New Zealand Aquatic
Environment and Biodiversity
Report No. 24
2008
ISSN 1176-9440

Electronic monitoring to assess protected species interactions in New Zealand longline fisheries: a pilot study

Howard McElderry
Jessica Schrader
Simon Anderson

Electronic monitoring to assess protected species interactions in New Zealand longline fisheries: a pilot study

Howard McElderry[1]
Jessica Schrader[1]
Simon Anderson[2]

[1]Archipelago Marine research Ltd
525 Head Street
Victoria, British Columbia
Canada V9A 5S1

[2]Lat 37 Ltd
P O Box 3058
Ohope 3161

New Zealand Aquatic Environment and Biodiversity Report No. 24
2008

Published by Ministry of Fisheries
Wellington
2008

ISSN 1176-9440

Citation:
McElderry, H.; Schrader, J.; Anderson, S. (2008).
Electronic monitoring to assess protected species interactions
in New Zealand longline fisheries: a pilot study.
New Zealand Aquatic Environment and Biodiversity Report No. 24. 39 p.

This series continues the
Marine Biodiversity Biosecurity Report series
which ceased with No. 7 in February 2005.

EXECUTIVE SUMMARY

McElderry, H.; Schrader, J.; Anderson, S. (2008). Electronic monitoring to assess protected species interactions in New Zealand longline fisheries: a pilot study.

***New Zealand Aquatic Environment and Biodiversity Report No. 24.* 39 p.**

Archipelago Marine Research Ltd. was contracted by the New Zealand Ministry of Fisheries to evaluate the feasibility of using electronic monitoring (EM) for assessing protected species interactions in demersal and pelagic longline fisheries. The EM systems used in the study consisted of up to three closed circuit television cameras, a GPS receiver, a hydraulic pressure sensor, winch sensors (one vessel only), and system control box. The EM systems and observers were simultaneously in place on two pelagic and two demersal longline vessels for a total of 8 trips and 198 fishing events, and about 100 days of vessel time at sea, providing the opportunity for comparison of protected species interactions and catch estimates over a range of conditions. The EM systems successfully captured 93% of the fishing events on video. However, sensor data collection was incomplete (54% captured) as one vessel had a faulty power source and three vessels turned the EM system off when the observer was not monitoring catch. EM sensor data provided accurate vessel position information and hydraulic pressure enabled identification of most setting and hauling events. EM and observer fishing events could be matched for 87% of the fishing events of which protected species were assessed on 122 fishing events and catch was assessed on 39. Observers reported nine protected species interactions in total, most of which were deck landings or brief encounters with longline and only two involved capture by fishing gear. EM and observers both detected the capture of one seabird hooked during retrieval, brought over the roller, and released. Another encounter involved a leatherback sea turtle caught in pelagic longline gear, brought alongside the vessel, and released. This interaction was reported by the observer and detected by EM, although initially missed. Among all catch items, the level of agreement between observers and EM varied considerably as a result of camera positions and, to a lesser extent, observer catch estimation methods. Among fishing events where these issues were less of a factor, the level of agreement between EM and observers was high, particularly for target species and conspicuous species. Overall, results of this study suggest that EM shows promise for demersal longline fishing and further work is needed to determine if the technology could be successfully applied in pelagic longline fishing.

1. INTRODUCTION

The New Zealand Ministry of Fisheries (MFish), formed in 1995, works to ensure that fisheries resources are used in a sustainable way and that we have a healthy aquatic ecosystem (online MFish accessed 3 November 2006). Historically, a number of fisheries in New Zealand have experienced high rates of incidental mortality of seabird and marine mammal species, and today these fisheries are faced with increasing regulations to reduce the level of non-fish captures. MFish wishes to advance approaches for monitoring protected species mortalities in New Zealand fisheries and is investigating the use of electronic monitoring (EM) technology on longline vessels.

An ongoing concern in New Zealand longline fisheries is fishing gear interactions with seabirds and marine mammals. Species interactions with these vessels generally occur while baited fishing gear is being set, with birds and marine mammals often getting hooked or entangled and subsequently drowning as the gear sinks. Enumerating captures of seabird and marine mammals is vital for understanding the effects of fishing related mortalities on population viability, and for assessing the ability of fisheries to meet sustainability requirements. At-sea observers are currently the primary method for monitoring protected species interactions in these fisheries although, with the high cost of observer programmes and many vessels not being suited to accommodate an observer, there is a need to examine alternative monitoring methods.

Recent developments in technology are allowing the remote monitoring of catch in fisheries through electronic monitoring. Archipelago Marine Research Ltd., a private consulting firm from British Columbia, Canada, has pioneered the development of electronic monitoring to meet a variety of fishery monitoring issues (McElderry et al. 2004, 2005, 2006). In 2003, Archipelago carried out a study using electronic monitoring to assess protected species interactions in the Canterbury set net fishery (McElderry et al. 2007b). Based on the successful results of this project MFish has contracted Archipelago to examine the use of electronic monitoring technology in New Zealand longline fisheries. In carrying out this project Archipelago worked collaboratively with Lat 37 Ltd., a New Zealand based company that specialises in applied technology for the fishing industry.

The specific video monitoring objectives of the longline project were to:

- trial the deployment of electronic monitoring systems in selected longline fisheries, monitoring incidental take of protected species;
- evaluate the efficacy of electronic monitoring in allowing enumeration and identification of protected species captures; and,
- recommend options for data management and information transfer arising from the deployment of electronic monitoring in selected fisheries.

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 armoured dome closed circuit television (CCTV) cameras (Figure 1). The control box was placed in a dry, enclosed location on the vessel, such as the wheelhouse, and continuously recorded sensor and image data, monitored sensor performance and control data recording as required, as well as providing continuous feedback on system operations through a user interface. Detailed information about the EM system is provided in Appendix 1.

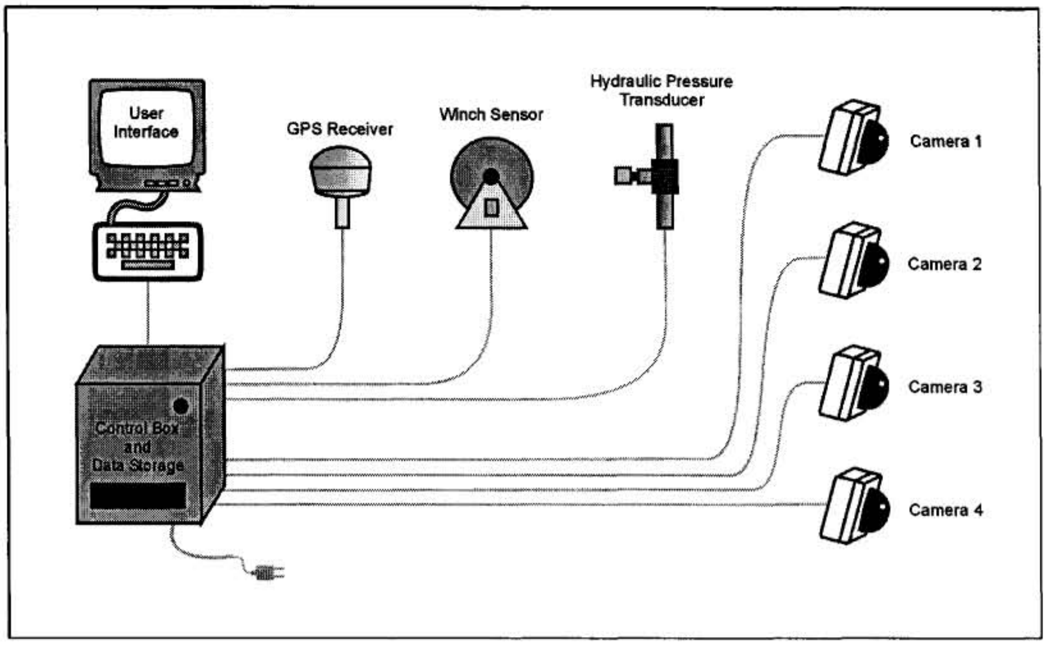

Figure 1: Schematic diagram of the electronic monitoring system, which can record video data from up to four cameras per vessel.

The EM system's GPS receiver mounts in the vessel rigging or on a cabin ceiling away from other electronics, and provided independent information on vessel position, speed, heading, and time. The electronic pressure transducer installs on the supply side of the hydraulic system and provided an indication when hydraulic equipment (winches, pumps, lifts, etc.) was operating. The optical winch sensor mounts onto the longline storage drums and is used to detect winch activity, indicating deployment or retrieval of the long line.

CCTV cameras were mounted to the vessel standing structure, in locations that provided unobstructed views of catch and fishing operations. As the placements were temporary, camera positions were opportunistic without custom fabrication of mounting positions.

EM control boxes were mounted in a secure dry area of each vessel, typically either the wheelhouse or forepeak. 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. A vessel's AC or DC electrical system was used to power the EM system.

EM data capture specifications

EM sensor data were recorded continuously while the EM system was powered, which was to be for the entire duration of the fishing trip. 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 20 minutes after either of these sensor triggers ceased. All imagery included text overlay with vessel name, date, time, and position.

An 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 about 60–100 MB per camera per hour, equating to a system capacity of 22–37 days of continuous recording when using three cameras and a 160 GB hard drive.

Field programme operations

In May 2006, project staff met MFish staff to provide an overview of the EM technology, discuss the methods for soliciting fishing vessel participation in the pilot, coordination with the MFish observer programme, and review specific information needs and data format requirements.

A New Zealand based field technician from Lat 37 Ltd. initiated communications with several potential vessels for the pilot study. A list of potential candidate vessels was passed to MFish staff who, in turn, contacted the skipper and secured their participation in the study. The Lat 37 technician then communicated directly with the vessel master for specific scheduling of EM system installation, servicing, and removals.

The EM system installation began with a meeting aboard the vessel between the Lat 37 technician and the captain to discuss basic operation and installation requirements of the EM system, and operational details concerning the pilot study. The captain was consulted regarding placement of EM equipment, wire routing, sensor placements, and EM system power requirements. The technician proceeded with the installation, which generally took a few days to complete. Upon completion, the EM system was powered up and sensors tested to ensure functionality.

Vessels participating in the pilot project usually carried an EM system for more than one fishing trip. While the vessel was in port after completing a trip, EM system performance was monitored through regular servicing that included an operational check of the equipment and a cursory analysis of the data collected. Because sensor signatures for vessels often vary, adjustments to EM system software settings were made to ensure that hydraulic pressure properly triggered image recording. Such changes generally occurred after the first fishing trip when data were available for examination.

This study involved the use of at-sea observers for comparison with data collected by an EM system. MFish observers were usually involved during the installation of the EM system and were briefed on its operation. While at sea, observers monitored retrieval operations and were instructed to record catch observations in a manner consistent with what could be obtained by viewers analysing EM imagery.

At the conclusion of the pilot, the Lat 37 technician removed the EM system and wiring and restored the vessel to its original condition. The EM data were copied to a backup hard drive then shipped to Archipelago's head office in Canada for comprehensive processing. Observer data were compiled by the MFish staff and delivered to Archipelago once image data were reviewed and delivered to MFish. Data in this pilot study were considered confidential and access was limited to the project team.

Vessel 1 - Demersal auto-longline vessel

The first vessel to participate in the pilot study was a large factory auto-longline vessel, measuring 46 m in overall length. Auto-longline vessels are equipped with automated machinery for gear storage, baiting and setting, and, as a result, fish using longer longlines than smaller coastal longline vessels. The auto-longline vessel participating in this study was equipped with onboard fish processing capabilities and generally made fishing trips over a month long. The opportunity for an EM system on this vessel was for a single fishing trip that was scheduled to last nearly 6 weeks and complete over 150 fishing events.

The EM system was installed while the vessel was in port preparing for departure. The control box was mounted in a locker in the forepeak where the equipment was secure and dry. Hydraulic lines and electrical power were available in the same locker space. The GPS receiver was positioned on the forward mast directly above the locker room. During the fishing trip the GPS was relocated adjacent to anchor winches to reduce the level of interference coming from the vessel's radar system. An optical winch sensor was not installed as no suitable mounting location could be found. Three CCTV cameras were installed on the vessel, two covering the hauling station and the third at the stern of the vessel over the longline deployment station (Figure 2). The primary hauling station camera was placed on a davit directly above the hauling station, providing a downward and slightly outboard view. The second hauling station camera was mounted under an overhang above the starboard bridge windows and provided a downward and forward looking view. Camera placements were mounted opportunistically on existing standing structures because of the temporary nature of the deployment. The resulting camera views were not ideal, particularly at the hauling station.

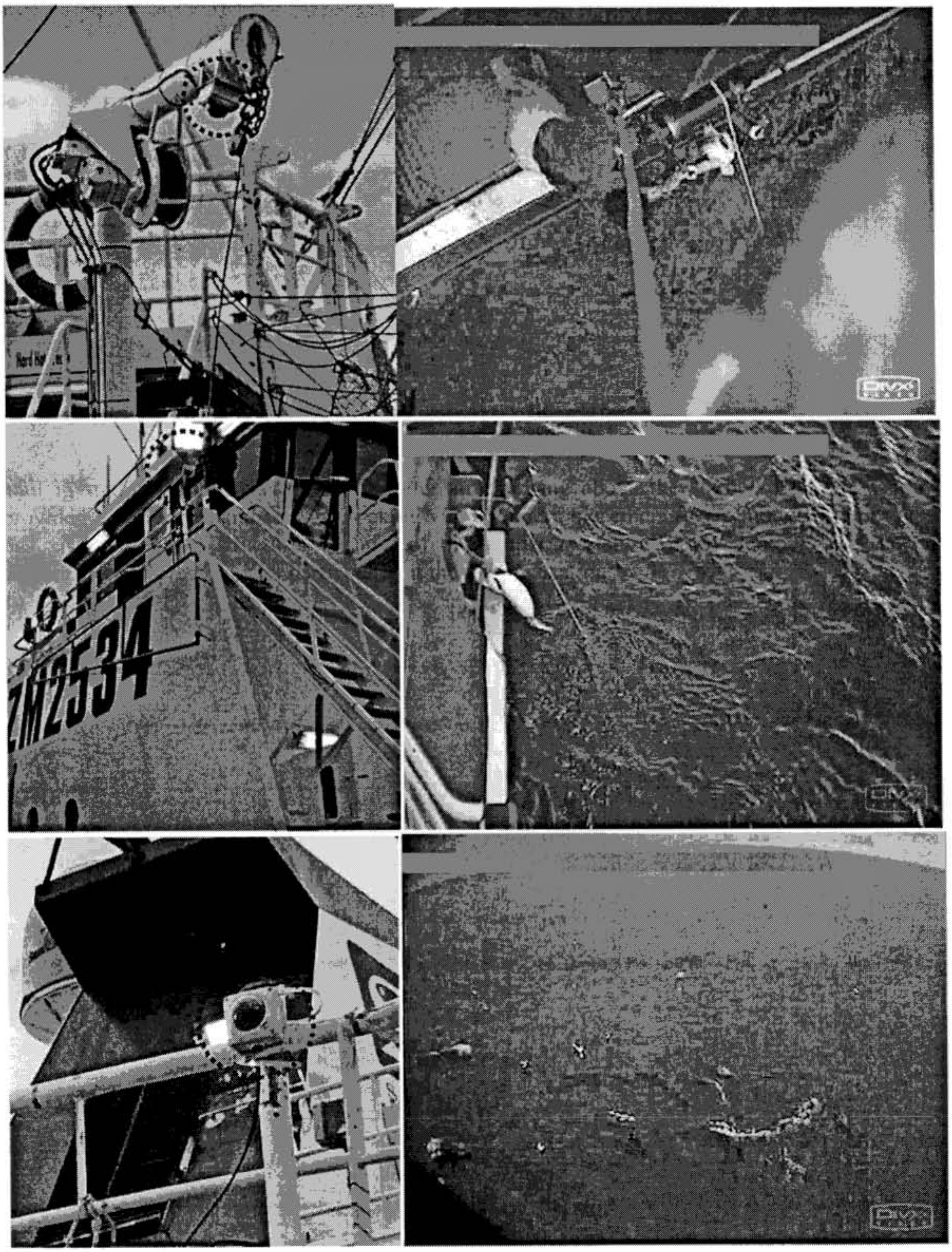

Figure 2: Auto-longline Vessel 1, showing CCTV camera position (left) and corresponding example of imagery (right). Middle panel shows close up locations of CCTV camera placements.

