Pilot study to test the effectiveness of electronic monitoring in Canterbury fisheries

Howard McElderry, Dale McCullough, Jessica Schrader and Jennifer Illingworth

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This report is dedicated to the memory of Bryon Hector Low, owner and skipper of FV *Dianne* and a director of the South East Finfish Management Company Ltd. Bryon was an enthusiastic supporter of fisheries research in the Canterbury area and a keen participant in this project. Bryon was tragically lost at sea on 6 March 2004. He is sadly missed by us all.

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Howard McElderry[1], Dale McCullough, Jessica Schrader and Jennifer Illingworth

[1]Archipelago Marine Research Ltd, 525 Head St, Victoria, British Columbia V9A 5S1, Canada. howardm@archipelago.ca

A B S T R A C T

A pilot study to test the use of electronic monitoring (EM) systems to examine interactions between protected species and fishing gear was conducted in the Canterbury coast, New Zealand, inshore set net and trawl fisheries between October 2003 and January 2004. The EM systems, consisting of two closed circuit television cameras, a GPS receiver, hydraulic and winch sensors, and on-board data storage, were deployed on one trawl and four set net vessels. The EM systems operated very reliably for the inshore set net and trawl fleet. Although there was a post-fishing trip data loss of 14% of the retrieval imagery, 85 set net events were available for analysis. Detailed catch enumeration of 46 events distinguished over 99% of the catch (c. 11 000 pieces) among 22 species or groups of morphologically similar species. A second analysis method was used on the balance of recorded set net events, examining imagery for protected species. This method required about a third of the time required for the detailed catch enumeration method and was successful in detecting two Hector's dolphin (*Cephalorhynchus hectori hectori*) entanglements. The study demonstrated that EM systems could effectively monitor retrieval operations and encounters with protected and endangered species in the set net fishery. Minor technical improvements to the EM system could include a more forward-directed camera field of view, and lengthening of the record time to increase image capture when retrieval stops for a period of time. In the trialled monitoring application, EM offered a number of advantages over observer programmes, including logistical efficiency, fleet suitability, and industry acceptance. Issues standing in the way of implementing an EM-based monitoring programme include expanding fleet awareness of EM programme requirements, developing local infrastructure to support an EM-based programme, and developing data-sharing agreements that specify the monitoring objectives, the information to be collected, and its use.

Keywords: electronic monitoring, observer programmes, set net fishing, Hector's dolphins, *Cephalorhynchus hectori hectori*, protected species, New Zealand

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1. Introduction

The Canterbury inshore set net and trawl fleet consists of 10–15 vessels, targeting species such as rig (*Mustelus lenticulatus*), school shark (*Galeorhinus galeus*) and elephant fish (*Callorhinchus milii*) along the northeast coast of the South Island of New Zealand (Starr 2005). The summer fishery overlaps the distribution range of Hector's dolphin (*Cephalorhynchus hectori hectori)*, the smallest marine cetacean in the world, which is endemic to New Zealand. The Department of Conservation Threatened Species Classification (2005) lists Hector's dolphin as 'Nationally Endangered'. The total population is estimated to be c. 7300 and the population of Hector's dolphin on the north, east and south coasts of the south island is c. 1900 (Slooten et al. 2002). At-sea monitoring in 1997–98 recorded nine entanglements of Hector's dolphin in the set net and trawl fishery, of which six mortalities were in the commercial set net fishery, providing a strike rate of 3% for the sets observed (Starr & Langley 2000).

In 2002, the Minister of Fisheries set a Maximum Allowable Fishing Related Mortality (MALFiRM) for Hector's dolphin in the 'Canterbury set net area'. A limit of three Hector's dolphin fishing related mortalities per fishing year was implemented from the Waiau River in the North to the Waitaki River in the South out to four n.m. seaward from the coast. If the limit is reached, fishing would be prohibited under Section 15(5) of the Act. The MALFiRM is designed to:

> 'ensure that Hector's dolphin populations should recover to at least 90% of carrying capacity (the maximum number of animals the environment would support) with a delay in recovery time of no more than ten years compared to the time that would be taken to achieve such a population status with zero fishing-related mortality.' (Letter from Minister of Fisheries to Stakeholders, 14 May 2002).

In response to potential fishery interactions with Hector's dolphins, South East Finfish Management Ltd (SEFM) instigated a variety of measures under its Set Net Code of Practice (SEFM 2002) to fishing vessels to avoid, remedy, or mitigate adverse effects of set net fishing. In 2002, the Minister of Fisheries challenged SEFM to design and implement an effective at-sea monitoring programme for the Canterbury set net management area, to monitor the interaction between inshore commercial set net fishing with Hector's dolphin and to investigate whether mitigation measures such as the Set Net Code of Practice and acoustic pingers were working (P. Dawson, SEFM, pers. comm.).

At-sea monitoring of this fishery using observers has been problematic. Monitoring efforts over a 3-year period (1998–2001) successfully achieved the 150-day coverage target in only 1 year and less than a third of the target was achieved in two of the years (Starr 2005). Difficulties with achieving monitoring targets occur as a result of the small size of the fishing vessels involved, many of which have only enough crew capacity for the intended fishing activity and cannot host an observer. Scheduling observed trips is also complicated by the fact that this fleet generally makes short fishing trips (1–2 days), often on short notice during favourable weather and sea conditions. The New Zealand fishing industry is concerned that the lack of formal safety training and maritime qualification of observers can impact on the safety of the skipper and crew who must not only carry out their own duties in an emergency but also look after an observer whose qualifications and experience may be limited (P. Dawson, SEFM, pers. comm.).

With these issues related to observer-based monitoring, there was a need to explore alternative methods for providing at-sea monitoring for this fishery. SEFM contacted Archipelago Marine Research Ltd, a Canadian company that has successfully used electronic monitoring (EM) systems in a variety of fishery applications (McElderry et al. 2003, 2004; Ames 2005; Ames et al. 2005). The potential for applying EM systems to address the monitoring issues in the set net and inshore trawl fishery seemed promising and formed the basis for the pilot study.

1.1 AIMS AND OBJECTIVES

This pilot study was undertaken to test the effectiveness of EM for fishery monitoring requirements for identifying fishing gear interactions with protected species in the Canterbury inshore set net and trawl fishery. The specific objectives of the project were to:

- Design and implement a pilot programme to evaluate the effectiveness of EM in detecting and identifying fishing gear interactions with protected species during the crucial time for interactions in the Canterbury set net and trawl fishery (1 October 2003 to 31 January 2004).
- Assess and address practical design considerations when fitting the components of EM to set net and trawl vessels.
- Assess the suitability of EM systems for various components of the fleet, obtain skipper and crew feedback on EM suitability, and foster fleet education of EM-based monitoring.
- Determine whether clear fish, marine mammal, and seabird identification was possible from digital video imagery.

2. Materials and methods

2.1 DESCRIPTION OF THE ELECTRONIC MONITORING (EM) SYSTEM

The EM system used in the trials integrated an assortment of available digital video and computer components with a proprietary software operating system to create a unique and powerful data collection tool. The system could operate on either DC or AC voltage to log video and vessel sensor data during the fishing trip. The EM system (Fig. 1) automatically restarts and resumes program functions following power interruption. The instrumentation can be configured to start image recording at power up, or the software can be set to automatically activate video collection whenever fishing activities are recognised in the sensor data.

