USE OF A VIDEO ELECTRONIC MONITORING SYSTEM TO ESTIMATE CATCH ON GROUNDFISH FIXED GEAR VESSELS IN CALIFORNIA: A PILOT STUDY

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ABSTRACT

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Archipelago Marine Research Ltd. was contracted by The National Marine Fisheries Service to carry out a study to demonstrate the feasibility of using video based electronic monitoring (EM) in the California fixed gear groundfish fleet, which could be used to augment observer programs, increase the accuracy of data collected by observers, and provide monitoring on the unobservable component of the fleet. EM systems consisted of three closed circuit television cameras, a GPS receiver, a hydraulic pressure transducer, a winch rotation sensor, and a system control box. EM systems were placed on three vessels for a total of 30 days at sea. EM and observer fishing event and catch data were available for comparison for a total of 150 fishing events. EM system at sea data collection on all participating vessels was virtually complete except for data loss occurring when vessel operators manually turned off the EM systems during transit in and out of fishing grounds, resulting in 93% overall sensor data completeness. EM data had 2% more pieces of catch than observer with high agreement on piece counts of sablefish and total rockfish between the two methods, with 2% and 0% differences respectively. EM has demonstrated to be an effective tool for at sea monitoring, delivering fishing effort and catch data comparable to on-board observers. Further emphasis on a monitoring program using EM to audit data from fishing logs will require the design of an audit framework and in-season reporting and feedback processes.

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1. INTRODUCTION

In 2005, a U.S. non-governmental organization, The Nature Conservancy (TNC), purchased several limited entry trawl-endorsed permits. TNC intends to use them to explore the economical and environmental feasibility of establishing a fixed gear fleet (longline and trap) off the coast of Morro Bay and Port San Luis, California. In order to do so, TNC requested an experimental fishing permit (EFP) that allowed three vessels to use horizontal and vertical longline gear as an alternative to trawl gear. The main objective of the EFP is to gather evidence of the economic and ecological feasibility of establishing a cooperatively managed, community based fishing association with shared total catch amounts for target and non-target species. The fishery mainly concentrated on targeting shortspine and longspine thornyheads and sablefish with horizontal longline gear and slope rockfish with vertical longline gear although the permit's quota included other catch like flatfish, dogfish, and lingcod.

As part of the EFP regulations, all fishing trips were required to carry a human observer on board to record fishing effort and catch information. Of particular importance was documenting full retention of rockfish, since the weights of all species were recorded at the time of offload to ensure that the strict hard quota caps on these species of are not exceeded. A fishing log was also designed for the EFP, and fishermen kept fishing effort and catch records for every trip. Due to the fishery's small scale and 100% observer coverage requirement, the National Marine Fisheries Service (NMFS) identified this fishery as a unique opportunity to gain insight on how to develop an objective, reliable and cost-effective monitoring program for a fixed gear, small vessel fleet based on individual accountability using video based electronic monitoring (EM).

Over the past decade, Archipelago Marine Research Ltd. has pioneered the development of EM technology and a number of pilot studies have been carried out to test the efficacy of this technology. Table 1 provides a listing of over 25 studies spanning diverse geographies, fisheries, fishing vessels and gear types, and fishery monitoring issues. The capabilities of EM have been reviewed in McElderry (2008).

NMFS contracted with Archipelago to demonstrate the feasibility of using EM in the California fixed gear groundfish fleet, which could be used to augment observer programs, increase the accuracy of data collected by observers, and provide monitoring on the unobservable component of the fleet. While the focus of the study is with the vessels fishing under the EFP held by TNC, a goal of the study is to demonstrate the technology for applicability to the Pacific longline fleet as a whole.

Table 1. Summary of Electronic Monitoring studies by Archipelago Marine Research Ltd. (McElderry, 2008).

Year	Project Location	Target Species	Gear	Monitoring Issue	Project Type*	Project Size**
2005	SA, Australia	Shark	Gillnet	Catch Monitoring	PS	1 / 16
2005	Antarctic, Australia	Toothfish	Longline	Catch Monitoring	PS	1 / 48
2005	TA, Australia	Redbait	Midwater Trawl	Protected Species	PS	1 / 42
2002	BC, Canada	Salmon	Seine	Catch Handling Discard Monitoring	PS	1 / 19
2003	BC, Canada	Halibut	Longline	Catch Monitoring	PS	19 / 459
2003	BC, Canada	Salmon	Troll	Catch	PS	4 / 60
2003	BC, Canada	Prawn	Trap	Catch/Gear	PS	1 / 60
1999-2008	BC, Canada	Crab	Trap	Gear	FI	50 / 4,000
2005-2008	BC, Canada	Groundfish	Longline	Catch	FI	230 / 12,000
2007-2008	BC, Canada	Inshore Groundfish	Trawl	Catch Monitoring	FI	9 / 840
2006-2008	BC, Canada	Hake	Trawl	Discard Monitoring	FI	34 / 2,100
2007	New Zealand	Groundfish/Pelagics	Longline	Protected Species	PS	4 / 100
2007	New Zealand	Groundfish	Gillnet	Protected Species	PS	5 / 82
2003	New Zealand	Hoki	Midwater Trawl	Protected Species	PS	1 / 31
2002	AK, USA	Halibut	Longline	Catch Monitoring	PS	2 / 120
2003	AK, USA	Groundfish	Trawl	Protected Species	PS	5 / 22
2005	AK, USA	Rockfish	Trawl	Discard Monitoring	PS	10 / 38
2006	AK, USA	Groundfish	Factory Trawl	Bin Monitoring	PS	1 / 14
2007	AK, USA	Rockfish	Trawl	Discard Monitoring	PS	1 / 14
2006	CA, USA	Swordfish	Drift Gillnet	Protected Species	PS	5 / 58
2007	CA, USA	Swordfish	Drift Gillnet	Protected Species	PS	1 / 3
2004	New England, USA	Cod/Haddock	Longline	Discard Monitoring	PS	4 / 10
2007	New England, USA	Groundfish	Longline/Gillnet	Catch Monitoring	PS	7 / 59
2007	New England, USA	Herring	Small Mesh Trawl	Catch Monitoring	PS	1 / 10
2002	West Coast, USA	Hake	Midwater Trawl	Discard Monitoring	PS	1 / 13
2004	West Coast, USA	Hake	Midwater Trawl	Discard Monitoring	FI	26 / 823
2005	West Coast, USA	Hake	Midwater Trawl	Discard Monitoring	FI	28 / 982
2006	West Coast, USA	Hake	Midwater Trawl	Discard Monitoring	FI	37/ 1,043
2007	West Coast, USA	Hake	Midwater Trawl	Discard Monitoring	FI	36 / 878

* Project Type: PS, Pilot Study; FI, Fully Implemented EM Program

** Project Size: # Vessels Monitored / # Seadays (per project or per annum)

2. MATERIALS AND METHODS

2.1 EM TRIALS ON FISHING VESSELS

EM System Specifications

Three vessels participated in this study, referred to as A, B, and C in order to protect their privacy. Each vessel was provided with a standard electronic monitoring system consisting of a control box, a suite of sensors including GPS, hydraulic pressure transducer, and up to three waterproof armored dome closed circuit television (CCTV) cameras (Figure 1). A winch rotation sensor was only installed in Vessel A. The characteristics of the hauler in all three vessels made standard installation of a winch sensor impossible as the back of the hauler has a non-moving plate and rotation can only be detected from the front, where the sensor would have been in the way of fishing operations. Vessel A was the only vessel that had a structure close enough to the hauler to allow the sensor to detect rotation and far enough to possibly stay out of the way of fishing operations.

The control box continuously recorded sensor data, monitored performance and controlled imagery recording according to programmed specifications, as well as provided continuous feedback on system operations through a user interface. Detailed information about the EM system is provided in Appendix I.

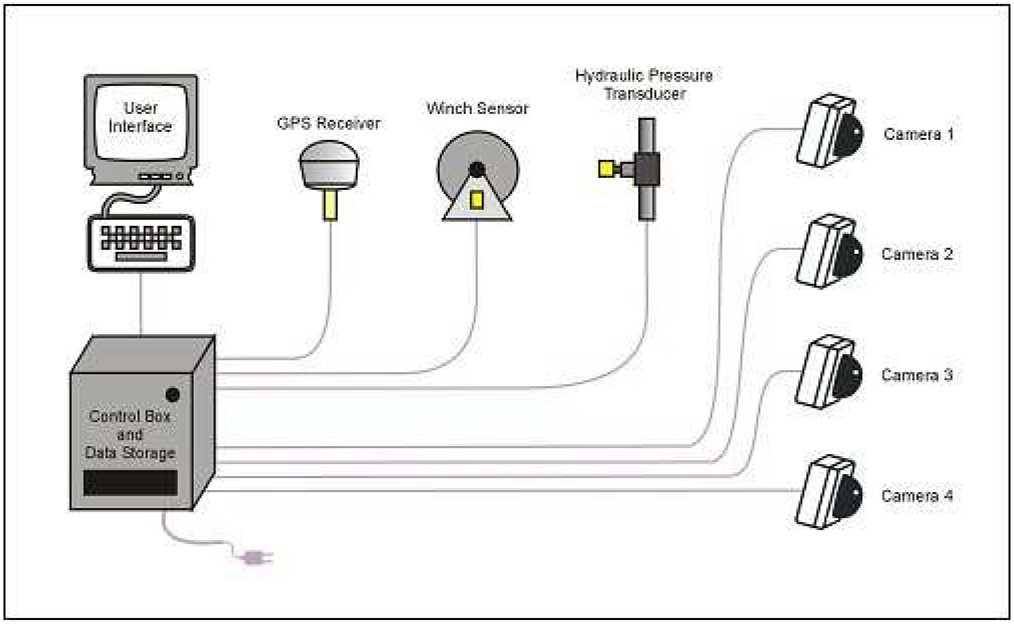

Figure 1. Schematic diagram of the electronic monitoring system, which can record video data from up to four cameras per vessel.

The EM system’s GPS receiver was mounted to existing structures above the cabin away from other electronics and provided independent information on vessel position, speed, heading, and time. The electronic pressure transducer was installed on the supply side of the hydraulic system and provided an indication when hydraulic equipment (winches, pumps, lifts, etc.) was operating. CCTV cameras were mounted on each vessel in locations that provided unobstructed views of catch and fishing operations.

EM control boxes, monitors, and keyboards were mounted in a secure dry area in the vessel cabin. Sensor cables were run through bulkheads where hydraulic and electrical lines were already in place for two of the vessels and vessel C required minimal alterations consisting of a gooseneck fitting provided by the vessel owner. The control box software was designed to boot up automatically when powered on, or immediately after power interruption.

EM data capture specifications

EM sensor data were recorded continuously while the EM system was powered, which was intended to be for the entire duration of the fishing trip (i.e. from the time the vessel leaves port to engage in fishing to the vessel’s return to port). Sensor data were recorded every 10 seconds with a data storage requirement of 0.5 MB per day. The control box software was set up to trigger image capture when hydraulic pressure exceeded base threshold levels or winch sensor detected rotation. Image recording ended about 20 minutes after the sensor trigger ceased for vessel A, 15 minutes for vessel B, and 15 minutes for vessel C. All imagery included text overlay with vessel name, date, time, and position.

Each EM system was capable of receiving video inputs from up to four CCTV cameras at selectable frame rates (i.e., images per second), ranging from 1 to 30 fps (motion picture quality). Using a frame rate of 5 fps the data storage requirement was 60–100 MB per camera per hour, equating to a system capacity of 22 to 37 days of continuous recording when using three cameras and a 160 GB hard drive.

Field Operations

The EFP was designed and managed by The Nature Conservancy (TNC), the National Marine Fisheries Service (NMFS), and the Community-Based Fishing Association (CBFA). Lisa Wise Consulting was hired by TNC to help in the management of the EFP. A committee chosen by the CBFA was responsible for selecting the most appropriate participating fishermen for the EFP from a pool of applicants.

Planning for the EM project component began in April 2008 with a meeting in Morro Bay, California. The meeting was attended by participating fishermen and staff from NMFS, TNC, CBFA, Lisa Wise Consulting, and Archipelago. The meeting included an overview presentation of EM technology and discussions surrounding project timelines, vessel requirements, project communications, and project methodology. Follow-up communication between Archipelago, the observer program, and The Nature Conservancy clarified EM, observer, and fishing log data collection methods and definitions of fishing events. For the purpose of this study, one horizontal longline fishing event would be considered from buoy to buoy, and one vertical longline event would be considered from anchor to buoy. A fishing trip was defined as the time between the vessel leaving port to engage in fishing, and the time it returned to port to deliver the fish.

Archipelago staff communicated with the vessel owners directly to discuss vessel requirements for install and answer any questions. Schedules for the EM system installations were organized by Lisa Wise Consulting staff. The three vessels participating in the project were different in size, deck layout, and processing (Figure 2). Fishing trips were planned to last about one or two days and all hailed from Morro Bay, CA.

Figure 2. The three vessels that participated in the project. Vessels are shown docked at Morro Bay.

