NOAA Technical Memorandum NMFS-AFSC-213

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center

December 2010

NOAA Technical Memorandum NMFS

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This document should be cited as follows:

> Cahalan, J. A., B. M. Leaman, G. H. Williams, B. H. Mason, and W. A. Karp. 2010. Bycatch characterization in the Pacific halibut fishery: A field test of electronic monitoring technology. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-213, 66 p.

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December 2010

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ABSTRACT

The increasing focus on the ecosystem approach to fisheries management and the requirement to include all sources of fishing mortality in single species stock assessments heightens the need for accurate and comprehensive catch data from all fisheries. In the waters off Alaska, Pacific halibut (*Hippoglossus stenolepis*) is harvested by longline in an individual fishing quota (IFQ) fishery. In general, the species composition of at-sea discards in this fishery is poorly characterized because the majority of vessels operating in this fishery are not required to have at-sea observer monitoring; hence, estimates of bycatch are not based on direct observation of the fishery. Current information on bycatch in the halibut fishery off Alaska is neither comprehensive nor representative and is derived primarily from unverified logbook reports, survey catches, or other indirect sources.

In this study, we compared estimates of bycatch (numbers of fish) based on dedicated fishery observer (hook-status) documentation of numbers of species hooked with estimates of bycatch based on review of electronic monitoring (EM) video recordings, and where possible, with estimates based on standard Alaska Fisheries Science Center (AFSC) Observer monitoring.

Participation from the halibut industry was lower than expected. Although many vessel owners expressed support for the project, we encountered reluctance by some vessel owners to bring either EM or observers aboard their vessels. We did successfully recruit four vessels to the study, one of which had not previously been subject to observer coverage requirements. We installed EM systems on these vessels and collected EM and observer data during fishing activities in the Bering Sea and the Gulf of Alaska.

During the study, we experienced unanticipated technical problems that resulted in data capture rates that were lower than expected. These issues were rapidly resolved in all cases. Lapses in EM data capture tended to encompass large portions of, or entire, fishing trips while lapses in observer data capture tended to be interspersed within individual trips.

Comparison of species identification of catch between standard observer estimation, complete hook-status observer coverage, and EM coverage showed statistically unbiased and acceptable comparability for almost all species except for some that could not be identified beyond the species grouping levels used in management. Similarly, comparisons of total species-specific numbers of fish estimated using EM-collected and hook-status observer-collected data showed few statistically significant differences.

Based on this study, although limited in scope, EM can provide an additional tool for catch monitoring in the commercial halibut fishery. However, the potential uses of EM need to be determined by the specific monitoring requirements of each management application. EM is not an alternative to observers for the collection of certain biological specimens (e.g., otoliths, scales, etc.) from the catch. With the further development of EM systems and procedures, estimation of bycatch species composition in numbers of fish in the Pacific halibut fishery could be achieved with a high degree of accuracy.

CONTENTS

INTRODUCTION

The increasing focus on the ecosystem approach to fisheries management and the requirement to include all sources of fishing mortality in single species stock assessments heightens the need for accurate and comprehensive catch data from all fisheries. In the waters off Alaska, Pacific halibut (*Hippoglossus stenolepis*) are harvested by longline (hook-and-line) gear in an individual fishing quota (IFQ) fishery. In general, the species composition of at-sea discards in this fishery is poorly characterized. While fishery observers are required on larger vessels (greater than 60 ft length overall (LOA)) harvesting groundfish in these waters, they are not required on vessels that are fishing exclusively under halibut IFQ regulations. Some observer coverage occurs during halibut fishing when vessels are also harvesting sablefish, which is considered to be a groundfish species, but this coverage is minimal. Thus, current information on bycatch in the halibut fishery off Alaska is neither comprehensive nor representative and is derived primarily from unverified logbook reports, survey catches, or other indirect sources.

Observers are considered to be a reliable source of bycatch information. However, observers can be expensive to deploy, and may be logistically difficult to place on halibut vessels, especially since many of these are rather small (55% of commercial halibut fishing vessels are ≤ 40 ft LOA; IPHC 2009) and operate from a large number of ports (over 45 ports recorded landings > 10,000 lb/year; IPHC unpub. data). In recent years, electronic monitoring (EM) has become an increasingly useful alternative for monitoring fishing activities. EM systems can be deployed on fishing vessels to collect information on, for example, fishing location, catch, catch handling, fishing methods, protected species interactions, and mitigation measures. EM has been particularly useful as a tool for compliance monitoring or verification of self-reporting and can provide useful information on catch or bycatch quantity and composition in most instances (McElderry 2008, see also NPFMC 2008 for additional examples). Here, EM is defined as digital video, used in conjunction with other sensors such as VMS (vessel monitoring systems), GPS, and devices which can detect when fishing operations are taking place. In a simplistic sense, digital video recordings obtained by EM systems can be reviewed by technicians who are skilled in species identification and the data obtained can, in many situations, be used to provide estimates of catch and bycatch. This approach is especially viable in longline fisheries where fish are retrieved individually and the video system can capture multiple images of each fish (NPFMC 2008).

Use of EM for monitoring bycatch on longline vessels targeting Pacific halibut was previously investigated by the International Pacific Halibut Commission (IPHC) in 2002 (Ames 2005) and again in 2004 (Ames et al. 2007). In both instances the research was conducted in controlled research conditions aboard contracted longline vessels, although gear was fished in a manner comparable to commercial fishing. Improvements made in EM collection methodology following the 2002 study (camera placement, recording speed, etc.) led to improved accuracy of the EM relative to observers, as reported in the 2004 study. In their comparison of the observer-based and video-based estimates of bycatch, Ames et al. (2007) found a statistically significant difference (sign test) for only one species group (grenadiers). In the 2002 study, no differences between video and observer estimates of the bycatch of grenadiers were detected. Significantly, these studies have highlighted the reality that the use of EM or observers each has its own suite of errors and there is no absolute standard of measurement for bycatch comparisons. Consequently, fishery managers need to consider the objectives of monitoring when choosing or evaluating the monitoring tools for each management application.

In this study, we build on the work conducted by Ames and his colleagues by comparing the performance of observers and EM systems for monitoring bycatch during normal fishing operations aboard commercial halibut vessels. This was accomplished by comparing estimates of bycatch based on an observer "census" of numbers of species hooked with estimates of bycatch based on review of video recordings (another "census"), and where possible, with estimates based on standard observer monitoring (i.e., sampling of catch). We installed EM systems on four vessels operating in the Bering Sea and the Gulf of Alaska. The EM systems were similar to those used by Ames et al. (2007).

Since we were interested in evaluating the performance of EM technology under actual fishing conditions, we endeavored to collect data aboard a number of different vessels operating in different areas and conditions. We also sought opportunities to collect data on vessels with differing harvesting capacities under expectations of different bycatch species composition. However, we encountered substantial difficulty in finding vessel operators who were willing to voluntarily work with us on this research study. Therefore, even though we were able to meet our primary objectives of successfully evaluating EM under commercial fishing operations and comparing EM and observer performance for monitoring bycatch, we were unable to make these comparisons under as broad a range of conditions as we had hoped.

Objectives

This study had two main objectives:

1. Collect catch and bycatch data using several methods:

    a. Estimate bycatch and bycatch rates from data collected using EM on commercial longline vessels.

    b. Estimate bycatch and bycatch rates from data collected using standard Alaska Fisheries Science Center (AFSC) observer monitoring on commercial longline vessels.

    c. Document hook-specific catch (by a second observer) of fish species on the fishing gear.

2. Evaluate the relative efficiency, cost, and bias of each of the two bycatch estimation methods (EM, AFSC Observers) relative to a standard (hook-by-hook, and hook-by-hook comparisons with observer) to determine their suitability for use in fisheries management.

METHODS

On each vessel included in the study group, we placed a full EM system (see details below) and a certified AFSC Observer Program observer (hook-status observer) to collect hook-specific observations of fish species for each hook on the retrieved gear (inclusive of species groups, empty hooks, and landing/release category). In addition, where possible, we placed a second certified observer (standard observer) to sample the catch using standard AFSC Observer Program methods.

We tested four principle hypotheses (Fig. 1). The first comparison tests the consistency in the species identification of a given fish made by an observer on the vessel and a video reviewer. For each hook, the species identifications (inclusive of empty hooks) were compared and the proportion of hooks with catch identified to the same species by both data sources was estimated. Similarly, in the third comparison we tested the consistency between numbers of fish (by species) estimated using data collected by the at-sea observer and data collected by the video reviewer. For each longline set monitored using both methods, the total numbers of estimated fish were compared and nonparametric methods were used to test whether the differences between the estimates were equal to zero.