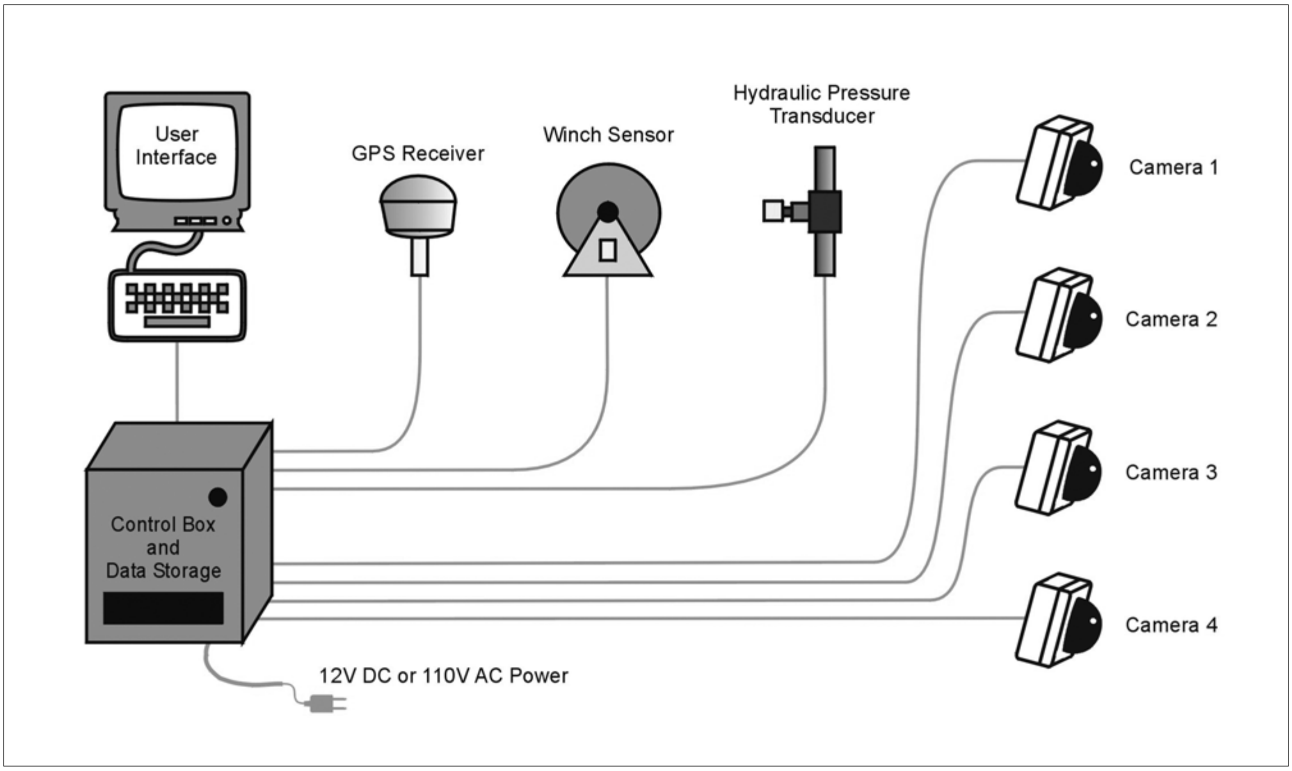

Figure 1. Schematic diagram of the electronic monitoring system.

2.1.1 Control box

The control box contained the computer systems, data storage components, and power supplies for the video cameras and peripheral vessel sensors. Two types of control boxes were used in this study. The more recent design (also the most compact of the two) consisted of a sturdy plastic instrument case (20 cm × 25 cm). The second (older) design contained similar components but was housed in an aluminium case (35 cm × 50 cm). Both control boxes had shrouded cooling fans and were spill- and splash-resistant, but not adequately weatherproof for on-deck deployment. The boxes had to be placed in a dry, ventilated interior location that was reasonably accessible for service technicians.

The EM system was designed to be powered by 120-V AC or 12-V DC sources, as is usual in North American fishing vessels. The EM system was easily adapted to the more common New Zealand power sources (240 V AC or 24 V DC) with either a DC transformer or an AC inverter. Large vessels have constant AC provided by a generator source. Smaller vessels have steady DC electrical power or AC supplied by an inverted DC.

The two core components in the control box were the data-logging and video computers. The data-logging computer continuously recorded digital sensor data to provide a time series record of the vessel activities during each fishing trip. Post-processed sensor information was used to detect specific actions on the vessel, such as setting or hauling fishing gear. The chronology of fishing activity derived from the sensor time series was used to identify time-matched video segments for review. The data-logging computer could be programmed to activate the video computer when certain fishing action was evident in the sensor data stream. Image recording began when hydraulic pressure exceeded a pre-determined threshold (approximately 25% of full pressure range) or when net drum rotation was sensed. Each sensor backed up the other to provide operational redundancy. This step was taken to ensure that the video system started whenever the drum was used, even if one of the sensors failed. The method of activating image recording also meant that setting operations were recorded as well as retrieval operations, even though setting imagery was of little value or interest to this study. Once image recording was activated, the system software was set up to record video for 15 min after hydraulic or sensor activity ceased. Whenever video was actively being captured, the data-logger sent a GPS caption sentence to the video computer to provide a geo-reference title for each frame of imagery.

The video computer digitised the incoming analog camera signal and stored the video imagery on removable computer hard disks. The video computer could be set, through its own operating system, to collect imagery at a wide selection of time-lapse frame rates and digital compression ratios. Video frame rate and compression settings were optimised to deliver the highest quality image with the lowest disk media storage requirement. The video computer could be preset to activate up to four cameras and several different recording scenarios on receipt of trigger signals from the data-logging computer. Digital video data were recorded on the hard disk as time-stamped clips that could be reviewed on the vessel during set up and fully processed later onshore. System capacity, in terms of the amount of imagery recorded, is a function of the number of cameras in operation, the rate of image recording (i.e. the number of images per second), the extent of software image compression, and the size of the hard drive. Programming the system to record imagery only during fishing events could significantly extend system capacity. In this study, image recording occurred during the period when the set net was being deployed and retrieved, as determined from winch and hydraulic sensor indications.

2.1.2 Closed circuit TV (CCTV) cameras

Waterproof armoured dome cameras were used in this study, having proven reliable in previous applications in extreme environmental conditions on long-term deployments (McElderry et al. 2003, 2004). The camera was lightweight, compact and quickly attached to the vessel's standing structure with a universal stainless steel mount and band straps. The camera electronics inside the sealed case were attached to a rotary gimbal mount that allowed rapid directional adjustment of the fixed lens camera. A choice of lenses from fisheye to telephoto enabled the service technician to adjust the field of view and image resolution to an optimal setting for each application (Fig. 2). Colour cameras with 350 TV lines of resolution and low-light capability (1.0 Lux at f/2) were chosen for deployment in New Zealand. These have been successfully used in Canadian and American fisheries programmes where species recognition and catch assessment was the focus of the video data collection.

Figure 2. An example view from the twin camera system mounted on a set net vessel. The photo on the left is through a wide-angle lens (3.6 mm) and that on the right is through a low-magnification telephoto lens (6 mm). Note that while these images are reproduced in black and white, the real images are in colour.

2.1.3 Global positioning satellite (GPS)

EM systems were equipped with a GPS receiver, independent from vessel navigation equipment. The GPS receiver was easily mounted in the vessel rigging and, when powered, delivered a digital data stream to the data-logging computer that provides an accurate time base, and vessel position, speed, and heading. The GPS information was updated and stored in the data logger every 10 s and was also captioned at the bottom of the digital video image to provide a 'burned in' geo-reference for each video frame.

