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The efficacy of electronic monitoring systems: a case study on the applicability of video technology for longline fisheries management

by

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Abstract

Longline fishing vessels in the United States, Canada, and worldwide have insufficient at-sea catch monitoring. Electronic monitoring (EM) technology was investigated in order to determine whether it could provide a viable solution to some of the catch monitoring deficiencies. EM systems are composed of automated processing devices with data loggers linked to digital video cameras, a hydraulic transducer, and a global positioning system. In 2002, EM systems were installed aboard two International Pacific Halibut Commission longline research vessels to evaluate the precision of EM video technology compared to at-sea samplers. Analyses of fishing effort, piece counts of catch, and catch composition were conducted. The results showed that both methods of quantifying fishing effort were biased, but the biases were insignificant, even considering external variables such as gear snarls and inclement weather. Five of the six piece count categories showed that the observational methods were not statistically different, even though the video analyst missed slightly more pieces than the at-sea sampler. High catch rates increased the observational discrepancies for two of the three piece count categories investigated. Catch composition results showed low *p1* and *p2* discrepancy rates (i.e. the rate of differences in observations) for most fish. However, seven of the 17 species investigated had *p1* discrepancy rates greater than ten percent. The causes of the high discrepancy rates occurred because the video analyst grouped catch into more general species categories than did the sea sampler.

Insufficient recording frame rates, image compression levels, and the lack of a second outboard camera with a wide-angle lens were the principal causes of the identification limitations. These limitations were related to the study design and not the use of video technology as a method for longline catch identification. These identification deficiencies could be resolved with the use of an improved camera layout and an increase in video frame rates and resolution.

Although some identification limitations were found during this study, overall the analyses demonstrated the effectiveness and benefits of EM technology for longline fisheries management. EM technology has a future role in the formation of a functional and cost-effective monitoring program for the conservation and sustainability of marine resources.

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Introduction

This study explores the efficacy of Electronic Monitoring (EM) technologies for use in longline fisheries management. EM systems are composed of automated processing devices with data loggers linked to digital video cameras, a hydraulic transducer, and a global positioning system (GPS) receiver. At present, there are insufficient estimates of catch composition for unobserved commercial longline fishing vessels in the United States, Canada, and worldwide. This study compares the accuracy of EM technologies to the traditional method of using at-sea samplers to collect data on fishing effort and catch composition. Analyses were performed to determine whether EM technologies could provide precise and verifiable fisheries data on commercial longline vessels, that would supplement and complement the data collected by fisheries observers.

This study is divided into four sections. The first section provides background information on fisheries management and monitoring strategies, with an emphasis on the Alaskan commercial longline fishing fleet. The research methodology section outlines the study objectives and the methods used to evaluate the EM systems. The results section presents the findings of the study and defines the relationship between the samplers' data and video data. The final section discusses the significance of the research and summarizes capabilities and future possibilities for EM technology in longline fisheries management.

1.0 Requirements for fisheries management

The industrial exploitation of the world's fishery resources has created a monumental task for international, national, and regional governing organizations to manage the fishery resources in a responsible and sustainable manner. Fishery managers' primary responsibilities extend from assessing the stock conditions to implementing regulations and policies based on the stock health. Additionally, managers must consider the economic and social effects of the imposed regulations. Discharging these responsibilities requires information on numerous variables that affect the marine ecosystem and the associated user groups.

The fundamental problem facing fishery managers is that fish populations cannot be observed directly (National Research Council 2000). Without reliable and accurate data on fish populations, a high level of uncertainty necessarily attends management decisions. Reducing this uncertainty requires extensive fisheries research and monitoring programs.

These research and monitoring programs collect two types of data: fishery independent and fishery dependent data. Fishery independent data are generally collected from research survey vessels. These data are used to monitor changes in stock biomass, growth, and mortalities in both target and non-target populations over time (International Pacific Halibut Commission [IPHC] 2002). These data are vital for stock assessment models, but are limited in their quantity and duration in comparison to the commercial fishery. Fishery dependent data are collected from commercial and recreational vessels, either at the port of landing or at sea during fishing operations. These data monitor a broader distribution of fishing effort over a greater portion of the year than survey data. They are important because the information may be used for in-season management and regulatory compliance. Information on fish population structure, gear selectivity through time, and the behavior of fish and fishers can also be obtained from fishery dependent data (National Research Council 2000). Both monitoring programs are needed in order to reduce the uncertainty in management decisions.

Under the present management structure in the United States and Canada, determining the accuracy of data collected from vessel landings and logbooks has created significant challenges for managers. There are many incentives for commercial fishers to misreport the amount and location of catch (Karp and McElderry 1999). Collecting data aboard fishing vessels provides an advantage over monitoring portside landings because the fishing location, catch quantity, and composition of the catch can be observed directly, reducing the size of the uncertainty.

The monitoring objectives for fishery dependent data are frequently divided into two categories: monitoring vessel compliance with regulations, and monitoring fishing effort and collecting biological data from fishing activities. For instance, observation of the Alaskan groundfish fishery incorporates both compliance monitoring and the collection of biological data. Regulatory compliance monitoring of the 17,000 domestic fishing vessels in Alaska is provided by surface and air patrols of the National Oceanic and Atmospheric Administration (NOAA) Office for Enforcement, the United States Coast Guard, and the State of Alaska, as well as vessel monitoring systems (VMS), and National Marine Fisheries Service (NMFS) fishery observers (Garofolo 1999). Random at-sea vessel inspections by the Coast Guard are useful when they occur, but the inspections are infrequent and ineffective at monitoring fishing vessels' daily operations in the vast fishing grounds of Alaska. The Coast Guard uses aerial surveillance, but this method of monitoring is limited as well. When a commercial vessel is observed, the only information the Coast Guard can acquire from aerial surveillance is the vessel's time, location, and activity. Aerial surveillance has been successful in observing blatant violations, such as vessels fishing in protected areas or out of the fishing season. However, daily fishing information on vessel catch composition is unattainable through aerial surveillance since the observational time is a few minutes at best. Additionally, the Coast Guard has a limited number of aircraft to cover the more than 950,000 square miles of the U.S. Exclusive Economic Zone (National Council for Science and the Environment, unpub.)[1].

Recently, VMS has permitted satellite monitoring and tracking of commercial fishing vessels. VMS allows enforcement agencies to track vessel movements in real-time, using mandatory and tamper resistant vessel transponders (Gribble and Robertson 1998). VMS is a useful tool for reducing unauthorized fishing because the vessel location is communicated continuously to an enforcement agency. However, VMS does not provide conclusive evidence of fishing

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[1] Selected U.S. Ocean and Coastal Data. http://www.ncseonline.org/nle/crsreports/briefingbooks/oceans/a4.cfm. December, 2003.

activities; for example VMS is unable to differentiate between a vessel that is actively fishing or simply transiting through a protected area. As stated by Rear Admiral Thomas Barrett (2000), commander of the Seventeenth Coast Guard District in Alaska: “Although VMS will greatly assist in the monitoring of closed areas, it is not a panacea. VMS does not ensure compliance with many other management measures such as gear and catch restrictions…”(p. 3). Neither the Coast Guard boarding of vessels, nor VMS provides daily fishing information on catch composition and fishing effort. Therefore, a large portion of the at-sea fishing activity is not monitored adequately using these existing methods.

The most effective method of obtaining at-sea fishing information is the placement of fishery observers aboard vessels. Observers provide information on regulatory compliance, as well as information on fishing effort, catch, and location. The development of observer programs has improved the quantity and quality of information obtained on commercial fishing activities significantly.

1.1 Responsibilities for fisheries management

The Magnuson Fishery Conservation and Management Act (NOAA 1976) and the Sustainable Fisheries Act (NOAA 1996) are the principal conventions that govern fisheries in the United States. The Sustainable Fisheries Act implemented in 1996 modified the Magnuson Fishery Conservation and Management Act by requiring the NMFS to develop a fishery management plan for each fishery, with specified objectives and measurable criteria. Since the Act was signed into law, NMFS has dramatically increased the number of U.S. observer programs, from 13 to 26 (NOAA 2003c). This increase has improved the ability of fishery scientists to quantify and incorporate commercial fishery removals into their stock assessment models.

The problems facing fishery managers in the U.S. are similar to those facing their counterparts in Canada. Fisheries and Oceans Canada (DFO) is the federal agency responsible for fisheries management in Canada. The Fisheries Act requires DFO to develop proper management strategies for the protection and conservation of fish stocks (Canadian Legal Information Institute n.d.). On the west coast of Canada, DFO has developed integrated fisheries management plans, similar to the U.S. plans in procedures and goals.

The most recent integrated fisheries management plan created by DFO for Pacific halibut (*Hippoglossus stenolepis*) outlines the prospects for the season and the current management issues (Fisheries and Oceans Canada 2004). DFO considers monitoring and reporting of commercial and recreational fisheries an important issue and an integral part of the overall fisheries management strategy. At-sea monitoring in the halibut fishery has become an important component in the strategy, with an increase in catch monitoring coverage of at sea days from 13.7 percent in 2003 to 19 percent in 2004 (Fisheries and Oceans Canada 2004). DFO relies strongly on observers to fulfill the at-sea monitoring coverage, but has become more progressive than the NMFS in utilizing advancements in video monitoring technologies, which is the focus of this study.

1.2 National and Regional Observer Programs

The U.S. National Observer Program (NOP) coordinates and supports the NMFS regional observer programs, improving their data collection and training methods (NOP, unpub.)[2]. There are 20 different fisheries in the U.S. that employ observer monitoring programs. Observer coverage

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[2] National Observer Program. http://www.st.nmfs.gov/st1/nop/ nop_regional.html. November, 2003

levels vary from region to region depending on the mission and the goal of the program, and the legislation under which the program was authorized. For example, between 1994 and 2001, the Southeast Region Shark Bottom Longline Observer Program provided about two percent of the at-sea observer coverage for the Atlantic shark commercial fishery. Between 1992 and 1998, the Southeast Fisheries Science Center Pelagic Longline Observer Program, operating out of Florida, has maintained fishing fleet sampling coverage levels of 2.5 - 5 percent, with over 1,000 permit holders operating between 250 - 300 vessels annually. In the Pacific, the Hawaii Pelagic Longline Fishery has approximately 110 vessels fishing actively, and 25 percent of the fishing trips by these vessels are monitored by observers. The North Pacific Groundfish Observer Program (NPGOP) has been considered by many as a successful program, providing data on fishing activities and effort in the Alaskan fishery (AFSC 2003). This study will focus primarily on the NPGOP, which is one of the largest observer programs in the North American fishery, with coverage levels reaching 30,000 - 35,000 fishing days annually (NOP, unpub.)[2].

1.2.1 North Pacific Groundfish Observer Program

The observers' primary duties in the NPGOP are to determine and record the fishing effort, quantity and composition of catch, compliance with fishing regulations, and interactions of the fishery with marine mammals and seabirds (NPGOP, unpub.)[3]. The North Pacific Fishery Management Council (NPFMC) is the primary governing body that administers and manages the Alaskan fisheries. The NPFMC requires mandatory observer coverage of 30 percent for groundfish vessels between 60 ft - 125 ft length-over-all (LOA), 100 percent coverage for groundfish vessels greater than 125 ft LOA, and coverage of shore-side plants based on the amount of fish processed per month (Karp and McElderry 1999; MRAG 2003). However, there is no at-sea observer coverage or other at-sea monitoring of catch by vessels under 60 ft LOA, and limited observer coverage on halibut vessels which are both greater than 60 ft, and are participating in other federally-managed fisheries (Ames at el. 2005).

1.2.2 Canadian Observer Programs

The Canadian observer programs are divided into two regions: the Atlantic region and the Pacific region of Canada (Karp and McElderry 1999). The Atlantic region has four separate observer programs comprised of 180 observers. The 180 observers are deployed annually for a total 15,000 days at sea, covering between 5 – 20 percent of the domestic fleet. The Pacific region has a variety of domestic observed fisheries. The trawl fleet is the largest observed fishery, receiving 100 percent at-sea observer coverage. The other Pacific region fisheries receive only limited at-sea monitoring.

1.3 Information deficiencies in at-sea monitoring

At-sea observers collect principal data on commercial fishing activities and the data are often used to make in-season management decisions on fishery status. The observer programs also demonstrate the information deficiencies for the majority of the fishing fleets' activities in the United States, Canada, and worldwide. Even with the increase in the number of observer programs, only relatively small portions of most commercial fleets have at-sea monitoring coverage. In the absence of observers, or of other monitoring programs, there is no way of

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[3] North Pacific Groundfish Observer Program. http://www.afsc.noaa.gov/refm/observers/PDF_DOCS/observer%20brochure%20web1104.pdf. September, 2003.

determining the quantity and composition of the catch or discards, if high grading of the catch occurred, or if the data obtained from the vessel operators are reliable (Karp and McElderry 1999).

Deficiencies in the existing observer coverage levels and patterns of deployment, and the lack of information on the majority of longline fleets' fishing activities and locations are examples of some of the fundamental problems that face fishery managers in quantifying the effects of fishing on fish stocks and areas sensitive to fishing effort. Various logistical factors may prevent the implementation of optimal observer coverage. Many commercial fishing vessels have insufficient sleeping and working space, and inadequate safety equipment (e.g., life raft capacity) to accommodate observers. Deploying observers on only those vessels that can accommodate observers creates issues of equity among fishers, and leads to data bias (MRAG 2003). Using the data collected from observed vessels to make inferences on vessels without observers has been considered misleading because the presence of observers on the vessels directly influences the crews' behavior and their fishing activities (Karp and McElderry 1999). In addition, even on vessels with observers, it is not possible to determine the accuracy of the data collection process, and therefore the degree to which the data may be biased (Barbeaux 2001). While the observer programs may provide guidance through designated sampling methodologies and procedures, the observers have great difficulty in applying those methods on most commercial vessels. Truly consistent and representative sampling is unattainable on most commercial vessels, and observers must sample using a best-fit design. Hence, consistency is not maintained, and the variability and biases in the sampling are unknown. As stated by MRAG (2003):

> The performance of individual observers is very variable… It is likely that the complexity of the available methods and reference materials, and heavy reliance on observers to find their own 'best methods' lead to much of the observer error (p. 5).

Additionally, the information obtained from observers is not verifiable once the fishing trip has been completed. Therefore, new technologies are being developed to assist at-sea observer programs in monitoring fishing activities, in order to determine how data quality and the knowledge of fishing activities can be improved.

Electronic monitoring is a new technology that may provide an effective solution for monitoring the presently unobserved portion of the fleet and a quality control mechanism aboard observed vessels. The processing of EM data at the end of each trip can provide precise and verifiable information on specific fishing activities (Archipelago Marine Research, Unpub)[4]. The implementation of EM technology may aid in the development of functional and cost-effective fisheries monitoring programs. A number of studies have investigated the effectiveness of EM technology; the most publicized being those carried out in fisheries in the north Pacific.

1.4 Literature review of electronic monitoring technologies

Digital Observer LLC envisioned a digital solution to some of the current observer problems in the Alaskan fisheries (Davis 2002). EM technologies were investigated for counting and identifying fish caught during commercial longline fishing operations, using digital video cameras linked to image recognition software. The results of the laboratory and at-sea field tests were uneven, demonstrating that, at best, the system was able to count and identify between 45 to 63 percent of the fish caught (Davis 2002). The reliance solely on image identification software for enumerating catch composition seems unlikely at this stage in EM development.

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[4] Electronic monitoring. http://www.archipelago.ca/em.aspx. October 2003.

Archipelago Marine Research, Inc. (AMR) has made significant progress in the development of a monitoring system that integrates electronic technology with some human applications during post-trip processing of the fishing data. AMR has been developing EM technologies since 1992, and it has achieved success in a number of EM applications in Canada, the United States, and recently in New Zealand (D. McCullough, 525 Head St. Victoria BC, V9A-5S1 personal communication). The information needs that have been addressed by AMR's EM monitoring programs include collecting accurate data on "fishing time and location, gear deployment and retrieval methods, catch and bycatch handling, catch identification, enumeration and disposition" (AMR, unpub)[5].

AMR has been involved in a number of Canadian fisheries, particularly the sablefish (*Anoplopoma fimbria*) trap and longline fishery. In cooperation with the Canadian Sablefish Association and the DFO, AMR provided EM technology for monitoring compliance of sablefish vessels fishing on offshore seamounts. This program has been in operation since 1992, and has proven both reliable and cost-effective. AMR has also provided EM technology for the British Columbia commercial Dungeness crab (*Cancer magister*) fishery, and this technology has proven to be both affordable and effective in controlling theft of catch and gear during at-sea crabbing operations (H. McElderry 525 Head St. Victoria BC, V9A-5S1 personal communication). This program has been in operation for three years, and is funded entirely by the crab industry. The majority of the crab fishery license holders have declared the monitoring program a great success. AMR President, H. McElderry (525 Head St. Victoria BC, V9A-5S1 personal communication), stated that "there is widespread feeling that the system provided a significant deterrent, creating an unprecedented degree of order and cooperation in the fishery".

In 2002, AMR in partnership with the DFO implemented a large-scale pilot project within British Columbia waters. This qualitative research study compared the EM system with conventional at-sea observers to gauge the differences between these data collection methods. EM systems were deployed on 19 commercial longline-fishing vessels, encompassing 59 fishing trips (McElderry at el. 2003). The EM video analysis provided encouraging results: "A high degree of accuracy was evident for most species identification," and "electronic monitoring may be appropriate to replace or complement at-sea observer programs, resulting in more strategic and cost effective monitoring" (AMR, unpub.)[6].

These EM research studies and programs have seen successful in various fisheries in Canada, United States, and recently in New Zealand. There has been however a lack of literature available on EM technologies and research, especially outside of Canada and the United States. As the potential benefits of EM technology become more clear, there will be an increase in attention and invested research, as seen in the research priorities defined in the 2003 draft Programmatic Supplemental Environmental Impact Statement (SEIS) for Alaskan fisheries. The National Oceanic and Atmospheric Administration in the SEIS (2003b) states: "promote advances in video monitoring of otherwise unobserved catch for improved estimation of species composition of total catch and discrimination of retained and discarded catch" (pp 5-10). EM technologies have a role in the future of fisheries management by providing solutions to some of the deficiencies in at-sea monitoring, and by reducing uncertainty in management decisions.

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[5] Electronic monitoring summary. http://www.archipelago.ca/em-projects.aspx. October 2003.

[6] BC Groundfish Longline Fisheries – catch and effort monitoring. http://www.archipelago.ca/em-projects-

Materials and Methods

2.0 Case study of electronic monitoring systems

The IPHC, in collaboration with the NMFS, conducted a study to examine the feasibility of employing electronic monitoring technologies in the Alaskan halibut longline fleet. This project was undertaken aboard two of the IPHC stock assessment survey vessels during the summer of 2002. The primary goal of the 2002 project was to evaluate the ability of EM technology to address several critical information needs involving endangered seabirds. Additionally, EM technology was compared in contrast to the traditional human method of collecting data on fishing activities.

The objective of this study is to provide an evaluation of the potential of EM technologies to fulfill the critical at-sea information gaps concerning longline-fishing activities. The evaluation is based on the following research questions:

- Can electronic monitoring video provide images of sufficient resolution and clarity to allow a video analyst to record fishing effort and piece counts of target and non-target species accurately? What factors influence the video analyst's ability to record fishing effort and piece counts? Fishing effort is defined as the number of hooks fished at each station, whereas piece counts refers to the number of individuals caught per station.
- Can electronic monitoring video provide images of sufficient resolution and clarity to allow a video analyst to identify species to those categories designated by the NPFMC and NMFS in their fishery management plans? What factors influence the video analyst's ability to identify species?

The identification criteria are based on the species and species groups outlined in the 2004 North Pacific Groundfish Observer Sampling Manual (AFSC 2004), and the NMFS 2003 groundfish plan for the Bering Sea and Aleutian Islands (NPFMC 2002).

The data examined in this report were collected in an earlier study (Ames et al. 2005). Portions of the research methodology have been paraphrased from the earlier study.

2.1 IPHC survey design

The purpose of the IPHC stock assessment survey is to provide fishery independent information on the distribution and abundance of Pacific halibut. Additionally, the survey vessels are used as research platforms to collect information or conduct experiments not associated with the halibut stock assessment. The survey consists of twenty-seven sub-regions throughout British Columbia, Canada, Alaska, Washington, and Oregon, USA (Fig. 1). Each region is divided into regularly distributed stations based on a ten by ten nautical mile geographical grid, with each station having predetermined latitude and longitude coordinates (IPHC 2002).

