USING ELECTRONIC MONITORING TO ESTIMATE REEF FISH CATCH ON BOTTOM LONGLINE VESSELS IN THE GULF OF MEXICO: A PILOT STUDY

By

Maria Jose Pria
Howard McElderry
Morgan Dyas
Paul Wesley

Archipelago Marine Research Ltd.
525 Head St.
Victoria, British Columbia, Canada
V9A 5S1
www.archipelago.ca

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ABSTRACT

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Archipelago Marine Research Ltd. was subcontracted by MRAG to carry out a study to test the feasibility of developing a monitoring system that would use Electronic Monitoring (EM) to satisfy the data needs of the reef longline fishery in the Gulf of Mexico. 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 six vessels for a total of over 148 days at sea. EM and observer fishing event and catch data were available for comparison for a total of 218 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, resulting in 65% overall sensor data completeness. EM sensor data provided accurate vessel position information and enabled identification of setting and hauling events. In terms of catch, both EM and observer methods were numerically within 2.7% of each other and EM detected and speciated two of the three turtles recorded in the observer data. Catch identification comparisons between observer and EM methods were generally good with 80% of catch pairing comparisons having a positive match on a hook-by-hook analysis. Some species showed identification discrepancies between observer and EM, shark species being predominant. These discrepancies were often offset when results from similar species were grouped, usually within the same genus or family. EM was not able to reliably determine catch discarding due to inconsistent catch handling and limitations from camera views. Overall, results of this study suggest that EM shows promise for collecting fishing activity spatial-temporal data and assessing catch composition and further work is needed to determine if the technology could provide reliable catch disposition data.

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1. INTRODUCTION

The need to provide better bycatch estimates in the Gulf of Mexico commercial longline reef fish fishery is the third action item priority for FY07-FY08 in the Southeast Region's Bycatch Implementation Plan. In partnership with industry, the NOAA Fisheries Service Southeast Fisheries Science Center (SEFSC) and Southeast Regional Office (SERO) are looking for cost-effective and reliable system options for monitoring bycatch, release mortality, handling of fishes, and other shipboard practices aboard bottom longline vessels in the Gulf of Mexico.

NOAA Fisheries identified a number of reasons why video based electronic monitoring (EM) should be tested in the Southeast Region. Currently, data on bycatch for the reef fish fishery in the Gulf of Mexico are provided primarily through a logbook program. All fishermen are required to complete logbooks but NOAA Fisheries selects 20% of fishermen to fill out logbooks on discarded catch. An observer program provides additional data, but coverage is limited to 1% and some boats may present safety concerns due to limited space to house an observer. Funds to expand the program are limited, and the small-scale sector of the fishery does not generate sufficient income for industry to fund the program. Therefore, NOAA Fisheries wishes to consider methodology that could reduce the need for observers but would improve data quality and quantity at reduced costs. NOAA Fisheries needs information that allows for the characterization of the entire catch that occurs in the fishery (retained and released), which would provide scientists and managers with useable and relevant information for inclusion in stock assessments, better data on ecosystems, and an opportunity to demonstrate the effect of regulations on fish released at sea.

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).

SEFSC contracted with MRAG Americas, Inc. and Archipelago to carry out a study to test the feasibility of developing a monitoring system that would use EM to satisfy the data needs of the longline fishery. The primary goal of the study was to evaluate the feasibility of using video monitoring in the Gulf of Mexico 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 video provide images of sufficient resolution and clarity to allow a video analyst to accurately record the number of hooks and counts of target and non-target species?

- Can electronic monitoring video provide images of sufficient resolution and clarity to allow a video analyst to identify species?

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

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

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 a photoelectric winch rotation sensor, and up to three waterproof armored dome closed circuit television (CCTV) cameras (Figure 1). 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.

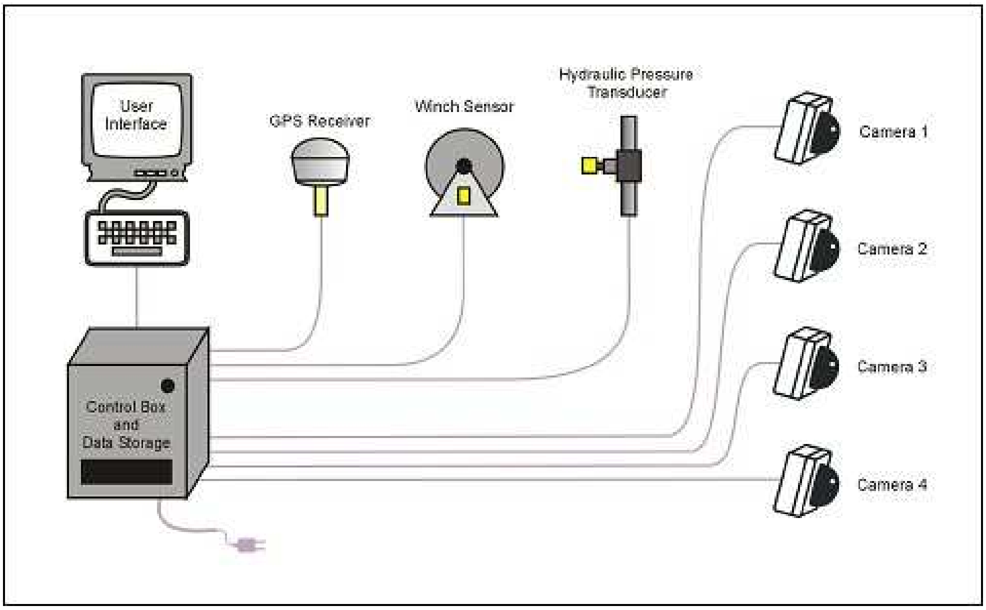

Figure 1. Schematic diagram of the electronic monitoring system, which can record video data from up to four cameras per vessel.

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. The optical winch rotation sensor was mounted onto the groundline drums and was used to detect winch activity, indicating deployment or retrieval of the long line. 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. 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. Image capture occurred only during fishing operations, beginning when winch rotations were sensed or when hydraulic pressure exceeded base threshold levels. Image recording ended about 10 minutes after both of these sensor triggers ceased except for vessel E where imagery recording only ran on for 5 minutes. 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

Project planning began in December 2007 with a meeting in St. Petersburg, Florida. The meeting was facilitated by MRAG and attended by interested industry representatives, National Marine Fisheries Service (NMFS) staff representing both the Gulf of Mexico Reef Fish Observer Program and SERO, and Archipelago. The meeting included an overview presentation of EM technology and discussions surrounding project timelines, vessel requirements, project communications, and observer coverage levels. A follow-up conference call between Archipelago and the observer program clarified EM and observer data collection methods and outlined how observers would be briefed and trained for the project.

In order to compare data collected by EM with data collected by observers, the project design targeted 50% of the fishing trips with EM systems aboard for onboard observer coverage. In addition to their regular duties, observers were tasked with monitoring the status of the EM system and collecting hook level catch data for a minimum of two sets per trip. The observer program area supervisor was trained in EM system function during the early part of the installation effort and was responsible for briefing observers on EM prior to deployments.

NMFS staff at SERO were responsible for selecting the most appropriate participants for the project from a pool of vessels that had been volunteered by their owners. Archipelago staff then communicated with the vessel owners directly to schedule the EM system installation, servicing, and removals. The six vessels participating in the project were typical of those operating in the

Gulf of Mexico reef fish fishery (Figure 2) and all hailed from Southwest Florida, five from the port of Cortez and one in from the port of Ruskin. Fishing trips were planned to last about 14 days and the vessels ranged between 40 and 50 feet in length.

Figure 2. Two representative longline vessels that participated in the project. Vessels are shown transiting the harbour in Cortez, Florida.

The field component began in the second week of March 2008 and continued through the first week in May 2008. An Archipelago EM technician installed the EM systems on all the vessels and remained on site until the last week in April. At the time of the EM technician's departure, four EM systems were still at sea collecting data. An arrangement was made with the owner of the vessels to have the remaining systems removed. The return shipment of EM equipment and the delivery of data were organized by NMFS staff at SERO. All data collected during the project were treated with complete confidentiality.

Installations began with the EM technician and the vessel's captain discussing EM system component placement, wire routing, fishing deck operations, and the vessel's power supply. EM system components were installed in similar locations on all vessels. The GPS receivers were fixed to existing structure above the cabin roof, hydraulic pressure and winch rotation sensors were both applied to the groundline drum (Figure 3) and the control box, monitor and keyboard were all secured in the vessel cabin. Power to the EM system was supplied by the vessel's 12 Volt batteries. 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.

Three cameras were installed on each vessel with the objective of capturing imagery of catch, catch handling, and catch disposition (Figure 4). A deployable outboard camera mount was fabricated and attached to the deck roof. Two cameras were fixed to this mount, one with a close-up view of the longline between the waterline and the crewmember handling the gear and the other with a wide-angle view of activity on both sides of the rail. The third camera was aimed at the cleaning station where both retained and discarded catch remained in view for several seconds. Camera views corresponding to the camera placements shown in Figure 4 are illustrated in Figure 5.

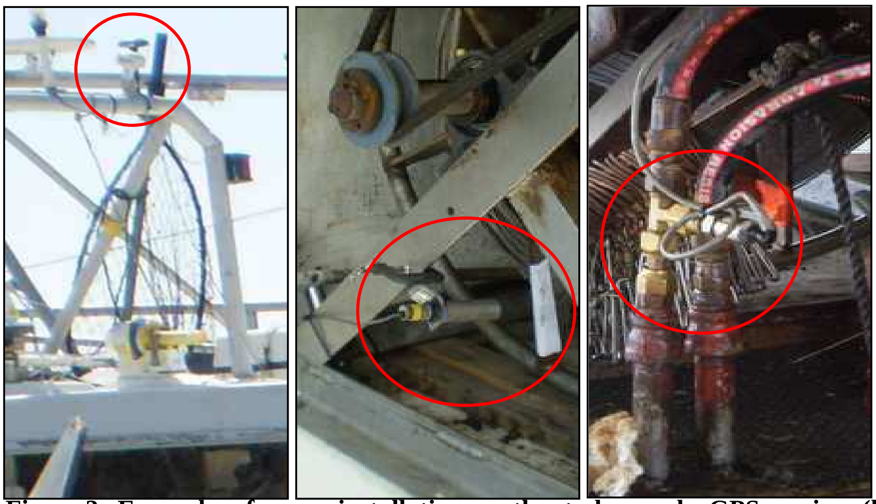

Figure 3. Examples of sensor installations on the study vessels: GPS receiver (left), winch rotation sensor (center), and hydraulic pressure sensor (right).