Vessel 2 - Demersal longline vessel

The second vessel was a coastal demersal longline vessel, measuring 14 m in overall length. This smaller vessel makes shorter fishing trips of 2 weeks or less with little or no onboard catch processing. The longline gear consisted of ground line and removable branch lines (ganglions, or snap gear). The ground line was stored on a drum and branch lines stored on racks. The EM system was aboard this vessel for two fishing trips, each lasting about 10 days.

The EM control box was mounted in the wheelhouse where a dry location and DC electrical power were available. The GPS receiver was mounted on the cabin top and the hydraulic sensor was mounted on the control valve at the hauling station. An optical winch sensor was mounted on the longline drum. Two cameras were mounted, one for hauling and the second for viewing gear shooting astern of the vessel (Figure 3). The hauling station camera was positioned on an overhead extension, providing a downward looking view of the hauling station. The second camera was mounted on the mast, providing a stern view where gear was set.

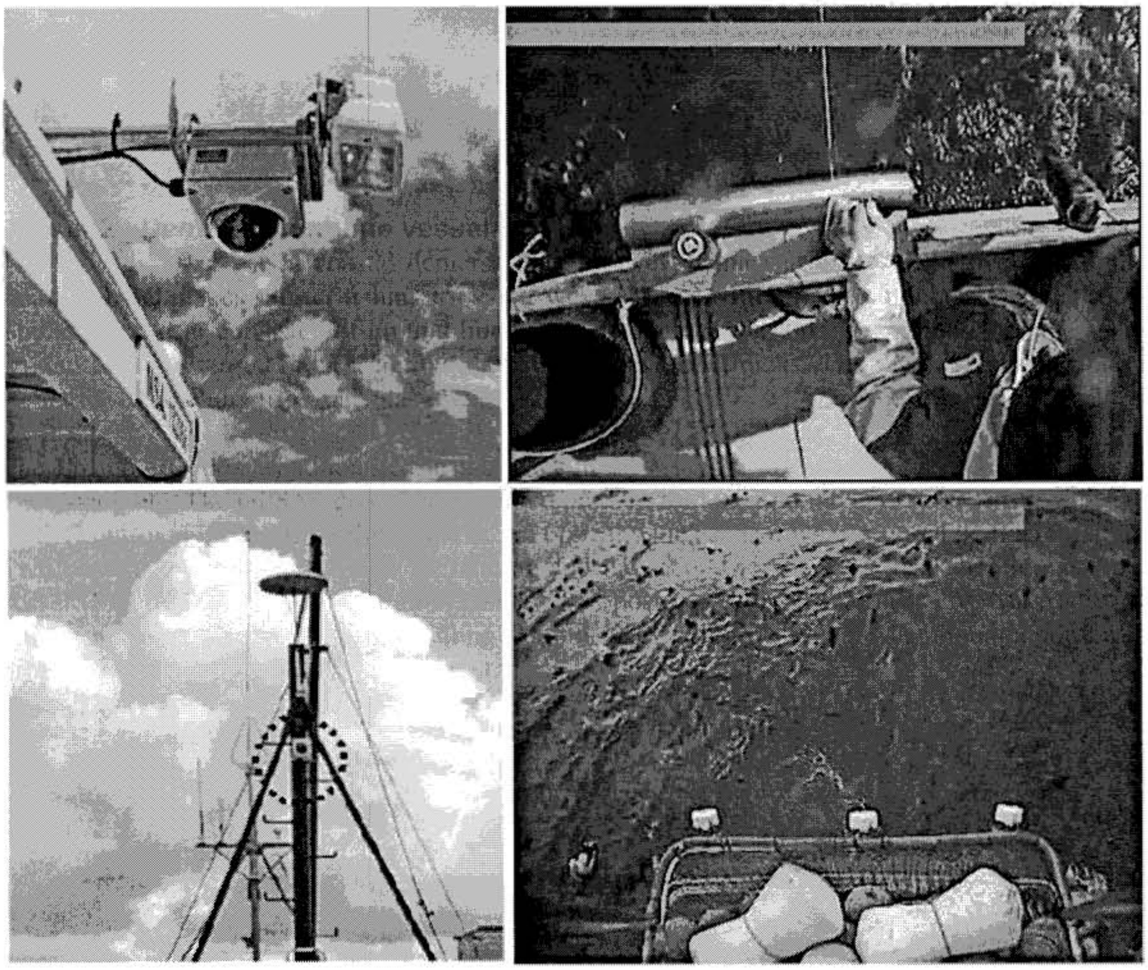

Figure 3: Vessel 2 showing camera positions (left) and corresponding sample of imagery (right).

Vessel 3 - Pelagic longline vessel

EM systems were placed on two pelagic longline vessels, the first of which was a larger vessel, measuring 24 m in overall length. Pelagic longlining targets tunas, billfish, and other midwater fish using monofilament main line and branch lines attached with snaps. Pelagic longline gear has branch lines that were much longer and spaced much further apart that demersal longline gear. The EM system was aboard Vessel 3 for four trips. An observer was present on three of these trips.

The EM system was installed in a similar configuration to pilot Vessel 1. The control box was located in a forepeak cabin, again with ready access to hydraulic lines and electrical power. The GPS receiver was mounted on the forward mast directly above the forepeak cabin. The vessel carried two longline drums and a winch sensor was fitted to each. Three CCTV cameras were mounted, two at the hauling station and one at the vessel stern (Figure 4).

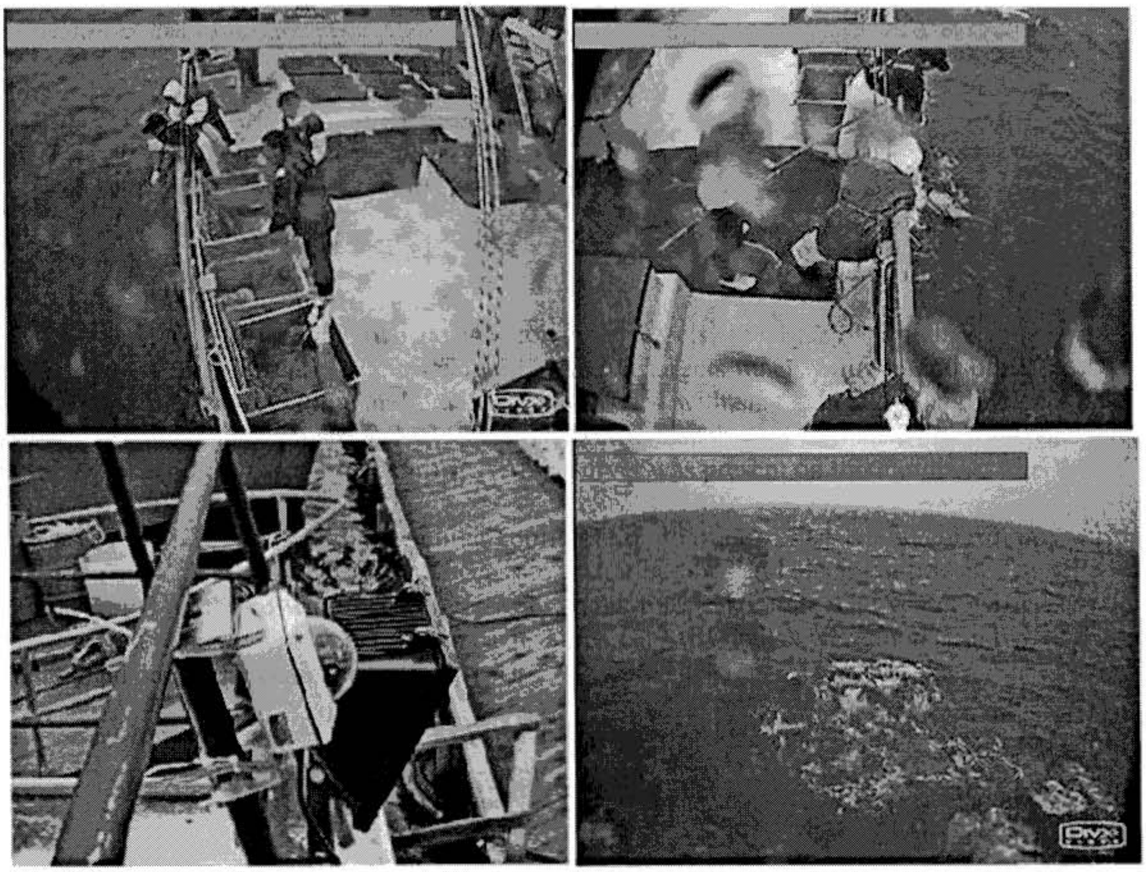

Figure 4: Vessel 3, showing CCTV camera views for the hauling station (top right and left) and stern camera (bottom left) and stern view (bottom right).

Vessel 4 - Pelagic longline vessel

The fourth vessel was also a longline vessel, targeting tuna. At 19 m length overall, this vessel was smaller than Vessel 3. An EM system and observer were aboard this vessel for two fishing trips.

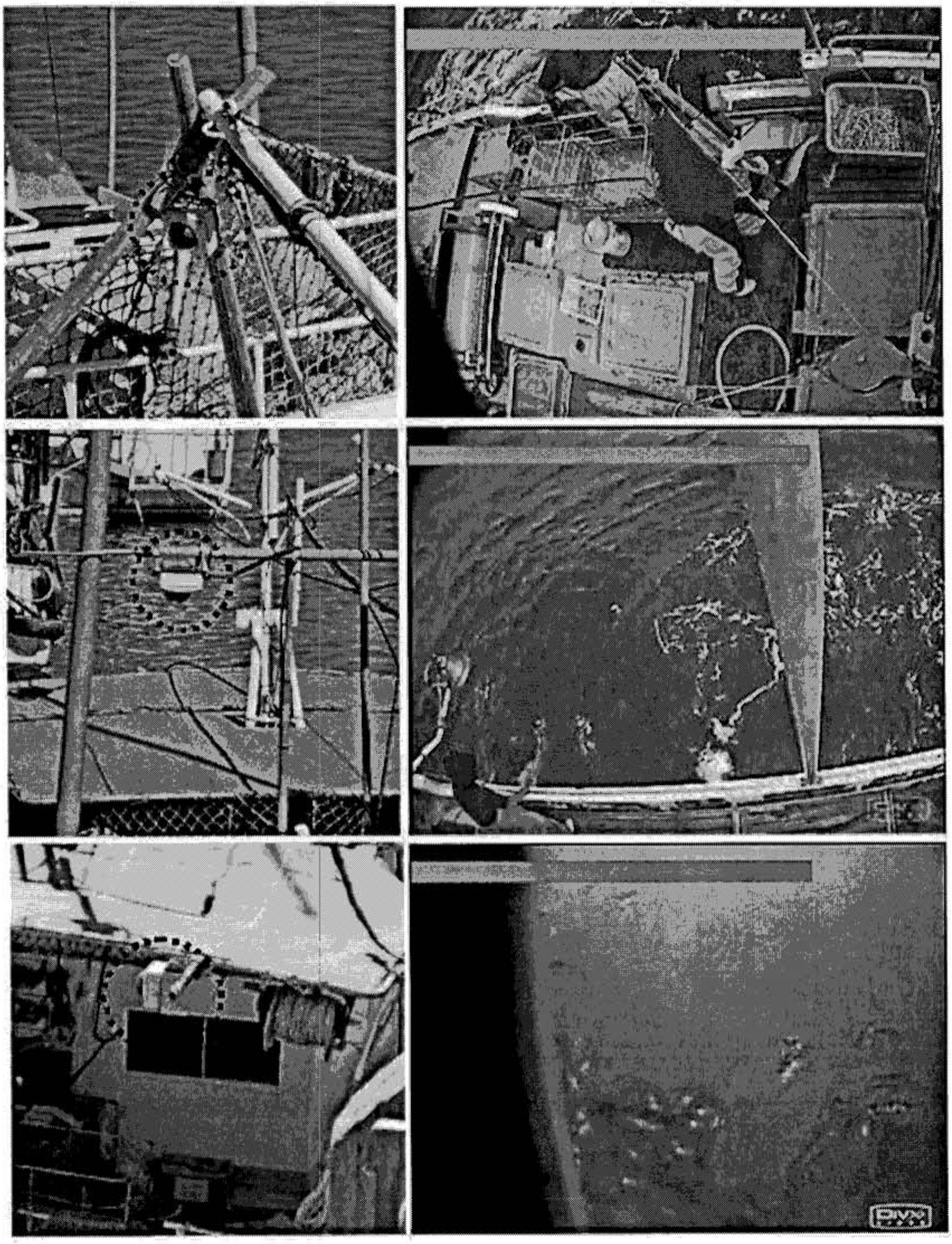

Figure 5: Vessel 4 showing CCTV camera positions on vessel (left) and corresponding camera imagery (right).

The EM system was installed with the control box located in a small aft cabin and powered directly from the vessel's AC generated power. The GPS was mounted on the stern mast and the hydraulic sensor was mounted in the engine room. No winch sensor was placed on this vessel. Three cameras were used, again two for the hauling station and one for the stern area (Figure 5). The first hauling station camera was mounted in a boom crosstree directly above the wheelhouse, providing a downward view of the hauling station and sea door. The second camera was mounted on an extension pole positioned over the starboard amidships, providing a forward view of the hauling station and sea door. The third camera was directed over the stern of the vessel, mounted under the awning on a strut where lighting fixtures were positioned.