2.2 Design of the 2002 project

2.2.1 Vessel attributes

EM systems were installed on the *F/V Heritage* and the *F/V Pacific Sun*, which were under contract to the IPHC to collect portions of the annual stock assessment data. The two longline halibut vessels completed the Unalaska, Adak, Attu, and 4A, 4D Edge charter regions in IPHC Regulatory Areas 4A, 4B, and 4D respectively (Fig. 1). The IPHC survey vessels were chosen for the EM study based on the following criteria:

- The vessels provided a controlled research platform with the freedom to change EM

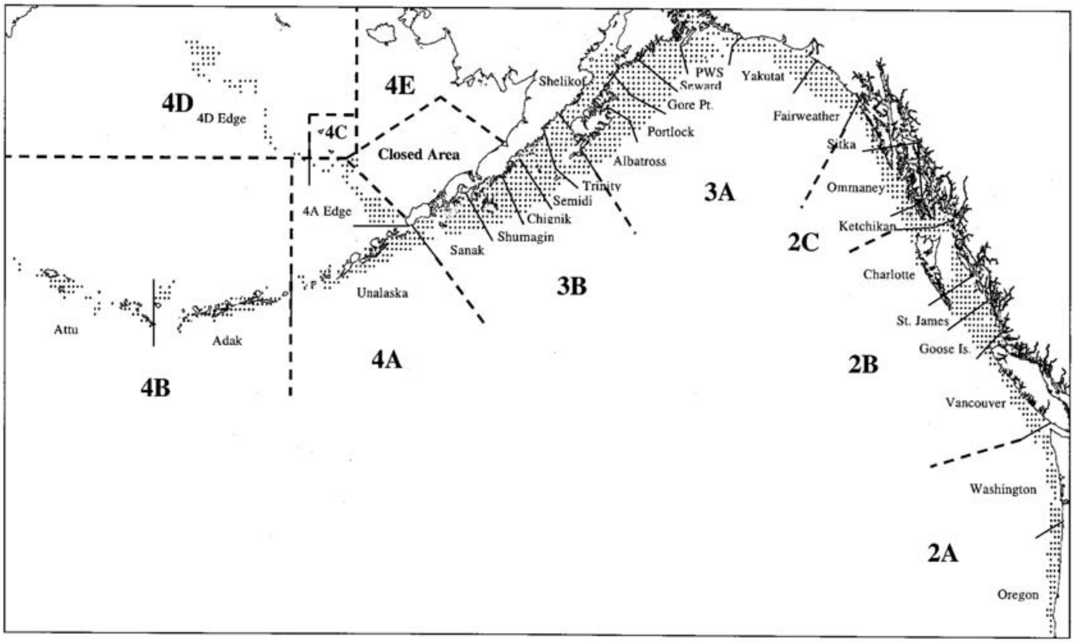


Figure 1. IPHC regulatory areas and charter regions. Each point on the map represents a survey station.

computer configurations and camera mounting locations in order to optimize EM performance. Experienced IPHC personnel (hereafter known as sea samplers) performed EM technical and experimental adjustments at sea.

- The vessels could accommodate an additional sea sampler for at-sea data collection, which provided a calibration component for the EM units. Under normal survey operations the vessels were required to accommodate only two sea samplers.
- The vessels covered a large geographic area, which allowed for operational tests of the EM units over a range of environmental variables including weather, oceanographic, and tidal conditions.
- The large geographic area also provided a variety of fishing depths and habitats with a diversity of bycatch species.
- The vessels completed multiple fishing trips that allowed an extended deployment of the EM units over the three-month survey duration.
- The vessels had different lengths, widths, styles, and deck layouts, which provided additional information on EM units' adaptability.

2.2.2 Third sea sampler duties during the 2002 at-sea EM study

Under normal survey operations, the IPHC assigns two sea samplers to each survey vessel to collect stock assessment data. During the EM project, a third sea sampler was assigned to each vessel to collect and record data during survey operations, and to ensure that the EM project objectives were met. The third sea samplers' responsibilities included:

- Supervising and maintaining the EM computers and equipment.
- Triggering the EM cameras to record the hauling events.
- Recording the hook status and species composition, which included identifying and recording all invertebrates and vertebrates caught.

2.2.3 EM configuration: the 2002 at-sea trials

The EM cameras on both vessels were strategically placed to maximize the quality of the recorded images for monitoring fishing effort and species identification during gear retrieval. The at-sea qualitative assessment reviewed: 1) recording image compression ratios, 2) lens focal length, and 3) image recording speeds (frame rates per second, or fps) (Table 1). Digital image recording compression is an algorithm-based process of decreasing the file size by reducing the amount of data in a given file. An increase in image compression is proportional to a decrease in image quality, and is non-reversible, but allows for an increase in the total amount of video recording time. An increase in lens focal length is proportional to an increase in image detail and clarity at a distance, but is also proportional to a decrease in the horizontal and vertical fields of view. An increase in recording image frame rate is proportional to an increase in the amount of image data in a given file, and a decrease in the total amount of video recording time. The optimal combination of image compression ratio and video recording frame rates was assessed to obtain the highest quality image with the lowest computer storage space.

2.3 Description of the electronic monitoring system

The EM system is a unique and powerful data collection tool, which integrates an assortment of available digital video and computer components with a proprietary software operating system. The system records video and logs vessel sensor data during the fishing trip. It operates on either

Table 1. Deck and roller camera lenses, compression ratios, and frame rates used to record hauling events on the *F/V Heritage* and *F/V Pacific Sun.*

F/V Heritage	Initial configuration	Second configuration
Deck lenses	12 mm	12 mm
Roller lenses	12 mm	12 mm
Deck compression ratios	20×	20×
Roller compression ratios	20×	20×
Deck frame rates (frames per second)	1	1, 1.5
Roller frame rates (frames per second)	1	2, 2.5, 4, 5

F/V Pacific Sun	Initial configuration	Second configuration
Deck lenses	8 mm	8 mm
Roller lenses	8 mm	8 mm
Deck compression rates	20×	20×
Roller compression rates	20×	20×
Deck frame rates (frames per second)	1	2
Roller frame rates (frames per second)	1	1, 2, 5

DC or AC voltage, and after an unexpected power interruption the system will automatically restart and resume program functions. Four closed circuit TV cameras, a GPS, and a hydraulic pressure sensor were the primary sensors employed during the IPHC study (Fig. 2).

2.3.1 EM computer control unit

The operating system, the data storage components, the power supplies for the video cameras, and the vessel sensors are contained in a durable aluminum case measuring approximately 55 cm x 33 cm x 12 cm. The aluminum case is not sufficiently weatherproof or waterproof for on-deck deployment, but it is water-resistant. The control unit can be mounted in any interior location with about 15.3 cm^3 of dry and ventilated space. This space must also be accessible to set-up and service technicians.

The data-logging and video computers are the two primary components in the control unit. The data-logging computer records the output from the GPS and the pressure sensor records continuously for the duration of the fishing trip. Post-trip processing of the sensor information

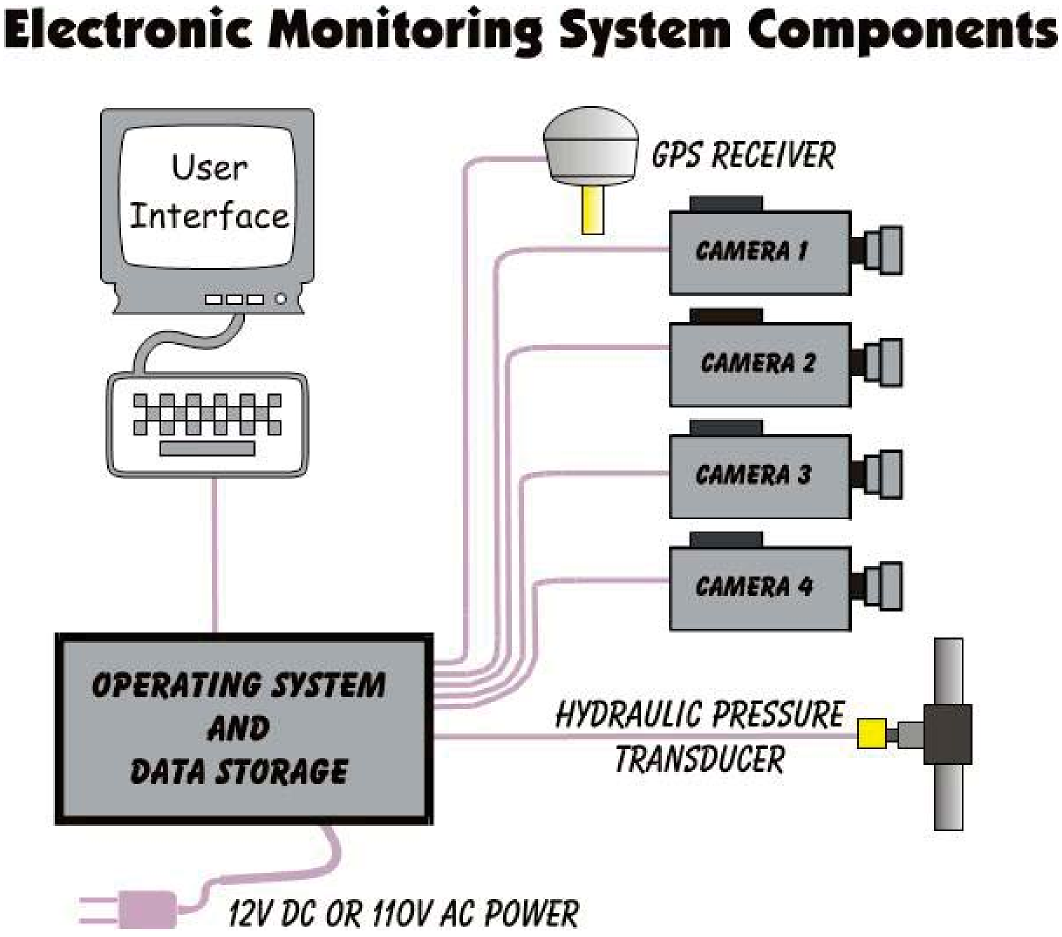


Figure 2. Schematic of the electronic monitoring system components (courtesy of Archipelago Marine Research).

provides a digital time series of the vessel activities, such as the setting and hauling of the fishing gear. The time series records are matched with video segments in order to provide a complete picture of the fishing trip and activities. During recording operations, the video computer digitizes the incoming analogue camera signal and stores the video imagery on removable computer hard disks. The video computer can record a wide range of recording frame rates and digital compression ratios. The video storage capacity of the monitoring system depends on the frame rate, image compression, and the size and number of electronic storage devices.

2.3.2 EM closed circuit TV cameras

The computer control unit of the EM systems is capable of handling up to four analogue closed circuit TV cameras. Two hauling cameras were used in this study to provide image redundancy, and to allow for different points of view at the hauling stations. Each camera was outfitted with a durable, weatherproof armored dome housing. Universal stainless steel mounts were used to fasten the cameras onto standing structures on the vessel that provided the best viewing angle of the hauling station. Each camera was mounted to a gimbal inside the armored dome. These gimbals provided three rotational degrees of freedom allowing for the optimal adjustment of the camera's field of view. In addition, the sea samplers had access to a number of lenses, ranging in scope from a wide angle to telephoto. The samplers were able to change the camera lenses and adjust the field of view to maximize the image resolution for each at-sea application. The sea samplers also had TV monitors that allowed real-time viewing of each camera image and permitted them to play back videos of settings and hauling.

2.3.3 EM global positioning system

An independent GPS receiver was installed on each vessel and was connected to the EM computer unit. This receiver delivered a digital data stream of the vessel's position, speed, heading, and corresponding time. The data were recorded at 15-second intervals, and were also imprinted into the digital video images to provide a "burned in" geographic reference for each video frame.

2.3.4 EM hydraulic pressure sensor

An electronic transducer was installed on the vessel's hydraulic winch to collect hydraulic pressure data. The activation of the winch for gear retrieval produced a record of the hydraulic pressure on the data-logging computer. A graphical display of the hydraulic pressure provided time-coordinates with the video segments documenting fishing retrieval activities.

2.3.5 F/V Heritage description and EM configuration

The *F/V Heritage* is estimated at 20 m length-over-all, with a 7 m width. The vessel has a typical modern longline layout with a forward deckhouse. An outboard camera and a deck camera were installed to monitor the hauling station. The outboard camera monitored the incoming gear from the waterline to the roller, and the deck camera monitored the gear as it was hauled aboard. A qualitative evaluation of the camera's location was performed at sea.

Both cameras were outfitted with 12 mm focal length lenses for the duration of the study. The deck camera was positioned to view the interior of the retrieval chute and the inside edge of the roller from a distance of 4.3 m . The outboard camera was mounted 2.91 m from the roller on a horizontal aluminum pole that extended 1.65 m from the starboard side of the vessel, with an estimated height of 2.4 m above the water line.

2.3.6 F/V Pacific Sun description and EM configuration

Originally designed for a crab fishery, the *F/V Pacific Sun* has been refitted for longline operations. It is the largest of the IPHC chartered vessels, measuring 37 m LOA and 12 m in width, and it has a large open work-deck area. Two cameras, an outboard camera and deck camera, were installed on the *F/V Pacific Sun* to monitor the hauling station. The outboard camera mounted atop the crab block arm that was swung out starboard during gear retrieval and viewed the incoming line from the waterline to the inside of the retrieval chute. The deck camera mounted atop a 2.4 m vertical wooden pole that was secured to the vessel's crab pot launcher, and viewed the inside of the retrieval chute. Both cameras were fitted with 8 mm focal length lenses for the duration of the study.

2.3.7 Vessel installation time of EM system

An AMR technician installed EM systems on both vessels and trained the IPHC sea samplers to service, maintain, adjust, and operate the equipment. Additionally, the sea samplers were taught to review the video and sensor data. The installation of the EM system on the *F/V Heritage* took 18 hours or 2.25 working days, while the installation of the system on the *F/V Pacific Sun* took 14 hours, or just under 2.0 working days.

2.4 Monitoring of catch

Monitoring of the vessel catch during the gear retrieval was performed simultaneously by the sea samplers and the EM cameras at each station. During the study, the sea samplers carried out an at-sea qualitative analysis in order to determine the optimal camera configuration. Only data collected with the optimal camera configurations were used in the analysis.

2.4.1 Traditional method of counting and identifying vessel catch: sea sampler data

During gear retrieval, the sea samplers stood at the railing aft of the roller and recorded the hook status and species composition of the catch, including the identification of all invertebrates and vertebrates, in sequential order. Both sea samplers were NMFS-certified groundfish observers with respectively four years and 2.5 years experience in the Alaskan groundfish observer program. Species identification categories and procedures used in this study were similar to the species and species groups outlined in the 2004 North Pacific Groundfish Observer Manual (AFSC 2004). Both sea samplers used reference materials by Eschmeyer (1983), Kramer at el. (1995), Kramer and O'Connell (1995), and the North Pacific groundfish observer species identification reference manual (AFSC 2000). The sea samplers were able to identify all organisms to species or group categories. Group codes were used for species that dropped off the longline prior to landing, and for other bycatch species that were too numerous for individual identification, or that proved difficult to identify from a distance. However, because of their physical presence, sea samplers had the opportunity under certain conditions to closely analyze other taxonomic features, such as morphometric measurements or meristic traits, which was beneficial for identifying similar species (Moyle and Cech 1996). Information on vessel, station, set, and dates for each fishing event was recorded, as well as information on gear damage, entanglements, or gear loss during hauling. Upon the completion of the survey, the data from each station were edited and entered into the IPHC SQL Server database by data entry transcribers. Two independent transcribers assured data quality by double entering the hauling information into the database. Any data differences were investigated and corrected.

2.4.2 EM method of counting and identifying vessel catch: video analyst data

The video analyst recorded the hook status and species composition of the catch using a method that was similar to the sea samplers' method. However, the video analyst's species identification process relied solely on anatomical characteristics and color patterns as viewed on the video. Important identification features included the organism's size, shape, and color, as well as other referenced information on species geographical and depth ranges that distinguished organisms by species.

The analyst evaluated the hauling video from each station to determine whether or not the EM video was clear enough to differentiate the individuals by species or species group. The analyst used the same species codes as the sea samplers, but created nine additional group codes for individuals that proved difficult to identify on the video. These additional group codes were divided into supra-species and general group categories. Five supra-species categories combined two species under one code, whereas each of the four general group categories contained three or more different species (Tables 2 and 3). The nine group codes were established to maximize the quality of the information provided by the video. Creating these extra categories for individuals that proved difficult to identify from the video was necessary because labeling some individuals by sea samplers' general species categories would have been less accurate, since certain species under the general category could be ruled out. For example, the sea-samplers' codes allowed them to select from only two alternatives when they were identifying skates, either the skate's species or Skate Unidentified, which included all skates within the Rajidae family. However, in some situations the video analyst was able to rule out a large number of the species in the Rajidae family. In these circumstances, the additional supra-species groups and categories allowed the analyst to make a more precise identification of the individuals on the video.

The reference materials used by the analyst in the video identification process were the same as those used by the sea samplers. The analyst's data were entered directly into a database during the video analysis of the hauling events, thus eliminating the time and the cost of using a data transcriber.

2.5 Analysis of catch data from the IPHC surveys

In order to answer the research questions, an evaluation of the hauling event video was required. The hauling event video was examined to determine whether the EM units could provide images of clarity sufficient for an analyst to:

- count the total number of hooks deployed at each station,
- count the number of individuals caught within six designated species categories, and
- identify targeted and non-targeted species with high precision.

The comparisons were performed between the sea samplers' at-sea records and the video analyst's office analysis records. The evaluation provided quantifiable means of determining whether a video analyst was capable of accurately recording fishing effort, catch piece counts of designated species categories, and catch identifications at least equivalent to those of a sea sampler. Equivalent capability was determined by the quantitative analyses described in sections 2.5.3 – 2.5.7. Four flowcharts outlining the analyses and order of the steps are provided in Appendix Figs. B1 – B4.

2.5.1 Analysis of catch data

The catch records, as described above, were matched and organized by station and vessel. The catch monitoring analysis was divided into a three-step process.

1. The catch records from both the sea samplers and the video analyst were entered into one database for data set alignment. These catch records included hook and catch enumeration, as well as species identification.
2. Comparisons were made between the sea samplers' and the video analyst's data sets.
3. Any discrepancies in the identification and the enumeration of the catch by the sea samplers and the video analyst were investigated by a second video examination, and a determination was made as to the type of discrepancy and the reason why it occurred.

2.5.2 Alignment and analysis of the database

The data from each of the two methods of enumerating hooks fished and catches were compiled into a single spreadsheet. The observations on the catch by station were matched and

Table. 2. The video analyst's additional five grouped-species categories, which combined two species under one code. Column two represents the total number of individuals caught within the given category as represented by the sea samplers' records. Column three represents the number of times the video analyst used the grouped-species categories.

Supra-species category	Total number of individuals caught within the given category	Number of times supra-species category were used
Alaska/Aleutian skate (*Bathyraja pariferma* or *aleutica*)	1125	36
Alaska/Bering skate (*Bathyraja pariferma* or *interrupta*)	813	75
Aleutian/Whiteblotched skate (*Bathyraja aleutica/ maculata*)	1246	12
dusky/northern rockfish (*Sebastes ciliatus* or *polyspinis*)	12	4
Greenland turbot/Kamchatka flounder (*Reinhardtius hippoglossoides* or *Atheresthes evermanni*)	591	137

Table 3. The video analyst's additional four general species categories, which combined more than two species under one code. Column two represents the total number of individuals caught within the given category as represented by the sea samplers' records. Column three represents the number of times the video analyst used the general categories.

General category	Total number of individuals caught within the given category	Number of time the general species category were used
white ventral side skate	2151	114
dark ventral side skate	6	1
unidentified king crab	11	14
unidentified red rockfish	359	25

aligned. The alignment process was accomplished by importing catch data into spreadsheet columns side by side, matching gear changes and obvious species, and aligning them into the same row by adding empty cells to either column as required. The completion of this process allowed for direct comparisons of station hook counts, piece counts, and species identification.

2.5.3 Comparing observational differences in fishing effort by station

The number of hooks fished at each survey station quantified fishing effort. At each of the survey stations three independent hook counts were taken: 1) during gear deployment by one of the primary sea samplers, 2) counted during gear retrieval by the third sea samplers, and 3) by the video analyst.

2.5.3.1. Testing station hook count differences: paired-sample t-test. The station hook totals were paired and the data were used in the paired-sample t-test. Equation 2.0 determined whether the station hook count differences were equal to the theoretical difference of zero. A difference of zero implies that the two observational methods provide the same measure of fishing effort. A mean difference that was outside the critical value of a normally distributed population implies the two observational methods are not the same, and the null hypotheses would be rejected. The two tailed hypotheses implied $H_0 : \mu_d = 0$ and $H_A : \mu_d \neq 0$. The test statistic for the null hypothesis is:

$$t = \frac{\bar{d}}{s_{\bar{d}}} \qquad 2.0$$

$$v = n - 1$$

Where $\bar{d}$ is the mean difference between the paired observations, and $s_{\bar{d}}$ is the standard error of the mean (Zar 1984). The degree of freedom denoted as v equals the number of cases in the sample minus one.

Statistical type II errors in the hypotheses testing were a concern, especially because of the low number of samples obtained from the *F/V Pacific Sun*. Analyses were undertaken, using $t_{\beta(1),v}$ to estimate the probability of detecting a true difference of one hook in station hook count differences. The procedure to calculate $t_{\beta(1),v}$ is as follows:

$$t_{\beta(1),v} = \frac{\delta}{\sqrt{\frac{s_d^2}{n}}} - t_{\alpha,v} \qquad 2.1$$

$$\text{Statistical power } = 1 - \beta$$

Where δ represents the smallest detectable sample difference, $t_{\alpha,v}$ symbolizes the critical value of the t distribution, and s_d^2 corresponds to the population variance. The critical values of the t distribution were obtained from Zar (1984 pp. 484-485). Table B.2 in Zar (ibid p. 483) allowed for the converting of $t_{\beta(1),v}$ to approximate β, which was used to calculate the statistical power of the test, denoted as $1-\beta$.

The sea samplers' logbooks and data forms were examined to determine whether hook losses during gear soak or hauling were sufficient to affect the t-tests results. The investigation was necessary since the number of hooks deployed during setting does not always equal the number of hooks retrieved. Under normal fishing operations hook losses during gear retrieval are common because the gear frequently snags on bottom objects.