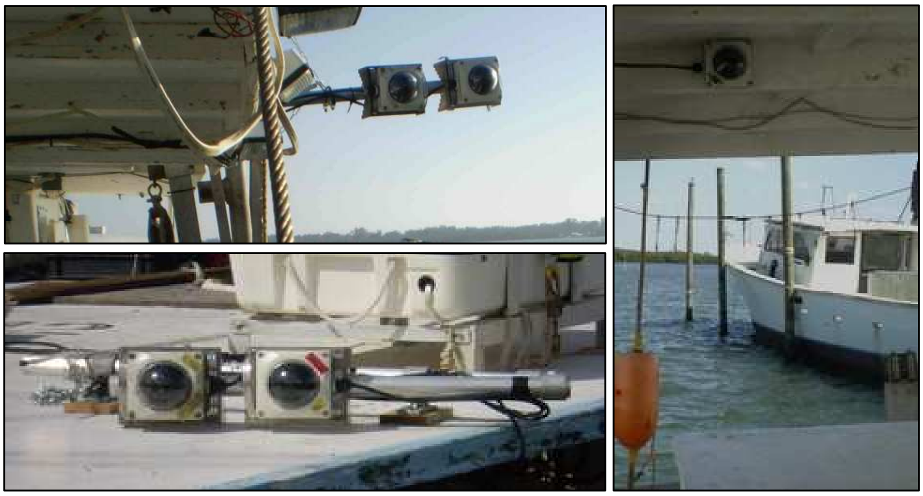

Figure 4. Cameras covering the rail area on the fabricated outboard mount shown in the deployed position (top left) and retracted position (bottom left) and the third camera covering the cleaning station (right).

Vessels participating in the pilot project carried an EM system for two fishing trips each. The EM technician monitored EM system performance during service events between the fishing trips. Servicing included several operational checks of the equipment, cursory analysis and retrieval of the data collected and a replenishment of empty media configured for the next trip. During the initial service events, adjustments to 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 website and imagery data were packaged and sent back to Archipelago's head office in Victoria, BC.

Figure 5. Sample camera imagery from one of the participating vessels, showing simultaneous close-up (top left) and wide-angle (top right) views of the longline coming aboard, and the cleaning station (bottom).

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 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 once all of the EM data were interpreted to ensure unbiased interpretation.

Sensor Data Interpretation

Raw sensor data (GPS, hydraulic, and winch rotation) 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 6. Vessel speed, hydraulic pressure, and winch sensor 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 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. The GPS receiver reports vessel position, speed, heading, and time (UTC, converted to Eastern Standard Time). Poor GPS receiver signal is usually the result of an intermittent GPS signal or interference from other vessel electronics. 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.

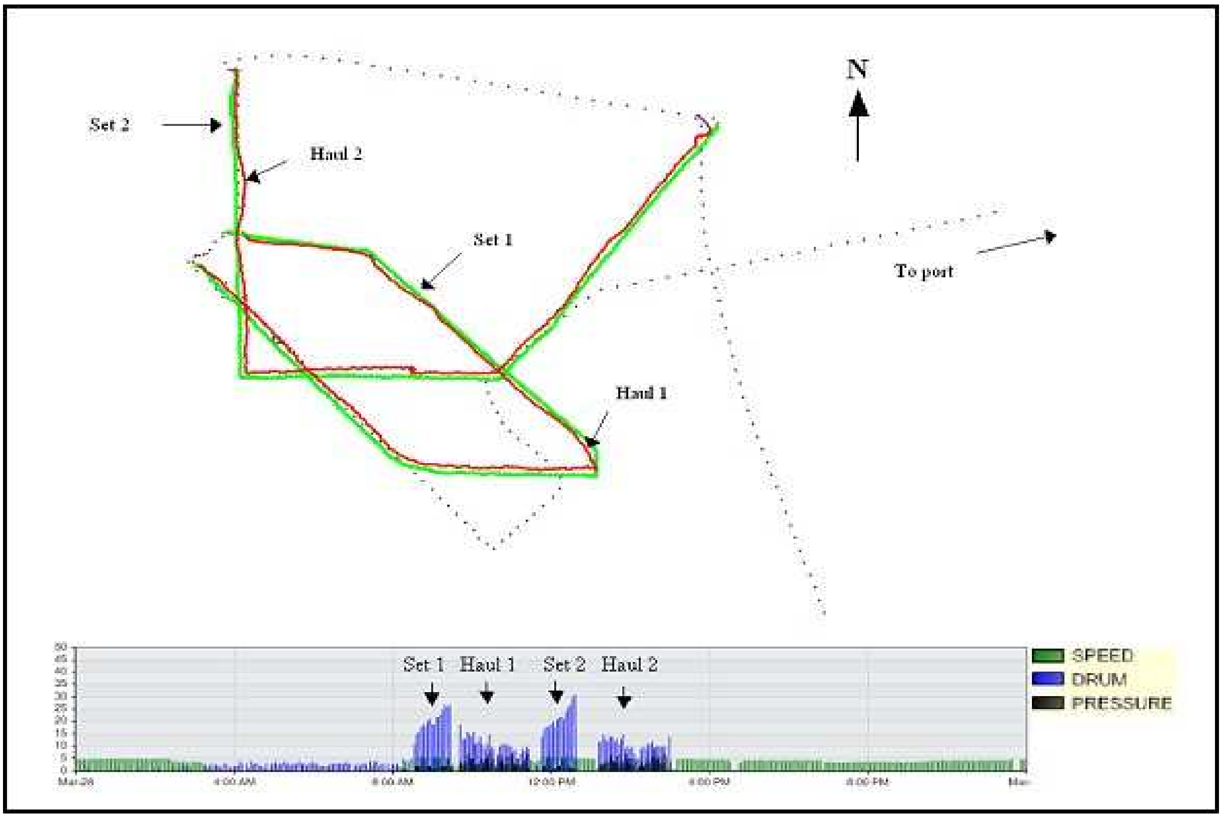

Figure 6. Example of sensor data from one of the project vessels for a period of 24 hours. The time series graphs (lower) show vessel speed (knots), hydraulic pressure (psi), and winch rotation (average counts per minute). Setting activity is associated to high drum rotation counts, low hydraulic pressure, 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.

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 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 interpretation was only done for trips that also carried a human observer on board. 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. Although image data were recorded during gear setting events, none of this imagery was reviewed, as the project was targeting imagery processing for hauling events only.

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). A count of blank hooks (i.e. hooks with no catch) was also done for those hauls for which the observer had done catch data collection at the hook level.

Image quality was assessed as an average for each haul event viewed, according to the rank scale illustrated in Figure 7 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 significantly diminished.

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

The main EM imagery data viewer involved with image interpretation had extensive experience with the identification of Northeast Pacific fish fauna but no experience identifying fish species from the Gulf of Mexico or previous knowledge of the catch diversity in the bottom longline fishery involved in this study. A reference text (Hoese and Moore, 1998) was used to aid in the identification of fish catch items.

Figure 7. Example imagery to illustrate the different image quality assessments. From left to right: high, medium, low, and unusable. 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 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 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, imagery, and observer 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 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. Analysis of hook-based data also required an additional alignment process since the observer and EM data sets almost never matched up hook-for-hook. Alignment was forced by copying each data set into the same spreadsheet where row adjustments in one data set could be made without displacing the order of the other. Changes were only made to the EM data set as the observer data is considered the standard in all EM data comparisons. Changes made were of two categories: adding and removing blank hooks and changing the order of a blank hook and a catch records. Alignment was not an arbitrary process and no catch records were added, deleted, or modified. Without alignments, the two data sets almost never matched up, resulting in very few true-paired observer-EM observations. For example, in the unaligned data set, a catch item such as a red grouper lining up with a blank hook represented a meaningless catch pair. The alignment process primarily consisted of adjusting the number or order of blank hooks to align the obvious catch patterns, thus creating meaningful catch pairs. Order changes typically occurred within a cluster of three records. Invertebrate catch was ignored for this analysis.

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 two-month period involving six vessels, each completing two fishing trips for a total of 148 days at sea. Every vessel also carried an observer for at least one trip for a total of seven trips with both observer and EM data available for comparison. EM collected a total of over 2,000 hours of sensor data at sea, and 645 hours of haul imagery associated with 325 fishing events.

Sensor data, which should have been recorded continuously from the start to the end of each fishing trip, was incomplete for all trips in various degrees. The overall sensor data capture success was 65%, ranging from 14 to 97% per trip. Gaps in the sensor data record occurred most commonly at night and during the vessel's final transit from the fishing grounds to port. About 92% of the data loss was caused by vessel operators turning off power to the EM system, with GPS signal interference and software lockups accounting for the remainder of the data loss. GPS signal interference was an issue on trip 1 on Vessel C and was addressed by moving the GPS receiver away from the vessel's satellite radio antenna. Software lock up was an issue on trip 2 on Vessel F and was probably a consequence of the repeated manual power interruptions to the EM system, which were routinely done by this vessel.

Sensor performance was high across all vessels, with three different trips on 3 different vessels experiencing incomplete data collection from one of the sensors (Table 3). The GPS problem was caused due to interference with the vessel's satellite radio as discussed earlier. The hydraulic pressure transducer problem occurred half way through the first trip of Vessel E and resulted in nearly seven days of data lacking hydraulic pressure readings. The winch rotation sensor malfunction occurred on the first trip of Vessel B where winch sensor data were recorded sporadically through the data set but not during fishing events. On both occasions, fishing activity was still distinguishable using speed and other sensor data and imagery recording was adequately triggered by the functioning sensor resulting in no loss of imagery data due to the sensor failure. All three sensor malfunctions were identified and corrected by the EM technician before the vessel went out on their second trip.

Vessel ID	Trip Number	Observer Present	Trip Start Date	Trip length (days)	Sensor Data Collected (hours)	Sensor Data Completeness (%)	Haul Imagery Captured (hours)	Hauls Captured
A	1		17-Mar-08	19.03 *	444.50	97.32%	99.53	32
	2	Yes	12-Apr-08	17.65 *	337.44	79.66%	74.98	24
Vessel Totals				**36.68**	**781.94**	**88.82%**	**174.52**	**56**
B	1		22-Mar-08	2.28 *	29.66	54.21%	1.69	1
	2	Yes	20-Apr-08	11.55 *	142.34	51.35%	55.61	31
Vessel Totals				**13.83**	**172.00**	**51.82%**	**57.29**	**32**
C	1	Yes	13-Mar-08	14.24 *	171.41	50.16%	47.27	26
	2	Yes	12-Apr-08	12.49	170.12	56.75%	62.40	35
Vessel Totals				**26.73**	**341.54**	**53.24%**	**109.67**	**61**
D	1		12-Mar-08	7.45 *	166.63	93.20%	15.12	7
	2	Yes	27-Mar-08	14.48	243.56	70.09%	86.87	51
Vessel Totals				**21.93**	**410.20**	**77.94%**	**101.98**	**58**
E	1		26-Mar-08	11.84	169.82	59.76%	58.07	35
	2	Yes	21-Apr-08	10.30	132.73	53.69%	49.58	30
Vessel Totals				**22.14**	**302.55**	**56.94%**	**107.65**	**65**
F	1	Yes	13-Mar-08	16.35 *	274.23	69.88%	77.14	39
	2		07-Apr-08	10.59 *	37.38	14.71%	16.88	14
Vessel Totals				**26.94**	**311.61**	**48.19%**	**94.02**	**53**
Overall Totals	**12**	**7**		**148.25**	**2319.83**	**65.20%**	**645.13**	**325**

* Trip duration estimated as EM system was powered down for transit back to port. Half a day was added as an estimate of transit to port, based on transit times from complete trips.