2.2 EM Data interpretation and analysis

Sensor data analysis

Sensor data (GPS, hydraulic and winch rotation) were analysed to interpret the geographic position of fishing operations and distinguish key vessel activities including transit, gear setting, and gear retrieval. EM sensor data interpretation was facilitated using a relational database as well as time series and spatial plots, which are illustrated in Figure 6. Raw data were first imported to an MS Access 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. Time breaks in the data record were the result of loss of power to the EM system, system lockup, or GPS signal failure.

The quality of the GPS receiver signal was also evaluated to determine reliability of position and time signal. The GPS receiver reports vessel position, speed, heading, and time (UTC, converted to NZ standard time). Poor GPS receiver signal was usually the result of an intermittent GPS signal or interference from other vessel electronics. In addition, sensor equipment including GPS receiver, hydraulic sensor, drum counter, and the CCTV cameras were evaluated for each trip as follows:

- *Complete* – sensors performed to their full capacity.
- *Incomplete* – intermittent failures, false readings, cameras pointed in the wrong direction, or view was obscured.
- *No data* – sensor did not operate during a trip, or camera view was completely blocked.

Once sensor data were evaluated for content and quality, the data set was imported to applications for time series and spatial plotting (Figure 6). Vessel speed, hydraulic pressure, and winch sensor (if available) often correlate uniquely for various activities such as transit, setting, and hauling. The spatial plot provides a perspective on the various activities in relation to one another and is useful to help associate specific setting and hauling events. 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.

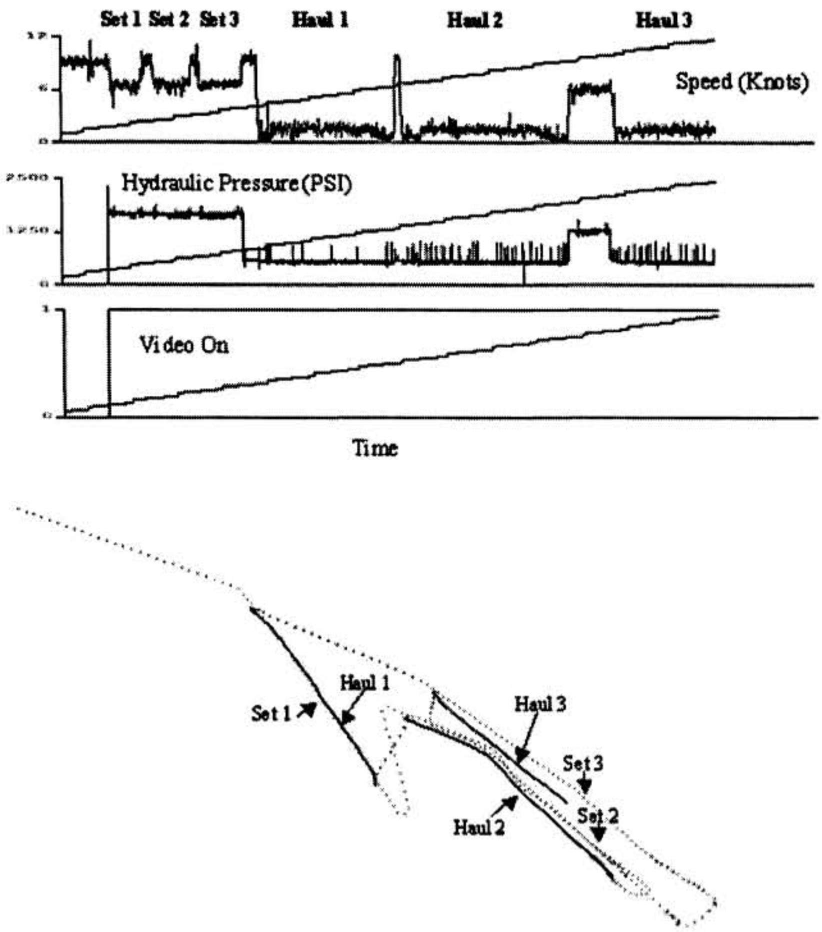

Figure 6: Example of sensor data from auto longline fishing for a period of about 24 hours. Time series graphs (upper) show vessel speed, hydraulic pressure, and status of video recording. The diagonal line shown in all graphs is a 24-hour time reference used to identify time breaks in the data set. The spatial plot (lower) shows the vessel cruise track for the same period with setting and hauling events distinguished.

Image data interpretation

The objectives of image interpretation were to first assess whether all the intended imagery was recorded properly. This was done by comparing haul times from sensor data with those available for image data. The next step in image data analysis was to select hauls for a detailed viewing of catch. Imagery was not examined for hauling events where imagery was incomplete or image quality was unusable. Likewise, due to the large number of hauling events with the auto longline vessel, only a portion of events was selected for analysis.

With the exception of Vessel 1, imagery from all retrieval events was examined and assessed on one of two levels.

- *All catch items* – Imagery was viewed at a speed to identify all catch items and record these observations in a data record. Catch was identified to species if possible, otherwise to general morphological group, or simply as unidentified.
- *Protected species only* – Imagery was viewed with the goal of identifying interactions with protected species. Viewers needed to play the imagery slowly enough to distinguish catch items from protected species, but were required to record events only where protected species were

encountered. As a result, image processing time with this method was thought to be much faster than assessment of imagery for all catch items.

Viewers involved with image processing had extensive experience with the identification of Northeast Pacific fish fauna. Their knowledge of New Zealand fish species was established using a reference text (Anon. 1994) and an image library established from an earlier study in New Zealand (McElderry et al. 2007b). The goal was to identify catch at least to morphological groups, recognising that viewers did not have a complete understanding of New Zealand fish species.

Imagery was examined using a few image player software products. Most of the catch assessment analysis was made using a custom software product that provided synchronised playback of all camera images, a data entry form for recording catch observations. Unfortunately this product had limited high speed playback which is useful to review large quantities of imagery with infrequent events of interest. Windows Media Player was also used for displaying a single camera view, particularly with protected species observations where annotations were infrequent and accelerated viewing speeds were often desired. Image playback speeds varied from about 1.5 to 10 times real time according to monitoring objective, catch density, and image quality.

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 quality* –camera lenses properly focused, viewing areas clearly visible, and gear retrieval and catch processing easy to assess.
- *Medium quality* - some loss of resolution from pixilation, sunlight glare, or moisture; poor camera positioning, or minor obstruction of view but gear retrieval and catch processing still assessable.
- *Low quality* – reduced light, increased pixilation, water spots on lenses, poor focus and fishing activity generally difficult to resolve.
- *Unusable* – images poorly resolved or obstructed such that fishing activity can not be reliably discerned.
- *N/A* – image files missing or incomplete and therefore analysis not possible.

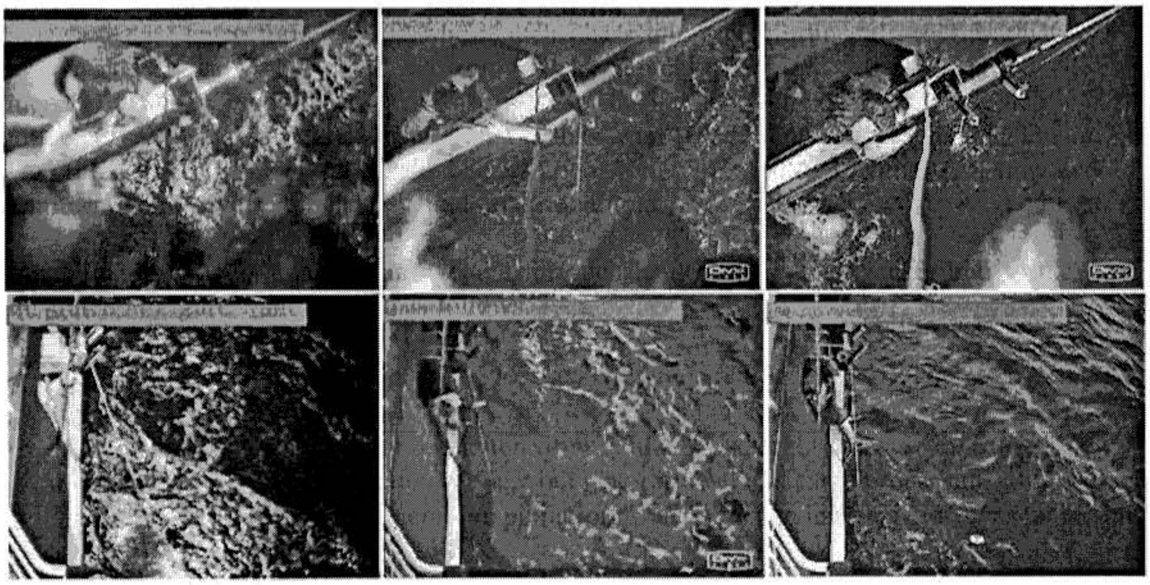

Figure 7: Hauling station views from auto longline vessel showing low (left), medium (middle) and high (right) quality images from hauling station davit (upper) and bridge (lower) CCTV cameras.

Imagery from setting observations was also assessed from the four fishing vessels to determine the quality of imagery and the ability to observe seabird activity during longline setting operations. As well, imagery was evaluated to determine the presence and effectiveness of seabird mitigation devices.

Analysis ratios

As image processing involves significant time expenditure, staff performing this work kept detailed records of time required to view imagery. This information, along with actual elapsed imagery time, was used to calculate image analysis ratios, defined as the ratio of analysis time to total elapsed time of the fishing operation.

2.3 Data management issues

In addition to fishery data, project staff kept records of data volumes required from EM deployments on the four vessels. The data volume for sensor and image data was recorded from each hard drive after the EM deployment was completed.

3. RESULTS

3.1 EM trials on fishing vessels

EM system deployments

EM system deployment results are summarised in Table 1. The pilot spanned a 9 month period involving four vessels, 9 fishing trips, 124 vessel days at sea, and a total of over 200 fishing events. The two demersal longline vessels collectively logged about half the sea time and 80% of the fishing events, and much of this came from the single deployment aboard the auto-longline vessel (Vessel 1). Among the two pelagic longline vessels, EM systems recorded slightly more time at sea with only 42 fishing events. An at-sea observer was present for all but one trip and five fishing events.

The data recording success of EM systems varied considerably among the four participating vessels. Sensor data, which should be logged continuously from the start to end of the fishing trip, were incomplete on significant portions of fishing trips for all but one vessel. On the basis of individual fishing trips, sensor recording success varied from 8 to 100% and the average among all trips was 54%. Image data, recorded during setting and hauling events only, were much more complete among all vessels, ranging from 82 to 100% and averaging 97% among all trips.

Table 1: Inventory of fishing trips monitored by EM for the four pilot vessels.

	Vessel ID	Trip #	Start date	End date	Days at sea	Observer present	Fishing Events Expected	Fishing Events Actual	%	Sensor (h) Expected	Sensor (h) Actual	%	Video (h) Expected	Video (h) Actual	%
Demersal Longline	1	1	06 Aug	06 Sep	46	Y	143	139	97.2%	1111	859	77.3%	651	633	97.2%
	2	1	06 Dec	06 Dec	6	Y	7	7	100.0%	149	12	8.0%	16	16	100.0%
		2	06 Dec	06 Dec	5	Y	9	9	100.0%	116	32	28.0%	20	20	99.9%
	Vessel Total	2			11		16	16	100.0%	265	44	16.7%	36	36	100.0%
	Total Demersal	3			57		159	155	97.5%	1376	903	65.6%	687	669	97.4%
Pelagic Longline	3	1	07 Mar	07 Mar	10	Y	2	1	50.0%	131	46	35.4%	3	3	100.0%
		2	07 Mar	07 Apr	22	Y	12	8	66.7%	524	101	19.3%	26	26	98.0%
		3	07 Apr	07 May	7	Y	8	2	25.0%	169	18	10.6%	7	6	87.4%
		4	07 May	07 Jun	9	N	5	5	100.0%	209	30	14.3%	16	13	82.6%
	Vessel Total	4			48		27	16	59.3%	1033	195	18.9%	52	48	92.0%
	4	1	07 Mar	07 Apr	9	Y	8	8	100.0%	217	217	100.0%	46	46	100.0%
		2	07 Apr	07 Apr	10	Y	9	9	100.0%	239	239	100.0%	50	49	99.1%
	Vessel Total	2			19		17	17	100.0%	456	456	100.0%	96	95	99.5%
	Total Pelagic	6			67		44	33	75.0%	1489	651	43.7%	148	143	96.8%
	Total All Vessels	9			124		203	188	92.6%	2865.22	1554	54.2%	835	812	97.3%

Unsuccessful data capture from the four EM deployments was primarily caused by the EM system being manually shut off. Time breaks recorded on Vessel 1 were generally long and often ended when the observer came on shift. This vessel also experienced time gaps early in the trip as a result of a poor GPS signal caused by interference from the vessel's radar. Similarly, time breaks recorded by Vessel 2 were probably caused by the EM system being powered down when fishing operations were not occurring. Vessel 3 recorded large time breaks in the sensor data and it appeared that this was caused by both a problem with the vessel's electrical system and the EM system being manually powered down. Unlike the previous two vessels, time breaks in the Vessel 3 data set were more numerous with many being very short, as would occur with an intermittent power source. The observer report noted: '*mechanical malfunctions, such as failure of the vessel's electrical and hydraulic power system and main engine, occurred frequently*'. Vessel 4 had a very complete data set for the two fishing trips, recording only one break in the data set of less than 5 minutes out of a total of 450 hours.

Image capture rate was generally high across the four vessels and it is estimated that EM systems successfully recorded 98% of fishing event activity. This result probably reflects efforts made by observers to ensure that EM systems were operating when hauling operations were underway.

Table 2 provides a further summary of EM success for monitored fishing events. Out of a total of 203 monitored fishing events, sensor data were recorded for gear setting and hauling on 132 events. EM systems recorded only during hauling for 20% of the total fishing events and there were 21 events where no sensor data were recorded. With the image data, all but 24 fishing events (88%) could be used for analysis; imagery was unusable for 9 events due to poor imagery quality and not available for 15 events due to numerous breaks in the data (Vessel 3). Among the usable fishing event imagery (179 events), 75% were analysed. Most imagery (65%) was assessed as medium quality and about 10% was considered high quality.

Table 2: Summary of data set recorded by EM and Observers for the four vessels.