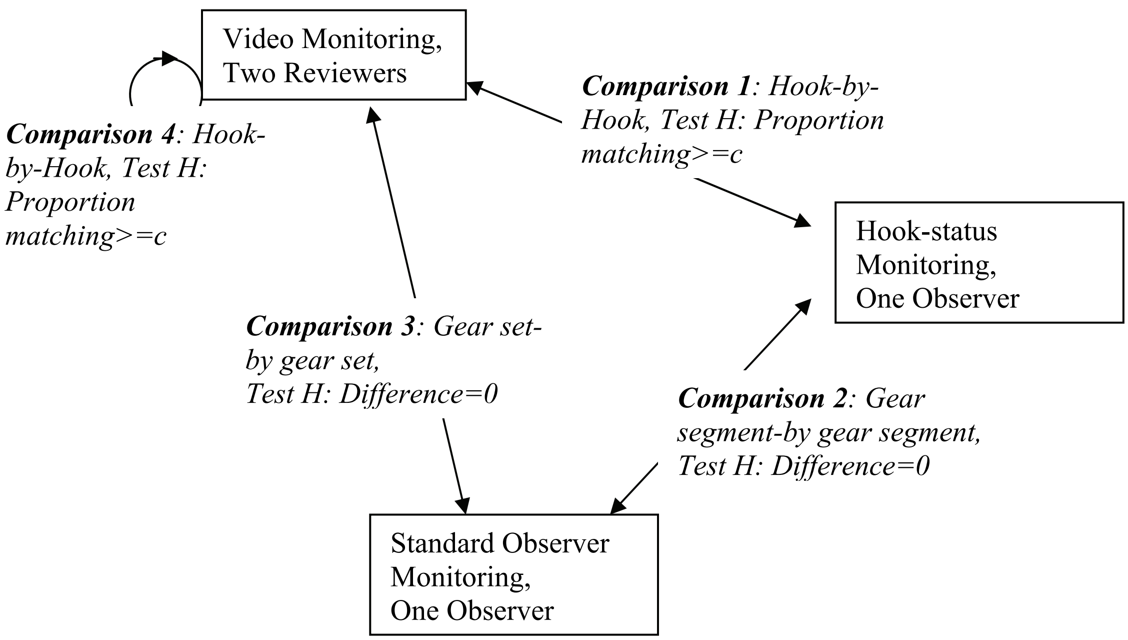


Figure 1. -- Data sources and comparisons used to assess the effectiveness of video monitoring.

The second and fourth comparisons were designed to assess the variability between two independent at-sea observers using two sampling methods (Comparison 2), and the variability between two independent video reviewers (Comparison 4).

The study design included comparisons both between the two monitoring methods (EM and at-sea observer; Comparisons 1 and 3) as well as comparisons within each methodology (Comparisons 2 and 4). These are summarized below and in Figure 1.

- Comparison 1: Comparison of observations of hook-specific species identification made remotely by a video reviewer with those made by an observer stationed on the vessel. This is a comparison of data collected using EM to that collected by an at-sea observer aimed at assessing the variability in species identification between the two data collection methods.
    - Hypothesis 1: The probability of hook-specific species identification agreement between EM video reviewers and at-sea observers is equal to or greater than some predefined constant (e.g., 0.95).
- Comparison 2: Comparison of the hook-status observer's species specific count of fish on the incoming gear with the species-specific count made by an observer operating under standard methods. This is a comparison of observer-collected data to observer-collected data aimed at

assessing the variability in fish counts made by different observers for each gear segment (skate, magazine).

  - Hypothesis 2: The difference between the two observers in the number of fish (of a given species) counted in a segment of gear is zero.

- Comparison 3: Comparison of the number of fish per longline set (for a given species) derived from data collected using EM and data collected by an at-sea observer. This is a comparison of data collected using EM with data collected by an at-sea observer aimed at assessing the variability between the two data collection methods in the number of fish caught by the gear.

  - Hypothesis 3: The difference in the number of fish (of a given species) counted in a segment of gear between the data collection methods is zero.

- Comparison 4: Comparison of the hook-specific species identification made by two video reviewers. This is a comparison of data collected by two different EM reviewers aimed at assessing the between reviewer variability in species identification.

  - Hypothesis 4: The probability of hook-specific species identification agreement between two EM video reviewers is equal to or greater than some predefined constant (e.g., 0.95).

This suite of comparisons and associated hypothesis tests was designed to fully assess the differences in the catch monitoring data collected using EM and at-sea observers.

Vessel Selection

This study was based on voluntary participation by vessel operators, given the design requirement of observing actual fishing operations. We employed four approaches for soliciting volunteer participants to the study: 1) contacting Alaskan commercial halibut fishing organizations to ask their assistance in identifying potential participants; 2) announcements and distribution of fliers at management meetings attended by vessel operators; 3) word of mouth by agency (IPHC and NMFS) staff on the docks; and 4) 'cold calls' to operators suspected of having interest. These efforts began in the fall of 2007, increasing in intensity in February 2008, and continued throughout the study.

When an operator was contacted, project staff explained the goals of the study and what would be required of the vessel in order for the vessel to participate in the study. Operators were supplied with an outline of the study and a description of the power, mounting, and hydraulic requirements of the EM systems. Operators were also notified that additional liability insurance would be reimbursed. Operators of vessels > 60 feet LOA were also apprised that the project observer would fulfill NMFS groundfish observer coverage requirements. Follow-up discussions focused on vessel schedules and other logistics.

Once participation was secured, the vessel schedule was passed to the NMFS AFSC Observer Program staff and the observer provider (MRAG Americas) to coordinate observer training, outfitting, and transportation. Archipelago Marine Research, Inc. (AMR) was contracted by the IPHC to provide, install, maintain, and remove EM equipment on the study vessels. AMR was also notified of the vessel schedule to coordinate EM installation.

Sampling Methods

For all three sampling methods (hook-status, video, standard observer), a standard set of species and species group codes was provided to both the onboard observers and the EM reviewers. In addition, species identification materials similar to those used by the AFSC Observer Program were distributed to observers and EM reviewers.

EM System

Each EM system consisted of sensors recording vessel activities and GPS positions, and two video cameras mounted on an outboard boom such that the cameras were approximately 4.5 m from the incoming gear. One camera was focused to cover a wide angle to record video imagery of all the gear as it left the water, therefore recording any fish that dropped off the line before being landed by the vessel. The imagery captured by the second camera included the gear and catch in the immediate vicinity of the roller exclusively, facilitating species identification of the catch. The cameras did not provide deck views.

There were two main computer components of the EM system: a data logging computer and a video computer. These were located in a tamper-proof container onboard each of the vessels. The data logger computer recorded the output from the various sensors and the GPS receiver. The video computer digitized and recorded the video images captured by the two cameras. Video imagery data were stored on removable hard disks. All necessary equipment was transported to Alaska by the EM contractor, AMR, although small items occasionally needed to be purchased locally to facilitate the installations. A more detailed description of the system can be found in Ames et al. (2007).

In addition to the standard video reviews for Comparisons 1 and 3, we had two individuals review the same 10% sample of the video imagery so that we could evaluate the repeatability of the EM observations (Comparison 4). For all other analyses, the number of fish of a given species on either a longline set, or a skate (segment) of gear, was based on the observations of a single video reviewer. These EM-based observations were assumed to be without sampling error (subject to measurement errors only).

Hook-Status Monitoring

Hook-status observers sequentially recorded both the catch for each hook in the set and the status of that catch (landed, removed intentionally from the line, dropped off the hook before or after the line left the water). The hook-status record (catch observation for each individual hook, sequentially for the set) was aligned with the video record so that direct comparisons could be made for each hook in the sample. In cases where hooks were misaligned due to missed hooks (by either the observer or the video reviewers), realignment was based on matching individuals of obvious species. In addition, hook-status observers were required to record the vessel information, date, set number, and skate number for all samples.

Since every fish on the longline was assumed to be documented by the hook-status observer, the total number of fish of a given species on the gear was assumed to be enumerated without sampling error (subject to measurement errors only).

Standard Observer Monitoring

The methods used by the AFSC Observer Program observers are well documented in the North Pacific Groundfish Observer Sampling Manual (AFSC 2007). These methods were used by the standard observer in this study with a few exceptions, which were outlined in a manual addendum produced specifically for this project.

The standard observer sampling duties were reduced and reprioritized to allow for additional EM-related tasking. The observers were instructed to forego any tasks that were not related to study objectives, including collecting biological data and specimens such as fish otoliths, length frequency data, and halibut injury assessment data. In addition, the standard observers were asked to keep track of the individual skates of gear (gear segments) sampled and record their data for each individual skate so that comparisons could be made between estimates based on different data sources at the skate level as well as the set level. Additionally, emphasis was put on the verification of gear, both total hooks and total skates fished, in order to minimize mismatches between the three sampling methods (EM, hook-status and standard).

For some comparisons in the analysis (see below), we used the total number of fish of each species counted on each skate of gear fished; hence, the estimator is simply the number of fish of a given species counted by the observer. Observer counts of numbers of fish per skate were expanded to estimates of number of fish for the entire longline for comparison with the video estimate of the number of fish of a given species for the longline set.

