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The Efficacy of Video-Based Electronic Monitoring for the Halibut Longline Fishery

Efficacité de la surveillance électronique basée sur la technologie vidéo pour la pêche du flétan à la palangre

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ABSTRACT

This project involved the large-scale deployment of electronic monitoring (EM) systems on the 2002 British Columbia halibut longline fishery to evaluate the feasibility of EM as an alternative to observer-based at-sea monitoring. EM systems were deployed on 59 regular halibut fishing trips involving 19 fishing vessels, providing about 700 usable sets, 1,000 hours of imagery, and 350,000 observed hooks. Catch items identified by EM represented over 60 fish, invertebrate or seabird species or species groupings, and the 15 fish most abundant species accounted for 98% of the catch. Data from fishing trips where EM and observers were deployed (about 55% of trips) were compared by total overall catch, total catch by set, and catch by individual hook. Overall EM and observer catch estimates agreed within 2%, and individual identifications by hook agreed in over 90% of the catch records. EM reliably (i.e., accuracy within 10%) distinguished thirteen species that represented 97% of the halibut fishery catch. Some species, particularly non-distinct forms, were not identified well by EM. Sample sizes were too small among half the species for determination of an EM species identification capability. Close agreement between EM and observer was also evident with species utilization determination (i.e., kept or discarded) and time, location and depth at set start and finish.

The results of this study demonstrated that EM is a promising tool for at-sea monitoring applications. EM and observer programs differ in many ways in terms of data collection capabilities and program design issues. While the utility of this new technology will depend upon the specific fishery monitoring objectives, the substantially lower cost and broader fleet suitability of EM over observers makes this an attractive option. The authors suggest that a combined EM-based monitoring for the halibut fishery should be continued using two approaches: an integrated EM-observer program using both methods in a complimentary fashion to achieve fleet sampling objectives; and using EM and an electronic fishing log as an at-sea monitoring audit tool. Further testing using combined EM and observers on the same trip should occur in the ZN fishery to improve EM rockfish identification capability. The authors also recommend that DFO more comprehensively define the at-sea monitoring objectives of the halibut fishery and strengthen their support for EM-based monitoring approaches to further the development of this technology.

RÉSUMÉ

Ce projet a consisté au déploiement à grande échelle de dispositifs de surveillance électronique (SE) dans le cadre de la pêche à la palangre du flétan en Colombie-Britannique en 2002 afin d'évaluer leur efficacité à titre de solution de remplacement à la surveillance en mer par des observateurs. Les dispositifs de SE ont été déployés au cours de 59 sorties de pêche régulières au flétan effectuées à l'aide de 19 bateaux et ont permis d'obtenir des données utilisables sur 700 mouillages et 1 000 heures d'imagerie et d'observer 350 000 hameçons. Les prises identifiées grâce à la SE étaient constituées de plus de 60 espèces ou groupes d'espèces de poissons, d'invertébrés ou d'oiseaux de mer, et les 15 espèces de poissons les plus abondantes comptaient pour 98 % des prises. Pour les quelque 55 % des sorties de pêche surveillées à la fois par SE et par des observateurs, les données des deux méthodes de surveillance ont été comparées à l'aide des prises totales dans leur ensemble, des prises totales par mouillage et des prises par hameçon. En moyenne, les estimations des prises à l'aide de la SE et celles faites par des observateurs ne différaient pas de plus de 2 %, et les identifications des prises individuelles concordaient pour plus de 90 % des prises. La SE a permis de distinguer de manière fiable (c.-à-d. exactitude à 10 % près) 13 espèces qui représentaient 97 % des prises de la pêche au flétan. Certaines espèces, particulièrement celles ayant des formes indistinctes, n'ont pas bien été identifiées par la SE. Pour la moitié des espèces, la taille des échantillons était trop petite pour déterminer la capacité d'identification des espèces à l'aide de la SE. Les résultats de la SE et des observateurs étaient également très semblables en ce qui concerne la détermination de l'utilisation des espèces (c.-à-d. conservées ou rejetées) et le moment, l'emplacement et la profondeur au début et à la fin de chaque mouillage.

Les résultats de cette étude montrent que la SE constitue un outil prometteur pour la surveillance en mer. Les programmes de SE et d'observateurs diffèrent grandement en termes de capacité de collecte de données et de conception. L'utilité de cette nouvelle technologie dépendra des objectifs spécifiques de surveillance des pêches. Son coût substantiellement plus bas et le fait qu'elle convient davantage aux flottilles que les observateurs en font une option attrayante. Nous suggérons de poursuivre la surveillance combinée dans le cadre de la pêche au flétan à partir de deux approches : un programme intégré de SE et d'observateurs utilisant les deux méthodes de manière complémentaire afin d'atteindre les objectifs d'échantillonnage des flottilles; l'utilisation de la SE et d'un registre de pêche électronique à titre d'outil de vérification de la surveillance en mer. D'autres essais combinant la SE et les observateurs au cours des mêmes sorties devraient être menés dans le cadre de la pêche à l'aide de bateaux exploitant un permis ZN afin d'améliorer la capacité d'identification des sébastes à l'aide de la SE. Nous recommandons également que le MPO définisse plus en détail les objectifs de surveillance en mer de la pêche au flétan et renforce son soutien des méthodes de surveillance électronique pour favoriser le développement de cette technologie.

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1. INTRODUCTION

Groundfish longline fisheries in British Columbia are under increased pressure to improve catch reporting processes. While mandatory dockside monitoring programs for these fisheries accurately account for all landed catch, fishing logbooks do not accurately account for at-sea fishing activities and little is known about catch which is discarded at sea, or cut up and used as bait. Rockfish are an emerging conservation concern because these species are common in groundfish longline fisheries, are long-lived, and usually experience 100% mortality upon capture. Declining rockfish quotas may limit a fisher's access to target species such as halibut or sablefish, a constraint that increases the likelihood that unreported rockfish might be discarded at sea in order to stay within by-catch limits. There are also concerns over seabird by-catch. The nature of the problem, or determining if a problem even exists, has not been established for British Columbia longline fisheries. In keeping with Canada's international commitments and sustainability goals, more at-sea information from groundfish longline fisheries will be needed.

Observer programs are currently seen as the only reliable means of estimating by-catch in longline fisheries. Many commercial fisheries use observers to ensure compliance with fishery regulations and to collect important information to support fishery management and research. Observer programs involve an independent third party data collection process to ensure validity and accuracy. Most at-sea observer programs are costly because of the high labour requirements associated with the field data collection by observers. Thus, the benefit afforded by these programs generally falls to fisheries that can bear such costs.

In 2002, Fisheries and Oceans Canada (DFO) implemented a 25% at-sea monitoring requirement for the British Columbia halibut longline fishery. The cost of observer coverage for this fishery was significant with the industry-funded portion of the program costing over $300 per day of at-sea monitoring. As well, there were a number of concerns with deploying observers on the halibut fleet, when about a third of the vessels are less than 40 feet, and may have insufficient bunk capacity, workspace, or safety equipment for an additional person. Limiting coverage to only those boats that can accommodate observers leads to equity issues and questions of bias. Furthermore, due to the management issues stemming from reduced rockfish by-catch quotas, even if observers could be placed at random on fishing vessels, many believe that the presence of an observer aboard the vessel will influence a vessel's fishing practices, further adding to the concerns about observational bias.

Archipelago Marine Research Ltd. is a fishery monitoring firm in British Columbia, annually providing over 7,000 at-sea observing days and monitoring services for approximately 15,000 commercial fishery offload events. Since 1999, Archipelago has been developing electronic monitoring (EM) equipment for commercial fisheries. The goal is to create automated monitoring equipment, which provides accurate, timely, and verifiable fisheries data of comparable veracity to that provided by at-sea observer programs. Development of such technology would be a significant breakthrough for many fisheries including the groundfish longline fishery.

Archipelago has operated a full-scale electronic monitoring program for the Area A crab fishery for the past three years. This program has demonstrated the effectiveness of the technology for monitoring fishery effort issues, such as vessel-based trap limits, trap soak intervals, and area closures. On the strength of the success of this program, the company began development of a more comprehensive monitoring system, tailored to groundfish longline fishery monitoring needs, addressing both catch and effort issues. This system was piloted in 2001, with the support of the Pacific Halibut Management Association (PHMA) and a grant from Fisheries Renewal BC. The outcome of the pilot project demonstrated to DFO that the technology could work, and that further testing should be applied on a larger scale. Accordingly, Archipelago worked with the PHMA and DFO to put in place an EM program for the 2002 halibut fishery.

The general goal of the 2002 EM program was to sample approximately 10% of the halibut longline fishery, which equated to 850 vessel days at sea. An EM program of this scale was necessary to accomplish the following objectives:

- Evaluate the technical performance of EM to assess its efficacy as an at-sea monitoring tool. This involved further evaluation of the technical issues with deployment of EM systems on the halibut fleet, thereby providing an understanding of EM equipment suitability for various vessel configurations, and an assessment of overall EM system reliability.

- Compare EM and observer data from the same fishing trip to compare species identifications and other fishing effort related data. While observer data are not without flaws, such data are currently regarded as the accepted standard for at-sea monitoring in the halibut longline and most other fisheries. Implementation of EM in this fishery requires an assessment of how well EM data compare to at-sea observer data and identification of the issues involved with combining data sets from these two monitoring methods.

- Compare costs, benefits and operational issues associated with EM and observer-based monitoring approaches.

This project was funded by the Pacific Halibut Management Association and included input from a project steering committee consisting of: Carole Eros (DFO Management), Rick Stanley (DFO Science), Chris Sporer (PHMA), and Howard McElderry (Archipelago). The project was not the result of a specific request from the Pacific Scientific Advice Review Committee, but the steering committee felt that, given the broad application of EM technology and the potential implications for at-sea monitoring in the halibut fishery, a formal review process for the study would be beneficial.

2. MATERIALS AND METHODS

2.1. DESCRIPTION OF THE ELECTRONIC MONITORING SYSTEM

2.1.1. Components

The EM system integrates an assortment of ‘off-the-shelf’ components to create a comprehensive data-logging device. The system operated on either DC or AC voltage and automatically recorded a variety of information continuously during the fishing trip. The EM system automatically restarted and resumed program functions following power interruptions, which can be frequent events on fishing vessels. The data storage capacity of the monitoring system is influenced by the rate of data capture and the size of storage devices. The configuration used in this project provided for up to 30 days of continuous sensor data logging, with image capture for about 40% of the time.

The electronic monitoring system was designed to independently monitor fishing activities of the vessel. As outlined in the system schematic (Figure 1), the monitoring system included the following components:

- *Operating System and Data Storag*e – The heart of the electronic monitoring system is a lockable, tamper-proof control box containing the operating system, data storage components and power supplies for the video cameras and peripheral vessel sensors. The control box is a robust aluminum container approximately the size of a business briefcase (30cm by 46cm by 10cm). It is spill and splash resistant but not adequately weatherproof for on deck deployment. The box requires about half of a cubic foot of dry and ventilated interior space for storage. The space must also be reasonably accessible to the setup and service technicians. On larger fishing vessels the monitoring system is usually powered by the onboard 120 volt AC supply although it can optionally be powered by a 12 volt DC source. Video camera and sensor cables are routed from the external devices to the internal control box through cable glands or compression fittings to maintain the hermetic integrity of the deck house structures.

  The two primary components in the control box are the video and data logging computers. The data logging computer captures and records the output from the GPS, pressure sensor and drum rotation counter. The data logging computer is designed to run continuously for the duration of the fishing trip to provide a digital time series record of the vessel activities. Post-processed sensor information is used to detect specific actions on the vessel, such as setting or hauling fishing gear. The chronology of fishing activity derived from the time series is used to identify time matched video segments for review.

  The video computer digitizes the incoming analog camera signal and stores the video imagery on removable computer hard disks. The video computer can be set up to collect imagery over a wide selection of time-lapse frame rates and digital compression ratios. Video frame rate and compression settings are selected to deliver the highest quality image with the lowest storage space requirement. Software on the data-logging computer can be set to activate the video system whenever specific fishing activities, such as a hydraulic pressure increase or drum rotation at a winch, are recognized in the sensor data. Autonomous video control also reduces the quantity of captured video and the labour requirement for post-process video review.

- *User Interface* – A small monitor and keyboard were included to provide basic system status information as well as user input. The monitor and keypad mounted inside the vessel cabin near the control box.

- *GPS Receiver* - An independent GPS receiver was installed on each vessel and connected to the EM system control box. GPS delivered a digital data stream, providing an accurate time base as well as vessel position, speed and heading. The GPS antenna was mounted on the cabin top or mast of the vessel.

- *Winch Sensor* - A sensor was mounted on the winch to detect and count drum rotations. Vessels fishing with snap gear typically deploy groundline from a winch and the winch sensor was helpful in detecting setting and hauling events. Fishing vessels using fixed gear do not use a winch and therefore no sensor was used.

- *Hydraulic Pressure Transducer* – An electronic pressure transducer was mounted on the supply side of the hydraulic pump system. The sensor records hydraulic pressure and, by inference, work conducted by devices such as winches, line haulers and other equipment. The hydraulic transducer information was useful in detecting longline-hauling events.

- *Cameras* – Two closed circuit TV (CCTV) cameras were used to provide imagery of the retrieval area during longline hauling operations. An armoured dome camera was chosen for fishing vessel applications and has proven reliable in extreme environmental conditions on long-term deployments. The camera is lightweight, compact and easily attached to the vessel's standing structure with a universal stainless steel mount and band straps. The camera electronics inside the sealed case are attached to a rotary gimbal mount that allows quick directional adjustment of the fixed lens camera. A choice of lenses from fisheye to telephoto enable the setup technician to optimally adjust the field of view and image resolution for each application. CCTV cameras used in this project were standard resolution colour (350 lines per screen) with a light sensitivity to about 0.8 Lux at F 2.0.

2.1.2. System Operation

The EM system was set up in advance of a fishing trip and was fully automated in operation. If the vessel's schedule was delayed, the EM system would be turned off and the skipper was instructed to turn the system on upon departure. The EM units were configured to record the following data:

- *ASCII Sensor Data* - GPS and sensor data was to be recorded at all times between hail out and hail in. The system logged these data about four times per minute.

- *Image Data* - CCTV imagery was initially set to record for the entire duration of the fishing trip. This setting was later changed to record at a slow frame rate (i.e., six times per minute) during non-fishing events and higher frame rate (two times per second) during retrieval events. Recording imagery during non-fishing events was later stopped to simplify system operation, reduce the amount of unnecessary imagery, and respect the privacy expectations of the crew.

- *Electronic Fishing Log Data (optional)* – The user interface enabled direct entry of catch and fishing effort information by the skipper. Fishing log data entry was an optional component of the program but some skippers took an active interest in using the software and providing comments on its use. During the course of the project, changes were made to the data entry software based on skipper feedback.

2.1.3. Field Operations

At the start of the halibut fishery there were four systems dedicated exclusively for the project and the number was increased to six EM units from May until the completion of the fishery. Eight other EM systems were also available for the project on a non-exclusive basis. The equipment included spare EM components, extra hard drives, and other service supplies.

Electronic monitoring equipment and technician services were available in the ports of: Victoria, Vancouver, Prince Rupert, and Port Hardy. The majority of halibut fishery activity was based from the latter two ports.

The PHMA was responsible for supplying names and contact information of PHMA members volunteering to take EM equipment. Archipelago was responsible for contacting these people, assessing vessel suitability for EM, and preparing an EM deployment roster for efficient scheduling of monitoring systems. Selection of vessels was opportunistic, with the goal of providing EM-based monitoring:

- Among skippers who show particular interest in helping develop the EM program,
- Among vessels planning to make multiple fishing trips for extended EM deployment,
- Over time and fishing area in a fashion comparable to the halibut fishery, and
- On a cross section of vessel sizes, with some emphasis on vessels too small to host an observer.

Initially, interest in the program was high and all the available equipment was kept in use. As the season progressed, fewer boats volunteered to take equipment, which necessitated a more active scheduling effort. Program staff began contacting vessel owners directly to inform them of the program and to solicit their cooperation. As well, as the season progressed, a more concerted effort was made to deploy EM equipment on fishing vessels that could also take an observer.

2.2. ONGOING DATA SYSTEM DEVELOPMENT

The large-scale deployment of equipment provided by this program enabled the continued development of the EM system in order to improve performance and more specifically address the monitoring needs of the halibut fishery. Areas of development included operating system software, sensor configurations, camera placement data analysis, and operational procedures.

As the season progressed, there were changes to the set-up and operation of equipment. These changes were made for a variety of reasons including: improving data quality, extending duration of data storage, reducing power consumption for vessels while at anchor, and respecting privacy expectations of the vessel crew. The most significant configuration change was placing both cameras on the stabilizer pole to obtain both a close focus and wide-angle view (Figure 2). Previous to this, it was difficult to balance the close focus needs for species identification with the wide field of view needs to ensure the groundline was always in view. Moving a camera from the mast to the stabilizer improved retrieval image quality considerably and met crew requests for more privacy.

The analysis procedures for EM-based monitoring data advanced considerably through the fishing season duration. On the sensor data analysis component, several improvements to the MS-Access application were made to speed up the processing time. The video analysis underwent the greatest progression, moving from paper to direct data entry. As well, as the season progressed, the ability to harmonize analysis procedures between different EM image analysts improved. These changes resulted in improved accuracy, decreased analysis time, and cost savings, as image analysis was the most labour intensive aspect of the project.

2.3. DATA ANALYSIS PROCEDURES

Upon completion of a fishing trip, a technician met the vessel to service the equipment and remove data. If the vessel was conducting further fishing trips with the equipment, the technician inspected the data set and image quality, refreshed the data storage capacity, and made adjustments to the system components as required. The data quality assessment included examining the raw sensor and image data, completing an inventory of stored data, and carrying out an initial assessment of data quality to identify any specific problems that occurred during the fishing trip. This assessment was particularly important for repeated EM deployments on the same vessel. If the fishing vessel declined further participation, the equipment was removed.

2.3.1. Sensor Data Analysis Procedures

The goal of analysis of sensor data (i.e., GPS, winch activity and hydraulics pressure) was to determine the overall quality of fishing trip data and identify time and location for the start and end of setting and hauling. The sensor data usually arrived in a zip file delivered from the field via email. The data were extracted to a trip folder and an MS-Access application was used for processing. There were seven steps carried out to process the data. The entire analysis and data display process could be completed in a few hours.

- *Importing Data Source* - Sensor data (in ASCII text format) were imported in to the MS-Access application for processing.

- *Processing* - The data were processed to produce relevant information, such as set and haul times, position, and speed of the vessel. A database was created to display the summarized information.

- *Export Data Files* – Data files were produced for exporting to graphics and GIS programs in order to display key sensor data in space and time (Figure 3).

- *GPS Data Quality Reports* – The data set was analyzed to evaluate the quality of GPS data and identify system time gaps. These reports were used to determine if the position information was reliable and if there were any instances where the EM system was not powered.

- *Fishing Activity Compilation* - A table was created based on threshold parameter settings to estimate setting and hauling activities. These same parameters were used in the GIS plots to highlight the setting and hauling activity. The sets and hauls were confirmed, and corrected if necessary, using information from the GIS cruise track and time series graphs. Set and haul events in the data set were also corroborated using data from observers or the fishing logbook, if available. These haul times were provided to the technician conducting the image viewing.

- *Apply Depth Information* – The depth associated with set and hauling locations was obtained by referencing the nearest position in an electronic depth data file obtained from NDI, a supplier of Canadian hydrographical charts in electronic format.

- *Generate Header Records* – Information describing the time, location, and depth of setting and retrieval, also known as header information, were generated for each set event and linked to catch data table. The catch data were then in a deliverable format comparable to at-sea catch data.

2.3.2. Image Data Analysis Procedures

Image data from fishing trips were processed by project staff either in Victoria or in Prince Rupert. At the beginning of the season, all image analysis involved a paper process of recording catch and empty hooks. Generally, tallying species and utilization (i.e., discarded or retained) with a simple tick box form was used, although on fishing trips where the observer recorded catch serially by hook, it was necessary for the EM analysis to record catch in the same manner (i.e., in sequential order). Forms were set up with boxes to record species code, utilization code, or a line through the box to indicate an empty hook. Victoria project staff processed all paper forms by data entry, either in summary format (i.e., species totals by utilization for a set), or in serial catch order.

Later in the season (June in Victoria and September in Prince Rupert) the paper form process was replaced with direct data entry into an MS-Access application. As well, hardware changes were made to display the video information on the computer screen, adjacent to the MS-Access catch logging application, and control the video play from the keyboard. With these changes, the data entry process improved significantly as the viewer no longer had to move their eyes from the screen to the paper and all data entry and frame display control occurred at the keyboard.

Video image analysis included the following steps:

- Assess overall quality of imagery in terms of the following categories:
    - *Usable Imagery* – Imagery was considered usable if the groundline was in the field of view for the entire retrieval duration, and did not necessarily depend on image quality. Usable imagery was further assessed by the following sub-categories:
        - *High* –High quality imagery with no viewing difficulties.
        - *Medium* – Image is slightly out of focus, or the view sometimes obstructed by sun glare or water drops on camera dome.
        - *Low* – Retrieval imagery is difficult to interpret due to various reasons including major groundline tangles, broken groundline, poor lighting, and very poor picture quality.
    - *Unusable Imagery* – Imagery was not considered usable if the groundline was not in view for the full retrieval period. Reasons for this could be the groundline moving out of the field of view, low light levels, or loss of EM power. The viewer determined at which point these conditions warranted the removal of the imagery from the data set. For example, a set, originally categorized as poor quality due to low light levels, may have such reduced light levels that the viewer was only able to see indistinguishable forms. This set would then be considered unusable. Since EM catch data was compared with observer catch data in this study, incomplete enumeration rendered the comparison meaningless. Thus, stringent criteria were necessary in determining usable and unusable imagery.
- Examine activities on the fishing deck to understand how fish are handled, in order to distinguish kept from discarded fish.
- Verify the time and location associated for set and retrieval events as determined from the sensor data analysis,
- Observe the retrieval process and, with specific reference to hook order, record empty hooks and all catch items, including fish, invertebrates and seabirds. Catch items were identified to species, if possible, or to taxonomic groupings. Utilization (i.e., kept or discarded) was recorded for all catch items.

A pool of about six staff carried out the video analysis. The following procedures were used to ensure quality control of image interpretations:

- Use certified dockside or at-sea observers with experience in groundfish species identification,

- Minimize the total number of staff involved with image data analysis,

- New staff reviewed reference material for developing species recognition ability,

- The consistency of image interpretations was verified by repeat analysis of retrieval imagery using a second viewer. The target for repeat sampling was one retrieval operation randomly selected per trip.

2.4. AT-SEA OBSERVER PROGRAM

The at-sea observer program provided observers for a number of fishing trips where EM equipment was deployed. The purpose of dual observer-EM monitoring was to create a set of paired observations to compare the methods, with particular attention to species identification. The regular duties of the observer that did not overlap with EM requirements included:

- Measuring all (or a sub-sample of) halibut intended for discard,

- Weighing all (or a sub-sample of) by-catch and indicating whether by-catch was to be used as bait,

- Counting the number of deployed and retrieved hooks, and

- Documenting seabird interactions, the use of seabird avoidance devices, and retention of any dead seabirds, if caught.

During trips where EM equipment was also on board, observers were to provide the following:

- During about half of the retrieval operations, observers were to observe the retrieval process and, with specific reference to hook order, record empty hooks and all catch items, including fish, invertebrates and seabirds. Other information was also recorded including tangled or damaged gear. The at-sea observer program independently developed forms with one hundred hooks per page. The observer found an appropriate spot on deck where the catch could be viewed during groundline retrieval.

- During the remaining retrieval operations, observers were to enumerate all catch items, including fish, invertebrates and seabirds, without specific reference to hook order.

- On all observed sets, catch items were identified to species, if possible, or to taxonomic groupings. Utilization (i.e., kept or discarded) was recorded for all catch items.

It was necessary for the observer to perform visual estimates of halibut lengths and by-catch weights during the sets when serial hook data were recorded. Other observer duties were not compromised and observers generally felt they could record catch in serial order of retrieval without feeling overwhelmed. There was some attempt made by the observer to indicate what string was being hauled or hook number intervals for alignment checks with the viewer. A clipboard with haul information (data, time, string #) was placed in camera view at the start of a hauling event. For hook number intervals (e.g., every 25 hooks) a hand or flag was waved in front of the camera. Both of these procedures were abandoned, as it was not possible for the viewer to read the clipboard or see the hand.

2.5. ALIGNMENT OF EM AND AT SEA CATCH DATA

Fishing trips with combined EM and at-sea monitoring produced parallel catch data sets of which about 50% were fishing sets with catch recorded in serial order of retrieval. In order to compare EM species identifications with those by the at-sea observer, it was necessary to couple the observer data set with that of the data interpreted from video imagery. Data alignment procedures were developed to position the EM and observer identification on the same record for comparison. These procedures are outlined in Section 3.2.3.

2.6. VIDEO CORROBORATION

Upon completion of the alignment process with observer and EM data sets, it became evident that further information was needed to determine why misalignment occurred. We randomly selected a sample of twenty-one retrieval operations where imagery was still available in order to review the imagery with the record of alignment changes made for that data set. The imagery was reviewed to determine the source of the misalignment, if possible. Each instance of misalignment was examined to determine the error source (EM, observer, or unknown) and a reason for the error.

3. RESULTS

3.1. EM PROGRAM OPERATIONS

3.1.1. Overall EM Deployment Summary

The EM system deployments conducted for this project are summarized in Table 1. During the period from the start of the halibut fishery (March 15th) to the end of October, there were a total of 59 fishing trips, involving 19 fishing vessels where EM equipment was deployed. On average, there were about 7.5 fishing trips monitored by EM per month. This amounted to a total of 1,062 fishing sets where EM was used. Usable data (i.e., the groundline was in the field of view for the entire retrieval duration) were available from 697 fishing sets, or about 66% of the total sets. The reasons for unusable data from certain electronic monitoring sets are discussed in Section 3.1.2. Among the usable sets, 64% were considered high quality imagery, 30% were medium quality, and about 6% were considered low quality imagery.