2.1.4 Hydraulic pressure and winch rotation sensors

A hydraulic pressure transducer was installed on the supply side of the vessel net drum on each of the vessels (see circle in Fig. 3). When the winch was activated to deploy or recover the fishing gear, the corresponding pressure increase was recorded in the data set. The net drum was also equipped with a rotation counter. A waterproof photoelectric sensor (see square, Fig. 3) was installed on the winch frame and one or more pieces of reflective tape were attached to the net drum. Each time a reflector passed in front of the photo-sensor, the invisible infrared beam was reflected back to the sensor receiver and a rotation count recorded in the data file.

2.2 FIELD PROGRAMME DESIGN

The field programme required an EM technician and EM systems for four vessels to be on site for a 1-month period at the start of the set net fishery. This began on 11 October 2003 and was planned to extend to mid-November 2003. However, most of the vessels previously identified as willing to participate in the project in the target ports of Lyttelton and Timaru were not ready to commence set net fishing in mid-October. As a result of the delays, the field programme was extended to 9 December 2003. With successful deployments of EM and general acceptance of the technology by the fishing industry, the field programme was further extended to keep a single EM system aboard one vessel until 31 January 2004.

The project design called for deployment of EM systems on three set net vessels and one trawler, with a minimum of ten fishing events monitored from each vessel.

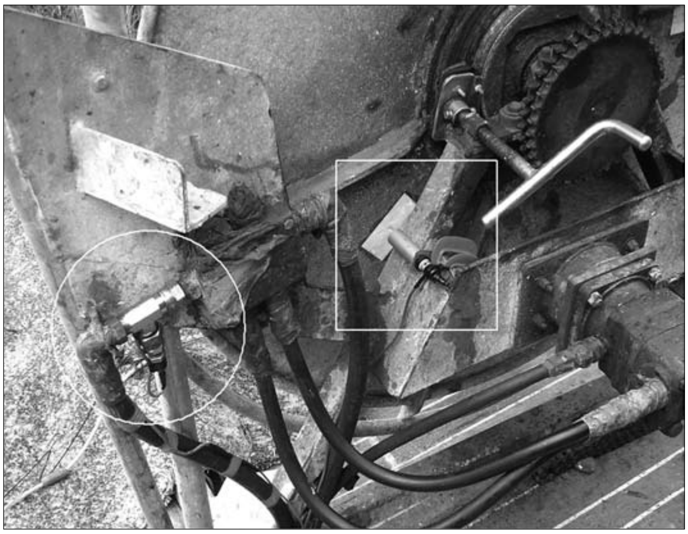

Figure 3. Drum sensor installations on a set net vessel. The photo sensor and reflector (square) provide counts of winch drum rotations and the hydraulic pressure sensor (circle), installed on the supply line, monitors power at the winch.

2.2.1 Trawler

Within a couple of days of the start of the field programme, the 16-m inshore trawler, code-named *TR 1,* was identified as a test platform and arrangements were made to facilitate EM system installation 2 days later.

Video imagery of the trawler was needed to document the net recovery process, the discharge of the net into the catch containment area (fish pound) and the catch as it was dispatched into the hold. Image capture from these activities would enable identification of catch quantity and species composition. As the net drum was active through most of the catch handling process, the control software used winch sensor information to activate image recording.

The cameras were installed a few metres forward of the fish handling area, looking toward the vessel stern and the net chute. A centrally-mounted camera viewed the contents of the fish pound through a close-up lens while the second camera, mounted off-centre to port, viewed the entire fish handling area through a wide-angle lens. The GPS was fastened to the vessel gantry and the hydraulic and drum rotation sensors were attached to the motor side of the net drum. The camera and sensor leads ran through an enclosed cabin window to the control box mounted on a shelf in the galley. The onboard 240-V AC generator provided EM system power.

2.2.2 Set net vessels

Two weeks after completing the *TR 1* installation, the first set net vessel became available for EM system installation. The 9-m vessel, code-named *SN 1*, was being prepared to begin day-fishing (using a single set net) out of Timaru. The standard fishing day on the vessel, as described by the owner/operator, started with a night departure from Timaru Harbour followed by transit to the fishing ground beyond 4 n.m. from shore. The set net was deployed in the very early morning hours and the vessel was anchored near one of the net marker floats for 4–6 h. The net was recovered in the mid-morning and the vessel returned to port to offload in the early afternoon. This process was repeated (weather permitting) on a daily basis.

The net on *SN 1* was set and hauled over a stern roller, so the cameras were mounted on the vessel trawl gantry facing aft. One camera was focused on the net roller and the other on the catch containment area between the net drum and roller (Fig. 2). The pressure and drum rotation sensors were installed on the motor end of the net drum. The net was set without hydraulics, so the rotation sensor would provide the only detection signal for net deployment. Hydraulically activated haul operations would be defined in the data record by both sensors. A compact control box was installed under the galley table in the vessel cabin. A 120 V DC inverter was connected to one of the engine start batteries to provide system power. *SN 1* departed for its first fishing trip a few days after the system was installed.

On 2 November 2003, 2 days after completing the system install on *SN 1,* a second set net operator based in Lyttelton agreed to take an EM system for trial. The 19-m fishing vessel *SN 2* was the largest set net vessel in the pilot study. Its net was set at the stern from a forward-mounted drum that can hold up to three nets. The net was hauled at the bow across a sorting table that provided an ideal camera view of the catch coming on board. A single camera, equipped with a close-up lens, was attached to a crossbar near the vessel bow and the camera view was focused on the sort table. Rotation and pressure sensors were attached to the motor side of the net drum. The external wiring entered the vessel cabin through a roof vent and the compact control box was mounted on an unused corner of the chart table. An onboard diesel AC generator reliably powered the EM system. *SN 2* fished the area around Banks Peninsula with a crew of three and was equipped to stay at sea for several days if necessary.

On 11 November 2003, the last of the four EM systems was installed on a 12-m set net vessel (*SN 3*) in Timaru. *SN 3* was similar in layout to *SN 1*, with an afterdeck net drum setting and hauling over a stern roller. The gantry provided an excellent camera mounting point with a clear view of the net roller and the fish pound. The pressure sensor was connected to the drum motor supply line and a rotation counter was clamped in an out of the way location on the drum frame. A 2-cm hole under the cabin overhang provided access for the sensor and camera wiring to the cabin interior. The control box was located at the base of the cabin settee and system power was taken from a DC to AC power inverter that was already present in the cabin. *SN 3* was equipped to stay at sea for 3 or 4 days if conditions allowed, although fishing trips could also be single day events.

On 18 November 2003, *SN 2* had recently returned from its third fishing trip without launching the net due to a transmission failure and was not likely to fish again for up to 10 days. The *SN 4*, a fourth set net vessel (from Timaru), had requested a system, so the EM complement from *SN 2* was installed on the *SN 4* on 23 November 2003, and an agreement reached for it to stay with the vessel until the end of January 2004. *SN 4* fished up to three set nets and could stay at sea for several days if desired. A large net drum was mounted on the afterdeck and, like *SN 2,* the net was deployed from the stern and hauled at the bow. Being able to shoot and haul the nets in forward gear enables the larger set net vessels to operate in heavier weather conditions.

The cameras on *SN 4* were mounted on the forward mast looking down on the net roller and fish-handling area on the foredeck. They were initially set up with a wide angle on the roller camera and a telephoto on the higher deck-view camera.

After reviewing the early video data, the lens on the roller camera, increasing the focal length to provide a more close-up image on the roller and to reduce the view of the sea surface at the vessel bow.