To estimate the total number of fish of a given species of a species from a given longline set, the mean number of fish per sampled skate of gear was expanded to the entire set. Let

$F_{v,s,i}$	= the number of fish of a given species in segment i, i=1, …n of set s on vessel v
$N_{v,s}$	= the total number of skates in set s fished by vessel v
$n_{v,s}$	= the number of sampled skates in set s fished by vessel v
$\hat{F}_{v,s}$	= the estimated number of fish of a given species in set s of vessel v.

The total catch in numbers of fish was computed using Eqn. (1)

$$\hat{F}_{v,s} = N_{v,s}\left[\frac{1}{n_{v,s}}\sum_{i=1}^{n_{v,s}} F_{v,s,i}\right]. \tag{1}$$

The variance of this estimate was generated using Eqn. (2)

$$V\hat{a}r(\hat{F}_{v,s}) = N_{v,s}^{2}\left[1-\frac{n_{v,s}}{N_{v,s}}\right]\left[\frac{\sum_{i=1}^{n}(F_{v,s,i}-\hat{F}_{v,s})^{2}}{n_{v,s}(n_{v,s}-1)}\right]. \tag{2}$$

Note that these equations are species-specific and those subscripts have been omitted for simplicity.

Observer Training

Observers working on this project were required to have a minimum of 60 sea-days of sampling experience on longline vessels as well as experience on vessels less than 80 feet LOA. This experience level is greater than required for most longline observers; however, it was necessary due to the research aspects of the work, rigors of monitoring entire sets of longline gear, and the complications of sampling on small vessels (higher rates of seasickness, space-related sampling problems). The observers were required to monitor the EM equipment and perform minimal EM equipment maintenance (cleaning lenses, check focus, etc) in addition to their regular duties.

Three observer training sessions were held for the project. The first (three participants) training session was held at the University of Alaska Observer Training Center (OTC) facility in Anchorage, Alaska. The second training was held in Seattle Washington for four observers, two of whom were deployed to study vessels. A final training was conducted in Seattle for two additional observers who were not deployed due to a lack of vessel participation.

Training classes lasted 2.5-3 days depending on class size and consisted of an introduction to the project, review of the modified standard data collection methods, an introduction and practice of the hook-status sampling, a discussion and review of the EM equipment and maintenance, and practice with data entry into the modified at-sea database program. Specialized data forms were created for both the standard observer and the hook-status observer. Additionally, small boat safety was emphasized and reviewed.

Training for the collection of hook-status data emphasized the use of the data forms and the hook-status codes. Laboratory EM training exercises focused on tallying fish for each hook based on video images.

Basic information regarding the EM equipment was provided in the classroom. This included an introduction to the different hardware components and a review of the protocols for seeking assistance in resolving technical problems. Further training was provided by an AMR technician while installations were being completed on each vessel.

Data Preparation and Analysis

AMR staff, subcontracted to the IPHC, reviewed video imagery for each longline set that was monitored by an observer and for which the video equipment functioned for the entirety of the gear retrieval. The catch for each hook monitored was recorded sequentially by the video reviewer. In addition, 10% of the reviewed sets from each study vessel were reviewed by a second independent video reviewer.

The observer hook-status data were transferred to AMR where the hook-specific catch records from the two data sources (EM and hook-status) were aligned (matched) for each longline set based on matching the hook number and unusual or rare species identifications. These aligned data were used to assess the consistency between EM video reviewers and at-sea observers in species identification (Comparison 1), in estimation of species-specific numbers for each set (Comparison 3), and in assessment of the variability in identification of species among video reviewers (Comparison 4).

The total catch of each species (in numbers) was estimated from both observer and EM data. For sets monitored by observers, these catch estimates were based on the sample method used. For standard sampling and hook-status methods, expansions of catch from the sample to the set were made based on the fraction of the skates sampled for the set (Eqns. (1) and (2)). For most sets with hook-status data, all hooks were monitored and expansion was not necessary. Similarly, catch of each species from EM data was estimated based on counts of individual fish of each species for the set. Only those sets with complete EM records were used in the analysis (EM data were not expanded).

Comparison 1: Comparison of Hook-status Observer and EM Reviewer Species Identification

In Comparison 1 (video monitoring to hook-status monitoring), we were interested in whether the species identification was consistent between video reviewers and observers. To avoid complications associated with sampling variance and data alignment, we only compared those sets with complete records of hooks for both data sets (EM data and hook-status observer data: one to one comparison). In this case, for each hook observed, there are two possible outcomes: either the results from the two monitoring methods match or they do not match. These data should follow a binomial distribution and may be over-dispersed due to vessel and / or area effects. Ames et al. (2007), indicated that the data from their study was not over-dispersed (due to skate or set dependences within the vessel), and since we similarly did not detect over-dispersion in the data (within vessels), we assumed there were no effects due to trips within vessels, longline sets within trips, or skates within sets. Therefore, hook-specific data were pooled within vessels. Furthermore, since only a small number of vessels participated in the study, statistical tests of vessel effects were not attempted and most analyses are vessel-specific.

The proportion of hooks with matching species identification was estimated as follows.

Let

$X_{i,v}$ = indicator of matching species identification for hook i on vessel v, $X_{i,v}=\{0,1\}$, $i=1, \ldots ,n_v$

n_v = number of hooks set by vessel v (all trips and longline sets)

v = index on the vessel, $v=1, \ldots. V$.

The estimated proportion of hooks with matching observations (for a given species) is given in Eqn. (3) with the empirical variance presented in Eqn. (4)

$$\hat{p}_v = \frac{\sum_{i=1}^{n_v} X_{i,v}}{n_v} \tag{3}$$

$$Var(\hat{p}_v) = \frac{\sum_{i=1}^{n_v} (X_{i,v} - \hat{p}_v)^2}{n_v - 1} \tag{4}$$

In addition, the parametric binomial variance computed using Eqn. (5) was compared visually with Eqn. (4) to verify there were no trip, set, or skate effects

$$Var(\hat{p}_v) = \hat{p}_v(1-\hat{p}_v) \quad (5)$$

Comparison 2: Agreement Between Standard Sampling and Hook-status Sampling

In Comparison 2, we tested whether the hook-status observer's identification of fish on the incoming gear was the same as the identification made by an observer using standard sampling methods. We assessed whether the two observers were counting the same number of fish of each identified species in each skate (gear segment). For two observers recording data for the same skate of gear, we compared whether they recorded the same number of fish of each species. We used a Wilcoxon signed-rank test to test the hypothesis that the median of the differences in the species-specific number of fish on each sampled skate recorded by the two observers was zero.

In addition, the data collected using standard sampling methods was used to estimate the total number of fish (species-specific) caught on the set using Eqn. (1). This estimate of total catch was compared with the total number of fish (species-specific) recorded by the hook-status observer. For each longline set, the 95% CI was computed using the variance described in Eqn. (2) and assuming the estimates follow a normal distribution: $95\%\ CI = \hat{F} \pm 1.96 \times \sqrt{V\hat{a}r(\hat{F})}$. If the assumptions underlying the construction of this confidence interval are valid (e.g., normally distributed estimates), then we would expect approximately 5% of the species-specific catch estimates from the hook-status observer to be outside this confidence interval.

Lastly, we were interested in evaluating whether the data collected using the standard sampling methods adequately characterized the variance in the species composition of the catch. This variance is used to estimate the uncertainty associated with catch estimates based on data collected using the standard sampling methods.

Since the hook-status observer recorded data for each skate in the entire longline set, the computed between skate variance is the 'true' variance in the population; not subject to sampling error. The coefficient of variation for the hook-status observer was estimated using Eqn. (6) where terms are as defined previously (with Eqn. (2))

$$CV_E = \frac{1}{F_{v,s}} \sqrt{\frac{N^2 \sum_{i=1}^{N} (F_{v,s,i} - \bar{F}_{v,s})^2}{(N-1)}} \quad (6)$$

Similarly, the coefficient of variation for the standard method observer was estimated using Eqn. (7). This estimate of CV is subject to sampling variability and represents the among-skate variance in species composition estimated from the standard observer data

$$CV_o = \frac{1}{\hat{F}_{v,s}} \sqrt{\frac{N^2 \sum_{i=1}^{n} (F_{v,s,i} - \bar{\hat{F}}_{v,s})^2}{(n_{v,s} - 1)}} \quad (7)$$

These coefficients of variance can be directly compared for each set to evaluate whether the variance estimated from standard observer data are biased.

Comparison 3: Agreement Between Observer (Standard /Hook-Status) Catch Estimates and EM Catch Estimates

Comparison 3 was intended to compare the catch estimates based on the data collected using standard methods with catch estimates based on data collected using EM. For those sets where both EM data and standard observer sample data were available, we tested whether the estimated number of fish per longline set (for a given species) was different between the two monitoring methods.

In addition, for those sets where hook-status data were available, we tested whether the species-specific number of fish recorded by the hook-status observer was the same as the species-specific number of fish recorded by the EM reviewer. In this comparison, neither estimate is subject to sampling errors, and any differences between the estimates would be due to non-sampling (measurement) errors.