3.1.1.1. EM Data Treatments

The EM data for fishing sets were divided into the following three treatments:

- *EM Only* - Sets where EM was deployed without a concurrent observer totalled 306, or 44% of the total usable sets. EM trips without an observer were made on 15 fishing vessels for a total of 29 trips.

- *EM/Observer by Hook* – This category included sets from fishing trips where both EM and an observer were deployed and catch items were recorded in serial order of retrieval. The observer and EM data sets were independent of one another, enabling an identification of each item of catch. There were a total of 176 usable sets in this treatment, or 25% of the total usable sets. These data came from 26 fishing trips involving 12 fishing vessels. Nineteen observers were involved in the collection of these data, of which 15 completed one trip, 2 completed two trips, 1 completed three trips, and 1 completed four trips. Their experience ranged from 42 to 986 sea days with a median experience level of 237 days at sea.

- *EM/Observer by Set* – This category included sets from fishing trips where both EM and an observer were deployed, but sets where catch was not recorded in serial order of retrieval. In this category where catch was simply summarized by set, there were 215 sets, or 31% of the total usable sets. These data came from the same number of trips and vessels as the previous category. As the EM/Observer by Hook could also be rolled up to set level resolution, the EM/Observer by Sets treatment totalled 391, or 56% of the usable sets.

3.1.1.2. Temporal Distribution of Data

The EM deployments are summarized monthly in Figure 4. The monthly number of fishing sets ranged from 140 to 190, except for the months of March and October. The proportion of usable sets, however, ranged between 75 and 160 if March and October are excluded.

The monthly volume of EM data for the three treatments is shown in Figure 5. The two categories with observers maintained a relatively constant level for every month except July and October where there were no observer deployments. EM sets without an observer showed greater monthly fluctuations. All trips in March had observers and none had observers in July.

3.1.1.3. Spatial Distribution of EM Sets

The location of EM sets was examined by comparing the general distribution of sets by the three treatments. The set locations encompassed the entire British Columbia coast and were concentrated in traditional halibut fishing areas. The EM-only sets appeared to more strongly represent Hecate Strait and eastern Dixon Entrance areas as compared to the EM/Observer sets. There were also some EM/Observer fishing trips where the target was for species such as rockfish and sablefish, while EM-only trips were primarily for halibut.

3.1.2. Technical and Operational Challenges

As mentioned in the previous section, about one-third of all EM sets were not usable for data analysis. There are several reasons for this primarily owing to the newness of the program for both program staff and participants in the fishing fleet. Out of the total fishing trips where EM equipment was deployed, 43% operated successfully without any lost data, 37% experienced some loss of data and the remaining 20% were trips with no usable data at all. The general reasons for lost data were as follows:

- *Start-up Issues* – Many EM deployments failed because of the lack of experience with the fleet to determine the best EM set-up approaches. For example, the initial location and lens settings for cameras required some experimentation to ensure the best view of the groundline for a variety of weather conditions. As experience was gained with the fleet it was possible to establish more successful system configurations.

- *Configuration Change Issues* – As the season progressed, changes were made to the EM programming and set up in order to improve performance and data quality. Transitioning to the newer configuration resulted in a new set of issues that could influence data capture performance. For example, in early August the EM system was programmed to record imagery triggered by hydraulic pressure. Some experimentation with the threshold pressure and timeout duration settings was required to ensure reliable image capture.

- *Set-Up Error* – There were also problems with the installation of the EM system for various reasons such as of lack of time, inadequate testing, incorrect placement of components, vessel personnel not being available for advice and system testing, etc. EM technician experience was also a factor, particularly in Port Hardy where the volume of EM installations was low. Staff in Prince Rupert has more dedicated EM service activity primarily because of the large volume of EM work with the crab fishery.

- *Equipment Error* – There were a few instances where the EM equipment failed to operate properly. These problems were more frequent early in the study.

- *Power Issues* – The EM system requires a power source that both supplied threshold amperage and accommodated peak amperage draws at EM system start-up. Some vessels had older batteries or other high current demands on their electrical system making power less stable. These problems were not always evident during EM set up.

- *Vessel Interference* – While the EM system was fully automated, some skippers preferred to manually power the system up for retrieval operations. This resulted in missed data when the skipper forgot to turn the system on and also made it more difficult to interpret the overall data set (e.g., set locations and retrieval order).

3.1.3. Limitations of the EM System

The EM equipment operated successfully on a wide variety of vessel sizes and configurations. Certain circumstances, however, would require specific modification for successful operation:

- *Camera Mounting Location* – The best position for the cameras was on the stabilizer pole, providing a side view of the fishing vessel retrieval area. Some fishing vessels did not have stabilizer poles or were sufficiently large that the stabilizer poles did not provide a good view of the retrieval area. Vessels with this configuration represented a small component of the halibut fleet but would need a custom camera configuration.

- *Electrical Power* – The supply of electrical power was a problem on some fishing vessels. The problem was usually the lack of stable power as opposed to not having enough power and was often the result of improper electrical system design or layout. The remedy for this problem would be to either repair the vessel electrical system or install an uninterruptible power supply (UPS) along with the EM system. This later option was not done in this study as such a UPS system for marine application is more complex than the UPS devices used for standard household 110 AC power applications.

- *Lighting* – Most of the fishing activity witnessed by the EM systems was during daylight hours. Early in the season, imagery of night fishing was captured and evaluated. The cameras used for this study have threshold light sensitivity at about 0.8 lux. Essentially, the camera is light sensitive to about the same level as the human eye. At low light levels the colour fades to black and white. Thus, supplemental lighting of the retrieval area would be necessary at night to ensure colour resolution. This customization would not be difficult for vessels planning to fish at night.

3.1.4. Fleet Refusals

As mentioned previously, deployment of EM equipment on the fleet was voluntary. PHMA produced a vessel contact list of potential participants for the EM program. Vessels from this list were asked whether they would be interested in taking an EM system aboard. As well, other owners and skippers were either contacted directly, or asked upon hailing in, or contacted in person on the dock. At the start of the season, interest was high and it was not difficult to find vessels willing to take equipment. By July however, finding volunteers became more difficult. Starting in August and for the balance of the season, a more concerted effort had to be made by program staff. The reasons for the refusals can be categorized as follows:

- *Opposed to Monitoring* – Many halibut fishermen objected to DFO's requirements for at-sea monitoring and were not willing to voluntarily cooperate with either observer or EM. This was the strongest view by far.

- *Opposed to EM* – Some halibut fishermen were not opposed to at-sea monitoring by observers but felt EM was intrusive. The primary reason was the camera surveillance. Some of these views may have been based on incorrect knowledge of when and where camera imagery was recorded.

Of the 103 vessels contacted, 51 declined to participate. Most did not provide a reason; however five vessel skippers or owners indicated that they might participate next year, two vessels cited power concerns, one privacy concerns, one was not planning to fish (leasing out quota) and two had logistical problems that prevented participation. There were also nine vessels that did not have enough quota left to participate, but expressed interest in participating next year. There were 24 vessels that initially expressed interest in participating in the EM program, but contact could not be re-established to make final arrangements to place a system on board. The remaining 19 vessels had EM systems installed at some point during the fishing season.

3.2. ANALYSIS OPERATIONS

3.2.1. Sensor Data

The time required to analyze an individual fishing trip depended on the number days of fishing, number of fishing events, the fishing locations (all in one spot or spread out over a different fishing grounds), and weather (interruption of hauling activity leading to hydraulic pressure fluctuations). Some sensor data problems affected the analysis process:

- *Incomplete Sensor Data* - The winch sensor and hydraulic transducer were necessary to detect setting and hauling activity and, when working properly, the start and end positions for setting and hauling could be generated automatically. If either of these sensors were not available (either there was no winch on board or the sensors were not performing properly) setting and hauling activity could still be determined from vessel speed and position data although this process was much more time consuming and required manual interpretation of the GIS cruise track plot.

- *Vessel Did Not Turn Power On For All Fishing Events* - Some vessels turned the EM unit on after arriving on the fishing grounds or after harbour time. Sometimes it was turned on for the first hauling event and thereby not capturing the first few setting events. This made it very difficult to determine the set/haul order when some fishing events (usually setting events) were not all captured.

Interpretation of the sensor data could be reduced using observer or the fishing log information to reference the number of fishing events and set and haul order. It is important to note that the information from these sources was not used to replace EM data, but only to assist in zeroing in on the time and location to examine in the electronic data set. The average amount of time for analysis of sensor data for a trip with complete data and good fishing conditions ranged from one to three hours. As the anomalies in data sets increased, so also did the analysis time.

3.2.2. Video Data

The 697 EM sets amounted to a total of 1,044 hours of retrieval imagery. This imagery was analyzed in 815 hours, an analysis to real time ratio of 0.78. On a set-by-set basis this ratio ranged from 0.25 (i.e., 15 minutes to analyze one hour of imagery) to 2.4 (Figure 6) with over 80% of the sets analyzed with a ratio of less than 1.0 (i.e., the same time as real time). Poor video image quality increased reviewing time because it made species identification more difficult. Empty hooks were also harder to detect when image quality was low. Sets with higher species diversity also increased analysis time as viewers required more time to examine and identify species, particularly the red-coloured rockfish (*Sebastes* spp.).

3.2.3. EM/Observer by Hook Data Alignment

There were 289 EM/Observer by Hook sets where catch data recorded by observers and EM could be compared. The two data sets almost never matched up hook for hook without alignment. Various reasons that accounted for the two data sets not aligning exactly are described in Section 3.2.4.

Alignment was forced by copying each data set to the same spreadsheet where row adjustments in one data set could be made without displacing the order of the other. Changes made in the data sets were of two categories: removal or addition of an empty hook, and changing the order for two or more hooks. Alignment was not an arbitrary process and no records of catch were added, deleted, or modified. Without alignment, the two data sets almost never matched up, resulting in very few true-paired EM-observer observations. For example, in the unaligned data set, a catch item such as a halibut lining up with a blank hook represented a meaningless catch pair. The alignment process primarily consisted of adjusting the number of empty hooks to align the obvious catch patterns, thus creating meaningful catch pairs. A less common alignment procedure involved changing the catch order to bring obvious pairs into alignment. For example both observer and EM may record three halibut and a rockfish, but in different order. Changing the order to align the two sets was justified, as we would not expect either EM or an observer to confuse a halibut for a rockfish. Order changes occurred within a small cluster of records (typically less than four) and only occurred with species that were grossly different such as flatfish, rockfish, skates, sharks, etc.

For consistency, adjustments were generally made to the at-sea observer data records. There were a few occasions when corrections to the EM side were necessary; as when the

EM viewer missed a fish in the middle of a group of fish, and an empty space was inserted to compensate.

An example of data set alignment is shown in Figure 7, with Part A showing the raw data sets and Part B showing the data sets aligned and change codes applied. The process simply brought obvious patterns of catch order into alignment. In order to keep track of changes made during the alignment process, alignment changes noted the number of records changed and the type of change using the following edit categories:

- *Missed Hook* - In many instances, the data sets are otherwise in alignment except for being offset due to missing empty hooks. If the missing hook was on the observer side, a hook was added to the observer side. If the reverse was true, a hook was removed from the observer side.

- *Missed Fish* - In some instances the data sets would otherwise be aligned except for a missed catch item from either observer or EM side. If the catch item was recorded by the observer but not EM, a hook was removed from the observer side. If the reverse was true, a hook was added to the observer side. The result was a catch item paired with an empty hook.

- *Order Change* - When the data sets were otherwise aligned except for the order of adjacent catch, or empty hooks with catch items, the order of the hooks was changed to align the catch items. Re-ordering of catch was only carried out over a small number of records, with obvious groupings such as rockfish and flatfish that would not be mistaken for one another.

Two common factors that influenced the complexity involved with the alignment process were the total number of hooks per set and groundline tangles. The hook count varied from just over a hundred hooks to over eleven hundred hooks. Tangles resulted in a different fish order and number of empty hooks that required adjustment. The time required aligning these sets ranged from two minutes to approximately 45 minutes. In some cases, the alignment process identified data entry errors, which were investigated and corrected.

In the 289 sets of EM/Observer by Hook treatment, there were a total of 92,363 records, within which 7,521 alignment changes were made, or 8% of the total records. The changes made are summarized in Table 2. The most common alignment change made was the addition or removal of an empty hook (82%) followed by order change (14%) and missed fish (4%).

3.2.4. Video Corroboration

After the alignment of EM/Observer by Hook treatment sets was completed, imagery from certain sets was re-examined in order to better understand why misalignment occurred. Imagery from a total of twenty-one sets from seven different observed trips was re-examined. These sets were selected from trips where the imagery was still available for viewing, as normally, the imagery was deleted after analysis and the hard drive prepared for another EM deployment. The twenty-one sets represented a total

11,203 records, or about 12% of the total aligned data. Within this sample there were 1,172 discrepancies identified between observer and EM data sets. Following re-examination of the imagery the discrepancies were identified by category of error, source of error (i.e., observer, EM, or unknown) and reason why the error occurred, if evident. The results from this analysis are presented in Table 3, with errors summarized by the following categories:

- *Hook* - The observer or the EM analyst either missed an empty hook and nothing was recorded, or erroneously observed and recorded an extra empty hook. Error in counting hooks accounted for 60% of the total errors and most (60%) of these errors were by the observer.

- *Misidentification* - About 14% of the errors were the result of a misidentification by either the observer or the EM analyst. Both observer and EM showed similar levels of misidentification, although 25% of the misidentifications could not be attributed to source.

- *General Identification* – About 10% of Species identifications by the observer and the EM analyst did not agree as a result of one providing a more general identification (e.g., flatfish instead of halibut) than the other. The EM analyst was about three times more likely to provide general identification that the observer.

- *Missed Fish* - Either the observer or the EM analyst missed a catch item. There were only 65 cases where a fish was missed and the observer error was about three times that of EM.

- *Fish/Empty Hook* - Either the observer or the EM analyst did not see a catch item and recorded an empty hook in its place. This error category represented about 6% of the errors, with EM slightly higher than the observer.

- *Order* - The order of recorded catch items does not agree between the observer and the EM analyst. This occurred in three percent of the errors with the observer error nearly twice that of EM.

An attempt was made to categorise the errors by the possible reason. In nearly 80% of the cases the reason for the error was not evident, while in the remaining cases the following causes were apparent:

- *Groundline Tangle* - About 10% of the errors were due to groundline tangle, where the serial order of hooks was not clearly evident. It was not possible to attribute error to source for about 60% of these events and among those where error could be attributed, observer and EM were roughly equivalent.

- *Poor or No Image* - In some instances (5.3%) the image was not sufficiently clear to distinguish activities and these problems were primarily attributed to EM.

- *Fell Off Early* – Catch items occasionally fall off as they leave the water making their recognition difficult. This occurred in 2% of the errors with EM being slightly higher than the observer and a quarter of the errors not attributable to source.

- *Close Spacing* - In a few instances the gangion snaps were closely spaced on retrieval and it was difficult to discern retrieval order. These instances accounted for only 1% of the errors and the incidence by observer and EM were approximately equal.

- *Data Processing Error* - Errors as a result of data processing were a small part of the errors identified. The process for coding observations and transferring these data into electronic format were different between EM and observers, resulting in some process related errors.

- *Video Problems* – In a few instances (0.4% of errors) there were vide recording problems that resulted in no imagery.

Overall, observer-based errors accounted for about half the total errors, while EM-based errors totalled 38%. About 11% of the total errors were not attributable to either EM or observer. In 80% of the errors, it was not possible to determine the reason for the error. Groundline tangles were the most common reason for observer error and poor quality or missing imagery was most commonly the reason for EM errors.

3.3. Electronic Monitoring Data

3.3.1. All EM Data Combined

The catch totals for all EM deployments are summarized in Table 4a and 4b, showing the recorded catch by EM Only and EM/Observer treatments separately. Catch estimates by the observer for the EM/Observer Treatment are also presented in Table 4a and 4b to provide a complete listing of species encountered in the study. As previously mentioned, the EM data were from 59 fishing trips over the duration of the fishing season for a total of 697 sets. This fishing activity consisted of about 347,000 hooks of which about a third of the hooks were populated with catch. Excluding unidentified categories, there were 53 species or taxonomic groupings of fish, invertebrates and seabirds, the former usually identified to species level and the latter two mostly identified to a more general taxonomic level. The ten most abundant species accounted for nearly 93% of the catch while the thirty least abundant species made up less than 0.5% of the catch. Specific observations for catch groups follow, while a comparison of EM and observer catch results is presented in the next section.

- *Rockfish* - Rockfish accounted for 23% of the total EM catch with 20 species identified and two aggregate groupings (i.e., unidentified rockfish and rougheye/shortraker rockfish). Most catch identifications were to a species level and about 6% were by aggregate groupings. Unidentified rockfish accounted for about 5% of the total rockfish catch. Four rockfish species, redbanded, rougheye, yelloweye, and shortspine thornyhead, accounted for nearly three quarters of the rockfish catch. Ten of the least common species accounted for less than 1% of the total rockfish catch. Catches of quillback, copper, tiger, and yelloweye rockfish were disproportionately higher while redbanded, rougheye and shortraker rockfish were disproportionately lower in the EM Only treatment. China rockfish was only present in the EM Only treatment.

- *Flatfish* - Overall, there were six flatfish species identified, representing 42% of the total EM catch with halibut making up over 86% of the flatfish. Arrowtooth flounder were the next most common, comprising about 12% of the flatfish. Unidentified flatfish made up 0.1% of the catch identifications.

- *Elasmobranchs* - There were ten species or taxonomic groups identified and elasmobranches collectively represented about 12% of the total catch recorded by EM. Two species, longnose skate and spiny dogfish made up over 85% of the catch in this category. General groupings of unidentified shark and unidentified skate made up less than 2% of the catch identifications in this category. Catches of big skate, sandpaper, starry skate, ratfish, and spiny dogfish were disproportionately higher in the EM-Only treatment.

- *Other Fish* - Other fish species made up about 22% of the catch items with sablefish accounting for about 80% of the catch, followed by lingcod at 12%. Unidentified fish accounted for about 2% of the other fish catch. Catches of Pacific cod were disproportionately higher while sablefish and grenadiers were disproportionately lower in the EM Only treatment. Kelp greenling was not present in the EM/Observer treatments.

- *Invertebrates* - Invertebrates made up a small percentage (0.4%) of the EM catch and were usually recorded to a more general taxonomic category than fish. Echinoderms, consisting almost entirely of starfish, were the most common.

- *Seabirds* - There were four takes of seabirds recorded in the EM data set. The EM analyst identified three as black-footed albatross and one as a cormorant although subsequent re-examination of the latter confirmed this also to be a black-footed albatross.

3.3.2. EM/Observer By Set Catch Data

3.3.2.1. Comparison of EM and Observer Catch – Overall Totals

There were 30 fishing trips with both EM equipment and at-sea observers on board with catch data enumerated from 391 usable sets (Table 1). The results of the summarized catch data are presented in Table 5a and 5b and the percent difference (relative to the observer estimate) is calculated for all catch categories where the EM and observer counts each exceeded 20 pieces. The species are grouped by general catch category as in Table 4, with further sub-grouping of categories by morphologically similar species. In particular, rockfish were divided into six sub-groupings of species that are similar in size, shape and colour pattern (sub-groupings were developed with the advice of the species identification trainer for Archipelago's at-sea observer program). Excluding unidentified categories, the observer data set distinguished 56 species, with seven species not recorded by EM, while EM recorded 49 species of which six were not recorded in the observer data set. Among the unidentified categories (e.g., unidentified rockfish, flatfish, etc.) or more general identifications (e.g., rougheye/shortraker) there were 1,754 EM records versus 76 observer records. These more general identifications represented 2.3% and 0.1% of the EM and observer catch records, respectively. Twenty-three species had catch totals greater than 20 pieces for EM and observer. These species represented 99.7% of the total fish catch and EM and observer catch totals were within 5% for 9 species, 5% to 10% for 5 species, 10% to 15% for 4 species and the remaining 5 species ranging from 20 to 60%. More specific details are presented by catch category below.

- *Rockfish* - EM and observer totals for rockfish were within 3% for all species combined and the totals by morphological sub-groupings ranged between 2% and 6%. Among individual species, level of agreement ranged from 2% (quillback rockfish) to 60% (rosethorn rockfish). Among the eleven species compared, seven had EM and observer catch totals within 10% and made up 83% of the rockfish catch. Shortraker rockfish accounted for 13% of the rockfish catch and there was poor agreement between EM and observer data sets (45%). Among the three remaining species where totals were compared, agreement between EM and observer was lower: canary (14%), shortraker (45%), yellowmouth (53%), and rosethorn rockfish (60%). Sample sizes for twelve species were inadequate for this comparison.

- *Flatfish* - Overall, EM and observer catch totals for flatfish were less than 1.5%, with individual species comparisons between 4% (halibut) and 42% (petrale sole). The morphological sub-groups of halibut and arrowtooth flounder had much higher level of agreement (1.4%) than either of these two species separately (4% and 14%, respectively). The morphological sub-group for more round shaped flatfish had poor agreement (40%). Sample sizes in three of the seven flatfish species were insufficient to compare EM and observer totals.

- *Elasmobranchs* - Catch totals for elasmobranches were within 8% for sharks, 5% for skates and 7% overall. Among individual species, four dominant species making up 94% of the elasmobranch catch had high levels of agreement: spiny dogfish (8%), longnose skate (5%), sandpaper skate (5%) and ratfish (4%). Big skate was also common (4%) in this group and agreement was lower (15%). Catches of seven species were too low to compare catch totals.

- *Other Fish* - Among the twelve species recorded in the other fish category, species catch comparisons were made for only four. Agreement was high for the numerically dominant species sablefish (3%) and lingcod (7%), and moderate for Pacific cod (14%) and grenadier (22%). Among all species combined the EM and observer catch totals were within 5%.

- *Invertebrates* - Out of the ten species recorded by EM and observer recorded only one, echinoderms, was sufficient to compare catch totals. The level of agreement was low with the EM total nearly half that of the observer. Also interesting was the large difference in the gastropod count: EM reported none while the observer recorded 113. There are two possible reasons for these results: the catch item was shaken off the hook before leaving the water or the catch item being too small and being mistaken for bait remaining on the hook.

- *Seabirds* - While there were four takes of seabirds recorded in the EM data set only one was from the EM/Observer treatment. In the original assessment, the EM analyst identified the single seabird take as being a cormorant although subsequent re-examination confirmed this to be a black-footed albatross.

3.3.2.2. Comparison of EM and Observer Catch –Totals by Set

Catch was grouped by species and totalled by set to compare EM and observer estimates. Table 6 provides a summary of all species recorded by the observer for the EM/Observer by Set treatment, showing the observer catch estimate and the number of sets where the species was present. As in Table 5, the species are grouped by general catch with further sub-grouping of categories by morphologically similar species. Where sample size (i.e., number of sets) was greater than 20, correlation coefficients, slope and intercept values were calculated (Table 6). A slope of one, an r^2 of one, and a y-intercept of zero would occur when EM and observer catch data exactly agreed. Scatter plots were also prepared for species where correlations were calcualted, showing EM and observer set totals (Figure 8-11). The plots show the relative distribution of EM and observer catch values, along with distribution patterns of bias, precision, and accuracy. Those species with high agreement between EM and observer catch totals show data points tightly distributed along the line showing the 1:1 relationship.

The level of correlation was high for general catch categories with r^2 values of 0.94, for all catch, 0.96 for all fish, 0.99 for rockfish, 0.99 for sharks, 0.95 for skates, 0.96 for flatfish, and 0.99 for other fish. Correlation among invertebrates was low (0.38), reflecting the lower EM detection level mentioned previously. Among the twenty most common species, nine were highly correlated ($r^2 > 0.90$), five were moderately correlated ($0.70 > r^2 > 0.90$) and six were poorly correlated ($r^2 < 0.70$). Shortraker rockfish was poorly correlated (r^2=0.52) between EM and observer estimates and, when combined with rougheye rockfish, the correlation was high (r^2=0.98). Comparison of catch by species sub groupings improved correlation with rougheye and shortraker rockfish (0.98), but had relatively little effect on other sub groups.

Many species recorded by the observer were infrequent, with only a few per set and in a small number of sets. Among species that occurred on more than twenty sets, correlation between EM and observer estimates was generally poor. This was evident with species such as Pacific Ocean perch, boccacio rockfish, rosethorn rockfish, greenstriped rockfish, sandpaper skate, big skate, petrale sole, and pacific cod. Twenty-three fish species occurred in less than twenty sets and most averaged less than a few pieces per set.

3.3.3. EM/Observer by Hook Catch Data

3.3.3.1. Description of Data Set

About half the sets on fishing trips with both EM and observers provided independent catch information serially by hook. As mentioned previously, data from EM/Observer by hook treatment were from 13 different fishing vessels on 30 fishing trips over a five-month period. In total there were 289 sets, which, after alignment, amounted to about 92,000 paired records of observation by hook (Table 7). About 65% of the records were of empty hooks, while the balance had either catch recorded by both observer and EM (33%), or catch reported by observer and not EM (0.7%), or the reverse (0.7%). Among the records containing catch, 88% were in agreement on species identification, about 8% were not in agreement, and 4% had catch paired with an empty hook. Including only those records where both recorded a catch item, EM and observer identifications matched in 92% of the cases.

Catch that was paired with empty hooks amounted to 1.4% of the total records with EM and observers each having about the same incidence of catch paired with an empty hook. Breaking these data down by species indicated similar levels between observer and EM for most species, and all representing a small percentage of the total species occurrence rate. While the reason for the camera to record a fish but not the observer is likely due to an observer not seeing the fish, the reverse may be due to a few reasons. In some cases, a fish was missed because the image quality was poor, or two hooks with came up together and one fish was not visible, or the groundline was tangled and fish was not visible. In other cases, particularly in relation to gear tangles, the catch could not be properly ordered and re-ordering of catch pairs in the alignment process was only carried out in obvious, closely grouped, cases.

3.3.3.2. Level of Species Identification by EM

One of the main goals of this project was to measure the ability of EM to identify various species of groundfish that commonly occur in the halibut fishery. The EM observer serial catch record provided the best means to do this with paired observations by EM and the observer. In order to measure identification rates, we assumed that the observer identification was the pragmatic choice for the benchmark to which the EM identification could be compared. In this analysis we have included only those records where there was a catch pair and where the observer identification was to species. Records with an empty hook paired with a catch observation were not included, as they did not represent a true identification comparison.