The GPS was installed on the cabin roof and the pressure and rotation sensors were installed at the net drum motor in a fashion similar to all the other set net vessels. The camera and sensor leads entered the cabin at the corner of the cabin door and the control box was installed on a shelf under the cabin settee. The vessel had an AC generator but it was not in general use while fishing so the power for the system was initially taken from a DC to AC power inverter. The power source during initial tests was occasionally unreliable, so a different DC to AC power inverter was installed on the vessel to solve the problem.

2.3 DATA ANALYSIS

A preliminary analysis was performed in the field to inventory the data set for completeness and quality. This initial analysis was completed shortly after each trip in order that problems could be identified and corrected on subsequent fishing trips. Following completion of the field programme, Archipelago staff conducted a thorough analysis of the EM datasets.

2.3.1 Sensor data analysis

The sensor data analysis included an assessment of the data quality, an evaluation of completeness of the dataset, and interpretation of sensor data to identify fishing events. This analysis was facilitated using a combination of three software tools and data presentation techniques:

Relational database—The raw ASCII sensor data was imported into a relational database application to perform a variety of tasks, including reformatting data and examining related records for anomalies in the data series (e.g. power interruptions or poor GPS signal quality).

Time series plotting—Selected variables from the monitoring system data were displayed in a time series graph. The sensor data presented in this format clearly distinguish vessel activities including transit, anchor, fishing, and periods when the system power was off.

Geographic plotting—Selected variables from the dataset were also displayed using a geographic information system (GIS) software tool. These plots enabled identification of the geographic position of fishing activity with a hydrographic chart and fishing boundaries.

Once the database application had processed the data, anomalies in the dataset could be identified. The most important anomalies to identify were time gaps, or breaks in the data-logging time series, usually caused by power interruptions. Minimal time gaps indicated that the data series was complete. Other dataset anomalies investigated included erroneous GPS readings, which indicated a temporary GPS data stream loss, usually caused by a poor GPS signal or interference from other vessel electronics.

The time series graphs displayed information such as hydraulic pressure, winch rotations, vessel speed and heading, plotted over time in order to more easily identify fishing activities (e.g. setting, hauling and towing) and other vessel activities such as transiting, departing, and landing times. A sample time series graph is shown in Fig. 4, showing sensor values and the time period when image capture was taking place. The data-logging interval (the time between adjacent data records) was also examined to identify gaps in the dataset, indicating periods when the system was not logging data (usually due to power outages).

A spatial plot of the fishing trip was used to provide a geographic representation of the vessel's cruise in relation to a nautical chart (Fig. 5). Transit, setting and hauling events were distinguishable from the sensor data (Fig. 4) and could be highlighted and represented spatially. Interpretation of both time series graphs and GIS plots, facilitated the detection of fishing events. These events, referenced by date and time, were then used to directly access the image data. Fishing events identified in this study were not cross-referenced to other data sources such as Ministry of Fisheries (MFish) catch effort data or industry logbooks.

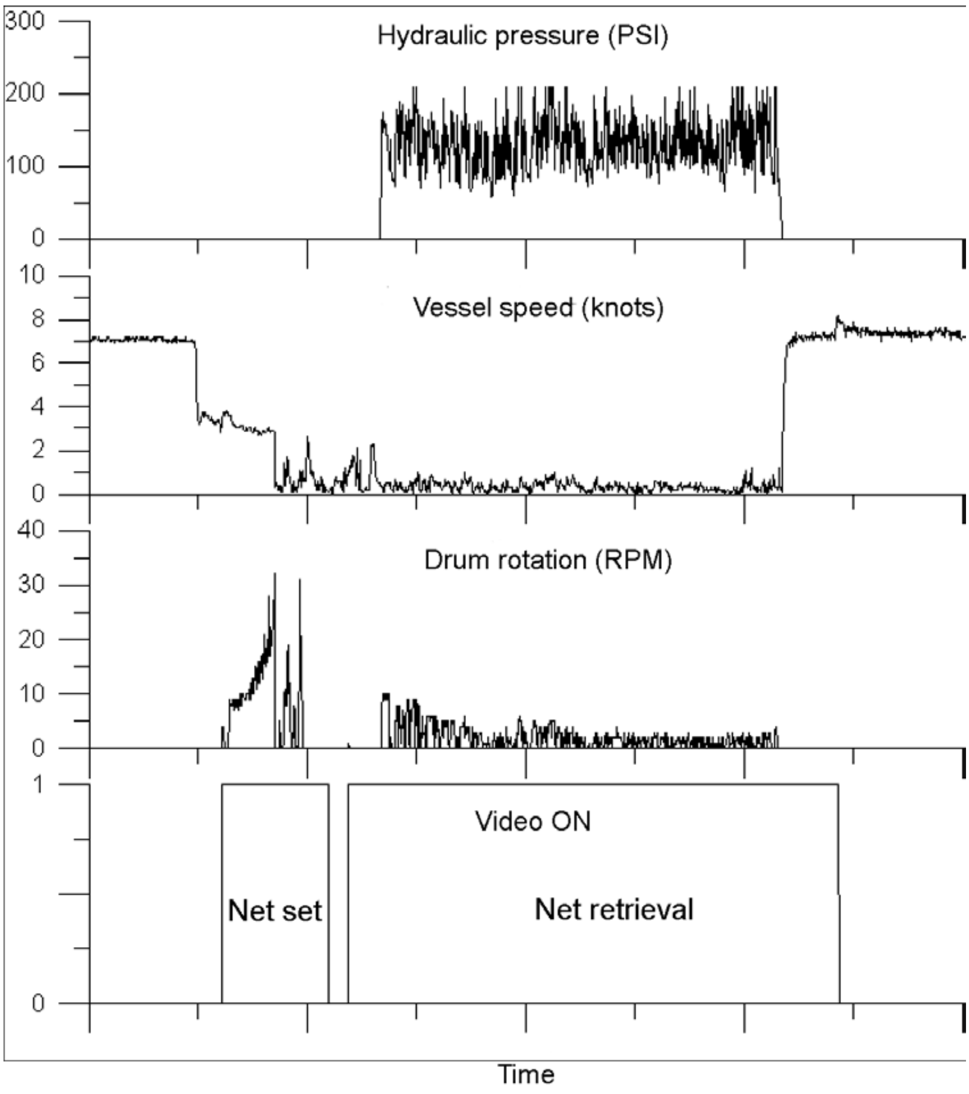

Figure 4. Time series graph showing sensor readings during a net setting and retrieval event.

2.3.2 Image data inventory and analysis

Image data inventory

An inventory of datasets from EM deployments was made to assess the overall success of data capture and to identify elements of the fishing trip for more detailed analysis of the imagery. The inventory process is outlined in a flowchart in Fig. 6, showing the categories used to separate the imagery dataset. The first stage in the process was to distinguish setting imagery from retrieval imagery. As collection of gear setting imagery was an artefact of the way the EM systems were programmed (i.e. they were set to record imagery with elevated hydraulic pressure and/or when winches rotated), setting imagery was ignored. With retrieval imagery, the dataset was subdivided into imagery that we were able to analyse from imagery that could not be analysed, usually for technical reasons. Lastly, within the retrieval imagery that could be analysed, the data set was divided between two separate catch analysis methods.

After inventory, there were three aspects of image data analysis. First, sensor data and image datasets were compared to verify that the image data set was complete. Second, analysed imagery was evaluated in terms of general quality criteria. Third, catch content images were inspected for detail.