2.5.3.2. Snarl affects on station hook count differences: paired-sample t-test. Station hook counts were re-examined individually in order to evaluate the effects of gear snarls on the sea samplers' and video analyst's hook totals, and whether gear snarls affected the hook count differences and the outcome of the t-tests significantly. For all data pairs, a second t-test was calculated after hook count discrepancies in association with snarls were corrected. Hooks were added to one of the data set columns when an empty cell(s) – missing hooks – were found in association with a snarl. Other empty cells that were not associated with snarls were not changed. It was impossible to know whether the empty cell or cells were a result of the snarled gear; however the presence of a snarl made this conclusion highly probable.

2.5.3.3. Station hook count differences: analysis of variance. Three other factors derived from the sea samplers' logbooks and data forms were examined.

- The order in which the stations were fished. Time may influence the hook count differences because of both physical and mental fatigue associated with a long charter.
- Individual station catch rates. Stations with high catch rates may introduce higher chances of causing either identification or recording errors.
- Beaufort sea state conditions during gear retrieval. Beaufort sea state codes and descriptions are found in Appendix Table A1 (IPHC 2004). Weather and sea state conditions, especially inclement conditions may affect working performance both physically and mentally.

For each station, the three variables were paired and tested independently with the station hook count differences in order to determine if there was a functional relationship. The dependent variable in all of these examinations was the hook count difference. The hook count differences were expressed in absolute values, which eliminated all negative values. Analysis of variance was used to test each of the null hypotheses in which the slopes of the regression lines were considered equal to zero. A regression line slope of zero would imply there was no relationship between the variables tested. The null hypotheses were denoted as, $H_O : \beta = 0$, and the alternate hypotheses, $H_A : \beta \neq 0$.

The overall variability of the hook count differences, the dependent variable (Y_i) was calculated by using the total sum of squares (total SS):

$$\text{total SS} = \sum Y_i^2 - \frac{\left(\sum Y_i\right)^2}{n}, \qquad df = n-1. \tag{2.2}$$

The linear regression sum of squares (regression SS) was calculated to determine the amount of variability the Y_i values had as a result of the linear regression. Here X_i represented the independent variable. The regression SS was computed as follows:

$$\text{regression SS} = \frac{\left(\sum X_i Y_i - \frac{\sum X_i \sum Y_i}{n}\right)^2}{\sum X_i^2 - \frac{\left(\sum X_i\right)^2}{n}}, \tag{2.3}$$

$$df = 1 \, .$$

The residual sum of squares (residual SS) were determined by subtracting the regression SS from the total SS:

$$\text{residual SS} = \text{total SS} - \text{regression SS}, \quad df = n - 2 \, . \qquad 2.4$$

The regression mean square (regression MS), and residual mean square (residual MS) were both calculated:

$$\text{regression MS} = \text{regression SS/ degrees of freedom}, \quad df = 1 \, , \qquad 2.5$$

and

$$\text{residual MS} = \text{residual SS/ degrees of freedom}, \quad df = n - 2 \, . \qquad 2.6$$

Finally, the null hypotheses were tested by the analysis of variance

$$F = \frac{\text{Regression MS}}{\text{Residual MS}} \, . \qquad 2.7$$

The slope of the regression line expresses quantitatively the dependence of the predicted Y on X, which estimates the functional relationship between the two variables.

2.5.4 Testing for equal counts of species by vessel

The individual species catch data were coded into six general fish categories (flatfish, roundfish, skates, sharks, rockfish, and other species) for subsequent analysis of piece counts.

2.5.4.1. Piece count comparison: McNemar's test. McNemar's test was used to measure the amount of difference in the piece counts. The null hypothesis was tested by a goodness of fit test with a 1: 1 ratio. The goodness of fit test compared the sea samplers' and video analyst's observed species frequencies (Zar 1984). The null hypothesis stated that the two observational methods would be equal only if both methods detected and counted the same frequencies of the individuals caught.

McNemar's test employed the Yates' correction for continuity; the following formula was used to calculate the disagreement between the sea samplers' and the video analyst's observations of individuals caught:

$$\chi^2 = \frac{(|R - S| - 1)^2}{(R + S)} \qquad 2.8$$

Here R represents the number of times the sea sampler saw an organism and the video analyst did not, and S represents the number of times the video analyst saw an organism and the sea sampler did not.

The differences in species identification resolution were not evaluated in this test. An organism identified to species in one observation and identified as a different species or to a category in the other was determined to be of different resolution, but of equal observed frequency, as long as the alternative species or category used was included in the general species category in question. The McNemar's test is a nonparametric test of two related dichotomous variables, therefore, all organisms of equal observed frequency were re-coded as number one and organisms of different observed frequency were re-coded as number zero. Different observed frequencies were defined by the total absence of an organism in the data of one of the observations, or alternatively the inconsistencies in the type of species identified, or in the species group. In either of these incidents, a missed species or the improper categorization of a species indicated an error by either the sea samplers or the video analyst.

The individuals of different observed frequency from the flatfish, roundfish, and skates categories were divided into two groups, missed species or improperly categorized species. The evaluation was used to determine if the sea samplers and video analyst missed and improperly categorized the same number of individuals. Finally, all the vessels piece count categories were combined, and both the sea sampler and video analyst discrepancies were compared against the total number of individuals caught. The comparison showed the magnitude and extent of the discrepancies in relation to the total number of individuals.

2.5.4.2. Piece count differences: analysis of variance. Reasons behind piece count differences were also analyzed. The number of differences in terms of missed species or improperly categorized species on each station were tallied. The tallied number of piece count differences by station and vessel was compared against each of the following variables.

- The order in which the stations were fished.
- The number of individuals from all categories caught per station.
- The number of individuals caught within the general species category per station.
- The station Beaufort sea state condition.

An analysis of variance was used to test the functional relationship of piece count differences and each of the above variables. The piece count differences and the variables were paired in a similar manner as the hook count differences described above, with the slope of the regression line and the null hypothesis for each test equaling zero, $H_O : \beta = 0$. Rockfish, shark, and 'the other' categories were not investigated because the sample sizes were too small.

2.5.5 Comparisons of the sea samplers' and video analyst's records

Exploratory analysis of catch was undertaken to examine data patterns, trends, and relationships. Catch rate and distribution were investigated along with identification precision. Identification precision was the number of agreements and disagreements between the two observational methods. All fish species caught were listed into their appropriate species or species group. A disagreement in the matching process indicated either a difference in species resolution, or that one of the identifications was wrong. The lists did not allow for the detection of the correct observation, but merely displayed in opposing columns both responses for each species or species group totals. These lists revealed the resolution of species identification that these sea samplers and video analyst were capable of achieving.

2.5.6 Species identification precision

The sea samplers' at-sea records were used as the standard for the discrepancy rate analyses because the current assumption in fisheries management is that the information from at-sea observers is accurate. The following formulae were used to express the expected relationships between the sea samplers and the video analyst, assuming accuracy of sea samplers' records.

$$\mathrm{n}_{videoanalyst} = \mathrm{n}_{seasampler} - e1 + e2 \qquad 2.9$$

Based on the above formula the following notations were developed:

N	Total number of fish caught at the station.
$n_{videoanalyst}$	Number of individuals of a given species counted by the video analyst.
$n_{seasampler}$	Number of the individuals of the same species counted by the sea sampler.
discrepancy 1	Instances in which the sea sampler saw and counted individuals that the video analyst did not.
discrepancy 2	Instances in which the video analyst saw and counted individuals and the sea sampler did not.
$e1$	Number of discrepancy of type 1.
$e2$	Number of discrepancy of type 2.
$p1$	Probability of a type 1 discrepancy.
$p2$	Probability of a type 2 discrepancy.

Note that $p1$ and $p2$ were essentially the false negative and the false positive discrepancy rates for the camera, when compared to the sea sampler. The hooks within a station were assumed to be independent from one another, and that the discrepancy probabilities $p1$ and $p2$ were the same for each hook. From these assumptions the following procedures were created:

$$e1 \sim Binomial\ (n_{seasampler}\ , p1) \tag{2.10}$$

and

$$e2 \sim Binomial\ (N - n_{seasampler}\ , p2) \tag{2.11}$$

The estimated parameters of $p1$ and $p2$ are as follows:

$$p1 = \frac{e1}{n_{seasampler}}, \tag{2.12}$$

and

$$p2 = \frac{e2}{N - n_{seasampler}}, \tag{2.13}$$

with the standard deviations

$$sd(p1) = \sqrt{\frac{p1(1-p1)}{n_{seasampler}}}, \tag{2.14}$$

and

$$sd(p2) = \sqrt{\frac{p2(1-p2)}{N - n_{seaseampler}}}. \tag{2.15}$$

Based on equation 2.12 and 2.13, estimates of discrepancy rates for both species and species categories were determined. Formula 2.13 provides a higher degree of precision than Formula 2.12. Formula 2.13 estimates the discrepancy rates based on all individuals caught, excluding the specific individuals being examined that were seen by the sea sampler. Formula 2.12, however, only determines the discrepancy rate based on the number missed by the video analyst of the particular species being examined, and does not take into consideration the other species that were caught. Individuals missed or identified to a species in one observation, and identified to a category in the other were classified as a discrepancy.

An important caveat is that the formulae 2.12 and 2.13 do not provide absolute error rates, because in most cases the inconsistencies between the observations were not resolvable using the data. It is important to note that the discrepancy rates indicate only that there is a difference between the two observations, and that this examination is not a measure of accuracy.

Species found with discrepancy rates ≥ 0.10 were further examined against the following variables in order to determine whether these variables contributed to the discrepancies.

1. The order in which the stations were fished.
2. The total number of individuals from all species caught per station.
3. The number of individuals caught within the general species category per station.
4. The number of individuals caught of the specific species per station.
5. The recorded weather condition during the hauling event.

These variables were tested in the same manner as the hook count and piece count differences. An analysis of variance was used to test the functional relationship of discrepancy rates and the five variables. The numbers of discrepancies were paired with each variable, and the null hypotheses were tested based on a regression slope of a line of zero, $H_O : \beta = 0$.

2.5.7 Investigation of the observational discrepancies

The source and reason for the observational discrepancies between the sea samplers' and analyst's data sets were examined. This consisted of determining the type and number of the discrepancies at each station, locating the errors in space and time on the video, and assigning the errors into one of four categories. The category descriptions were based on the following designations of error source:

- drop off overlooked,
- incorrect identification,
- recording error, and
- a retrieved individual overlooked.

Time constraints limited the total number of errors reviewed, resulting in 42 randomly selected stations from the *F/V Heritage*, and all 21 stations from the *F/V Pacific Sun* were re-examined. Only observational or recording errors were re-examined, whereas resolution differences were not considered errors and were not investigated.

The re-examination process had several limitations, which restricted the analyst's ability to determine the correct observation. In some cases the correct species identity was never known because both observational methods classified the individual to supra-species or general species categories, and in other cases, the video re-examination did not provide enough information to determine error source.

The re-examination process was considered both a quantitative and qualitative analysis because the video might provide evidence of the correct observation, but the cause of the errors was not fully understood. For example, the sea sampler might record an individual species and the video analyst might record an empty hook. The re-examination process may show that the identified individual was only partially visible in the video and dropped off prior to landing. The reason the video analyst missed this particular individual can not be fully understood. The most probable cause would be that the video analyst overlooked the individual because it was only partially visible in one or two frames and dropped off the gear. The observer may have had greater opportunity to observe and identify the species prior to drop off. For these reasons, the re-examination exercise was limited in its effectiveness and value.

2.5.8 Study design considerations

The author collected the catch data aboard the *F/V Heritage*, as well as performed the video analysis of all the stations for both vessels, and the re-examination of the video for observational accuracy. This aspect of the design may restrict the conclusions drawn from these data analyses.

Results

3.0 Analysis of vessel effort and catch data

A total of 83 stations from the *F/V Heritage* and 21 stations from the *F/V Pacific Sun* were matched and compared.

3.0.1 Comparing observational differences in fishing effort

To test the sea samplers' gear deployment and gear retrieval station hook counts, as well as the video analyst's station hook counts, six paired-sample t-tests with exploratory statistics were computed (Table 4).

Table 4. Paired-sample t-tests of the hook differences between the three observational hook counts from each vessel.

F/V Heritage

Comparison of mean difference in station hook totals	Number of Stations	P-value	Mean difference	Std. error mean	95% confidence interval	
					Lower	Upper
setting and video hook counts	78	0.18	0.62	0.45	-0.28	1.51
video and hauling hook counts	83	0.00	1.65	0.34	0.97	2.33
setting and hauling hook counts	78	0.02	-0.86	0.37	-1.59	-0.13

F/V Pacific Sun

Comparison of mean difference in station hook totals	Number of Stations	P-value	Mean difference	Std. error mean	95% confidence interval	
					Lower	Upper
setting and video hook counts	11	0.16	13.55	8.95	-6.40	33.49
video and hauling hook counts	20	0.03	-1.85	0.77	-3.45	-0.25
setting and hauling hook counts	11	0.11	15.27	8.68	-4.07	34.62

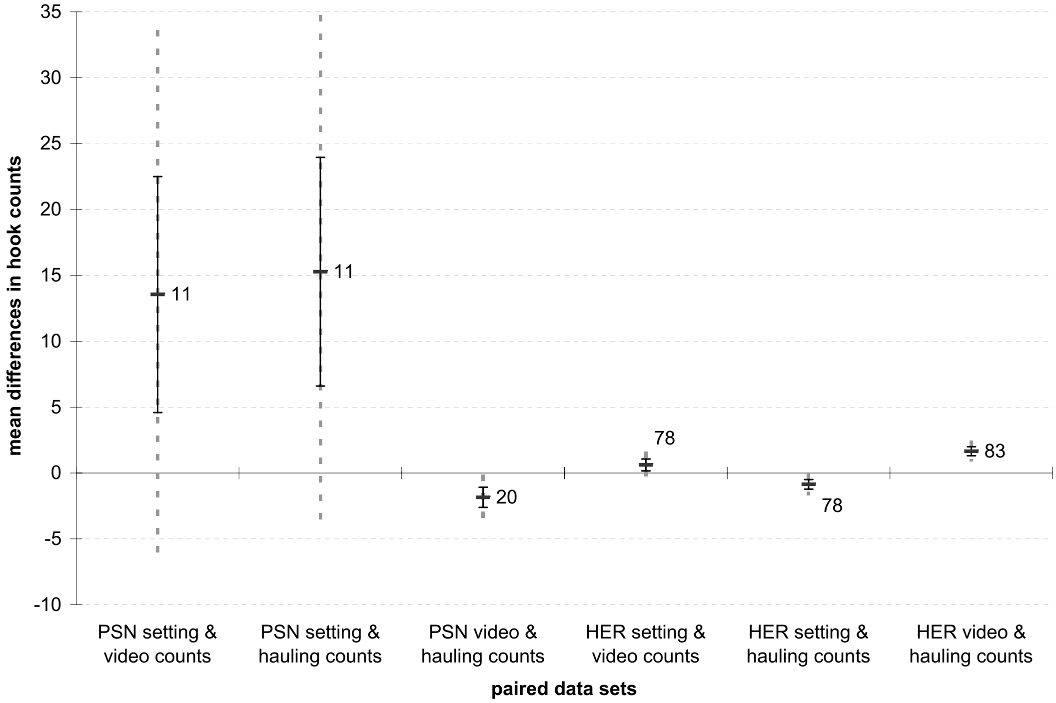


Figure 3. Mean difference in hook counts between observational data set records, indicating the mean, the mean 95% confidence interval (vertical dashed lines), standard errors (vertical lines), and sample size.

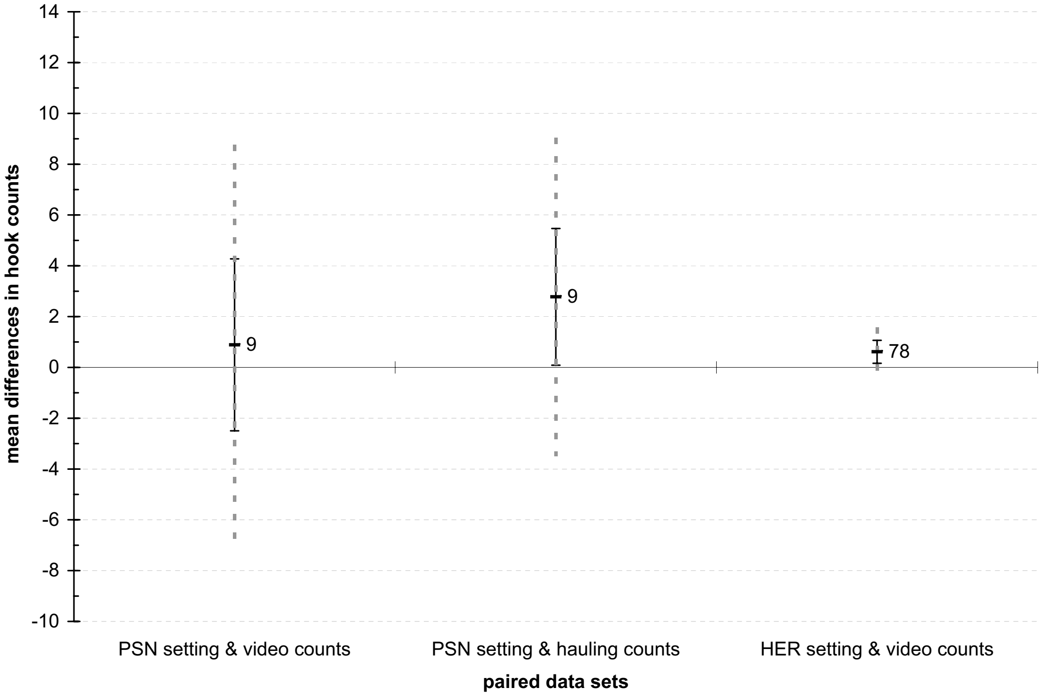


Figure 4. Mean difference in hook counts between observational data records with the elimination of the *F/V Pacific Sun's* and *F/V Heritage's* gear lost outliners.

Three of the six initial t-tests showed that the hook differences were not statistically significant. However, of the three t-tests that showed insignificant differences, two of those involved were setting counts collected on the *F/V Pacific Sun*. Those two data sets had high standard errors with a large 95 percent confidence interval in comparison to the other four-paired data sets (Fig. 3). The *F/V Pacific Sun* small sample size produced a high chance of causing a type II error. The probability of detecting a true difference based on the statistical power of these paired sample t-tests was small. The power estimates for both tests were less than 0.5, which are below the level needed to accurately predict if the null hypotheses were false and rejected correctly (Zar 1984 p. 483). Therefore, the conclusions based on these two t-test results are considered questionable at best. The third t-test that showed insignificant differences had a larger sample size and a lower measure of dispersion than the latter two t-tests. Using a minimum detectable difference of one, the power value was estimated at 0.59, which indicated that there was a 59 percent chance of rejecting a false null hypothesis. However, using a minimum detectable difference of two hooks greatly increased the power value to 0.92. A larger sample size was needed in order to understand if these two observational methods were truly equal at a minimum difference of one hook.

The data from the three t-tests that were not statistically significant were examined more thoroughly. The *F/V Pacific Sun's* setting counts as well as sea sampler and video hauling counts revealed data point outliners at three stations. Two of the outliners were a result of gear lost during gear retrieval, which changed the mean and variance of the *F/V Pacific Sun's* comparisons substantially, although the measure of dispersion and large confidence interval were still significantly higher than the *F/V Heritage* comparisons (Fig. 4). Gear losses on the *F/V Heritage* were insignificant in magnitude and did not affect the measures of central tendency and dispersion.

The sea samplers' and video analyst's gear retrieval hook count differences showed a low measure of dispersion with data points tightly clustered around the mean difference. However, on both vessels the measures of dispersion and the 95 percent confidence intervals do not incorporate zero, the measure of equivalence (Fig. 3).

The effect of hook snarls was examined by removing those data from the comparison and then re-testing. The *F/V Heritage's* hook data showed that of the approximate 40,000 hooks retrieved there were 86 occurrences of hook snarls. The *F/V Pacific Sun's* hook data showed that of the approximate 9,500 hooks retrieved there were 17 instances in which the hooks were snarled. Hook discrepancies associated with these snarls were of various sizes; ranging from zero hooks to a maximum of 11 hooks. The paired-sample t-tests were computed a second time after removing the hooks that were associated with gear snarls.

Three of the six t-tests on the adjusted data showed no statistical significance (Table 5), which was consistent with the unadjusted data (Table 4). The results indicated that hook count adjustments decreased the setting, hauling, and video hook count differences as well as the measurements of dispersion. However, the *F/V Heritage's* setting and hauling hook counts showed a decrease in the p-value and an increase in measures of dispersion.

The sea samplers' and video analyst's station hook count differences on both vessels did not show any correlation with the order in which the stations were fished suggesting that the hook differences were independent of this temporal factor (Figs. 5 and 6). The *F/V Heritage's* data showed no relationship between hook differences and station catch rates, however the *F/V Pacific Sun's* data indicated a weak linear relationship, which showed hook differences decreased as station catch rates increased. The relationship was insufficient to reject the null hypothesis (Figs. 7 and 8).

A positive linear relationship between station hook differences and weather conditions was found for the *F/V Heritage* (Fig. 9). As the weather conditions worsened, the hook count differences increased significantly. However, the weak linear relationship between station hook

Table 5. Paired-sample t-tests with adjusted snarl hook differences from each vessel.