The results for identification comparisons are presented in Table 8, with species grouped by category, the percent of records where the EM identification matched the observer identification and the sample size (number of records) by species and species category. Ignoring the records where the observer could not identify the species (59), the number of records with paired identifications was 31,412. Including only these records, 94% of identifications made by observers and EM matched. Over 98% of the EM identifications matched the observer to the level of general taxonomic category, although the identification values for individual species varied considerably. Histograms in Figures 12 to 17 provide additional information for the more abundant species, showing the EM identification profiles for the species identified by the observer.

Rockfish

In total, rockfish accounted for 24% of the 31,412 paired identification comparisons in the serial catch data set. The observer recorded sixteen species although seven species were infrequent and, when combined, made up 1% of the total rockfish catch. Except for shortraker rockfish, correct identifications of the seven most common species by EM was between 84% and 95%. The remaining species had identification rates between 0 and 67%. Among all rockfish species combined, matching identifications by EM and the observer occurred in 80% of the cases. Combining rougheye and shortraker rockfish, the percentage of EM and observer matching rockfish identifications increases to 87%. The following are species-specific results, which are also reported in Figures 14 and 15.

- *Rougheye Rockfish* – Rougheye rockfish was the most common rockfish species, accounting for 35% of the rockfish, and was the third most common species in the EM/Observer by Hook data set. EM identifications matched the observer in 91% of the cases. Other EM identifications were at trace levels from eight species or species categories.

- *Shortraker Rockfish* – Shortraker rockfish ranked third among rockfish catch (11.2%). Matching identifications occurred in 34% of the records, with rougheye rockfish being the most common category for this species (46%). Rougheye rockfish is very difficult to identify, even for an observer, without close inspection. It is possible that some of the mismatching could also be due to observer error.

- *Rougheye/Shortraker* – When these two species are combined EM identifications matched those of the observer in 91% of the records. The next most significant EM identification category was unidentified rockfish (4%).

- *Redbanded Rockfish* - This species was the second most common rockfish species (23%) in the EM/Observer by Hook data set. Eighty-nine percent of redbanded rockfish identified by the observer were recorded as such by EM. The remaining records were of different species or species groups in trace levels.

- *Shortspine Thornyhead* – EM identifications of shortspine thornyheads matched those of observers 87% of the time. Unknown rockfish and rougheye rockfish accounted for the 10% of the cases where identifications did not match.

- *Quillback Rockfish* – This distinctive species had the highest percentage of matching identifications by EM and observers (95%) among all rockfish. The remaining 5% of the records were either unidentified rockfish or species other than rockfish (denoted as other).

- *Yelloweye Rockfish* - EM identifications matched those of observers in 84% of the records. Unidentified rockfish was the next most common rockfish groups at 9%.

- *Canary Rockfish* - Only about 40% of records matched for this species with yelloweye rockfish (27%) and yellowmouth rockfish (22%) accounting for the majority of other EM identifications.

- *Silvergray Rockfish* - Eighty-seven percent of EM and observer records matched and the most common rockfish species were bocaccio rockfish (4%) and unidentified rockfish (6%).

- *Bocaccio Rockfish* - EM records match observer identifications in only 56% of the records. The most common other species was silvergray rockfish (22%) followed by rougheye (19%).

- *Yellowmouth Rockfish* - This species had the lowest level of agreement (7%) of the rockfish numbering more than 100 pieces. Common EM identifications for yellowmouth rockfish were unknown rockfish (51%), followed by rougheye rockfish (21%) and yelloweye rockfish (8%). Identification agreement with this species likely improved during the year as EM experience improved.

Flatfish

In total, flatfish species accounted for 39% of the 31,412 fish recorded in the EM/Observer by Hook data set. Six species were recorded by the observer, among which halibut and arrowtooth flounder accounted for 99.6% of all flatfish pieces. Overall, 96% of the flatfish records had the same identification by EM and the observer. Identifications for two most abundant flatfish species are reported below and in Figure 16.

- *Halibut* – Halibut was the most numerous species in the data set, accounting for about a third of the total records. This species recorded the highest level of matched identifications (99.1%) among all species in the EM/Observer by Hook data set.

- *Arrowtooth Flounder* - Identifications by EM matched those of the observer in 82% of the records with the most common other flatfish species being halibut (15%). This result was likely due to arrowtooth flounder and small halibut being mistaken for one another.

Elasmobranchs

In total, elasmobranchs accounted for 11% of the 31,412 fish recorded in the EM/Observer by Hook data set. While the observer recorded 14 species, four species (noted below) accounted for 98% of the elasmobranches and spiny dogfish was accounted for most of the catch. Skate species accounted for 3.6% of the EM/Observer by Hook data records, the majority of which was longnose skate. Identifications of broad skate by the observer were more likely sandpaper skate as the former is a deep-water species. Overall, 94% of the elasmobranch records had the same identification by EM and the observer. Identifications for the more abundant elasmobranches are reported below and in Figure 16.

- *Spiny Dogfish* – This species was the fourth most common species overall and had very high levels of agreement (98.4%) between the observer and EM.

- *Longnose Skate* – Ninety-five percent of observer and EM identifications matched for this species. Other EM identification categories used were other (not a skate) and big skate (both 2%).

- *Big Skate* - Only half of the observer identifications of this species match the EM identifications. The majority of other records were either unidentified skate (25%) or longnose skate (19%).

- *Ratfish* - Ratfish accounted for less than 0.5% of the serial catch data set records. The species was fairly distinctive and about 96% of the observer EM identifications matched. Mismatched records were either dogfish (3%) or unidentified.

Other Fish

This general grouping accounted for 23% of the catch in the EM/Observer by Hook data set, of which sablefish accounted for nearly 90%. Combination sablefish-halibut fishing trips in the data set influenced the high level of occurrence for this species. Among the remaining five species in this group, lingcod was the most numerous, followed by Pacific cod and grenadier. Overall, species identifications by EM and observer matched in 98% of the records for this group. EM identification patterns are reported below and in Figure 17.

- *Sablefish* – This easily recognized species showed the second highest identification match (98.9%) of all species in the EM/Observer by Hook data set. The next most common EM identification category was other (0.8%), consisting of mostly dogfish and ratfish.

- *Lingcod* - This species was also quite distinctive, by shape, colour and large mouth size. EM and observer identifications matched in 98% of the records, with sablefish (1%) accounting for much of the balance.

- *Grenadier* – Twenty-five records of this species were in the data set and about 25% of the observer identifications matched those of the EM. EM identified most of the observer grenadier identifications as sablefish (76%). The two species are fairly distinctive and the poor match was probably due EM analyst inexperience with this species (grenadier are not common at offloads).

- *Pacific Cod* – About 60% of the observer Pacific cod identifications matched those of EM with the next most common category being sablefish (30%).

3.3.3.3. Influence of Experience on EM Identifications

As the fishing season progressed several modifications were made to the video analysis process in order to improve accuracy, analysis time, and uniformity between various analyzers. Changes to camera positioning were thought to improve the overall image resolution and quality. As well, preliminary analysis of the EM/Observer by Hook data set in early August provided valuable feedback to the EM analysis process. For example, observer data compared with EM provided a better understanding of where identification problems were occurring. We chose to analyze how these changes may have influenced the frequency of observer and EM identification matching for selected species. The EM/Observer by Hook data set was divided into periods prior to July and after July (there were no EM/Observer deployments in July), which was a natural break in the data set and coincided with the period when many changes occurred. The percentage of observer identifications that matched EM identifications was compared by species for the two periods. Twenty-four of the original species were eliminated, as the numbers were very low or only represented in one of the two periods. We were particularly interested in the result for canary rockfish although all but one of the 94 pieces observed came from

Period 1. The results for the remaining nineteen species are presented in Table 9 and Figure 18.

Among all species combined, the percent of matching observer and EM identifications increased for all species combined decreased by 2%. On a species level however, six showed little or no change (i.e., less than 3%) and twelve species showed increases ranging from 5% to 49%. Most notable among these increases were arrowtooth flounder, which increased from 76 to 94% and shortspine thornyhead, which increased by 11%. Also notable was shortraker rockfish that nearly tripled between the two periods, although the Period 2 result was still low (37%).

Rougheye rockfish, declined significantly (-15%) between Period 1 and 2. The reason is possibly due to the higher level of incorrect rougheye rockfish identifications resulting from trying to distinguish more shortraker rockfish. As well, the higher diversity of rockfish from which these data originated. Period 2 rougheye rockfish data were from ten sets (three fishing trips) where rockfish were targeted.

3.3.3.4. Comparison of Catch by Species and Disposition

The EM/Observer by Hook data were analyzed to determine the level of agreement between EM and observers for the kept and discarded utilization categories. The analysis included only the records where the observer identification was to species and where the EM and observer identifications matched. The resulting data set included about 28,000 records from which the EM species and utilization was compared with that of the observer. The results are summarized in Table 10.

Thirty-one species were included in the analysis of which thirteen had counts of less than 25. Generally, the level of agreement between EM and the observer in determining kept and discard utilization was over 90% for the majority of species. This result could be expected since many species are either usually kept or usually discarded, but not both. However, some species will be kept under certain circumstances depending upon size, area closures, or other factors. Species in this category include halibut, arrowtooth flounder, lingcod, sablefish and skates. The level of agreement between EM and the observer for kept and discard utilizations of these species was greater than 90% in all cases except for longnose skate and big skate (kept) and halibut (discarded). The most likely reason for this result is that fish were brought aboard and sorted later.

3.4. EFFORT DATA COMPONENTS

In addition to catch information, an important goal of the study was to compare fishing effort information obtained by EM sensor analysis with that recorded by the observer. Information including time, location and depth at the start and end of the set and haul was compared using 640 sets from 30 trips from the EM/Observer treatment (both by hook and by set categories). EM and observer data from each of these categories was compared to determine the level of agreement.

- *Date and Time* - Information from the EM GPS unit provided an accurate time base from which to reference vessel fishing activities. Of the 640 set records, 41 were missing from the EM data set due to the vessel powering down the unit during setting events. The remaining set records provided identical dates as those recorded by the observer. Analysis of EM sensor data for set start and finish times was successful for all but 41 missing start times and 12 missing end times. Figure 19(A and B) demonstrate the high correlation of start and end times, respectively between EM and observer data. Some set records are offset by an hour as EM-derived times were Pacific Standard Time while observer times were either standard or daylight savings time.

- *Position* - EM positions for start and end of sets was derived from GPS data. The geometric difference between the EM and observer-recorded positions was calculated and plotted in Figure 20. Over 60% of the EM set positions were within 400 metres of the observer position. A small number of positions (<8%) were over a kilometre apart. The most likely cause for this would be reversed start and end positions by either EM or the observer, or EM system power down. In the latter case, when power is resumed the GPS signal records the previous position (prior to power down) until new coordinates are established.

- *Depth* - Set start and end depths were compared between EM and observer data sets. EM depths were derived from electronic chart data by referencing the nearest depth to an EM-derived position. Figure 21 depicts the correlation between EM and observer-recorded depths. Both start and end depths show a tighter correlation at depths less than 200 metres, with the scatter expanding at greater depths. This would be expected, as depth data are sparser at greater depths. Overall, about 80% of all EM-derived depths were within 50 metres of the observer-recorded depth.

3.5. ELECTRONIC FISHING LOG COMPARISON

A number of skippers were very interested in the electronic fishing log software provided with the EM unit. Over the course of the season software improvements were made based on skipper feedback. Once we were satisfied with the software performance and the skipper's ability to operate the program, data recorded by the skipper were compared with that obtained from EM analysis. Catch data was collected on five vessels for a total of 10 trips and 87 sets. The catch results are summarized in Table 11. Two of the trips (from two different vessels) had no catch data associated with set information. Twelve species in total were recorded in the electronic logs, for a total of 6,923 pieces. The corresponding EM piece total was 6,989 pieces, for a difference of only 0.44%. Rockfish totals differed by 1% and flatfish totals differed by less. Six of the twelve species totals had less than 1% difference. Two species had less than 5% difference and two were between 20% and 22%.

4. DISCUSSION

4.1. OBJECTIVE 1 – TECHNICAL PERFORMANCE EVALUATION

The first objective of the study was to evaluate the technical issues of EM deployment on the halibut fleet. As this was the first large-scale deployment of EM systems in the halibut fishery the study design included making developmental changes, as necessary, with equipment and operational procedures. With ongoing program development as part of the study EM capabilities improved but the evaluation process was more complicated.

In terms of the general goal of sampling about 10% of the fishery, the program achieved only 60% of the targeted amount of fleet sampling. The shortfall was due to the lack of volunteers to take EM equipment. At the beginning of the fishery, all four of the EM systems were in use. By June, the amount of EM systems available ranged from six to fourteen and only briefly was there more than four systems in continuous use. Fleet coverage targets could have been achieved had there been greater participation by the fleet.

In trying to solicit volunteers for deployment of EM equipment, many halibut fishermen declined simply because they did not wish to be monitored by either EM or observers unless required to do so. The voluntary deployment of EM systems hampered program operations. In the future, like the existing observer program, EM would need to become a compulsory requirement if EM were to be used for fleet monitoring. It is unknown if DFO has the authority to impose EM-based monitoring on the fleet although this requirement could be achieved indirectly by requiring an observer, with the option of taking EM equipment. In moving from voluntary to compulsory EM deployments there would also be a need for controls to prevent tampering and misuse of EM equipment. The EM program for the Area A crab fishery, now in its fourth year, ensures effective use of EM equipment through administrative controls managed by the Area A Crab Association. Similar arrangements would need to be developed for the halibut fishery through consultation with the PHMA.

Other than refusals to participate, there were few instances where the EM equipment was not suited to the vessel. Suitability of the EM equipment was demonstrated on a wide variety of vessels in the fleet, including a few fishing vessels not suitable for an observer. However, the voluntary nature of EM-based deployments precluded the ability for a rigorous control in the sample design to ensure representative sampling of various fleet heterogeneities such as vessel size, fishing locations and season. As discussed in Section 3.1.3, limitations to the use of EM on the halibut fishery included: camera mounting locations, for vessels that do not use stabilizer poles; electrical power requirements, for vessels with limited electrical power; and lighting for vessels fishing at night. In our view, these issues would be properly addressed by providing written technical specifications to vessels that require customisations. This would apply to very few vessels in the fleet as few fish at night and most have stabilizer poles and adequate electrical power.

Among the fishing trips where EM was deployed, usable data were successfully obtained for about two-thirds of the fishing trips. The loss of data was disappointing but not an unexpected result, owing to development activities with EM equipment, operating procedures, and the introduction of EM equipment to the fleet. As well, some data loss occurred because only complete sets of imagery were used. The proportion of usable data would have been higher if, for example, we chose to analyse portions of fishing sets. Loss of data with an EM deployment was usually caused by problems with EM installation and set up rather than by technical failure of the EM equipment. Program staff underwent a learning process to get EM equipment installed and operating properly. At the same time, technical changes were being made to improve EM equipment performance. Changes to equipment and associated set up procedures extended the technician learning process. As well, vessel skippers not being available or familiar enough with their vessel also added to set up problems. For example, EM technicians required vessel involvement in the selection of access points for power and hydraulics, locating sensors and wire routing. A letter to all licence holders, sent prior to the start of the fishery, communicated the EM set up requirements, although this was of little benefit to disinterested skippers. Skippers interested in the program found the information useful, and were generally prepared for the EM installation, which generally led to successful EM performance.

Deployment of EM systems on this scale has significantly advanced the technology and operational procedures for the use of EM-based monitoring in the halibut fishery. Changes to the design and configuration of the EM systems improved performance and data quality through the course of the study. As well, greater familiarity with the fleet enabled EM customization to better meet fleet requirements. Experience in operating the program improved technician capabilities and increased the level of understanding by the fleet for the program and its needs. With future EM-based monitoring on the halibut longline fishery we would expect a much higher level of successful deployments (>90%), largely because there are few development related changes required and there is greater familiarity with equipment set-up and installation requirements by both the fleet and program staff. It is noteworthy, that the EM program for the Area A crab fishery, now in its forth year of operation, experienced a data capture rate of 99.6% during over 2,500 fishing vessel days at sea. Such levels may not be attainable in the halibut fishery as EM equipment installation is temporary, whereas it is permanent in the crab fleet.

The main shortcoming of EM field operations was the time required to install and test equipment prior to deployment. Installation time ranged from four to eight hours, depending upon the vessel layout, access to skipper for advice and the level of vessel preparation made in advance of the installation. Once a vessel had been outfitted with EM equipment, subsequent installations required much less time. Consequently, the lengthy time of EM installation will decline as more vessels are outfitted with EM. Installation timesaving may also be achieved with the EM components and how they are fitted to the vessel. For example, the winch sensor used in this study was time consuming to install, and has been replaced with an optical device that is much simpler to install. An important future goal for EM programs will be to continue reducing equipment installation time.

4.2. OBJECTIVE 2 - COMPARISON OF EM AND OBSERVER DATA SETS

The second objective of this study, to compare EM and observer data, was more involved because of the complexity of the data and methodology. It is noteworthy that, while the study provided a relative assessment of EM performance, it does not describe the efficacy of EM for the halibut fishery, as the at-sea monitoring objectives are not precisely defined. DFO should organize a process to define more comprehensively the at-sea monitoring objectives of the fishery, incorporating the needs of science, management, enforcement, and industry, with consideration given to the capabilities of the available monitoring tools, and the potential for observational bias affecting the sampling design. This process would be very beneficial in ensuring that the necessary information is collected in the most effective manner. It should be recognized that objective setting for a fishery monitoring program is ongoing process, building on the new information and adapting to changing user needs and priorities.

The process of objective setting is very important for the development of EM-based programs and provides a framework for determining their suitability for various monitoring applications. While there are limitless solutions for improvement of EM, technology development activities are costly and understanding the specific fishery monitoring requirements guides the process for equipment design, development of operational procedures in the use of the equipment, and development of data analysis procedures.

4.2.1. EM Catch Monitoring - Methodology Considerations

The basic study design to measure the accuracy of EM-based data used observer data as a benchmark. The assumption in this design was that observer data are currently the accepted standard in at-sea monitoring so the evaluation consisted of determining how well EM results would match observer data. However, a key problem was that observer data are not without error. The results of the video corroboration analysis (Table 3), using the video imagery to resolve discrepancies between observer and EM data sets, estimated observer and EM error associated with the EM/Observer by Hook treatment. Among the total sample, observer error level was about 5.2%, EM was 3.9%, and error not attributable to source was 1.1%. As mentioned previously, 60% of the errors were related to hook counts and the balance were catch related issues. Observer error was higher than EM for hook counts and missed fish, misidentifications were equivalent, and EM was almost three times more likely to record species to a more general category than the observer. Among all catch issues combined (i.e., misidentification, more general identification, and missed fish), observer error level was 1.4% for all hooks, or 4.2% for all catch items (i.e., 4.2 errors per 100 catch items), compared with an EM error level of 1.8% for all hooks and 5.2% for catch items. These error levels would probably be considered low for fishery data and the presence of error by both methods complicates evaluation of the EM method. Using observer data as a benchmark for EM data resulted in differences that were not solely due to EM error.

The sequential catch recording procedure in the EM/Observer by Hook treatment probably introduced error that would not normally occur in observer data. Viewing an entire retrieval event, without breaks, would be very tedious for an observer, particularly with long sets and sets with high catch rates. As well, observers could easily miss or double count empty hooks or catch items, as visual contact changed between the groundline and the data form. The irregular speed of groundline hauling, as is normal during retrieval operations, makes it difficult for observers to develop a sense of cadence for viewing and recording. Species identification error was also introduced as identifications were generally made as catch items came out of the water.

The EM/Observer by Set treatment followed the usual observer catch estimation methods, whereby discarded catch was identified and enumerated as it came out of the water and retained catch was identified and enumerated on deck. As compared with the EM/Observer by Hook treatment, this method would probably improve retained catch estimates and provide a poorer estimate of drop off and discarded catch. The EM/Observer by Hook treatment also incorrectly reflected the accuracy of hook counts as observers usually count the racked hooks after the retrieval rather than counting the individual hooks during the retrieval.

We believe that EM image processing was less likely to miss retrieval events for several reasons: viewing speed could be controlled, viewer rest breaks were included to avoid fatigue, and the time-stamped imagery could be replayed to double-check interpretations. As well, the data entry program and the imagery were displayed on the same viewing screen, keeping both within the same field of view. Typically, imagery was viewed rapidly between hooks, slowing to a frame-by-frame scan when a hook or catch item came into view. The quality of imagery in terms of clarity, colour, focus and field of view strongly influenced image interpretation ability. Loss of data from EM analysis was usually the result of close hook spacing, groundline tangles or poor quality imagery.

The video corroboration results probably overestimated the level of observer error associated with hook counts and species identifications and underestimated error associated with drop off and discarded fish. On the EM side, the interpretation method was the same for all treatments (i.e., EM only, EM/Observer by Set and EM/Observer by Hook); thus, the error level identified during the video corroboration would apply to all treatments. Improvements to the technology and analysis procedures made during the course of the project reduced the EM error levels reported in Table 3, in particular hook counts and species identifications.

The necessity to re-align records in the EM/Observer by Hook treatment reflected the imprecision of the data recording method. A criticism of the analysis for the EM/Observer by Hook treatment could be in how observer and EM catch data was aligned. In a total data set of over 92,000 records, it was necessary to re-align about 8% of the records in order to bring the obvious patterns of catch into alignment (Table 2). On first glance, this process may seem like the data were 'adjusted' to obtain an artificial fit. However, without alignment the two data sets almost never matched up, resulting in very few true-paired EM-observer observations. Over 85% of the changes consisted of adding or removing hooks to align the obvious catch patterns, thus creating meaningful catch pairs. Less common (14% of the changes) was re-ordering catch to bring obvious pairs into alignment. In no case were records of catch added, removed or modified from either data set. As well, changes in catch order only occurred with morphologically dissimilar species that would not be mistaken for one another. In our view, the alignment process created a more meaningful pairing of catch items for comparison and was necessary to correct for imprecision of the data collection method.

Future studies involving comparisons of EM and observer identifications should avoid this alignment problem by keeping the observations synchronised. While visual methods of signalling using a clipboard in this study were not successful, it would be relatively easy to place coloured flag tape markers at twenty-five hook intervals on the groundline during the setting operation. In this way, both observers and EM analysts could cluster their observations into more manageable hook groupings.

The EM species identification assessment was also influenced by the species identification methodology. A staff of nineteen at-sea observers and six EM analysts provided the species identifications in this study. Both groups were experienced with groundfish species identifications and were free to use their best judgement in determining catch species. Identifications for both groups were based on recognition of key features as well as making inferences using other criteria such as other species present during the retrieval, fishing depth and location. It is expected that there would be variability in species identification consistency between and among observers and EM technicians. An alternative approach, eliminating the guesswork, would require specific identification criteria before identification is determined. This method would improve identification accuracy and consistency at the expense of producing more unidentified catch items. However, the 'best judgement' decision approach is the accepted methodology for at-sea observer programs and explains some of the species identification error shown in the video corroboration results.

Also influencing the comparison was the manner in which usable imagery was selected. The analysis included all imagery deemed to be usable (i.e., groundline always in view for the entire set), regardless of quality. Identification accuracy of EM would be greater by using only high quality imagery (about a third was medium or low quality). As well, selection of data sets from later in the season would have improved the results. Over the duration of the project technical and operational program improvements, and staff learning improved the amount of usable data and the accuracy of EM species identifications, the latter by 5 to 50% for twelve of the nineteen species examined (Figure 18). As a result, the identification results presented in this study likely underestimate the present capability of EM-based species recognition.

The species diversity pattern for the halibut fishery made estimation of EM recognition rates difficult for all but the most abundant species. Among the more than sixty fish species, the top five accounted for 75% of the catch, the top fifteen for 98%, and the fifteen least abundant accounted for 0.04% of the catch. Many species occurred too infrequently to collect adequate sample sizes for assessment of EM recognition capability. Species of importance that were not addressed in this study could be better studied in a more targeted manner where they would be more likely to occur. Given the particular management interest in rockfish, we recommend that further use of combined EM/Observer deployments occur in the directed rockfish fishery (i.e., ZN licensed vessels), or selected rockfish/halibut combination fishing trips, in order to further develop EM technology and provide better estimates of EM species identification rates.

An important consideration in the interpretation of the results is how the EM sample compared with true species occurrence patterns in the halibut fishery. Fishing vessels volunteering to use EM represented a small sample of the fishery, and several trips were combination fishing trips where halibut fishing was combined with directed fishing for sablefish and rockfish. In comparing the EM results with observer data, the best indication of catch patterns in the halibut fishery, rockfish and sablefish were over represented in the EM sample by nearly a factor of five, while the EM halibut catch was about 45% of the catch level in the observer data. This outcome benefited the study with more samples of these less common species, although the results should not be directly translated the halibut fishery without correcting for species composition differences.

EM catch monitoring (enumeration and species identification) was compared with observer data in three ways: overall totals by species, species totals by set and a comparison of identification by individual hook. The former method combined catch data for the entire EM/Observer data set and provided a useful general index of comparison but lacked information about variability within the data set. The second method, comparison of species totals by set, contained the same amount of data as the first method and provided more useful information about distribution of catch totals by set. This method provided poor correlations for low abundance species where only a few pieces occurred per set. The last method, comparing EM and observer identifications by hook, was the most powerful of the three, but contained about half the data and smaller sample sizes for many species. The individual hook comparison provided further information about EM misidentified species but the comparison was weakened by observer misidentifications and the imprecision in alignment of the EM and observer data sets.

4.2.2. Comparison of EM and Observer Data Elements

In order to provide an assessment of the suitability of EM for the halibut fishery, it is useful to compare the capabilities for various data categories. In the following sections we have assigned scores, on a scale of zero (low) to five (high), ranking the ability for EM and observer monitoring methods to accurately record each data category. The ranking also includes rational for assigned scores.