The field component began in the second week of August 2008 and continued through early December 2008. An Archipelago senior EM technician installed the EM systems on all the vessels and remained on site for a week afterwards to attend the first service for vessels A and C, vessel C did not complete a fishing trip until later due to bad weather and logistics. Archipelago's EM senior technician trained both observers in EM system function and troubleshooting during the installation effort and first data retrievals. To simplify field effort data management, one observer was designated as the on-site EM service technician. The EM service technician's responsibilities included the retrieval, archiving, and shipping of all EM, troubleshooting EM systems at the dock, and contacting Archipelago if any system problems arouse. All data collected during the project were treated with complete confidentiality.

Installations began with Archipelago's senior EM technician and the vessel's captain discussing EM system component placement, wire routing, fishing deck operations, and the vessel's power supply. Hydraulic pressure transducers where installed on the pressure side of the hauler circuit and out of the way from vessel operations. The GPS receivers were fixed to existing structure above the cabin roof, (Figure 3) and the control box, monitor and keyboard were all secured in the vessel cabin. Due to the characteristics of the participating vessel's haulers, only one vessel was originally installed with a winch rotation sensor. Power to the EM system was supplied by the vessel's 12 Volt batteries for two of the vessels, with the third vessel providing 120V from the inverter. Upon completion of the installation, the EM system was powered up and sensors and cameras tested to ensure functionality. The skipper was also given an overview of the EM user interface and basic EM functionality. Both skipper and observer were asked to monitor the status of the EM system throughout fishing trips.

Three cameras were installed on vessels A and C, and two cameras in vessel B, with the objective of capturing imagery of catch, catch handling, and catch disposition (Figure 4). In vessel A, two cameras were fixed to the stabilizer pole, one showing a close up of the hauling area, and one showing a wide angle view of the starboard side of the vessel on both sides of the rail. A third camera was fixed to the mast to provide a deck view, mostly to help the skipper monitor the gear setting operation from the wheel house but also to aid in discard monitoring. For vessel B a deployable outboard camera mount was fabricated and attached to the boom so that it would extend past the stern of the vessel. A camera was fixed to this mount to provide a view of the hauling area. A second camera was fixed to the mast to provide a deck view where catch sorting and processing took place.

For vessel C a deployable outboard camera mount was fabricated and attached to the deck roof. One camera was fixed to this mount, to provide a close-up view of the longline between the waterline and the crewmember handling the gear. Two other cameras were fixed to the mast, one to provide a deck view and the other to provide a view of a second hauling station on port side that the skipper thought may have been used for vertical longline gear but was never used during the study.

Figure 3. Examples of sensor installations on the study vessels: GPS receiver (left), monitor and keyboard (center), and hydraulic pressure sensor (right).

Vessels participating in the pilot project carried an EM system for 7 to 11 fishing trips each. The on-site EM technician monitored EM system performance during service events between the fishing trips. Servicing included several operational checks of the equipment and retrieval of the sensor data collected. Since memory requirements were relatively small for each trip, imagery data collection and replenishment of empty media took place roughly every month.

During the initial service adjustments, sensor placements, threshold settings, and camera angles were sometimes necessary since sensor signatures resulting from at sea activity did not always reflect those encountered at dockside and the camera views selected did not always completely capture the activities intended. The sensor data retrieved was uploaded to a secure ftp site and imagery data were backed up to a 500 GB external hard drive for archiving and a small 360 GB external hard drive for shipping. The 360 GB hard drive was packaged and sent back to Archipelago's head office in Victoria, BC every three to four weeks.

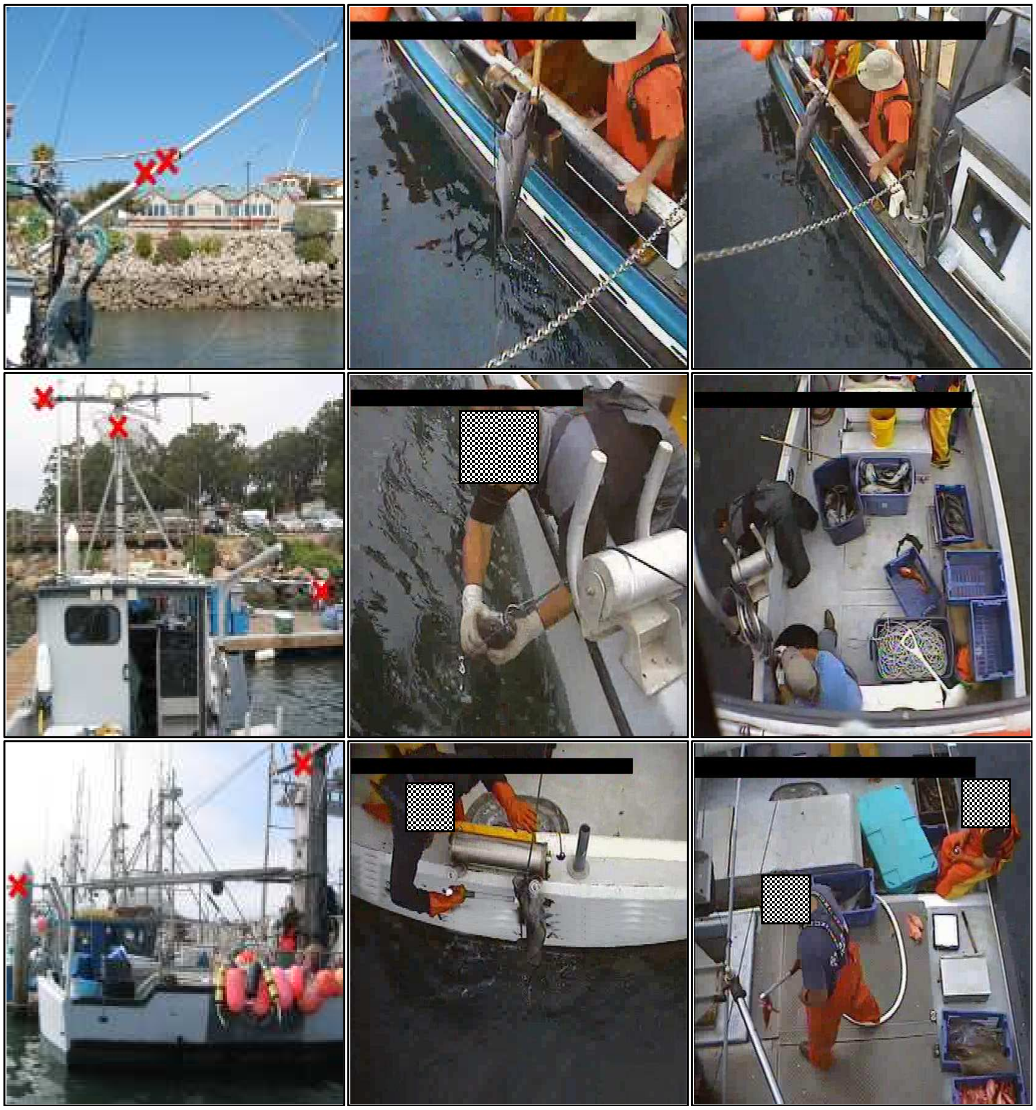

Figure 4. Camera locations (left) for each vessel, marked with a red X, along with camera view samples for the main rail view used to identify catch and detect drop offs (center), and deck views used to further identify catch as needed and determine disposition (right).

2.2 EM DATA INTERPRETATION AND ANALYSIS

Data were processed in batches as it arrived to Archipelago's headquarters in Victoria, BC, Canada with no specific trip prioritization. Data interpretation protocols were designed and communicated to the data technicians involved in the study before any of the data were processed and were based on the study's objectives, project methodology talks during the project planning stage, and experience accumulated from similar studies carried out in the past. The data technicians involved in data interpretation were also asked to record relevant feedback into a database to aid in data analysis. Sensor data interpretation was carried out before image interpretation to inform the EM imagery viewer of haul times without having to review all of the imagery for a trip. The observer data were received in two batches once all of the EM data were interpreted to ensure unbiased interpretation.

Sensor Data Interpretation

Raw sensor data (GPS, and hydraulic) were first imported to an MS SQL database and analysed to determine the completeness of each data set by checking for time breaks in the data record, as indicated by the duration between records exceeding the expected 10-second time interval.

Sensor data were then analysed to interpret the geographic position of fishing operations and distinguish key vessel activities including transit, gear setting, and gear retrieval. All of the sensor data collected during the project were interpreted. EM sensor data interpretation was facilitated using a relational database as well as time series and spatial plots, which are illustrated in Figure 5. Vessel speed and hydraulic pressure often correlate uniquely for various activities such as transit, setting, and hauling. The spatial plot provided a perspective on the various activities in relation to one another and was useful to help associate specific setting and hauling events. Setting and hauling events were matched to each other by interpreting physical proximity and timing. When displayed in this manner, the analyst reviewed the trip, interpreted vessel activity, and made annotations in the sensor record for haul and setting events. Haul start and end times from sensor data interpretation provided an initial reference for accessing image data.

Part of the sensor data interpretation also involved the evaluation of the EM system sensors. The electronic pressure transducer and winch sensor signals were evaluated for completeness throughout each trip. The quality of the GPS receiver was evaluated to determine reliability of position and time signal. Poor GPS receiver signal is usually the result of an intermittent GPS signal caused by interference or a large satellite error in determining position. For each trip, each sensor's signals were rated as follows:

- Complete. The sensor performed to its full capacity.
- Incomplete. The sensor experienced intermittent failures or false readings.
- No data. The sensor did not operate during the trip.

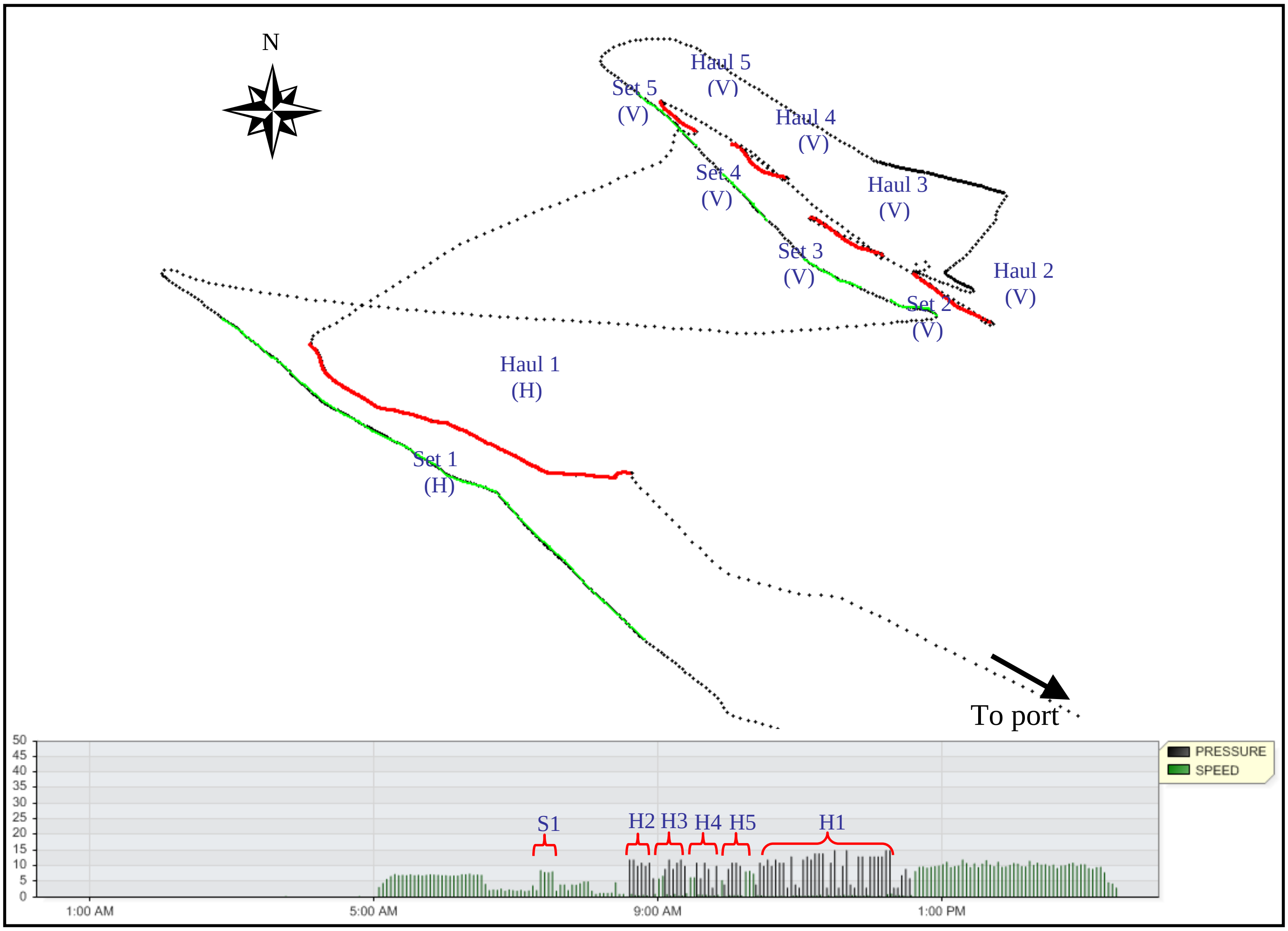

Figure 5. Example of sensor data from one of the project vessels for a trip. The time series graphs (lower) show vessel speed (knots), and hydraulic pressure (psi). Setting activity for horizontal longline was associated with constant and relatively high speed, relatively constant heading, and physical proximity to a haul. A consistent signature for vertical longline setting was not found, although some vertical longline setting was detected due to constant speed and heading and geographic proximity to hauling events as in this example. Hauling for both vertical and horizontal longline was associated with high hydraulic pressure and relatively low speed. The spatial plot (upper) shows the vessel's cruise track for the same period, with setting highlighted in green and hauling in red with fishing activity is labelled H for horizontal longline, and V for vertical longline.