Summary by fishing events	Fishery and vessel ID: Demersal Longline 1	Demersal Longline 2	Pelagic Longline 3	Pelagic Longline 4	Totals
Sensor data					
Setting/hauling complete	112	2	1	17	132
Setting events only	9	0	1	0	10
Hauling events only	17	14	9	0	40
No sensor data	5	0	16	0	21
Totals	143	16	27	17	203
Image data					
Imagery analysed	89	15	14	17	135
Imagery unusable	6	1	2	0	9
Imagery not available	4	0	11	0	15
Imagery not analysed	44	0	0	0	44
Totals	143	16	27	17	203
Image quality					
High	3	1	1	8	13
High/Med	0	0	0	4	4
Med	58	13	12	5	88
Med/Low	10	0	1	0	11
Low	18	1	0	0	19
Totals	89	15	14	17	135

Interpretation of EM sensor data

Identification of vessel fishing activity was discerned from hydraulic pressure and GPS data. Data from the winch sensors on Vessels 2 and 3 were incomplete and not used. Examples of the time series graphs are shown in Figure 8 for the four vessels, showing vessel speed (VS) and hydraulic pressure (HP) over a 24-hour period. Sensor data patterns differed by vessel and the ability to discern setting and hauling events also varied. In general, hydraulic pressure pattern differed between setting and hauling activities and was absent or reduced when the vessel was transiting or standing by. Hydraulic pressure also fluctuated more during hauling than setting, corresponding to starting and stopping of the longline to retrieve catch items. Vessel speed was generally lower and more variable during hauling than setting, again corresponding to work associated with catch retrieval. Distinguishing adjacent setting or hauling events was usually evident by increased vessel speed while repositioning the vessel (e.g., Vessel 1). In some instances this did not occur, making it difficult to distinguish different sets.

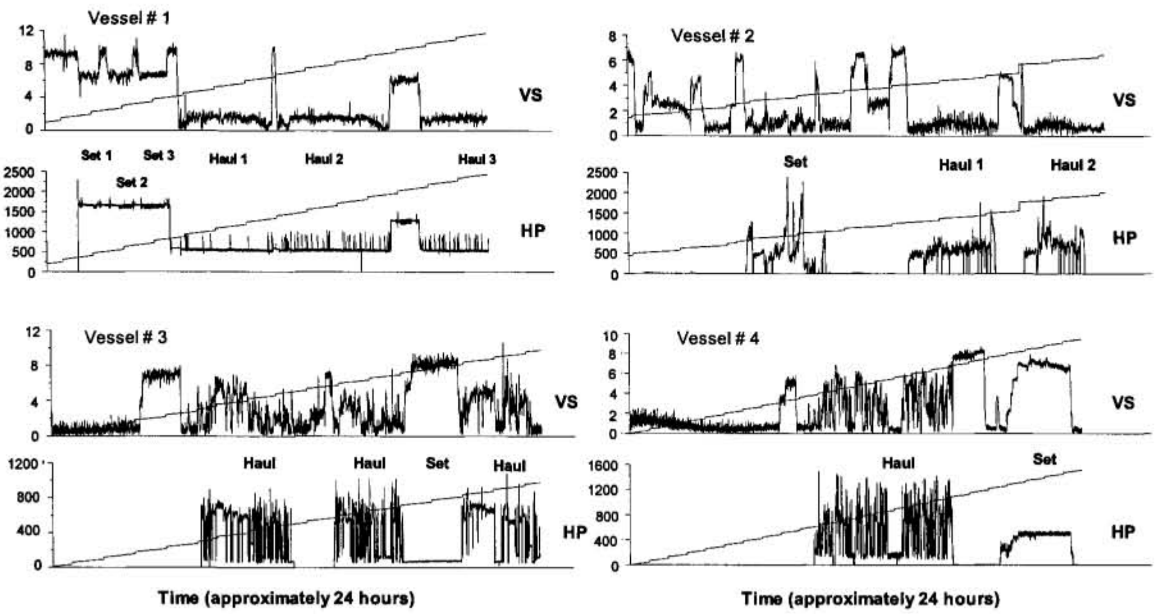

Figure 8: Sensor data examples from four vessels showing vessel speed (VS) and hydraulic pressure (HP) readings at approximately 10 second intervals over about 24 hours. Setting and hauling events are noted in each instance. The diagonal line in each graph shows incremental time of day.

Changes to CCTV camera positions on vessels

Except for Vessel 1, EM systems were aboard vessels for multiple trips. Often during initial installation it was difficult to assess how well camera placements would capture fishing activities: this information becomes available once actual fishing activities are reviewed in the imagery. Upon completion of a fishing trip the EM technician inspected imagery and made adjustments to camera positions, if necessary. One of the two CCTV cameras was adjusted in Vessel 2, extending the camera further outboard over the hauling station (Figure 9). This change slightly improved the view of catch coming out of the water and approaching the roller, but was obstructed by the crewman working at the roller.

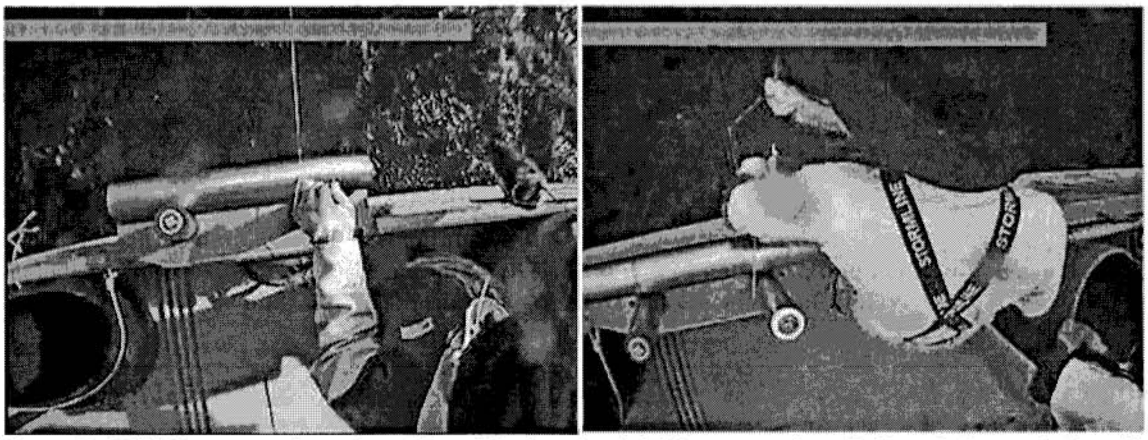

Figure 9: CCTV camera views from Vessel 2, showing initial camera view (left) and changed view (right).

Changes in camera positions on Vessel 3 were more significant (Figure 10). Both hauling station cameras were repositioned after the first trip in an effort to improve the view of the sea door where catch was typically brought aboard. In one case the camera position was extended further outboard and the lens magnification increased (Figure 11, upper). This change significantly improved the view of the crewmember working at the hauler and of catch approaching the sea door. The second bridge mounted camera, providing a forward view of the hauling station, was repositioned to the port side showing the forward deck area where catch was brought aboard. While this camera angle improved the view of catch landed on board, it was at the expense of the outboard view. Imagery outboard and aft of the sea door was lost.

Figure 10: CCTV camera views from Vessel 3, showing initial camera view (left) and changed view (right).

Similarly, the cameras on Vessel 4 were repositioned after the first fishing trip (Figure 11). The first hauling station camera, mounted in the boom crosstree (see Figure 5), was redirected outboard slightly to improve the view of the catch as it reached the rail. The second camera, mounted on an extension pole positioned over the starboard amidship, provided a forward directed view of the water aft of the sea door. After the first trip a new camera mount was fabricated to extend the camera view further outboard. The lens magnification was also increased and the camera was directed aft to discern catch trailing amidships and off the stern quarter of the vessel. Rather than getting an outboard view over the hauling station, this camera angle was repositioned to account for any catch that may have been discarded by the hauling station crewman releasing the snood. As a result, there was no outboard view at the hauling station after the first fishing trip. The third camera was directed over the stern of the vessel, initially mounted on an afterdeck lighting pole under the awning. The resulting camera view was obscured by the camera housing and provided a distorted view behind the vessel. This camera was later moved to an elevated location on the aft mast, providing a stern view from above the awning.

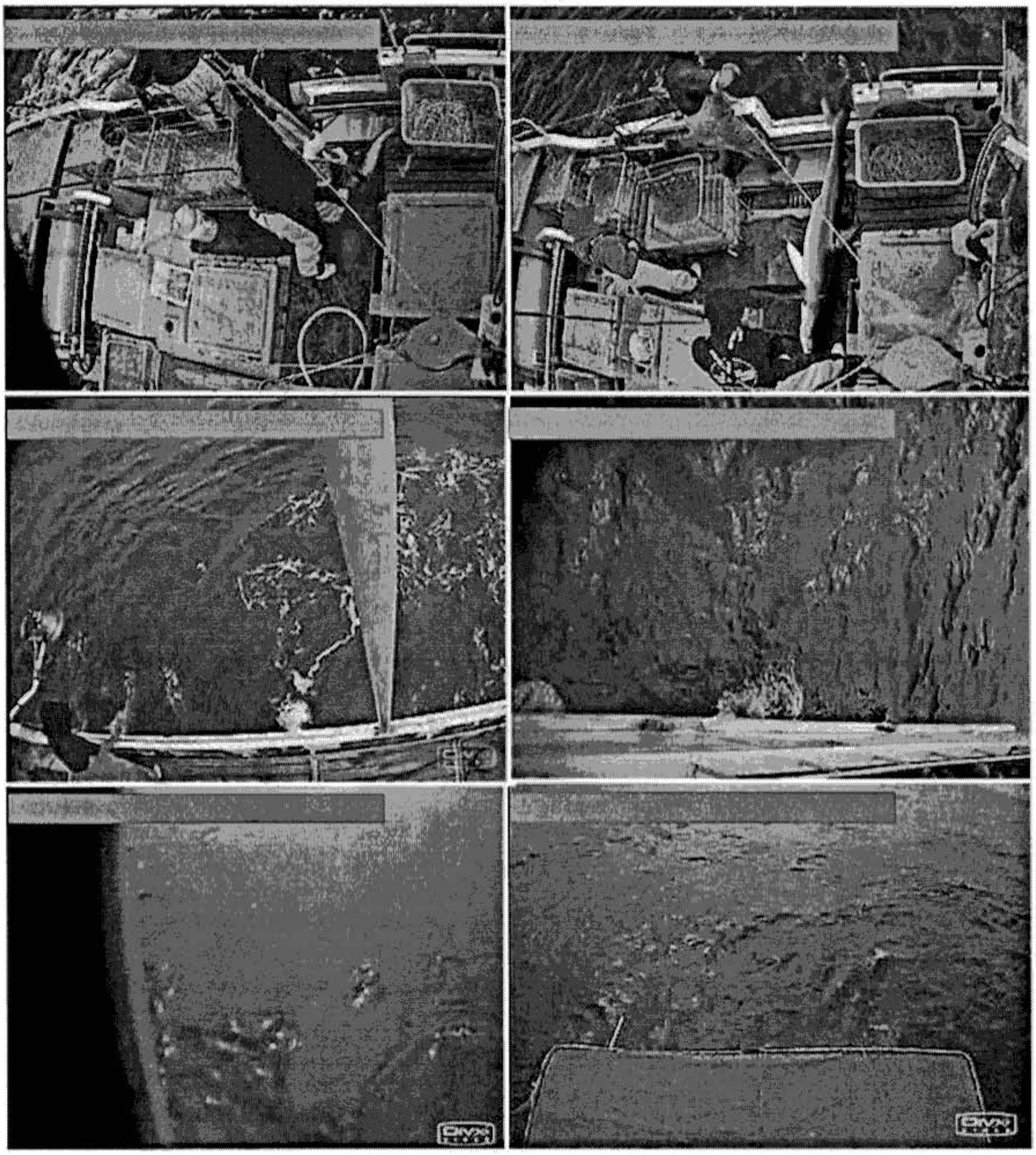

Figure 11: CCTV camera views from Vessel 4, showing initial camera view (left) and changed view (right).

3.2 EM data interpretation and analysis

Matching of EM and observer catch data sets

As one of the main goals of the study was to compare EM and observer estimates of protected species interactions, it was important to match the two data sets. The matching results from the eight trips where both EM and observers were present are summarised in Table 3. Taken separately, EM and observer data sets recorded different numbers of fishing events (183 versus 187, Table 3). When these were matched using time of haul start, 198 unique fishing events were identified. Most fishing events (172 or 86%) were in common with both data sets, while there were similar numbers of fishing events recorded by one method and not the other. The matching process was not very straightforward and was complicated by several factors. An inability to match all fishing events between EM and observers is probably the result of missing data or error; the true number of fishing events is probably between 185 and 190. With Vessel 1 the observer recorded one more set than EM and each had 4–5 fishing events not detected by the other. There were large intervals when the EM system was turned off and detection of fishing events from the sensor data was difficult. Fishing events matched exactly for Vessel 2, but Vessel 3 fishing events were poorly aligned, again probably because of the aforementioned issues with power loss and incomplete sensor data. Vessel 4 curiously resulted in only 13 of 17 fishing events matching, with EM recording four more events than the observer.

The difficulties in associating EM and observer data were probably due to several factors. In the case of EM data, the estimations for the start and end of longline set and retrieval were approximate, unless confirmed by examination of imagery (see Figure 8). Time breaks in the EM data set of an hour or more resulted in missed fishing events. When a set event was missed but a hauling event was present it was possible to reconstruct the missing events but with difficulty. Also affecting fishing event matching was set and haul order. The order in which gear was set did not always follow the order of retrieval, and therefore set numbering between EM and observers could differ. Vessel 1 carried out operations continuously and the observer was present for only some of the events. Finally, the accuracy of time recording by the observer or vessel could significantly affect the ability to match fishing activities.

Table 3: Summary of matched sets from EM and Observer data sets.

Fishing events by category	Demersal Longline 1	Demersal Longline 2	Pelagic Longline 3	Pelagic Longline 4	Total
Total unique	143	16	22	17	198
EM record	139	16	11	17	183
Obs record	138	16	20	13	187
EM+ Obs-	5	0	2	4	11
EM-Obs+	4	0	11	0	15
EM+Obs+	134	16	9	13	172
Total	143	16	22	17	198
Usable for comparison	129	15	9	13	166
Image analysis objective					
All catch	20	15	0	4	39
Protected species only	65	0	9	9	83
Not analyzed	44	0	0	0	44
Total	129	15	9	13	166

Overall, there were 172 fishing events that matched between EM and observer data sets and 166 could be used for comparison of protected species and catch observations (6 had unusable imagery or observer was not on shift for operation). There were 122 fishing events analysed for protected species of which 39 were also examined for all catch species. Due to the large number of fishing events for Vessel 1 not all were analysed. Fishing events for Vessel 3 were analysed only for protected species and thus there were no 'all catch' comparisons for this vessel.