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

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

Sensor Performance	GPS Receiver	Hydraulic Pressure Transducer	Winch Rotation Sensor
Complete	11	11	11
Incomplete	1	1	1
No Data	0	0	0
Total number of trips	**12**	**12**	**12**

Details on the hauling events for the seven observed trips are shown in Table 4. The table 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 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 data were collected for a total of 245 hauls, out of which 219 were fully captured by EM. This included six hauls with corrupt video files that were recovered fully. Only EM imagery data from hauls completely captured by EM were reviewed, as the incomplete hauls would have resulted in inconclusive catch comparisons. The number of hauls included in the analysis per vessel varied significantly, with two vessels contributing 50% of the hauls available for interpretation.

Incomplete or missed EM data from fishing events was strictly due to manual EM system power interruptions. This resulted in nine hauls being missed and 17 hauls being partially captured by EM. Out of the 17 hauls partially captured by EM, three resulted from vessel operators turning off the EM system before the haul had ended and 14 resulted from turning off the EM system shortly after the haul had ended. Power interruptions during image recording can result in corrupted files because files are open at the time of power failure. Although there were complete sensor data for hauls where a manual power down had occurred shortly after the end, imagery data were incomplete as the last video clip file did not close properly. An attempt was made to repair any corrupt image files with varying degrees of success.

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

Vessel ID	Trip Number	Observer Recorded Hauls	EM Complete	EM Incomplete	EM Missed
A	2	24	24	0	0
B	2	31	28	3	0
C	1	33	24	2	7
C	2	37	35	0	2
D	2	51	51	0	0
E	2	30	28	2	0
F	2	39	29	10	0
	Total Hauls	**245**	**219**	**17**	**9**

Image quality ratings for all hauls reviewed are shown in Table 5. Image quality was rated as medium for 67% of the hauls reviewed. The main issue surrounding these hauls was the EM imagery viewer's perception of difficulty determining catch disposition, caused by a combination of catch handling and camera views. Low image quality was assigned to 26% of the hauls analyzed due to difficulties determining catch dispositions as well as lower than expected image clarity. All evening hauls, except for one vessel, had insufficient and/or poorly placed lighting for EM image interpretation purposes. Extremely low lighting during a night haul resulted in one haul being unusable for catch analysis by EM. A general issue surrounding image quality was that some camera angles did not capture what was intended, mostly in terms of species close ups for identification and deck views for monitoring catch disposition.

Catch comparison analysis between observer and EM data was done on 218 hauls out of 245 recorded in the observer data.

Table 5. Summary of EM imagery data quality assessments.

Vessel ID	Trip Number	High	Medium	Low	Unusable	Total Hauls Reviewed
A	2	0	20	4	0	24
B	2	0	25	3	0	28
C	1	2	6	16	0	24
C	2	7	26	2	0	35
D	2	0	46	5	0	51
E	2	6	17	4	1	28
F	2	0	6	23	0	29
	Total Hauls	**15**	**146**	**57**	**1**	**219**

3.2 EM DATA INTERPRETATION AND ANALYSIS

Interpretation of EM sensor data

Examples of the time series graphs are shown in Figure 8 for the six vessels, showing vessel speed, winch rotation, 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, winch rotation counts, and/or speed than others, but the overall sensor signature was similar for all vessels. In general, the hydraulic pressure pattern showed higher hydraulic pressure readings during hauling and lower readings during setting, and was absent or minimal when the vessel was transiting or standing by. The only exception was for the first trip on Vessel C, where the hydraulic pressure sensor was installed on the return side resulting on higher pressure readings during setting than hauling. Although this is not ideal it did not affect the ability to identify fishing activity during sensor data interpretation. Hydraulic pressure also tended to fluctuate more during hauling than setting, corresponding to starting and stopping of the longline to retrieve catch items. Similarly, vessel speed was generally lower and more variable during hauling than setting, again corresponding to work associated with catch retrieval.

Longline gear was always hauled shortly following setting with only one groundline soaking in the water at any one point in time. Distinguishing fishing activity through sensor data analysis was a relatively straightforward process for all vessels. Matching setting events to their corresponding hauling events, however, became difficult when there were large gaps in the data, mainly because it created uncertainty that the sets and hauls seen actually corresponded to each other as there may have been events in between that were not captured by the EM system.

Observer and EM Data Alignment

Observer and EM fishing event alignment resulted in very high agreements of set start and haul end date and time data. On average, observer set start data were 0.01 minutes ahead of the EM set starts while observer haul end data were 0.98 minutes ahead of EM.

The matching process also allowed for the correction of EM data interpretation in one occasion. EM had incorrectly assigned a haul in trip 2 for Vessel C as part of another event. The error stemmed from the fact that the set for the second haul occurred during a gap in the EM data record and the data technician had no reference to determine that the two hauling events, although in the same area, had been set independently.

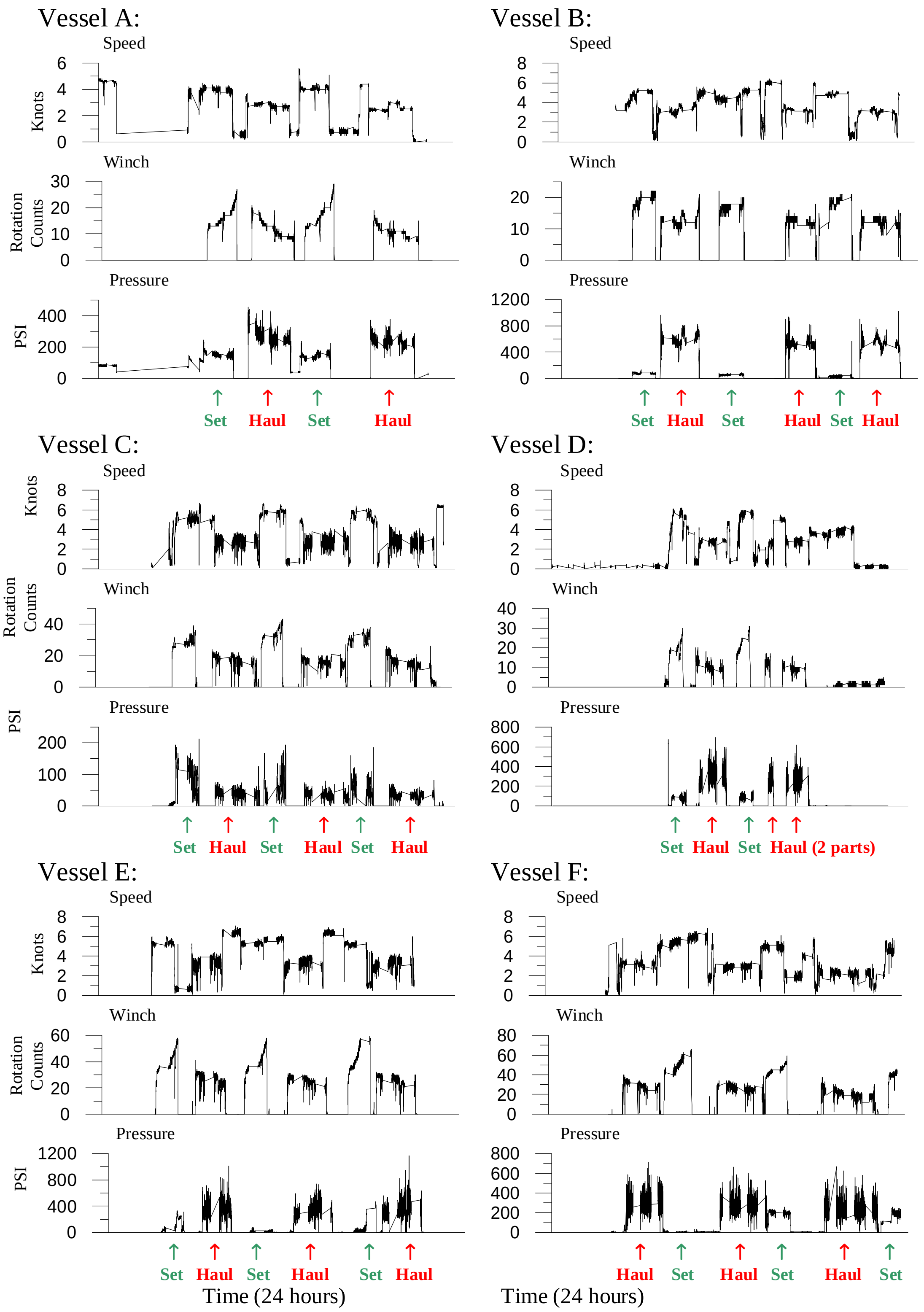

Figure 8. Sensor data examples from all six vessels showing vessel speed, winch rotation counts, and hydraulic pressure readings at approximately 10-second intervals over a period of 24 hours. Setting and hauling events are noted in each instance.

Comparison of EM and Observer Catch Observations

Observer catch data consisted of a total of 74 catch categories including 65 species, 5 genera, 3 families, an unknown fish category, and an unknown sea turtle category. EM data categorized catch in 52 species, 7 genera, and 4 families and an unknown fish category. The more general classifications to genera and families by EM correspond to a lower ability to speciate catch compared to the observers.

The overall 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 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. Both indices are based on observer data. The table 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 10,000 total catch items with red grouper being the most common species under both abundance indices, followed by three species categories of sharks, and gag grouper as a distant third. EM data generally had fewer pieces per species than the observer data with 2.7% less overall catch items. High agreement between observer and EM data was found for many species including red grouper with 2% difference and gag grouper with –1.6% (observer - EM). The greatest difference in total pieces by species category was for Atlantic sharpnose, blacknose, and general sharks. However, grouping these three species categories in both the observer and EM catch yields a difference of –1% and grouping all sharks together results in a 3% piece difference. EM categorized more catch items as unknown fish than the observer did, although unknown fish accounted for only 0.2% of all EM records. Most of these catch items were small fish that did not get handled in the same way as most of the other catch (i.e. it was not brought close enough to the camera). In general, agreement between observer and EM piece counts by species increased when looking at species grouping totals rather than at individual species (e.g. total sharks, total amberjacks, total toadfishes, total morays, etc).