Image Data Interpretation

Image data were interpreted using a custom software product that provided synchronised playback of all camera images 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 the catch comparison analysis.

Image data interpretation was done for all hauls captured by EM. The first step of image interpretation was to assess whether all the intended imagery was recorded properly. This was achieved by comparing the haul start and end times from the sensor data with those available for image data. The hauls that were deemed to have complete imagery were reviewed for catch assessment and image quality.

The EM imagery data viewer counted and identified target and non-target catch to the highest taxonomical grouping possible and also kept track of catch disposition. EM catch disposition data included: retained, released, and drop-off (catch that fell off the gear before the fisherman had control over it).

Image quality was assessed as an average for each haul event viewed, according to the rank scale illustrated in Figure 6 and defined as follows:

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

- Medium. The view was acceptable, but there may be some difficulty assessing discards. Slight blurring or slightly darker conditions hamper, but do not impede analysis.

- Low. The imagery is difficult to assess. Some camera views may not be available. Imagery is somewhat blurred or lighting has largely diminished. Some factors such as the fishing line going out of camera view or crew standing between the catch and the camera for extended periods of time may have also occurred.

- Unusable. The imagery is poorly resolved or obstructed such that fishing activity cannot be reliably discerned.

Figure 6. Example imagery to illustrate the different image quality assessments. From left to right: high, medium, and low. Image quality is determined as an average of all cameras throughout an entire haul. Some cameras may yield a better angle and image clarity than others within the same haul but it is the overall ability to meet imagery review objectives that ultimately determines the imagery quality rating.

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 itself was done once all of the sensor and image data were interpreted. After comparing observer and fishing log data to EM data, a second review of selected portions of the imagery was done by a second EM imagery data viewer only to gain further insight on possible reasons surrounding specific catch discrepancies. 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, imagery, observer data, and fishing log data) were available in relational databases allowing all the data analysis to be carried out using an MS Access database. The data processing tracking and management was also done using an MS Access application.

As one of the main goals of the study was to compare EM, observer, and fishing log estimates of catch species, it was important to appropriately match the three data sets. Fishing event matching between observer and EM was done using the set start and haul end date and time as determined by each data source. Fishing event matching between EM and fishing log was initially attempted using the same methodology, but had to be complemented by using gear type alignment since fishing log date and time data was inconsistent as compared to both EM and observer data and some events did not have haul time information.

3. RESULTS

2.1 EM TRIALS ON FISHING VESSELS

EM System Deployments and Data Capture

EM system deployment results are summarized in Table 2. The data collection for the pilot study spanned a three and a half month period involving three vessels, each completing between 7 and 11 fishing trips for a total of 30 days at sea. Every vessel also carried an observer and filled out a fishing logbook for every trip. EM collected a total of over 497 hours of sensor data at sea, and 108 hours of haul imagery associated with 155 fishing events.

The overall sensor data capture success was 93%, ranging from 45% to 100% per trip. Gaps in the sensor data record occurred most commonly during the vessel's initial or final transit from the fishing grounds to port. For example, the largest gap, which resulted in 45% sensor capture success, was caused by the vessel leaving port in the afternoon, probably anchoring up in a protected cove overnight, and not turning the EM system on until part way through the transit to the fishing grounds the next morning. Only one time gap, which lasted 2.4 minutes, occurred in the middle of a fishing trip and was related to a very short power interruption. There is no evidence of sensor data gaps caused by system errors and, according to observer data, no fishing activity was missed due to sensor data gaps.

Sensor performance was high across all vessels (Table 3). The winch rotation sensor installed in vessel A recorded data for a portion of the first trip but the sensor was damaged during fishing operations. The sensor was not installed again as there was no better place to install it. The GPS problem was most likely caused due to temporary interference as it only occurred sporadically for about a three-hour period, and all other sensor data continued to be recorded. Imagery for one of the three cameras in vessel C was not available for one trip. The problem occurred in the vessel's last trip and so it was not diagnosed for a solution.

Table 2. Inventory of fishing trips monitored by EM for the three participating vessels.

Vessel ID	Trip Number	Departure	Trip Duration (Hours)	TimeGap (Hours)	Time Gap Category	Sensor Data Collected (Hours)	Sensor Data Completeness (%)	Haul Imagery Collected (Hours)	Hauls Captured
A	1	16-Aug-08	22.6	0.00		22.6	100%	2.9	2
A	2	23-Aug-08	23.1	0.00		23.1	100%	4.6	8
A	3	28-Aug-08	21.8*	0.98	End	20.9	96%	4.8	10
A	4	06-Sep-08	58.7*	0.04	End	58.7	100%	3.8	9
A	5	14-Sep-08	17.6	0.00		17.6	100%	3.9	2
A	6	18-Sep-08	25.8*	3.97	End	21.8	85%	6.4	10
A	7	24-Sep-08	21.3*	3.70	End	17.6	83%	6.0	12
Vessel Totals			**190.9**	**8.7**		**182.2**	**95%**	**32.3**	**53**
B	1	23-Aug-08	18.7	0.00		18.7	100%	4.3	4
B	2	29-Aug-08	19.4*	4.85	Start	14.6	75%	4.6	4
B	3	10-Sep-08	17.1	0.00		17.1	100%	4.5	3
B	4	04-Sep-08	34.0	0.00		34.0	100%	4.4	5
B	5	18-Sep-08	21.6	0.00		21.6	100%	5.9	7
B	6	26-Sep-08	21.0*	5.53	Start	15.5	74%	5.1	7
B	7	03-Oct-08	17.3	0.00		17.3	100%	4.1	9
Vessel Totals			**149.1**	**10.4**		**138.8**	**93%**	**32.8**	**39**
C	1	16-Aug-08	22.1	0.00		22.1	100%	3.3	1
C	2	28-Aug-08	14.4	0.00		14.4	100%	4.6	5
C	3	11-Sep-08	12.2	0.00		12.2	100%	3.6	5
C	4	04-Sep-08	28.5	0.04	Mid-Trip	28.4	100%	3.9	5
C	5	14-Sep-08	11.4	0.00		11.4	100%	3.4	5
C	6	23-Sep-08	26.7*	14.63	Start	12.1	45%	4.2	5
C	7	29-Sep-08	24.4	0.00		24.4	100%	3.4	5
C	8	17-Oct-08	12.4	0.00		12.4	100%	3.6	5
C	9	17-Nov-08	16.3	0.00		16.3	100%	6.0	14
C	10	07-Nov-08	14.2*	2.45	Start	11.8	83%	4.5	5
C	11	23-Nov-08	10.9	0.00		10.9	100%	2.8	8
Vessel Totals			**193.6**	**17.1**		**176.5**	**91%**	**43.4**	**63**
Overall Totals	**25**		**533.6**	**36.2**		**497.4**	**93%**	**108.5**	**155**

* Observer information used when EM information not available due to EM system powered down for transit either out or into port.

Table 3. Summary of sensor performance for all trips throughout the pilot study.

Sensor Performance	GPS Receiver	Hydraulic Pressure Transducer	Winch Rotation Sensor	Cameras
Complete	24	25	0	24
Incomplete	1	0	1	1
No Data	0	0	0	0
Not Installed	0	0	24	0
Total number of trips	**25**	**25**	**25**	**25**

Table 4 shows 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 a portion of the haul was not available for review, and missed when observer and sensor data showed that a haul occurred but there was no imagery data triggered. A fishing event involving trap gear was captured by both EM sensor and imagery data, however the event was likely a personal trap and was not found in the observer data and hence not included in any of the analysis.

Observer data were collected for a total of 154 hauls, out of which 150 were fully captured by EM. Only EM imagery data from hauls completely captured by EM were compared, as the incomplete hauls would have resulted in inconclusive catch comparisons. Each vessel contributed a different amount of hauls to the total 150 analyzed, ranging from 25% from vessel B to 41% from vessel C.

Incomplete imagery from hauls was due to pressure readings falling below threshold while the haul was still occurring. In one occasion this was due to a large tangle on the line that forced hydraulic pressure to fall below for about half an hour. Even though the EM system was configured to remain recording 20 minutes after pressure dropped below threshold the extended period of pressure inactivity resulted in a ten-minute time gap. The other incomplete hauls resulted from pressure dropping below threshold towards the end of the haul as the skipper and crew began to manually retrieve in the gear rather than using the hauler. In these occasions too the video run-on time was not enough to capture the entire haul as hooks were seen to still be coming up when video stopped.

Table 4. Summary of hauling events captured by observer and EM.

Vessel ID	Trips	Observer Recorded Haul	EM Sensor Data Complete	EM Imagery Data Complete	EM Imagery Data Incomplete	EM Imagery Data Missed
A	7	52	52	51	1	0
B	7	39	39	37	2	0
C	11	63	63	62	0	1
Totals	**25**	**154**	**154**	**150**	**3**	**1**

3.2 EM DATA INTERPRETATION AND ANALYSIS

Interpretation of EM sensor data

Examples of the time series graphs are shown in Figure 7 for the three vessels, showing vessel speed and hydraulic pressure over a 24-hour period. Each vessel displayed slightly different sensor readings during fishing activity, with some vessels recording higher pressure readings and/or speed than others, but the overall sensor signature was similar for all vessels. Both vertical and horizontal gear hauling events were characterized by high hydraulic pressure and relatively low vessel speed, with both pressure and speed tending to fluctuate corresponding to work associated with catch retrieval. There were no specific sensors used to detect setting events since the vessels set the gear directly from tubs. However, the combination of relatively high and constant speed, consistent heading, and geographical proximity to the haul was a reliable way to determine setting for horizontal longline events. In comparison, vertical longline setting events proved to be very difficult to be consistently detected by EM. There were large variations on average hauling event durations by gear type, with 2.25 hours for horizontal longline hauls versus 10.8 minutes for vertical longline ones.

Distinguishing hauling activity through sensor data interpretation was a relatively straightforward process for all vessels, although setting activity for vertical longline was not discerned every time. Matching setting events to their corresponding hauling events when sets were identified was also relatively straightforward. Set-haul order varied from trip to trip although most of the time a horizontal longline would get set before the vertical longlines. Since EM did not consistently detected vertical longline setting it is not possible to say whether the gear was set in the same order as they were hauled or not; however it is certain that more than one line was often soaking at any one time.

Interpretation of EM imagery data

Image quality ratings for all hauls reviewed are shown in Table 5 for the 150 hauls compared to observer data. Image quality was rated as high or medium for 86% of the hauls reviewed. The main issues surrounding these hauls was the EM imagery viewer’s difficulty keeping track of the catch and uncertainty speciating catch upon first view, caused by a combination of crew behaviour, camera angles, and environmental conditions, mainly glare reflecting from the water and catch. Low image quality was assigned to 14% of the hauls analyzed due to increased difficulties keeping track of catch dispositions as well as lower than expected image clarity for the purpose of speciation. Low image quality ratings were mostly due to back lighting from deck and camera pixilation during night hauls. Out of the 19 hauls rated with low imagery quality, 10 were night hauls (starting after 18:00). Secondary causes of low ratings were having a camera missing for the second to last trip for vessel C and then having the angle for one of the cameras shifted on the last trip for vessel C. The reason behind the camera shift is unknown, but possibly due to accidental interaction with gear.

General issues surrounding image quality were that some imagery showed pixilation due to problems in the camera recording settings, generating lower resolution images than usually recorded in other pilot studies, and that crew behaviour caused the groundline to go out of camera view when the line was hauled by hand and catch was out of camera view due to crew inadvertently placing themselves between the camera and the catch.

Image playback speeds during interpretation varied from about 1.5 to 4 times real time according to the monitoring objective, catch density, and image quality. Average viewing analysis ratios, expressed as the length of the haul divided by how long it took to review, were 0.55 for horizontal longline and 0.60 for vertical longline. Imagery review was most efficient when image quality was high or medium, fish came on board one by one and always in camera view, fish handling on board was consistent, and discarding took place in camera view and in a way that facilitated piece counting. Hauling fish partially out of the close up camera view (due to manual hauling), gear tangles, inconsistent fish sorting, and fish discarded partially outside camera view and/or en mass required imagery playback to be slowed down or paused and rewound to minimize the likelihood of missing something.

Table 5. Summary of EM imagery data quality assessments.