4.2.2.1. Species Recognition: EM-3 Observer -5

Clearly, one of the important questions concerning EM-based monitoring is with the ability to recognize different fish species. The results of this study reflect the capabilities of EM, given the current state of technology and operational procedures applied in the program. The EM data set distinguished nearly fifty species, compared with fifty-six by the observer, and a total of about sixty species in the EM/Observer data set. While both EM and observers identified over 98% of catch items to species, there were significantly higher levels of EM identifications to more general taxonomic groups. Using the minimum sample size criteria of 20 pieces or sets, about half of the species identified in this data set were sufficient in numbers to evaluate EM identification rates by the three assessment methods. The EM identification results were generally consistent between the three methods (summarised in Table 12.). That is, species with a low percent difference between the EM and observer data sets also had high correlation by set and a high percent match by hook. Using these results and taking into consideration improvements to EM species identification observed during the study, EM species recognition in the halibut fishery can be summarized as follows:

- *High EM Recognition High* – This category includes eight species where EM identifications would probably be accurate within 5%: halibut, sablefish, rougheye rockfish, spiny dogfish, longnose skate, lingcod, quillback rockfish, and ratfish. The species accounted for 77% of the catch in the EM study and we estimate them to account for about 92% of the catch in the halibut fishery.

- *EM Recognition Moderate* – This category includes five species where EM identification accuracy would be within 10%: redbanded rockfish, arrowtooth flounder, shortspine thornyhead, yelloweye rockfish and silvergray rockfish. These species accounted for 17% of the EM catch and about 5% of the catch in the halibut fishery.

- *EM Recognition Low* – EM identification was low in the remaining twelve species examined: shortraker rockfish, canary rockfish, yellowmouth rockfish, bocaccio rockfish, Pacific Ocean perch, rosethorn rockfish, greenstriped rockfish, grenadier, petrale sole, Pacific cod, big skate, sandpaper skate. These species accounted for about 5% of the EM catch and about 3% of the halibut fishery catch.

- *EM Recognition Not Tested* – Twenty-three species, collectively accounting for 0.2% of the EM catch (0.6% of halibut fishery catch), were not encountered in sufficient numbers to estimate EM recognition.

In summary, results from this study indicated that EM reliably (i.e., accuracy within 10%) distinguished thirteen species that represented 94% of the EM catch, or 97% of the halibut fishery catch. These thirteen fish species represented about half the species where sample size was sufficient to estimate EM recognition and about 20% of the total encountered in the fishery.

EM provided very good catch identification for basic taxonomic categories. Overall catch comparisons between EM and observer were within 3% for rockfish, 1.5% for flatfish, 8% for sharks, 5% for skates, and 5% for other fish. These groups also had a high correlation for catch summarised by set ($r^2 > 0.95$). The EM/Observer by Hook treatment also showed the same pattern with very high (>98%) EM identifications to the same taxonomic category as the observer. These results indicate that EM was very reliable for enumeration of catch to general taxonomic grouping and it was not surprising that EM identification errors were primarily within rather than between these taxonomic categories.

The analysis attempted further sub grouping of morphologically similar species to provide improved species identifications. The rougheye and shortraker rockfish species pair was a clear example where the identification rates of each were improved by combining the species. This result was observed with all three EM species recognition methods. The results were not as conclusive for the other species sub groups examined, although its potential use for rockfish species should be examined further.

EM results for the non-fish species were examined in less detail. EM underestimated the invertebrate catch, enumerating less that half the observer count. The reasons for this result were thought to be either small size of catch item, particularly with gastropods, or catch items falling away from the hook before leaving the water. The catch of seabirds was also not examined in detail due to small numbers observed. There was one black-footed albatross in the EM/Observer and three in the EM only treatment. This species was very distinctive in the imagery and, given EM analyst training, identification would seem possible.

The results describe EM species recognition capability for the level of technology and program procedures used in the study. It was also evident that changes to the program improved the level of species recognition. It is useful to consider how further changes may affect species recognition. There are four program areas where species recognition capability can be significantly influenced:

- *Technology* – This category includes the specific components in the EM system and how they operate. Other than changes to the operating system software, very few changes were made to the EM system in this study.

- *Installation Specifications* – Specifications in the installation and setup of EM components also influence the capability of the system. Changes to camera position, field of view, and image capture rate significantly affect the quality of imagery and potential for correct species identifications. The installation specifications should closely relate to the kinds of fish expected and the features that must be discernible.

- *EM Analyst Training* – While all EM analysts in this study were experienced with groundfish species identifications, species identification from imagery is different from identification in hand. Improvements in identification would result from training analysts to recognize key features readily visible from imagery. Included in training would be development of appropriate taxonomic categories where speciation may not be necessary or possible. This could include subgroups of rockfish, flatfish, invertebrates and seabirds.

- *Fleet Cooperation* – This category pertains to ways that vessel personnel can participate to ensure the EM system operates most successfully. While the system is designed for autonomous operation, there are several things vessel personnel could do to improve data quality. For example, identifications improve significantly when catch items are properly oriented toward the camera. In this study, the distinctive redbanded rockfish were occasionally misidentified when only the ventral side was visible.

The interrelationship of these program areas on EM species recognition capability is significant, much more so than the specific capabilities of the equipment alone.

Improvements to an EM program would very likely gain further species resolution than was observed in this study. To assess how such improvements may influence EM species recognition in the halibut fishery, we have separated the fish species by level of identification difficulty (Table 13). Including other information such as depth and location, species recorded in the halibut fishery fit into one of the following identification categories:

- *Identification Possible from Primary Feature* – This category includes species that are readily distinguished by a primary feature such as colouration and shape. We estimate that there are twenty-eight species in this category, which combined make up about 91% of the halibut fishery catch. EM could identify species in this group with a relatively small amount of additional program development.

- *Identification Possible from Secondary Feature* – This category includes species that are not distinguished without viewing secondary features such as fin shape, colour markings, ventral patterns. We estimate that this category includes about thirty species, which make up about 8% of the halibut fishery catch. EM recognition of species in this group could occur, but would involve further program change, particularly with fleet co-operation.

- *Close-Up View or Specimen Required* – This category includes species or species groups (e.g. Cottidae, Onchorynchus sp.) that can not be distinguished without close viewing of specific features such as lateral lines, fin spine length, mouth features, etc. We estimate that there are seven species in this category, which account for about 1% of the catch. The two rockfish species in this category are rougheye and shortraker rockfish. While close-up inspection is often necessary to separate these species, rougheye rockfish is a much more abundant species. It is unlikely that EM recognition could occur for species in this group without significant program development.

Thus, with increasing levels of program development effort, EM should provide higher levels of species resolution. In our view, an EM program should be able to achieve the first level (primary feature) identifications (91% of the catch and 43% of the species). With more effort an EM program could achieve both the first and second level identifications (99% of the catch and 89% of the species). It is unlikely however that the third level identifications could be achieved by an EM program, leaving 1% of the catch and 11% of the species not distinguished. In contrast, an at-sea observer program should be able to distinguish all three levels of species identifications, given the observer duties allow sufficient time for hands on catch inspection.

4.2.2.2. Catch and Hook Enumeration: EM-5 Observer-4

The results of this study clearly showed the reliability of EM as a basic catch enumeration tool. Overall catch comparisons between EM and observer were within 3% for catch items and 5% for hooks and catch combined (Table 5). Similarly, totals by set (Table 6) were also highly correlated for fish catch (r^2=0.96), but less so for catch and hooks combined (r^2=0.90). On an individual hook basis, EM and observer data sets were within 0.1% in the number of catch items (Table 7).

Overall catch comparisons between EM and observer were within about 8% for empty hooks, and empty hook totals by set were also moderately correlated (r^2=0.75). On an individual hook basis, EM and observer data sets differed by about 7% in the total number of empty hooks (Table 2). Video corroboration results estimated EM hook counting error at about 2%, or 20 errors per thousand hooks set and observer hook counting error at 3.5%. As mentioned previously we believe the video corroboration results overestimated observer hook counting error.

We believe that, for purposes of hook and catch enumeration EM provided equivalent or better results than the observer method. The reasons for this, stated previously, include: observer fatigue during retrieval events; the possibility of an observer missing discard catch; and the permanent EM image record that can be repeatedly reviewed in a controlled manner.

This study did not attempt to enumerate lost hooks. Observer estimates of lost hooks are usually determined by comparing hook counts made prior to gear setting and after gear retrieval. Enumeration of hooks by EM was only during retrieval and the number of hooks set was not determined. Estimation of hooks set would require further technology development, either with camera monitoring of the set or by sensor detection of deployed hooks.

4.2.2.3. Catch Weight: EM-0 Observer-4

The EM monitoring approach did not address catch weight, which is estimated by at-sea observers. EM-based monitoring provided counts of catch in pieces and there was no attempt to estimate weight of catch. This information could come from dockside estimates for retained catch and conversion standards developed by at-sea observers for discarded catch. Observer program have the opportunity to weigh catch but often average piece weights are applied to counts of catch items. To address this problem, it would be beneficial to obtain estimates of piece counts and average piece weights during offload monitoring, thereby enabling comparison of at-sea and dockside data sets.

4.2.2.4. Catch Disposition: EM-3 Observer-5

Catch items in the halibut fishery are generally either retained, or immediately discarded, or retained and subsequently used as bait. Most species in the halibut fishery are usually either kept or discarded, and a few species are kept or discarded, depending upon circumstances such as size, area closures, or other factors. Results from this study showed that species disposition estimates by EM and observer methods were in close agreement for all species, regardless of category, except for halibut and longnose skate. EM reliably distinguished catch sorted at the rail, and could not easily distinguish catch brought aboard and sorted later. EM also only recorded imagery during retrieval events and would not detect sorting of catch at other times.

4.2.2.5. Time and Location of Fishing : EM-5 Observer-4

EM is a very reliable tool for monitoring the time and location of fishing activities. The continuous data record, the accuracy time and location information, and the ability to detect fishing activity from sensor information, proves to be an effective means to determine where and when fishing occurs. An at-sea observer can perform the same functions although this requires recording the information from the bridge at the appropriate time. This may not be possible if recording position information conflicts with other observer duties.

Differences in time between EM and observers were very low for both start and end of set (r^2>0.94) and the inconsistent observer recording of time by daylight and standard time accounted for most of the difference. Position differences between EM and observers were also low with most differences less than 500 metres. Position recording error is more likely by observers (failing to accurately record the information) but could also be EM error, especially with intermittent power, which can cause faulty GPS readings.

4.2.2.6. Fishing Depth: EM-3 Observer-5

The correlation between EM and observer fishing depths was moderate for start (r^2>0.65) and higher for finish (r^2>0.80) set depths. The difference between EM and observer depths was most likely related to the different sources for the information: observer values came from the vessel depth recorder, while EM values were derived by interpolation from an electronic chart database. There was greater agreement between EM and observers at fishing depths less than 200 metres, below this however, depth data in electronic chart database were more sparse and interpolation distances become greater. Overall, 80% of EM and observer depth values were within 50 metres.

The method for determining depth by EM would be inadequate for monitoring vessel compliance to depth related management regulations, such as the ban on commercial fishing within 100 fathoms in place in west coats US states. Improvement in EM depth accuracy could be achieved by recording depth sounder NMEA digital output, which is available on most of the newer depth sounder equipment.

4.3. OBJECTIVE 3 – COMPARISON OF EM AND OBSERVER PROGRAM ISSUES

The third objective of the study was to examine costs, benefits and other issues associated with EM programs. In considering an EM based monitoring program there are a number of program related issues that are quite separate from basic capability to capture various categories of data. In the following sections these issues are examined in relation to observer programs.

4.3.1. Cost Issues

The lower cost of EM to observers is one of the main reasons for considering the use of EM in a monitoring application. Currently, the halibut fleet pays about \$320 per observer day at sea, including observer sea time, briefing, travel and other expenses. In addition, program infrastructure costs, funded by the federal government, are about \$130 per day, bringing the at-sea observer program cost to \$450 per observer day at sea. The cost of observer monitoring in the 8,500 fishing day halibut fishery is significant – the current cost is about \$380,000 per 10% increment of fishery. The large volume of observer days (>6,000) for the groundfish trawl fishery provides economies of scale and, in its absence, monitoring costs for the halibut fishery would likely be higher. In contrast, the EM program cost about $210 per vessel day at sea, and assuming a 90% success rate for EM deployments the cost of EM-based data would be about $200,000 per 10% increment of the halibut fishery. The current cost recovery method for EM programs is 100% funded by industry with no federal contribution. Thus, we estimate EM programs would be a little over half the cost of an observer program.

There are a number of issues affecting the future cost of EM-based programs. As this technology area becomes more developed, it is expected that equipment costs will decline. However, the greatest area of potential cost savings will be with strategies to manage labour cost. Three-quarters of the daily EM cost covers the labour to install and service EM equipment, and analyse and produce EM data. Optimisations with installations and servicing decrease costs, while the increased number of single trip EM installations increase costs. The EM data analysis process consumes the greatest amount of labour effort. Optimisations are possible through further improvements to the image analysis software and possible procedural changes to the analysis process. Image analysis time is directly related to the diversity and complexity of the catch, and the labour requirement depends upon the specific analysis objectives. One possible fleet monitoring design might be using both EM and observers (on separate platforms) with EM-monitored component providing basic catch data by general species categories and the observer-monitored component providing full species composition information. Another design might involve large-scale deployment of EM systems on the fleet with image data selectively analysed according to a specific sample design. In this way, the analysis effort changes from full interpretation of all imagery from a fishing trip to sampling the fleet monitoring imagery for sets or portions of sets. In both cases, the image analysis labour effort, the major EM cost component, becomes more strategically applied.

With fisheries where high monitoring levels are necessary, another labour cost management strategy would be to change the program design. Currently, monitoring programs (either observers or EM) provide catch estimates that are independent from the skipper logbook estimates. Instead of not using the skipper data, an alternative program design would be to provisionally accept the skipper data and use EM as a verification tool. The electronic fishing logbook, used on a trial basis this year, was designed specifically as a tool for a skipper to declare their catch. Under the revised program design, EM analysis would progressively sample the EM imagery to measure the accuracy of the skipper's declared catch. Using this approach, the level of analysis effort would be directly related to skipper data quality: skippers that routinely provide accurate catch data require less analysis time, and lower cost, than those that provide poor quality data. Linking this method to user-pay cost recovery there is a strong incentive for industry to improve data quality, reduce analysis time, and thereby reduce the at-sea monitoring cost. In addition to reducing monitoring costs for compliant fishers to a fraction of current observer costs this data collection model also benefits resource stewardship co-management initiatives by encouraging greater fishery participant involvement in the data collection process. In small vessel fisheries such as the halibut fishery, we feel that this approach may be the only cost effective way of achieving higher fleet monitoring levels. We recommend that further work be carried out to examine the feasibility of this approach.

4.3.2. Technical Complexity and Versatility

EM-based monitoring programs are technologically more complex than observer programs. In a new fishery monitoring application, lead-time may be required for the EM system and software development. As well, EM programs require an infrastructure of skilled personnel for both field operations (fleet servicing) and office operations (image interpretation, data analysis and reporting). In contrast, observer programs of a similar fleet monitoring scale have greater challenges for skilled personnel and simpler equipment requirements.

Versatility reflects the monitoring system capabilities in terms of the diversity of data collection activities performed and the ability for these activities to be adaptive. Observer programs generally provide much more versatile data collection opportunities than EM programs. For example, the methods employed by an observer vary according to a variety of circumstances such as catch contents, weather, sampling space, crew co-operation and other needs. As a result, observers can generally deal with more complex sampling, choosing the best method for the situation. The protocols for EM are comparatively simple, providing observations at specific control points, and are generally not adaptive to changes during a fishing trip.

4.3.3. Data Issues

4.3.3.1. Data Capacity

Data collection capacity refers to the quantity of information that can be obtained from a monitoring program. In this aspect, EM excels by non-stop data collection for days at a time, simultaneously recording different events around the vessel. The amount of data storage, rate of recording and the quantity of information recorded limit EM data capacity. High capacity hard drives over 40 gigabytes provide sufficient capacity for a very comprehensive data record for halibut fishing trips. In contrast, observers record lower volumes of data and have set priorities for their work on the vessel. Some of their monitoring activities preclude others, as it is not possible to be in more than one place at a time. It may be difficult for observers to monitor events that continue over a long time period or happen quickly with a number of separate activities occurring at the same time.

4.3.3.2. Data Processing Complexity

EM and observer programs provide similar information outputs although the means to this end differ. Observers typically employ standardised sampling methodology and summarise their data onto keypunch forms, usually transcribed from initial observations recorded in a field notebook. More time-sensitive information (i.e., compliance issues) may be transmitted real time although most data are keypunched after the trip is completed. Some observer data forms are designed for scanning and interpretation using optical character reading software. In contrast, EM programs capture a comprehensive set of fishing vessel data from which pertinent fishery data are extracted after the trip is completed. While the sensor information is already in electronic format, a potentially time-consuming aggregation and interpretation process may be required for translation observer data formats. For example, an EM sensor data set from a typical fishing trip may contain over 150,000 data records, which are aggregated to a few dozen data lines in the observer data set. Image data are manually interpreted with observations keypunched. Unlike observer data, EM data processing is more involved and requires about a week after the fishing trip is completed for the finished electronic data. EM systems used in this study did not have the capability for real time transmission and, while this is technically possible, we consider it to be economically impractical unless the volume of transmitted information was substantially reduced.

4.3.3.3. Privacy Expectations

Fishermen are often concerned about the intrusiveness of having an observer aboard their vessel. This problem is exacerbated on smaller vessels where personal space is more limited. In discussions with fishermen, there is generally more support for EM since it is less obtrusive. However, the comprehensive nature of data collected by EM systems leads to privacy issues not as apparent in observer programs. There is a risk that EM data 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. As well, fishing activities, especially those involving sensitive species, portrayed in a motion picture medium (as opposed to a data point), could be used inappropriately in a powerful manner. With observer programs these sensitivities are protected in the manner in which the program is designed - usually data collection is structured and confined to specific fishery issues such as making independent estimates of catch and collecting biological samples. EM programs are at risk of the information being used for purposes outside of the original scope of the program. In our view, data from EM programs should be analysed to meet clearly established information objectives set forth at the onset of the program. Once these objectives are met, it is important to carefully consider whether the uses of the information can be confined to the original objectives that fishermen accepted in allowing the EM system aboard.

4.3.4. Fleet Suitability

Many observer programs in North America began with monitoring large factory vessels where there was ample accommodation and workspace for an observer. As different fisheries take steps to improve the quality of catch reporting information, issues concerning fleet suitability for placement of observers have emerged. The issue of vessel suitability is complex and DFO, observer suppliers, and industry have not been able to prepare specific guidelines to determine when a vessel is suitable to host an observer. Small vessels are not intrinsically unsafe, however adding an observer to the crew complement on small vessels is more likely to impact observer duties, workspace, accommodations, safety equipment, fishing operations, and crew and observer safety. As well, skipper experience and qualifications and required safety equipment for small vessels is generally lower than larger vessels. These issues make deployment of observers on small vessel fleets problematic and create more risk to observers, fishing vessels, observer suppliers and DFO.

EM helps address this problem by providing a monitoring approach for fishing vessels where observer placement is questionable. In our view, improved catch accountability in the halibut fishery with higher fleet coverage levels and more randomly distributed fleet sampling would be best served with an integrated observer and EM-based monitoring program. Such a program would utilize both observers and EM in a complimentary fashion to achieve fleet sampling objectives. Vessels selected for monitoring would take either EM or an observer depending upon sampling needs, vessel specifications and other considerations. The combined sampling methods would make it easier to follow a sample plan and accomplish the overall fleet coverage levels at a lower cost. We recommend that an integrated EM/observer program be pursued for the halibut fishery.

5. CONCLUSIONS AND RECOMMENDATIONS

The results of this study demonstrated that EM is a promising tool for at-sea monitoring applications. EM and observer programs differ in many ways in terms of data collection capabilities and program design issues. While the utility of this new technology will depend upon the specific fishery monitoring objectives, the substantially lower cost and broader fleet suitability of EM over observers makes this an attractive option. As the use of EM expands, there are immense data opportunities, currently unavailable to fisheries agencies, which increase knowledge and improve management and decision making in the fishery. We offer the following specific recommendations:

- DFO should more comprehensively define the at-sea monitoring objectives of the halibut fishery, incorporating the needs of science, management, enforcement, and industry, with consideration given to the capabilities of the available monitoring tools, and the potential for observational bias affecting the sampling design.

- Species of importance that were not addressed in this study could be better studied in a more targeted manner where they would be more likely to occur. Given the particular management interest in rockfish, we recommend that further use of combined EM/Observer deployments occur in the directed rockfish fishery (i.e., ZN licensed vessels), or selected rockfish/halibut combination fishing trips, in order to further develop EM technology and provide better estimates of EM species identification rates.

- We recommend that further work be carried out using EM and an electronic fishing log as an at-sea monitoring audit tool.

- Improved catch accountability in the halibut fishery with higher fleet coverage levels and more randomly distributed fleet sampling would be best served with an integrated observer and EM-based monitoring program. Such a program would utilize both observers and EM in a complimentary fashion to achieve fleet sampling objectives. Vessels selected for monitoring would take either EM or an observer depending upon sampling needs, vessel specifications and other considerations. The combined sampling methods would make it easier to follow a sample plan and accomplish the overall fleet coverage levels at a lower cost.

- DFO should strengthen their support for the use of EM-based monitoring approaches in order to promote further development of this technology.

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Treatment	# of Vessels	# of Trips	Sea Days	Usable Sets	Quality High	Quality Med	Quality Low	Unusable Sets	Total Sets
EM Only	**15**	**29**	**219**	**306**	**185**	**101**	**20**	**139**	**445**
EM/Observer by Set	**13**	**30**	**240**	**391**	**260**	**109**	**22**	**226**	**617**
EM/Observer by Hook				176	128	43	5	113	289
Total EM	**19**	**59**	**459**	**697**	**445**	**210**	**42**	**365**	**1,062**

Table 1. Summary Of EM Deployments In The 2002 Halibut Fishery. The EM/Observer by Hook totals are a subset of EM/Observer by Set treatment.

	# of Records	# of Changes	% of Edits	% of Total
Hooks Added	1,894	2,234	29.7%	2.4%
Hooks Removed	2,523	3,968	52.8%	4.3%
Missed Fish	290	291	3.9%	0.3%
Order Change	565	1,028	13.7%	1.1%
Total	**5,272**	**7,521**		**8.1%**
Records not Edited	87,091			94.3%
Total	**92,363**			

Table 2. Summary Of Alignment Changes Made To EM/Observer By Hook Data Set. The # changes reflects total edit steps (additions, deletions, order changes) while the # records reflects the number of records associated with the edit steps.

	Observer	EM	Unknown	Total	Percent
Type of Error					
Hook	399	222	71	692	60.6%
Misidentification	58	65	42	165	14.5%
General Identification	28	83	0	111	9.7%
Missed Fish	45	16	4	65	5.7%
Fish/Empty Hook	29	37	5	71	6.2%
Order	22	12	3	37	3.2%
Total	**581**	**435**	**125**	**1,141**	
Reason for Error					
Unknown/Other	536	341	32	909	79.7%
Groundline Tangle	24	27	71	122	10.7%
Poor or No Image	1	45	14	60	5.3%
Fell Off Early	8	10	6	24	2.1%
Close Spacing	6	5	2	13	1.1%
Data Process Error	6	2	0	8	0.7%
Video Problems	0	5	0	5	0.4%
Total	**581**	**435**	**125**	**1,141**	
Percent	**50.9%**	**38.1%**	**11.0%**		

Table 3. Summary Of Video Corroboration Results For Twenty-One Sets And Seven Trips. See text for description of terms.

a) Rockfish and Elasmobranchs

Species	Scientific Name	EM/Observer Trips Observer	EM/Observer Trips EM	EM Only Trips	All EM Trips
Rockfish					
Rougheye Rockfish	*Sebastes aleutianus*	6,879	7,542	1,137	8,679
Redbanded Rockfish	*Sebastes babcocki*	4,201	4,026	1,297	5,323
Shortspine Thornyheads	*Sebastolobus alascanus*	1,941	2,042	903	2,945
Yelloweye Rockfish	*Sebastes ruberrimus*	1,446	1,530	2,126	3,656
Shortraker Rockfish	*Sebastes borealis*	2,532	1,380	124	1,504
Silvergray Rockfish	*Sebastes brevispinis*	1,043	1,011	498	1,509
Quillback Rockfish	*Sebastes maliger*	537	548	939	1,487
Canary Rockfish	*Sebastes pinniger*	236	203	149	352
Yellowmouth	*Sebastes reedi*	256	121	1	122
Bocaccio Rockfish	*Sebastes paucispinis*	81	84	69	153
Rosethorn Rockfish	*Sebastes helvomaculatus*	66	26	14	40
Yellowtail Rockfish	*Sebastes flavidus*	14	18	27	45
Tiger Rockfish	*Sebastes nigrocinctus*	5	18	31	49
Greenstripe Rockfish	*Sebastes elongatus*	21	16	9	25
Pacific Ocean Perch	*Sebastes alutus*	36	6	0	6
Copper Rockfish	*Sebastes caurinus*	6	4	33	37
Black Rockfish	*Sebastes melanops*	0	2	0	2
Widow Rockfish	*Sebastes entomelas*	1	1	0	1
Redstripe Rockfish	*Sebastes proriger*	11	0	0	0
Darkblotch Rockfish	*Sebastes crameri*	6	0	0	0
Dusky Rockfish	*Sebastes ciliatus*	4	0	5	5
Harlequin Rockfish	*Sebastes variegatus*	1	0	0	0
Sharpchin Rockfish	*Sebastes zacentrus*	1	0	0	0
China Rockfish	*Sebastes nebulosus*	0	0	60	60
Rougheye/Shortraker Complex		0	65	2	67
Unidentified Rockfishes		1	1,216	278	1,494
Rockfish Total		**19,325**	**19,859**	**7,702**	**27,561**
Elasmobranchs					
Spiny Dogfish	*Squalus acanthias*	4,477	4,818	4,791	9,609
Blue Shark	*Prionace glauca*	12	15	3	18
Sleeper Shark	*Somniosus pacificus*	15	13	3	16
Soupfin Shark	*Galeorhinus zyopterus*	3	0	0	0
Six Gill Shark	*Hexanchus griseus*	2	0	0	0
Unidentified Sharks		0	4	2	6
Longnose Skate	*Raja rhina*	2,001	2,098	1,287	3,385
Big Skate	*Raja binoculata*	364	308	236	544
Sandpaper Skate	*Bathyraja interrupta*	106	111	242	353
Starry Skate	*Raja stellulata*	2	9	33	42
Black/Roughtail Skate	*Bathyraja trachura*	14	2	0	2
Deep Sea Skate	*Raja abyssicola*	1	0	0	0
Unidentified Skates		64	150	56	206
Ratfish	*Hydrolagus colliei*	384	401	543	944
Elasmobranch Total		**7,445**	**7,929**	**7,196**	**15,125**

b) Flatfish, Other Fish, Invertebrates and Seabirds.