Comparison of EM and observer protected species observations

Results from observer data indicated there were nine protected species interactions documented (Table 4). These nine interactions consisted of eight seabird incidents and one sea turtle (Table 4) and only two of the incidents were considered within view of the EM cameras. Among the seabirds, three species, all petrels, were recorded. Four of the eight seabird encounters were deck landings (seabirds landing on deck) and not in view of EM cameras. Two further encounters involved cape petrels (*Daption* spp.) colliding with the mainline and becoming briefly entangled during hauling. The observer records are unclear about these incidents but through discussion with the MFish Observer

Programme Manager (Andrew France) it seems likely that they were briefly tangled, self-released unharmed, and did not come aboard at the roller. There were a further two incidents on Vessel 2 where black petrels (*Procellaria parkensoni*) were hooked at the hauler. The first of these was brief and the seabird was released alive before the roller. The second was also brief and the vessel crew released the seabird after coming aboard at the hauler. EM detected the last event (Figure 12, upper) where the bird could be clearly seen diving toward bait, becoming hooked, and being released at the hauler.

Table 4: Summary of matched sets from EM and observer data sets.

Vessel ID	Date	Set #*	Common name	Scientific name	Interaction	Outcome	Detection
Not within view of EM cameras							
2	06 Dec	3	Black Petrel	*Procellaria parkinsoni*	Deck landing	Released alive	Obs
2	06 Dec	5	Black Petrel	*Procellaria parkinsoni*	Deck landing	Released alive	Obs
2	06 Dec	10	White-chinned Petrel	*Procellaria aequinoctialis*	Deck landing	Released alive	Obs
3	07 Apr	3	Pycroft's Petrel	*Petrodroma cookie/pycrofti*	Deck landing	Released alive	Obs
2	06 Dec	3	Black Petrel	*Procellaria parkinsoni*	Briefly hooked at hauler	Dislodged alive before roller	Obs
1	06 Sep	54	Cape Petrel	*Daption* spp.	Tangled in groundline	Released alive	Obs
1	06 Sep	83	Cape Petrel	*Daption* spp.	Tangled in groundline	Released alive	Obs
Within view of EM cameras							
2	06 Dec	5	Black Petrel	*Procellaria parkinsoni*	Hooked at hauler	Released alive	Obs & EM
4	07 Mar	3	Leatherback Turtle	*Dermochelys coriacea*	LF flipper tangled in mainline	Released alive	Obs

* - Set numbers according to observer record.

A leatherback turtle (*Demochelys coriacea*) was entangled in the mainline by its left front flipper on the first trip of Vessel 4. The crew halted retrieval operations for about a half an hour to bring the animal alongside and disentangled it by using a de-hooking device (shown hanging from the camera mount in Figure 12 lower right). The turtle was released alive, apparently unharmed. During the initial review of the EM imagery, viewers did not detect this encounter primarily because they were viewing camera 1 (Figure 12, bottom left) where most activity was outboard and aft of the sea door (Figure 12, bottom right). Subsequent examination of the imagery clearly showed the interaction, particularly in camera 2 (Figure 12, lower right) where a positive identification could be made.

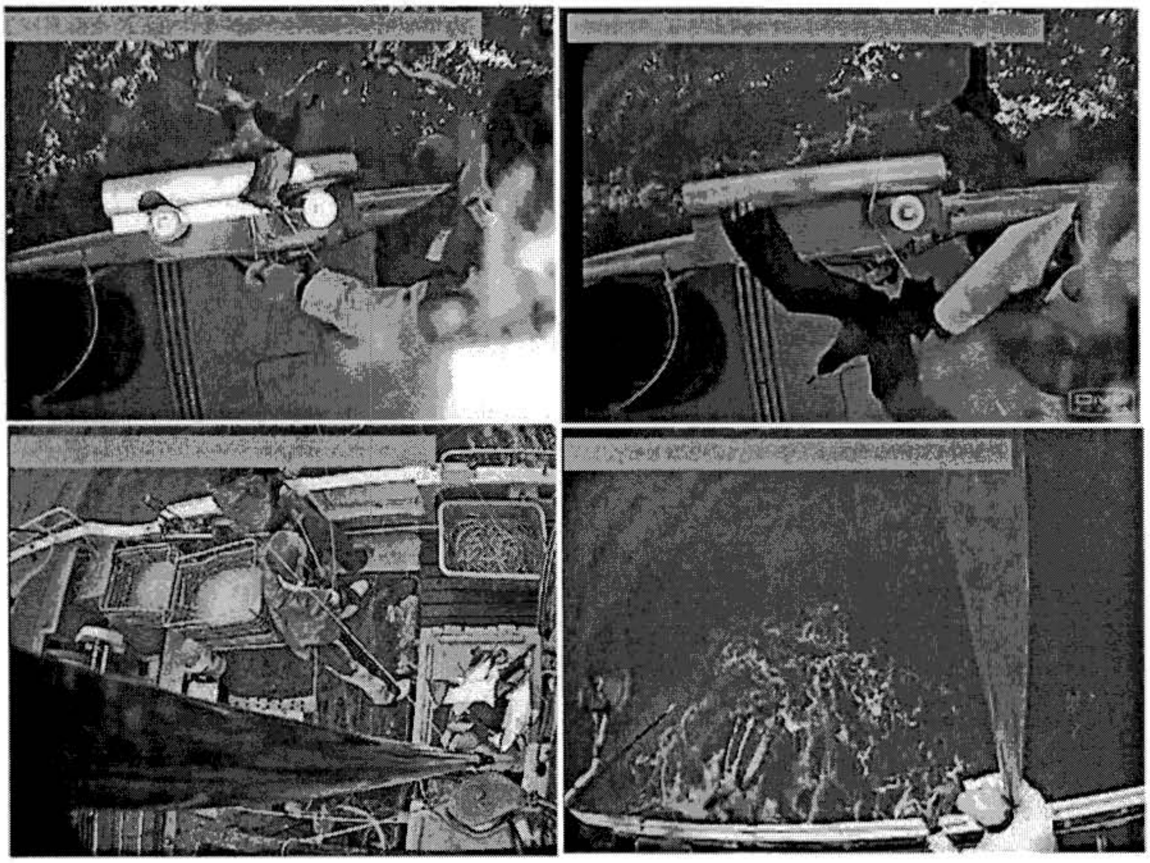

Figure 12: Imagery of protected species encounters recorded by EM. Upper photographs show black petrel interaction recorded on Vessel 2. Lower photographs show leatherback turtle interaction recorded on Vessel 4.

Comparison of EM and observer catch observations

EM and observer data records of all catch (excluding protected species) summed by fishing event are compared in Table 4. The 39 fishing events were from three of the four vessels, with 90% being from the two demersal longline vessels. Catch levels ranged from under 100 pieces for pelagic vessels and levels approaching 3000 pieces for demersal vessels. The percent agreement ((obs-EM/obs)*100) varied from 0.1 to 80% across all vessels and about 60% of the sets had levels of agreement of less than 20%. The EM counts were lower than observer counts in all but 10 fishing events, suggesting that not all recorded catch was viewable by EM. With Vessel 1, sets with the lowest levels of agreement were those that were only partially monitored by observers, suggesting that the error was related to the observer data source. Further, observer catch estimates for 3 of the 20 Vessel 1 sets were based on vessel logbook records (Table 4, Observer assessment code 12 and 22) rather than from direct observations (Observer assessment code 11 and 31). Generally, observers derive independent catch estimates but vessel logbook records are used when this is not possible. The different observer assessment codes distinguish the two data sources.

Table 4: Summary of matched sets from EM and observer data sets.

Vessel ID	Trip #	Set #*	Piece counts EM	Piece counts Obs	% Difference	Image quality	Observer assessment	Full or partial
1	1	19	1 904	1 797	-6%	M	22	F
1	1	15	1 809	1 935	6.5%	M	11	F
1	1	61	1 549	1 685	8.1%	M	11	F
1	1	115	2 864	2 581	-11.0%	L/M	11	F
1	1	84	1 474	1 308	-12.7%	L/M	11	F
1	1	106	1 391	1 202	-15.7%	M	11	F
1	1	11	1 038	1 232	15.7%	M	31	F
1	1	20	1 662	1 981	16.1%	M	31	F
1	1	64	1 892	2 274	16.8%	L	11	P
1	1	110	1 940	1 654	-17.3%	M	11	F
1	1	137	3 044	3 681	17.3%	M	11	F
1	1	121	2 316	1 953	-18.6%	M	11	F
1	1	12	1 247	1 612	22.6%	M	31	F
1	1	16	1 007	1 357	25.8%	M	31	F
1	1	101	1 050	1 450	27.6%	L/M	11	P
1	1	138	1 435	2 338	38.6%	L/M	11	P
1	1	136	1 120	1 888	40.7%	L/M	11	P
1	1	103	673	1 209	44.3%	M	11	P
1	1	17	463	1 669	72.3%	L	12	P
1	1	122	422	1 897	77.8%	L/M	22	P
	Vessel total		30 300	36 703	17.4%			
2	2	15	50	48	-4.2%	M	11	
2	2	10	182	191	4.7%	M	11	
2	2	9	229	216	-6.0%	H	11	
2	2	13	37	40	7.5%	M	11	
2	1	3	114	129	11.6%	M	11	
2	1	4	121	141	14.2%	M	11	
2	2	11	33	39	15.4%	L	11	
2	2	16	104	90	-15.6%	M	11	
2	2	8	30	36	16.7%	M	11	
2	1	7	92	116	20.7%	M	11	
2	1	5	97	125	22.4%	M	11	
2	1	2	83	112	25.9%	M	11	
2	2	14	34	27	-25.9%	M	11	
2	2	12	23	32	28.1%	M	11	
2	1	6	117	223	47.5%	M	11	
	Vessel total		1 346	1 565	14.0%			
4	1	3	33	39	15.4%	M	100%	
4	1	4	22	26	15.4%	M	100%	
4	2	9	8	39	79.5%	H	100%	
4	2	8	3	15	80.0%	H	100%	
	Vessel total		66	119	44.5%			

* Set numbers from observer data set

Table 5 provides further comparison of EM and observer catch estimates according to species group categories. In general, EM used broad catch categories while observers identified catch to species, resulting in about twice the number of catch categories as EM. To facilitate comparison, observer and EM data were grouped into the more general species group categories, ranging from the species level for distinctive items (e.g., ling) to groups for less distinctive catch items (e.g., bluenose and warehou). Totals for each vessel are shown, as well as totals for selected events where agreement was better than the overall vessel total. Scatter plots are shown in Figure 13, which provide a fine scale comparison of EM and observer catch estimates the fishing event level.

Vessel 1 had the highest numbers of fishing events compared (20) among the three vessels with catch data and total catch levels exceeded 30 000 pieces. The level of agreement between observers and EM was much higher when partially monitored sets were removed, both overall (Table 5, 3.1% versus 17%) and by individual set comparisons (Figure 13, lower right). The level of agreement was very high on fully monitored sets for target species including ling and red cod. The level of agreement was less (12.6%) for fully monitored sets of sea perch where EM appeared to have consistently higher catch totals per set than observers. The level of agreement for dogfish was 7.2% (fully monitored sets) and EM estimates per set were often lower than observer estimates. Among the predominantly discarded species, like eels and rat tails, the agreement was low and EM estimates were more often higher than observers. The low agreement with the shark category (35.5%) was probably due to this group encompassing a wide range of species some of which are kept, others finned, and others discarded whole.

The EM-Observer catch comparison for Vessel 2 showed overall improvement from the first to the second trip (0.4% versus 14.1%) as a result of the repositioned hauler camera (see Figure 9). Consequently, the second trip is shown separately in Table 5. Total counts per set for all species combined aligned closely for all but one set (Table 4; trip 1, set 6) where counts differed by about 50%. Nearly three-quarters of the catch was the target species bluenose and warehou, with EM and observer estimates comparing very closely (1.3%) overall and on individual fishing events (lower right, Figure 14). Counts of dogfish differed by 20%, perhaps because this species was low in abundance and possibly discarded before the hauler. Counts of the other major species (sea perch, alfonsino, ling, and sharks) were within a few pieces on individual sets and overall.

Among the pelagic longline vessels four sets were examined on Vessel 4. The level of agreement between EM and observers declined after the first trip 1 (30.3% versus 15.6%) when the amidships camera was repositioned. The total number of sets sampled and pieces caught were low, making comparison difficult. In general, the level of agreement was much lower than with the demersal longline vessels. Counts of species like sharks, swordfish, tunas, and opahs differed by a few pieces or less with observer estimates higher than those by EM.

Table 5: Summary of catch in pieces by species category for EM and observer data sets.

Category	Sets	EM	Obs	% Diff	Sets	EM	Obs	% Diff
Vessel # 1	Fully and partially observed sets				Only fully observed sets			
Dogfish spp	20	19 958	24 914	19.9%	13	15 553	16 763	7.2%
Ling	20	6 681	7 942	15.9%	13	5 223	5 027	-3.9%
Perch	20	1 557	1 687	7.7%	13	1 243	1 104	-12.6%
Red Cod	17	739	815	9.3%	13	342	347	1.4%
Sharks	19	94	417	77.5%	13	351	259	-35.5%
Eels	20	416	338	-23.1%	12	66	215	69.3%
Ratfish spp	20	441	315	-40.0%	13	253	143	-76.9%
Skates and Rays	19	145	156	7.1%	12	77	66	-16.7%
Groper	5	55	47	-17.0%	2	9	5	
Hagfish	12	0	26		9	0	18	
Grenadiers	8	0	19		7	0	18	
Bluenose/Warehou	3	7	14		2	0	5	
Bream	3	0	6		2	0	4	
Other spp	5	0	5		3	0	3	
Hake	2	0	2		1	0	1	
Unknown spp	19	207	0		12	128	0	
Totals	20	30 300	36 703		13	23 245	23 978	3.1%
Vessel #2	Trips 1 and 2 combined				Trip 2 only			
Bluenose/Warehou	15	908	1 153	21.2%	9	537	544	1.3%
Dogfish spp	14	52	64	18.8%	9	38	48	20.8%
Perch	10	32	57	43.9%	7	29	31	6.5%
Alfonsino	13	51	47	-8.5%	8	20	16	
Sharks	11	39	46	15.2%	5	10	12	
Ling	5	29	30	3.3%	3	4	4	
Gemfish	9	8	24		4	2	5	
Groper	6	5	12		1	1	1	
Red Cod	2	0	11		1	0	8	
Eels	2	0	9		1	0	1	
Hagfish	1	0	8					
Skates and Rays	1	9	8					
Hoki	3	2	2		2	2	1	
Bream	10	43	0		6	32	0	
Hake	1	1	0					
Other spp	12	0	94		7	0	48	
Unknown spp	15	165	0		9	47	0	
Totals	15	1 344	1 565	14.1%	9	722	719	-0.4%
Vessel # 4	Trips 1 and 2 combined				Trip 1 only			
Sharks	4	31	59	47.5%	2	29	33	12.1%
Swordfish	4	6	9		2	2	3	
Tunas	4	11	10		2	9	6	
Opahs	3	4	4		2	2	2	
Sunfish	3	0	6					
Skates and Rays	1	0	1					
Bluenose/Warehou	3	10	0		2	9	0	
Other spp	4	0	29		2	0	20	
Unknown spp	2	3	0		2	3	0	