Vessel ID	Horizontal Longline			Vertical Longline			Total Hauls Compared
	High	Medium	Low	High	Medium	Low	
A	7	4	1	25	9	5	51
B	3	6	0	6	20	2	37
C	5	3	1	15	26	12	62
Totals	**15**	**13**	**2**	**46**	**55**	**19**	**150**

Observer and EM Data Alignment

Observer and EM fishing event alignment resulted in high agreements of haul date and time data. On average, observer haul data were 1.23 minutes ahead of the EM haul end data while the absolute average difference was 13.12 minutes. Observers only recorded one date/time parameter for each haul but did not consistently recorded the haul end information, sometimes recording haul start information instead. This analysis was ran on the assumption that observer data was for haul ends only and so most of the greater discrepancies between EM and observer haul date/time data were caused by discrepancies in data recording methods.

Haul information inconsistencies and the lack of EM set information for vertical longline sets made observer-EM event matching a relatively labour intensive process.

The matching process also allowed for the correction of EM data interpretation when EM would have not been able to verify if what looked like a haul due to speed and cruise track shape but had no pressure signature and no imagery triggered, was indeed a fishing event.

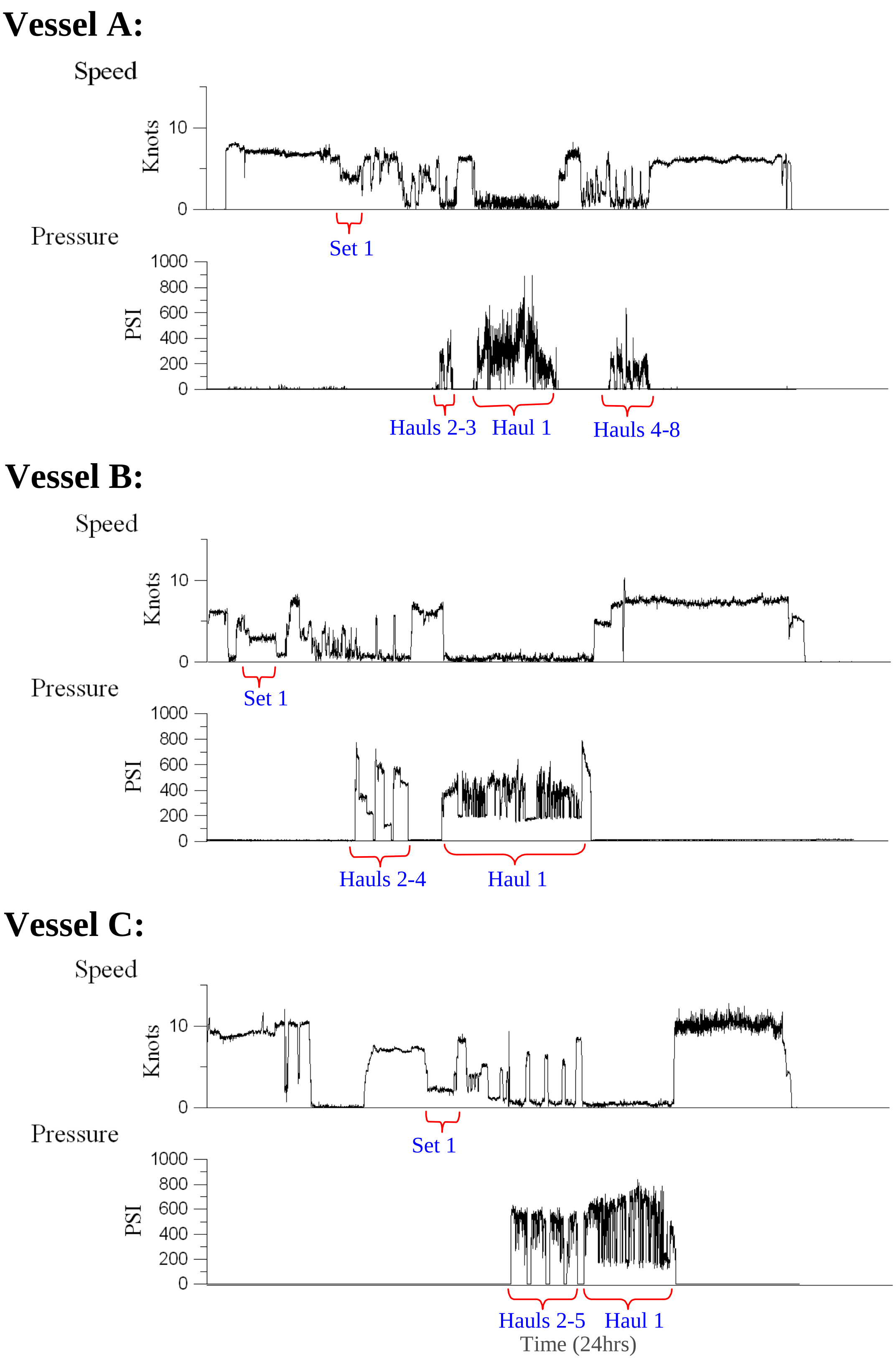

Figure 7. Sensor data examples showing vessel speed and hydraulic pressure readings at approximately 10-second intervals over a period of 24 hours. Setting and hauling events are noted in each instance. Only horizontal longline sets are noted as there was no consistent signature for vertical sets found.

Comparison of EM and Observer Catch Observations

Catch comparisons between EM and observer data were done for the 150 hauls completely captured by EM imagery. From these hauls, observer fish and macro-invertebrate catch data consisted of a total of 28 catch categories including 22 species, 1 genus, 2 families, 1 order, 1 superorder, and 1 class. EM data categorized catch in 22 categories of 13 species, 3 genera, and 3 families, 1 order, 1 class, and an unknown fish and unknown invertebrate category. The more general classifications to genera, families, and unknown categories by EM correspond to a lower ability to speciate catch compared to the observers.

EM did not attempt to distinguish between 2 species of thornyheads (*Sebastolobus sp.*) as previous experience has shown that the confidence in this identification is very low. Due to this, observer entries for shortspine (*Sebastolobus alascanus*) and longspine (*Sebastolobus altivelis*) thornyheads were grouped for comparison to EM. Observer data only included one piece of longspine thornyhead. EM attempted to speciate all other catch.

The overall fish catch comparison between the observer data and the imagery data is presented in Table 6, showing catch by species (or species categories) and two indices of abundance. Percent occurrence reflects the percentage of analyzed hauls where the species was detected, and the average pieces per haul illustrate how many pieces on average are found in the hauls where the species were detected. Table 6 also shows total pieces as recorded by observer and EM along with the total piece difference (observer pieces - EM pieces) and a percent difference calculated as (observer pieces - EM pieces)/observer pieces and only shown if the number of observer pieces was greater than 50. Only the most common fish species are listed in the table, and all others are shown as species group totals for general comparison purposes. A complete table with all the species can be found in Appendix II.

Both observer and EM data contained over 16,000 total fish catch items with sablefish (*Anoplopoma fimbria*) being the most common species under both abundance indices in both data sets, followed closely by blackgill rockfish (*Sebastes melanostomus*). EM data contained 2% more overall catch items than observer data, EM had more catch records for all species groups except pacific hake and sharks.

For target catch, there was high level of agreement between observer and EM data for sablefish with a minus 2% difference, and overall rockfishes (*Sebastes sp.*) and flatfishes (order Pleuronectifomes) with 0% differences (observer-EM). There were large differences in total pieces by species category for both rockfishes and flatfishes. EM categorized 22% of the total rockfishes categorized as “red rockfish”. In turn, EM did not detect three of the eight species identified by the observer, these being aurora (*Sebastes aurora*), splitnose (*Sebastes diploproa*), and bank rockfish (*Sebastes rufus*). EM identified one catch item as yelloweye rockfish (*Sebastes ruberrimus*), while none were found in the observer data.

Skates (family Rajidae) were the most abundant bycatch group. EM detected 10% more skates than the observer, but could only confidently identify 95% of them failing distinguish sandpaper skates (*Bathyraja interrupta*) as in the observer data. Sharks (superorder Selachimorpha) constituted the second most abundant bycatch group. There was a high level of agreement between observer and EM data at the total sharks level (1%) and for spiny dogfish sharks (*Squalus acanthias*) (-4%). Speciation for all other sharks was not consistent in the two data sets with EM greatly over representing brown cat sharks and failing to detect three species of shark identified by the observer.

EM categorized some catch items as unknown fish, although unknown fish accounted for only 0.2% of all EM records. Most of these catch items were either hard to identify due to crew blocking the field of view and night hauls, most likely corresponding to either sablefish and pacific hake (*Merluccius productus*), and relatively small catch, like hagfishes (family Myxinidae) and macro-invertebrates, to a lesser degree.

Table 6. Summary table showing the comparison of observer and EM total catch by species or species group.

Species Name	Obs Percent Occurrence	EM Percent Occurrence	Obs Avg Pcs Per Set	EM Avg Pcs Per Set	Obs Pieces	EM Pieces	Total Piece Difference	Percent Difference
Blackgill Rockfish	82.0%	74.0%	19.02	16.95	2340	1882	458	20%
Thornyheads (Grouped)*	26.0%	18.7%	8.21	10.54	320	295	25	8%
Aurora Rockfish	16.7%	0.0%	2.00	0.00	50	0	50	
Bank Rockfish	5.3%	0.0%	4.88	0.00	39	0	39	
Darkblotched Rockfish	6.0%	0.7%	1.67	1.00	15	1	14	
Redbanded Rockfish	3.3%	1.3%	1.20	1.00	6	2	4	
Splitnose Rockfish	2.7%	0.0%	1.00	0.00	4	0	4	
Red Rockfishes (Unidentified)	0.0%	64.7%	0.00	6.23	0	604	-604	
Rockfishes (Unidentified)	0.0%	0.7%	0.00	1.00	0	1	-1	
Yelloweye Rockfish	0.0%	0.7%	0.00	1.00	0	1	-1	
Total for Rockfishes					**2774**	**2786**	**-12**	**0%**
Sablefish	84.7%	84.0%	93.43	95.78	**11866**	**12068**	**-202**	**-2%**
Dover Sole	11.3%	5.3%	2.53	2.00	43	16	27	
Petrale Sole	4.0%	0.0%	1.17	0.00	7	0	7	
Flatfish (Unidentified)	0.0%	14.7%	0.00	1.59	0	34	-34	
Total Flatfish					**50**	**50**	**0**	0%
Brown Cat Shark	11.3%	18.7%	11.53	10.18	196	285	-89	-45%
Filetail Cat Shark	8.0%	0.0%	7.83	0.00	94	0	94	
Spiny Dogfish Shark	24.7%	24.7%	2.19	2.27	81	84	-3	-4%
Shark (Unidentified)	4.7%	0.0%	1.57	0.00	11	0	11	
Blue Shark	4.0%	4.0%	1.00	1.00	6	5	1	
Pacific Sleeper Shark	0.7%	5.3%	1.00	1.63	1	13	-12	
Brown Smoothhound Shark	0.7%	0.0%	1.00	0.00	1	0	1	
Cat Unid Shark	0.7%	0.0%	1.00	0.00	1	0	1	
Total Sharks					**391**	**387**	**4**	**1%**
Longnose Skate	34.7%	36.0%	16.67	17.07	867	922	-55	-6%
Sandpaper Skate	5.3%	0.0%	1.63	0.00	13	0	13	
Skate (Unidentified)	0.0%	16.0%	0.00	1.88	0	45	-45	
Total Skates					**880**	**967**	**-87**	**-10%**
Pacific Hake	23.3%	15.3%	2.17	2.30	76	53	23	30%
Fish (Unidentified)	0.0%	13.3%	0.00	1.60	0	32	-32	
Other Fish	0.0%	2.0%	0.00	1.00	9	6	3	
Total Other Fish					**85**	**91**	**-6**	**-7%**
Overall Totals					**16122**	**16402**	**-280**	**-2%**

* Thornyheads are grouped in this table as EM did not differenciate shortspine and longspine thornyheads. However, observer data had these species broken down and included one piece of longspine thornyhead.

On the basis of individual fishing events, the scatter plot shown in Figure 8 indicates that, for most hauls, there was a very close agreement in the total number of pieces between observer and EM. The graph also shows a slight bias with EM having more pieces per event, resulting in a minus 2.02 average piece difference per haul, or 1.9% of the observer catch per event on average.

Vertical longline hauls accounted for 80% of the hauls compared, while horizontal longline hauls accounted for 85% of the total fish catch compared. However, there were no large differences in the EM to observer comparison based on gear type, with EM total catch being 2% higher than the observer counts on average for horizontal longline events, and 1% lower than the observer counts on average for the vertical events. There were no evident vessel specific trends when comparing observer data to EM data.

There were three outlier vertical longline comparisons (circled in Figure 8), one with EM pieces considerably lower than the pieces in the observer data and two others with EM pieces considerably higher than the observer pieces. The event with less EM catch was caused by the imagery viewer having difficulties in detecting catch as catch were not consistently in view due to a camera malfunction and crew behaviour (standing between the deck view camera and the catch). The reason why EM had considerably more catch than the observer could not be explained based on EM equipment performance so a second EM count was done by a different imagery viewer, who obtained the same EM count independently for one event and one less piece for the other.