Again, due to small sample sizes and apparent non-normality in the data, we used a Wilcoxon signed rank test of the hypothesis that the mean of the differences in the paired estimates was zero.

The sample variance was computed based on a sample of one third (0.33) of the skates fished for the set using Eqn. (8) where $n_{hyp,v,s}$ is the hypothetical number of skates sampled

$$V\hat{a}r(\hat{F}_{v,s}) = N_{v,s}^2 \left[1 - \frac{n_{hyp,v,s}}{N_{v,s}}\right] \left[\frac{\sum_{i=1}^{N_{v,s}} (F_{v,s,i} - \hat{F}_{v,s})^2}{n_{hyp,v,s}(N_{v,s} - 1)}\right] \quad (8)$$

The hypothetical number of skates sampled was one-third the number of skates fished, rounded to the nearest integer.

This sample variance data was then used to construct hypothetical 95% confidence intervals, based on the assumption of normality, for the observer estimates of catch based on the data collected by the hook-status observer: $95\%\ CI = \hat{F} \pm 1.96\sqrt{V\hat{a}r(\hat{F})}$. If the assumptions underlying the construction of this confidence interval are valid (e.g., normally distributed estimates), then we would expect approximately 5% of the species specific catch estimates based on the EM data to be outside this confidence interval.

Comparison 4: Proportion Matching Species Identifications Between two EM Independent Reviewers

Lastly, in Comparison 4, we assessed the repeatability of the video monitoring by comparing (hook-by-hook) the identification of fish by the two video reviewers for a sample of the video record. This analysis was essentially the same as Comparison 1.

RESULTS

Vessel Solicitation and Participation

Cooperation with the commercial halibut longline fleet was expected to result in a sufficient number of boats for the study. Many vessel owners expressed support for the project during the planning stages, particularly because of the identified lack of catch monitoring as a shortcoming during the Marine Stewardship Council (MSC) Certification of the fishery (see http://www.msc.org/documents/fisheries-factsheets/net-benefits-report/US-North-Pacific-halibut.pdf). Actual responses from vessel operators were quite varied, ranging from strong interest to none. No one we contacted directly was familiar with this project, though many had knowledge of the use of EM in the Canadian halibut fishery. Most were interested to see how EM performed in the Alaskan halibut fishery but many had concerns about the additional space required to have an observer(s) on board. Operators of smaller (e.g., < 60 ft LOA) vessels often cited lack of bunk space or working space on deck. Most declined for these reasons. Operators of larger vessels, which had previous experience with observers, had greater hesitation with the space requirements of two observers and usually declined for those reasons.

After several operators declined to participate, citing space issues, alternative sampling plans were devised which required only one observer per vessel. Subsequent solicitations were made based on the one-observer plan to which operators were more agreeable. Working out scheduling and other logistics made up the remainder of the negotiations.

For those vessel owners who did wish to participate we experienced difficulties in obtaining final commitments due to:

- Perception of inadequate space onboard by the vessel for observers
- Lack of remuneration for taking observers
- Unexpected changes in vessel schedules and fishing plans

The remaining opportunities were inherently fraught with challenges due to changes in vessel fishing schedules and ports of landing and air travel disruptions due to volcanic eruptions. While we were working on the basis of no less than a 1 week advance notice to AMR and MRAG, occasionally an operator would call with only a few days notice and would need to leave port before EM equipment could be installed. Some operators also worked out of a port with no daily air services, making logistics difficult. Finally, the July 2008 eruption of a volcano near Dutch Harbor halted air traffic into that port, delaying the arrival of the observer, the EM equipment and the AMR installation technician, which resulted in several missed trips in the Bering Sea.

Project Costs

Here we present information on the costs of collecting the study data with EM and observers. Although the work was carried out on vessels conducting normal commercial halibut fishing and not research fishing, we wish to stress that the costs presented here are probably not reflective of costs that would occur under a typical fishery monitoring deployment of EM or observers during fishing operations. However, the cost information we are able to provide may be useful in planning additional studies and understanding some of the relative costs of EM and observers.

Study costs were comprised of expenses for placing observers on vessels and contract expenses for the use of EM systems. For observers, field costs included equipment (laptops, not standard sampling gear), training and debriefing, and daily rates for in-port and at-sea days. PSMFC contracted with MRAG Americas for observers, and the daily rates charged were similar to rates currently charged for deployment of observers in the Alaska groundfish fisheries. IPHC contracted with AMR to provide all EM-related services. This included the lease of systems, installation and removal of the systems from the study vessels, and video review (analysis). Agency (e.g., IPHC, NMFS and PSMFC) staff time is not included in these cost estimates. The study costs also do not include several other expenses, such as additional data entry and agency overhead for project oversight and contract management.

Based on this approach, a total of $194,491 was spent during the course of the study (Table 1). Slightly more than half, or approximately $103,000, was spent on the EM coverage and analysis. However, excluding the expense of the project planning meetings with AMR to discuss logistics and data structure, the costs of observer coverage and EM were very similar for the coverage levels obtained.

Table 1. -- Summary of study costs.

	EM	Observer
EM Planning		
Labor	$ 5,458	$ 0
Travel	$ 871	$ 0
Total	**$ 6,329**	**$ 0**
Field Work		
Labor	$ 27,561	$ 61,213
Travel	$ 22,210	$ 23,045
Equipment	$ 15,400	$ 6,752
Other Expenses	$ 6,197	$ 490
Total	**$ 71,368**	**$ 91,500**
Video review		
Labor	$ 25,294	$ 0
Total	**$ 25,294**	**$ 0**
GRAND TOTAL	**$ 102,991**	**$ 91,500**

Data Collection

We collected side-by-side EM and observer data on four vessels during the summer of 2008 with a total data collection of 13 trips and over 200 sets with data collected using one of the three methods. A summary of the fishing effort and data collected is presented in Table 2.

Table 2. -- Summary of fishing characteristics and data collected for participating vessels.

					Number of Sets	
Vessel	Length	Area Fished	Months Fished	Number of Trips (number of sets)	EM Operating	Observer Data Collected
A	>60’	GOA	May – June	2 (43)	9	43
B	>60’	BS (0.5 trip GOA)	July – September	6 (168)	168	141
C	>60’	GOA	August	2 (20)	12	19
D	<60’	GOA	April; July-August (2 trips)	3 (19)	13	17
Total	**---**	**---**	**---**	**13 (250)**	**202**	**220**

The number of sets with EM operating includes sets where video data were collected for all or part of the set. Similarly, the number of sets with observer data collected includes hook-status data (entire or partial monitoring) and standard data collection methods.

Of the four vessels that participated in the study, one was < 60 ft LOA and therefore not subject to observer coverage when participating in Alaska groundfish fisheries. The other three vessels would be subject to observer coverage requirements while fishing for sablefish, but not while fishing exclusively for halibut. Three of the vessels fished in the Gulf of Alaska while one fished primarily in the Bering Sea. This suite of vessel sizes and areas fished deviates somewhat from our original study plan to collect data balanced among areas and vessel sizes (observer coverage requirements), however, availability of vessels from the commercial fishery was a limiting factor.

Data Capture Results

The number of sets where data were captured is summarized in Table 3 for each vessel and data collection method. Only those sets with observer hook-status data were reviewed by AMR, hence the number of sets reviewed (Table 3) differs from the number of sets during which the EM system were operating (Table 2). On some sets, the hook-status observer did not sample the entire set, but rather sampled a randomly selected portion of the set. Intermittent image recording due to EM system malfunction resulted in partial review of the set for a few sets.

Table 3. -- Summary of the amount of sampling conducted on Hook-status, standard sampling, and EM monitored sets.

	EM Sets		Hook-status Sets		NPGOP Sets
Vessel	No. of Sets Reviewed	No. of EM Sets with Full Review (Fully Monitored)	No. of Sets with Hook-Status Monitoring	No. of Fully Monitored Hook-status sets	No. of Sets with standard observer sampling
A	9	7	41	38	22
B	140	140	141	129	0
C	10	10	14	4	5
D	11	11	16	16	1
Total	**172**	**168**	**212**	**187**	**28**

The observers assigned to study vessels were able to collect data for the majority of sets fished (Fig. 2). Due to space and safety limitations, on all vessels with the exception of the first trip on Vessel A, only a single observer was deployed. As a result, hook-status data were collected for all monitored sets where a single observer was deployed since these data provided a more rigorous comparison with the EM data.

On Vessel A, two observers were deployed for the first trip and all sets were sampled using both the standard groundfish observer sampling and the hook-specific census methods. On the second trip, only a single observer was deployed and collected data for all sets using the hook-specific methods.