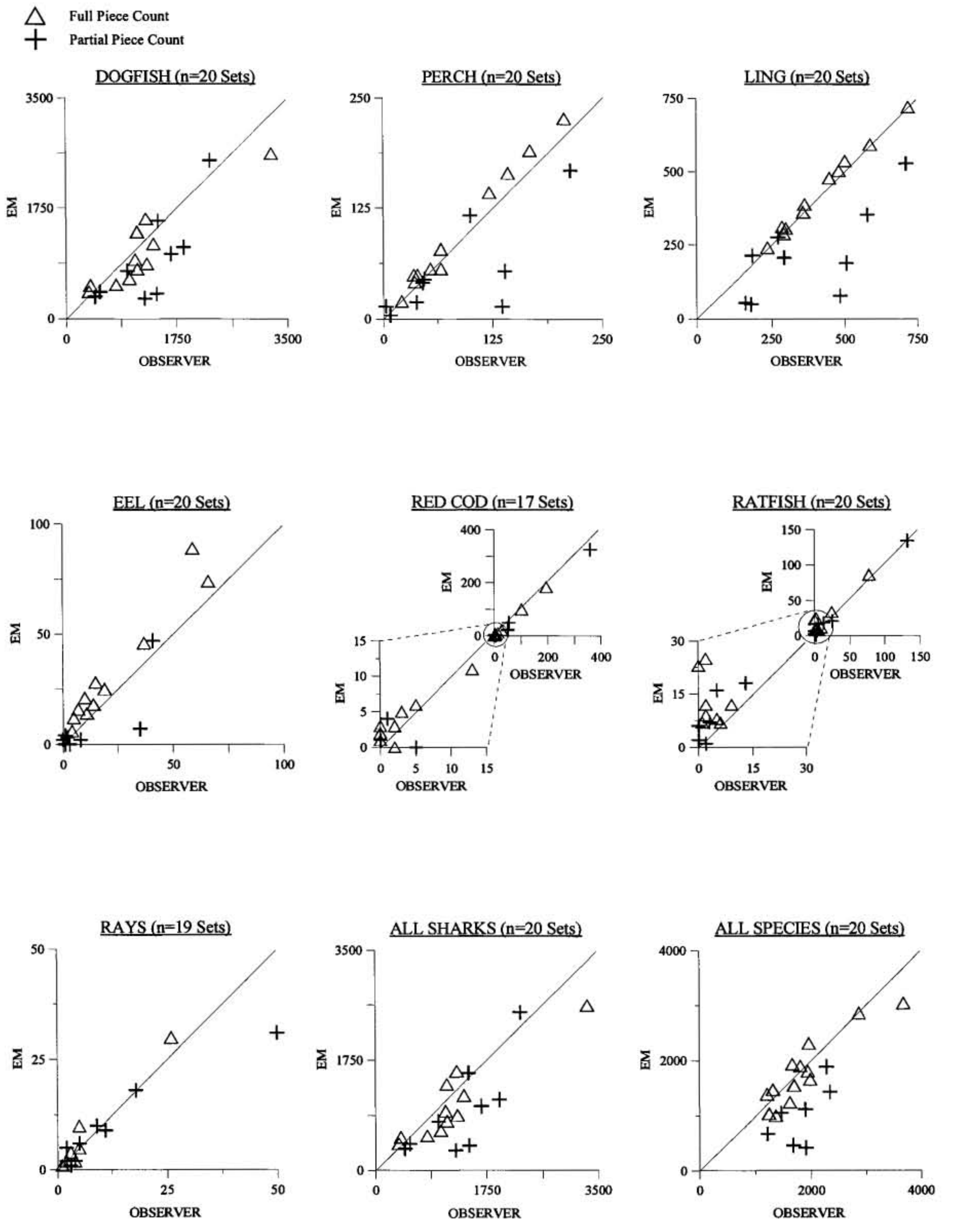

Figure 13: Scatter plots of catch categories from Vessel 1 showing counts per set for EM and observers. Sets fully monitored by the observer are labelled differently from partially monitored sets. The diagonal line represents the expected level of agreement between observers and EM.

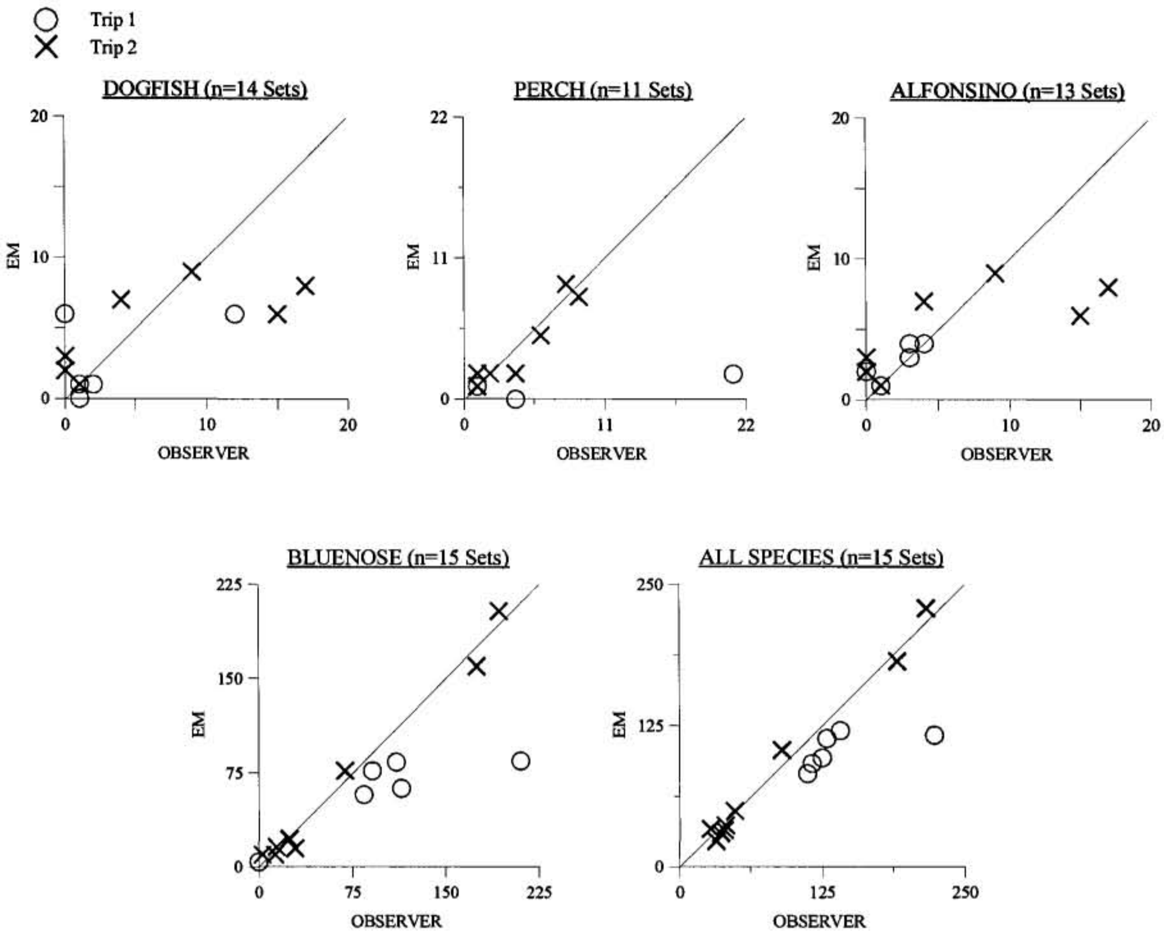

Figure 14: Scatter plots of dominant catch categories from Vessel 2 showing counts per set for EM and observers. Sets from trips 1 and 2 are labelled differently. The diagonal line represents the expected level of agreement between observers and EM.

Assessment of imagery for longline setting operations

Imagery was successfully recorded from the four vessels during longline setting operations. In general, the quality of setting imagery was much lower than imagery from the hauling cameras because of vessel motion and the viewing angle of cameras being directed downward from above the longline deployment area. During daylight it was usually possible to discern the longline being deployed, although it was difficult to resolve specific detail such as bait or longline sinking. Likewise seabirds were evident in the field of view but their specific behaviour in relation to setting was difficult to discern. Streamer lines were also evident in the imagery, but their performance was difficult to assess from the camera perspectives.

Analysis ratios

Analysis ratios (i.e., the ratio of image analysis time to real time) were computed for all imagery examined, including some sets that could not be compared with observer data. The results from this analysis are shown in Figure 15 and Table 6. The amount of time required to analyse imagery for protected species was generally about 0.4 of real time across the four vessels, ranging from 0.09 to 1.03. The time required for full catch census was more variable among the vessels and overall about double the time required for protected species. With Vessel 1 catch analysis was 0.96, indicating that an hour of hauling would take nearly an hour to analyse. Vessel 2 had higher catch analysis numbers (1.32), most likely the result of the difficult viewing conditions with this vessel. Catch analysis time for the pelagic longline vessel was considerably lower than for the demersal vessels owing to lower catch densities.

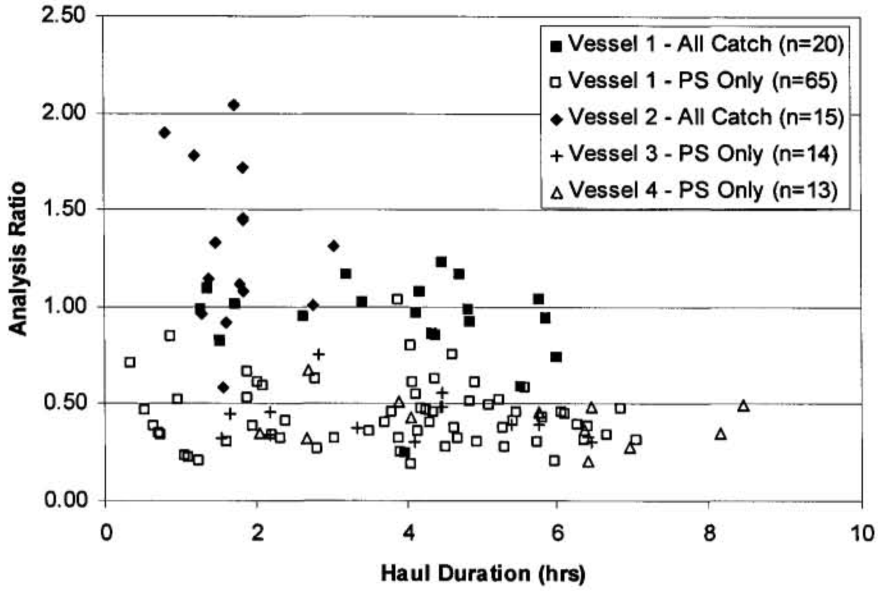

Figure 15: Analysis ratios for image processing shown by vessel number and analysis objective (PS = protected species).

Table 6: Summary statistics for image analysis ratios calculated on monitored sets, shown by vessel and image analysis objective.

	Mean	Variance	Min	Max	n
Haul duration					
Vessel 1	3.84	3.053	0.35	7.05	86
Vessel 2	1.74	0.317	0.80	3.05	15
Vessel 3	3.95	2.863	1.55	6.45	14
Vessel 4	5.67	5.767	2.05	10.28	16
PS analysis ratio					
Vessel 1	0.44	0.027	0.19	1.03	65
Vessel 3	0.43	0.015	0.30	0.76	14
Vessel 4	0.33	0.010	0.09	0.49	13
All catch analysis ratio					
Vessel 1	0.96	0.053	0.25	1.32	21
Vessel 2	1.32	0.165	0.59	2.04	15
Vessel 4	0.47	0.038	0.21	0.68	4

3.3 Data management issues

Data volumes

Data volumes recorded by EM systems are summarised in Table 7. Overall sensor data volumes varied from 0.13 to 0.8 MB per day although theoretically sensor data would require about 0.5MB per 24-hour time interval. Image data were considerably larger representing about 770 GB overall and 1–3 GB per fishing event for demersal vessels and 5–7 GB per fishing event for pelagic longline vessels.

Data volumes recorded by Vessel 3 were anomalous as there was very little sensor data and large amounts of image data recorded, but not in relation to the number of fishing events.

Table 7: Summary of data volumes recorded on hard drives for the trips monitored by EM systems.

				Sensor data (MB)		Sensor data (GB)	
Vessel ID	Trip	Days	Sets	Total	per day	Total	per set
1	1a	19	52	15.33	0.81	115.00	2.21
1	1b	16	45	12.62	0.79	138.00	3.07
1	1c	13	34	8.01	0.62	99.40	2.92
2	1	6	7	1.54	0.26	7.60	1.09
2	2	5	9	0.67	0.13	6.42	0.71
3	1	5	1	1.18	0.24	18.70	18.70
3	2	22	8	1.33	0.06	87.40	10.93
3	3	7	2	0.58	0.08	60.30	30.15
3	4	9	5	3.76	0.42	124.00	24.80
4	1	9	8	4.80	0.53	45.40	5.68
4	2	10	9	5.12	0.51	66.30	7.37
All		107	174	54.94	0.51	768.52	4.42

4. DISCUSSION

4.1 Technical assessment of the EM system

In this study, EM equipment was deployed on four vessels for a collective total of 9 fishing trips, 203 fishing events (sets), and about 3000 hours of vessel time at sea. Capture success for sensor data averaged 54% overall; the primary cause of data loss was EM systems being manually powered off and, secondarily, an electrical problem on one vessel. Capture success with image data was much higher with EM systems recording longline retrieval operations about 98% of the time. This latter result is not surprising as observers were present on most of the trips and they had a role in confirming that EM systems were operating when they were monitoring retrieval operations. Indeed, the main goal of the pilot study was to collect a paired set of catch retrieval observations.

One of the main issues to resolve in a future application involving EM would be to ensure 100% complete data capture. The lack of complete sensor data in this study made it more difficult to match the observer and EM data records. About 13% of the fishing events could not be aligned properly. 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. In this study, Vessels 1, 3, and 4 had electrical generators and Vessels 1 and 3 require continuously generated electricity to power hydraulic systems and thus the EM systems were powered by the AC system. Although Vessel 4 had AC power their generator was used intermittently so DC powered the EM system through an inverter. The EM system on Vessel 2 was powered by DC batteries through an inverter. It is understandable that vessel crew would power down the EM system during idle periods to conserve battery power. It is also easy to understand that crew would be inclined to turn an EM system off when the vessel was inactive or when the observer is off duty, without realising that vessel monitoring during inactive periods is important.