Species	Scientific Name	EM/Observer Trips Observer	EM/Observer Trips EM	EM Only Trips	All EM Trips
Flatfish					
Pacific Halibut	*Hippoglossus stenolepis*	23,945	24,933	17,945	42,878
Arrowtooth Flounder	*Atheresthes stomias*	4,068	3,471	3,204	6,675
Petrale Sole	*Eopsetta jordani*	62	36	14	50
Dover Sole	*Microstomus pacificus*	21	12	22	34
Rock Sole	*Lepidopsetta bilineata*	11	5	3	8
Butter Sole	*Isopsetta isolepis*	0	3	0	3
Unidentified Flatfish		0	49	3	52
Flatfish Total		**28,107**	**28,509**	**21,191**	**49,700**
Other Fish					
Sablefish	*Anoplopoma fimbria*	16,794	17,303	4,101	21,404
Lingcod	*Ophiodon elongatus*	1,643	1,754	1,182	2,936
Pacific Cod	*Gadus macrocephalus*	106	92	279	371
Wolf Eel	*Anarrhichthys ocellatus*	0	3	1	4
Pollock	*Theragra chalcogramma*	6	1	0	1
Hagfish	*Eptatretus spp.*	5	1	0	1
Pacific Flatnose	*Antimora microlepis*	1	0	0	0
Kelp Greenling	*Hexagrammos decagrammus*	0	0	1	1
Grenadiers	*Coryphaenoides spp.*	81	63	0	63
Sculpin	*Cottidae*	4	1	6	7
Salmon	*Salmonidae*	0	1	0	1
Eelpout	*Zoarcidae*	3	0	0	0
Unidentified Fish		8	370	209	579
Other Fish Total		**18,651**	**19,589**	**5,779**	**25,368**
Invertebrates					
Octopus	*Octopus dofleini*	7	8	26	34
Echinoderms	*Echinodermata*	565	284	115	399
Anthozoans	*Anthozoa*	70	5	2	7
Sponges	*Porifera*	18	1	0	1
Gastropods	*Gastropoda*	113	0	0	0
Scallops	*Pectinidae*	1	0	0	0
Dungeness Crab	*Cancer magister*	0	1	0	1
Tanner Crab	*Chionoecetes*	1	0	0	0
Lithoid Crab	*Lithodidae*	0	1	0	1
Tube Worm	*Sedentaria*	0	0	1	1
Unidentified Invertebrates		3	0	0	0
Invertebrates Total		**778**	**300**	**144**	**444**
Seabirds					
Black-footed Albatross	*Diomedeidae*	1	1	3	4
Seabirds Total		**1**	**1**	**3**	4
Total Catch (All Groups)		**74,307**	**76,187**	**42,015**	**118,202**
Total Empty Hooks		**151,518**	**139,220**	**90,053**	**229,273**
Total Catch and Hooks		**225,825**	**215,407**	**132,068**	**347,475**

Table 4. Summary Of Species Observed During The Study By Observer And EM.

a) Rockfish and Elasmobranchs

Species	EM/Observer Trips Observer	EM	Percent Difference*
Rockfish			
Rougheye Rockfish	6,879	7,542	9.64%
Shortraker Rockfish	2,532	1,380	45.50%
Rougheye/Shortraker	0	65	
Subtotal	**9,411**	**8,987**	**4.51%**
Redbanded Rockfish	4,201	4,026	4.17%
Tiger Rockfish	5	18	
Subtotal	**4,206**	**4,044**	**3.85%**
Yelloweye Rockfish	1,446	1,530	5.81%
Canary Rockfish	236	203	13.98%
Yellowmouth	256	121	52.73%
Pacific Ocean Perch	36	6	
Redstripe Rockfish	11	0	
Subtotal	**1,985**	**1,860**	**6.30%**
Bocaccio Rockfish	81	84	3.70%
Silvergray Rockfish	1,043	1,011	3.07%
Yellowtail Rockfish	14	18	
Black Rockfish	0	2	
Widow Rockfish	1	1	
Dusky Rockfish	4	0	
Subtotal	**1,143**	**1,116**	**2.36%**
Shortspine Thornyheads	1,941	2,042	5.20%
Rosethorn Rockfish	66	26	60.61%
Greenstripe Rockfish	21	16	
Darkblotch Rockfish	6	0	
Harlequin Rockfish	1	0	
Sharpchin Rockfish	1	0	
Subtotal	**2,036**	**2,084**	**2.36%**
Copper Rockfish	6	4	
Quillback Rockfish	537	548	2.05%
Subtotal	**543**	**552**	**1.66%**
Unidentified Rockfishes	1	1,216	
Rockfish Total	**19,325**	**19,859**	**2.76%**
Elasmobranchs			
Spiny Dogfish	4,477	4,818	7.62%
Blue Shark	12	15	
Sleeper Shark	15	13	
Soupfin Shark	3	0	
Six Gill Shark	2	0	
Unidentified Sharks	0	4	
Shark Total	**4,509**	**4,850**	**7.56%**
Longnose Skate	2,001	2,098	4.85%
Big Skate	364	308	15.38%
Sandpaper Skate	106	111	4.72%
Starry Skate	2	9	
Black/Roughtail Skate	14	2	
Deep Sea Skate	1	0	
Unidentified Skates	64	150	
Skate Total	**2,552**	**2,678**	**4.94%**
Ratfish	384	401	4.43%
Elasmobranch Total	**7,445**	**7,929**	**6.50%**

* - relative to observer estimate

b) Flatfish, Other Fish, Invertebrates and Seabirds.

Species	EM/Observer Trips Observer	EM	Percent Difference*
Flatfish			
Pacific Halibut	23,945	24,933	4.13%
Arrowtooth Flounder	4,068	3,471	14.68%
Subtotal	**28,013**	**28,404**	**1.40%**
Petrale Sole	62	36	41.94%
Dover Sole	21	12	
Rock Sole	11	5	
Butter Sole	0	3	
Subtotal	**94**	**56**	**40.43%**
Unidentified Flatfish	0	49	
Flatfish Total	**28,107**	**28,509**	**1.43%**
Other Fish			
Sablefish	16,794	17,303	3.03%
Lingcod	1,643	1,754	6.76%
Pacific Cod	106	92	13.21%
Wolf Eel	0	3	
Pollock	6	1	
Hagfish	5	1	
Pacific Flatnose	1	0	
Grenadiers	81	63	22.22%
Sculpin	4	1	
Salmon	0	1	
Eelpout	3	0	
Unidentified Fish	8	370	
Other Fish Total	**18,651**	**19,589**	**5.03%**
Invertebrates			
Octopus	7	8	
Echinoderms	565	284	49.73%
Anthozoans	70	5	
Sponges	18	1	
Gastropods	113	0	
Scallops	1	0	
Dungeness Crab	0	1	
Tanner Crab	1	0	
Lithoid Crab	0	1	
Unidentified Invertebrates	3	0	
Invertebrates Total	**778**	**300**	**61.44%**
Seabirds			
Black-footed Albatross	1	1	
Seabird Total	**1**	**1**	**0.00%**
Total Catch Pieces	**74,307**	**76,187**	**2.53%**
Empty Hooks	**151,518**	**139,220**	**8.12%**
Grand Total	**225,825**	**215,407**	**4.61%**

* - relative to observer estimate

Table 5. Summary Of Catch Totals For EM/Observer Treatment.

a) Rockfish and Elasmobranchs

Species	Number Of Sets	Total Catch*	Mean # per Set*	r^2 (correlation)	*m* (slope)	*b* (y-intercept)	Scatter Plot
Rockfish							
Rougheye Rockfish	194	6,879	35.46	0.95	0.99	3.85	Y
Shortraker Rockfish	137	2,532	18.48	0.52	0.46	1.64	Y
Rockfish Subgroup 1 Total	**208**	**9,411**	**45.25**	**0.98**	**0.97**	**-0.38**	**Y**
Redbanded Rockfish	295	4,201	14.24	0.93	0.97	-0.11	Y
Tiger Rockfish	9	5					
Rockfish Subgroup 2 Total	**297**	**4,206**	**14.16**	**0.93**	**0.97**	**-0.07**	**Y**
Yelloweye Rockfish	175	1,446	8.26	0.88	0.89	1.37	Y
Canary Rockfish	38	236	6.21	0.45	0.63	1.46	Y
Yellowmouth	60	256	4.27	0.03	0.10	1.59	Y
Pacific Ocean Perch	21	36	1.71	0.20	-0.09	0.45	
Redstripe Rockfish	1	11	11.00				
Rockfish Subgroup 3 Total	**218**	**1,985**	**9.11**	**0.87**	**0.90**	**0.38**	**Y**
Bocaccio Rockfish	61	81	1.33	0.08	0.31	0.96	Y
Silvergray Rockfish	127	1,043	8.21	0.96	0.96	0.11	Y
Yellowtail Rockfish	14	14	1.00				
Widow Rockfish	1	1	1.00				
Dusky Rockfish	2	4	2.00				
Rockfish Subgroup 4 Total	**140**	**1,143**	**8.16**	**0.96**	**0.96**	**0.14**	**Y**
Shortspine Thornyheads	244	1,941	7.95	0.80	0.99	0.47	Y
Rosethorn Rockfish	50	66	1.32	0.00	0.04	0.47	Y
Greenstripe Rockfish	21	21	1.00	0.00	0.00	0.76	Y
Darkblotch Rockfish	5	6	1.20				
Harlequin Rockfish	1	1	1.00				
Sharpchin Rockfish	2	1	0.50				
Rockfish Subgroup 5 Total	**272**	**2,036**	**7.49**	**0.82**	**1.01**	**0.07**	**Y**
Copper Rockfish	7	6	0.86				
Quillback Rockfish	38	537	14.13	0.95	1.04	-0.32	Y
Rockfish Subgroup 6 Total	**39**	**543**	**13.92**	**0.95**	**1.05**	**-0.41**	**Y**
Unidentified Rockfishes	1	1	1.00				
All Rockfish	**381**	**19,325**	**50.72**	**0.99**	**1.01**	**1.07**	**Y**
Elasmobranchs							
Spiny Dogfish	301	4,477	14.87	0.99	1.02	0.90	Y
Blue Shark	17	12	0.71				
Sleeper Shark	13	15	1.15				
Soupfin Shark	4	3	0.75				
Six Gill Shark	2	2	1.00				
All Sharks	**313**	**4,509**	**14.41**	**0.99**	**1.02**	**0.86**	**Y**
Longnose Skate	338	2,001	5.92	0.88	0.94	0.61	Y
Big Skate	152	364	2.39	0.61	0.65	0.47	Y
Sandpaper Skate	65	106	1.63	0.68	1.19	-0.23	Y
Starry Skate	7	2	0.29				
Black/Roughtail Skate	11	14	1.27				
Deep Sea Skate	1	1	1.00				
All Skates	**355**	**2,552**	**7.19**	**0.95**	**1.03**	**0.11**	**Y**
Ratfish	115	384	3.34	0.90	1.00	0.14	Y

* - relative to observer estimate

b) Flatfish, Other Fish, Invertebrates and Seabirds.

Species	Number Of Sets	Total Catch*	Mean # per Set*	r^2 (correlation)	*m* (slope)	*b* (y-intercept)	Scatter Plot
Flatfish							
Pacific Halibut	365	23,945	65.60	0.96	0.96	3.60	Y
Arrowtooth Flounder	282	4,068	14.43	0.84	0.84	0.21	Y
Flatfish Subgroup 1 Total	**382**	**28,013**	**73.33**	**0.96**	**0.94**	**3.90**	**Y**
Petrale Sole	36	62	1.72	0.54	0.71	-0.22	Y
Dover Sole	17	21	1.24	0.58	0.77	-0.25	Y
Rock Sole	11	11	1.00				
Flatfish Subgroup 2 Total	**56**	**94**	**1.68**	**0.59**	**0.75**	**-0.31**	**Y**
All Flatfish	**383**	**28,107**	**73.39**	**0.96**	**0.95**	**3.70**	**Y**
Other Fish							
Sablefish	293	16,794	57.32	0.98	1.03	-0.03	Y
Lingcod	229	1,643	7.17	0.97	1.01	0.44	Y
Pacific Cod	54	106	1.96	0.72	0.84	0.05	Y
Pollock	4	6	1.50				
Hagfish	5	5	1.00				
Pacific Flatnose	1	1	1.00				
Grenadiers	18	81	4.50	0.76	0.77	0.03	
Sculpin	5	4	0.80				
Eelpout	2	3	1.50				
Unidentified Fish	4	8	2.00				
All Other Fish	**384**	**18,651**	**48.57**	**0.99**	**1.03**	**0.60**	**Y**
Invertebrates							
Octopus	10	7	0.70				
Echinoderms	116	565	4.87	0.48	0.41	0.44	Y
Anthozoans	42	70	1.67				
Arthropods	2	1	0.50				
Sponges	15	18	1.20				
Gastropods	19	113	5.95				
Scallops	2	1	0.50				
Invertebrates Total	**140**	**778**	**5.56**	**0.38**	**0.32**	**0.33**	**Y**
Seabirds							
Black-footed Albatross	1	1	1.00				
Seabird Total	**1**	**1**	**1.00**				
Total Fish Catch	**391**	**73,528**	**188.05**	**0.96**	**0.97**	**0.53**	**Y**
Total All Catch	**391**	**74,307**	**190.04**	**0.94**	**0.98**	**8.12**	**Y**
Total Empty Hooks	**391**	**151,518**	**387.51**	**0.75**	**0.83**	**27.73**	**Y**
Total Hooks and Catch	**391**	**225,825**	**577.56**	**0.90**	**0.92**	**11.95**	**Y**

* - relative to observer estimate

Table 6. Correlation, Slope And Y-Intercept For EM/Observer By Set Treatment.

Hook by Hook Category	Number of Hooks	Percent Overall	Percent with Catch	Percent w/ Catch Pair
Both Blank Hook	59,566	64.5%		
Positive ID	28,976	31.4%	88.3%	92.1%
Negative ID	2,495	2.7%	7.6%	7.9%
EM Fish/Obs Blank Hook	687	0.7%	2.1%	
EM Blank Hook/Obs Fish	639	0.7%	1.9%	
Total Overall	92,363			
Total w/ Catch	32,797			
Total w/ Catch Pair	31,471			

Table 7. Summary Hook Pair Categories From EM/Observer By Hook Treatment.

Species	ID Match (%)	Sample Size	Species	ID Match (%)	Sample Size
Rockfish			**Elasmobranchs**		
Rougheye Rockfish	91.2%	2,809	Spiny Dogfish	98.4%	2,113
Red Banded Rockfish	88.8%	1,813	Blue Shark	75.0%	8
Shortraker Rockfish	34.4%	899	Sleeper Shark	75.0%	4
Shortspine Thornyhead	86.6%	804	Six-gill Shark	0.0%	2
Yelloweye Rockfish	84.1%	705	Salmon Shark	0.0%	1
Silvergray Rockfish	87.2%	398	Soupfin Shark	0.0%	1
Quillback Rockfish	95.1%	183	**Shark Subtotal**	**98.4%**	**2,129**
Yellowmouth Rockfish	6.9%	102	Longnose Skate	95.3%	949
Canary Rockfish	37.6%	93	Big Skate	49.1%	167
Bocaccio Rockfish	55.6%	27	Sandpaper Skate	75.0%	48
Rosethorn Rockfish	10.5%	19	Broad Skate	0.0%	6
Green Stripe Rockfish	66.7%	12	Black/Roughtail Skate	0.0%	2
Pacific Ocean Perch	0.0%	11	Starry Skate	0.0%	2
Yellowtail Rockfish	62.5%	8	Deepsea Skate	0.0%	1
Darkblotch Rockfish	0.0%	3	**Skate Subtotal**	**98.1%**	**1,175**
Tiger Rockfish	50.0%	2	Ratfish	95.8%	144
Subtotal	**99.2%**	**7,888**	**Elasmobranch Subtotal**	**98.2%**	**3,448**
			Other Fish		
			Sablefish	98.9%	6,493
Flatfish			Lingcod	97.6%	678
Pacific Halibut	99.1%	10,705	Pacific Cod	58.3%	60
Arrowtooth Flounder	81.7%	2,060	Granadier	24.0%	25
Petrale Sole	65.6%	32	Pollock	25.0%	4
Dover Sole	42.9%	14	Hagfish	0.0%	2
Rock Sole	0.0%	2	**Subtotal**	**99.1%**	**7,262**
Butter Sole	100.0%	1			
Subtotal	**99.4%**	**12,814**	**Total**	**99.0%**	**31,412**

Table 8. Summary Of The Percentage Of Matching EM And Observer Identifications By Species In The EM/Observer By Hook Treatment. Sample size refers to the observer species totals.

Species Name	Period 1 n	Period 1 Percent	Period 2 n	Period 2 Percent	Period 1 and 2 n	Period 1 and 2 Percent	Change +/-
Pacific Cod	28	32.1%	32	81.3%	60	58.3%	49.1%
Big Skate	106	36.8%	61	70.5%	167	49.1%	33.7%
Petrale Sole	23	56.5%	9	88.9%	32	65.6%	32.4%
Shortraker Rockfish	101	12.9%	798	37.1%	899	34.4%	24.2%
Yellowmouth	65	0.0%	37	18.9%	102	6.9%	18.9%
Arrowtooth Flounder	1,427	76.2%	633	94.0%	2,060	81.7%	17.8%
Shortspine Thornyheads	378	81.5%	332	92.5%	710	86.6%	11.0%
Rosethorn Rockfish	13	7.7%	6	16.7%	19	10.5%	9.0%
Ratfish	80	92.5%	64	100.0%	144	95.8%	7.5%
Yelloweye Rockfish	549	82.7%	156	89.1%	705	84.1%	6.4%
Silvergray Rockfish	356	86.5%	42	92.9%	398	87.2%	6.3%
Redbanded Rockfish	1,004	86.6%	809	91.6%	1,813	88.8%	5.0%
Quillback Rockfish	80	93.8%	103	96.1%	183	95.1%	2.4%
Sablefish	1,876	97.3%	4,617	99.5%	6,493	98.9%	2.2%
Pacific Halibut	9,131	99.0%	1,574	99.7%	10,705	99.1%	0.8%
Spiny Dogfish	1,838	98.4%	275	98.5%	2,113	98.4%	0.1%
Lingcod	430	97.7%	248	97.6%	678	97.6%	-0.1%
Longnose Skate	678	96.2%	271	93.0%	949	95.3%	-3.2%
Rougheye Rockfish	2,035	95.5%	774	79.7%	2,809	91.2%	-15.8%
Total	**20,198**	**93.8%**	**10,841**	**91.4%**	**31,039**	**92.9%**	**-2.3%**

Table 9. Comparison Of Matching EM And Observer Identifications Over Time: Period 1, Prior To July; And Period 2, After July.

Species Category and Name	Total Pieces	Utilization (observer)		% EM Match	
		% kept	% Discard	Kept	Discarded
Rockfish					
Rougheye Rockfish	2,561	99.5%	0.4%	100%	45%
Red Banded Rockfish	1,610	94.8%	3.2%	100%	77%
Shortspine Thornyheads	615	89.4%	8.1%	95%	76%
Yelloweye Rockfish	593	92.4%	6.6%	98%	97%
Silvergray Rockfish	347	78.4%	21.3%	99%	91%
Shortraker Rockfish	309	100.0%	0.0%	100%	
Quillback Rockfish	174	93.1%	6.3%	100%	91%
Canary Rockfish	35	97.1%	2.9%	100%	0%
Bocaccio Rockfish	15	86.7%	13.3%	100%	100%
Greenstripe Rockfish	8	87.5%	12.5%	100%	100%
Yellowmouth	7	100.0%	0.0%	100%	
Yellowtail Rockfish	5	100.0%	0.0%	100%	
Rosethorn Rockfish	2	100.0%	0.0%	100%	
Tiger Rockfish	1	100.0%	0.0%	100%	
Flatfish					
Pacific Halibut	10,608	61.3%	38.3%	92%	80%
Arrowtooth Flounder	1,682	18.6%	81.3%	94%	97%
Petrale Sole	21	57.1%	42.9%	100%	100%
Dover Sole	6	16.7%	83.3%	100%	100%
Butter Sole	1	0.0%	100.0%		100%
Elasmobranchs					
Spiny Dogfish	2,080	0.1%	99.0%	0%	100%
Blue Shark	6	0.0%	100.0%		100%
Sleeper Shark	3	0.0%	100.0%		100%
Longnose Skate	904	19.2%	79.1%	83%	99%
Big Skate	82	18.3%	81.7%	87%	100%
Sandpaper Skate	36	0.0%	100.0%		94%
Ratfish	138	1.4%	98.6%	50%	100%
Other Fish					
Pacific Cod	35	97.1%	2.9%	97%	100%
Pollock	1	0.0%	100.0%		0%
Lingcod	662	50.6%	49.4%	99%	95%
Grenadiers	6	0.0%	83.3%		100%
Sablefish	6,420	63.9%	34.8%	95%	90%

Table 10. Summary Of Matching EM And Observer Records By Species Utilization (EM/Observer By Hook Treatment). The table shows observer utilization determinations and the level of EM agreement with observer.

Species	E Log Totals	EM Totals	% Difference
Rockfishes			
Rougheye Rockfish	18	18	0.00%
Redbanded Rockfish	167	166	0.30%
Shortraker Rockfish	14	9	21.74%
Yelloweye Rockfish	1	0	100.00%
Shortspine Thornyhead	92	93	0.54%
Subtotal	292	286	1.04%
Flatfishes			
Halibut	4,639	4,641	0.02%
Arrowtooth Flounder	165	156	2.80%
Subtotal	4,804	4,797	0.07%
Sharks and Skates			
Dogfish	764	764	0.00%
Big Skate	26	11	40.54%
Other			
Pacific Cod	3	2	20.00%
Sablefish	1,033	1,123	4.17%
Lingcod	1	1	0.00%
Total	6,923	6,984	0.44%

Table 11. Comparison Of EM And Electronic Fishing Log Data. The catch estimates from the electronic fishing log were recorded by the skippers from participating vessels.