On Vessel B, the observer was unable to collect data on 27 of 168 sets, primarily due to adverse weather conditions and associated safety concerns that prevented the observer from conducting their sampling duties. On Vessel C, the observer was able to census 4 of 20 sets fished, however, hook-specific data were collected for (randomly selected) portions of an additional 10 sets. For five sets on the second trip, the observer collected data using the standard method. On this vessel, one set was not monitored by the observer. The vessel was fishing long sets, in excess of 3,000 hooks per set, and was fishing 24 hours a day. Since there was only one observer onboard, the observer was unable to record data for the entirety of each set. On Vessel D, two sets were not sampled due to observer illness.

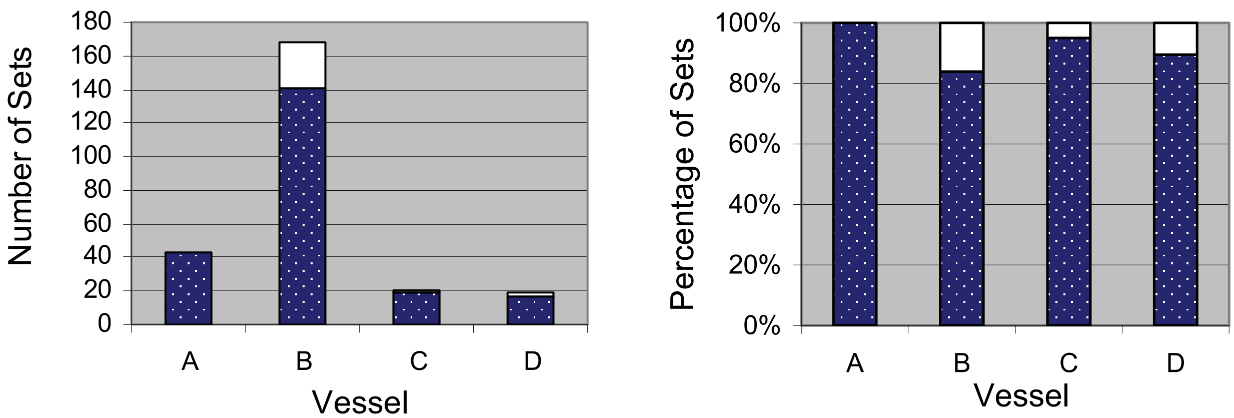


Figure 2. -- Data capture results for observer relative to all sets fished; number of sets sampled by vessel (left) and percentage of sets (right). Sets where data were recorded are indicated in dark blue; sets during which data were not recorded are indicated in white.

Electronic monitoring of fishing activities was successful for the majority of sets (Fig. 3). In order to minimize project costs, after the first trip of the study (Vessel D), EM imagery was reviewed and catch was documented only for those sets where hook-status observers also collected data.

We encountered technical difficulties and equipment failures on the first two trips in the study (Vessels A and D). On these vessels the EM functioned properly for 23 of the 58 monitored sets over the course of five trips. The EM failure during the first trip was due to incompatibilities between the EM system software and a new version of the Microsoft operating system on the EM computer. This problem was exacerbated by an uneven supply of power to the EM system. The vessel operator (vessel D) was unwilling to wait in port until the problem was resolved and no video data were recorded for that trip. On the next two trips these problems were resolved and no additional issues were encountered on this vessel on subsequent trips.

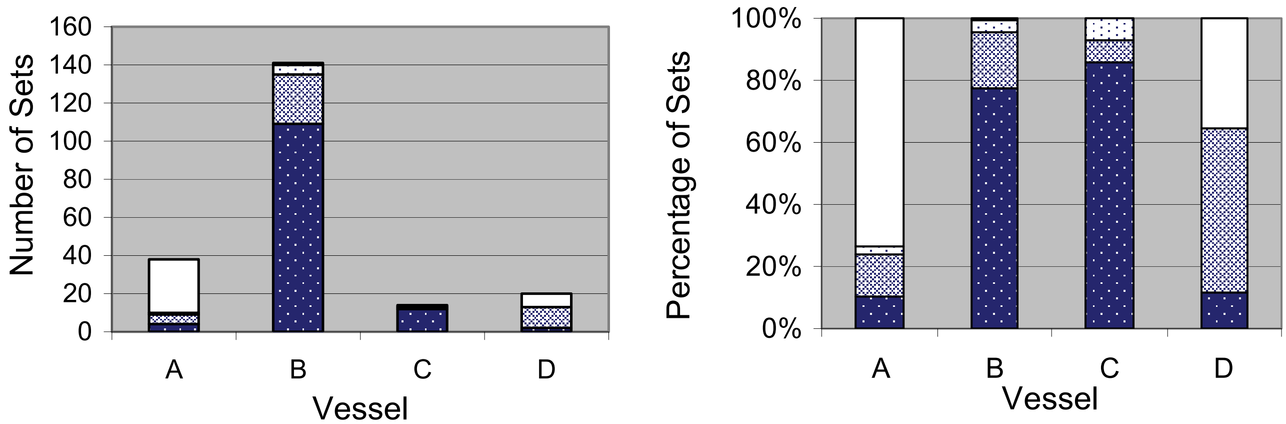


Figure 3. -- Image quality and capture for the number of sets (left) and percentage of sets (right) where the observer collected data. Sets without recorded data are indicated in white; sets with high image quality are indicated in dark blue with white stippling; sets with medium image quality are indicated in white with blue crosshatching; sets with low image quality are indicated in white with blue stippling.

Technical difficulties were encountered on the second trip in the study (Vessel A). On this trip, the video recording equipment failed to operate properly. In a typical set up, as the gear is retrieved, the hydraulic pressure increases. Once this pressure reaches a preset trigger point, the video cameras start to record the catch. Unfortunately, for both trips on this vessel, the trigger point was set higher than the hydraulic pressure typically encountered by the vessel when gear was being retrieved. As a result, the cameras did not record any imagery. An AMR technician reset the sensor following trip 1. On subsequent sets when the cameras were activated, the pressure did not remain high enough for continuous video recording, and the imagery recorded for these sets was intermittent. Of the 43 sets fished on this vessel (two trips), a complete video record of the catch was recorded by the EM system for 7 sets. For five of these sets, the complete review of images resulted in approximately 95% or more of the gear retrieval while for two sets the review of images encompassed 100% of the gear retrieval time. Although this was not a complete record of the gear retrieval, AMR staff indicated that no catch records of hooks were omitted, and that the missing (approximate) 5% of the gear retrieval time consisted of the leading and trailing (non-fishing) portions of the gear. Hence these sets were included in most analyses. Images captured for three additional sets was intermittent (24%, 77%, and 92% of gear retrieval time).

On Vessel C, the EM computer system malfunctioned (hard drive failure) on the first trip and no video data were recorded after the third set. On this trip, once the observer determined that the EM system was not recording data, they discontinued hook-status sampling and sampled the remaining sets using standard sampling methods. The EM control box was replaced between trips and no further problems were experienced on this vessel. On the second trip, EM data were recorded for all fished sets. On Vessel B, all sets where the observer was able to record data also had complete data recorded for the set by the EM system. The EM system functioned properly for all six trips (168 sets).

General Catch Compositions and Vessel Fishing Characteristics

For all four vessels, Pacific halibut was the predominant species in the catch; other prevalent species included sablefish (*Anoplopoma fimbria*), Pacific cod (*Gadus macrocephalus*), rockfish (Scorpaenidae), and grenadiers (Macrouridae) (Figs. 4 and 5). The species composition of each set was estimated using the observer hook-status data. In cases where the observer sampled the catch, the samples were expanded to the set by dividing the tally of fish taken during the sample period by the proportion of skates of gear that were sampled (sample fraction). The observer hook-status data were used since this type of data was collected most often. Note that these data encompass catch for four vessels only and may not be representative of species composition of the catch for other vessels participating in the Pacific halibut fishery in Alaska.

In Figure 4, the mean number of organisms of each species or species group per set is presented along with the number of sets (in parentheses) in which that species or species group was identified by the observer. The error bars are two standard deviations; the variance between sets. Any within-set variance that arose from sampling was not included in this variance. Note that on Vessels B and C some sets were sampled, and the sample data were expanded to the set (see Table 3). While this may account for some of the variance, on Vessel D all sets were completely monitored (no within-set variance) by the observer and on Vessel A only three sets were sampled (the remaining had no within-set variance).