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. Also of note, since this study was conducted EM systems have been equipped with 'smarter' power supplies, which prevent battery depletion by monitoring battery voltage and vessel activity, and initiating an EM 'sleep cycle" (partial shut down) when conditions warrant.

A second technical issue encountered in this study was with the sensors. In one instance the placement of the GPS receiver resulted in lower quality position data caused by interference with other vessel electronics. This was easily remedied and would be less of an issue in the future as field technicians gain experience with the fleet.

Hydraulic pressure sensors were in place on all four vessels and provided the main tool for distinguishing fishing activity. The hydraulic pressure pattern for the autoline vessel was unusual for what is normally recorded during retrieval operations, and indicates that in the future more information on the hydraulic system is needed to properly place this sensor. There are probably multiple hydraulic systems on this vessel and there may be other options that would provide more meaningful vessel activity information.

The optical winch sensor was not successfully deployed in this study. This sensor provides an important backup for the hydraulic sensor and is very helpful in distinguishing between setting and hauling events. The sensor is more difficult to mount and more prone to failure because of its exposed location. The longline winch systems for Vessels 2, 3, and 4 are common and conducive to using a winch sensor. Vessel 3 carried two longline drums so a sensor would be required on each. The autoline vessel has more complicated machinery and more careful study would be needed to determine the best sensor location. Future deployments of EM systems on longline fishing vessels should include this sensor.

A final issue concerning technical suitability of EM for these vessels concerns the placement of cameras. On all four vessels camera placement was opportunistic, using existing standing structures as much as possible. In a few instances a customised camera mount pole was used to place cameras where no mounts were present. In nearly all instances the camera placements were not ideal and this affected the quality of catch information that could be obtained. Whereas many longline vessels in British Columbia have stabiliser poles that provide ideal camera mounting locations, most vessels in the New Zealand fishing fleet do not use them. Because this was a voluntary pilot study and there was little advance warning, vessel masters were reluctant to make structural modifications for this study. In future, more attention should be given to the use of custom camera mounts to properly position cameras. For example, vessels could be fitted as shown in Figure 16 with movable swing arm mounts such as has been fitted on small longline vessels operating on the east coast of the US.

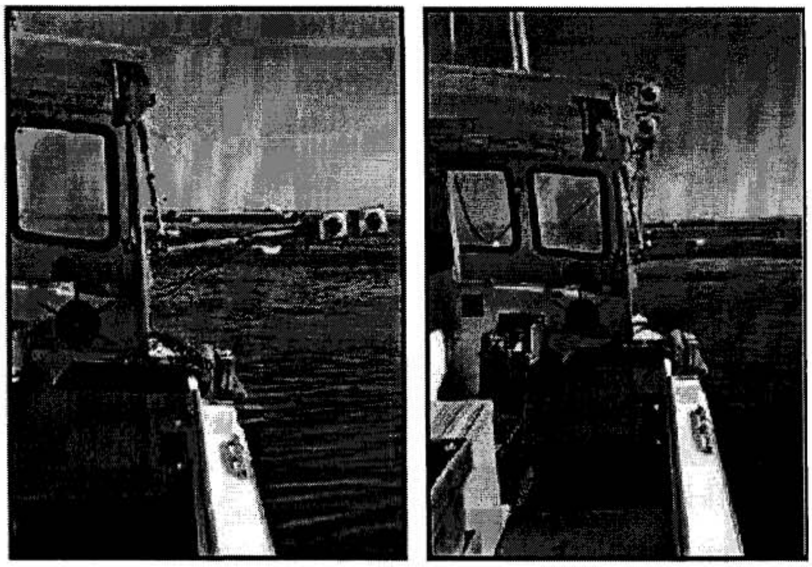

Figure 16: Movable camera mount used on a small longline vessel on the east coast of the US (from McElderry et al. 2007a).

Camera placements on the two demersal longline vessels were significantly better than those on the pelagic longline vessels. The shorter branch lines with demersal longline gear made camera placements easier as the field of view was smaller. The autoline vessel (#1) had two cameras covering the retrieval area, both of which were too far away, so that the catch images were very small and difficult to resolve. The other demersal longline vessel (#2) had just one camera on the hauling station and the field of view was obscured by the vessel operator much of the time. Ideally, there should be a minimum of two hauling station cameras and they should be 2–3 metres from the area of interest and extended overboard, providing a view toward the side of the vessel, unobscured by the rail and crew activities. While close up views of catch as they pass over the roller is important, equally important is an unobstructed view of catch as it emerges from the water and approaches the roller. At least one camera should monitor the longline as it emerges from the water.

Camera placements on the two pelagic longline vessels are also in need of improvement. In comparison with demersal longline fishing, pelagic longline branch lines are long and catch items are comparatively few and vary considerably in size. Whereas demersal catch simply comes out of the water and over the rail, landing pelagic catch can be more involved, manoeuvring the catch alongside and through the sea door. Certain catch/species may not be brought aboard at all, either released with hook and branch line attached or brought alongside and cleared of as much of the terminal gear as possible. For cameras to successfully capture this style of fishing is considerably more demanding than with demersal longline fishing. Whereas demersal longline cameras need to cover the hauling station and the immediate water area where the longline emerges, pelagic longline cameras would need to monitor the hauling station, the area where catch is boarded, and a fairly large (5–6 m) area around the sea door where catch is manoeuvred. Ideally, there should be a minimum of two cameras to cover the water area adjacent the hauling area and sea door. These cameras should be extended overboard as much as possible to provide a view toward the vessel. As well, one or more cameras are needed to monitor crew activities at the hauling station and the areas where catch is brought aboard.

Another issue concerns the ability to resolve small catch items from the wide field of view cameras used in this study. Improving imagery of small catch items can be accomplished in two ways. First, the use of additional cameras to create a higher resolution mosaic image of the working area would improve detection of catch items. However, additional cameras carry higher data demands and complicate the image viewing process. A second approach would be to work with vessel crews to better coordinate camera placements with catch handling procedures. A coordinated approach would place higher resolution close up imagery in areas of the fishing deck where smaller fish pass through, while maintaining the wide field of view cameras for the working deck areas.

The level of industry cooperation strongly affects the success of an EM-based monitoring programme. In this study, it was difficult to find vessels interested in participating. Among the four volunteers, there were both willing and reluctant participants. In a broader fleet-wide application involving EM, it is clear that there would be a significant component of the fleet unwilling to accept EM. 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 protected species interactions

The pilot study resulted in catch data from 8 trips and 170 fishing events that could be reliably matched between the EM and observer data sets. The imagery was assessed for protected species interactions only on 122 events and 39 fishing events were compared for all catch items, including protected species. While the focus of the study was toward protected species it was not expected that many encounters would occur and, therefore, image viewing was expanded to include all catch species in selected instances in order to provide a better assessment of how well catch items could be identified from EM imagery.

Observers recorded nine protected species interactions, but only two of these were considered interactions that were within the EM camera views. Seven interactions with seabirds included four deck landings and brief entanglements or contact with retrieved fishing gear. The observer is required to report these incidents but their relevance as a monitoring issue seems unclear. Of the two incidents within view of EM cameras, EM reviewers detected one on first review while the second event was initially missed but later detected. The second incident involved a leatherback sea turtle, which could be seen in the overboard hauling station camera but not in the inboard hauling station camera. It is important to note the relationship of viewer experience with the fishery and incidence of detection. The viewing technician was very likely not aware of the sequence of events that happen on board the vessel to alert them of important activity on another camera – as in the case of the sea turtle. Simultaneous image viewing and viewer experience will increase the likelihood of detection for this fishery.

Methodological issues complicated the comparison for fishing events examined for all catch items. As already mentioned, camera views were not ideal and resolving catch species was more difficult than would normally be expected. As most vessels made multiple trips, there were necessary changes to camera configurations in an attempt to improve the quality of imagery. This trial and error approach resulted in a moving target for comparison. Indeed, the comparisons improved on Vessel 2 when the hauling station camera was extended further overboard. In contrast, the level of agreement was reduced for Vessel 4 when the overboard camera position was changed after the first trip. There were also issues with observer data that influenced the comparison. The observer on Vessel 1 worked in shift periods and it was difficult to compare sets that were not fully monitored. While most sets were personally observed, there were instances when the observer data came from the vessel logbook. The observer on Vessel 2 advised caution with some of the catch figures, as the vessel was a crewmember short on one trip the observer assisted with catch processing. As the study occurred over a much longer period than envisioned, it was difficult to carefully monitor and control consistency on certain catch monitoring issues. For example, would an observer record a fish if it dropped off the hook before it came in view of the camera? Future studies involving both EM and observers need to more carefully control issues that affect data alignment.

Regardless of these issues, the comparison between observers and EM showed promising results for demersal longline vessels. The two vessels examined provided the most data for comparison with 35 fishing events and over 30 000 catch items. Piece count differences for Vessels 1 and 2 were 3.1% and 0.4%, respectively, for selected sets (fully observed sets on Vessel 1 and trip 2 on Vessel 2). Certain species groups such as red cod, ling, and bluenose/warehou compared very closely between observer and EM data sets. We have no doubt that improvements to this comparison would occur with improved positioning of cameras and improvements to the observer data record. In a large British Columbia study with the demersal longline halibut fishery, EM and observer catch estimates agreed within 2% and individual species identifications by hook exactly matched in over 90% of the catch records (McElderry et al. 2003). Similar or better results could be expected in demersal longline fisheries of New Zealand as the installation configuration improves.

Results from the pelagic longline vessels are inconclusive. There was just one protected species interaction in the 22 fishing events witnessed by EM and observers from the two vessels. As already mentioned, EM reviewers initially missed this event but later detected it when imagery was re-examined after comparing with observer data. Among the four fishing events examined for 'all catch' categories, the agreement between EM and observers was also not high. The main reason for these results would be camera placements, as already mentioned, and secondarily, the more complicated image review process. Whereas demersal longline catch observations would come from primarily one camera, catch observations from pelagic fishing would come from multiple cameras based on the type of catch encountered. Image viewing software for such fishing operations must synchronously display multiple camera images. The software available for use in this study had this capability but playback speed was not fast enough for pelagic longline fishing operations where the retrieval operations are long (5–6 hours) and the numbers of catch items few in comparison to the hooks deployed. Software performance is continually being improved but viewers in this study opted to use a single image software viewing tool with higher performance. Lastly, catch handling procedures by the crew play an important role in catch items being successfully monitored. We understand that unwanted catch items may avoid detection if the crew immediately release the branch line into the sea. This is an issue for catch detection by both EM and observers although more significantly the former. Placement of an amidships camera on the extended pole looking aft on Vessel 4 would be the best position to check for this type of discarding event. Further testing of EM is needed on this fishery.

The usefulness of EM for monitoring protected species interactions during setting operations is also inconclusive since the setting imagery from the four vessels was of limited use. In all cases cameras were mounted high on the vessel with the longline and streamer lines appearing against an ocean backdrop. The ability to resolve lines and seabirds against a constantly moving ocean background is problematic, especially with the wide field of view used in this study. Lowering the camera position to the same level or below the longline shooting area would make it easier to resolve features, as they would appear above the horizon and contrast against the sky. As many of the setting operations on the pelagic longline vessels were at night, very little could be resolved from the imagery. Restricting the field of view behind the vessel to where the longline enters the water would improve the ability to discern seabird activity during setting. However, with vessel motion it is unlikely that the imagery would resolve incidents such as bird strikes or hooked seabirds. In our view, setting imagery would be useful for mitigation monitoring (performance of seabird streamer lines) or detecting general seabird activity levels rather than attempting to detect specific encounters such as seabird strikes. This conclusion was also reached in previous EM studies with trawl vessels (McElderry et al. 2004a, 2004b).

The analysis ratios measured in this study provide some interesting observations on the effort required to obtain fishing event data. Image viewing for protected species only could be accomplished at about 50% of real time whereas interpretation for all catch was almost the same as real time. These ratios were higher than expected and what has been measured in other EM studies and we attribute this result to the camera views. Improvements in imagery will make interpretations easier and reduce the analysis time. It is interesting to note that the autoline vessel was at sea for 46 days (1100 hours), and spent about 540 hours retrieving longline that would require 240 hours for protected species analysis and 520 hours for all catch analysis. The coastal longline vessel was at sea for 11 days (265 hours), yet spent about 30 hours retrieving longline gear that was analysed in 38 hours. The pelagic longline vessel (#4) was at sea for 19 days (456 hours) and spent about 100 hours retrieving longline. Analysis requirements for this vessel were 32 hours for protected species and 45 hours for all catch items. While it is expected that the analysis requirements would change with improvements to the EM set up, the overall numbers provide a useful measure of time expenditure, particularly for on board observers. For example, for coastal longline fishing an observer labour expenditure of 11 days is needed to obtain about 30 hours of retrieval observations.

4.3 Data management issues

Unlike observer programmes, EM systems record a large amount of raw sensor and image data that is later reviewed and interpreted for meaningful fisheries data. In this study, we estimated sensor data requirements average about 0.5 megabytes per day and image data requirements per fishing event vary by fishing type: about 2.7 gigabytes for autoline, 0.9 for coastal longline, and about 6.5 for pelagic longline. The data storage requirements (sensor and imagery) for a typical fishing trip by these vessels works out to about 490 gigabytes for autoline, 9 for coastal longline, and about 60 for pelagic longline. At the completion of a fishing trip, the EM data are retrieved by physical removal of the hard drive; transmittal of data via wireless or hard-wired Internet would not be practical. Once removed from the vessels, sensor data can be easily transmitted via the Internet while image data are distributed by physical shipment of hard drives. In this study, back up copies of hard drives were made which was efficient for consolidating data and practical for data security.

Summarised data from raw sensor and image data is different from that provided by observers. Sensor data provide much finer scale of temporal and spatial resolution than is typically provided by observers while catch data derived from imagery may not resolve species as clearly. Multiple reviewers can interpret imagery while a single viewing opportunity exists with observers. These issues and others suggest that fishery monitoring with EM will require consideration of data formats and metadata requirements to ensure that these differences are not lost and the strengths of observer and EM data sets are used.

Agencies will need to consider concerns the longterm storage requirements for raw EM data. Expanding the data volumes from this study by the fleet coverage levels provides an overall perspective of the data storage requirements that may be required. As an example, if 100 trips from each category were monitored per annum, the data storage requirement would be about 56 terabytes. The storage requirements grow further when consideration is given to redundancy back ups and agency archive policies (some agencies have a five year data storage requirement).