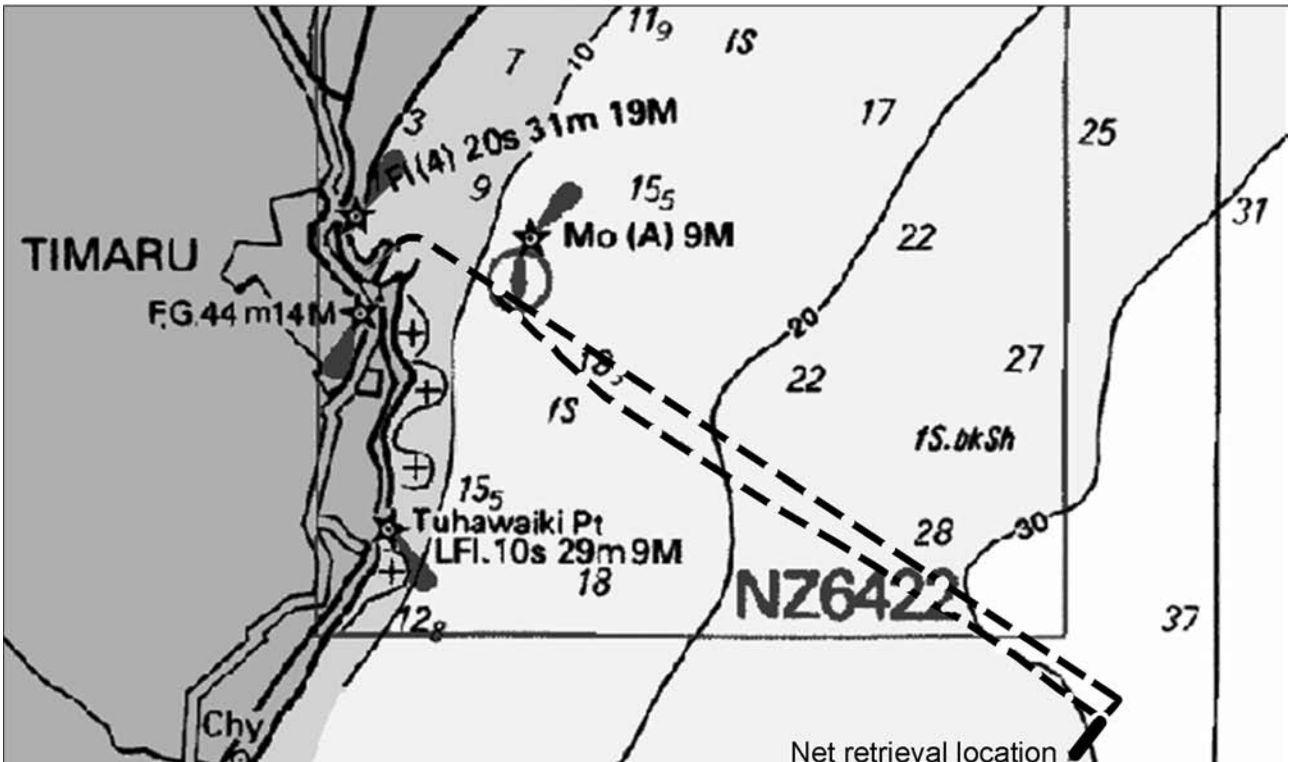

Figure 5. Plot showing vessel cruise track for a fishing trip. Heavier portion of cruise track shows set net retrieval location.

Figure 6. Flowchart showing the dataset inventory categories.

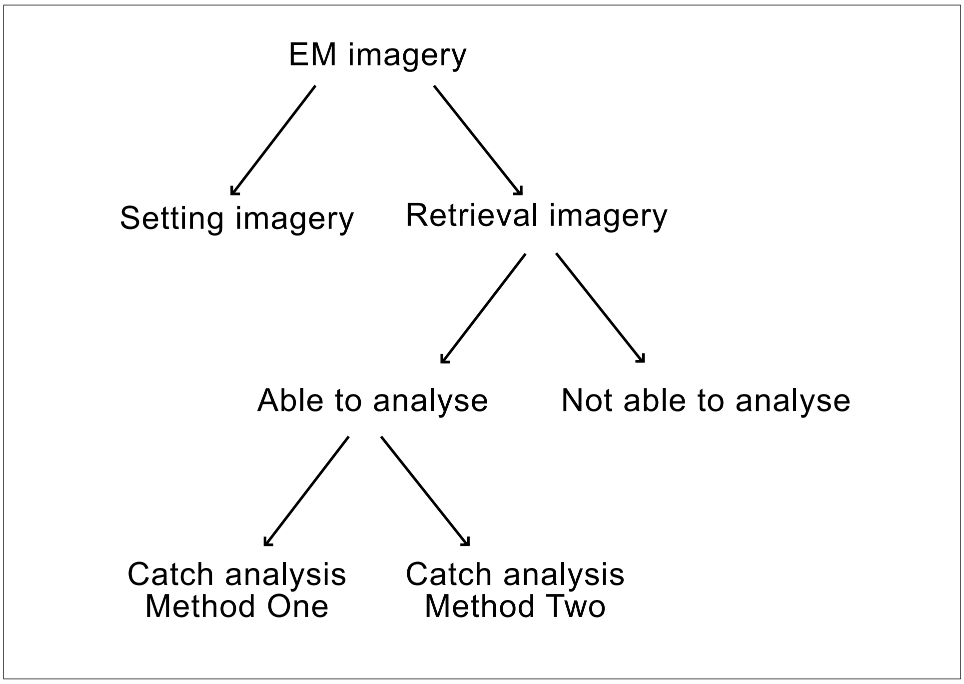

Image quality

Image quality was assessed as:

High—when the lens was properly focused, the viewing area was clearly visible and net retrieval and catch identification was easy to assess.
Medium—when there was some loss of resolution, but the ability to view net retrieval and catch identification was not greatly hampered.
Low—when reduced light, water spots on the lens or poor focus made fishing activity difficult to resolve.
Unusable—when the light levels or image quality became so poor that analysis was not possible.

Weather conditions contributed to image quality and were categorised as follows:

Good—sunny or partially sunny, and seas relatively calm.

Moderate—overcast, cloudy, light rain and choppy seas.

Poor—overcast, cloudy, heavy rain and stormy seas.

Catch image analysis

The third component to the image analysis involved a detailed inspection of the catch contents. Two analysis methods were used, both of which included the identification of any instances where catch and catch handling could not be seen, such as might occur if the crew wanted to remove a catch item before coming into camera view. Method One involved a detailed enumeration and identification of all catch items while Method Two involved examination of the imagery specifically for Hector's dolphins.

Method One examined the catch imagery in detail in order to identify catch and bycatch species to the greatest detail possible. Playback could be stopped to identify items. We sought to classify catch and bycatch species according to the following recognition categories:

Category 1—Catch and bycatch species that could consistently be identified to species correctly.
Category 2—Catch and bycatch species that could consistently be identified to a more general taxonomic grouping (such as family).
Category 3—Catch and bycatch species that were difficult to identify to any taxonomic grouping. This category also included species or species groups that might be identified under ideal circumstances but would otherwise be considered as 'unidentified fish'.

Method Two involved examination of imagery looking only for Hector's dolphin encounters and instances where catch handling was taking place out of the view of the camera (for example, handling of the catch over the rail). The analysis consisted of reviewing the imagery played at a higher speed to confirm that all catch items could be identified, without stopping playback to identify and record items. This analysis method, while equally sensitive to the presence of Hector's dolphins, provided a more realistic measure of the time required to analyse imagery when its focus is solely to detect interactions with protected species.

The time taken to analyse imagery by both methods was recorded to give an 'analysis ratio'. This was the ratio of the 'real' time of the recording to the actual time required to analyse the imagery for each retrieval event.