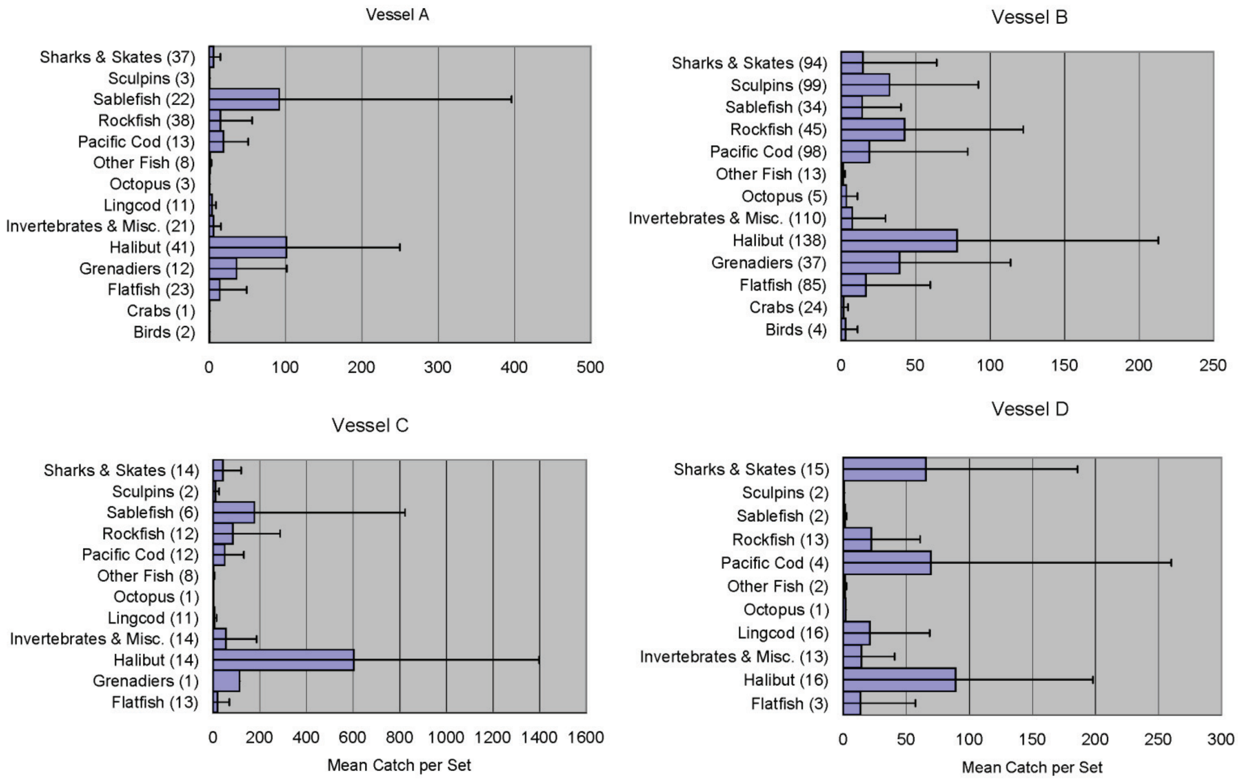


Figure 4. -- Mean number of organisms per species group per longline set for each vessel. Error bars are two standard deviations; error bars that extended below zero were truncated at zero. The number of sets on which the organism occurred is parenthetical. Mean includes positive sets only; sets within which a particular species or species group did not occur are not included in the calculation of the mean.

The distribution of the catches per set tended to be skewed to the right with a few sets having large catches for a given species (Fig. 5). Although some sets were sampled and not completely monitored, these sets are not consistently the extreme catch values (over all sets for a vessel). Therefore, it does not appear that the within-set variance is causing the skewness in the distribution of catches.

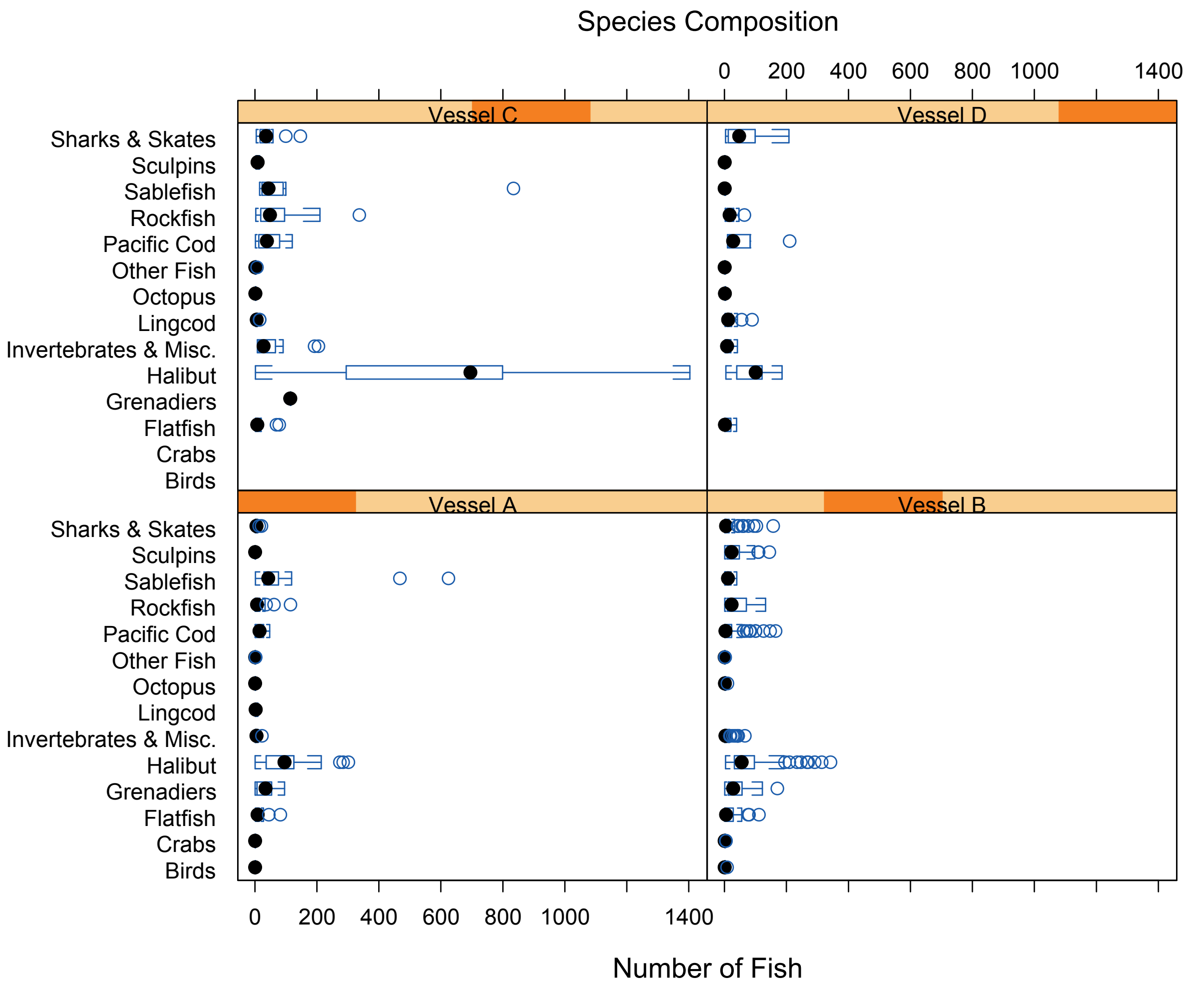


Figure 5. -- Species composition (number of fish for each set) for catch on each vessel based on hook-status observer counts. Includes all monitored sets; expanded catch totals for sets with incomplete monitoring (see Table 2 for summary of monitored sets). The dots indicate the median differences, the boxes represent the center half of the data (25th and 75th quartiles), and the whiskers extend to the largest data point that is within 1.5 times the inter-quartile range. The dark orange bars indicate vessels.

All vessels fished in the GOA with the exception of Vessel B which fished primarily in the Bering Sea (Table 5). Vessel D tended to fish shorter sets and was the smallest of the vessels. Vessel B fished the longest sets. The number of fish species identified (in total) did not appear to vary between the EM and the observer datasets (the aligned data) except for Vessel D where the number of species groups identified by the EM reviewer was greater than the number identified by the observer. Additionally, there were some species identified in the EM dataset, and not in the observer data sets. In particular, cabezon

(*Scorpaenichthys marmoratus*) were identified by the EM reviewer on five sets (30 fish, 26 on one set) in the Bering Sea (observer recorded sculpin (Cottidae) species group) and bocaccio (*Sebastes paucispinis*) were identified on one set in the Gulf of Alaska (observer recorded shortraker / rougheye rockfish group). Neither cabezon nor bocaccio are common in Alaska.

AMR aligned the hook-specific data from the video review and from the hook-status observer by matching the records for each hook from the two data sources. A total of 150 of the longline sets that were completely monitored (all hooks documented) by both the hook-status observer and the EM data recorder were included in the aligned data set used in most analyses comparing EM and observer data directly (Table 4). This set of data is the intersection of data collected using monitoring method.

Table 4. -- Number of sets included in data alignment.

Number of Sets	Vessel A	Vessel B	Vessel C	Vessel D	Total
Aligned Dataset	7	128	4	11	150

The EM-based mean hooks per set was determined by counting the number of records (empty hooks and hooks with catch) from the 150 aligned sets provided by AMR. While the mean number of hooks documented for each vessel varied between the hook-status observer and the EM data recorder; neither method resulted in estimates of hooks fished that was consistently higher (or lower) than the other method (Table 5). Thus, there does not appear to be a bias in the estimates of number of hooks fished.