Observer data contained three protected species catch records consisting of three sea turtles. EM was only able to detect two of the three sea turtles. The third turtle could not be detected in the imagery data due to poor lighting provided during a night haul. The observer had two turtles identified to loggerhead and one as unknown since the observer was trying to get a camera for a picture and did not get a good look of the animal. The EM imagery viewer identified the two turtles detected as loggerhead turtles.

On the basis of individual fishing events, the scatter plot shown in Figure 9 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 underrepresentation of catch by EM, resulting in a 1.27 average piece difference per haul, or 2.5% of the observer catch per haul on average.

Table 6. Summary of total catch by species or species group.

Species (Common Name; *Latin Name*) And Species Groups	Percent Occurrence	Average Pieces per Set	Total Observer Pieces	Total EM Pieces	Total Piece Difference	Percent Difference
Red Grouper; *Epinephelus morio*	96.3%	40.7	8598	8428	170	2.0%
Gag; *Mycteroperca microlepis*	18.7%	1.5	61	62	-1	-1.6%
Yellowedge Grouper; *Epinephelus flavolimbatus*	2.3%	12.2	61	52	9	14.8%
All other groupers	16.0%	1.3	56	24	32	57.1%
Total for Groupers			**8776**	**8566**	**210**	**2.4%**
Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	46.1%	4.5	457	898	-441	-96.5%
General Sharks (Family); Carcharhinidae	21.0%	6.0	275	26	249	90.5%
Blacknose Shark; *Carcharhinus acronotus*	36.5%	3.1	244	66	178	73.0%
Nurse Shark; *Ginglymostoma cirratum*	9.6%	1.3	28	19	9	
Silky Shark; *Carcharhinus falciformis*	7.8%	1.4	24	7	17	
All other sharks	19.7%	1.2	59	38	21	35.6%
Total for Sharks			**1087**	**1054**	**33**	**3.0%**
Red Snapper; *Lutjanus campechanus*	28.8%	2.0	124	119	5	4.0%
All other snappers	39.7%	1.7	52	40	12	23.1%
Total for Snappers			**176**	**159**	**17**	**9.7%**
Total for Porgies	14.2%	1.5	48	42	6	
Total for Lizardfishes	13.2%	1.4	42	44	-2	
Total for Morays	11.4%	1.3	35	27	8	
Total for Tilefishes	1.8%	3.8	23	22	1	
Total for Toadfishes	8.2%	1.1	19	19	0	
Total for Rays and Skates	3.7%	1.3	10	10	0	
Total for Tunas, Bonitos, and Mackerels	3.2%	1.0	7	6	1	
Total for Eels	1.8%	1.3	5	4	1	
Total for Jacks	10.0%	1.7	37	37	0	
Total for Drums	1.4%	1.0	3	4	-1	
Total for Seabasses	0.9%	1.0	2	1	1	
Unknown Fish	0.9%	1.0	2	22	-20	
Total for Other Fish	32.0%	1.3	113	91	22	19.5%
Loggerhead Turtle; *Caretta caretta*	0.9%	1.0	2	2	0	
General Turtle	0.5%	1.0	1	0	1	
Total for Turtles			**3**	**2**	**1**	
Overall Catch Totals		**47.3**	**10388**	**10110**	**278**	**2.7%**

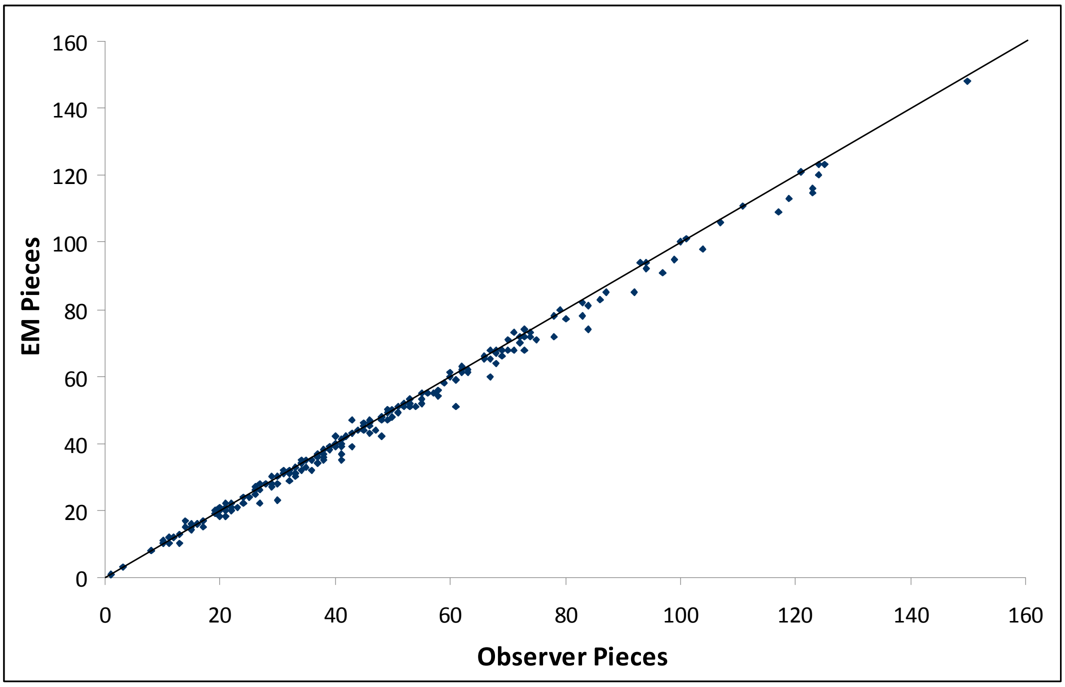

Figure 9. Scatter plot of observer data total catch per haul versus EM data total catch per set. Only fish species were considered for this analysis.

The piece count differences between observer and EM for the most common species and species groups are shown in Figure 10 in relation to their occurrence. Each bar graph also provides the average piece difference and the total number of hauls in which the species or species group occurred. Sharks are grouped due to the discrepancies in species identification for the most common species. Figure 10 shows that species comparisons at the haul level behaved similarly as they did in the overall catch analysis, with all species groups having less than one piece difference on average. In fact, all the major species groups represented were within one piece in over 73% of the hauls where they occurred, 100% for gag and red snapper. Red grouper had the largest spread in distribution with piece differences ranging from –7 to 10. However, this species was also the most abundant in the catch and the largest piece differences represented 6% to 13% of the red grouper catch for those hauls.

Observers and EM image viewers used different categories for catch disposition, especially when catch was not retained. Observers recorded non-retention disposition with a high degree of detail on the condition of the fish (i.e. alive, dead, or undetermined), whereas viewers categorized non-retention by the circumstances surrounding it (i.e. catch dropped off the line before the fisherman had a handle on it, released at the rail, or released after it had been brought over the rail). Observer data also contained an unknown category, although it was only used in one haul. Due to the differing detail, catch disposition was only comparable using two broad categories: retained, not retained. The haul that contained observer catch data on unknown disposition was removed from the catch disposition analysis due to the impossibility of translating this code. Catch disposition comparisons for total catch per haul are shown in Figure 11. EM was not able to reliably determine catch disposition, greatly over-representing retention (average piece difference by haul of –14.53) and under representing non-retention (average piece difference by haul of 16.25).

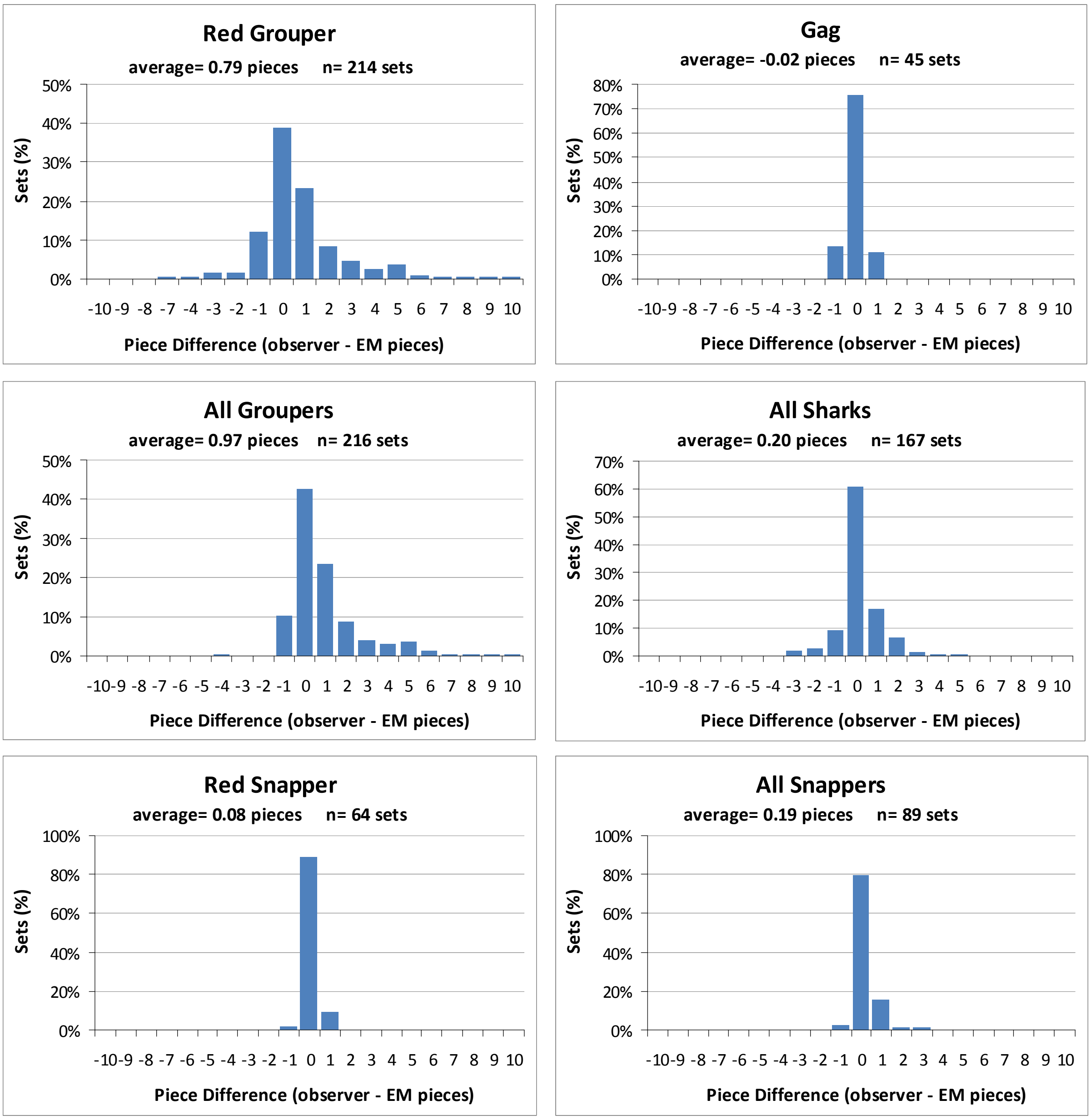

Figure 10. Distributions of piece differences for the most common species and species groupings by the percentage of hauls in which they occurred.