F/V Heritage

Comparison of mean difference in station hook totals	Number of Stations	P-value	Mean difference	Std. error mean	95% confidence interval	
					Lower	Upper
setting and video hook counts	78	0.62	-0.19	0.39	-0.97	0.59
video and hauling hook counts	83	0.00	0.84	0.22	0.40	1.29
setting and hauling hook counts	78	0.01	-0.95	0.37	-1.68	-0.22

F/V Pacific Sun

Comparison of mean difference in station hook totals	Number of Stations	P-value	Mean difference	Std. error mean	95% confidence interval	
					Lower	Upper
setting and video hook counts	11	0.17	13.36	8.99	-6.67	33.40
video and hauling hook counts	20	0.04	0.95	0.42	0.07	1.83
setting and hauling hook counts	11	0.18	13.09	9.00	-6.95	33.13

differences and weather conditions found on the *F/V Pacific Sun* were insufficient to reject the null hypothesis. Opposite to the findings on the *F/V Heritage*, the hook count discrepancies on the *F/V Pacific Sun* decreased as the weather conditions worsened (Fig. 10).

3.0.2 Testing for equal counts of species by vessel

McNemar's tests focused on the six general fish species categories (i.e., flatfish, roundfish, skates, sharks, rockfish, and 'other species') outlined in Section 2.5.4.1. The calculation determined whether the sea samplers' and the video analyst's data sets provided equal counts – piece counts – of species caught from each of the six general fish categories, including both targeted and non-targeted species.

General species category test results showed that the sea samplers' and the video analyst's records were not statistically different, except for the shark category, which were significantly different (Table 6 and 7). The *F/V Heritage* results established that the video analyst failed to observe 12 sharks on the gear, while the sea samplers missed only two sharks that the video analyst recorded. The *F/V Pacific Sun* caught only three sharks during the study; therefore the shark category was not tested.

In all three categories investigated, the video analyst missed a higher number of individuals than the sea samplers, except for the skate general species category from the *F/V Pacific Sun*. Rockfish, shark, and 'the other' categories were not investigated because the sample sizes were too small. On the *F/V Pacific Sun* the sea sampler missed a higher number of individuals than did the video analyst. In general the video analyst also improperly categorized more species than the sea sampler did, but these instances were of a lesser magnitude when compared to the number of pieces missed (Figs. 11, 12, and 13). The data from both vessels were combined and the discrepancies were presented against the number of individuals caught by category (Fig. 14). Although the video analyst missed and improperly categorized more individuals, overall the magnitude of discrepancies were small when considering the number of species caught.

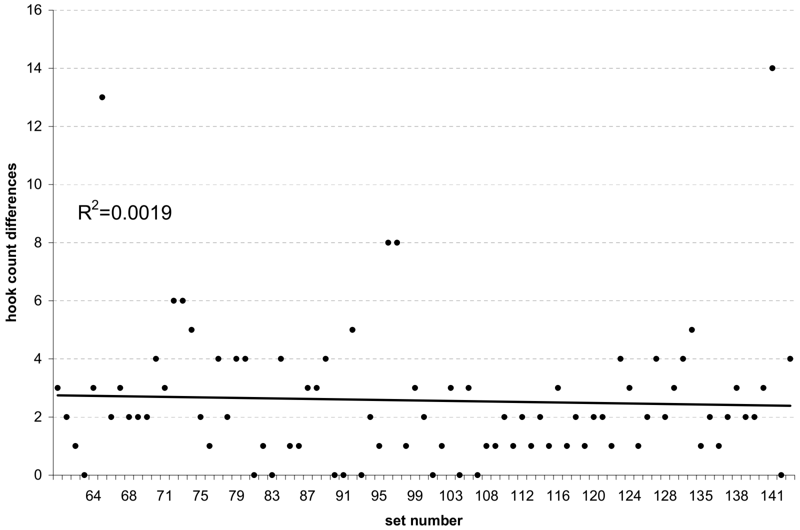


Figure 5. ***F/V Heritage*** **gear retrieval hook differences (absolute values) from the sea sampler's and video analyst's data records compared with set order.**

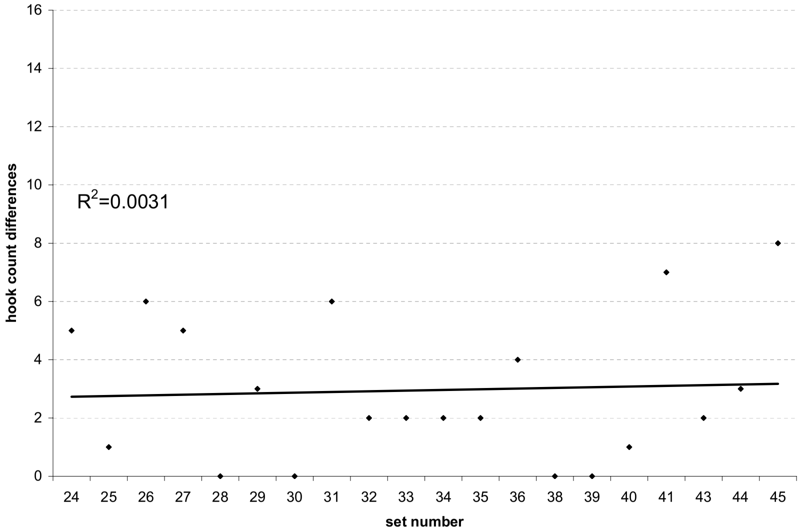


Figure 6. ***F/V Pacific Sun*** **gear retrieval hook differences (absolute values) from the sea sampler's and video analyst's data records compared with set order.**

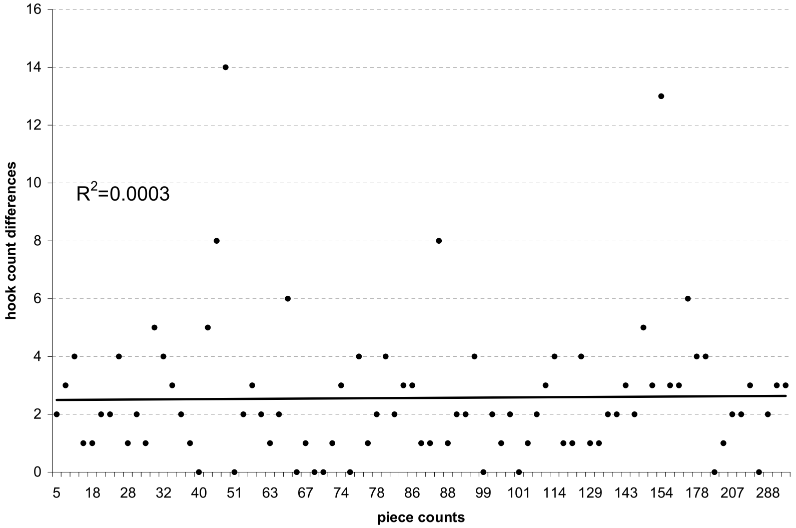


Figure 7. ***F/V Heritage*** **gear retrieval hook differences (absolute values) from the sea sampler's and video analyst's data records compared with station piece counts.**

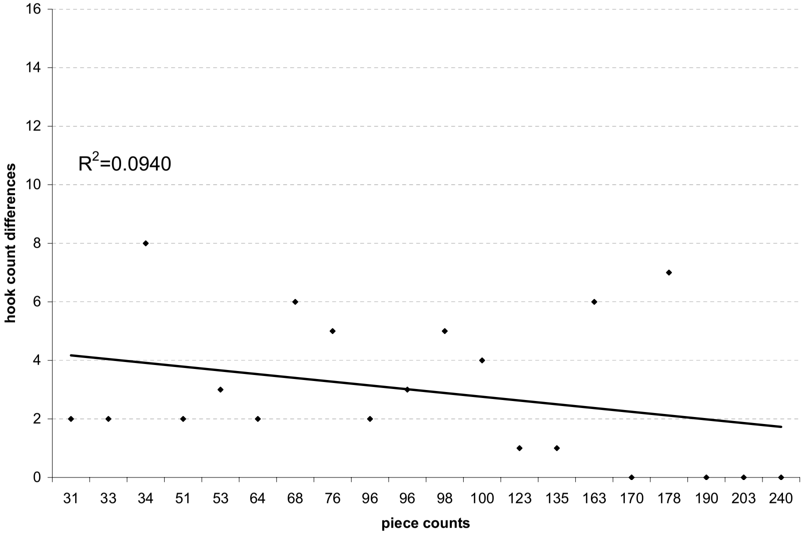


Figure 8. ***F/V Pacific Sun*** **gear retrieval hook differences (absolute values) from the sea sampler's and video analyst's data records compared with set order.**

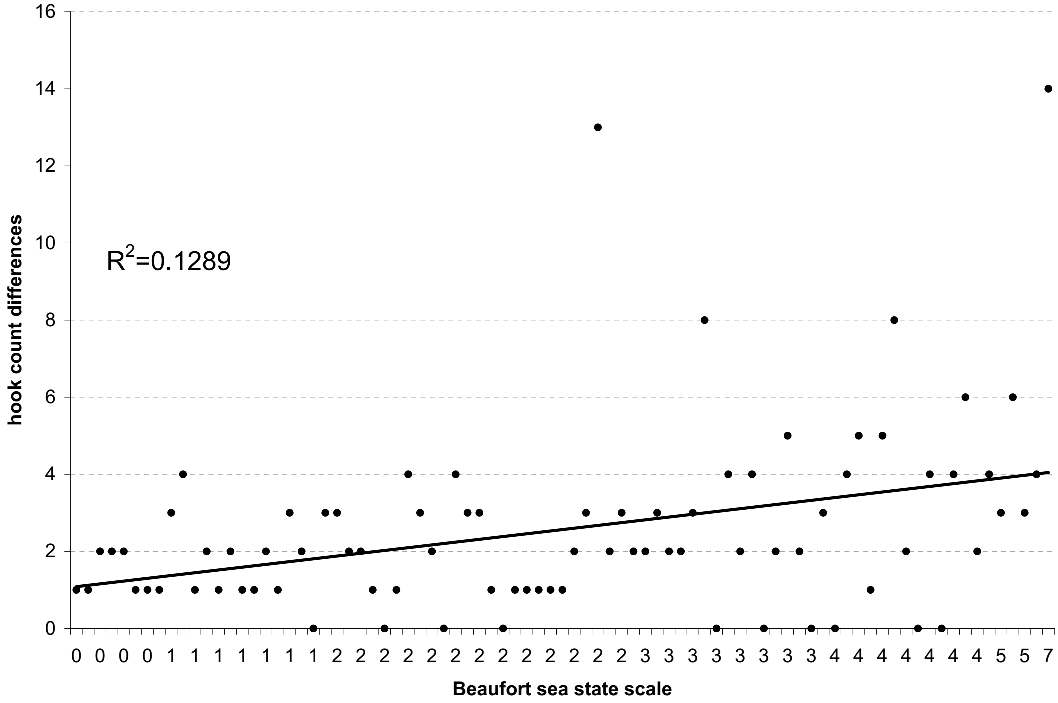


Figure 9. ***F/V Heritage*** **gear retrieval hook differences (absolute values) from the sea sampler's and video analyst's data records compared with stations Beaufort sea state.**

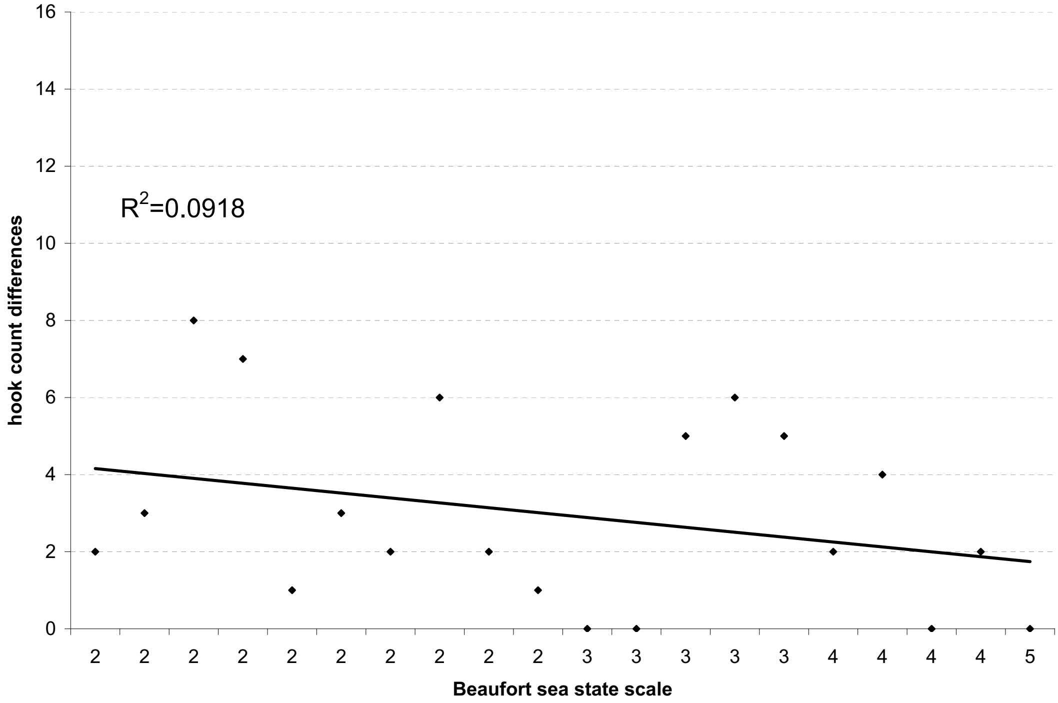


Figure 10. ***F/V Pacific Sun*** **gear retrieval hook differences (absolute values) from the sea sampler's and video analyst's data records compared with stations Beaufort sea state.**

Table 6. McNemar's tests of the piece count differences between the sea samplers' and the video analyst's from the *F/V Heritage*.

Species categories	Number caught (N-value)	Number identified by both the video analyst and sea sampler	Observational differences		McNemar's P-value	95% confidence interval	
			Number identified exclusively by video analyst	Number identified exclusively by sea sampler		Lower	Upper
Flatfish	3742	3672	27	43	0.07	0.373	1.040
Roundfish	2629	2565	24	40	0.06	0.346	1.020
Shark	89	75	2	12	0.01	0.018	0.749
Rockfish	244	238	4	2	0.68	0.045	3.489
Skate	1679	1646	13	20	0.30	0.297	1.373
Other species	19	17	0	2	0.48	–	–

Table 7. McNemar's test of the piece count differences between the sea samplers' and the video analyst's data sets from the *F/V Pacific Sun.*

Species categories	Number caught (N-value)	Number identified by both the video analyst and sea sampler	Observational differences		McNemar's P-value	95% confidence interval	
			Number identified exclusively by video analyst	Number identified exclusively by sea sampler		Lower	Upper
Flatfish	766	750	10	6	0.46	0.549	5.580
Roundfish	979	953	9	17	0.17	0.796	4.809
Shark	–	–	–	–	–	–	–
Rockfish	137	132	1	4	0.375	0.005	2.526
Skate	498	485	7	6	1.000	0.238	2.979
Other species	30	20	5	5	1.000	0.230	4.345

The analysis of variance showed no sufficient correlation between the flatfish piece count differences and any of the variables considered. However, on both vessels, an increase in roundfish catches affected linearly the number of roundfish piece count differences (Figs. 15 and 16). The same relationship was found in the skate piece count category in which the differences in skate piece counts were dependent on the skate catch rates by station (Figs. 17 and 18). The analysis of variance results for both roundfish and skate piece counts on both vessels were significant (Tables 8 and 9).

3.0.3 Species identification: comparisons of the sea samplers' and video analyst's records

Species catch rates varied considerably across stations (Fig. 19). In addition, the evenness of the species distribution also varied considerably. A scatter plot of the total number of individuals

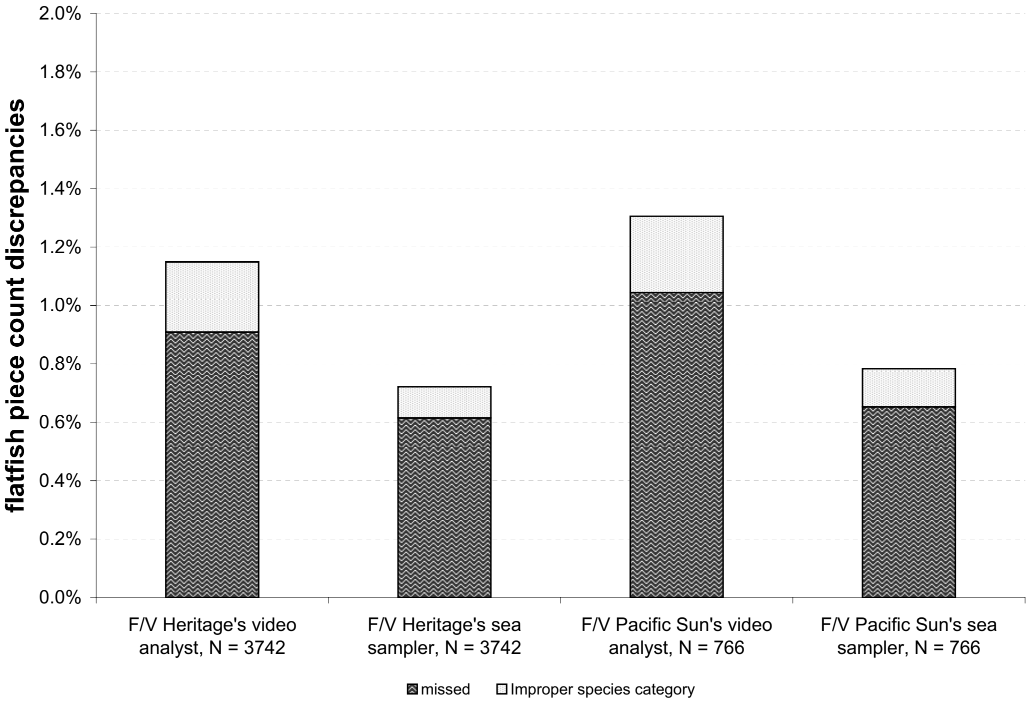


Figure 11. Comparing and delineating the sea samplers' and video analyst's flatfish piece count differences with respect to the percent of the total number of flatfish caught.

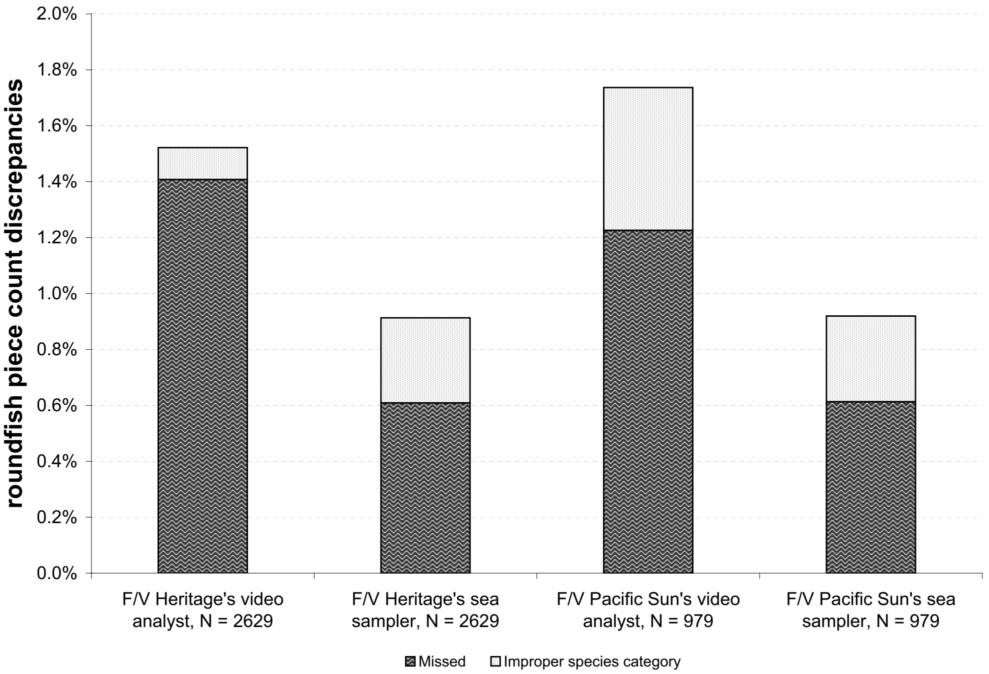


Figure 12. Comparing and delineating the sea samplers' and video analyst's roundfish piece count differences with respect to the percent of the total number of roundfish caught.