Table 5. -- Summary of catch characteristics and set length for each vessel participating in the study for hook-status data (187 completely monitored sets) and aligned data (150 sets completely monitored by both EM and hook-status observer).

	Unaligned Data	Aligned Observer Data			Aligned EM Data		
	Mean Hooks Fished per Set	Mean Hooks Fished per Set	Number of Species	Number of Species Groups	Mean Hooks Fished per Set	Number of Species	Number of Species Groups
Vessel A	1054.0	866.3	12	6	820.6	13	8
Vessel B	950.3	949.5	17	14	989.9	15	12
Vessel C	4225.0	3209	12	6	2930	12	3
Vessel D	408.3	420.5	15	4	424.5	18	12

On Vessel C, some sets were made at night and the lighting conditions were not sufficient to allow counting of empty hooks (four sets). Those hooks were removed from the aligned datasets (for both the observer data and the EM data) by AMR during the alignment process, however, the sets are included in later analyses of catch. The mean number of hooks fished is also reported for all sets for which the hook-status data are available and the set was completely monitored.

For Vessels A and C, the mean hooks fished per set was greater when estimated from the hook-status sets prior to alignment. For Vessel B the estimated mean hooks per set was similar between the aligned and raw datasets. This vessel had no technical difficulties with the EM equipment and the observer did not subsample sets.

Looking at individual sets in the aligned dataset, the number of hooks fished documented by the hook-status observer and independently documented by the primary video reviewer were in good agreement, showing a linear relationship (Fig. 6).

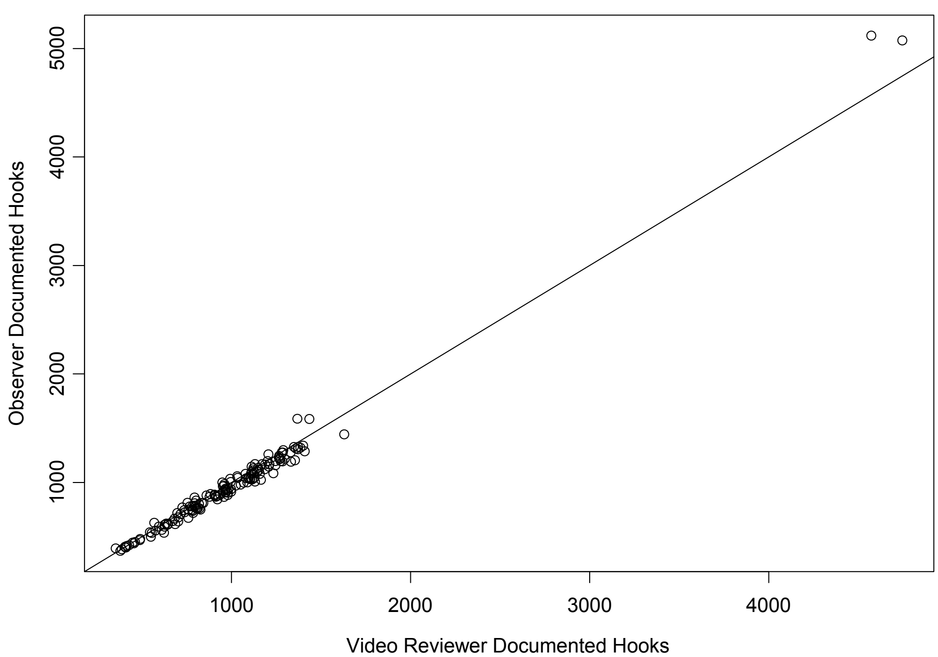


Figure 6. -- Comparison of total hooks documented by EM reviewer and by at-sea observer

Of the 150 sets with complete monitoring by both the hook-status observer and the EM reviewer, the number of hooks documented by the observer was greater than the number of hooks documented by the EM reviewer on 31 sets (20.7%). There were 119 (79.3%) sets where the number of hooks documented by the EM reviewer was greater than the number documented by the observer. On no set was the number of hooks documented by the two data sources equal. In general the magnitude of the differences was small, with the largest differences observed on Vessel C (Fig. 6 two data points in upper right hand portion of plot).

Comparison 1: Comparison of Hook-status and EM Reviewer Species Identification

The first comparison of interest was used to assess the consistency of species identification between the observer on the vessel and the video reviewer. In this case, the aligned data (150 sets) were used and the agreement between the two data sets, for each hook, was determined. Only those sets with a complete record of EM recording (reviewed by AMR and included in the aligned data set) and with a complete record from the hook-status observer were included in the following analysis.

For each hook in the aligned dataset, the two data sources were considered in agreement if the same species of fish was identified for that hook in both datasets. Invertebrate species, unidentified fish, and miscellaneous items (organisms and inanimate objects) are not commonly recorded by AMR in the video review process. In particular, the video reviewers for this study were not consistently recording observations of invertebrates, corals, and seaweeds although these are typically documented by the observers. Hence, the data analysis was conducted without those "species".

Additionally, the video reviewers at AMR recorded fish species using common names of species. This resulted in a potential inconsistency in the species identification between observers and EM reviewers. Greenland turbot are recorded by North Pacific groundfish observers as turbot, (*Reinhardtius hippoglossoides)* (species code 102). In British Columbia, however, arrowtooth flounder (*Atheresthes stomias*) are often referred to as 'turbot', and hence may have been recorded as such by the video reviewers. All observations of arrowtooth flounder, Kamchatka flounder (*Atheresthes evermanni*), arrowtooth/Kamchatka flounder group, Greenland turbot/arrowtooth/Kamchatka flounder species group, and turbot were coded as the same species in all data analyses (species code 102).

The proportion of hooks in the aligned dataset for each vessel where both the EM reviewer and the hook-status observer documented the same outcome (fish species, species group, or empty hook) is presented in Table 6. These proportions include cases where one data recorder documented a fish or invertebrate and the other data recorder documented an empty hook or missed the hook. Missed hooks are defined as those hooks that are added during the data alignment process so that obvious fish species are matched. These are hooks that were presumably 'missed' by one of the data recorders. In this and subsequent tables presenting proportions of matching species identifications, the reported variance is the empirical variance computed using Eqn. (4). The proportion of hooks in agreement was 94% or greater for all vessels and image qualities.

Table 6. -- Summary of proportion of species identification agreement for each study vessel for all documented hooks. Empty and 'missed' hooks are included, as are observations of invertebrates and miscellaneous items.

Hooks with Catch	**Proportion Species-specific Identification in Agreement (Variance, Number of Hooks) ALL HOOKS**			
Vessel	**High Image Quality**	**Medium Image Quality**	**Low Image Quality**	**Total**
A	0.946 (0.051; 2,432)	0.977 (0.023; 3,173)	0.961 (0.038; 640)	0.963 (0.035; 6,245)
B	0.970 (0.029; 103,073)	0.945 (0.044; 23,902)	0.940 (0.057; 5,747)	0.966 (0.033; 132,722)
C	0.961 (0.038; 13,484)	---	---	0.961 (0.038; 13,484)
D	0.983 (0.017; 868)	0.962 (0.036; 3,912)	---	0.966 (0.033; 4,780)
Total	0.968 (0.031; 119,857)	0.958 (0.041; 30,987)	0.942 (0.055; 6,387)	0.965 (0.034; 157,231)

In order to evaluate the consistency of species identification between the two data collection methods, the analysis was repeated using only those hooks with catch recorded in both datasets. This comparison of species-specific agreement between the fish species identified by the two data sources is presented in Table 7. This comparison only includes those aligned hooks where both data sources identified a fish species including the grouping of arrowtooth flounder, Kamchatka flounder, and turbot and omitting invertebrates and miscellaneous species.

The proportion of hooks where species-specific identifications were in agreement was over 85% for all combinations of vessel and image quality. These proportions are lower than the proportions of hooks in agreement presented in Table 6, likely since the majority of hooks in the previous analysis were empty (or missed by one of the data recorders). In general, the proportion of species identifications in agreement tended to slightly increase with increasing image quality; however, this was not universally the case.

Table 7. -- Summary of proportion of species identification agreement for each study vessel. Empty and 'missed' hooks are not included, nor are observations of invertebrates and miscellaneous items.

Hooks with Catch	Proportion Species-specific Identification in Agreement (Variance, Number of Hooks) FISH ONLY			
Vessel	**High Image Quality**	**Medium Image Quality**	**Low Image Quality**	**Total**
A	0.849 (0.129; 529)	0.951 (0.047; 410)	0.916 (0.078; 119)	0.896 (0.093; 1,058)
B	0.886 (0.101; 13,125)	0.871 (0.112; 4,795)	0.883 (0.103; 1,259)	0.882 (0.104; 19,179)
C	0.973 (0.027; 3,173)	---	---	0.973 (0.027; 3,173)
D	0.985 (0.015; 469)	0.969 (0.030; 2,282)	---	0.972 (0.027; 2,751)
Total	0.904 (0.087; 17,296)	0.906 (0.086; 7,487)	0.886 (0.101; 1,378)	0.903 (0.087; 26,161)

Since observers are required to identify some species to a species-group if they do not have the fish in-hand for inspection, the analysis was repeated after grouping data into the observer species-groups for those species. The species groupings used are defined as: Northern and Southern rock sole, Kamchatka and arrowtooth flounder, shortraker and rougheye rockfish, Tanner crabs, king crabs, longspine and shortspine thornyheads, *Bathyraja* skates, and Irish lord sculpins.