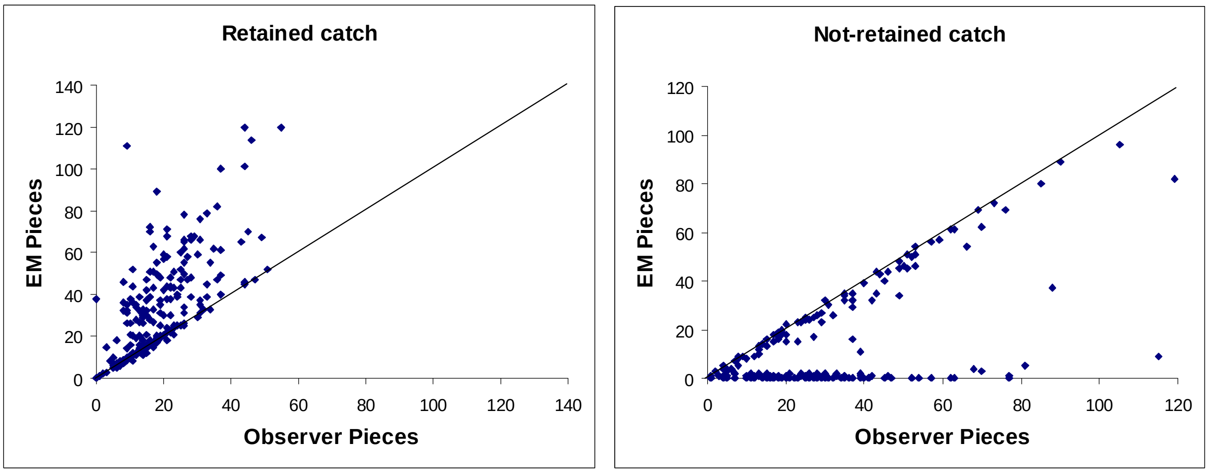

Figure 11. Scatter plot of retained and non-retained observer data total catch per haul versus EM data total catch per haul.

A hook-by-hook analysis of catch was available for 22 hauls resulting in 19,131 total hooks (blank and catch hooks) recorded in the observer data versus 17,078 detected in the EM data. Figure 12 shows a comparison between observer and EM total number of hooks per haul. EM generally underestimated the total number of hooks with an average hook difference of 93 hooks or 11% of the hooks per haul on average. On four of the comparisons, EM significantly underestimated total number of hooks by 20% to 67% (labelled A through D in Figure 12). All of these hauls occurred on Vessel C, with outliers A and B occurring on the second trip and C and D on the first trip. Blank hooks accounted for most of the differences in these outliers. Imagery data from Vessel C made it especially difficult to count blank hooks due to a combination of the groundline being barely visible, sun glare and water spots affecting image quality, and the camera view of the groundline being periodically blocked by the fisherman positioning himself between the camera and the groundline.

Table 7 shows the results of the editing process when aligning observer and EM catch records. The table shows the number of records that did not need editing, and the number of records edited broken down by editing categories. The vast majority of records (85%) did not need to be edited. The main edit needed to align the catch clusters was the insertion of records to the EM data (13% of all records compared) due to EM under representing blank hooks, followed by removing blank hook records. Blank hook record inserting for the four outlier hauls labelled A through D in Figure 12 accounted for 67% of all insert edits. Please note that the total number of editing steps exceeds the total number of observer hooks recorded due to the need to remove 471 blank hooks in the EM data during the alignment process.

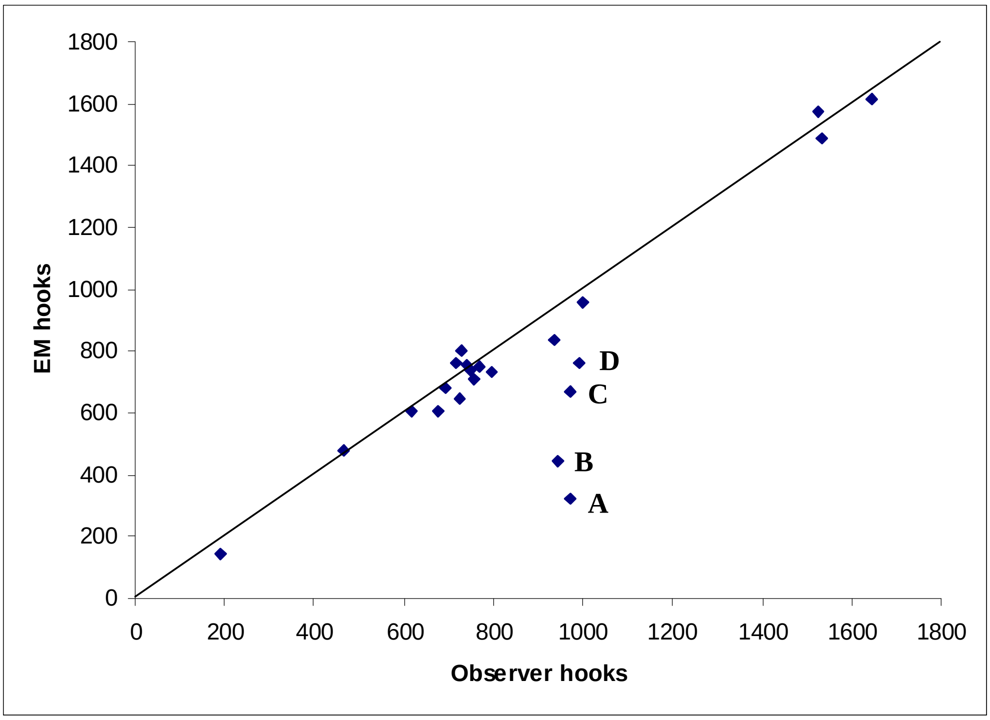

Figure 12. Scatter plot of total hook counts in observer and EM data sets per haul.

Table 7. Summary of alignment changes made to the EM data set for hook-based comparisons.

Editing Steps	Number of Records	Percent of Total Steps	Percent of Edits
Records Not Edited	16582	84.6%	
Records Edited	3020	15.4%	
Insert	2521	12.9%	83.5%
Remove	471	2.4%	15.6%
Order	28	0.1%	0.9%
Total Editing Steps	**19602**		

Hook-by-hook comparison results after alignment was complete are summarized in Table 8. The table categorizes comparisons depending on whether only blank hooks were paired or whether there was catch involved in the comparison. Catch comparisons are then further divided by the comparison outcome. Positive identification refers to record pairings where both observer and EM identified catch the same, misidentified refers to the pairings where two catch items were identified differently, Obs+ EM- refers to comparisons where a catch item in the observer data was paired to a blank hook in the EM data, and the opposite outcome is denoted by Obs- EM+. Invertebrate catch was encountered in a total of 10 comparisons and these were ignored for this analysis as they were not catch of concern for this study.

Blank hook comparisons comprised 93% of all comparisons, with comparison involving catch only accounting for 7% of the total paired records compared. Among the comparisons with catch, about 80% were identical between observer and EM and 11% due to misidentifications and errors in the alignment process. Nearly 9% of the catch comparisons involved a blank hook compared with a catch item, observer catch paired with a blank hook was over ten times more common than the opposite situation.

Table 8. Summary of hook-by-hook comparison results.

Comparison	Number of Records	Percent of Total Records	Percent within Category
Blank Hook Comparisons	17,772	92.9%	
Catch Comparisons			
Positive ID	1089	5.7%	80.1%
Misidentified	155	0.8%	11.4%
Obs+ EM-	106	0.6%	7.8%
Obs- EM+	9	0.0%	0.7%
Total for Catch	**1359**	**7.1%**	
Total Records Compared	**19,131**		

Hook-by-hook catch identification results are shown for the most common species is shown in Table 9 taking the observer identification as the correct reference (see Appendix III for full results of all species). Consistent with the overall catch comparison results, hook-by-hook results show that EM identified individual red grouper pieces correctly 92% of the time. EM also identified gag grouper pieces correctly in nine out of eleven encounters and red snapper in nine out of nine encounters. EM misidentification of catch was done within the same species group (i.e. sharks, groupers, lizardfishes, etc.) in 97% of the total misidentified pairs.

Gag grouper was involved in five misidentifications, once when a gag grouper in the observer data was misidentified by EM as a red grouper, and the rest when scamp and a red grouper in the observer data were misidentified by EM as gag. However, a second imagery data review showed that it is likely that in three occasions this was due to a difference in the catch recording order between the EM and the observer data sets rather than a situation involving misidentification. On these three occasions, EM recorded a gag within the same catch cluster as the observer but differences in catch order resulted in observer and EM gag records not being paired to each other. The same would also explain why EM seemed to have missed a gag grouper, although what was missed was a red grouper which could not be found in the secondary imagery data review, probably because it dropped off before it came into camera view. A data entry error on the part on the EM imagery viewer explains the misidentification of a red grouper as an Atlantic sharpnose shark by EM, after a secondary review of the imagery data clearly shows the catch item is a red grouper.

Table 9. Summary of hook-by-hook catch comparison results.

Observer Identification	Positive ID	Misidentified	Total
Red grouper	948	5	953
General Sharks	0	85	85
Atlantic Sharpnose Shark	72	2	74
Blacknose Shark	19	34	53
Other Sharks	6	12	18
Gag	9	1	10
Red Snapper	9	0	9
Other Grouper	2	2	4
All others	24	14	38
Total	**1089**	**155**	**1244**

Hook-by-hook comparison analysis also confirms that there was a high discrepancy between the observer and EM identification of sharks. Overall, EM identified most sharks as Atlantic sharpnose while observers mostly grouped sharks in the general shark category followed by Atlantic sharpnose and blacknose sharks. Figure 13 illustrates the proportion of observer identifications for catch items identified as Atlantic sharpnose by EM. Of all catch identified by EM as Atlantic sharpnose shark, 37% were also identified by observers as Atlantic sharpnose shark, 42% as general sharks, 16% as blacknose sharks, and four other species accounting for the remainder 6%.

