suggest a control point approach be taken with discarded catch, making sure that all items are brought to a single place (e.g., seaward of sea door) that is clearly in view of a camera. Industry input is needed to design this process that minimally impact fishing operations.

Improvements to species identification from EM imagery could be addressed in two ways. Firstly, species identifications would improve with image reviewing staff based in Hawaii experience in central Pacific fauna is more accessible. Secondly, improvements to camera configurations would benefit EM image reviewer ability to identify catch. We believe that many species in these fisheries could be identified correctly provided they are sufficiently large in the camera images. To address both catch detection and identification, a mix of both wide angle and close up camera views is needed. In an effort to limit data volumes in this study, two of the vessels had three cameras and one had four. In the future, all vessels should be equipped with four or more cameras in order to provide wide angle coverage of fishing operations and close up views at designated control points. A good example of this approach has been developed in the Alaskan trawl fishery were detailed accounting of halibut is required (Bonney and McGauley, 2008).

An obvious catch monitoring weakness of EM, and also observer programs, is that only catch items detected will be reported. With long branch lines in pelagic longline gear, vessel operators could escape by catch detection by unclipping and releasing the line before the item comes into view. The occurrence (or perception of occurrence) of undetected dropped clips will impede confidence in bycatch estimates and therefore monitoring needs to account for all gear deployed of whether it contains catch or not. During the hauling event, cameras must provide clear imagery of all gear handling, from clip removal to when the catch or empty hook comes aboard. Hook census results in this study suggest that EM could address this requirement, provided that activities occur in the camera field of view.

Returning to the key questions surrounding suitability of EM for pelagic longline fisheries, the pilot study does not show that EM offers similar results as an observer. We believe that for issues such as fishing time and location, and counts of gear used, EM would provide more accurate assessments than observers. For issues including counting and identification of catch and bycatch observers provided clearly superior assessments. The suggested improvements to camera placements and more structured catch handling procedures would significantly improve the ability of EM for catch and bycatch assessments, although we would expect that observer assessments are likely to be more detailed, particularly with species identification. In terms of protected species takes, EM and observer results were very comparable although we would expect observers to have greater ability to identify to species and make more detailed assessments of animal condition.

From a broad perspective, Hawaiian pelagic longline fisheries are under scrutiny and there is presently strong political will to improve visibility into the fishery through an observer program. The existing monitoring program is expensive to maintain which puts the fishery at risk if funding priorities change. Furthermore, alignment of observer availability with fishing schedules and all the issues with hosting an additional person aboard add to the complexity of a large observer program. A technology based monitoring alternative comes into consideration because of the potential to lower monitoring costs in the fishery and improve efficiencies. EM based programs generally cost a quarter to a third of observer programs and are more scalable to higher levels of monitoring because labour requirements are much lower (McElderry, 2008). In our view the pelagic longline fishery could be monitored using a combination of EM and observers, the former being widely used for key issues such as catch and effort, and protected species takes, while the latter to support more detailed data collection needs such as fine scale species resolution and biological sampling. A key dependency for EM to be successful is the level of industry support. We understand that some of the captains involved in the pilot study liked EM because it provided multiple camera views from which they could oversee operations from the bridge. Additional required support would include vessel personnel taking responsibility to ensure the EM system is performing properly (powered on, cameras clean, etc.) and ensuring that catch handling activities always occur within camera view. Further discussion with industry is needed to explore this possibility.

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