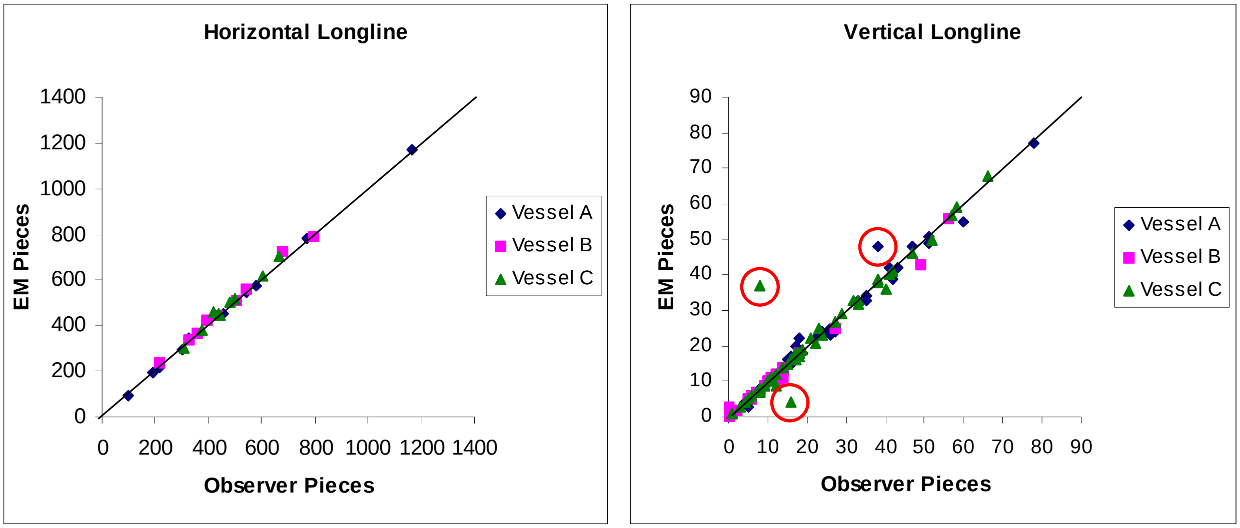

Figure 8. Scatter plot of observer data total catch versus EM data total catch per fishing event showing horizontal and vertical longline gears separately. Only fish species were considered for this analysis. Outliers displayed with a red circle are described in the text.

Piece count differences by categories and selected species at the haul level follow the trends seen in the total catch results (Figure 9). Individual rockfish species where generally underrepresented by EM compared to observer data. EM piece counts of blackgill rockfish per fishing event were 3.65 pieces under the observer count on average, although 69% of the events show only a difference of ±3 pieces, and EM thornyhead rockfish piece counts per set were 0.69 under the observer counts, with ±3 piece difference in 90% of the sets. Once all rockfish per fishing event were grouped, EM piece counts were 0.04 pieces greater than observer, or 0.2% of the observer average pieces per fishing event.

Sablefish piece count differences between EM and observer data show a very high level of agreement, with EM piece count being 1.55 pieces greater than observer on average or 1.7% of the observer average pieces per fishing event. Flatfish are only represented at the species group as EM identified 68% of the flatfish to the general flatfish category, and the highest piece count per set of any one species was six pieces in the observer data. The average overall flatfish piece difference between observer and EM data was 0.0 per fishing event.

Total piece differences per fishing events for skates are also displayed, as skates were the most abundant bycatch. Not withstanding the speciation differences, total piece counts for skates at the fishing event level show high agreement between observer and EM (-1.46 average piece difference per fishing event), with the piece differences being greater on events with high total number of skates.

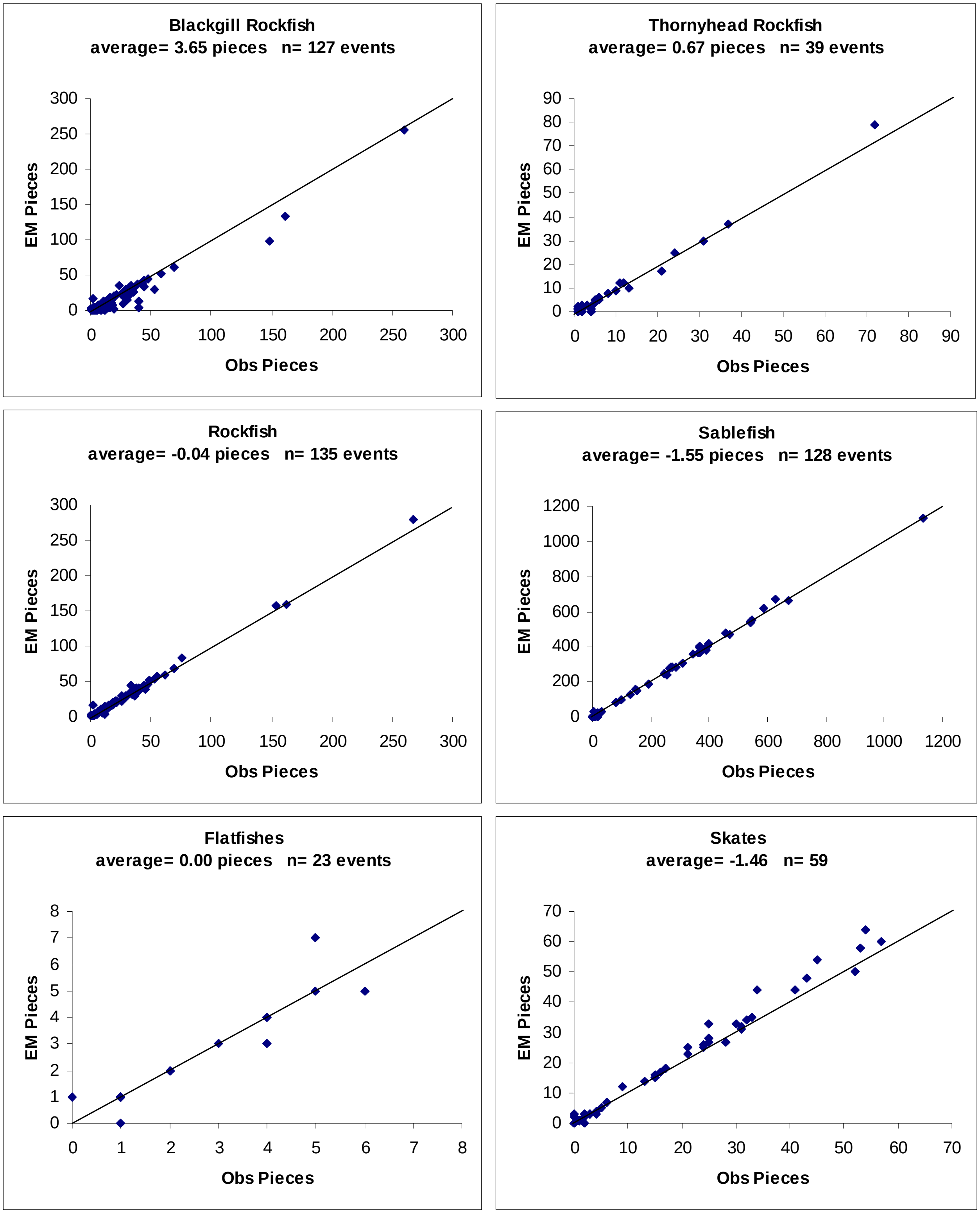

Figure 9. Scatter plots for EM data catch versus observer data total catch per fishing event for the most common target species, grouped rockfish, and the most common bycatch species group. Each plot also shows the average observer minus EM piece difference and the total number of events compared for each species or species group.

Observers and EM image viewers used slightly different categories for catch disposition when catch was not retained. Observers recorded non-retention disposition as ‘Released’, whereas viewers categorized non-retention either as ‘Released’ or ‘Drop-off’. The ‘Drop-off’ disposition was given to catch that dropped off the gear before the fisherman had taken control over the gear. Due to the differing detail in non-retained catch, catch disposition was compared after grouping EM “lost” and “released” catch. Observer data recorded 89% of the fish catch as retained. Catch disposition comparisons of EM and observer data for total fish catch per haul are shown in Figure 10. EM slightly over-represented retention (average piece difference by haul of –3.6 pieces or 4% of the average observer retained catch per set) and under represented non-retention (average piece difference by haul of 2.3 or 13% of the average observer non-retained catch per set). Most of the outliers in the non-retained graph correspond to bycatch that EM detected when it was brought onboard, but was not detected when discarded. Figure 11 shows that, although total catch items for the main species and species groups are close between observer and EM, there is large differences in retained versus non-retained ratios for flatfishes, sharks, skates, and pacific hake. Those ratios are much more consistent for rockfishes and sablefish, likely due to the very low rates of discarding for these species.

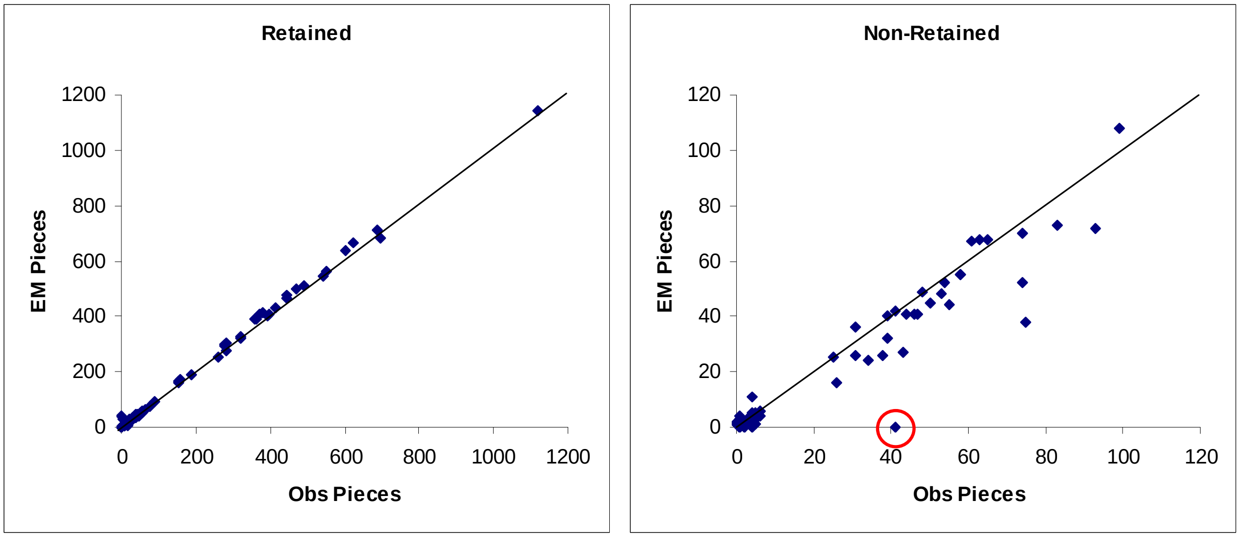

Figure 10. Scatter plot of retained and non-retained observer data total fish catch per haul versus EM data total catch per haul. The outlier displayed with a red circle are described in the text.

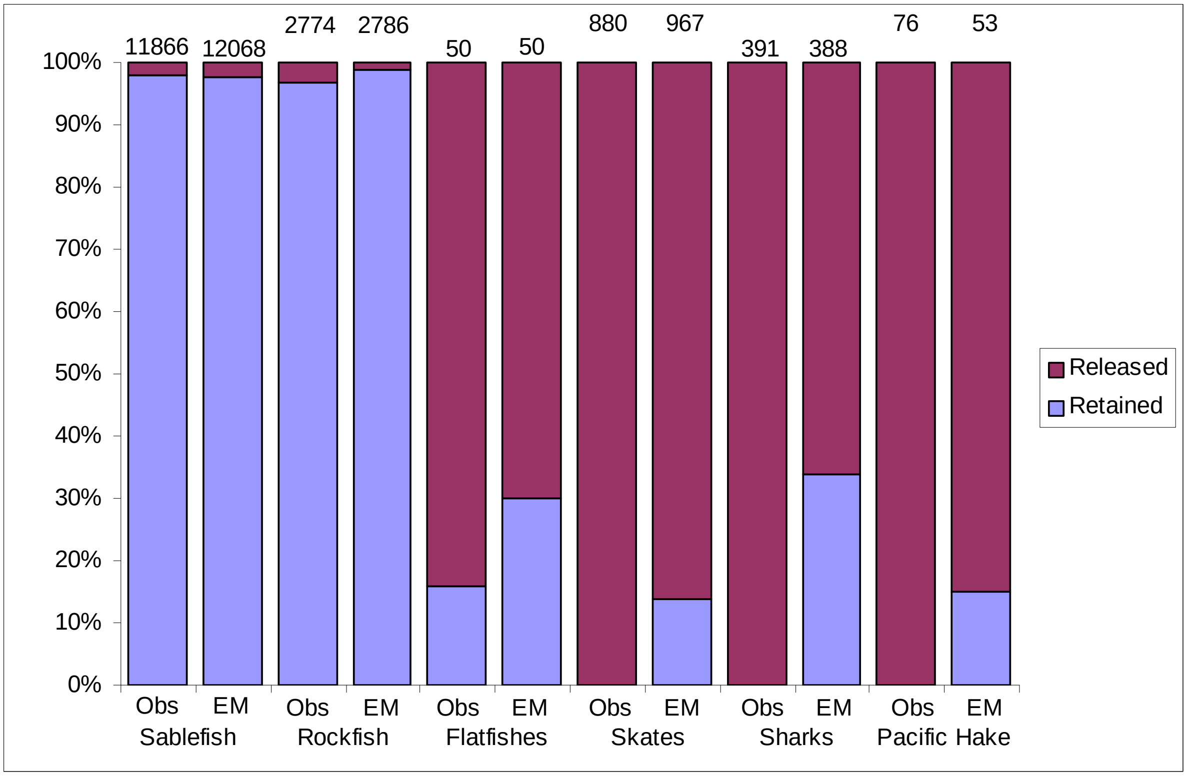

Figure 11. Bar graph showing the differences in retained and non-retained brake down between observer and EM for the main catch species and species groups. Total number of pieces are shown at the top of each bar.