Species Name	Percent Difference*	r2	Percent Match	Sample Size overall	by hook	by set
Pacific Halibut	4.1%	0.96	99.1%	23,945	10,705	365
Sablefish	3.0%	0.98	98.9%	16,794	6,493	293
Rougheye Rockfish	9.6%	0.95	91.2%	6,879	2,809	194
Spiny Dogfish	7.6%	0.99	98.4%	4,477	2,113	301
Redbanded Rockfish	4.2%	0.93	88.8%	4,201	1,813	295
Arrowtooth Flounder	14.7%	0.84	81.7%	4,068	2,060	282
Shortraker Rockfish	45.5%	0.52	34.4%	2,532	899	137
Longnose Skate	4.8%	0.88	95.3%	2,001	949	338
Shortspine Thornyheads	5.2%	0.80	86.6%	1,941	804	244
Lingcod	6.8%	0.97	97.6%	1,643	678	229
Yelloweye Rockfish	5.8%	0.88	84.1%	1,446	705	175
Silvergray Rockfish	3.1%	0.96	87.2%	1,043	398	127
Quillback Rockfish	2.0%	0.95	95.1%	537	183	38
Ratfish	4.4%	0.90	95.8%	384	144	115
Big Skate	15.4%	0.61	49.1%	364	167	152
Yellowmouth	52.7%	0.03	6.9%	256	102	60
Canary Rockfish	14.0%	0.45	37.6%	236	93	38
Pacific Cod	5.7%	0.72	58.3%	106	60	54
Sandpaper Skate	4.7%	0.68	75.0%	106	48	65
Bocaccio Rockfish	3.7%	0.08	55.6%	81	27	61
Grenadiers	22.2%	0.76	24.0%	81	25	18
Rosethorn Rockfish	60.6%	0.00	10.5%	66	19	50
Petrale Sole	41.9%	0.54	65.6%	62	32	36
Pacific Ocean Perch		0.20	0.0%	36	11	21
Dover Sole		0.58	42.9%	21	14	17
Greenstripe Rockfish		0.00	66.7%	21	12	21
Sleeper Shark			75.0%	15	4	13
Black/Roughtail Skate			0.0%	14	2	11
Yellowtail Rockfish			62.5%	14	8	14
Blue Shark			75.0%	12	8	17
Redstripe Rockfish				11		1
Rock Sole			0.0%	11	2	11
Copper Rockfish				6		7
Darkblotch Rockfish				6		5
Pollock			25.0%	6	4	4
Hagfish			0.0%	5	2	5
Tiger Rockfish			50.0%	5	2	9
Dusky Rockfish				4		2
Sculpin				4		5
Eelpout				3		2
Soupfin Shark			0.0%	3	1	4
Six Gill Shark			0.0%	2	2	2
Starry Skate			0.0%	2	2	7
Deep Sea Skate			0.0%	1	1	1
Harlequin Rockfish			0.0%	1	3	1
Pacific Flatnose				1		1
Sharpchin Rockfish				1		2
Widow Rockfish				1		1
Black Rockfish				0		
Butter Sole			100.0%	0	1	
Rougheye/Shortraker				0		
Salmon				0		
Wolf Eel				0		
Broad Skate			0.0%	0	6	
Salmon Shark			0.0%	0	1	
Totals				**73,455**	**31,412**	**3,851**

Table 12. EM Species Recognition Results Summarized from Tables 5,6 and 8.

a) Identification Possible from Primary Feature

Rockfish		Primary Feature Discerned	Secondary Feature Visible	Secondary Feature Specimen Required	Other Information
Redbanded Rockfish	H	4 broad red bands			deeper (>80fm)
Tiger Rockfish	H	5 dark bands			shallow (<30fm) rocky
Canary Rockfish	H	mottled yellow color	anterior sloping anal fin		
Darkblotch Rockfish	H	5 dark blotches dorsally		blunt symphyseal, 3>2 anal spine	
Redstripe Rockfish	H	red lateral line on green body		foreward symphyseal, 2=3 anal spine	
Greenstriped Rockfish	H	3 to 4 green stripes	rounded body	small fish, 2>3 anal spine	
Rosethorn Rockfish	H	green/pink colour, pink white spots	pink/white spots dorsally	small fish, 2>3 anal spine	
Shortspine Thornyheads	H			3rd dorsal spine not longest, pale in mouth	likely if depth <250fm
Longspine Thornyheads	H			3rd dorsal spine is longest, dark in mouth	
Bocaccio Rockfish	H	uniform olive or burnt orange color		deep notch in dorsal fin	
Silvergrey Rockfish	H	silvergrey dorsal, pink white ventral		moderate notch in dorsal	
China Rockfish	H	black and yellow color, yellow lateral line			
Elasmobranchs					
Spiny Dogfish	H	2 dorsal fins preceeded by spines, no anal fin	grey dorsal, white ventral, spots in young		
Salmon Shark	H	torpedo shape with keel on caudal peduncle	2nd dorsal and anal very small		
Sixgill Shark	H	grey/brown dorsally, whiter ventral, one dorsal fin		six gill slits	
Pacific Sleeper Shark	H	black/brown colouration throughout	2 dorsal fins, no anal fin (floppy fins)		
Brown Cat Shark	H	very small size, brown color	2 dorsal fins far back on body, one anal		
Spotted Ratfish	H	large snout, spotted colour	one gill slit		
Flatfish					
Pacific Halibut	H	robust body, white blind side, marbled brown	semi forked tail		
Arrowtooth Flounder	H	deciduous scales, grey color, grey blind side	forked tail, partially migrated left eye		
Starry Flounder	H	dark bands on dorsal, anal and caudal fins			
English Sole	H	diamond body, pointed head			
Other Fish					
Sablefish	H	black/grey coloration, forked tail	short fins (2 dorsal. 1 anal)		
Pacific Hake	H	silver coloration, semi forked tail	elongated fins (2 dorsal, 1 anal)		not common on LL
Lingcod	H	mottled green/brown colour, large mouth, fanlike pects	no spotting		
Pacific Cod	H	mottled green/white color, 3 dorsal, 2 anal fins	large barbel		
Walleye Pollock	H	mottled green color, 3 dorsal, 2 anal fins -- purple head	no barbel, purple tinged fins		
Pacific Tomcod	H	green/brown dorsally --- silver sheen	small barbel, small fish		shallow water, small fish -- no LL
Wolf Eel	H	elongate body, large dark spots on body	no pelvic fins		
Grenadiers	H	long tapered body with caudal, dorsal and anal fins merged	ridge below eyes forms "pointed" rostrum	speciation requires specimens?	
Hagfish	H	no paired fins, no jaw	speciation by colour		

Table 13. Recognition Characteristics Of Fish Species In The Halibut Fishery. The table is in three parts: A (above), species easily identified by primary feature; B (next page), species identified by primary and secondary feature; and C (next page), species identified only by close inspection.

b) Identification Possible from Secondary Feature

Rockfish		Primary Feature Discerned	Secondary Feature Visible	Secondary Feature Specimen Required	Other Information
Yelloweye Rockfish	M	yellow orange colouration, deep body	rounded anal fin		
Yellowmouth Rockfish	M	yellow orange colouration, moderate body	dusky blotch on operculum,	yellow and black in mouth	
Pacific Ocean Perch	M	bright red pectoral fins		foreward symphyseal, 3>2 anal spine	
Sharpchin Rockfish	M	red colour with dusky blotches	indented forehead	foreward symphyseal, 2>3 anal spine	
Harlequin Rockfish	M	red colour with dusky blotches	black dorsal fin membrane		rare catch item
Yellowtail Rockfish	M	green color, yellow tinged fins	anal fin vertical, pectoral = pelvic fin		
Widow Rockfish	M	brown color	anal fin slants posterior, pectoral>pelvic		
Dusky Rockfish	M	brown / black colour -- depends on depth	anal vertical, pectoral>pelvic		not common below Dixon Entrance
Black Rockfish	M	mottled black/grey colour	rounded anal fin slants anterior		shallow water
Quillback Rockfish	M	brown speckling on yellow	deeply incised dorsal fin spines		
Copper Rockfish	M	brown with copper/pink	posterior 2/3 of lateral line clear		
Vermillion Rockfish	M	bright red mottled on grey color	rounded anal fin		shallow
Splitnose Rockfish	M	red colour, washed out appearance		2 toothed lobes form upper jaw	
Aurora Rockfish	M	bright red colouration		2>3 anal spine (marked difference	deep water with Rougheye, rare
Elasmobranchs					
Longnose Skate	M	very concave pectorals, dark spot at base of pectorals	Dark (grey/black) ventral side		
Deepsea Skate	M	concave pectorals, no spots on pectorals	Dark (grey/black) ventral side	3 scapular spines confirm id	deep water only
Big Skate	M	slightly concave pectorals, ocelli on pectorals	white ventral side		
Starry Skate	M	convex pectorals, numerous spots on grey dorsal			
Sandpaper Skate	M	convex pectorals (brown to grey dorsally)	white ventral side		
Black/Roughtail Skate	M	convex pectorals (black / grey dorsally)	Dark (grey/black) ventral side		deep water
Soupfin Shark	M	enlarged upper lobe of caudal	2 dorsal fins, one anal fin, grey colur		
Blue Shark	M	slender body form, elongated pectoral fins	striking blue coloration		
Flatfish					
Dover Sole	M	slender body, small mouth,	short pectoral fin		small mouth --- not caught often
Rex Sole	M	slender body, small mouth,	long pectoral fin		small mouth --- not caught often
Curlfin Sole	M	round body	eyed side uniform brown color	dorsal fin extends past mouth on blind side	shallow, small mouth -- not caught often
C-O Sole	M	round body	eyed side brown with blotching (dot)	dorsal fin doesn't extend past mouth on blind side	shallow, small mouth -- not caught often
Pacific Sanddab	M	left eyed flounder, small, deciduous scales	no spotting on eyed side	pectoral extends to orbit	
Speckled Sanddab	M	left eyed flounder, small, deciduous scales	spotting on eyed side	pectoral doesn't extend to orbit	very shallow, no LL catches
Other Fish					
Greenlings	M	mottled green/brown colour, small mouth, fanlike pects	spotting easily deiscerned		
Eelpouts	M	long slender body with caudal, dorsal and anal merged	overhanging upper jaw	speciation requires specimens?	
Pricklebacks	M	long slender compressed body, anal fin large		speciation requires specimens?	
Chinook Salmon	M	black spotting dorsally and on both lobes of tail		black gums	
Oncorhynchus sp.	M		some speciation	some speciation requires specimens	

c) Close-Up View or Specimen Required

Rockfish		Primary Feature Discerned	Secondary Feature Visible	Secondary Feature Specimen Required	Other Information
Rougheye Rockfish	L	deep red / black colouration		long gill rakers on first gill arch	
Shortraker Rockfish	L	pink-red colouration (faint red banding)		short gill rakers on first gill arch	
Flatfish					
Petrale Sole	L	diamond body profile, large mouth		slight interorbital ridge, 2 rows of teeth upper jaw	
Flathead Sole	L	diamond body profile, large mouth		raised interorbital ridge, 1 row of teeth upper jaw	
Rock Sole	L	oval body, small mouth		short accessory lateral line	small mouth --- not caught often
Butter Sole	L	oval body, small mouth		long accessory lateral line	small mouth --- not caught often
Other Fish					
Cabezon	L	marbeled coloration		flaplike cirrus on snout	
Sculpins	L	large head, narrow caudal peduncle region		speciation requires specimens?	

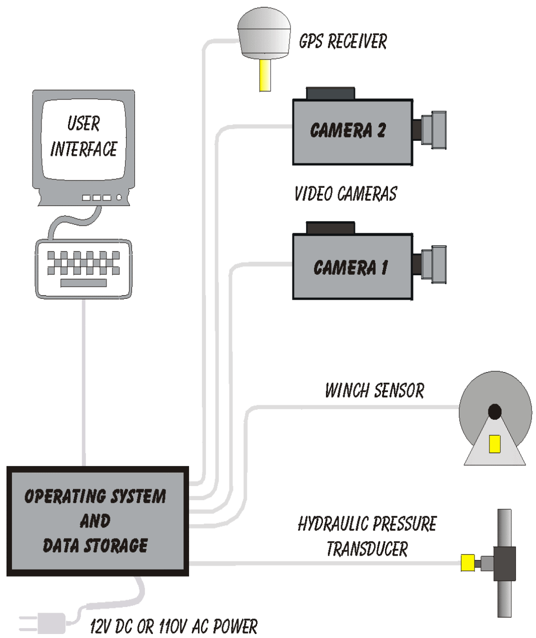


Figure 1. Schematic Diagram Of The EM System.

Figure 2. Example Of Paired Camera Imagery: A) Initial configuration with one camera mounted on the mast providing a view of the deck and another camera mounted on the stabilizer providing a view of the side of the vessel where the fish are brought aboard; and B) Modified configuration with both cameras mounted on stabilizer and equipped with close focus (left) and wide angle view (right).

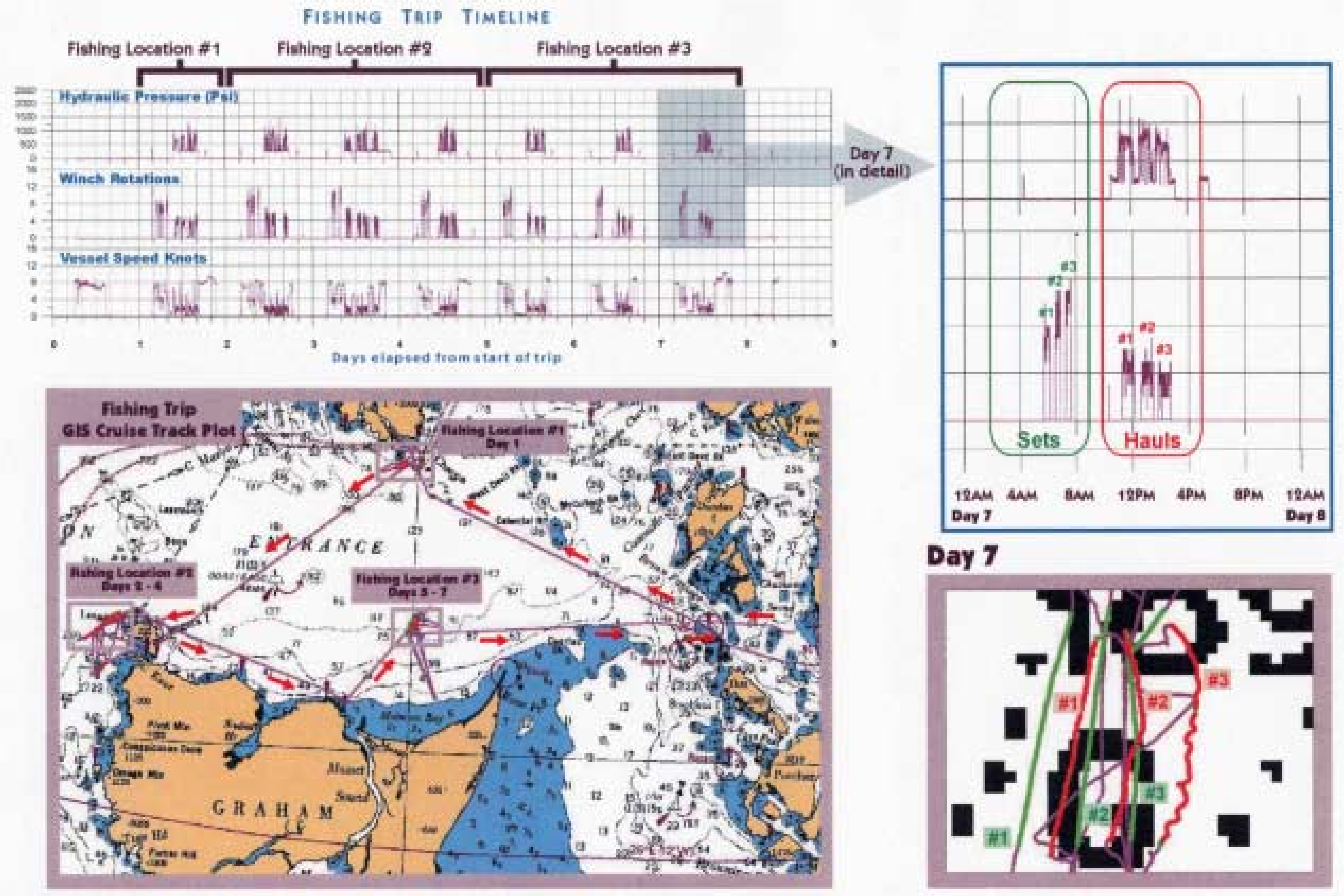


Figure 3. Example Of Time Series Graph And GIS Plot For A Halibut Fishing Trip. Time series graph (upper left) shows sensor data for entire fishing trip. Close-up graph (upper right) shows sensor data for setting and hauling. GIS plot (lower left) shows cruise track for fishing trip with lower right showing set and haul details.

A B

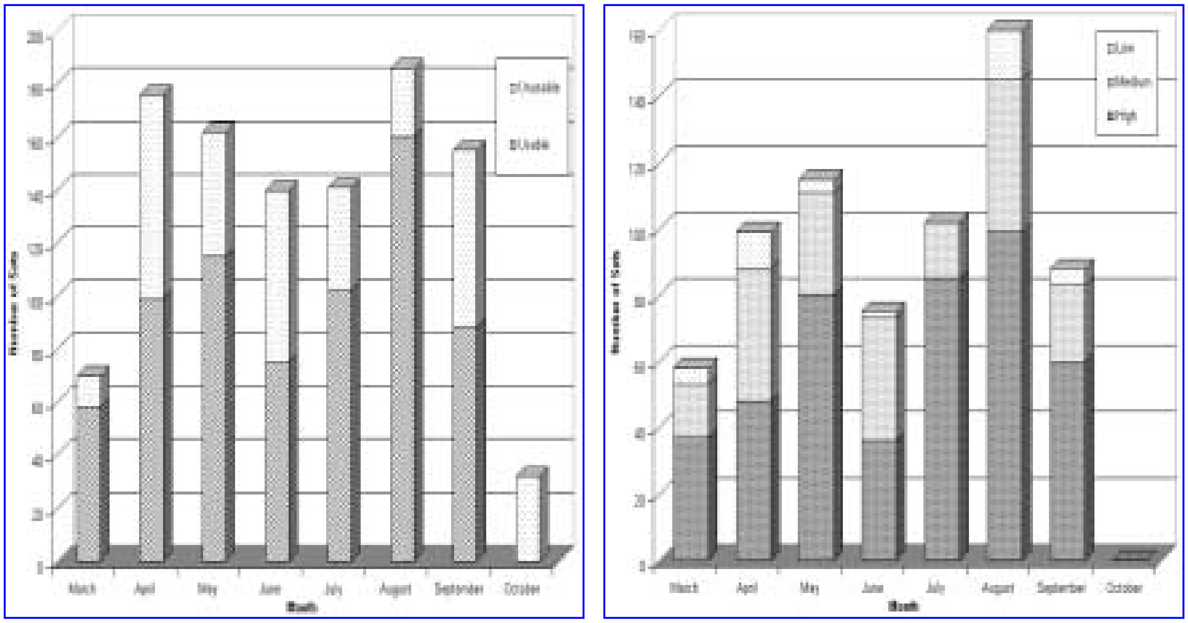


Figure 4. Summary Of Monthly EM Deployment Totals. A, denotes monthly totals of all sets broken out by usability; B, denotes usable sets by low, medium, and high quality criteria. See text for definition of usability and quality categories.

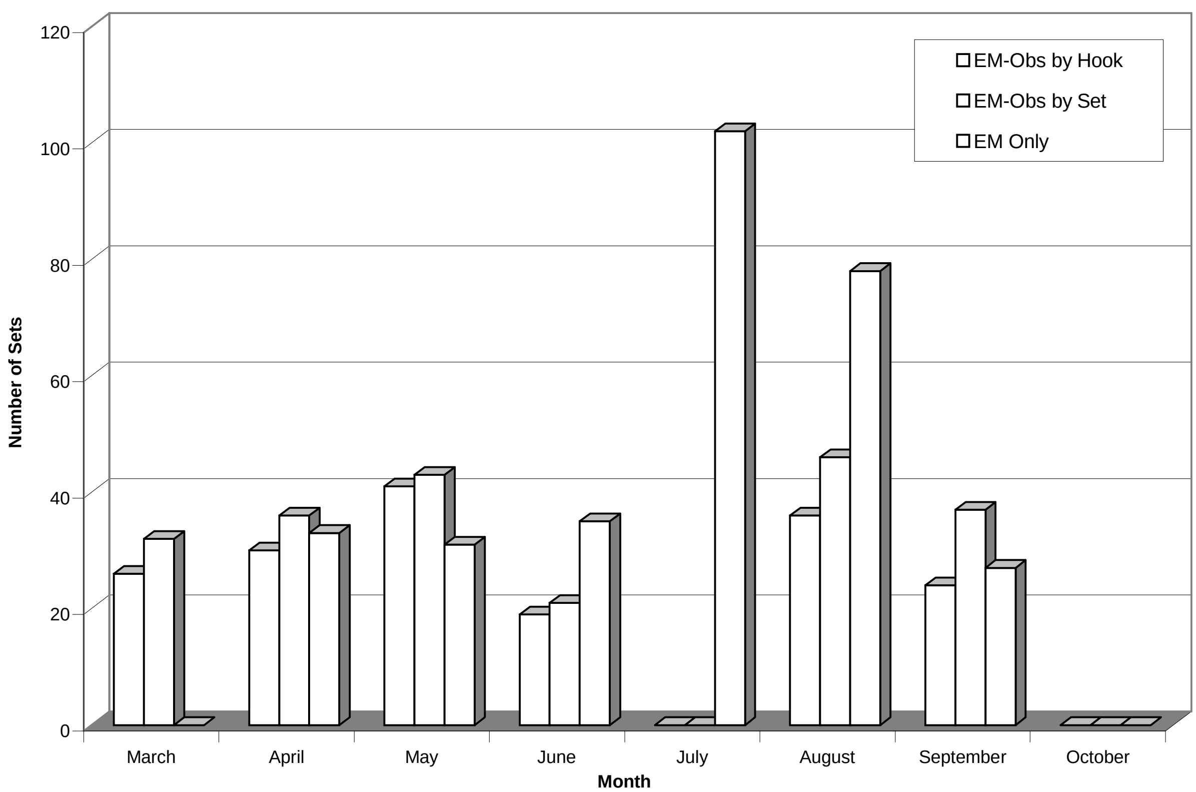


Figure 5. Summary Of Monthly EM Deployments By Treatment Category. See text for description of categories.

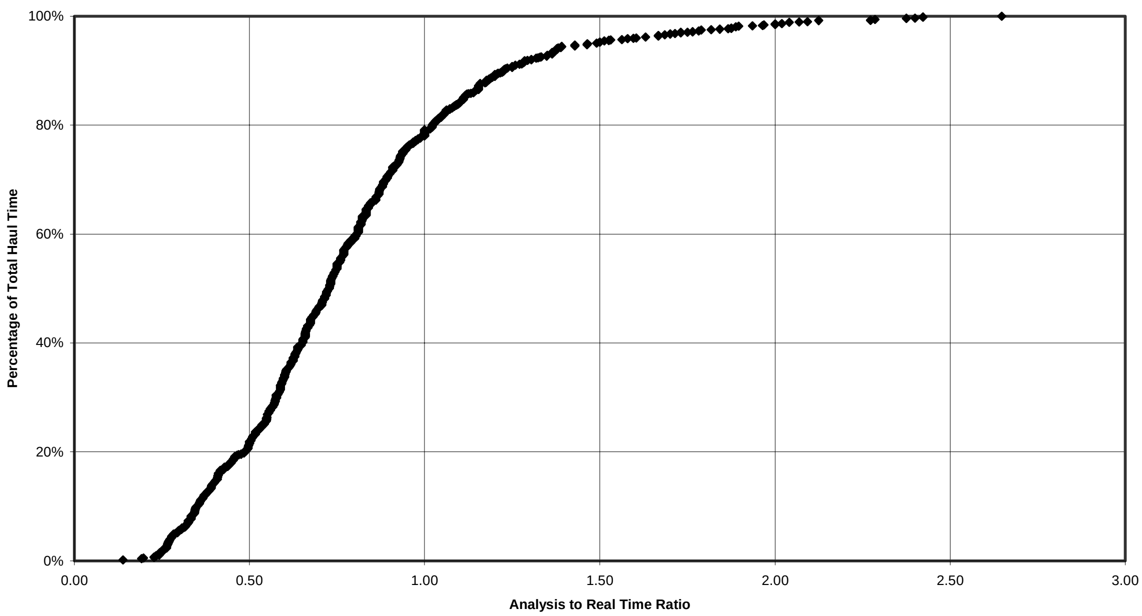


Figure 6. Plot Showing The Relationship Between Cumulative Total Haul Time (%) And Analysis Time To Real Time Ratio, In Increasing Order. The line shows the proportion of haul times associated with different ratios.

1.1. A Before Changes (Orginal Data)

Observer			Viewer			Change Code
Hook #	Util	Species	Hook #	Util	Species	
502			**502**			
503			**503**	6	614	
504	1	614	**504**			
505	6	602	**505**	6	614	
506	6	602	**506**	1	614	
507	6	614	**507**	6	602	
508			**508**	6	614	
509			**509**	6	614	
510			**510**			
511	1	614	**511**			
512	6	602	**512**			
513	1	614	**513**	1	614	
514	1	614	**514**	6	602	
515	1	614	**515**	1	614	
516	6	602	**516**	1	614	
517	1	614	**517**	1	614	
518			**518**	6	614	
519	6	602	**519**	1	614	
520	6	614	**520**			
521	6	614	**521**	6	602	
522			**522**			
523	1	614	**523**	6	614	
524	1	614	**524**	6	614	
525	6	602	**525**			
526			**526**	1	614	
527			**527**	1	614	
528	6	602	**528**	6	597	
529			**529**			
530			**530**	6	614	
531	1	614	**531**			

1.2. B After Changes (Aligned Data)

Observer			Viewer			Change Code
Hook #	Util	Species	Hook #	Util	Species	
502			**502**			
503			**503**	6	614	f
504			**504**			
505			**505**	6	614	f
506	1	614	**506**	1	614	
507	6	602	**507**	6	602	
508	6	602	**508**	6	614	
509	6	614	**509**	6	614	
510			**510**			
511			**511**			
512			**512**			
513	1	614	**513**	1	614	
514	6	602	**514**	6	602	
515	1	614	**515**	1	614	
516	1	614	**516**	1	614	
517	1	614	**517**	1	614	
518	6	602	**518**	6	614	
519	1	614	**519**	1	614	
520			**520**			
521	6	602	**521**	6	602	
522			**522**			x
523	6	614	**523**	6	614	
524	6	614	**524**	6	614	
525			**525**			
526	1	614	**526**	1	614	
527	1	614	**527**	1	614	
528	6	602	**528**	6	597	
529			**529**			
530	6	602	**530**	6	614	xx
531			**531**			

Figure 7. Example Of EM/Observer By Hook Data Set Alignment: Before (A) And After (B). Change code f, denotes blank hook added to align missed fish; x, denotes hook added; and xx, denotes hook removed.

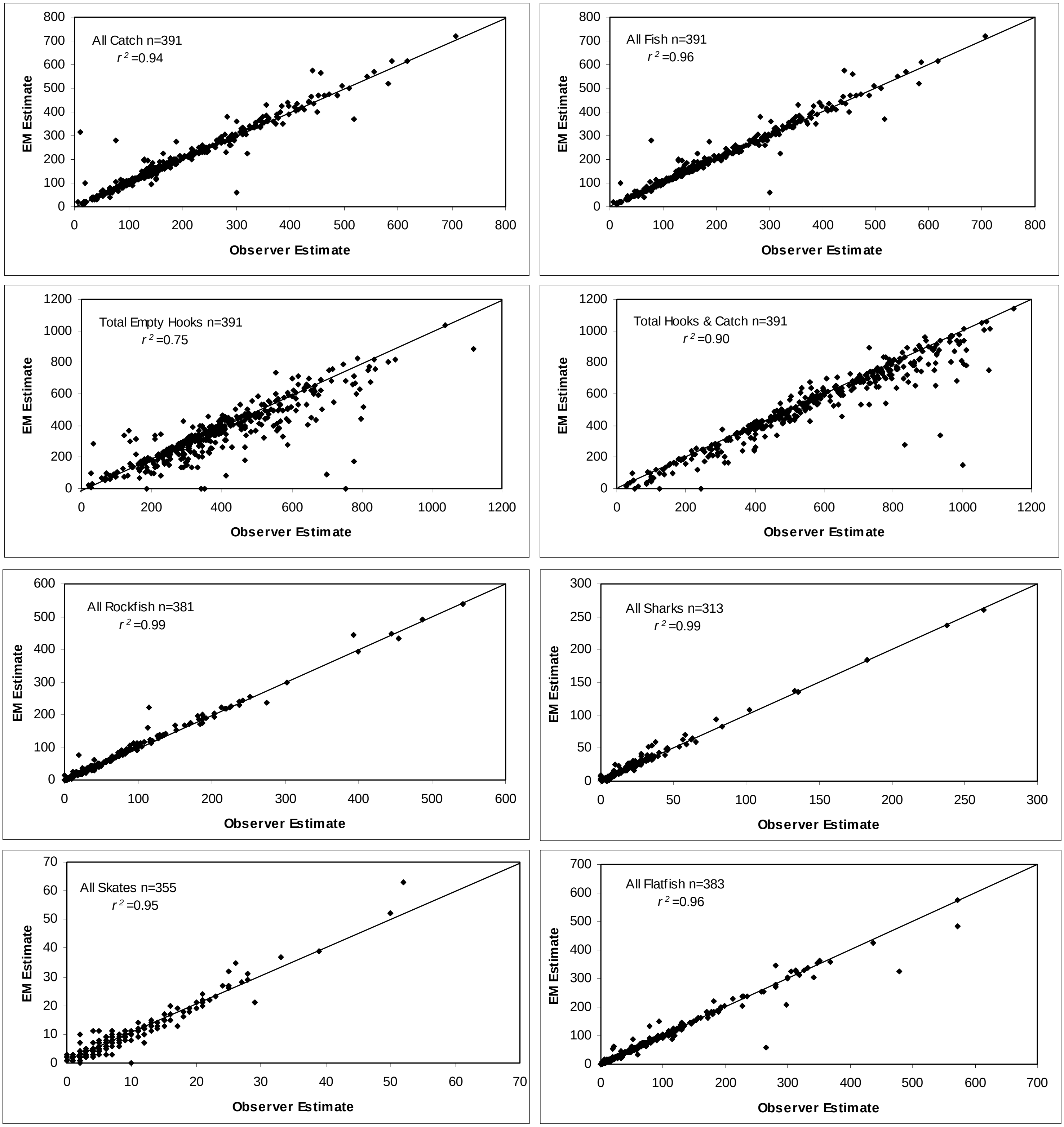


Figure 8. EM And Observer Catch Totals By Set For The Major Groups Of Fish. The sample size (n) denotes number of sets and the 1:1 line was added to illustrate expected correlation (i.e., EM estimates equal to Observer estimates).