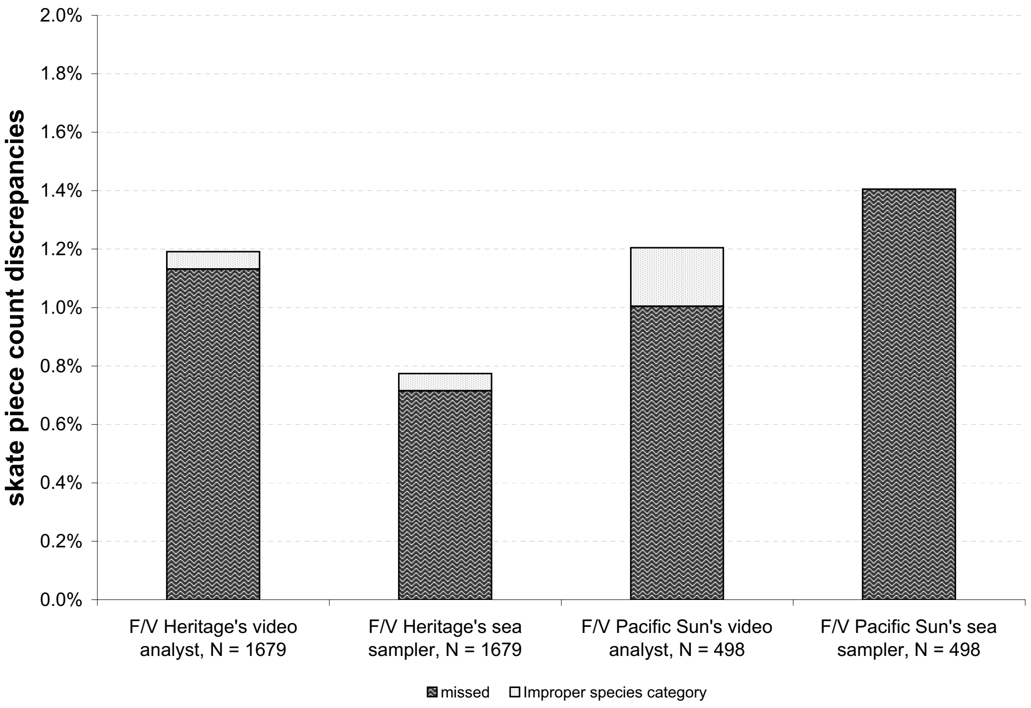


Figure 13. Comparing and delineating the sea samplers’ and video analyst’s skate piece count differences with respect to the percent of the total number of skates caught.

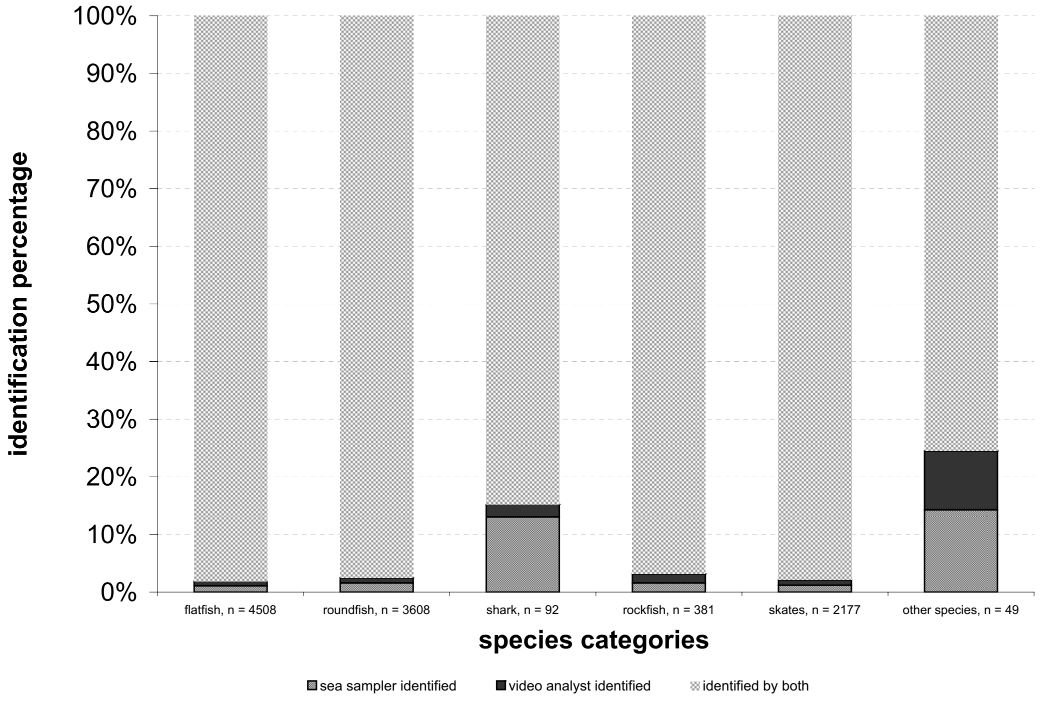


Figure 14. Percentages from piece count discrepancies between the sea samplers' and video analyst's data records in contrast to the percentage of the total general piece count catches.

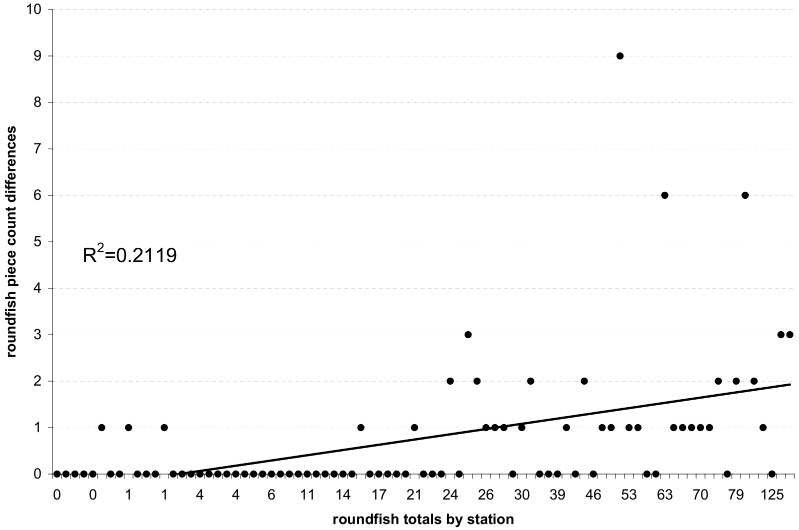


Figure 15. ***F/V Heritage*** **gear retrieval roundfish piece count diffrences between the sea sampler's and video analyst's data records compared with roundfish catch rates by station.**

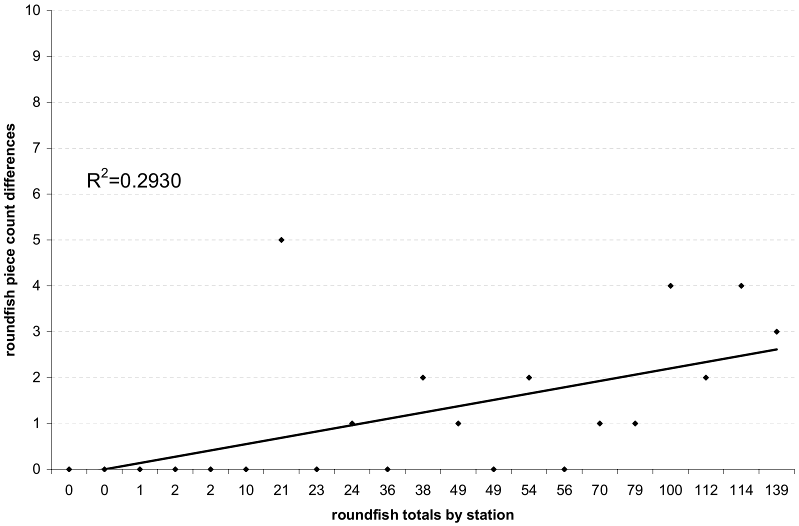


Figure 16. ***F/V Pacific Sun*** **gear retrieval roundfish piece count diffrences between the sea sampler's and video analyst's data records compared with roundfish catch rates by station.**

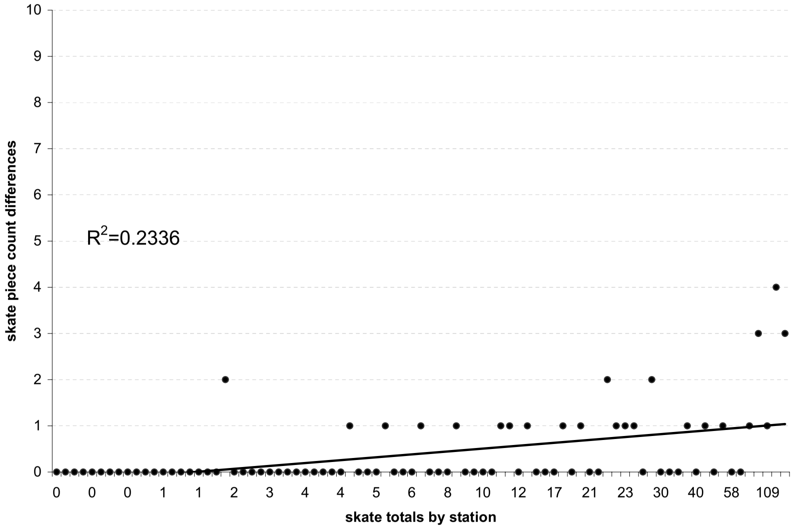


Figure 17. ***F/V Heritage*** **gear retrieval skate piece count diffrences between the sea sampler's and video analyst's data records compared with skate catch rates by station.**

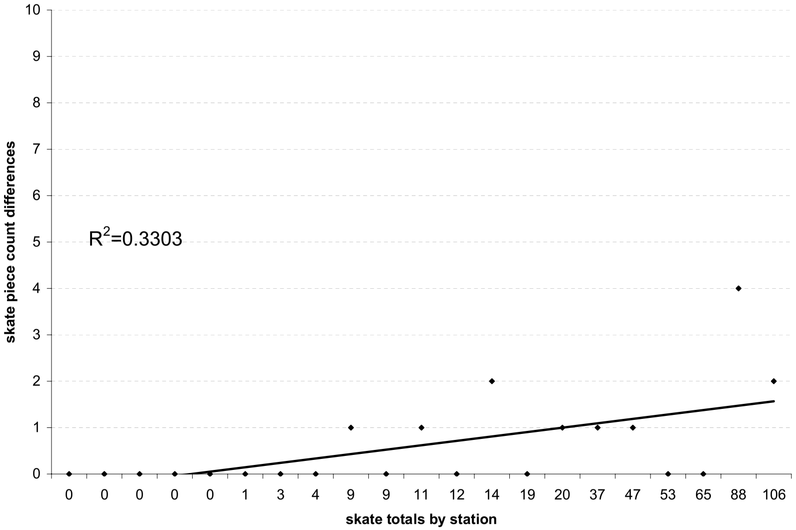


Figure 18. ***F/V Pacific Sun*** **gear retrieval skate piece count diffrences between the sea sampler's and video analyst's data records compared with skate catch rates by station.**

Table 8. The analysis of variance results from the *F/V Heritage* data on the roundfish and skate piece count categories.

F/V Heritage	***F*-value**	**standard error of estimate**	**critical value**
Roundfish category	20.07	1.33	$H_0 : \mu_d = 0$
Skate category	57.86	0.60	$H_A : \mu_d \neq 0$

Table 9. The analysis of variance results from the *F/V Pacific Sun* data on the roundfish and skate piece count categories.

F/V Pacific Sun	***F*-value**	**standard error of estimate**	**critical value**
Roundfish category	10.56	1.30	
Skate category	13.39	0.80	$\iota - \frac{}{s_{\bar{d}}}$

by species showed that Pacific halibut was the most abundant species caught during the study, contributing 33 percent of the total catch, with Pacific cod (*Gadus macrocephalus*) the second most abundant species at 20 percent (Fig. 20).

The species data comparison lists provided two perspectives. The first perspective showed the different types of errors or discrepancies committed by the video analyst when using the sea samplers' data as the standard. The second perspective showed the opposite, comparing the sea samplers' data with the video analyst's data as the standard. The species that were observed most frequently during the study were chosen for the six listed examples (Appendix Tables A2 – A7). The lists did not illustrate the correct observation, but showed that the sea samplers' record was generally more precise with fewer individuals assigned to a general species category than that of the video analyst. The lists also showed that both observational methods portray some uncertainty.

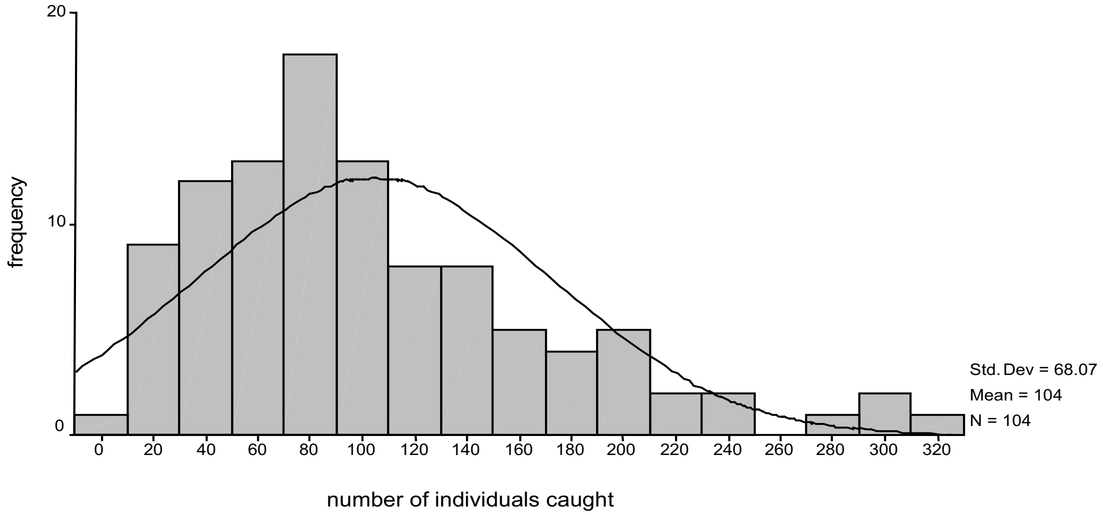


Figure 19. Frequency histogram of catch.

3.0.4 Species identification precision

Species discrepancy rates with parameter estimates were computed to determine the video analyst's precision in relation to the sea samplers' record (Tables 10 and 11). High *p1* rates (i.e., the rate of differences in observations) $\geq$0.10 were found for arrowtooth/Kamchatka flounders (*Atheresthes stomias* and *A. evermanni*), Greenland turbot (*Reinhardtius hippoglossoides*), Alaska skate (*Bathyraja pariferma*), Aleutian skate (*Bathyraja aleutica*), and shortraker/rougheye rockfish (*Sebastes borealis* and *S. aleutianus*). These discrepancies occurred because the video analyst assigned most of the species in disagreement into a more general species category than did the sea sampler (Fig. 21). These five species showed a positive discrepancy relationship with the number of individuals caught per station (Table 12). For example, Greenland turbot showed increased *p1* rates with an increase in station catch rates of Greenland turbot. However, no other significant correlation with other outside variables was found.

High *p1* rates $\geq$0.10 also appeared in the unidentified sharks (order Squaliformes) and unidentified octopus (order Octopoda) categories (Fig. 21). The absence of certain shark and octopus species from the video analyst's record implies that the video analyst missed these species more frequently than other species during hauling events. Both shark and octopus species categories showed a correlation with the number of individuals caught per station (Table 12). No significant correlation with the other variables was found.

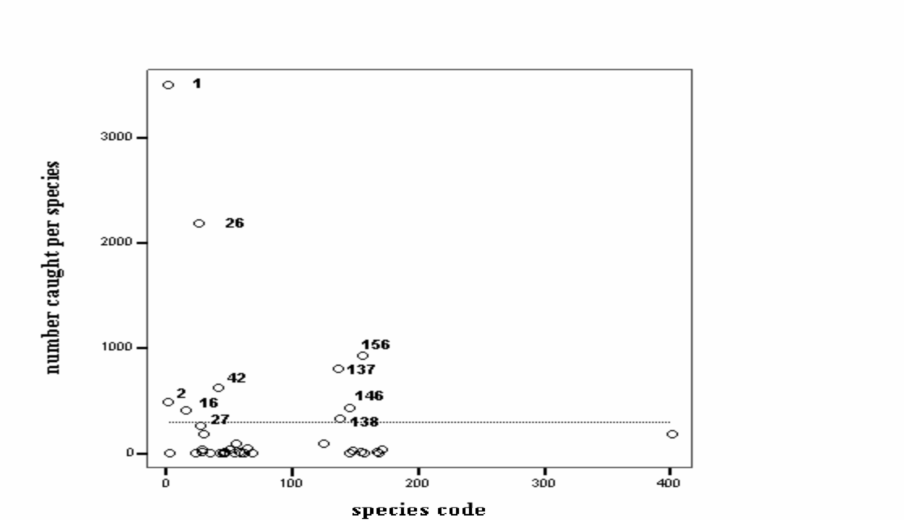
3.0.5 Source of discrepancies

Re-examinations of the discrepancies between the sea samplers' and video analyst's observation records were conducted in order to determine the source of the errors. The analysis of the *F/V Heritage's* data showed that the video analyst made more errors than the sea sampler, but the opposite was true for the *F/V Pacific Sun's* data (Table 13). For example, data from the *F/V Heritage* showed that 60 percent of the 42 errors committed by the video analyst were from missed fish, but this jumped to 76 percent of the 25 errors from the *F/V Pacific Sun* data. The sea sampler errors also varied between vessels. The *F/V Heritage's* data showed that 86 percent of the 21 errors committed by the sea sampler were a result of failing to notice fish, whereas on the *F/V Pacific Sun* only 49 percent of the 33 errors were from missed fish. The errors were organized into groups based on the type and expected source of the errors (Figs. 22 and 23).

The re-examination concluded that when there was a discrepancy, 28 percent of the time the video did not provide enough information to determine the correct observation. The results showed that for 37 percent of the 54 events, in which observational accuracy could not be determined, the sea sampler recorded the presence of an individual and no such individual was seen on the re-examined video. This indicates that the sea sampler made a recording error or the individual dropped off the gear before entering into the video field of view (Fig. 24).

Discussion

The IPHC case study revealed the effectiveness and limitations of EM technologies for quantifying fishing effort and catch composition. This chapter will discuss the significance of the research findings, with suggestions on improving EM technology for use in longline fisheries management. In addition, this chapter will outline the benefits of a comprehensive longline monitoring program; integrating EM technologies and observers to improve catch accountability.



Species code	Species
1	Pacific halibut (*Hippoglossus stenolepis*)
2	arrowtooth/kamchatka flounder (*Atheresthes stomias* and *evermanni*)
16	greenland turbot (*Reinhardtius hippoglossoides*)
26	Pacific cod (*Gadus macrocephalus*)
27	sablefish (*Anoplopoma fimbria*)
42	grenadier (Family Macrouridae)
137	Alaska skate (*Bathyraja pariferma*)
138	Aleutian skate (*Bathyraja aleutica*)
146	yellow Irish lord sculpin (*Hemilepidotus jordani*)
156	whiteblotched skate (*Bathyraja maculata*)

Figure 20. Scatter plot of the sea samplers' records of the total number of individuals caught by species.

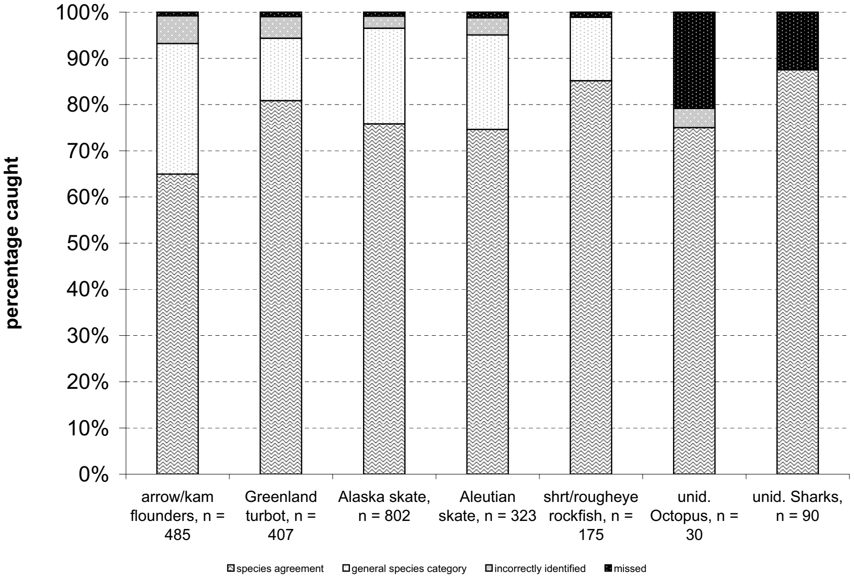


Figure 21. Delineation of the video analyst's data record compared to the sea samplers' record of the seven species with high *p1* rates.

Table 10. Species name, number of species encountered during the study, and the discrepancy rates of *(p1)* with descriptive statistics.