Fishing Log and EM Data Alignment

Out of the 150 complete hauls captured by EM, the fishing log did not have haul time information for a total of 11 fishing events, corresponding to six trips and two vessels. For the fishing events with haul time information, fishing log haul data were, on average, 10.7 minutes behind the EM haul end data while the absolute average difference was 18.0 minutes. Similar to the observer-EM alignment, most of the greater discrepancies between EM and fishing log data were caused by inconsistencies in the fishing log data, as some haul information related to the beginning of the haul and other related to the start of the haul.

Haul information inconsistencies, the lack of EM set information for vertical longline sets, and the lack of time information for some fishing log events made EM-fishing log event matching a relatively labour intensive process and resulted in doubtful alignments for 20% events.

Another factor affecting data alignment was that the number of sets recorded in the fishing log did not match the number of events captured by EM for all vessels. A summary of total number of sets per vessel is shown in Table 7. One event from each vessel was not comparable due to a 10-minute time gap for vessel A, manual hauling for vessel B, and not enough pressure to trigger imagery recording for vessel C. Three of the events not recorded in the fishing log for vessel C had no catch; all other events had catch according to EM.

Table 7. Summary of hauling events captured by EM and fishing log.

Vessel ID	Trips	EM Complete Events	Fishing Log Events	Comparable Events
A	7	51	52	51
B	7	37	32	31
C	11	62	62	61
Totals	**25**	**150**	**146**	**143**

Comparison of EM and Fishing Log Catch Observations

In the events compared with fishing log, EM data categorized catch in 14 species, 2 genera, and 3 families, a class, and an unknown fish category. Fishing log catch data consisted of a total of 19 fish catch categories including 16 species, a genus, a family, and a class. The more general classifications by EM correspond to rockfish and flatfish species, while fishing log data assigned more general categories to bycatch species.

Table 8 shows the total piece comparison between EM and fishing log data by species or species category, the observer pieces and their comparison to fishing log data are also provided as a reference. The fishing log data contained 4% less overall fish catch items compared to the EM data, with 2% less items for rockfishes and sablefish respectively. Fishing log counts for flatfish and bycatch such as skates and sharks were considerably lower than EM counts, except for pacific hake. EM was not able to identify 0.2% of the catch and grouped them to unidentified fish or round fish; these are most likely to be sablefish or pacific hake or relatively small catch items like hagfish or invertebrates.

In terms of speciating catch, the fishing log data contains a good representation of rockfish and flatfish species caught according to the observer data. The only two rockfish species found only in one data source were seven pieces of chillipper rockfish in the fishing log data, and one piece of yelloweye rockfish in the EM data. Fishing log data has little speciation of bycatch other than to general species categories such as unidentified skates and sharks.

Total catch by fishing event comparisons are shown in Figure 12. The average fishing log minus EM piece difference for all vessels for horizontal longline gear is 23.2 pieces or 5% of the average number of EM pieces per event, and 0.3 pieces or 1% of the average number of total EM pieces per event for vertical longline. Piece differences per vessel varied considerably, with vessels A and C having an average of 2% of the average number of total EM pieces per event while vessel's C was 11%. The greater overall fishing log to EM difference for vessel C is mainly due to a consistent underestimation of pieces in the fishing log data set for vessel C as compared to EM.

Three extreme outliers were identified in the total catch per event comparisons and are displayed with a red circle on Figure 12. The outlier corresponding to vessel A could not be explained, since the observer data record matched the EM piece counts and no other event for this trip would be a better match to this event based on haul date/time parameters or catch. The two outliers corresponding to vessel B belong to the same trip and it is likely that the event alignment should be reversed, as that would reduce the catch differences from 20 and 32 pieces to 14 and 2 pieces. However, the alignment was kept this way since neither the date/time or gear type parameters justified a different alignment partly due to there being no haul time for one of these events in the fishing log data record.

Table 8. Summary table showing the comparison of fishing log and EM total catch by species or species

Species Name	EM Pieces	Fishing Log Pieces	Total Piece Difference	Percent Difference
Blackgill Rockfish	1876	2328	-452	-24%
Thornyheads (Grouped)*	294	271	23	8%
Aurora Rockfish	0	44	-44	
Bank Rockfish	0	31	-31	
Darkblotched Rockfish	1	14	-13	
Redbanded Rockfish	2	6	-4	
Splitnose Rockfish	0	4	-4	
Red Rockfishes (Unidentified)	594	0	594	
Rockfishes (Unidentified)	1	0	1	
Yelloweye Rockfish	1	0	1	
Chilipepper	0	7	-7	
Total for Rockfishes	**2769**	**2705**	**64**	**2%**
Sablefish	**11654**	**11391**	**263**	**2%**
Dover Sole	16	26	-10	
Petrale Sole	0	7	-7	
Flatfish (Unidentified)	33	0	33	
Rex Sole	0	1	-1	
Total Flatfish	**49**	**34**	**15**	
Brown Cat Shark	285	0	285	100%
Spiny Dogfish Shark	83	67	16	19%
Shark (Unidentified)	0	187	-187	
Blue Shark	5	0	5	
Pacific Sleeper Shark	13	0	13	
Total Sharks	**386**	**254**	**132**	**34%**
Longnose Skate	895	92	803	90%
Sandpaper Skate				
Skate (Unidentified)	45	646	-601	
Total Skates	**940**	**738**	**202**	**21%**
Pacific Hake	53	71	-18	-34%
Spotted Ratfish	3	2	1	
Fish (Unidentified)	31	0	31	
Round Fish (Unidentified)	3	0	3	
Total Other Fish	**90**	**73**	**17**	**19%**
Fish total	**15888**	**15195**	**693**	**4%**

* Thornyheads are grouped in this table as EM did not differenciate shortspine and longspine thornyheads. However, fishing log data had these species broken down and included one piece of longspine thornyhead.

group.

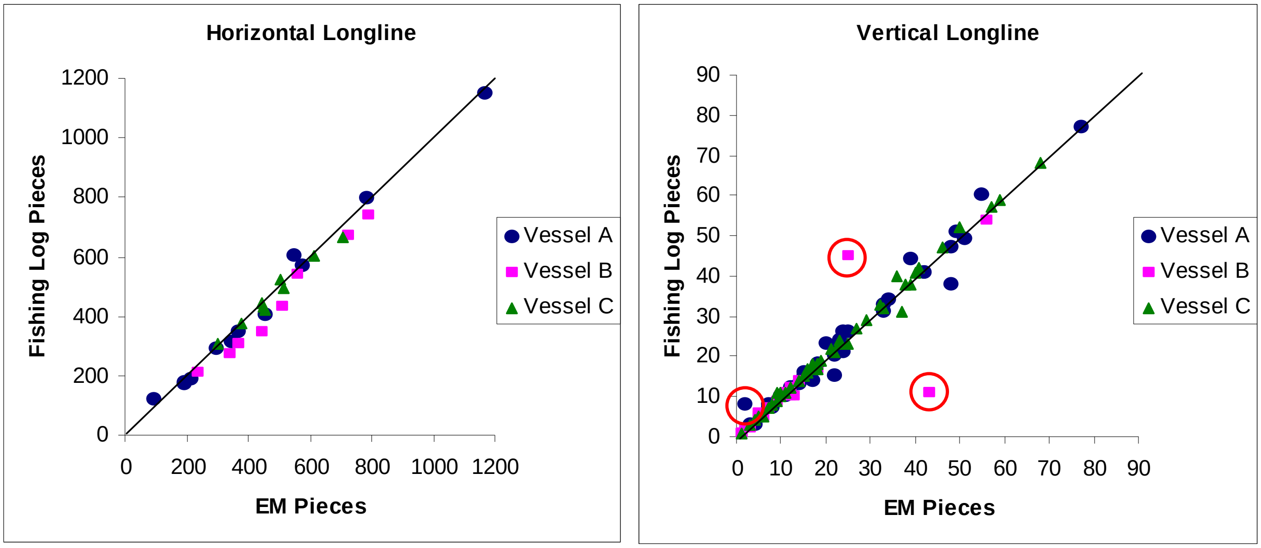

Figure 12. Scatter plot of EM data total catch per haul versus fishing log data total catch per fishing event. Only fish species were considered for this analysis. Outliers displayed with a red circle are described in the text.

Similar to the EM to observer comparisons, piece count differences by species at the fishing event level also follow the trends seen in the total catch results (Figure 13). Blackgill rockfish piece counts were generally higher in the fishing log data set than in EM but all other major species or species groupings piece counts were on average higher in EM than fishing log data. The was very high agreement between fishing log and EM piece counts for rockfishes and sablefish, both within 2% of the average EM pieces per set, but agreement is lower for non-target species like flatfishes and skates, with a few fishing log events not recording them at all.

Comparing fishing log catch by species and species groups showed that the vessel specific differences identified in the total catch comparisons were mostly caused by underestimating bycatch more so than rockfishes and sablefish. However, piece differences per vessel still show variability, with vessels A and C having an average of 2% and 1% less pieces than the average number of rockfish EM pieces per event and 0% and 2% for sablefish, while vessel C average differences were 5% and 7% of rockfish and sablefish EM average pieces per event.

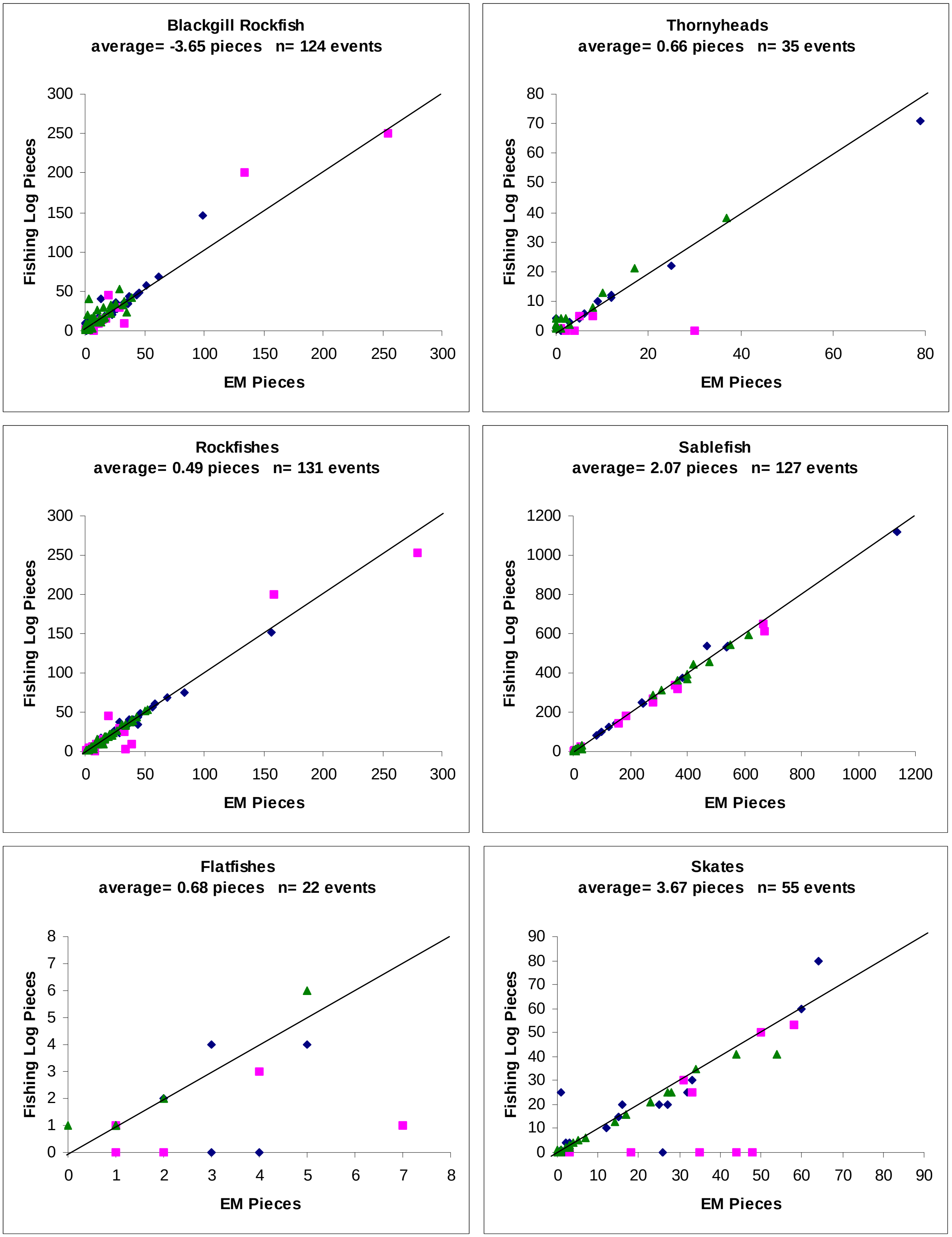

Figure 13. Scatter plots for fishing log data catch versus EM data total catch per fishing event for the most common target species, grouped rockfish, and the most common bycatch species group. Each plot also shows the average EM minus fishing log piece difference and the total number of events available for each comparison.