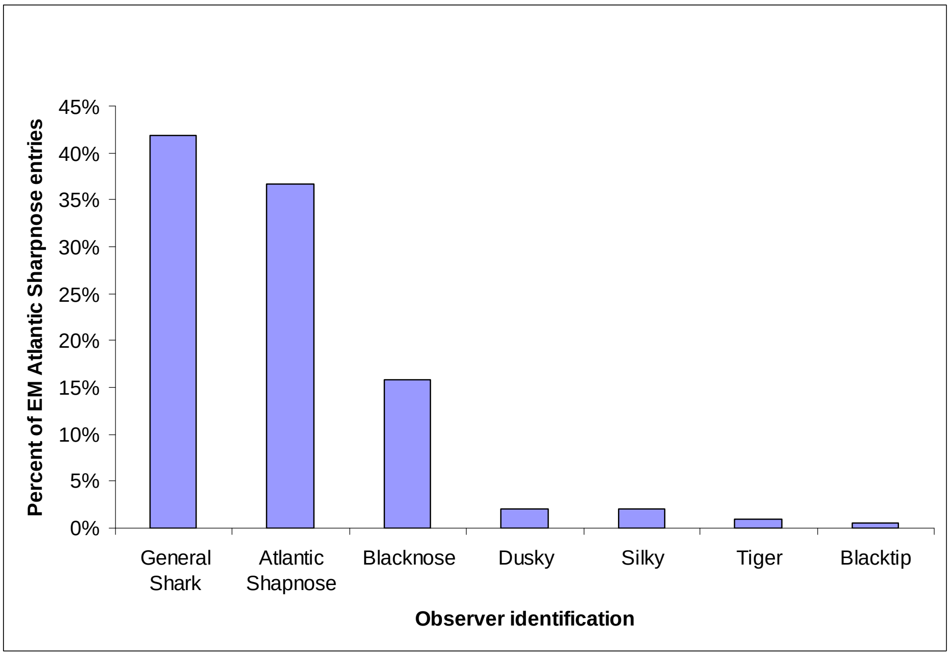

Figure 13. Comparison of EM Atlantic sharpnose shark records identified as other shark categories in the observer data set. There were a total of 196 Atlantic sharpnose shark records in the EM data that were identified as other sharks by the observer.

4. DISCUSSION

4.1 TECHNICAL ASSESSMENT OF EM SYSTEM

EM equipment was deployed on six vessels for a collective total of 12 fishing trips, over 2,000 vessel hours at sea of EM data, and a total of 325 fishing events captured by EM. Overall sensor data capture success was about 65.2%. However, if the equipment had not been manually turned off, the capture success would have been 98% with 2% data loss mainly caused by GPS signal interference and a software lockup problem.

Hydraulic pressure and winch sensors had a 100% success rate at triggering image recording when hauling occurred. However, 11% of the observed hauls were missed or only partially captured by EM. Imagery capture success was impacted by vessel operators manually turning off the EM system. Missed hauls seemed to occur due the system being off during idle moments, and vessel operators forgetting to turn it back on when fishing activity was resumed and incomplete hauls occurred when the EM system was manually turned off either shortly before or shortly after the end of a haul. Powering the EM system down shortly after a hauling event resulted in partially captured hauls due to the fact that the EM system was still recording imagery when it was powered down. The EM system needs to properly close all imagery files, otherwise unclosed files are left corrupted and sometimes cannot be fully repaired. Image file corruption is usually eliminated when the EM system is left powered on.

The main issue to resolve in a future application involving EM would be to ensure 100% data capture. The lack of complete sensor data in this study made it in some cases more difficult to reconstruct the trip during sensor data interpretation, resulted in missed fishing activity, and generally did not allow for complete accounting of the fishing trip by EM. In a monitoring application involving only EM systems, complete data capture would be required to ensure that all activity during the fishing trip is accounted for.

Vessel operators manually powered down the EM systems mainly due to concerns over power draw by the EM system during non-fishing periods. EM systems were designed to limit power consumption by shutting down and entering ‘sleep mode’ when three criteria were met: the vessel’s 12 Volt power supply fell below a designated voltage range, the vessel was moving at a speed of less than 0.4 knots, and imagery recording was off. Subsequently, software powers up or ‘wakes’ the EM system when the battery voltage rises to a charging level or every 30 minutes to check for vessel activity.

Early on in the study, two vessels reported that the EM system continued to record imagery well after the designated 10 minute run on time and did not shutdown overnight. In both cases, imagery recording remained on because the light reflector was passing in front of the optical winch sensor as the weighted drum rocked back and forth. Similarly, sleep mode was prevented on other trips when vessels gathered speed during drifting or at anchor on the open sea. These instances, coupled with a sometimes longer than expected wait for the required voltage drop, resulted in vessel operators losing confidence in the EM systems ability to automatically limit power consumption. Of note, since this study took place further development work has been carried out to improve the reliability of the sleep cycle process.

Vessels participating in this pilot study may not have had adequate battery capacity or were being cautious about running electrical devices for extended periods of time with the engine off. Power consumption becomes less of an issue with more permanent EM installations where vessels make accommodation for the equipment in much the same way as they would for other high demand equipment such as radar.

Issues encountered with GPS signal interference from other vessel's electronics were easily remedied and would be less of an issue in the future as field technicians gain experience with the fleet. Also, current software in the EM system allows for sensor data from other sensors to continue to be collected even while GPS signal is lost. EM software lockup could be avoided by eliminating stress on the system caused by routinely tuning off the EM system while at sea.

A final issue concerning technical suitability of EM for these vessels revolves around the placement of cameras and imagery quality. On all six vessels camera placement was done using a combination of existing standing structures and custom built mounts. For every vessel there was at least one camera angle that was not ideal and this affected the quality of catch information that could be obtained. In many cases this could have been corrected by changing the aim and/or zoom of the camera lens more so than by changing the mounting structure or the camera position itself. Also, except in Vessel F, deck lighting used during evening hauling was insufficient and/or poorly placed for EM image data interpretation purposes. In a longer running study or in an established monitoring application using EM, feedback from the imagery viewers would help improve the camera views and catch processing behaviour to improve imagery interpretation. The EM technician installed cameras based on conversations with the vessel operator and crew on catch processing and behaviour on deck. However, it is the imagery viewer who will in the end be able to assess the camera view based on actual fishing operations in diverse conditions and circumstances.

The high proportion of medium quality imagery was due to less than ideal camera angles but also to lower than expected image resolution from the cameras with a recoding setting that allowed for smaller file sizes. The lower image resolutions from these cameras added difficulty to species identification. In the future it would be advisable to use higher storage capacity EM hard drives to reduce the need for smaller imagery file sizes and put a higher emphasis on image resolution.

Hydraulic pressure and optical winch sensors were in place on all six vessels and provided the main tools for distinguishing fishing activity. Both hydraulic pressure and winch rotation patterns were easily recognizable during sensor data interpretation and worked reliably throughout the study. Ten out the twelve trips monitored had no problems with either of these sensors. No data were lost due to hydraulic pressure or winch sensor malfunctions since at least one of these sensors was always working properly. This is one of the main reasons both sensors are installed whenever possible as it creates a back up to ensure imagery recording is triggered as needed.

The level of industry cooperation strongly affects the success of an EM-based monitoring programme. For this study, vessel owners willingly volunteered to participate. 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 significantly improve the success of the technology. For example, small changes to catch handling could significantly improve EM viewer catch identification ability. Strategies to build industry support will be important.

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.

The pilot study resulted in seven trips being monitored by both observer and EM with 218 hauls compared at the haul level, and 22 hauls at the hook level. One haul was unusable for EM catch assessment due to extremely low light levels during night hauling and was not used in the analysis. Although two vessels contributed to over half of the hauls analyzed, there was no vessel specific trend found that biased the catch results observed.

Both observers and EM recorded over 10,000 pieces of catch. Poor lighting conditions resulted in EM not being able to detect one sea turtle that was detected by the observer. Two other sea turtles were detected by both methods. Fish catch was higher in observer data than in EM with 2.7% overall piece difference and 2.5% average haul piece difference. Camera placements were aimed to capture catch handling and, while they still provided some view of the water, did not offer a complete view of drop off catch whenever the line drifted to the edge of camera view. EM may have missed drop-off catch that the observer was able to see and speciate accounting for differences in total catch recorded. This comparison was not possible since observer data did not contain details on drop-off catch.

EM was generally successful at identifying catch to species groups when compared to observer data. Comparisons of catch by species varied, with most common species having high agreement between observer and EM data such as red grouper, gag, and red snapper. Gag piece counts were identical on 76% of the hauls and always within one piece. Identification discrepancies in the hook-by-hook data were only due to misidentifications on two occasions. Agreement with the observer and EM counts for sharks and other species with lower occurrences were generally very good when compared at a species group level (genus or family), although EM identification at the species level may have not matched the observer in some cases. For sharks, results show that EM over represented the amount of Atlantic sharpnose sharks and under represented blacknose sharks. However, it is hard to assess the actual success of shark speciation by EM since 42% of the sharks identified as Atlantic sharpnose by EM were paired to the general shark category in the hook-by-hook analysis.

Species identification discrepancies were mainly due to sub-optimal imagery quality (a combination of camera angles and image clarity), viewer inexperience with Gulf of Mexico species, and species similarities. Sub-optimal imagery quality due to inappropriate lighting provided during a night haul was also the reason for one sea turtle not being detected during imagery review. Future work with this fishery could build on the experience gathered during the study. Changing the camera angles to allow for better close-up views of the catch and changing the image recording setting to deliver higher resolution imagery would help improve species identification in future applications. Having appropriate lighting for night hauls and catch handled in a particular way by the skipper or crew so that the fish is easily seen in the camera would also have a significant positive effect on species identification. Judging by the amount of catch identified to the general shark level, it is possible that these species are hard to distinguish even by observers unless handled in a specific way. Having locally based EM imagery data viewers who are experienced identifying fish species caught in this fishery would also help improve species identification and so would a monitoring system design that allowed for imagery viewers to get feedback on their species identification as the project went along. Even if local imagery viewers are comfortable identifying fish catch in this fishery, future studies may want to allow for 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 would be useful for future training needs.

EM counts of blank hooks were accurate within 15% of observer counts. EM counts of blank hooks were difficult as the groundline and the hooks were generally hard to distinguish on the imagery. In many cases the viewer was forced to detect blank hooks by watching the fisherman’s behaviour rather than positively identifying the blank hook itself. However, most of the blank hook discrepancies were concentrated in only four hauls from the same vessel, pointing to the fact that blank hook counts are especially affected by factors such as sun glare, dirty lenses, and fisher behaviour.