3. Results

3.1 SUMMARY OF EM DEPLOYMENTS

A field technician was on site from 11 October to 9 December 2003 to deploy EM systems on four set net vessels (code-named *SN 1, SN 2, SN 3* and *SN 4*A) and one trawl vessel (*TN 1*). After 9 December 2003, a single EM system on *SN 4* (*SN 4*B) was left in place until 31 January 2004. These data for *SN 4* are shown separately in the following tables as a different catch analysis method was used. The EM systems performed well and achieved image and sensor data collection for all vessel deployments. Overall, a total of 82 fishing days and 113 fishing events were recorded by the EM systems (Table 1). Most (79%) of the total number of monitored fishing events were from set net vessels and fishing events of one vessel (*SN 4*) made up 65% of the set net sets monitored.

Analysis of the data record provided information on periods when the EM system was not powered. All four set net vessels provided a continuous EM data record when net retrieval operations were under way. Two of these (*SN 1* and *SN 2*) powered the system down between set and retrieval, leading to a risk of then forgetting to turn the EM system back on (as occurred for one setting event on *SN 2*). One vessel (*SN 4*) initially had power problems, with 67 power loss events of less than 10 min and six ranging from 12 min to 67 min. This problem was corrected by replacing the vessel's DC to AC power inverter. Using the data from this study, we calculated that a single (80 gigabyte) hard drive could accumulate about 30 fishing days' worth of data.

3.2 IMAGE DATA INVENTORY

The initial post-collection image data inventory showed that a total of 299 h of EM imagery (representing nearly 100% of active fishing time) had been gathered from all vessels. Net setting accounted for 10% of this and net retrieval for 90%. Of the retrieval imagery, 84% could be analysed (38% by Method One and 46% by Method Two; see Section 2.3.2—Catch image analysis).

Table 2 provides a summary of the total hours of retrieval imagery, shown by fleet and vessel category. There were two instances of imagery that we were unable to analyse. Both were the result of post-collection data loss from hard drive failures. In these instances, imagery was successfully recorded by the EM system but was subsequently inaccessible on the hard drive (labelled as 'not analysed' in Table 2). The data loss occurred with both fleets: a single drive from *SN 4*A resulting in a loss of four sets (17.5 h or 6.5% of total set net retrieval imagery); and a single drive from *TR 1*, resulting in a loss of 24 haul events (1.9 h or 100% loss of trawl imagery). Among the imagery that was available for analysis, there were 85 set net retrievals, for a total of 250 h. The trawl imagery was examined in the field and one retrieval event was archived prior to the data loss.

Drum rotation and hydraulic pressure sensors were found to be quite reliable in triggering image recording during net set and retrieval events. This method eliminated constant image recording, which is often the norm in pilot studies.

The imagery for three of the set net vessels was complete for all retrieval events. There were four instances on *SN 4* of interrupted imagery during net retrieval operations. Two of these events involved crew working on the net out of camera view and two were due to retrieval operations being stopped for extended periods of time, causing the image recording to also stop. When retrieval operations resumed, there was about a 2-min delay before recording started.

3.2.1 Image analysis times

Retrieval imagery was analysed in detail, with Method One being used on 54% of the sets (45% of the hours) and Method Two for the other sets (Table 2). The analysis ratio with Method One ranged from 33% to 72% of real time (i.e. 1 h of recorded imagery would take between 18 min and 42 min to analyse),

TABLE 1. SUMMARY OF EM DEPLOYMENTS.

VESSEL	START DATE	END DATE	NO. OF FISHING DAYS	NO. OF SETS	SETTING TIME (h)	RETRIEVAL TIME (h)	TOTAL IMAGERY (h)
Set net							
SN 1	5 Nov 2003	26 Nov 2003	8	9	3.0	20.1	23.1
SN 2	13 Nov 2003	18 Nov 2003	5	11	2.5	15.5	18.0
SN 3	12 Nov 2003	10 Dec 2003	9	11	3.2	19.6	22.8
SN 4A	25 Nov 2003	9 Dec 2003	25	19	5.1	75.1	80.2
SN 4B	10 Dec 2003	30 Jan 2004	28	39	11.4	137.3	148.7
Subtotal			75	89	25.2	267.6	292.8
Trawl							
TR 1	19 Oct 2003	15 Nov 2003	7	24	3.9	1.9	5.8
Subtotal			7	24	3.9	1.9	5.8
TOTALS			82	113	29.1	269.6	298.7

TABLE 2. TOTAL HOURS OF EM IMAGERY FOR ALL VESSELS WITH SUCCESSFUL DATA CAPTURE.

VESSEL	RETRIEVAL IMAGERY				CATCH ANALYSIS: METHOD ONE				CATCH ANALYSIS: METHOD TWO			
	TOTAL NO. OF SETS	NOT ANALYSED (h)	ANALYSED (h)	TOTAL (h)	NO. OF SETS	REAL TIME (h)	VIEWING TIME (h)	ANALYSIS RATIO	NO. OF SETS	REAL TIME (h)	VIEWING TIME (h)	ANALYSIS RATIO
Set net												
SN 1	9	0.0	20.1	20.1	9	20.1	6.8	34%				
SN 2	11	0.0	15.5	15.5	11	15.5	6.2	40%				
SN 3	11	0.0	19.6	19.6	11	19.6	14.1	72%				
SN 4A	19	17.5	57.6	75.1	15	57.6	19.2	33%				
SN 4B	39	0.0	137.3	137.3					39	137.3	18.4	13%
Subtotal	89	17.5	250.1	267.6	46	112.8	46.3	41%	39	137.3	18.4	13%
Trawl												
TR 1	24	1.9	0.0	1.9	0	0.0	0.0	0%				
Subtotal	24	1.9	0.0	1.9	0	0.0	0.0	0%				
Totals	113	19.5	250.1	269.6	46	112.8	46.3	41%	39	137.3	18.4	13%

with an average of 41% (25 min). Using Method Two, 1 h of imagery required 8 min to analyse (an analysis ratio of 13%). The time difference for image analysis between these two methods was entirely due to the significantly lower level of data interpretation associated with Method Two. The variability in image analysis time between sets was due to several factors, including analyst experience, vessel catch handling procedures, image quality, and catch levels. These values represent averages that could be used in planning image analysis effort in a future EM programme.

3.2.2 Image quality and weather conditions

An assessment of image quality and weather conditions from all analysed imagery is presented in Table 3. Image quality during set net retrieval operations was mostly high (67%), with medium- and low-quality imagery primarily related to reduced light levels. No imagery was considered 'unusable'. The greater amount of gear deployed by *SN 4* resulted in more retrieval time occurring during low light levels. As set net fishing generally requires good weather conditions, it was not surprising that image analysts recorded predominantly good weather conditions. Weather and light levels were the main external factors that affected quality, while internal EM system-related factors affecting quality included lens focus, camera configuration (field of view), and image recording specifications (frame recording rate and image compression ratio).

3.2.3 Catch image analysis: Method One (full enumeration)

This involved a comprehensive analysis of retrieval imagery in an attempt to enumerate and identify all catch (see section 2.3.2—Catch image analysis). The catch results for this component of the retrieval imagery are summarised in Table 4. In total, there were 22 species or species groups identified in the imagery of 46 sets. Ninety-three percent of the total number of catch items (pieces) consisted of three species: rig (*Mustelus lenticulatus*), spiny dogfish (*Squalus acanthias*) and elephant fish (*Callorhinchus milii*). These species also occurred in 100% of the sets. Seven taxa and the category 'unknown fish' occurred in 30%–60% of the sets; and 12 occurred in less than 10% of the sets. Seabirds were present in three sets. No Hector's dolphins were observed in the retrieval imagery analysed using this method.