4. DISCUSSION

4.1 TECHNICAL ASSESSMENT OF EM SYSTEM

EM equipment was deployed on three vessels for a collective total of 25 fishing trips, over 490 vessel hours at sea of EM data, and a total of 155 fishing events captured by EM. Overall sensor data capture success was about 93%. However, if the equipment had not been manually turned off at the beginning and end of the trips, the capture success would have been over 99.99%, with one 2.4-minute gap caused by a brief power interruption.

> **Recommendation #1:** We recommend more rigid guidelines to encourage vessel operators to keep EM systems continually powered while the vessel is at sea.

Sensor performance was high throughout the study, with one incidence of interference with the GPS data signal and one trip for which there was no imagery signal from one camera. Hydraulic pressure sensors worked well on every trip and had a 100% success rate at triggering image recording when the hauler was used for hauling. However, a haul was missed and three were only partially captured by EM due to manual hauling. Also, setting events were not consistently detected by EM for lack of specialized sensors as the gear was directly set from tubs.

> **Recommendation #2:** We recommend extending the run-on time (i.e. the time the EM system continues to record after hydraulic pressure has fallen bellow the pre-set threshold) in future applications in order to ensure that all catch handling operations are captured by EM imagery. We also recommend a different trigger for imagery recording to capture manual gear hauling which would involve speed parameters, as is currently used in hand line vessels on the Groundfish fishery in British Columbia, and/or the use of radio frequency tags on the fishing gear. This would increase the amount of fishing and non-fishing imagery data collected in an effort to ensure imagery recording for all fishing activity.

> **Recommendation #3:** If EM detection of setting activity was a necessary component of at-sea monitoring, the actions described in recommendation #2 would also allow for imagery data recording during setting. Imagery could then be used to confirm sensor data time and location of setting activity.

Another issue concerning technical suitability of EM for these vessels revolves around imagery quality and catch handling. The high proportion of medium and low quality imagery was largely due to crew and observer behaviour and inadequate lighting during night hauls.

> **Recommendation #4:** We recommend developing a timely feedback mechanism from the imagery analysis to the fishermen, to change behaviour so that the fish are easily seen in the imagery, and to EM service technicians, to adjust camera angles to facilitate catch detection as necessary. Changes to the deck lighting can also greatly improve viewing of night hauls while changes to the video recording settings can deliver sharper images with the same amount of frames per second.

The level of industry cooperation strongly affects the success of an EM-based monitoring programme. For this study, vessel owners accepted the use of EM as part of the EFP and showed cooperation in keeping the systems running resulting in high data collection success and excellent sensor performance. The EM system is not tamperproof and can be interfered with in various ways such as shutting off the power, disconnecting or diverting certain sensors, interfering with CCTV cameras, etc. While an EM system is designed to operate autonomously and be tamper evident, a tamperproof design is probably not practical. It is also noteworthy that industry support can considerably improve the success of the technology. For example, small changes to catch handling could considerably improve EM viewer catch identification ability.

> **Recommendation #5:** Future EM work should continue to build support and develop a strong relationship with industry. This will depend on working together with industry to improve data quality, deliver feedback in a format that is useful to industry, and add value to the program by making certain data accessible.

4.2 EFFICACY OF EM FOR CATCH ACCOUNTING

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 the method is that observer data also contain errors (Karp and McElderry, 1999). Observer error was not measured in this study but should be kept in mind in interpreting the results of this study. The lack of agreement between observer and EM catch results can be partly attributed to observer error.

Both observers and EM recorded over 16,000 pieces of catch. Fish catch was lower in observer data than in EM data with -2% overall piece difference and 2% and 1% average haul piece differences in horizontal and vertical longline hauls respectively. These results were consistent with other studies in longline fisheries in British Columbia (McElderry et al., 2003), Antarctic (McElderry et al., 2005), New England (McElderry et al., 2007), New Zealand (McElderry et al., 2008), and Florida (Pria *et al*., 2008).

For rockfishes and sablefish, the main target species groups, EM was very successful at detecting and identifying catch to species groups when compared to observer data with rockfishes having an overall difference of 0% and sablefish –2%(observer-EM). In terms of rockfish identification, EM failed to identify three of the six rockfish species in the observer data, and was not able to speciate thornyheads. Species identification discrepancies were mainly due to the similarities between red rockfish species, sub-optimal imagery quality (a combination of camera angles and image clarity), and viewer inexperience identifying certain species of the area.

> **Recommendation #6:** We recommend exploring the possibility to have locally based EM imagery data viewers who are experienced identifying fish species caught in the area. We also recommend that future studies take into consideration special training on identifying the catch on the imagery data since identifying fish in a video requires a different set of skills

> than that what is usually described in conventional at-sea training material. Imagery collected during this study could be useful for future training needs.

In a full-rockfish retention setting, as is the case in this study's EFP, rockfish identification can be done at the time of landing by a dockside observer. The dockside observer has the advantage of handling the specimens to ensure proper identification. Rockfish discarding can be detected by comparing the number of rockfish counted on the imagery versus the number of rockfish counted at the dock. For this strategy to work, full dockside coverage would be required in the fishery. Non-retention of rockfish in this study was small, with 97% of the catch retained according to observer data. Hence most efforts regarding rockfish identification would be concerning rockfish pieces that drop off the line since there are low catch limits for species like yelloweye rockfish (*Sebastes ruberrimus*) and cowcod (*Sebastes levis*). EM data for this study only had four pieces of "red rockfish", four pieces of thornyheads, and three pieces of 'fish (unidentified)' as drop offs, showing that this is not a very common occurrence.

Flatfishes and bycatch species also had high agreement at the species group level, but EM did not account for the full species diversity as compared to observer data. The above remarks for species identification also apply to bycatch species. Flatfishes and bycatch also accounted for most of the discrepancies in catch disposition. Although total catch per haul had high agreement between observer and EM data, overall EM had more catch recorded as retained compared to observer data likely meaning that EM was able to detect the catch come on board but not its disposition. This was mainly due to catch handling procedures on deck as not all points of discard were in camera view, the observer often discarded catch en mass from a basket, not allowing for proper piece counting, and some catch was left on deck for sampling after the imagery recording had ended for that haul. The best way to deal with this problem would be through the development of more standardized catch handling procedures and modifying the camera positioning to best match these catch handling practices, or compare total catch from EM to dockside counts as the difference can be accounted to discarding. In a project setting where there is no observer on board, some of these problems would be also be minimized as catch would not have to get put aside for sampling and the observer would not be trying to discard catch away from fishing operations to minimize obstruction.

> **Recommendation #7:** We recommend to keep developing clear definitions for catch disposition, data recording for target and non-target catch, and fishing events to allow better comparisons between data collection methods. Clear definitions will also serve a key role in creating strategies to encourage or minimize specific behaviour. For example, having strict regulations to discourage rockfish discarding and clear definitions for what a drop-off is (i.e. only catch that dropped off the gear before the fisherman had taken control over the gear), would help ensure accurate rockfish piece counts by both EM and dockside monitoring.

> **Recommendation #8:** We recommend encouraging fishermen to establish consistent catch handling processes to facilitate catch disposition detection by EM, which would increase efficiency of the imagery review and could also improve efficiency of catch processing. Feedback from EM imagery viewers will play a key part in achieving this.

> **Recommendation #9:** We recommend that EM, dockside, and fishing log data be brought together for analysis as this will help bring further understanding of the whole data package available from the fishery as well as start developing appropriate ways of comparing and presenting the fishery's data.

4.3 EFFICACY OF EM FOR AUDITING FISHING LOG DATA

The greatest challenge with auditing fishing log data will be to improve the alignment between EM and fishing log data. Results on this study show that fishing log haul time information, usually used to align the two data sets, was inconsistent and some fishing events were not recorded in the fishing log at all. These inconsistencies create additional labour and uncertainty when aligning the two data sets.

> **Recommendation #10:** Improved date and time collection can be achieved by providing in season feedback to the fishermen to allow for better fishing log to EM fishing event alignment. Alignment between the two data sets can also be aided through the use of the 'event marker' function available in the EM system to 'mark' the events in the EM data record, and the use of electronic fishing logs.

Fishing log and EM data had very high agreement for target species catch records with EM, with fishing log underestimating both rockfish and sablefish pieces per set by 2% of the EM average piece counts. Fishing log also showed similar levels of speciation of rockfish species as compared to observer data. The fishing log layout and instructions purposely concentrated on the recording of target species as those have the greatest impact on the management of the fishery. It was thought that adding emphasis to bycatch might have had negatively impacted the ability of fishermen to account for target species, especially rockfish. This, as well as a natural tendency to pay less attention to bycatch species compared to target species, is likely the reason for the low agreement seen between EM and fishing log counts of bycatch.

> **Recommendation #11:** We recommend increasing the fishing log emphasis on collecting bycatch data, if managers wish to see bycatch data quality increase in fishing log records. **.**

Data from this study show that there are slight differences between the fishing log data of one vessel versus the others as compared to EM, while such a trend is absent in the observer to EM comparison. This points to the fact that accurate catch accounting was possible on all three vessels, but for some reason the methods used for filling out the log book on one vessel consistently yielded lower catch numbers than those of the other vessels.

> **Recommendation #12:** We recommend delivering timely feedback to the fishermen in the form of an audit to improve data quality and individual accountability. Fishing effort and catch accounting accuracy is likely to improve with specific feedback based on comparisons of fishing log data to other data source such as EM and dockside observers or a combination of the above, as fishermen may require to experiment with different methods for recording these data. However, data obtained in this EFP shows that accurate fishing effort and catch accounting can be obtained from fishing logs.

4.4 CONCLUSIONS

Future work with the use of EM technology with the fixed gear fishery in Morro Bay and other parts of California should start with discussions with stakeholders since the monitoring program must to meet the needs of managers, while buy-in from industry is key to the success of the program. This project has led to three key conclusions for moving forward in developing an audit-based model of fishing log data:

1. EM has been demonstrated to be an effective tool for at sea monitoring, delivering fishing effort and catch data comparable to on-board observers. There is likely no need for continuing to concentrate future efforts on comparing EM data with observer data. Next steps should concentrate on developing a comprehensive monitoring program involving tools such as fisher lob books, dockside monitoring, EM, and observers as necessary.

2. An audit-based monitoring program, with fishing logs providing fishing effort and catch data and EM being used as a tool to audit the data provided in the fishing log, is likely the most cost-efficient way to provide full at-sea monitoring of the fixed gear fishery in Morro Bay and other parts of California. Further emphasis on an audit-based monitoring program requires the design of an audit framework that includes a scoring system, in-season reporting, and feedback processes.

3. Cost efficiency of an audit-based EM program will require a certain amount of local infrastructure. This study successfully accomplished a partnership using an on-site EM technician to monitor EM system performance, schedule services, and retrieve data from the vessels, archive and ship the necessary data, and remove the equipment off the vessels at the end of the field effort period. This is a promising approach for future EM projects since it could offer a faster turn around of feedback and reporting to managers and fishermen and allows for prompt response in case of equipment problems. Similarly, locally based EM imagery viewers would likely increase species identification success as well as offer many of the advantages described for EM service technicians.

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APPENDIX I – EM TECHNICAL SPECIFICATIONS

Overview of the EM System

The EM systems operate on the ship's power to record imagery and sensor data during each fishing trip. The software can be set to automatically activate image recording based on preset indicators (e.g. hydraulic or winch threshold levels, geographic location, time of day,). The EM system automatically restarts and resumes program functions following power interruption, or if a software lockup is detected. The system components are described in the following sections.

Control Box

The heart of the electronic monitoring system is a metal tamper-resistant control box (approx. 15x10x8" = 0.7 cubic feet) that houses computer circuitry and data storage devices. The control box receives inputs from several sensors and up to four CCTV cameras. The control box is generally mounted in the vessel cabin and powered from the vessel electrical system. The user interface provides live images of camera views as well as other information such as sensor data and EM system operational status. The interface has been designed to enable vessel personnel to monitor system performance. If the system is not functioning properly, technicians can usually troubleshoot the problem based on information presented in the screen display.

EM systems use high capacity video hard drives for storage of video imagery and sensor data. The locked drive tray is removable for ease in replacement. Depending upon the number of cameras, data recording rates, image compression, etc., data storage can range from a few weeks to several months. For example, using the standard recording rate of 5 frames per second, data storage requirements are 60-100 megabytes per hour, depending upon the image compression method. Using a four-camera set up and 500-gigabyte hard drive, the EM system would provide continuous recording for 52-86 days.

Figure A1. EM control box and user interface installations on two different vessels.