Maintenance of large data storage systems is quite costly and may not be necessary. In other large-scale EM programmes carried out by Archipelago, raw image data are generally deleted after being processed. Operationally, a large reserve of hard drives is maintained and used for placement on active fishing vessels. Once a fishing trip has been completed and EM data analysed, image data are deleted when the data summary is completed and no further use is identified. Compliance issues and other critical events would warrant the imagery being archived for evidence purposes. The Canadian fisheries agency decision to keep only summarised data and selected raw data provided huge cost savings for data storage and successfully put to rest industry sensitivities about their fishing imagery sitting in archive and possibly being used (or misused) for purposes other than the original intent of monitoring.

While not a specific objective of the study it is important to consider how EM data are treated with respect to privacy expectations of fishermen and confidentiality capabilities of agencies. Industry support for an EM programme will depend on the rules concerning what information is collected and how it is used. The comprehensive nature of data collected by EM systems leads to privacy issues not as apparent in observer programmes. There is a risk that EM data may be analysed for purposes outside the fishery monitoring objectives with potentially adverse or unexpected outcomes. The problem is mainly with image data that could compromise the privacy expectations of vessel crew or reveal various techniques, work practices, safety procedures, etc., which were not part of the fishery monitoring objectives. Video imagery from fishing operations involving sensitive or charismatic species has a more powerful effect than a data point. In our view, data from EM programmes should be analysed to meet well defined information objectives that are clearly communicated to industry.

4.4 Conclusions and recommendations

EM technology was introduced to a range of vessel sizes in pelagic and demersal longline vessels. There were no instances of malfunctioning equipment resulting in data failure and the EM systems were considered suitable for all vessels in the study. The technical issues such as battery and sensor placements are resolvable and would not detract from the future use of this technology. This conclusion would also apply to the component of the fleet considered too small or not suited for placement of observers. The camera placement issues are also probably resolvable and show promise for the demersal longline fishery. Further study is required to determine applicability for pelagic longline fisheries.

In either of the two fleets the next step should be to share the results of this study with industry participants and determine if, and under what circumstances, there would be support for EM-based monitoring. EM will likely depend on several issues, the main ones being cost and convenience (as compared with observers), opportunities for value-adding EM by addressing data needs of industry, and policies governing the use and ownership of data.

With regard to demersal longline fisheries, further work is needed to determine appropriate placements for cameras and sensors across a range of vessel configurations. In our view, it would not be necessary to conduct further work with both EM and observers. Increased monitoring on this fleet with EM will serve to resolve the EM configuration issues, improve EM data quality, increase industry awareness of EM technology, and provide an option for monitoring small vessels in the fleet that are currently not observable.

The utility of EM technology for pelagic longline fisheries has yet to be established. As mentioned, the camera configuration is more complicated than for demersal longline fishing and further work is needed to determine if cameras can successfully monitor catch retrieval operations. While paired EM and observer data sets would be useful for this work, it would be more practical to delay deployment of observers until the technical issues are resolved. Additional trials with EM and observers should be more carefully controlled to enhance the data comparison. In our view, industry support for EM should be high in order to be successful with catch monitoring, particularly the interactions with non-landed catch species.

Some of the results of this study were an artefact of the study being staged in New Zealand using Canada-based EM expertise. The successful use of EM will rise with increased use of the technology and the development of New Zealand based infrastructure for field services and data analysis.

5. ACKNOWLDGMENTS

This project was funded by the New Zealand Ministry of Fisheries (MFish) contract ENV2006/05. We are grateful for the cooperation and support of the skippers and crews of the four participating vessels who agreed to carry EM systems and observers for this study. We are also grateful for the efforts of the observers who, in addition to their regular observing duties, helped keep EM equipment operating and provided useful feedback throughout the study. Andrew France (MFish) helped greatly in the success of the project with organising fishing vessel participation and providing advice throughout the project. We are also appreciative of other MFish staff, in particular Nathan Walker and Susan Waugh, who provided support and advice for the study. The study also benefited from the useful advice of members of the Aquatic Environment Working Group. Several Archipelago staff participated in this

project including, Richard Rees, Val Ethier, Rhonda Reidy, Morgan Dyas, Kristin Tryon, and Dale McCullough.

6. REFERENCES

Anon. (1994). Guide book to New Zealand commercial fish species. New Zealand Fishing Industry Board, Wellington, New Zealand. 216 p.

McElderry, H.; Dyas, M.; Reidy, R.; Pahti, D. (2007a). Electronic monitoring of the Cape Cod gillnet and longline fisheries – a pilot study. Unpublished report prepared for the Cape Cod Commercial Hook Fishermen's Association (CCCHFA) by Archipelago Marine Research Ltd., Victoria, BC Canada. 54 p.

McElderry, H.; McCullough, D.; Schrader, J.; Illingworth, J. (2007b). Pilot study to test the effectiveness of electronic monitoring in Canterbury fisheries. DOC Research and Development Series 264. Department of Conservation, Wellington, New Zealand. 27 p.

McElderry, H; Reidy, R.; Pahti, D. (2006). A pilot study to evaluate the use of electronic monitoring on a Bering Sea groundfish factory trawler. Technical Report No. 51. International Pacific Halibut Commission, Seattle Washington USA. 32 p.

McElderry, H.; Crumpacker, A.; Wright, R.; McCullough, D. (2005). Electronic monitoring for the 2005 U. S. shore-based Pacific hake fishery--a pilot study. Unpublished report prepared for the National Marine Fisheries Service, Northwest Fisheries Science Center, National Oceanic & Atmospheric Administration, Department of Commerce by Archipelago Marine Research Ltd., Victoria, BC Canada. 43 p.

McElderry, H.; Schrader, J.; McCullough, D.; Illingworth, J.; Fitzgerald, S.; Davis, S. (2004a). Electronic monitoring of seabird interactions with trawl third-wire cables on trawl vessels – a pilot study. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-AFSC-147. 39 p.

McElderry, H.; Schrader, J.; McCullough, D.; Illingworth, J. (2004b). A pilot test of electronic monitoring for interactions between seabirds and trawl warps in the Hoki trawl fishery. Unpublished report prepared for the Hoki Fishery Management Company Ltd. by Archipelago Marine Research Ltd., Victoria, BC Canada. 35 p.

APPENDIX 1 – EM system description

Overview of the EM system

The EM system supplied by Archipelago operated on the ship's power to record imagery and sensor data during each fishing trip. The software was set to automatically activate image recording based on preset sensor indicators (e.g., longline retrieval). The EM system automatically restarts and resumes programme functions following power interruption. 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. 38x25x20 cm = 0.02 cubic meters) 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 with 12 volts DC or 120/240 volts AC. With AC power, the control box may be also fitted with a UPS, to ensure continuous power supply. 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 solve 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.

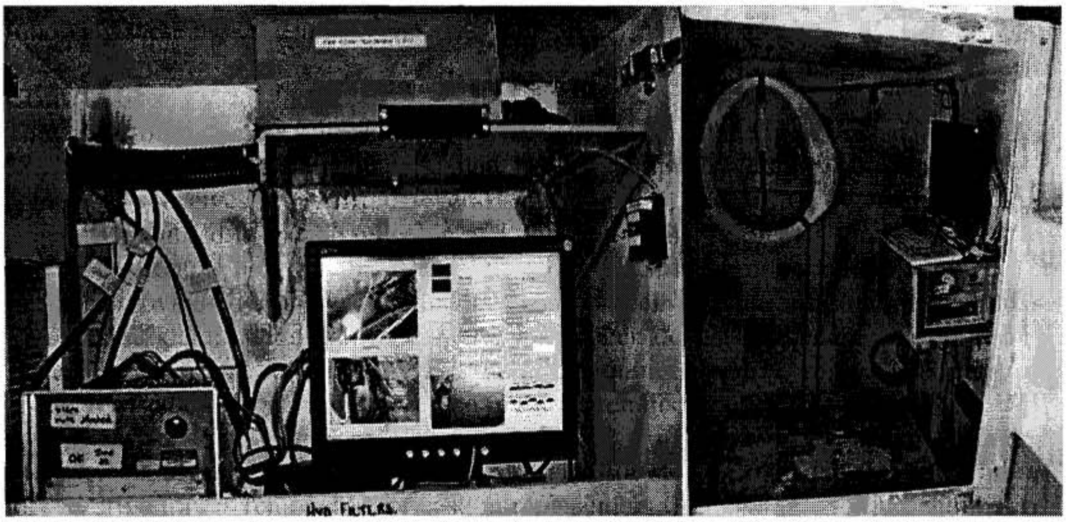

Figure A1: EM control box and user interface installations on two different vessels.

CCTV cameras

Waterproof armoured dome cameras were used as they have proved 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 were used to cover general fish and longline handling activity and areas around the vessel.

Colour cameras with 480 TV lines of resolution and low light capability (1.0 lux @ F2.0) were used in this application. 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.

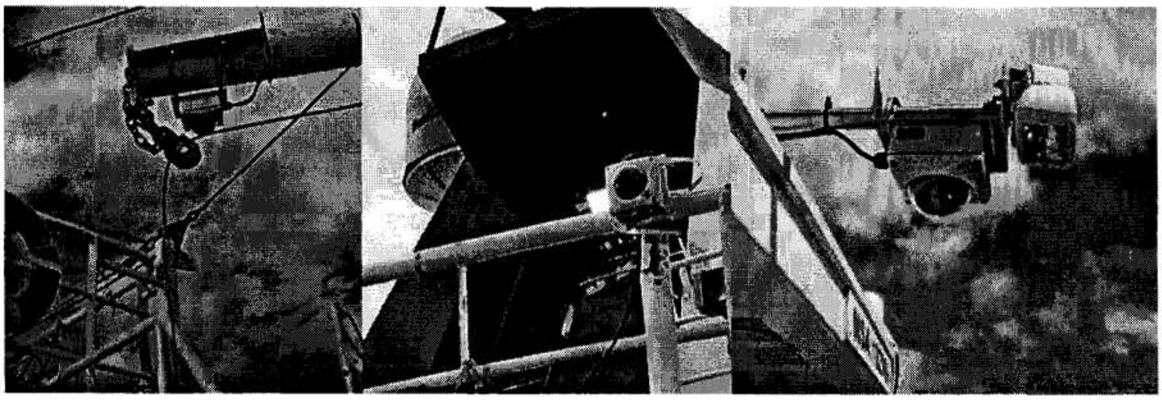

Figure A2: CCTV camera installations on three different fishing vessels. Each camera has a mounting bracket and stainless steel mounting straps.

GPS receiver

An independent Garmin 17N GPS receiver is installed with the EM system. The GPS receiver and antenna are integrated into a single plastic dome that is wired directly to the control box; there is no attached display interface. The GPS receiver is mounted on top of the wheelhouse away from other antennae and radars.

The Garmin 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 centred on that point.

The GPS time code delivered with the Garmin 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 data-logging computer 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.

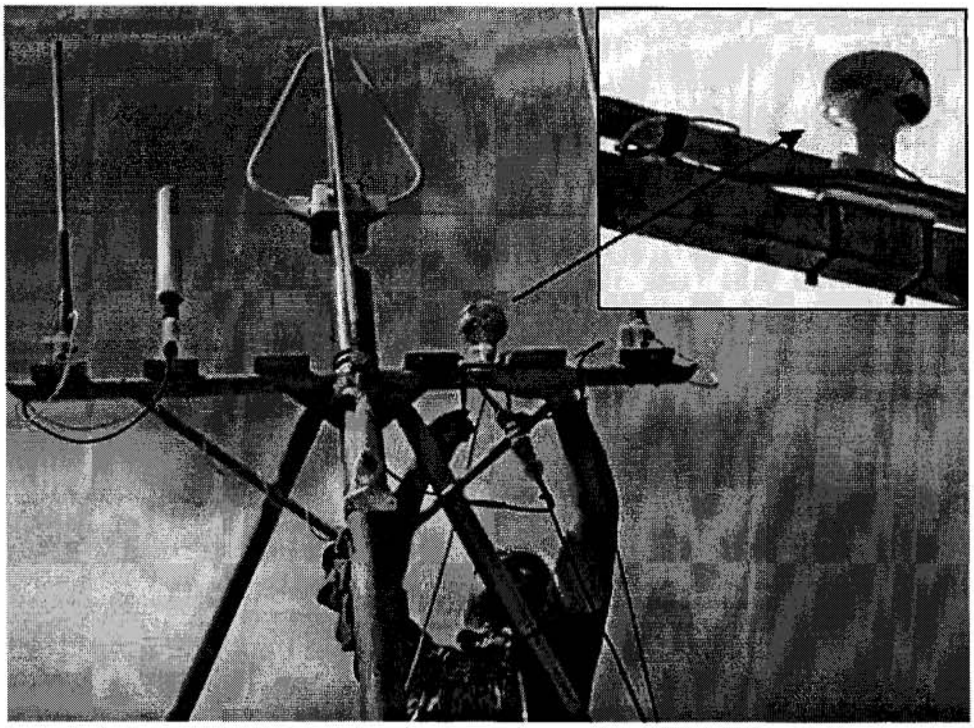

Figure A3: GPS receiver installed in the rigging of a vessel and a close up photograph of the mounted GPS.

Hydraulic pressure transducer

An electronic pressure transducer was attached to the hydraulic system (Figure A4) of each vessel to provide a record of fishing activity. 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 usually mounted on either the warp winch or net drum of each vessel. 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 A4).

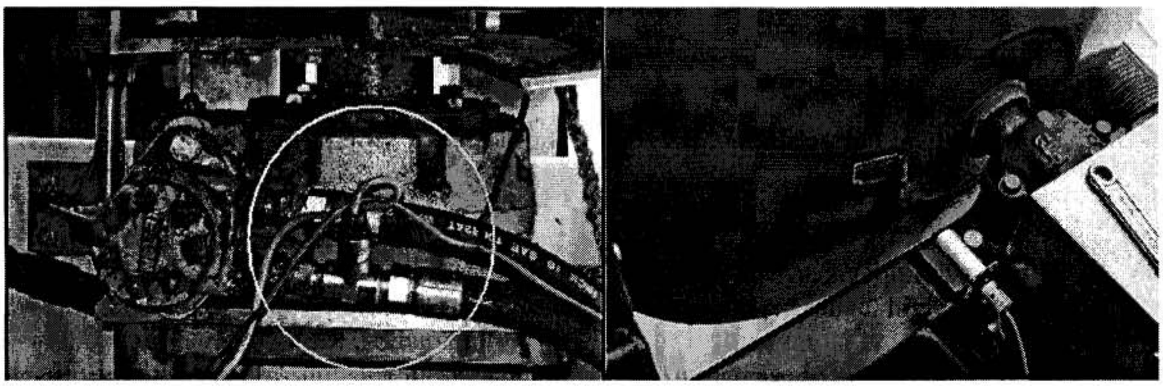

Figure A4: A hydraulic pressure sensor installed on the supply line of a vessel line hauler (left). Drum rotation sensor (right) mounted on pelagic longline vessel, showing optical sensor and reflective surface.