The category 'unknown fish' represented instances where the analyser was not able to make a fish identification. This category represented less than 1% of the catch, indicating that the EM analysis was usually able to resolve species to the levels identified. Among the other categories, twelve were to species level while the remainder were species groups of taxonomically similar species.

TABLE 3. ANALYSIS OF IMAGE QUALITY AND WEATHER CONDITIONS.

VESSEL	NO. OF SETS	TOTAL HOURS	IMAGE QUALITY (%)				WEATHER (%)		
			HIGH	MEDIUM	LOW	UNUSABLE	GOOD	MODERATE	POOR
Set netters									
SN 1	9	20.1	100.0	0.0	0.0	0.0	100.0	0.0	0.0
SN 2	11	15.5	100.0	0.0	0.0	0.0	87.7	12.3	0.0
SN 3	11	19.6	95.0	5.0	0.0	0.0	100.0	0.0	0.0
SN 4A	15	57.6	51.3	44.9	3.7	0.0	100.0	0.0	0.0
SN 4B	39	137.3	60.6	37.7	1.7	0.0			
Total	85	250.1	66.8	31.4	1.8	0.0	44.3	0.8	0.0

The recognition category (see section 2.3.2—Catch image analysis) given to each species or species grouping reflects the confidence in identifications to species (category 1), a higher taxon (category 2), or not to any taxon (3). The results indicate that about half the categories could be identified to species level and half to taxonomic grouping level. The level 3 category occurred in about half the sets and represented less than 0.6% of the total pieces.

3.2.4 Catch image analysis: Method Two (protected species only)

Thirty-nine of the analysed sets of retrieval imagery were analysed using analysis Method Two (Table 2). The analysis ratio for this method was about three times less than for Method One (Table 2) and would be representative of analysis procedures and time required to detect the presence of Hector's dolphins. The main difference between the two methods was that in Method Two, the image playback was not stopped for catch items to be identified and recorded. The large size and distinctiveness of Hector's dolphins enabled this rapid rate of analysis. Other than Hector's dolphins, there were no catch results produced for these operations, although the analysis could have included a count of catch items without significantly increasing the analysis time.

The analysis of the 39 net retrieval events resulted in detection of two Hector's dolphin encounters. Details of these encounters have been kept confidential, although they were obtained from both the EM data analysis and, subsequently, a detailed report provided by SEFM.

TABLE 4. CATCH IMAGE ANALYSIS USING METHOD ONE.

COMMON NAME	SPECIES NAME	NUMBER OBSERVED	OCCURRENCE IN SETS (%)	AVERAGE NO. PER SET	RECOGNITION CATEGORY
Rig	*Mustelus lenticulatus*	5785	100.0	125.8	1
Spiny dogfish	*Squalus acanthias*	2696	100.0	58.6	1
Elephant fish	*Callorhinchus milii*	1990	100.0	43.3	1
Red gurnard	*Chelidonichthys kumu*	183	43.5	4.0	1
Carpet shark	*Cephaloscyllium isabellum*	165	56.5	3.6	1
Skates	Rajidae	81	60.9	1.8	2
Unknown fish	Osteichthyes	71	45.7	1.5	3
Groper	*Polyprion oxygeneios*	69	32.6	1.5	1
Flatfish general	Pleuronectidae	57	41.3	1.2	2
School shark	*Galeorhinus galeus*	54	47.8	1.2	1
Seabirds*	Procellariidae	36	6.5	0.8	2
Red cod	*Pseudophycis bachus*	10	6.5	0.2	2
Blue warehou	*Seriolella brama*	7	8.7	0.2	2
Barracouta	*Thyrsites atun*	6	10.9	0.1	2
Sculpins	Cottidae	5	6.5	0.1	2
Kahawai	*Arripis trutta*	2	4.3	0.0	2
Monkfish	*Kathetostoma giganteum*	2	4.3	0.0	1
Ratfish	*Hydrolagus novaezelandiae*	2	4.3	0.0	1
Billfishes	Istiophoridae or Xiphiidae	1	2.2	0.0	2
Scallops	Pectinidae	1	2.2	0.0	2
Thresher sharks	*Alopias vulpinus*	1	2.2	0.0	1
Ling	*Genypterus blacodes*	1	2.2	0.0	1
Tunas	Scombridae	1	2.2	0.0	2
Totals		11 226		35.3	

* Later determined to be mutton birds (Sooty shearwater, *Puffinus griseus*).

The first of the encounters occurred on 10 December 2003. The vessel was estimated to be about 2.5 n.m. from shore. The dolphin had become wrapped in the net and had been hauled up to the bow roller, before it broke free of the net and fell back into the water. On the capture vessel, the catch sorting area and net hauling station were aft of the cabin and crew would not normally be in the bow where the net is hauled. As a result, we consider it unlikely that the crew had been aware of this encounter. Subsequent information from an interview with the skipper indicated that he had been aware that something large was in the net but did not know it was a Hector's dolphin. EM imagery of the encounter clearly showed the head, side markings and tail fluke, providing a positive identification. The imagery from the encounter is too brief to indicate the viability of the animal when it returned to the water, although the skipper's report stated the following: 'From the footage recovered, the nature of the animal when captured in nets, the absence of a carcass near the vessel, and the absence of any reports of beach cast dolphins along the adjacent stretch of coastline, it is likely that this animal released itself from the net alive and survived'.

The second Hector's dolphin was encountered on 26 January 2004. The vessel was estimated to be 0.97 n.m. (1722 m) from shore at the time. In this instance, the dolphin was clearly visible in the water as the vessel approached, obviously entangled in the net ahead. Images show the head and distinctive side markings, providing a positive identification. The dolphin was not hauled aboard. Rather, it was cleared from the net out of camera view before net retrieval was resumed. In this instance it appeared that the crew were aware of the encounter and removed the dolphin from the net away from the camera view. The skipper report provided the following account: 'on spotting the dolphin in the net, he allowed the vessel to slowly overrun the net so that the animal passed down the starboard side of the vessel to the aft deck where the crew could more easily release the animal from the net while it remained in the water. This took approximately 5 minutes'. As with the first encounter, the dolphin imagery was brief and did not reveal information concerning its viability. The skipper report stated that: 'the animal was a live Hector's dolphin and that it was successfully released from the net alive'.

The entire net retrieval imagery from the sets of both dolphin encounters was re-examined to determine the presence of mitigation measures such as acoustic pingers. In the first instance, two pingers were seen at the end of the retrieval, whereas the dolphin encounter was encountered within 10 min of the start of retrieval. In the second instance no pingers were noted and the dolphin was seen about three-quarters of the way through the retrieval. The absence of pingers in the imagery could mean that they were present but hidden from view by the net or catch items. The skipper reports acknowledged that for various reasons pingers were in short supply and were not properly deployed on the nets during these two fishing operations.

4. Discussion

4.1 TECHNICAL ASSESSMENT OF EM SYSTEM

The results from this study indicate that EM offers opportunities for monitoring protected species interactions in the Canterbury inshore set net and trawl fleet. The five vessels sampled represented a range of the vessel types in the fleet, from the larger multi-day fishing vessels to smaller, day-fishing vessels. In all cases, there was enough space for the EM equipment and there was adequate electrical power to keep the EM system operating continuously (in some cases after minor modification or the provision of inverters at low cost).