EM Power Requirements

An EM control box should be continuously powered (24hr/day) while the vessel is at sea. The EM system can use either AC or DC electrical power however DC is recommended. In the case of AC power, the control box is generally fitted with a universal power supply (UPS), to ensure continuous power supply. The recommended circuit capacity for an EM system is 400 watts if using 110-volts AC, or 20 amps with 12-volts DC. The EM system amperage requirements vary from about 6 amps (at 12-volts DC) when all cameras are active, to less than 3 amps without cameras (sensors only), and about 20 milliamps during the 'sleep cycle'. The EM system continuously monitors the DC supply voltage and can be set to initiate a sleep cycle to save power when the vessel is idle and the engine is off, and shut off completely when vessel power drops below critical levels. During the sleep cycle the EM system box will turn on for 2 minutes every 30 minutes to check status and record sensor data. The EM system will resume functions when the engine re-starts.

CCTV Cameras

Waterproof armored dome cameras are generally used (Figure A2), as they have been proven reliable in extreme environmental conditions on long-term deployments on fishing vessels. The camera is lightweight, compact and quickly attaches to the vessel's standing structure with a universal stainless steel mount and band straps. In general, three or four cameras are required to cover fish and net handling activity and areas around the vessel. In some cases it is necessary to install a brace or davit structure in order to position cameras in the desired locations.

Color cameras with 480 TV lines of resolution and low light capability (1.0 lux @ F2.0) are generally used. A choice of lenses is available to achieve the desired field of view and image resolution. The cameras have an electronic iris that adjusts automatically to reduce the effects of glare or low light levels on image quality. The output signal is composite video (NTSC) delivered by coaxial cable to the control box and converted to a digital image (480 x 640 pixel resolution). Electrical power (12 volt DC) is carried to the camera on conductors packaged in a single sheath with the coaxial cable.

Figure A2 CCTV camera installations on three different fishing vessels. Each camera has a mounting bracket and stainless steel mounting straps.

Figure A3 Installation showing a swing arm camera mount.

GPS Receiver

Each EM system carries an independent GPS, integrated receiver and antenna, which is wired directly to the control box (there is no attached display interface). The GPS receiver is fixed to a mount on top of the wheelhouse away from other vessel electronics (Figure A4).

The GPS receiver is a 12 channel parallel receiver, meaning it can track up to 12 GPS satellites at once while using 4 satellites that have the best spatial geometry to develop the highest quality positional fix. The factory stated error for this GPS is less than 15 metres (Root Mean Square). This means that if the receiver is placed on a point with precisely known coordinates, a geodetic survey monument for example, 95% of its positional fixes will fall inside a circle of 15 metres radius centered on that point.

The GPS time code delivered with the positional data is accurate to within 2 seconds of the Universal Time Code (UTC = GMT). The EM control box software uses the GPS time to chronologically stamp data records and to update and correct the real time clock on the data-logging computer.

When 12 volts DC is applied the GPS delivers a digital data stream to the control box that provides an accurate time base as well as vessel position, speed, heading and positional error. Speed is recorded in nautical miles per hour (knots) to one decimal place and heading to the nearest degree.

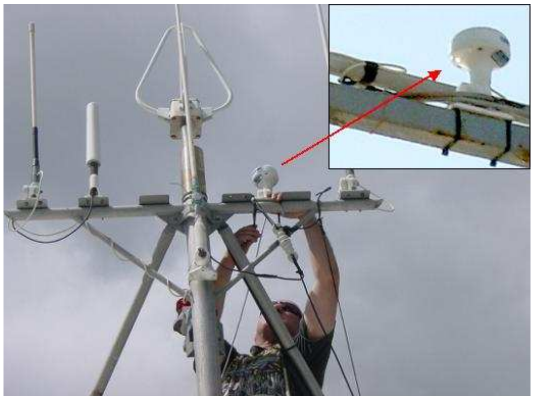

Figure A4. GPS receiver installed in the rigging of a vessel and a close up photograph of the mounted GPS.

Hydraulic Pressure Transducer

An electronic pressure transducer is generally mounted into the vessel hydraulic system (Figure A5) to monitor the use of fishing gear (e.g., winches, line haulers, etc.). The sensor has a 0 to 2500 psi range, high enough for most small vessel systems, and a 15,000 psi burst rating. The sensor is fitted into a ¼ inch pipe thread gauge port or tee fitting on the pressure side of the hauler circuit. An increase in system pressure signals the start of fishing operations such as longline retrieval. When pressure readings exceed a threshold that is established during system tests at dockside, the control box software turns the digital video recorder on to initiate video data collection.

Drum Rotation Sensor

A photoelectric drum rotation sensor is generally mounted on either the warp winch or net drum to detect activity as vessels often deploy gear from these devices without hydraulics. The small waterproof sensor is aimed at a prismatic reflector mounted to the winch drum to record winch activity and act as a secondary video trigger. (Figure A5).

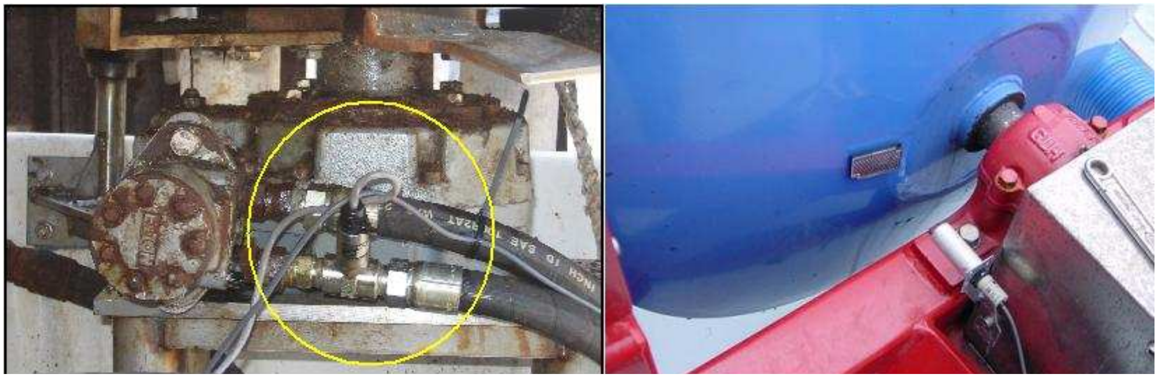

Figure A5. A hydraulic pressure sensor installed on the supply line of a vessel line hauler (left). Drum rotation sensor (right) mounted on pelagic longline vessel, showing optical sensor and reflective surface.

APPENDIX II – TOTAL CATCH BY OBSERVER AND EM METHODS

Table II.1 Total catch by species as recorded by observer and EM methods with two indices of catch abundance in observer data.

Species Name	Percent Occurrence	Average Pieces Per Set	Observer Pieces	EM Pieces	Total Piece Difference	Percent Difference
Blackgill Rockfish	82.0%	19.02	2340	1882	458	20%
Thornyheads (Grouped)*	26.0%	8.21	320	295	25	8%
Aurora Rockfish	16.7%	2.00	50	0	50	
Bank Rockfish	5.3%	4.88	39	0	39	
Darkblotched Rockfish	6.0%	1.67	15	1	14	
Redbanded Rockfish	3.3%	1.20	6	2	4	
Splitnose Rockfish	2.7%	1.00	4	0	4	
Red Rockfishes (Unidentified)			0	604	-604	
Rockfishes (Unidentified)			0	1	-1	
Yelloweye Rockfish			0	1	-1	
Chilipepper			0	0	0	
Total for Rockfishes			**2774**	**2786**	**-12**	**0%**
Sablefish	**84.7%**	**93.43**	**11866**	**12068**	**-202**	**-2%**
Dover Sole	11.3%	2.53	43	16	27	
Petrale Sole	4.0%	1.17	7	0	7	
Flatfish (Unidentified)			0	34	-34	
Rex Sole						
Total Flatfish			**50**	**50**	**0**	**0%**
Brown Cat Shark	11.3%	11.53	196	285	-89	-45%
Filetail Cat Shark	8.0%	7.83	94	0	94	
Spiny Dogfish Shark	24.7%	2.19	81	84	-3	-4%
Shark (Unidentified)	4.7%	1.57	11	0	11	
Blue Shark	4.0%	1.00	6	5	1	
Pacific Sleeper Shark	0.7%	1.00	1	13	-12	
Brown Smoothhound Shark	0.7%	1.00	1	0	1	
Cat Unid Shark	0.7%	1.00	1	0	1	
Total Sharks			**391**	**387**	**4**	**1%**
Longnose Skate	34.7%	16.67	867	922	-55	-6%
Sandpaper Skate	5.3%	1.63	13	0	13	
Skate (Unidentified)			0	45	-45	
Total Skates			**880**	**967**	**-87**	**-10%**
Pacific Hake	23.3%	2.17	76	53	23	30%
Hagfish Unid	3.3%	1.20	6	0	6	
Spotted Ratfish	2.0%	1.00	3	3	0	
Fish (Unidentified)			0	32	-32	
Round Fish (Unidentified)			0	3	-3	
Total Other Fish			**85**	**91**	**-6**	**-7%**
Tanner Unid Crab	4.0%	1.17	7	6	1	
Brittle/Basket Star Unid	0.7%	3.00	3	0	3	
Anemone Unid	0.7%	1.00	1	0	1	
Tanneri Tanner Crab	0.7%	1.00	1	0	1	
Invertebrates (Unidentified)			0	2	-2	
Crabs			0	1	-1	
Total Invertebrates			**12**	**9**	3	
Mud rocks kelp etc.	0.7%	1.00	1	4	-3	
Overall Total			**16058**	**16358**	**-300**	**-2%**

* Thornyheads are grouped in this table as EM did not differenciate shortspine and longspine thornyheads. However, observer and fishing log data had these species broken down and included one piece of longspine thornyhead.

APPENDIX III – TOTAL CATCH BY EM AND FISHING LOG METHODS

Table II.1 Total catch by species as recorded by EM and Fishing Log methods with two indices of catch abundance in EM data, also showing observer catch as an additional reference for fishing log accuracy

Species Name	EM Pieces	Fishing Log Pieces	EM-FLog Piece Difference	EM-Flog Percent Difference	Observer Pieces	Obs-Flog Piece Difference	Obs-Flog Percent Difference
Blackgill Rockfish	1876	2328	-452	-24%	2327	-1	0%
Thornyheads (Grouped)*	294	271	23	8%	317	46	15%
Aurora Rockfish	0	44	-44		50	6	12%
Bank Rockfish	0	31	-31		38	7	
Darkblotched Rockfish	1	14	-13		15	1	
Redbanded Rockfish	2	6	-4		6	0	
Splitnose Rockfish	0	4	-4		4	0	
Red Rockfishes (Unidentified)	594	0	594		0	0	
Rockfishes (Unidentified)	1	0	1		0	0	
Yelloweye Rockfish	1	0	1		0	0	
Chilipepper	0	7	-7		0	-7	
Total for Rockfishes	**2769**	**2705**	**64**	**2%**	**2757**	**52**	**2%**
Sablefish	**11654**	**11391**	**263**	**2%**	**11479**	**88**	**1%**
Dover Sole	16	26	-10		42	16	
Petrale Sole	0	7	-7		7	0	
Flatfish (Unidentified)	33	0	33		0	0	
Rex Sole	0	1	-1		0	-1	
Total Flatfish	**49**	**34**	**15**	**31%**	**49**	**15**	**31%**
Brown Cat Shark	285	0	285	100%	196	196	
Filetail Cat Shark	0	0	0		94	94	
Spiny Dogfish Shark	83	67	16	19%	80	13	
Shark (Unidentified)	0	187	-187		11	-176	
Blue Shark	5	0	5		6	6	
Pacific Sleeper Shark	13	0	13		1	1	
Brown Smoothhound Shark	0	0	0		1	1	
Cat Unid Shark	0	0	0		1	1	
Total Sharks	**386**	**254**	**132**	**34%**	**390**	**136**	**35%**
Longnose Skate	895	92	803	90%	845	753	
Sandpaper Skate					13	13	
Skate (Unidentified)	45	646	-601		0	-646	
Total Skates	**940**	**738**	**202**	**21%**	**858**	**120**	**14%**
Pacific Hake	53	71	-18	-34%	76	5	
Hagfish Unid					6	6	
Spotted Ratfish	3	2	1		3	1	
Fish (Unidentified)	31	0	31		0	0	
Round Fish (Unidentified)	3	0	3		0	0	
Total Other Fish	**90**	**73**	**17**	**19%**	**85**	**12**	**14%**
Tanner Unid Crab	6	4	2		7	3	
Brittle/Basket Star Unid	0	0	0		3	3	
Anemone Unid	0	1	-1		1	0	
Tanneri Tanner Crab	0	0	0		1	1	
Invertebrates (Unidentified)	2	0	2		0	0	
Crabs	1	0	1		0	0	
Total Invertebrates	**9**	**5**	**4**		**12**	**7**	
Mud rocks kelp etc.	4	0	4		1	1	
Overall Total	**15897**	**15200**	**697**	**4%**	**15630**	**430**	**3%**

* Thornyheads are grouped in this table as EM did not differenciate shortspine and longspine thornyheads. However, observer and fishing log data had these species broken down and included one piece of longspine thornyhead.