Species and species categories	N-value	*(p1)* Discrepancy rate	± Std. deviations	95% Confidence interval	
				Lower	Upper
Flatfish discrepancy rate					
Pacific halibut (*Hippoglossus stenolepis*)	3493	0.0086	0.0031	0.0055	0.0116
Arrowtooth/Kamchatka flounder (*Atheresthes stomias* and *evermanni*)	485	0.3505	0.0425	0.3081	0.3930
Greenland turbot (*Reinhardtius hippoglossoides*)	407	0.1916	0.0382	0.1534	0.2299
Roundfish discrepancy rate					
Pacific cod (*Gadus macrocephalus*)	2179	0.0119	0.0046	0.0074	0.0165
sablefish (*Anoplopoma fimbria*)	251	0.0159	0.0155	0.0004	0.0314
walleye pollock (*Theragra chalcogramma*)	39	0.0256	0.0496	-0.0240	0.0752
great sculpin (*Myoxocephalus polyacanthocephalus*)	28	0.0714	0.0954	-0.0240	0.1668
grenadier (Family Macrouridae)	620	0.0323	0.0139	0.0184	0.0462
yellow irish lord sculpin (*Hemilepidotus jordani*)	425	0.0212	0.0137	0.0075	0.0349
Skate discrepancy rate					
Alaska skate (*Bathyraja pariferma*)	802	0.2419	0.0296	0.2123	0.2715
Aleutian skate (*Bathyraja aleutica*)	323	0.2539	0.0475	0.2064	0.3013
whiteblotched skate (*Bathyraja maculata*)	923	0.0845	0.0179	0.0666	0.1025
Rockfish discrepancy rate					
unidentified thornyheads rockfish (unidentified *Sebastolobus*)	184	0.0761	0.0383	0.0378	0.1144
shortraker/rougheye rockfish (*Sebastes borealis* and *aleutianus*)	175	0.1486	0.0527	0.0959	0.2013
Other species discrepancy rate					
unidentified sharks (family Squalidae)	90	0.1333	0.0702	0.0631	0.2036
unidentified octopus (order Octopoda)	30	0.2000	0.1431	0.0569	0.3431
unidentified crab (order decapoda)	13	0.0769	0.1449	-0.0679	0.2218

Table 11. Species name, number of species encountered during the study, and discrepancy rates of *(p2)* with descriptive statistics.

Species and species categories	N-value	*(p2)* Discrepancy rate	± Std. deviations	95% Confidence interval	
				Lower	Upper
Flatfish discrepancy rate					
Pacific halibut (*Hippoglossus stenolepis*)	3493	0.0047	0.0016	0.0031	0.0063
Arrowtooth/Kamchatka flounder (*Atheresthes stomias* and *evermanni*)	485	0.0049	0.0018	0.0031	0.0067
Greenland turbot (*Reinhardtius hippoglossoides*)	407	0.0079	0.0025	0.0054	0.0105
Roundfish discrepancy rate					
Pacific cod (*Gadus macrocephalus*)	2179	0.0025	0.0013	0.0013	0.0038
sablefish (*Anoplopoma fimbria*)	251	0.0003	0.0006	-0.0003	0.0009
walleye pollock (*Theragra chalcogramma*)	39	0.0012	0.0017	-0.0005	0.0029
great sculpin (*Myoxocephalus polyacanthocephalus*)	28	0.0007	0.0013	-0.0007	0.0020
grenadier (Family Macrouridae)	620	0.0103	0.0052	0.0051	0.0154
yellow irish lord sculpin (*Hemilepidotus jordani*)	425	0.0058	0.0032	0.0027	0.0090
Skate discrepancy rate					
Alaska skate (*Bathyraja pariferma*)	802	0.0039	0.0015	0.0024	0.0055
aleutian skate (*Bathyraja aleutica*)	323	0.0042	0.0017	0.0025	0.0058
whiteblotched skate (*Bathyraja maculata*)	923	0.0071	0.0025	0.0046	0.0097
Rockfish discrepancy rate					
shortraker/rougheye rockfish (*Sebastes borealis* and *aleutianus*)	175	0.0021	0.0020	0.0000	0.0041
Other species discrepancy rate					
unidentified sharks (family Squalidae)	90	0.0005	0.0006	-0.0002	0.0011
unidentified octopus (order Octopoda)	30	0.0026	0.0029	-0.0003	0.0055
unidentified crab (order Decapoda)	13	0.0067	0.0092	-0.0026	0.0159

Table 12. Analysis of variance of the number of species discrepancies between the sea sampler and the video analysis, and the station catch rates of each species. All seven species listed below showed a correlation with the number of individuals caught per station

Species	Number of stations	F statistic	$\bar{d}$	P value	Std. error of estimate
Arrowtooth/Kamchatka (A*theresthes stomias or evermanni*)	104	74.62	3.92	0.000	2.71
Greenland turbot (*Reinhardtius hippoglossoides*)	104	23.77	3.92	0.000	2.12
Alaska skate (*Bathyraja pariferma*)	104	94.55	3.92	0.000	2.93
Aleutian skate (*Bathyraja aleutica*)	104	215.69	3.92	0.000	1.97
shortraker/rougheye rockfish (*Sebastes borealis/aleutianus*)	104	50.41	3.92	0.000	0.80
unidentified sharks (family Squalidae)	104	71.79	3.92	0.000	0.33
unidentified octopus (order Octopoda)	104	208.66	3.92	0.000	0.25

Table 13 . Re-examinations of the discrepancies between the sea samplers' and video analyst's observation records. The table outlines the distribution of errors committed by both the sea samplers and video analyst by vessel.

Vessel	Stations re-examined	Discrepancies investigated	Sea sampler correct	Video analyst correct	Both observational methods correct	Unable to determine observational accuracy
F/V Heritage	42	97	43%	22%	1%	34%
F/V Pacific Sun	21	78	32%	42%	5%	21%
Totals	63	175	38%	31%	3%	28%

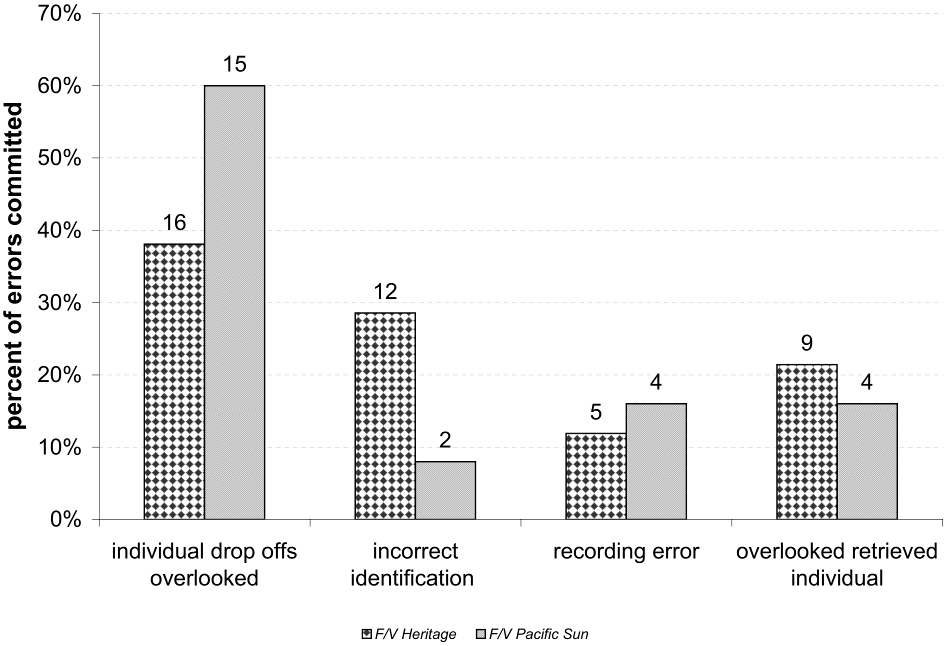


Figure 22. Video analyst errors on the initial observations, by category and vessel.

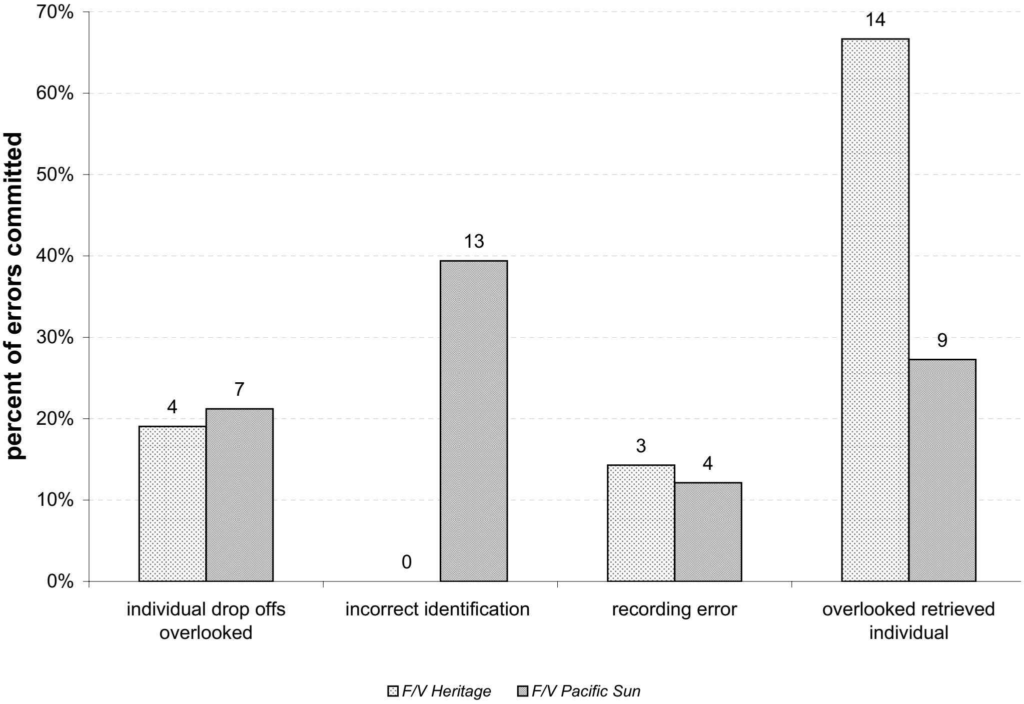


Figure 23. Sea samplers' errors from their catch observations, by category and vessel.

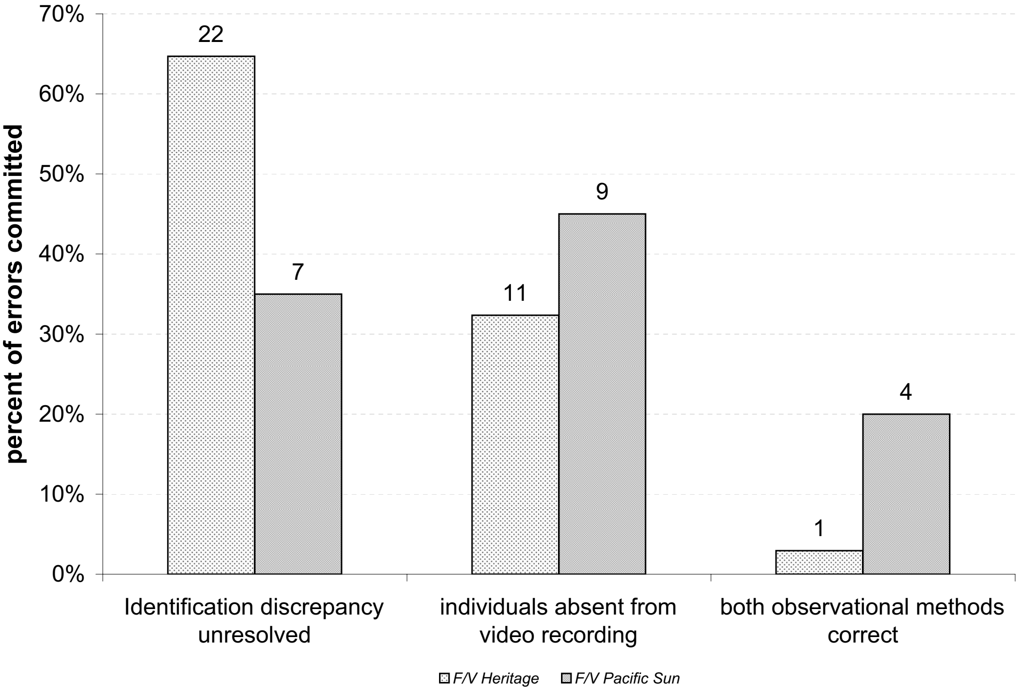


Figure 24. Results of the re-examination of video observations of discrepancies between the video analyst and the observers.

4.0 Case study of electronic monitoring systems

4.0.1 EM configuration: the 2002 at-sea trials

Sea trials on EM adaptability and the determinations of the optimal recording configurations were discussed by Ames et al. (2005). The findings were consistent with the expectation that a relationship existed between species identification accuracy and EM recording frame rates. Ames et al. (ibid) states:

The faster frame rate provided the analyst with a greater number of images of the salted seabirds[7], and thus created a higher probability of capturing an image that contained a unique species characteristic (p 28).

Ames et al. (ibid) investigated the ability of EM systems to capture images for accurate identification of incidentally caught seabirds. The same relationship between fast frame rates and accurate identification of fish species was expected. Therefore, only optimal recording configurations were used in this study analysis. Optimal recording configurations were the adjustments made at sea to the EM units, which included an increase in the camera recording frame rates. This is represented in Table 1 under "second configuration".

4.0.2 Comparing station observation differences in fishing effort

4.0.2.1. Testing station hook count differences: paired-sample t-test. Three of the six initial t-test results established that the observational methods of fishing effort were not statistically different. The results were inconsistent with the expectations that the sea sampler's gear retrieval hook counts and video analyst's counts would be equal, or would be more consistent with each other than with the sea samplers' setting counts. Essentially, it was assumed that the number of hooks set would not equal the number of hooks returned because of hook losses associated with fishing and hauling operations. However, the t-test results of the *F/V Heritage* hook comparisons showed that the sea samplers' setting counts and the video analyst's hauling counts provided the most consistent and the most accurate record of fishing effort, contradicting preliminary expectations. The *F/V Pacific Sun's* data showed similar results, the sea samplers' setting counts and the video analyst's hauling counts were not statistically different, however the high measure of dispersion and the low statistical power of the tests did raise doubts on the significance of these findings. The low number of samples completed on the *F/V Pacific Sun* and the high possibility of causing a type II error limits the conclusions reached here, and the ability to determine if in fact these two methods provide a comparable measure of fishing effort. Nevertheless, the setting counts and the video counts were the most accurate method of deriving fishing effort based on the t-test results.

The *F/V Pacific Sun's* setting counts also showed significant variability in relation to the sea sampler's gear retrieval counts, which added to the uncertainty surrounding the setting data. Even with the removal of the two outliners associated with gear loss, the *F/V Pacific Sun's* setting count comparisons to both the video data and the sea sampler retrieval data were still highly variable (Fig. 4). The *F/V Pacific Sun's* setting count comparisons still showed that the measure of central tendency and dispersion were significantly larger than all of the other four data set comparisons. The large variability could be a function of either a vessel effect or of poor data collection by sea samplers during setting operations. The *F/V Pacific Sun's* incomplete documentation of the setting event suggests that the sea samplers were the principal cause of

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[7] Salted seabirds were frozen seabird specimens that were deliberately set with the fishing gear to determine the feasibility of using video images or detecting and identifying incidentally caught seabirds.

these inconsistencies. The *F/V Pacific Sun's* inconsistency reduces the overall significance of these results, and limits the ability to reach sound conclusions.

Nevertheless, the *F/V Heritage* t-test results imply that there are advantages to counting hooks during setting and by video during hauling, than counting hooks at sea during hauling. During gear deployment the sea sampler's primary task was to determine the exact number of hooks deployed. Setting counts by the sea sampler were arguably the most accurate method of performing hook counts because counting errors associated with fatigue or outside distractions were minimized, with few opportunities to double or miss count hooks during the short 20 minute setting event. However, counting hooks during gear retrieval was a much more tedious and less precise task because the gear retrieval varied from 54 to 243 minutes in duration and could induce fatigue. In addition, the sea samplers took their eyes off the longline to make close inspections of some species that were brought aboard for identification purposes, which introduced some uncertainty into which hooks were or were not counted. Although the video analyst had similar difficulties with respect to hauling duration, the video analyst had the ability to stop, pause, fast forward, or rewind the digital video. Under problematic conditions, the video analyst would rewind the video to an obvious point of reference, such as a skate change, reducing the chance of over or under counting hooks. The result indicated that the sea sampler setting counts and video counts from the *F/V Heritage* were the most consistent, providing an equivalent account of fishing effort outside the effects of lost gear. However, based on the test power, it is impossible to answer this question definitively without a larger sample size.

The gear retrieval counts from the sea samplers and video analyst were fairly consistent on both vessels, with small standard errors. However, in both cases the measures of dispersion and the 95 percent confidence intervals did not incorporate zero, the measure of equivalence, suggesting that during retrieval the sea sampler from the *F/V Heritage* consistently over counted the hooks or that the video analyst under counted. The results from the *F/V Pacific Sun* are conflicting; the sea sampler consistently under counted the hooks or the video analyst over counted the hooks. These findings suggest that both methods do not provide an equivalent measurement of fishing effort during retrieval. The fact that the mean differences are on opposing sides of the x-axis, the measure of equivalence, implies that there is an individual hook counting bias, or a vessel effect. Theoretically, if the bias were related to limitations of the EM systems, then both mean differences would be displaced on the same side of the x-axis. The study included two different vessels in order to measure if there was any vessel effect. However, the numbers of observations by each vessel were significantly different. The *F/V Heritage* comparisons were based on 83 stations incorporating approximately 40,000 hook observations, whereas the *F/V Pacific Sun* had only 20 stations with approximately 9,500 hook observations. These differences affect the results profoundly because as the n value increased the deviation of data points within the data sets became more statistically significant. Thus, the *F/V Heritage's* data set provides a better estimate of the parameters and a statistic than does the *F/V Pacific Sun's* data. Nevertheless, the conflicting results do raise some important questions about counting biases. The results do not definitively answer the question of which observational method provided the least bias. The results do however indicate that regardless of the bias the differences in hauling counts were minimal with standard errors for *F/V Heritage* and *F/V Pacific Sun* of ±0.34 and ±0.77 hooks, respectively. These findings support the ability of EM systems to provide estimates of fishing effort consistent with the sea samplers' hauling hook counts.

4.0.2.2. Delineating station hook count differences: analysis of variance. A positive linear regression was found between *F/V Heritage's* hook differences and the sea conditions experienced. However, the opposite relationship was found on the *F/V Pacific Sun*; the hook differences decreased as weather deteriorated. Although, the *F/V Pacific Sun's* data display a linear relationship, the relationship is weak with insufficient evidence to reject the null hypothesis.

The small sample size and the small range of weather conditions experienced are possible causes of the weak linear relationship. Nevertheless, an opposing relationship was found on the two vessels.

The stronger linear relationship displayed by the *F/V Heritage's* data reveal that the weather conditions affect the hook discrepancies more significantly on the *F/V Heritage* than the *F/V Pacific Sun*. The most plausible explanation was that the weather conditions affected the video analyst's ability to count hooks. As the weather worsened the video analyst was unable to correct the video's confined field of view in order to compensate vessel movement and the reduced visibility produced by wave action, spray, and rainwater interference. Furthermore, vessel movement and reduced camera visibility may be compounded on smaller vessels such as the *F/V Heritage*. The roller height on the *F/V Heritage* is about 90 cm above water level when measured during calm seas, in contrast to the 146 cm roller height on the *F/V Pacific Sun*. Positioning a roller close to water level reduces the time and distance needed to bring fish aboard. The disadvantage is that the roller and roller station are subject to increased wave action during poor weather, especially on smaller vessels. Increased wave action reduces gear visibility and the time that the gear is within the cameras' field of view. Therefore, poor weather and missed hooks would likely be related more strongly with small vessels and vessels with rollers that are situated close to water level.

4.0.3 Testing for equal counts of species by vessel

4.0.3.1. Piece count comparison: McNemar's test. The data from the *F/V Heritage* showed that five of the six general species categories tested were not statistically different, indicating that the sea samplers' and the video analyst's records were equivalent. The shark piece count category from the *F/V Heritage* was statistically different with the video analyst missing a higher number of shark animals than the sea sampler. The *F/V Pacific Sun* results were consistent with the *F/V Heritage*; however the shark piece count category on the *F/V Pacific Sun* was precluded because of insufficient sample size. The high ratio of missed sharks would suggest that the video analyst was either less observant when the sharks were caught, or there were difficulties distinguishing the sharks from the background during the video review process. The latter statement appears to be more likely because only a low ratio of missed individuals was evident in the other species categories.

A number of factors contributed to the missing shark data. Sleeper sharks (*Somniosus pacificus*) comprised 99 percent of the shark species caught during the study. Sleeper sharks are rarely landed because of their heavy weight and large size, ranging to 7 m (Eschmeyer et al. 1983). As the shark breaks the water's surface, the hooks are routinely torn from the shark's jaw because of their immense weight, which reduces the shark's exposure to the recording cameras. Their blackish brown to slate green color also blends into the dark green Bering Sea surface background, which reduces visibility. The camera placement and the lenses used during this study also limited the view of the locations in which the gear would exit the sea surface, and are the most plausible reasons for the missing shark data on the *F/V Heritage*.

The video analyst missed more individuals than did the sea sampler in other categories with the exception being the skate category from *F/V Pacific Sun*. However, the number of missed individuals were not of the same magnitude as the shark category, but the trend was consistent. The most probable reason for the missed pieces was the cameras' limited field of view. Weather, tide, bottom snags, and large objects or animals on the line below the sea surface influenced the gear's surfacing locations. When the gear surfaced outside the field of view the video analyst would not be able to notice individual drop-offs. Although, gear-surfacing locations were considered during the study design, more emphasis was given to species identification. Therefore, lenses that produced closer images were considered most important, sacrificing the wider field of view.

These findings suggest that the lenses used during this study were the primary cause of the missed individuals and not the EM technology. The study results underestimate the effectiveness of the EM technologies when used to enumerate catch.

McNemar's tests showed that all categories were not statistically different except for the shark category. Combining both vessel data sets illustrated the limited magnitude of the discrepancies encountered, especially when considering the large number of species caught within each given piece count category.