The suitability of EM for fishery monitoring applications will depend upon the reliability of the equipment. In this study, EM equipment was deployed on five vessels for a total of 82 monitored fishing days and 113 fishing events. The EM system performed reliably in all cases, with data capture of all fishing events. While data capture performed well, there were two separate instances where hard drive failure resulted in the loss of imagery: of all 24 sets on the trawl vessel and four sets on a set net vessel. The drive failures resulted in a loss of about 7% of the total retrieval imagery. In this study, both image dataset losses occurred with one type of control box (there were two system designs used) and we suspect that part of the problem may be related to the control box itself. There were no problems with the smaller control box design, which had a newer operating system and video computer components. Because we expect that the newer control box would be used in a true monitoring application, we would expect a lower rate of data loss than we experienced in this study. Even still, hard drive failures occur and the only effective safeguard is an archival backup process.

Some image loss occurred when pauses during retrieval events exceeded the 15-minute delay interval following cessation of hydraulic and winch activity. This problem resulted in very small amounts of image data loss and could easily be resolved by increasing the interval to 30 minutes.

The level of cooperation of vessel crew also determines the reliability of EM equipment. In this study all vessels volunteered to take EM systems and their support for the programme clearly grew over time. In a fleet-wide monitoring application it is probable that EM equipment would be placed aboard unwilling vessels, creating a risk of tampering. While the EM system components are rugged and reasonably tamper-proof, the system can be interfered with in various ways such as powering down the system, disconnecting certain sensors, or covering the cameras. It would be very difficult to make these systems fully tamper-proof, and the more likely approach would be to discourage interference through incentives built into the monitoring programme. For example, in the Canadian 'Area A' crab EM programme, if there is evidence of tampering, fishers may be required to place a performance bond, take an at-sea observer or pay more for additional data analysis (McElderry 2003).

In terms of the main objective of monitoring protected species interaction with set net gear, EM imagery was very reliable in the detection of catch in general. EM was successful in documenting the two entanglements of Hector's dolphins in set nets from imagery obtained over the course of the study. In addition to the dolphin encounter imagery, EM systems provided information including the enumeration and identification of other catch items. While catch monitoring was not a specific objective of this study, a significant quantity of the retrieval imagery was analysed to identify individual catch items, as a means of assessing how recognisable Hector's dolphins would be if they were to occur in the catch. Catch identification to the species or group level occurred in over 99% of the records and 98% of catch items were classified to species level. Species identifications of catch in general (categories such as skates and flatfish) could be improved with greater EM analyst knowledge of coastal New Zealand fish species. Seabird identifications from the imagery would be difficult without better close-up imagery; however, the imagery could be used to audit the requirement to deliver seabirds samples ashore. Given the high quality of the imagery, the ability of analysts to identify most catch items, and the low degree of missing imagery in the dataset, we conclude that encounters with Hector's dolphin would generally be detectable from the EM imagery.

Catch identification from video imagery also depends on the camera view, uniqueness of the species, taxonomic level of identification required, the experience of the analyst and the level of crew cooperation. There is room for improvement in these areas, although the need for this would depend upon the objectives of the monitoring programme.

As well as documenting encounters with protected species, the EM system could be effective in monitoring mitigation measures such as placement of acoustic pingers on the net and documenting the area and time of fishing operations. Neither catch method included a rigorous examination for the presence of pingers, except in the two instances where Hector's dolphins were caught. There were several instances during image analysis where pingers were noted, but we could not determine whether a failure to note pinger presence was due to their absence or their being hidden from view. However, future monitoring in this fishery should include documentation of pingers, either by their being conspicuously coloured to facilitate their recognition or perhaps by incorporating a hydrophone in the EM system.

While the quality of EM imagery enabled a high degree of catch identification, neither of the two Hector's dolphin encounters resulted in the dolphin being brought aboard the vessel directly into the camera field of view. While the imagery was adequate to detect and identify these as Hector's dolphin encounters, a more forward-directed camera placement would have provided a better view of the net ahead of the vessel and the net as it emerged from the water. This adjustment to camera view could be easily accommodated using the same equipment used in this study and perhaps minor modifications to the fishing vessels. We recommend this change, both as a means of increasing the detection of Hector's dolphins in the net and in determining the viability of dolphins after such encounters.

Information about the time and location of fishing events was also a very useful part of the dataset. The sensor dataset provided a quick way to evaluate the overall fishing trip in terms of duration, fishing location and completeness of data. On a large spatial scale, track plots showed the location of gear setting and hauling events and, in particular, distance from shore. On a fine scale, track plots provided detailed information about the retrieval operations, particularly in relation to specific events such as the dolphin encounters.

Unfortunately, the loss of the trawl vessel imagery prevented any intensive analysis of that imagery. However, the field technician was able to view all the imagery at sea and was satisfied that the two CCTV cameras provided a clear view of trawl net contents; but it was not possible to estimate catch quantity and determine the level of species identification possible without the detailed on-shore analysis. Based on our experience with catch monitoring in other fisheries, however, we would expect the trawl EM imagery to resolve some species, particularly large or distinctively marked ones. As trawl catch becomes a concentrated mass of fish in the cod end of the net, determination of catch quantity would more likely be achieved using a volumetric estimate as opposed to the piece-by-piece enumeration used in set net gear. The ability to make a volumetric estimate would be determined by the holding pen configuration, as catch volume would be estimated by comparing with a holding pen of known volume. Given the image quality and area of coverage obtained so far, we believe that EM would reliably show Hector's dolphins caught in the trawl catch.

4.2 FEASIBILITY OF EM FOR THE CANTERBURY INSHORE SET NET AND TRAWL FLEETS

Based on our study, we believe that EM would be very suitable for monitoring fishing operations aboard the Canterbury set net and trawl fleets. Our results indicate that the equipment is reliable, suited to the fleet, and provides data that meet or exceed the monitoring objectives of the fishery. The data capacity of the system provides for many days of monitoring between data retrieval operations. Very few changes in equipment design would be needed to move toward a fully operational fleet monitoring programme. The main challenges would lie with organisational elements of the programme, such as:

- **Increasing fleet awareness**—Further outreach efforts would be required to familiarise participants in the fishery with the technology and what is necessary to make it work effectively.
- **Building a monitoring programme governance framework**—For an objective fleet monitoring programme, a governance framework would be needed to compel fishers to keep the EM system operating and prevent tampering with components of it, particularly because high compliance is needed to detect the rare encounters that may threaten the viability of the fishery.
- **Developing programme capacity**—An effective EM programme requires establishing field services infrastructure to provide trained staff to install, service and remove data from EM systems. As well, a data analysis service would be required to receive EM data, provide analysis and report to the appropriate agency. Ideally, this analysis service should be independent from both industry and government as a means to ensure objectivity and protect the privacy expectations of fishing vessels and crew.
- **Establishing data sharing agreements**—Industry support for an EM programme will depend on the rules concerning what information is collected and how it is used. As EM data produces a larger volume of recorded images than observer data, there is a risk that the information could be used for

purposes other than the original monitoring objectives. It is likely that raw EM information will need to be translated to address the specific monitoring objectives and then any other ancillary information would need to be protected from distribution.

5. Conclusions

This pilot study demonstrated that EM systems operated very reliably on inshore set net and trawl vessels and could be used to effectively monitor dolphin encounters and mitigation measures for both the set net and trawl fisheries. The set net imagery could also be used to identify the majority of catch to species or species group. Improvements needed include minor technical alterations to the EM system, such as a more forward directed camera field of view, and lengthening recording time to increase image capture when retrieval stops for a period of time. As a monitoring tool, EM potentially offers a number of advantages over observer programmes, including lower cost, labour savings, logistical efficiency, fleet suitability, and industry acceptance. Issues standing in the way of implementing an EM-based monitoring programme include expanding fleet awareness of EM programme requirements, developing local infrastructure to support an EM-based programme, and developing data-sharing agreements that specify the monitoring objectives, what information is collected, and how it will be used.

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