In this pilot study, EM was not able to determine catch disposition. Although total catch per haul had high agreement between observer and EM data, in most hauls EM had much more catch recorded as retained compared to observer data 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 catch was rarely handled consistently and there seemed to be various points of discard, not all captured by EM imagery. Catch being cut-off the line bellow the surface may have also caused some of the differences seen between observer and EM data, although this comparison was not possible as observer data did not include information on how or when catch was released. The best way to improve EM detection of catch disposition in future studies would be through the development of more standardized catch handling procedures and modifying the camera positioning to best match these catch handling practices.

EM has great potential to improve ecosystem knowledge due to the serial catch accounting method followed during imagery data interpretation. Serial catch data per haul provides information on which species are caught together, and can then also be associated with geographical data using sensor data interpretation. This may be of special interest in the bottom longline reef fish fishery where there is a great variety of rarely caught species. Other important additional information that could be collected with EM relates to life history of released species as EM has been proven to allow the collection of length data on released catch in other fisheries (Bonney and McGauley, 2008) and verification of released catch length by EM is currently used in the management of the groundfish hook and line fishery in British Columbia. Further work would be needed to explore the possibility of EM collecting additional data already collected by observers such as condition of the fish brought on board.

4.3 CONCLUSIONS AND RECOMMENDATIONS

Future work with the use of EM technology with the longline reef fish fishery in the Gulf of Mexico should start with discussions with vessel owners and operators over the results of this study and possible areas of improvement. As identified in this study, greater cooperation from vessel operators regarding the continuous operation of the EM system and changes in catch handling is needed to improve data collection from EM. Changes in the camera views and image recording settings would also help improve catch accounting and speciation and would be achieved by establishing a feedback process involving vessel operators, EM field technicians, and EM data technicians. Industry input would be needed to design an improved monitoring approach for this fleet.

Results from this study demonstrated that EM has strengths in monitoring time and location of fishing, providing very high resolution data on fishing vessel activity. This information would be a useful tool for fisheries management to characterize the fishery in time and space. Results from this study also show that EM is a promising tool in providing catch composition data on a haul and hook level for target, non-target, and protected species. Further work will be needed to assess the true potential of EM to identify catch disposition in this fleet.

The use of EM in this fleet will likely depend on several issues, the main ones being cost and convenience (as compared with observers), incentives for industry to accept EM monitoring, opportunities for value-adding EM by addressing the data needs of industry, and policies governing the use and ownership of data.

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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.

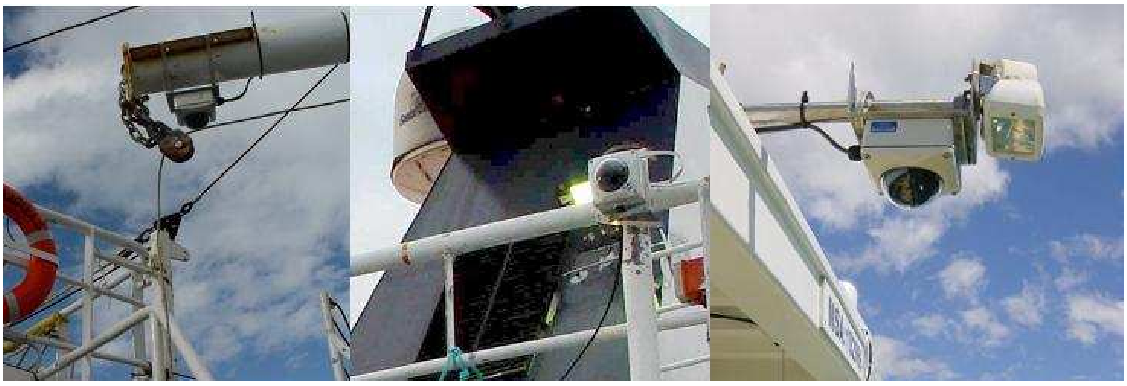

Figure A2 CCTV camera installations on three different fishing vessels. Each camera has a mounting bracket and stainless steel mounting straps.

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.

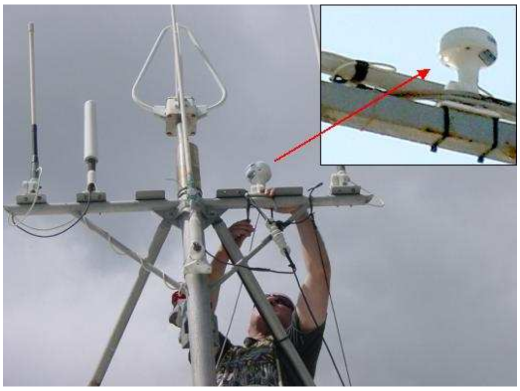

Figure A4. GPS receiver installed in the rigging of a vessel and a close up photograph of the mounted GPS.

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).

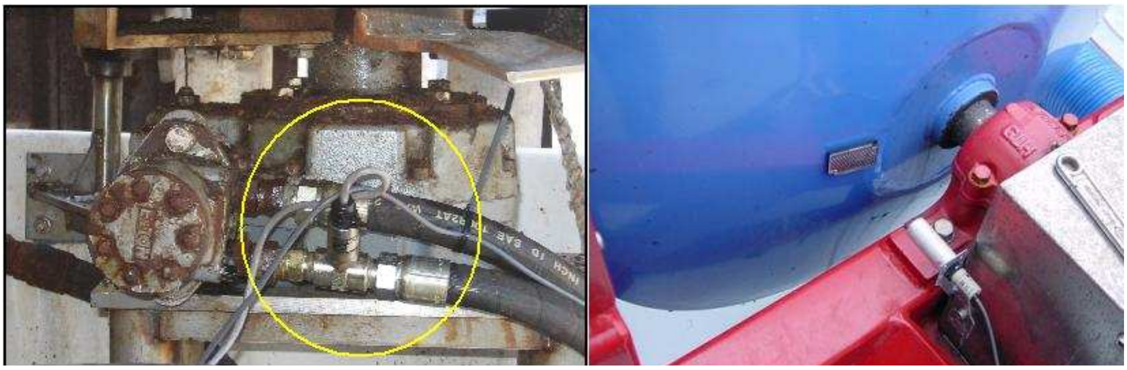

Figure A5. A hydraulic pressure sensor installed on the supply line of a vessel line hauler (left). Drum rotation sensor (right) mounted on pelagic longline vessel, showing optical sensor and reflective surface.

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 (Common Name; Latin Name)	Percent Occurrence	Average Pieces per Set	Total Observer Pieces	Total EM Pieces	Total Piece Difference	Percent Difference
Red Grouper; *Epinephelus morio*	96.3%	40.7	8598	8428	170	2.0%
Gag; *Mycteroperca microlepis*	18.7%	1.5	61	62	-1	-1.6%
Black Grouper; *Mycteroperca bonaci*	2.7%	1.0	6	4	2	
Goliath Grouper; *Epinephelus itajara*	1.4%	1.0	3	1	2	
Snowy Grouper; Epinephelus niveatus	1.4%	2.3	7	7	0	
Yellowedge Grouper; *Epinephelus flavolimbatus*	2.3%	12.2	61	52	9	
Speckled Hind; *Epinephelus drummondhayi*	5.5%	1.5	18	0	18	
Scamp; *Mycteroperca phenax*	8.2%	1.2	22	12	10	
Total for Groupers			**8776**	**8566**	**210**	**2.4%**
General Sharks (Family); Carcharhinidae	21.0%	6.0	275	26	249	90.5%
Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	46.1%	4.5	457	898	-441	-96.5%
Blacknose Shark; *Carcharhinus acronotus*	36.5%	3.1	244	66	178	73.0%
Blacktip Shark; *Carcharhinus limbatus*	6.4%	1.2	17	19	-2	
Bull Shark; *Carcharhinus leucas*	0.5%	1.0	1	0	1	
Dusky Shark; *Carcharhinus obscurus*	0.9%	2.0	4	3	1	
Hammerhead Shark (Genus); *Sphyrna sp*	0.5%	1.0	1	0	1	
Great Hammerhead Shark; *Sphyrna mokarran*	1.8%	1.0	4	0	4	
Hammerhead Scalloped Shark; *Sphyrna lewini*	0.5%	1.0	1	9	-8	
Nurse Shark; *Ginglymostoma cirratum*	9.6%	1.3	28	19	9	
Sandbar Shark; *Carcharhinus plumbeus*	3.7%	1.4	11	2	9	
Sand Tiger Shark; *Odontaspis taurus*	0.5%	1.0	1	0	1	
Silky Shark; *Carcharhinus falciformis*	7.8%	1.4	24	7	17	
Spinner Shark; *Carcharhinus brevipinna*	0.5%	1.0	1	0	1	
Tiger Shark; *Galeocerdo cuvier*	7.3%	1.1	18	5	13	
Total for Sharks			**1087**	**1054**	**33**	**3.0%**
Drum (Family); Sciaenidae			0	1	-1	
Red Drum; *Sciaenops ocellatus*	1.4%	1.0	3	3	0	
Total for Drums			**3**	**4**	**-1**	
Snake Eel (Family); Ophichthidae			0	3	-3	
Pale Spotted Eel; *Ophichthus puncticeps*	1.8%	1.3	5	1	4	
Total for Eels			**5**	**4**	**1**	
Jack (Family); Carangidae	0.5%	1.0	1	0	1	
Jack (Genus); *Caranx sp.*	0.5%	1.0	1	0	1	
Greater Amberjack; *Seriola dumerili*	7.3%	1.9	30	18	12	
Lesser Amberjack; *Seriola fasciata*	0.9%	1.5	3	17	-14	
Almaco Jack; *Seriola rivoliana*	0.5%	1.0	1	1	0	
Common Crevalle Jack; *Caranx hippos*	0.5%	1.0	1	1	0	
Total for Jacks			**37**	**37**	**0**	
Inshore Lizardfish; *Synodus foetens*	7.8%	1.2	20	37	-17	
Offshore Lizardfish; *Synodus poeyi*	1.8%	1.0	4	0	4	
Sand Diver; *Synodus intermedius*	4.1%	2.0	18	7	11	
Total for Lizardfishes			**42**	**44**	**-2**	
Moray (Genus); *Gymnothorax sp.*	0.9%	1.0	2	20	-18	
Blacktail Moray; *Gymnothorax kolpos*	0.9%	2.0	4	0	4	
Green Moray; *Gymnothorax funebris*	0.0%	0.0	0	4	-4	
Purplemouth Moray; *Gymnothorax vicinus*	0.9%	2.0	4	2	2	
Spotted Moray; *Gymnothorax moringa*	8.7%	1.2	23	1	22	
Reticulate Moray; *Muraena retifera*	0.9%	1.0	2	0	2	
Total for Morays			**35**	**27**	**8**	