4.0.3.2. Piece count differences: analysis of variance. External variables were investigated to determine whether additional factors affected the sea samplers' and video analyst's piece count consistencies. The roundfish and skate category count differences were positively affected by the number of individuals caught within their given categories. These findings are consistent with expectations that higher catch rates would be associated with higher discrepancy rates. However, other factors were influencing the results because, contrary to expectations, the flatfish discrepancies did not show dependence on flatfish catches.

Although all the categories were treated equally during the analysis of variance examination, underlining factors complicated the comparison. Specifically, the grouping of individual species into general categories caused difficulties because high catch rates of any single species within the general categories influenced the results for the entire category. The results were highly dependent on the number of missed or improperly categorized individuals of the dominant species. Within the flatfish category the dominant species was Pacific halibut, which is the target species of the IPHC survey. The IPHC survey crewmembers are instructed to bring aboard all halibut regardless of size. Even when halibut drop off the hook a crewmember's gaff will prevent the loss of the fish, in most cases. Crewmembers are instructed to discard all other flatfish other than halibut, as well as other bycatch species using outboard careful release methods. The dominance of Pacific halibut, their large visible size, and the effort invested in retaining them reduced the relationship between station catch rates and observational discrepancies within the flatfish category.

The results from the flatfish category suggest that a target species, which is in most cases the dominant species, would be counted with a high degree of precision by both observational methods. This is explicit from the results, but also implicit, because the rollerman's behavior directly aids the sea samplers and video analysts in spotting target species. The rollerman's body language and attempt to retain the target species alerts the sea sampler and video analyst, and directs their attention toward the emerging line. The extra set of eyes watching for the target species provides an ad hoc quality control, which in turn increases piece count precision.

4.0.4 Species identification precision

4.0.4.1. Species identification discrepancy rates using the sea samplers' records as a standard. There were limitations to video identification of some species. High *p1* rates (i.e. the rate of differences in observations) were found for seven of the 17 species examined during this study. The first five species with high *p1* rates were arrowtooth/Kamchatka flounders, Greenland turbot, shortraker/rougheye rockfish, Alaska skate, and Aleutian skate. The examination of these species showed that a large number of observational discrepancies were caused by the video analyst grouping individuals into more general species categories than did the sea sampler. The video analysts' inability to identify these species definitively was a result of improper camera placements, recording speeds, and the image compression level.

Arrowtooth flounders, Kamchatka flounders, and Greenland turbot have similar anatomical characteristics, particularly shape and color patterns. Consequently, for species with similar anatomical characteristics, increased discrepancy rates between the video and at-sea observations would be expected. It would also be expected to see increased discrepancy rates for these species even if the two observational methods were the same (e.g., two independent sea samplers identifying species simultaneously prior to landing). The results of this study showed the video analyst grouped these species together into general species categories more frequently than did the sea sampler, suggesting insufficient images and video clarity to make the proper identifications. Increasing the EM recording speed would provide more images for the video analyst, and a decrease in image compression would enhance image clarity. These improvements would increase the video analyst's ability to distinguish the subtle anatomical differences and reduce *p1* rates of these two fish categories.

Likewise, shortraker and rougheye rockfish have very similar anatomical characteristics, but are different from other rockfish that are found in the Bering Sea. This study grouped shortraker and rougheye rockfish together into one category because the species are presently managed as a group in Alaska (AFSC 2004). In addition, these two fish are difficult to distinguish, even in hand, because of the anatomical similarities. The cause for grouping these rockfish into more general species categories is similar to the factors effecting the arrowtooth/Kamchatka flounders and Greenland turbot high *p1* rates. However, these findings are more profound because as described in Eschmeyer et al. (1983) there are no other rockfish species found in Alaska that are considered similar to these two species. Although, there are other rockfish in Alaska that have similar overall coloration, there are clear visible distinctions, such as size, shape, and pigmentation patterns. The analyst's inability to clearly distinguish specific anatomical traits and pigmentation patterns were the primary causes for the high *p1* rates for these two rockfish. Decreasing the video compression levels would provide more image detail, emphasizing edge distinctions between features in the video. Edge distinctions are important for determining overall shape, subtle anatomical traits, and pigmentation patterns. Both an increase in recording speed and decrease in image compression would reduce *p1* rates of the shortraker/rougheye rockfish category.

The Alaska and Aleutian skates also have high *p1* rates, but these discrepancies were attributed to other problems in addition to video resolution. Alaska and Aleutian skates have a number of anatomical characteristics that can be used to differentiate these two species. High portions of the discrepancies were caused by the orientation of the fish to the video cameras during gear retrieval. The video analyst identified 47 percent of the Alaska skate discrepancies and 53 percent of Aleutian skate discrepancies as unidentified skates or as white ventral side skates. The video analyst was unable to view enough of the dorsal side of the skate, which provides critical diagnostic information. The use of only one outboard camera was insufficient to make proper identification when the skates were retrieved facing the other direction. An additional outboard camera would provide another viewing angle and allow the video analyst to make more definitive species determinations.

The last two species from the group of seven with high *p1* rates were unidentified sharks and unidentified octopus categories. These two species groups were, for the most part, identified correctly and the high *p1* rates were associated with failure to notice them on the line. The fact that they were not noticed suggests that those individuals were difficult to detect from the video or they did not enter the camera's field of view. The re-examination process showed that only partial shark and octopus bodies were visible in the video's field of view before they dropped off the line, or only empty hooks were seen. The *p1* rates for these groups could be decreased with the addition of another outboard camera with a wider-angle lens.

The fundamental problems that prevented the video analyst from identifying the same number of individuals to species level as the sea samplers were:

- the video clarity was of insufficient quality,
- the video recording rate produced too few images,
- the video viewing angle was inadequate and limited identification,
- the video analyst was inexperienced, and

- the long hours of viewing induced fatigue decreasing the analyst’s ability to concentrate.

All of these factors contributed to some degree, but the most important was the combination of the video clarity, recording rate, and viewing angle. The level of experience was not examined in this study and may have played a role in the discrepancy rates. However, the sea sampler and the video analyst were the same individual for a large portion of the data comparisons, and any misidentifications would be expressed in both data sets and not affect comparisons. Fatigue may have also contributed to the discrepancy rates, but it is believed to be a more secondary effect because four of the five most dominant species caught during the study had relatively low *p1* rates. If fatigue were a major cause of the discrepancies it would be expected that the high *p1* rates would be more uniform, affecting all the species caught evenly.

4.0.5 Investigation of the observational discrepancies

The re-examination of the video data showed that both the sea sampler and the video analyst made species identification errors. The initial assumption of the study was that the sea sampler data would provide an accurate account of the hauling event. However, the re-examination process showed that both methods contained errors, and that the sea samplers’ data results were inconsistent with the initial assumption. The re-examination results suggest a number of possibilities, either that the sea samplers made almost as many errors as the video analyst did, or that the re-examination process was flawed. Both possibilities may have influenced these results, even though the video analyst took extreme care in locating the identification discrepancies in time and space on the video. The re-examination process may have located and examined incorrect images, producing false error results. Nevertheless, the sea sampler likely made some of these errors and the lack of agreement between the data sets was not always the result of a video identification error. Both video *p1* and *p2* actual discrepancy rates would probably be lower than reported in this study. These findings are important because, like sea samplers, fishery observers may also misidentify with unknown consequences to the management of the fisheries resource. The accuracy of observer data is directly related to individual experience, ability, and willingness to perform their duties with professional acumen (MRAG 2003).

4.1 Conclusions

4.1.1 Fishing effort: electronic monitoring vs. observer estimates

The results show that regardless of the monitoring procedure there will be biases associated with counting hooks to quantify longline fishing effort. More importantly, within the Alaskan and Canadian longline fisheries the use of EM technologies to determine fishing effort is comparable to at-sea observers with negligible differences. The biases between the observational methods are not meaningful when considering the scope of the longline industry. The mean difference with gear snarls on the *F/V Heritage* was 1.65±0.34 SE hooks over an average of 499.8 hooks fished per station. Similarly, on the *F/V Pacific Sun* the mean difference with gear snarls was -1.85±0.77 SE hooks over an average of 487.4 hooks fished per station. In both cases the mean differences are less than one percent of the total hooks retrieved.

Currently, in Alaska the NPGOP relies on observers and vessel captains to determine fishing effort. The NPGOP guidelines require observers to sub-sample 33 percent of hooks fished, which is less precise than the census method employed during this study. NPGOP requires observers to count hooks during a designated tally period or sub-sample outside of the tally period, by counting one-fifth of each set twice per week (AFSC 2004). The use of EM systems to count hooks using the NPGOP sub-sampling guidelines would likely produce equivalent results to that of observers, based on the findings of this study.

4.1.2 Fishing composition: electronic monitoring vs. observer estimates

The results indicate that EM systems are capable of producing images that would allow a video analyst to count and identify most fish species encountered during this study with precision similar to that of observers. Even when considering the species with high *p1* rates, two of the seven species had identification difficulties that were not isolated to video resolution problems alone, but to problems with identifying these similar fish species. These problems face at-sea observers as well:

> Observers on longliners are often unable to identify rare or similar species to species level during the tally period. This is especially true of fish that fall off the line before they are landed. The quality of species composition data will therefore vary with the ability of the observer (MRAG 2003, p. 111).

The results for two of the remaining five species associated with high discrepancy rates indicate that the species were easily identified through the video when seen, but drop-offs were the primary cause of high *p1* rates. Regardless, video clarity, recording rate, and image angle were the primary causes of high *p1* rates. Nonetheless, the video analyst counted and identified most fish species encountered during this study with precision similar to that of the sea samplers, who were certified NPGOP observers.

Observers, like the sea samplers and the video analyst, identify species primarily by visually associating known anatomical characteristics, as opposed to using morphometric measurements or meristic traits. Using morphometric measurements and meristic traits for identifying all catch is unreasonable in most situations because it is too time-consuming (AFSC 2004). The NPGOP requires observers to conduct their tallies from a location that provides a clear line of sight to the longline during retrieval. The location must be close enough for accurate fish identifications prior to landing (ibid). The observer process of identifying species on the line prior to landing is consistent with the methods used in this study by the sea samplers and the video analyst. Therefore, both the sea samplers and video analyst are in the same predicament as observers, facing similar challenges in identifying organisms using primarily anatomical characteristics from afar. The identification problems encountered during this study were a consequence of the study design and not the use of video technologies for species identification, nor the method of identifying exclusively by anatomical characteristics. The camera placement, recording frame rates and image compression levels were insufficient to make accurate identifications of some species. These identification problems could be resolved easily with the use of an improved camera layout and an increase in video resolution.

Two cameras would need to be installed outboard the vessel in order to resolve the identification deficiencies. The first camera would provide a close view of the gear and catch at the roller by using a telephoto lens. The second camera would provide a wide-angle view covering all gear surfacing locations. The second camera would increase video piece count precision and would decrease *p1* rates by reducing the number of missed species due to drop-offs. In addition, decreasing video compression levels and increasing recording speed would enhance the identification capabilities for both cameras (Table 14). The increase in the number of images and in image clarity would provide a higher probability of capturing an image that contains a unique identifying species characteristic.

Following the completion of this EM assessment, IPHC conducted another study in 2004 using EM technologies incorporating the above recommendations. The EM systems were installed on the *F/V Heritage* using a proper outboard boom for mounting two cameras. In addition, three 120 GB hard drives were used to store video data compared to the three 32 GB hard drives used during this study. The increased recording rate with reduced image compression has proven to be significant at reducing the analyst's need to use general species categories. This study was not intended to evaluate the technology, thus the calculation of both *p1* and *p2* rates have not occurred at this time. However, the reduction of assignment to general species categories, with more individuals identified to species level, suggests that this study is a conservative estimate of the EM video capabilities.

4.1.3 The advantage of EM technology: electronic monitoring vs. observer estimates

EM technologies have some advantages over conventional observers in species composition tally estimates. In the NPGOP, several limitations restrict the statistical consistency of the observer estimates of longline catch numbers. Observers quantify vessel catches through designated composition tally periods (AFSC 2004). The tally periods along with estimates of total number of hooks fished are used to calculate the number of individuals of each species caught per set. Observers must extrapolate the mandatory 33 percent observed portions of the longline to the whole string. The NPGOP relies on random sampling to produce statistically reliable estimates. However, commercial vessel configurations and daily schedules differ considerably causing difficulties in collecting true random samples (MRAG 2003). Additionally problematic is that a 33 percent sample may provide a good estimate of commonly encountered species, but rarely encountered species may be missed entirely. Furthermore, the larger catcher-processor vessels fish continuously, which creates difficulties in obtaining reliable catch estimates because observers require downtime for sleep and paperwork. Observers rely on sampled sets or ‘like sets’ to project the composition of the unobserved sets. This technique is frequently used in Alaska and provides the best alternative available when using observers exclusively. However, the biases associated with this technique are unknown, which increases the uncertainty in vessel catch estimates. These composition tally deficiencies in the observer program can be resolved using EM technology.

EM technology provides several advantages over observer composition tallies because all portions of each set and all sets can be tallied. In addition, the sets can be tallied at a faster rate than at-sea observers with similar identification precision for most species. As well, the EM systems can be automated to record only hauling events during fishing trips, which would allow the analysis of every set and eliminate the need to use ‘like sets’. Quantifying catch during hauling events would be accomplished efficiently by video analysts, whereas 68 percent of the observer time aboard vessels is allocated to non-fishing activities (MRAG 2003). Finally and most importantly, a permanent record of the hauling event is archived on a hard disk, allowing either a census of all catch for all sets or sub-sampling. In either case, the EM system would provide a better estimate of the statistical parameters of fishing effort, piece counts, and composition of most species than would observers. True random sampling is possible using EM data because the

Table 14. Optimal roller cameras, lenses, compression rates, and frame rates per second.

Camera specification	Hauling configuration
Two roller camera lenses	8 mm and 12 mm
Two roller camera compression ratios	10×
Camera one frame rates (frames per second)	7.5
Camera two frame rates (frames per second)	7.5

total hauling times, the total lengths, and the exact locations and times of the longline sets can be derived from the EM logged data. If EM units were to be deployed and the degree of precision desired for determining fishery removals and mortalities was known, a sampling frame could be constructed to achieve this precision. This type of program would have a significant advantage over present observer programs because the managers could focus their efforts strictly on the analysis of specific vessels, geographical areas, or fishing times of interest, with multiple video analysts sampling the same sets if verification is desired.

4.1.4 Impact of EM technology on the Alaskan longline fishery

Presently in Alaska, the observer coverage levels and patterns of deployment are insufficient to meet the needs of current and future management objectives (AFSC 2003). The lack of information on the majority of longline fishing activities and locations, as well as uncertainty about the statistical reliability of catch and bycatch data are problems that can not be resolved with the current observer coverage levels.

There are a number of applications suited for an EM program, both in a complementary and supplementary capacity of the observer programs. EM systems could be placed aboard both vessels that require observers and those that do not. An EM complementary program would provide an independent quality control of observer data and would aid in developing reliable estimates of the statistical parameters surrounding observer fishing effort and composition estimates. Moreover, an EM supplementary program would provide vital information on vessels that have traditionally been exempt from observer coverage because of logistical reasons.

The NPGOP provides the primary mechanism by which, catch and bycatch limits are estimated. However, observer coverage is not comprehensive and is of particular concern to managers because coverage levels and deployment patterns cannot be tailored to respond to the current needs of individual fisheries (AFSC 2003). The incorporation of EM systems within the Alaskan monitoring program would provide a major improvement in defining total longline catch and bycatch mortalities for groundfish and halibut fisheries, benefiting both the management agency and the fishers.

Data from EM deployment would supplement in-season harvest rate estimates, reducing the uncertainty in determining when the total allowable catch is reached. The EM system in concert with observer data would allow for more precise catch accounting, which could ultimately benefit fishers if they were able to harvest the entire total allowable catch. Over the long-term, the increased catch and subsequent increase in fishing revenue could compensate the initial costs to the fishers of a combined EM and observer program.

Future studies should investigate other functions and benefits of EM technologies that were not directly evaluated by this study. EM technologies are capable of verifying the vessel's fishing locations, which aids in determining catch distribution patterns spatially and temporally, and in enforcement monitoring of sensitive marine areas or closed areas. Maps with locations, dates, and times can be matched with the digital video of each fishing event, providing precise catch accounting. In addition, the EM data would aid in the prosecution of illegal fishing activities because the evidence is archived and objective, removing any human biases from the equation. Observer related cases have been difficult to prosecute because defense lawyers challenge observer credibility or professionalism to cast doubt on their data during the prosecution process (Karp and McElderry 1999).

Increased monitoring also provides a psychological effect, which reduces non-compliance with fishing regulations and other negative fishing behaviors. This effect is evident when observers are present: "the presence of observers directly influences crew behavior …" (Karp and McElderry 1999 section 7.2.1.). The same effect could be seen with EM systems because the crew would be aware of the video surveillance. Behavioral changes may include a reduction of high grading of catch, or illegal fishing.

The Alaskan observer program is an essential component for providing independent information on fishing activities and the removals of target and non-target species. However, various logistical factors have prevented the implementation of optimal observer coverage. A comprehensive fisheries monitoring program, integrating both EM and observer data would increase the accuracy of fisheries dependent data because all vessels would have monitoring coverage. The expense to the vessel owners for developing space for observers as well as providing additional safety equipment would be unnecessary using EM technology. In addition, a monitoring program using EM technologies would be more cost effective to operate than using observers. Ames et al. (2005) reported that an EM Alaskan halibut program covering all vessels, monitoring both setting and hauling events would cost significantly less than a traditional observer program. Ames et al. (2005) state:

> The calculations showed that an on-board observer program to monitor all setting and haul back activities of vessels fishing for halibut off Alaska would cost $8.46 million, based on data from 2001… (whereas) Using EMS (electronic monitoring systems) to monitor the fishery is estimated at $2.7 million, about one-third as much as an observer program (pp 28-29).

This section has outlined the most obvious benefits to the Alaskan fishery and has provided solutions to resolving the current and longstanding problems that face the Alaskan groundfish observer program. Increasing monitoring coverage to an optimal level by implementing EM technologies would reduce the effect of observer biases and non-compliance with fishing regulations, as well as increase the statistical reliability of catch and bycatch data.

4.2 Summary

The IPHC case study has shown the efficacy of EM technologies for fisheries management, both for quantifying fishing effort and catch composition for most species. All the methods examined for quantifying longline-fishing effort showed some level of bias, however the biases encountered were not meaningful. Moreover, the sea sampler and video analyst retrieval hook count differences were minimal with small standard errors. Even with the effect of large snarls and poor weather, the hook counts remained relatively consistent.

The study also indicates that EM technology would provide similar estimates of piece counts to that of observers. Fish categories showed that the video data and the sea sampler data were not significantly different. The shark category was the only exception with the cameras' limited field of view, and the dominance of one species influencing the results significantly. Other findings showed that observational discrepancies were affected by the number of dominant individuals caught within each given category and by high station catch rates. However, higher catch rates did not affect the flatfish category because the dominant species was the target species and the target species was counted with the highest precision.

The results of the individual discrepancy examination showed that EM technology would provide similar composition estimates to observers for most species. Most of the fish examined showed low $p1$ and $p2$ discrepancy rates, especially for the most commercially valuable species. However, some species investigated had high $p1$ rates. The high $p1$ rates were caused by the video analyst grouping some of the catch into more general species categories than did the sea sampler. The identification problems encountered during this study were a consequence of the study design, specifically recording frame rates and image compression and not the use of video technologies for species identification, nor the method of identifying exclusively by anatomical characteristics. Thus, the video identification deficiencies are resolvable using an improved camera layout with increased video resolution. The findings of this study support the efficacy of EM technology for quantifying fishing effort and catch compositions for most species.

EM technologies in concert with observers could provide reliable and precise data on fishing effort, catch composition, and regulatory compliance. Without such data on the fleets' fishing activities, a high level of uncertainty necessarily attends management decisions. This view is consistent with the Scientific and Statistical Committee of the NPFMC, which concluded that unobserved longline vessels require verifiable information on catch composition (NOAA 2003a). Without the use of EM technology it would be difficult to implement the optimal level of at-sea monitoring of catch in order to achieve accurate information for in-season management and regulatory compliance. This study provides a quantitative evaluation of the capabilities of the EM technology, as well as a working baseline. The analysis shows clearly the effectiveness and benefits of EM technology, as well as its potential role in establishing a functional and cost-effective monitoring program for the conservation and sustainability of marine resources.

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Appendix A.

Table A1. The Beaufort sea state descriptions as recorded by the sea samplers during vessel hauling events.

Code	Knots	Air	Sea Description
0	0	Calm Air	Sea like a mirror.
1	1-3	Light Air	Ripples with the appearance of scales are formed, without foam crests.
2	4 - 6	Light Breeze	Small wavelets, still short, but more pronounced, crests have a glassy appearance but do not break.
3	7 - 10	Gentle Wind	Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses (white caps).
4	11 - 16	Moderate	Small waves, becoming longer; fairly frequent white horses.
5	17 - 21	Fresh Wind	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray).
6	22 - 27	Strong Wind	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray).
7	28 - 33	Near Gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks the direction of the wind.
8	34 - 40	Gale	Moderately high waves of greater length; edges of crests begin to break into the spindrift; the foam is blown in well-marked streaks along the direction of the wind.
9	41 - 47	Strong Gale	High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble, and roll over; spray may affect visibility.
10	48 - 55	Storm	Very high waves with long overhanging crests; the resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; on the whole, the sea surface takes a white appearance; the tumbling of the sea becomes heavy and shock-like; visibility affected.
11	56 - 63	Violent Storm	Exceptionally high waves (small and medium-sized ships might be lost to view for time behind the waves); the sea is completely covered with long white patches of foam lying along the direction of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected.
12	64+	Hurricane	The air is filled with foam and spray; sea completely white with driving sprays; visibility very seriously affected.