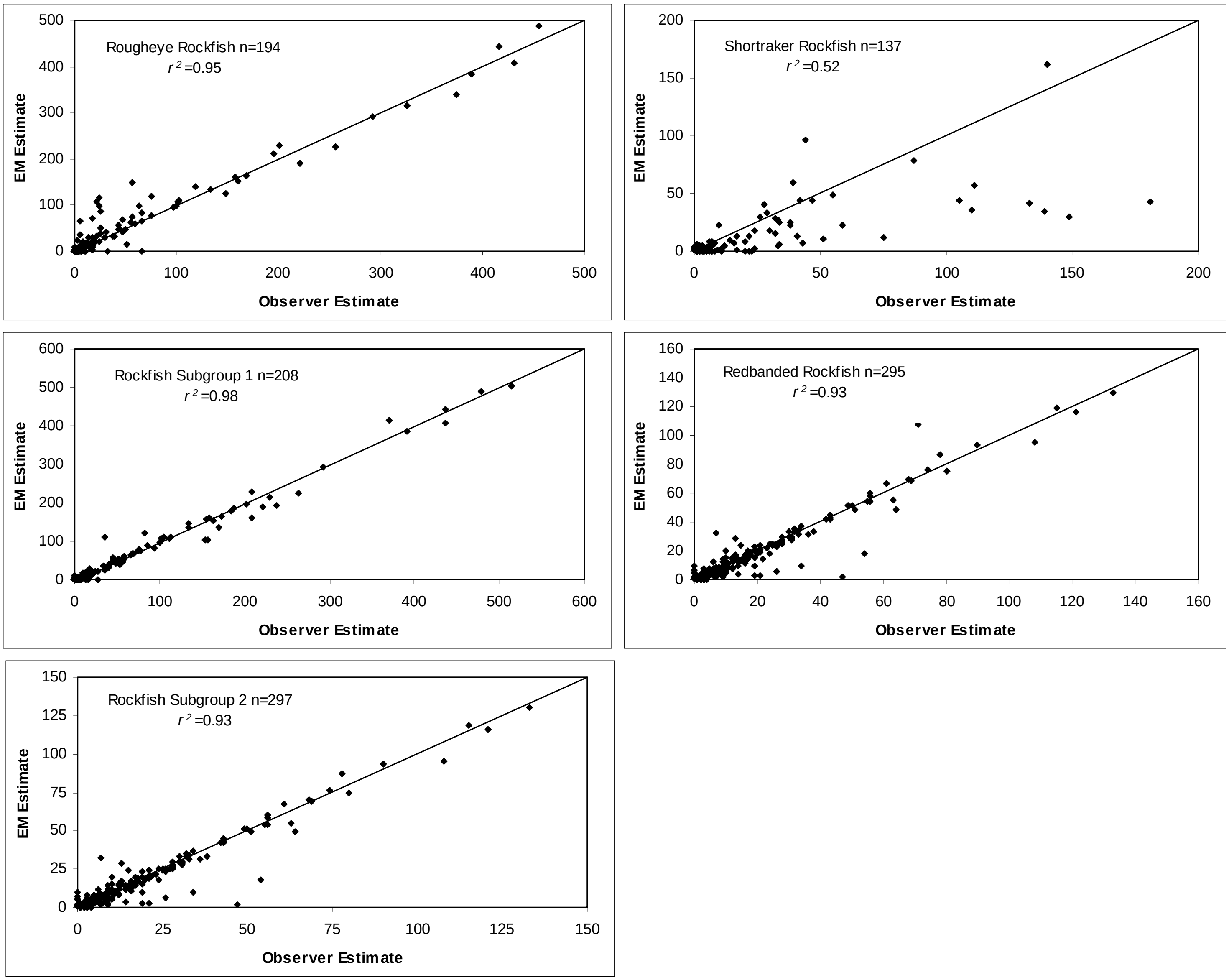


Figure 9. EM And Observer Catch Totals For Rockfish Subgroups 1 & 2 (See Table 6). The sample size (n) denotes number of sets and the 1:1 line was added to illustrate expected correlation (i.e., EM estimates equal to Observer estimates).

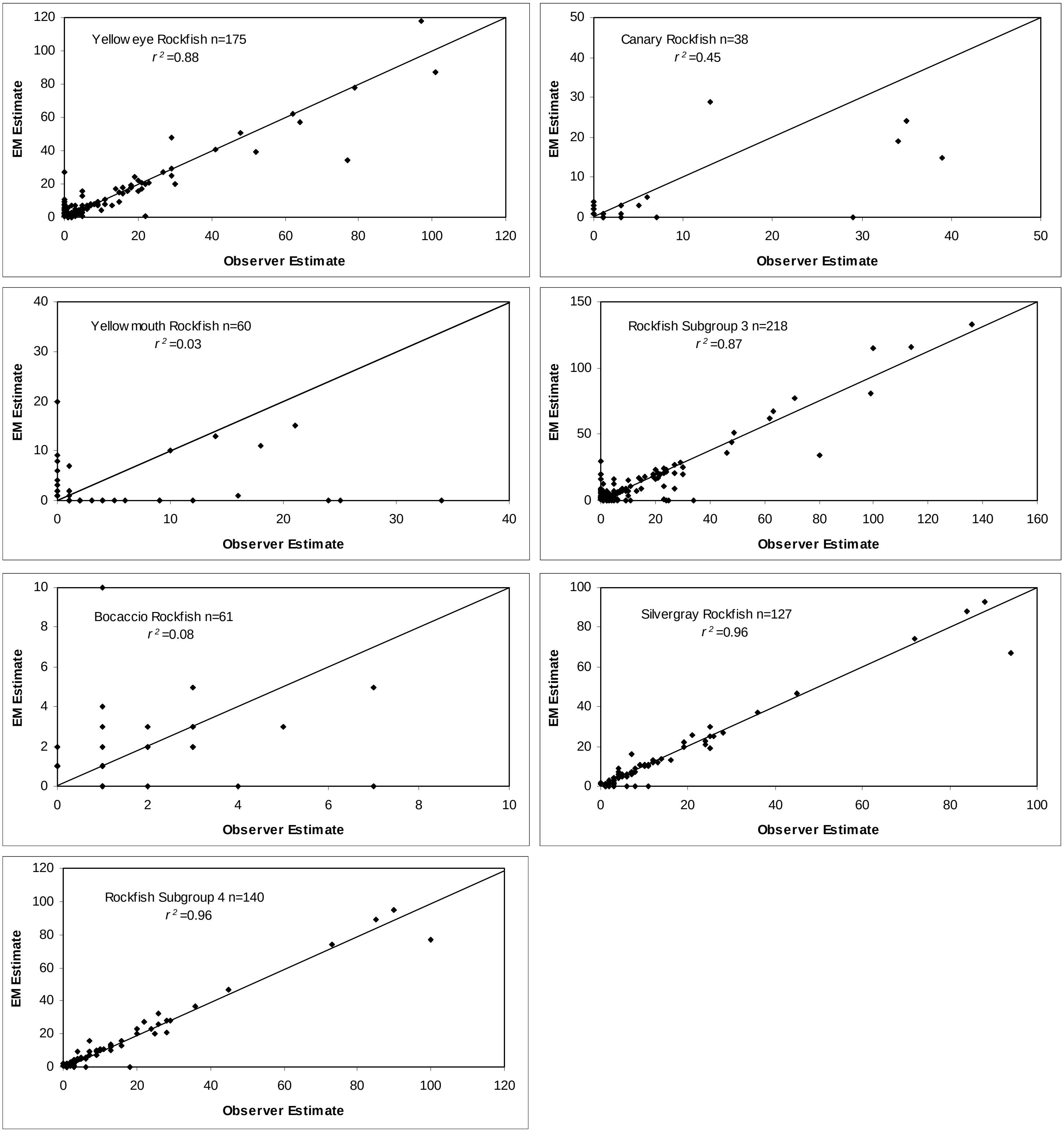


Figure 10. EM And Observer Catch Totals For Rockfish Subgroups 3 & 4 (See Table 6). The sample size (n) denotes number of sets and the 1:1 line was added to illustrate expected correlation (i.e., EM estimates equal to Observer estimates).

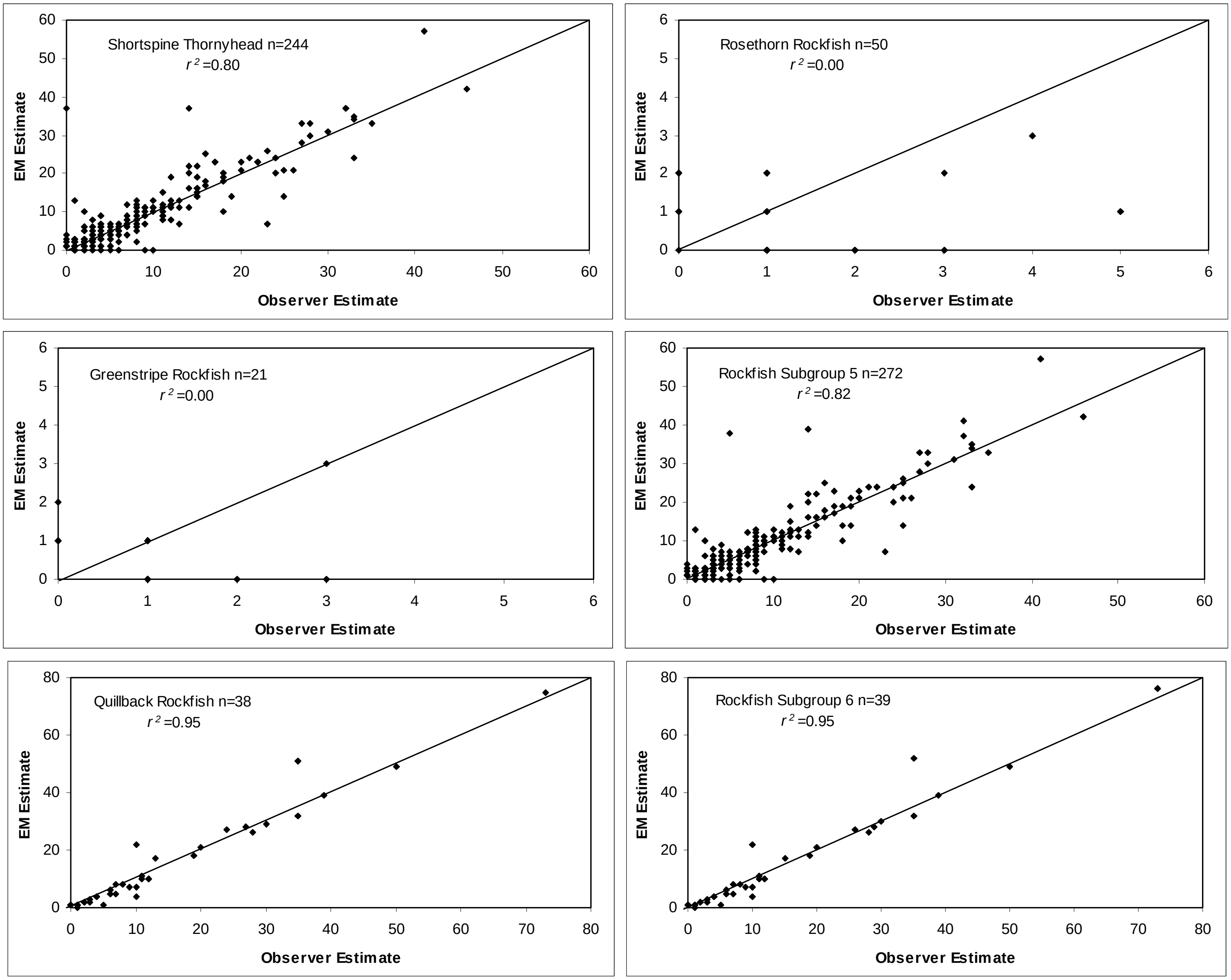


Figure 11. EM And Observer Catch Totals For Rockfish Subgroups 5 & 6 (See Table 6). The sample size (n) denotes number of sets and the 1:1 line was added to illustrate expected correlation (i.e., EM estimates equal to Observer estimates).

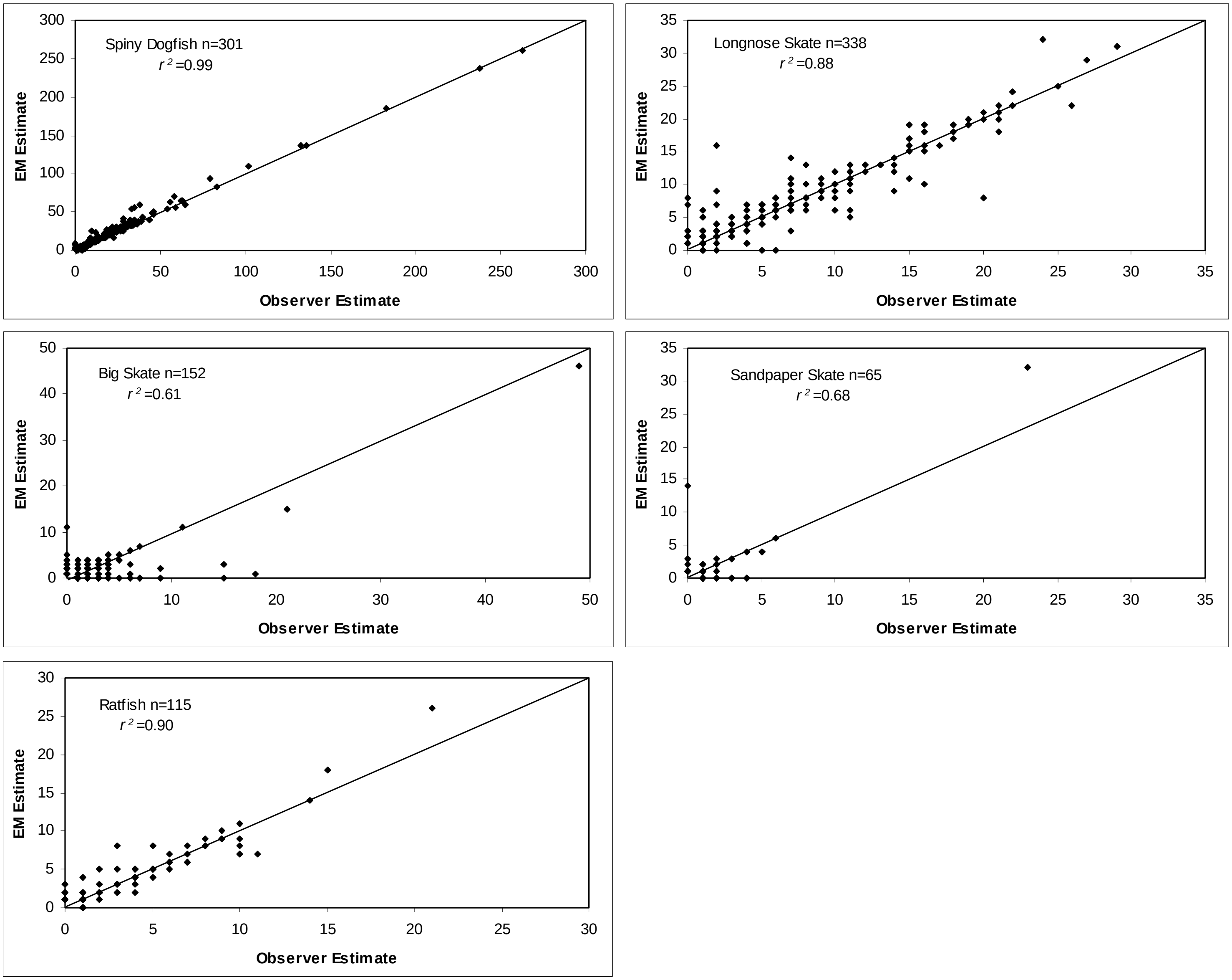


Figure 12. EM And Observer Catch Totals For Elasmobranchs. The sample size (n) denotes number of sets and the 1:1 line was added to illustrate expected correlation (i.e., EM estimates equal to Observer estimates).

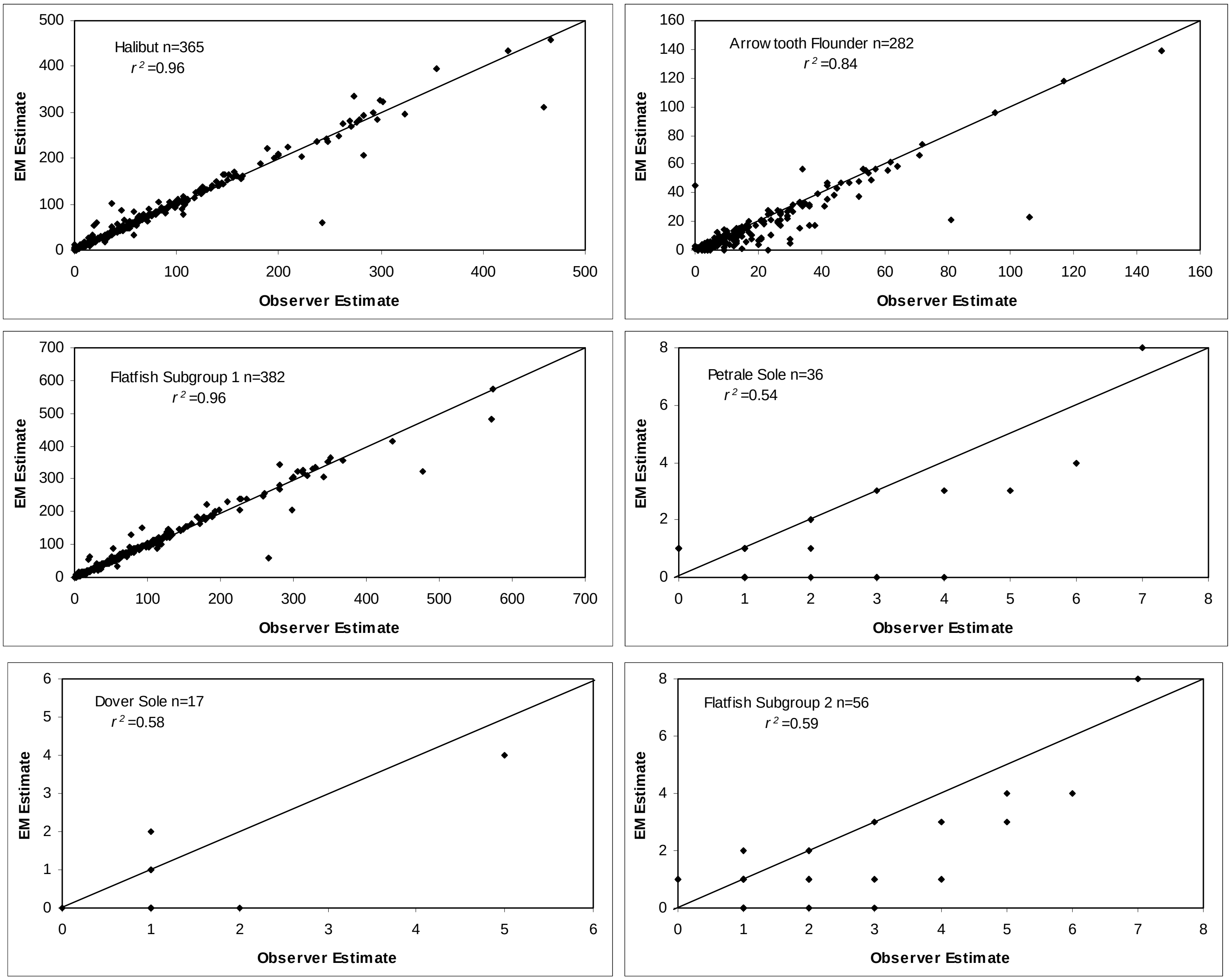


Figure 13. EM And Observer Catch Totals For Flatfish. The sample size (n) denotes number of sets and the 1:1 line was added to illustrate expected correlation (i.e., EM estimates equal to Observer estimates).

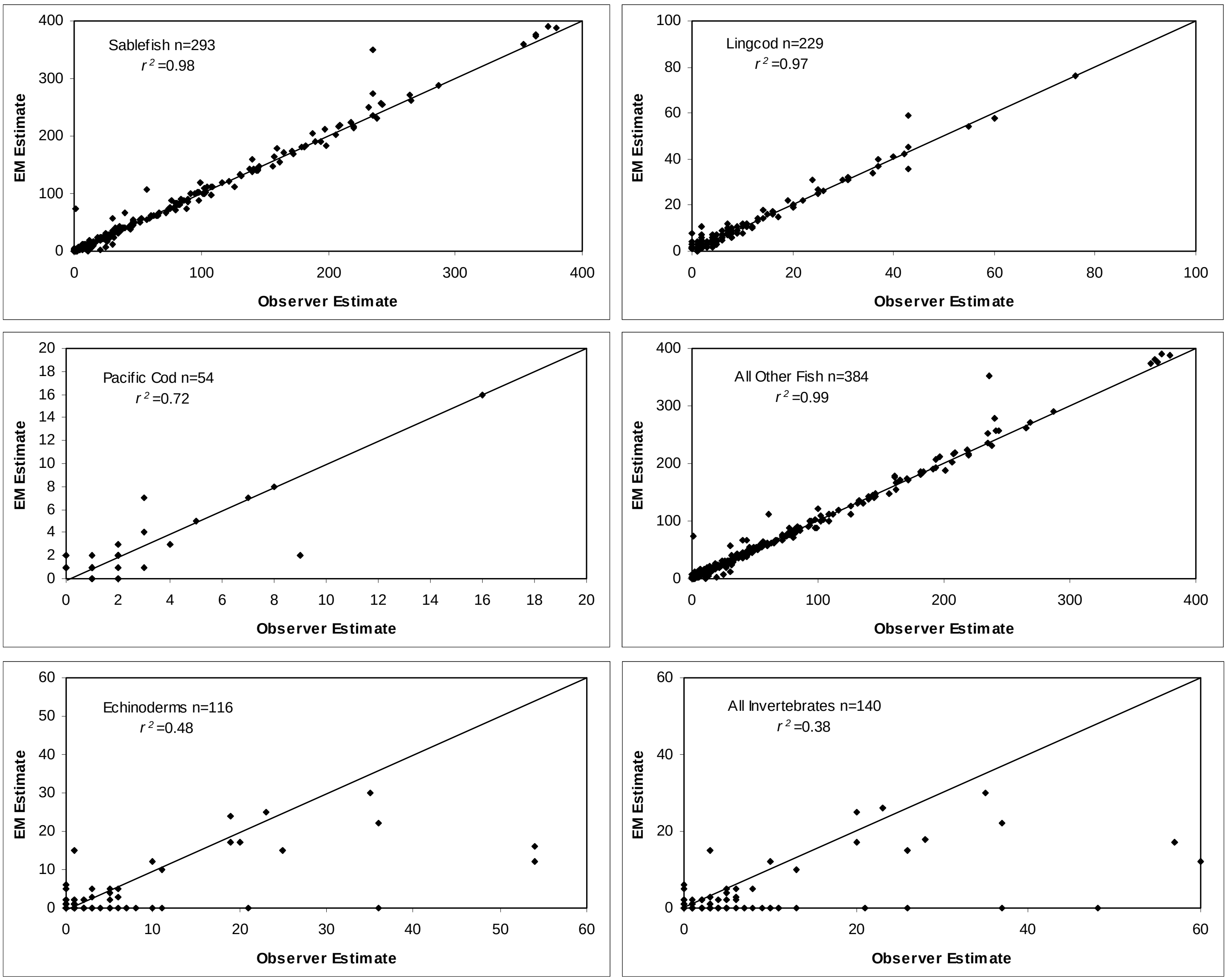


Figure 14. EM And Observer Catch Totals For Other Fish And Invertebrates. The sample size (n) denotes number of sets and the 1:1 line was added to illustrate expected correlation (i.e., EM estimates equal to Observer estimates).