Table II.1 Continued

Species (Common Name; Latin Name)	Percent Occurrence	Average Pieces per Set	Total Observer Pieces	Total EM Pieces	Total Piece Difference	Percent Difference
Porgie (Family); Sparidae			0	1	-1	
Porgy (Genus); *Calamus sp.*			0	29	-29	
Porgy (Genus); *Pagrus sp.*			0	2	-2	
Jolthead Porgy; *Calamus bajonado*	11.9%	1.5	40	10	30	
Knobbed Porgy; *Calamus nodosus*	1.4%	1.0	3	0	3	
Red Porgy; *Pagrus pagrus*	1.8%	1.3	5	0	5	
Total for Porgies			**48**	**42**	**6**	
Seabass (Family); Serranidae	0.5%	1.0	1	0	1	
Seabass (Genus); *Centropristis sp.*			0	1	-1	
Bank Seabass; *Centropristis ocyurus*	0.5%	1.0	1	0	1	
Total for Seabasses			**2**	**1**	**1**	
Snapper (Genus); *Lutjanus sp.*			0	3	-3	
Snapper, Gray; *Lutjanus griseus*	2.3%	1.2	6	1	5	
Lane Snapper; *Lutjanus synagris*	2.7%	1.3	8	8	0	
Mutton Snapper; *Lutjanus analis*	5.0%	1.5	17	20	-3	
Red Snapper; *Lutjanus campechanus*	28.8%	2.0	124	119	5	4.0%
Vermillion Snapper; *Rhomboplites aurorubens*	7.8%	1.1	19	7	12	
Yellowtail Snapper; *Ocyurus chrysurus*	0.9%	1.0	2	1	1	
Total for Snappers			**176**	**159**	**17**	**9.7%**
Tilefish (Genus); *Caulolatilus sp.*			0	10	-10	
Blueline Tilefish; *Caulolatilus microps*	1.8%	4.8	19	12	7	
Tilefish; *Lopholatius chamaeleonticeps*	0.9%	2.0	4	0	4	
Total for Tilefishes			**23**	**22**	**1**	
Toadfish (Genus); *Opsanus sp.*	0.9%	1.0	2	19	-17	
Leopard Toadfish; *Opsanus pardus*	7.3%	1.1	17	0	17	
Total for Toadfishes			**19**	**19**	**0**	
Atlantic Bonito; *Sarda sarda*	0.5%	1.0	1	0	1	
Bonito; *Euthynnus alletteratus*	1.8%	1.0	4	4	0	
King Mackerel; *Scomberomorus cavalla*	0.9%	1.0	2	2	0	
Total for Tunas, Bonitos, and Mackerels			**7**	**6**	**1**	
Butterfly Ray (Genus); *Gymnura sp.*	0.5%	1.0	1	0	1	
Rosette Skate; *Raja garmani*	0.5%	1.0	1	0	1	
Clearnose Skate; *Raja eglanteria*	2.3%	1.4	7	8	-1	
Southern Stingray; *Dasyatis americana*	0.5%	1.0	1	2	-1	
Total for Rays and Skates			**10**	**10**	**0**	
Great Barracuda; *Sphyraena barracuda*	4.1%	1.3	12	11	1	
Ling Cobia; *Rachycentron canadum*	7.8%	1.1	19	18	1	
Yellow Conger; *Hildebrandia flava*	0.5%	1.0	1	0	1	
White Grunt; *Haemulon plumieri*	0.9%	1.0	2	2	0	
Atlantic Needlefish; *Strongylura marina*			0	1	-1	
Sand Perch; *Diplectrum formosum*	5.9%	1.0	13	7	6	
Smooth Pufferfish; *Lagocephalus laevigatus*	0.5%	1.0	1	1	0	
Remora; *Remora remora*	0.5%	1.0	1	1	0	
Blue Runner; *Caranx crysos*	0.5%	1.0	1	1	0	
Sharksucker; *Echeneis naucrates*	17.8%	1.4	54	46	8	14.8%
Sheepshead; *Archosargus probatocephalus*			0	1	-1	
Snakefish; *Trachinocephalus myops*	0.9%	3.5	7	0	7	
Squirrelfish; *Holocentrus adscensionis*	0.5%	1.0	1	1	0	
Queen Triggerfish; *Balistes vetula*	0.5%	1.0	1	1	0	
Unknown Fish	0.9%	1.0	2	22	-20	
Total for Other Fish			**115**	**113**	**2**	**1.7%**
Loggerhead Turtle; *Caretta caretta*	0.9%	1.0	2	2	0	
General Turtle	0.5%	1.0	1	0	1	
Total for Turtles			**3**	**2**	**1**	
Totals			**10388**	**10110**	**278**	**2.7%**

APPENDIX III – HOOK-BY-HOOK CATCH COMPARISONS

Table III.1 Number of positive and misidentified catch comparisons by species from hook-by-hook analysis.

Observer Identification	Positive ID	Misidentified	Total
Red Grouper; *Epinephelus morio*	948	5	953
General sharks	0	85	85
Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	72	2	74
Blacknose Shark; *Carcharhinus acronotus*	19	34	53
Jolthead Porgy; *Calamus bajonado*	4	7	11
Gag; *Mycteroperca microlepis*	9	1	10
Red Snapper; *Lutjanus campechanus*	9	0	9
Great Barracuda; *Sphyraena barracuda*	5	0	5
Silky Shark; *Carcharhinus falciformis*	1	4	5
Sharksucker; *Echeneis naucrates*	4	0	4
Tiger Shark; Galeocerdo cuvier	1	3	4
Dusky Shark; *Carcharhinus obscurus*	0	4	4
Ling Cobia; *Rachycentron canadum*	3	0	3
Mutton Snapper; *Lutjanus analis*	3	0	3
Blacktip Shark; *Carcharhinus limbatus*	2	1	3
Inshore Lizardfish; *Synodus foetens*	1	2	3
Scamp; *Mycteroperca phenax*	1	2	3
Nurse Shark; *Ginglymostoma cirratum*	2	0	2
Black Grouper; *Mycteroperca bonaci*	1	0	1
Clearnose Skate; *Raja eglanteria*	1	0	1
Greater Amberjack; *Seriola dumerili*	1	0	1
Sand Perch; *Diplectrum formosum*	1	0	1
White Grunt; *Haemulon plumieri*	1	0	1
Butterfly Ray; *Gymnura sp.*	0	1	1
Jack (Genus); *Caranx sp.*	0	1	1
Leopard Toadfish; *Opsanus pardus*	0	1	1
Offshore Lizardfish; *Synodus poeyi*	0	1	1
Spotted Morray; *Gymnothorax moringa*	0	1	1
Total	**1089**	**155**	**1244**

Table III.2 Misidentified catch pairs by species from hook-by-hook analysis.

Observer Identification	EM Identification	Number of Pairs	Percent of Misidentified Comparisons
Within Sharks			
Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	Blacknose Shark; *Carcharhinus acronotus*	2	1.3%
Blacknose Shark; *Carcharhinus acronotus*	Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	31	20.0%
Blacknose Shark; *Carcharhinus acronotus*	General Sharks	2	1.3%
Blacknose Shark; *Carcharhinus acronotus*	Silky Shark; *Carcharhinus falciformis*	1	0.6%
Blacktip Shark; *Carcharhinus limbatus*	Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	1	0.6%
Dusky Shark; *Carcharhinus obscurus*	Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	4	2.6%
General Sharks	Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	2	1.3%
General Sharks	Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	80	51.6%
General Sharks	Blacknose Shark; *Carcharhinus acronotus*	1	0.6%
General Sharks	Blacktip Shark; *Carcharhinus limbatus*	2	1.3%
Silky Shark; *Carcharhinus falciformis*	Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	4	2.6%
Tiger Shark; Galeocerdo cuvier	Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	2	1.3%
Tiger Shark; *Galeocerdo cuvier*	General Sharks	1	0.6%
Within groupers			
Gag; *Mycteroperca microlepis*	Red Grouper; *Epinephelus morio*	1	0.6%
Red Grouper; *Epinephelus morio*	Gag; *Mycteroperca microlepis*	3	1.9%
Red Grouper; *Epinephelus morio*	Unknown Fish	1	0.6%
Scamp; Mycteroperca phenax	Gag; *Mycteroperca microlepis*	1	0.6%
Scamp; *Mycteroperca phenax*	Red Grouper; *Epinephelus morio*	1	0.6%
Within genus			
Inshore Lizardfish; *Synodus foetens*	Sand Diver; *Synodus intermedius*	2	1.3%
Jolthead Porgy; *Calamus bajonado*	Porgy (Genus); *Calamus sp.*	6	3.9%
Leopard Toadfish; *Opsanus pardus*	Toadfish (Genus); *Opsanus sp.*	1	0.6%
Offshore Lizardfish; *Synodus poeyi*	Inshore Lizardfish; *Synodus foetens*	1	0.6%
Spotted Moray; *Gymnothorax moringa*	Green Moray; *Gymnothorax funebris*	1	0.6%
Other			
Butterfly Ray; *Gymnura sp.*	Southern Stingray; *Dasyatis americana*	1	0.6%
Jack (Genus); *Caranx sp.*	Greater Amberjack; *Seriola dumerili*	1	0.6%
Jolthead Porgy; *Calamus bajonado*	Snapper (Genus); *Lutjanus sp.*	1	0.6%
Red Grouper; *Epinephelus morio*	Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	1	0.6%
Total Misidentifications		**155**	

Table III.3 Blank hook versus catch pairs by species from hook-by-hook analysis.

Species	Obs+ EM-	Obs- EM+
Atlantic Bonito; *Sarda sarda*	1	0
Atlantic Sharpnose Shark; *Rhizoprionodon terraenovae*	5	5
Blacktip Shark; *Carcharhinus limbatus*	1	0
Gag; *Mycteroperca microlepis*	1	0
General Sharks	4	1
Great Hammerhead Shark; *Sphyrna mokarran*	1	0
Greater Amberjack; *Seriola dumerili*	1	0
Nurse Shark; *Ginglymostoma cirratum*	1	0
Red Grouper; *Epinephelus morio*	80	3
Sandbar Shark; *Carcharhinus plumbeus*	1	0
Scamp; *Mycteroperca phenax*	1	0
Sharksucker; *Echeneis naucrates*	1	0
Snakefish; *Trachinocephalus myops*	3	0
Spotted Moray; *Gymnothorax moringa*	2	0
Unknown Fish	1	0
Vermillion Snapper; *Rhomboplites aurorubens*	1	0
Yellow Conger; *Hildebrandia flava*	1	0
Total	**106**	**9**