Table A2. Example of one of the six general species categories outlined in section 2.5.2. The first column represents all the observations associated with Pacific halibut *(Hippoglossus stenolepis)* during the study. The second column shows the video analyst's observational errors when using the sea-sampler's record as the standard. The third column shows the sea-sampler's observational errors when using the video analyst's record as the standard.

Flatfish category example	Sea sampler's record as the standard		Video analyst's record as the standard	
Observations	*Sea sampler*	*Video analyst*	*Video analyst*	*Sea sampler*
Pacific halibut (*Hippoglossus stenolepis*)	3493	3463	3495	3463
arrowtooth/kamchatka (At*heresthes stomias* or *evermanni*)	0	0	0	5
greenland turbot (*Reinhardtius hippoglossoides*)	0	0	0	4
Pacific cod (*Gadus macrocephalus*)	0	3	0	3
Alaska skate (*Bathyraja pariferma*)	0	0	0	1
unknown/unspecified	0	3	0	0
unidentified coral (Order Scleractinia)	0	0	0	1
empty hook	0	15	0	14
missing	0	9	0	4
Totals	3493	3493	3495	3495

Table A3. Example of one of the six general species categories outlined in section 2.5.2. The first column represents all the observations associated with Pacific cod *(Gadus macrocephalus)* during the study. The second column shows the video analyst's observational errors when using the sea-sampler's record as the standard. The third column shows the sea-sampler's observational errors when using the video analyst's record as the standard.

Roundfish category example	Sea sampler's record as the standard		Video analyst's record as the standard	
Observations	*Sea sampler*	*Video analyst*	*Video analyst*	*Sea sampler*
Pacific cod (*Gadus macrocephalus*)	2178	2153	2168	2153
Pacific halibut (*Hippoglossus stenolepis*)	0	2	0	3
walleye pollock (*Theragra chalcogramma*)	0	1	0	0
unidentified octopus (Order Octopoda)	0	1	0	0
yellow irish lord (*Hemilepidotus jordani*)	0	1	0	0
Alaska skate (*Bathyraja pariferma*)	0	0	0	1
unknown/unspecified	0	1	0	1
unidentified coral (Order Scleractinia)	0	1	0	0
empty hook	0	17	0	9
missing	0	1	0	1
Totals	2178	2178	2168	2168

Table A4. Example of one of the six general species categories outlined in section 2.5.2. The first column represents all the observations associated with sleeper sharks *(Somniosus pacificus)* during the study. The second column shows the video analyst's observational errors when using the sea-sampler's record as the standard. The third column shows the sea-sampler's observational errors when using the video analyst's record as the standard.

Shark category example	Sea sampler's record as the standard		Video analyst's record as the standard	
Observations	*Sea sampler*	*Video analyst*	*Video analyst*	*Sea sampler*
sleeper shark (*Somniosus pacificus*)	88	76	78	76
empty hook	0	12	0	2
Totals	88	88	78	78

Table A5. Example of one of the six general species categories outlined in section 2.5.2. The first column represents all the observations associated with whiteblotched skate *(Bathyraja maculata)* during the study. The second column shows the video analyst's observational errors when using the sea-sampler's record as the standard. The third column shows the sea-sampler's observational errors when using the video analyst's record as the standard.

Skate category example	Sea sampler's record as the standard		Video analyst's record as the standard	
Observations	*Sea sampler*	*Video analyst*	*Video analyst*	*Sea sampler*
whiteblotched skate (*Bathyraja maculata*)	923	845	876	845
Alaska skate (*Bathyraja pariferma*)	0	1	0	2
Aleutian skate (*Bathyraja aleutica*)	0	0	0	7
Aleutian/whiteblotched skate *(Bathyraja aleutica/maculata*)	0	7	0	0
white ventral side skate (Order Rajifomes)	0	20	0	0
skates (Order Rajifomes)	0	44	0	16
unknown/unspecified	0	2	0	0
empty hook	0	4	0	5
Missing	0	0	0	1
Totals	923	923	876	876

Table A6. Example of one of the six general species categories outlined in section 2.5.2. The first column represents all the observations associated with unidentified thornyhead rockfish (unidentified *Sebastolobus***) during the study. The second column shows the video analyst's observational errors when using the sea-sampler's record as the standard. The third column shows the sea-sampler's observational errors when using the video analyst's record as the standard.**

Rockfish category example	Sea sampler's record as the standard		Video analyst's record as the standard	
Observations	*Sea sampler*	*Video analyst*	*Video analyst*	*Sea sampler*
unidentified thornyhead rockfish (unidentified *Sebastolobus*)	184	170	173	170
unidentified red rockfish (Family Scorpaenidae)	0	7	0	0
unidentified rockfish (Family Scorpaenidae)	0	1	0	0
shortraker/rougheye rockfish (*Sebastes borealis/aleutianus*)	0	3	0	0
greenland turbot (*Reinhardtius hippoglossoides*)	0	0	0	1
empty hook	0	3	0	2
Totals	184	184	173	173

Table A7. Example of one of the six general species categories outlined in section 2.5.2. The first column represents all the observations associated with unidentified octopus (Order Octopoda) during the study. The second column shows the video analyst's observational errors when using the sea-sampler's record as the standard. The third column shows the sea-sampler's observational errors when using the video analyst's record as the standard.

Other species category example	Sea sampler's record as the standard		Video analyst's record as the standard	
Observations	*Sea sampler*	*Video analyst*	*Video analyst*	*Sea sampler*
unidentified octopus (Order Octopoda)	30	24	27	24
Pacific cod (*Gadus macrocephalus*)	0	1	0	1
yellow irish lord (*Hemilepidotus jordani*)	0	0	0	2
unidentified starfish (Class Stelleroidea)	0	1	0	0
unknown/unspecified	0	1	0	0
empty hook	0	3	0	0
Totals	30	30	27	27

Appendix B.

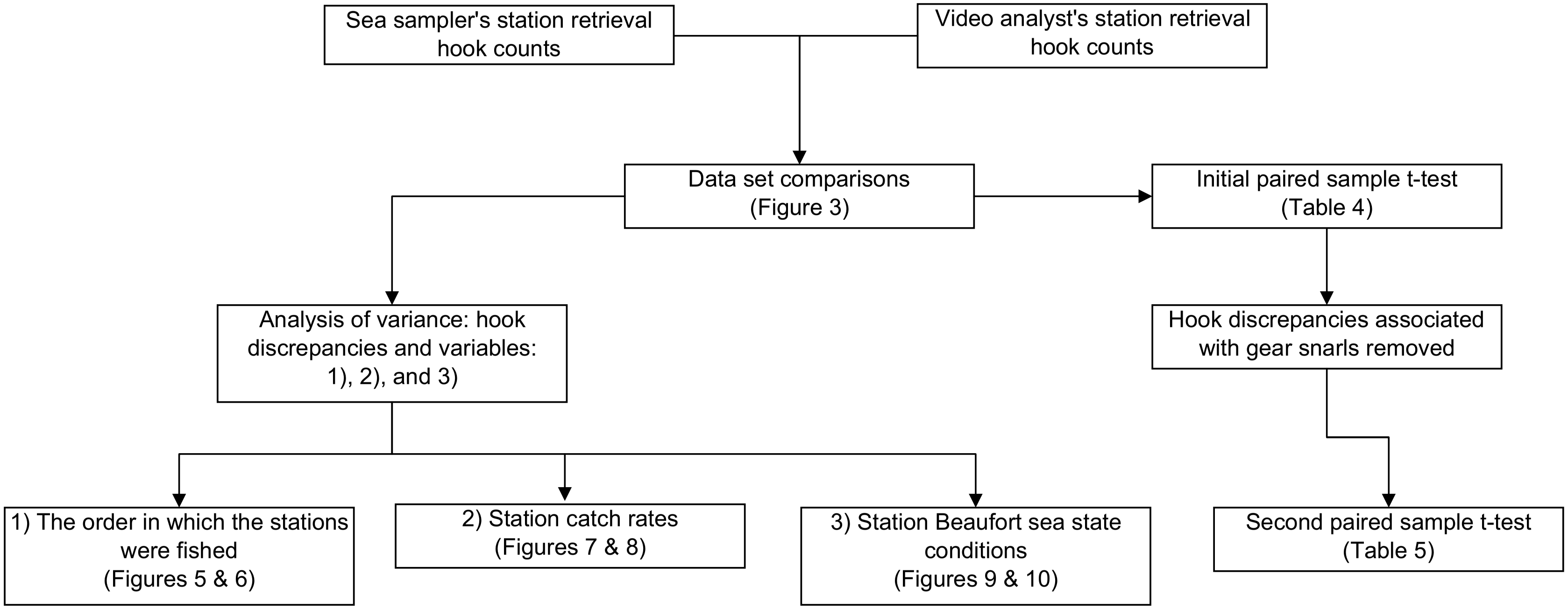


Figure B1. The order of the analyses used to compare the sea samplers' and video analyst's station retrieval hook counts.

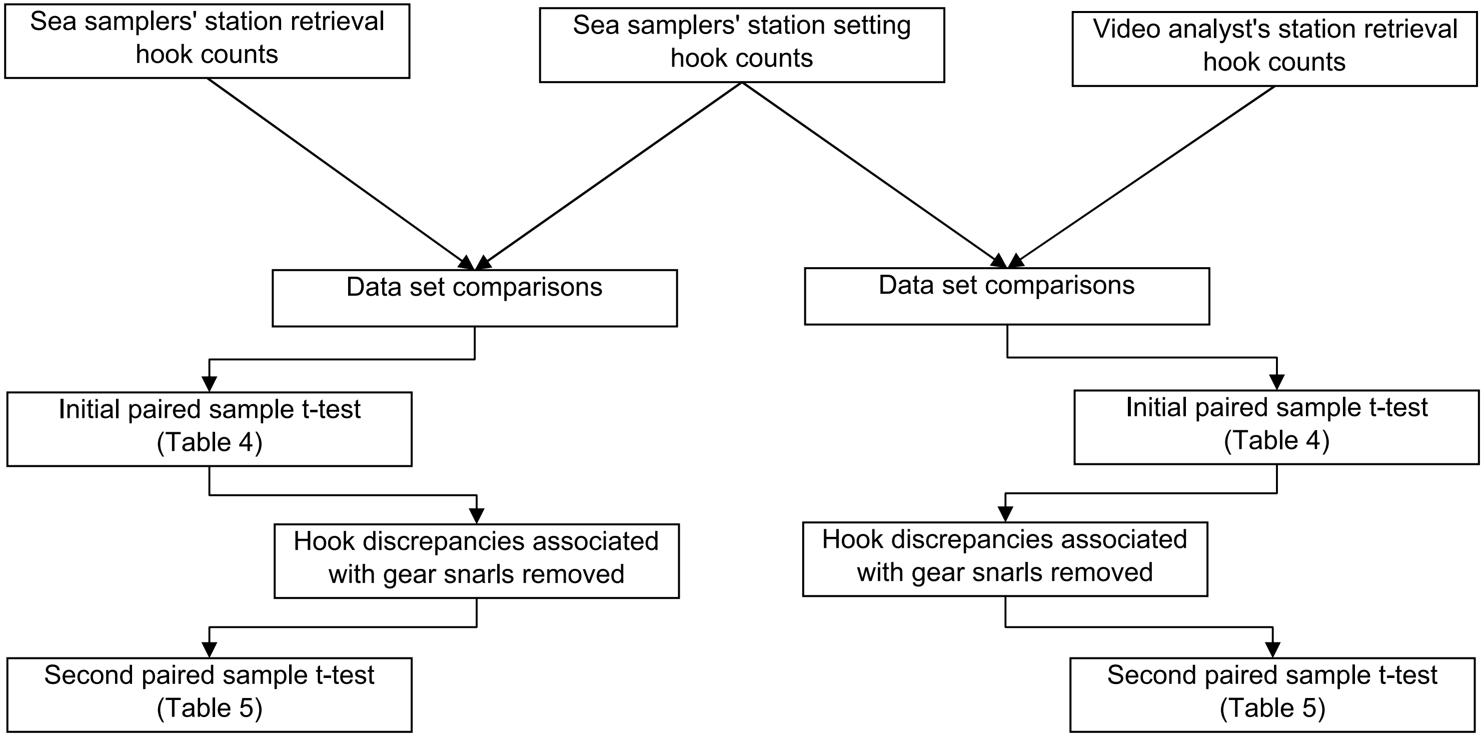


Figure B2. The order of the analyses used to compare the sea samplers' and video analyst's station setting and retrieval hook counts.

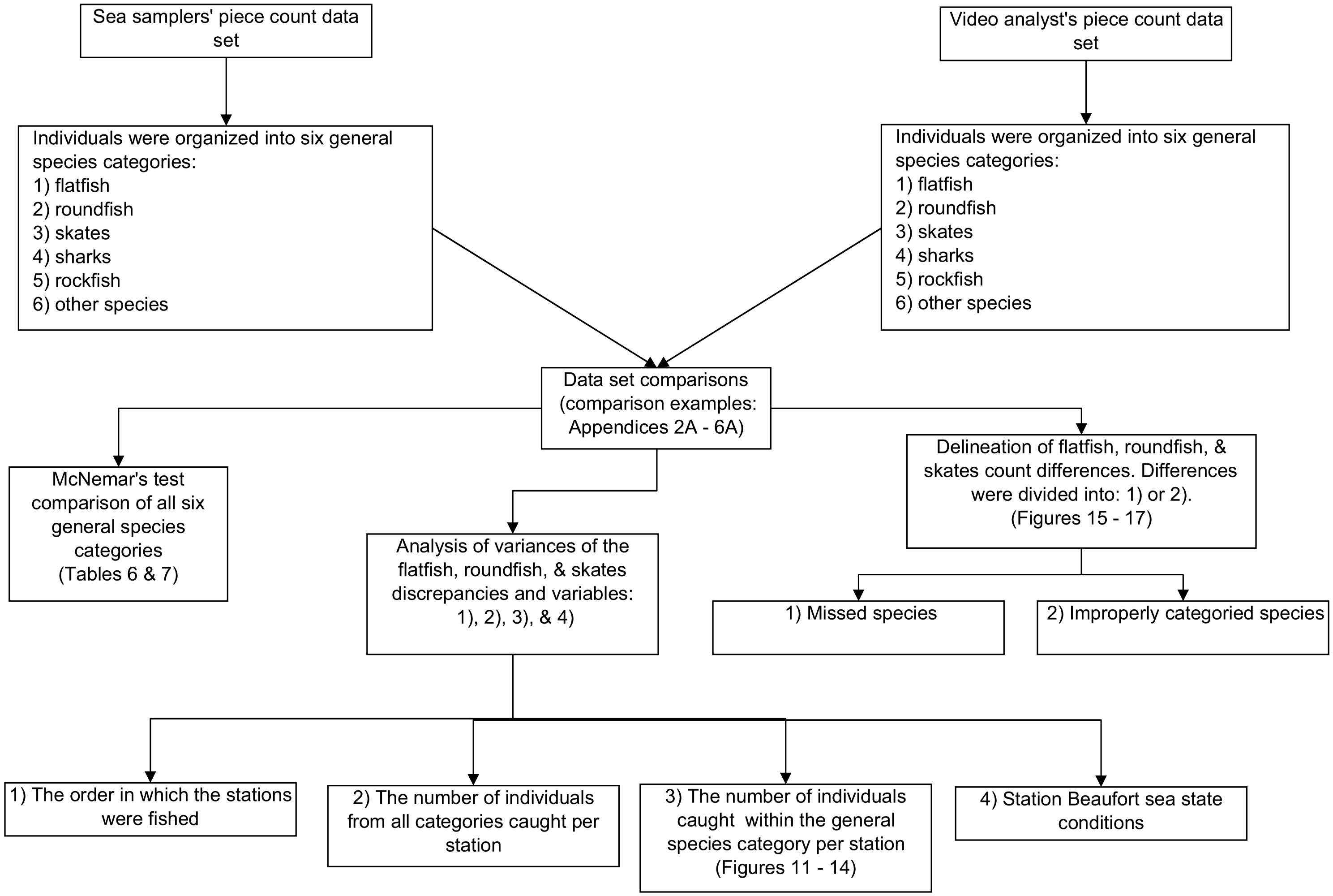


Figure B3. The order of the analyses used to compare the sea samplers' and video analyst's station piece counts.

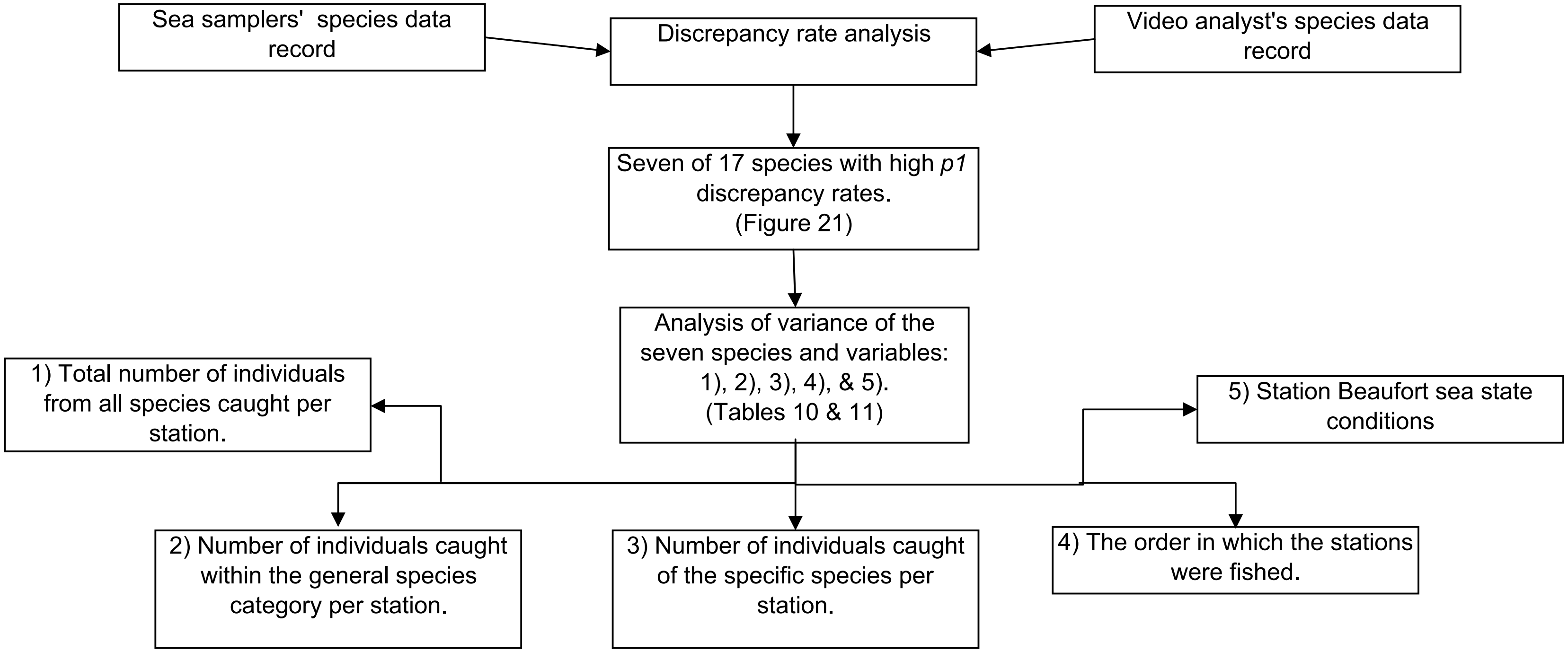
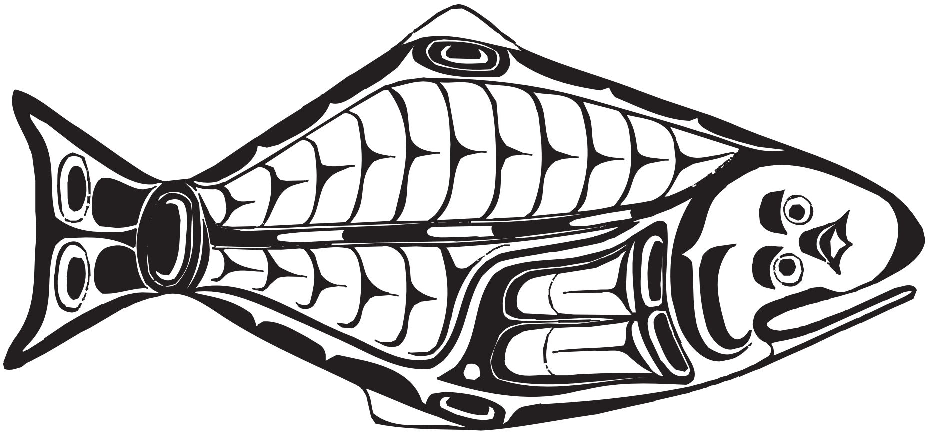


Figure B4. The analyses used to delineate the sea samplers' and video analyst's high species discrepancy rates.



Halibut crest - *adapted from designs used by Tlingit, Tsimshian and Haida Indians.*