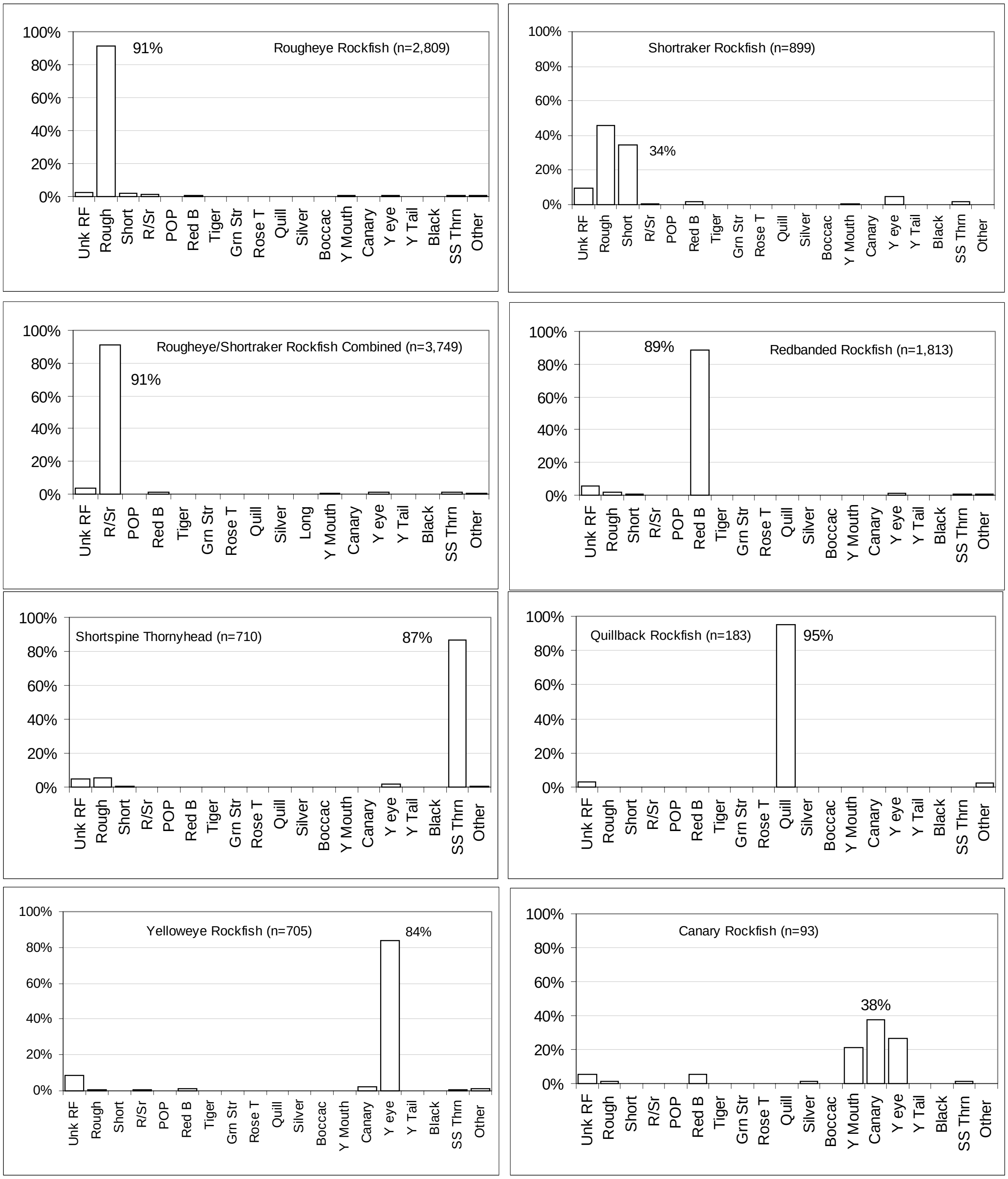


Figure 15. EM Identification for Rockfish #1 – Histograms showing the EM species identification pattern for species identifications by the Observer.

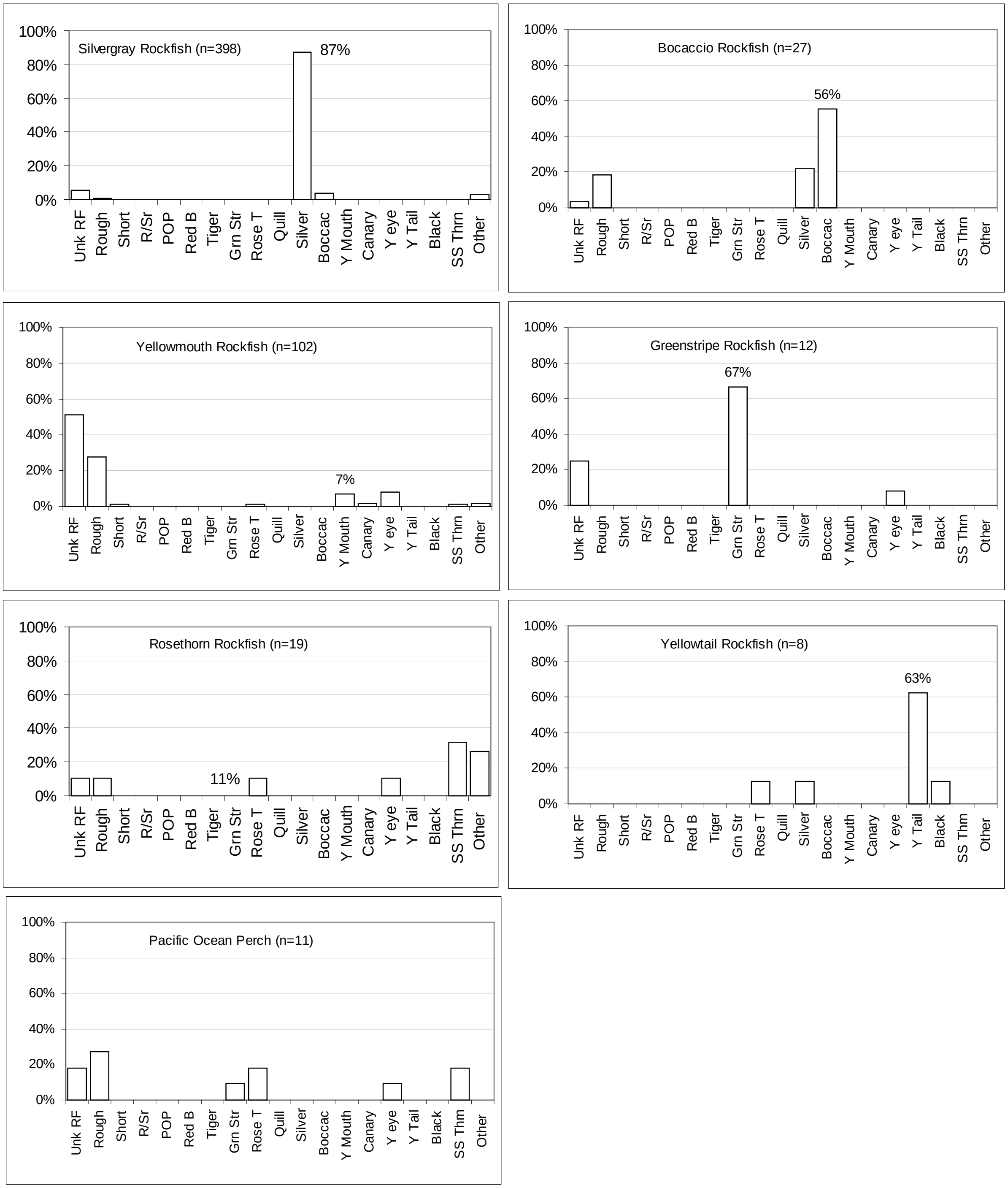


Figure 16. EM Identification for Rockfish #2 - Histograms showing the EM species identification pattern for species identifications by the Observer.

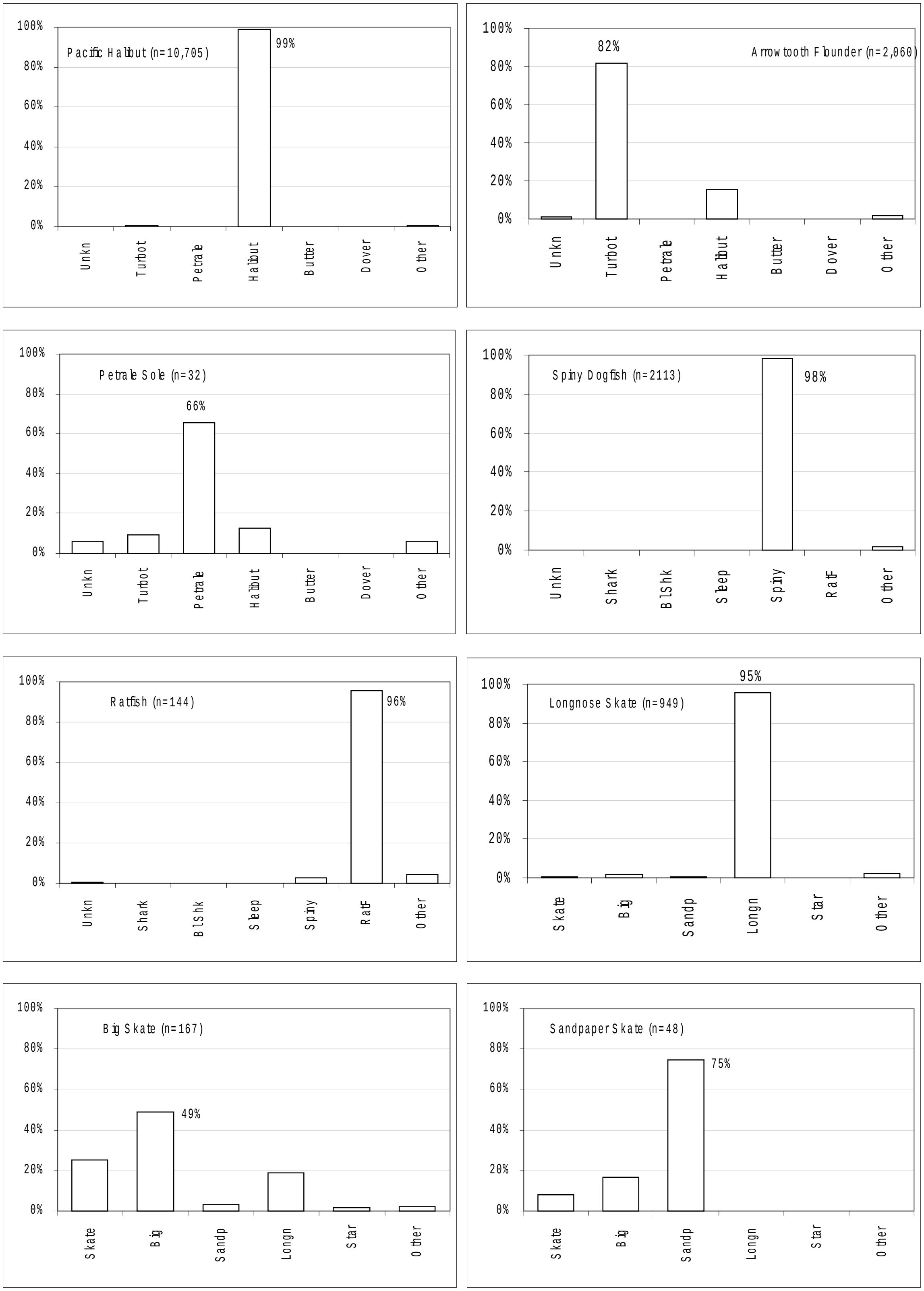


Figure 17. EM Identification for Flatfish, Shark, and Skate - Histograms showing the EM species identification pattern for species identifications by the Observer.

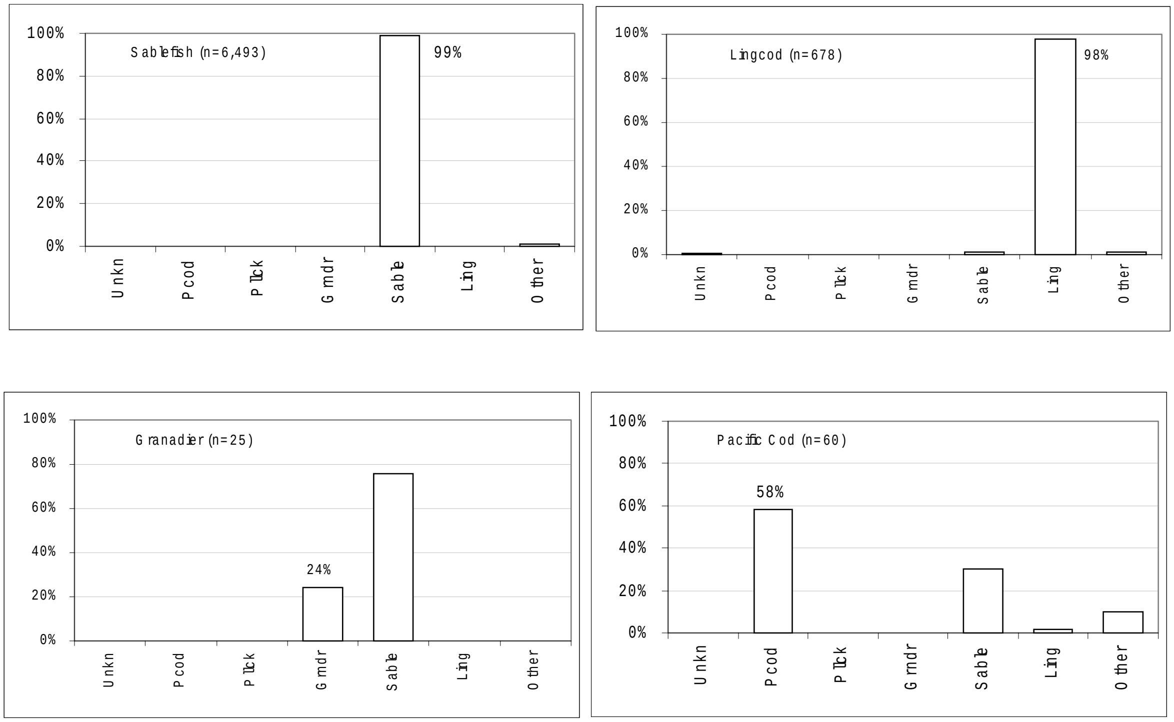


Figure 18. EM Identification for Other Species - Histograms showing the EM species identification pattern for species identifications by the Observer.

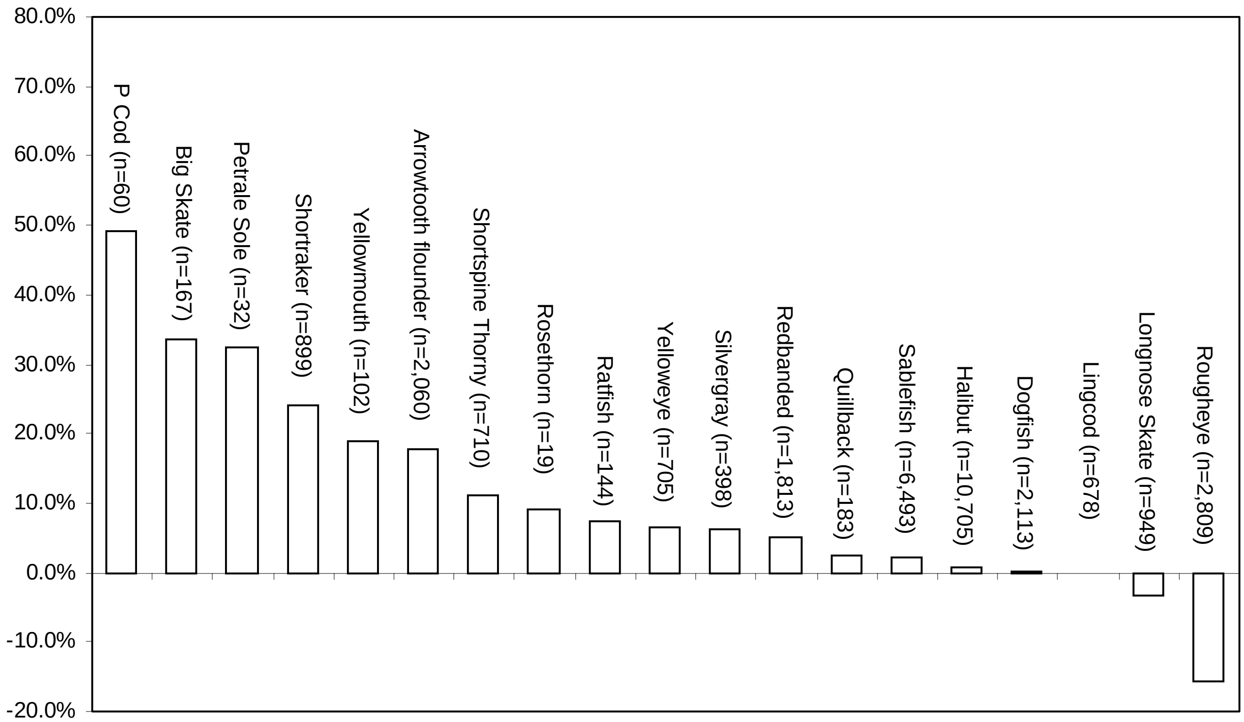
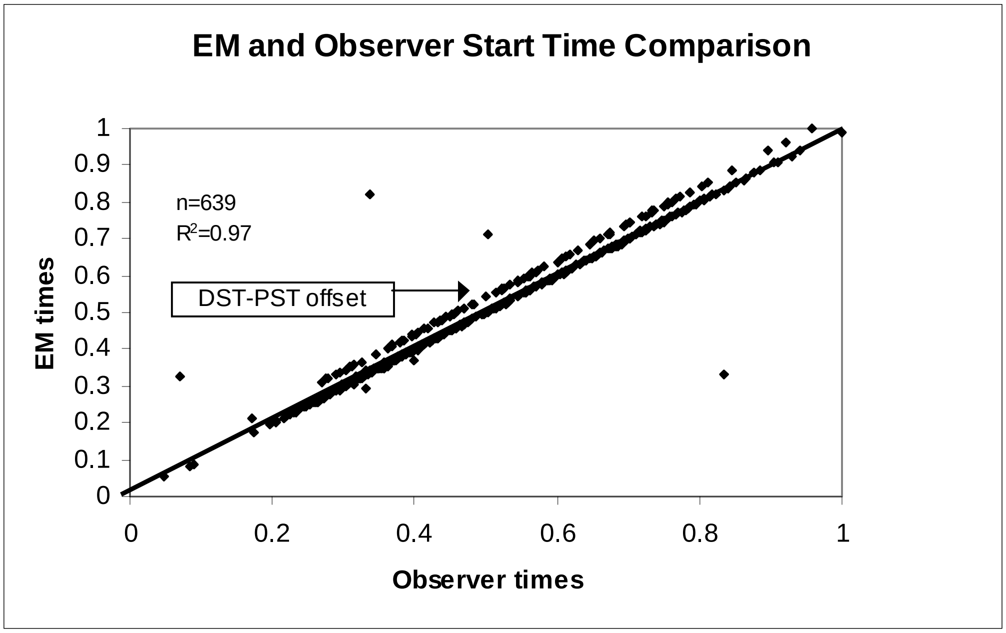


Figure 19. Change In EM Species Identification (%) Between Period 1 And Period 2 (See Table 9).

A



B

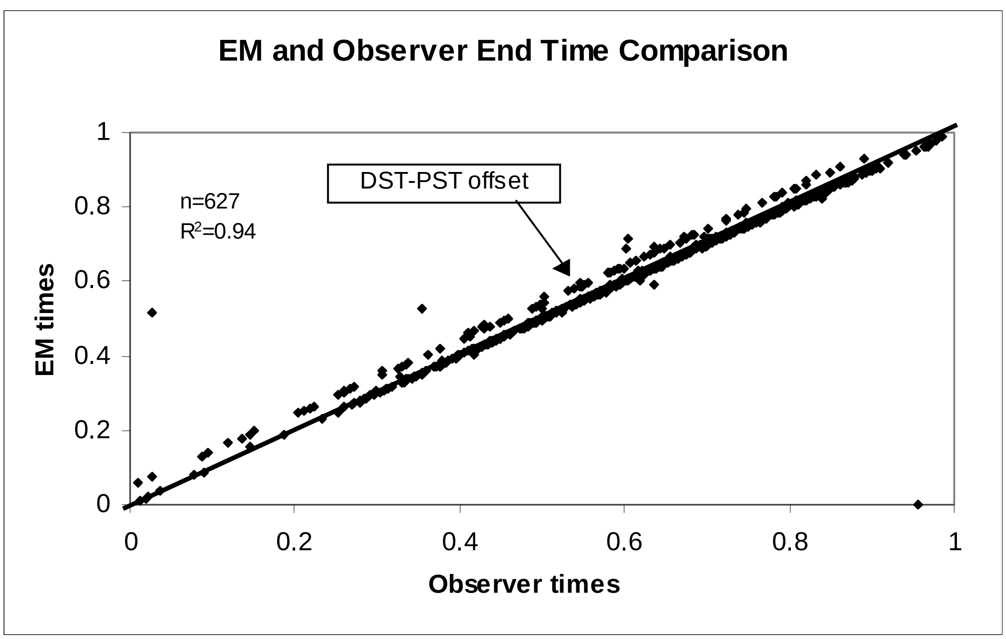


Figure 20. EM And Observer Set Start (A) And End (B) Time Comparisons. There is a 1 hour offset due to EM times not shifting to daylight savings. Twenty-four hour time expressed as fractions of a day (i.e., 0.5=noon, 0.75=18:00, etc.). Sample size (n) denotes number of sets.

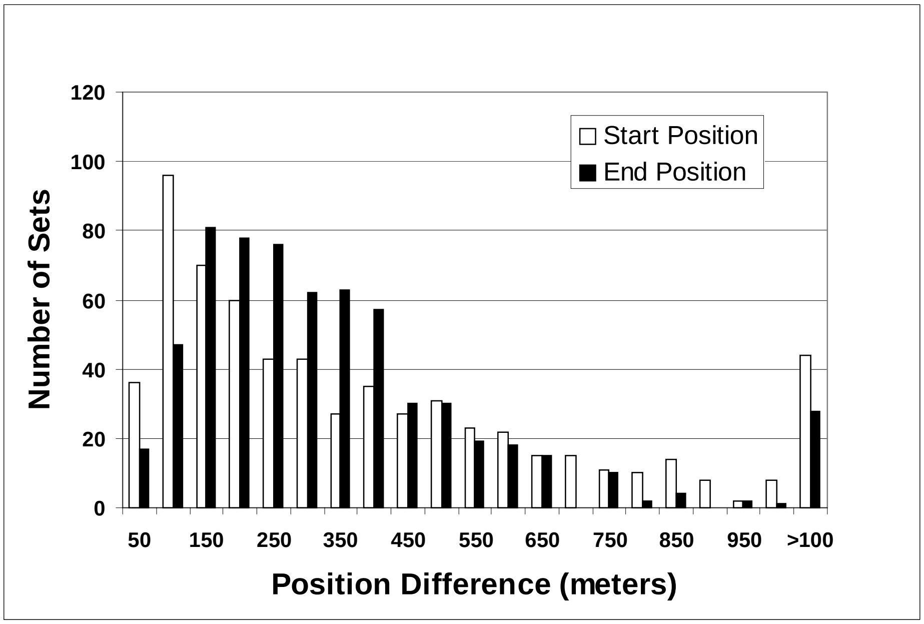


Figure 21. Histogram Showing The Distance Between EM And Observer Set Start And End Positions (N=640 Sets).

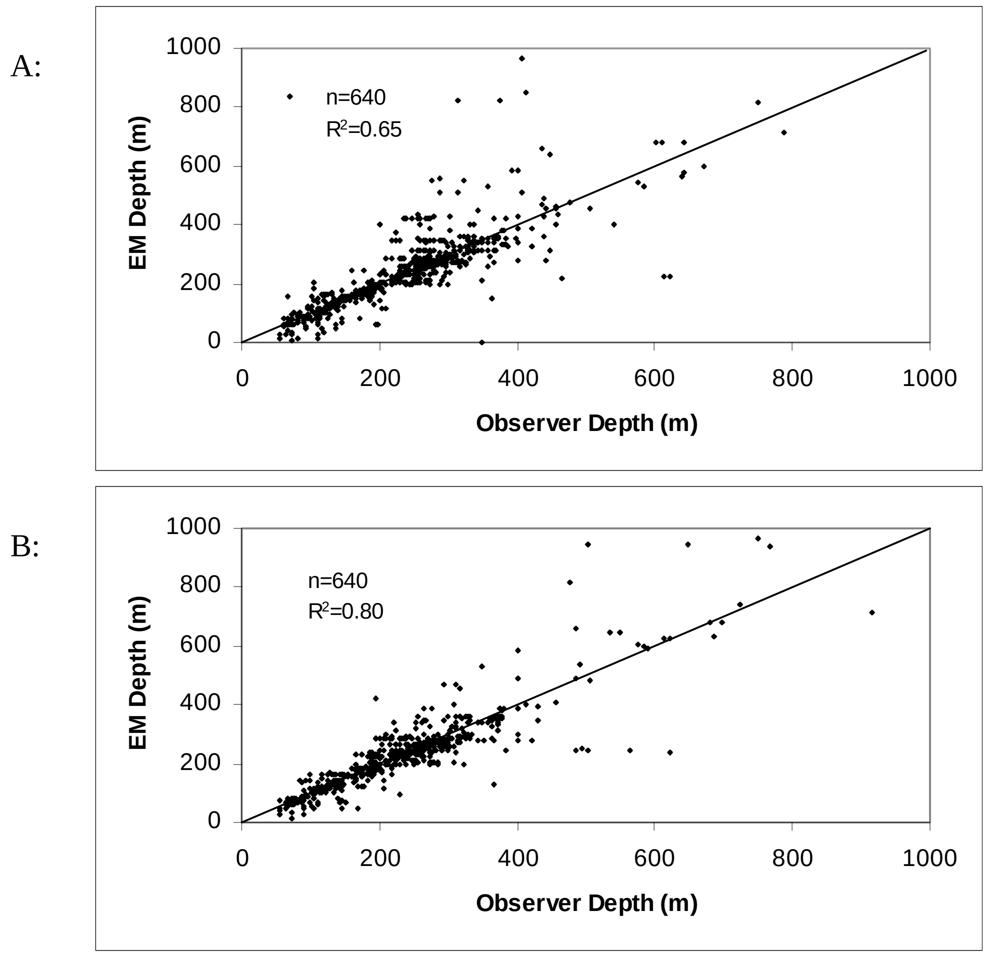


Figure 22. Scatterplot Showing EM And Observer Start (A) And End (B) Depths. The sample size (n) denotes number of sets and the 1:1 line denotes expected correlation (i.e., EM depth equal to observer depth).