The proportion of the observations in agreement increased slightly for some vessels and image qualities (Table 8), however the grouping of species to the groups required to be used by observers did not change the proportion of species identifications in agreement substantially. While observers are required to record certain species identification to species-groups when they are tallying catches as the line was retrieved, if the observer has the fish in-hand, identification to the species level is expected. Thus, although the observer groups are required to be used while the gear is retrieved, if the bycatch is saved (generally the case) and is therefore available to the observer, species-specific identification can be made.

Table 8. -- Summary of proportion of species identification agreement for each study vessel, species are grouped for both observer and EM data into required observer groupings. Observations of invertebrates and miscellaneous items are not included in these proportions.

	Proportion Species-specific Identification in Agreement (Variance, Number of Hooks) FISH ONLY; Observer groups			
Vessel	**High Image Quality**	**Medium Image Quality**	**Low Image Quality**	**Total**
A	0.881 (0.105; 529)	0.961 (0.038; 410)	0.916 (0.078; 119)	0.916 (0.077; 1,058)
B	0.891 (0.097; 13,114)	0.872 (0.112; 4,795)	0.883 (0.103; 1,259)	0.886 (0.101; 19,168)
C	0.973 (0.026; 3,172)	---	---	0.973 (0.026; 3,172)
D	0.985 (0.015; 469)	0.969 (0.030; 2,282)	---	0.972 (0.027; 2,751)
Total	0.908 (0.083; 17,284)	0.906 (0.085; 7,487)	0.886 (0.101; 1,378)	0.906 (0.085; 26,149)

This project was focused primarily on monitoring of bycatch in the Pacific halibut fishery, and hence the proportion of matching species identifications was computed after removing halibut from the set of aligned hooks included in the previous two assessments. These results are presented in Table 9.

The proportion of species identifications in agreement was lower when only bycatch (non-halibut and non-invertebrate) species were included in the analysis. The observer-required species groupings, and the grouping of turbot, arrowtooth and Kamchatka flounders were included in this summary. The proportion of species identifications in agreement did not consistently decrease with decreasing image quality. This may be the result of relatively few aligned hooks for some vessel-image quality combinations.

Since some of the disagreement in species identification may be the result of one data recorder using a larger species grouping than the other data recorder, the analysis was repeated after grouping species into large species-type groups (e.g., rockfish, flatfish, etc*)*. The proportion of species identifications in agreement increased to near complete concurrence (Table 10). These species groupings are listed in the Appendix.

Table 9. -- **Summary of proportion of species identification agreement for each study vessel, species are grouped for both observer and EM data into required observer groupings. Observations of empty and 'missed' hooks, halibut, invertebrate species, and miscellaneous items are not included in these proportions.**

	Proportion Species-specific Identification in Agreement (Variance, Number of Hooks) BYCATCH ONLY			
Vessel	**High Image Quality**	**Medium Image Quality**	**Low Image Quality**	**Total**
A	0.751 (0.188; 225)	0.909 (0.083; 121)	0.550 (0.261; 20)	0.792 (0.165; 366)
B	0.774 (0.175; 6,240)	0.779 (0.172; 2,678)	0.811 (0.153; 720)	0.778 (0.173; 9,638)
C	0.887 (0.101; 627)	---	---	0.887 (0.101; 627)
D	0.973 (0.027; 219)	0.952 (0.046; 1,369)	---	0.955 (0.043; 1,588)
Total	0.789 (0.166; 7,311)	0.839 (0.135; 4,168)	0.804 (0.158; 740)	0.807 (0.156; 12,219)

In the above analysis, all hooks within a vessel or image quality category were pooled for analysis. This assumes that there were no trip or set-specific effects and that the probability of a species identification for a specific hook being in agreement was not a function of the vessel, trip or set. Although this assumption was not tested explicitly, there was no evidence of over dispersion in the data based on a comparison of the empirical variances presented in the previous tables and the parametric variances expected under a binomial distribution. This indicates that there was no clustering in the data, which would be expected if there were vessel, trip or set effects.

Table 10. -- Summary of proportion of species identification agreement for each study vessel, species are grouped for both observer and EM data into species-type groupings. Observations of empty and 'missed' hooks, halibut, invertebrate species, and miscellaneous items are not included in these proportions.

	Proportion Species-specific Identification in Agreement (Variance, Number of Hooks) SPECIES GROUPS, BYCATCH ONLY			
Vessel	**High Image Quality**	**Medium Image Quality**	**Low Image Quality**	**Total**
A	0.996 (0.004; 225)	1.0 (0; 121)	1.0 (0; 20)	0.997 (0.003; 366)
B	0.995 (0.005; 6,240)	0.982 (0.018; 2,678)	0.976 (0.023; 720)	0.990 (0.010; 9,638)
C	0.980 (0.019; 627)	---	---	0.981 (0.019; 627)
D	1.0 (0; 219)	0.992 (0.008; 1,369)	---	0.993 (0.007; 1,588)
Total	0.994 (0.006; 7,311)	0.986 (0.014; 4,168)	0.977 (0.022; 740)	0.990 (0.01; 12,219)

Comparison 2: Agreement Between Standard Sampling and Hook-status Sampling

Comparison 2 was used to assess the consistency in species identification and species-specific counts of fish between observers and sampling methods. On Vessel A, we were able to deploy one standard observer and one hook-status observer simultaneously for one trip. Assuming that the two observers produced independent observations of the catch, these two data sources can be compared to assess the consistency between the two observers in the number and identification of fish, although this comparison can only be made for the one trip where the two observers were able to concurrently sample 20 sets. In all cases, the species identifications were grouped to the required observer groups.

For those skates of gear where both observers were simultaneously collecting data, the total numbers of fish of each species for each skate were compared (Fig. 7).

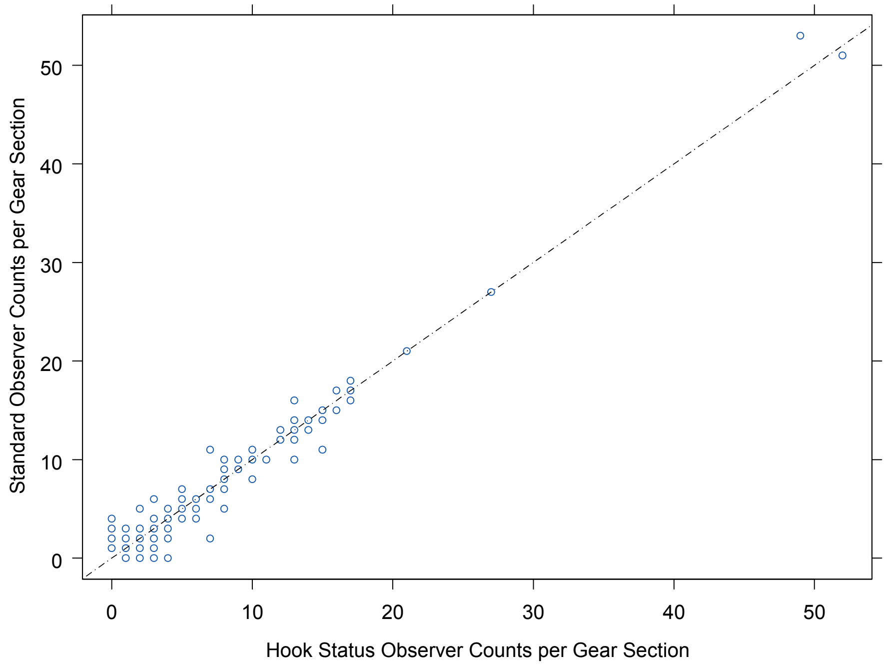


Figure 7. -- Comparison of fish counts per gear section for observer standard methods (y-axis) and hook-status methods (x-axis) for those skates simultaneously sampled.

The correlation between the number of each species for each skate estimated using data collected with the standard methods and the data collected using the hook-status methods was 0.977 (357 df). This does not include empty hooks as a species category. When the predominant species (Pacific halibut) was removed from the data, the correlation between the species-specific totals decreased to 0.908 (277df). Note that the high correlation between the data sets does not necessarily imply perfect matching since the linear relationship between the two datasets may be offset by a consistent amount. However, since the data are clustered around the 1:1 line in Figure 7, the high correlation does indicate a high degree of agreement between the data sources independent of the amount of total catch (scale independence).

The difference between the catch estimates resulting from each of the data collection methods was generally close to zero, and was at most five fish per skate (Fig. 8).

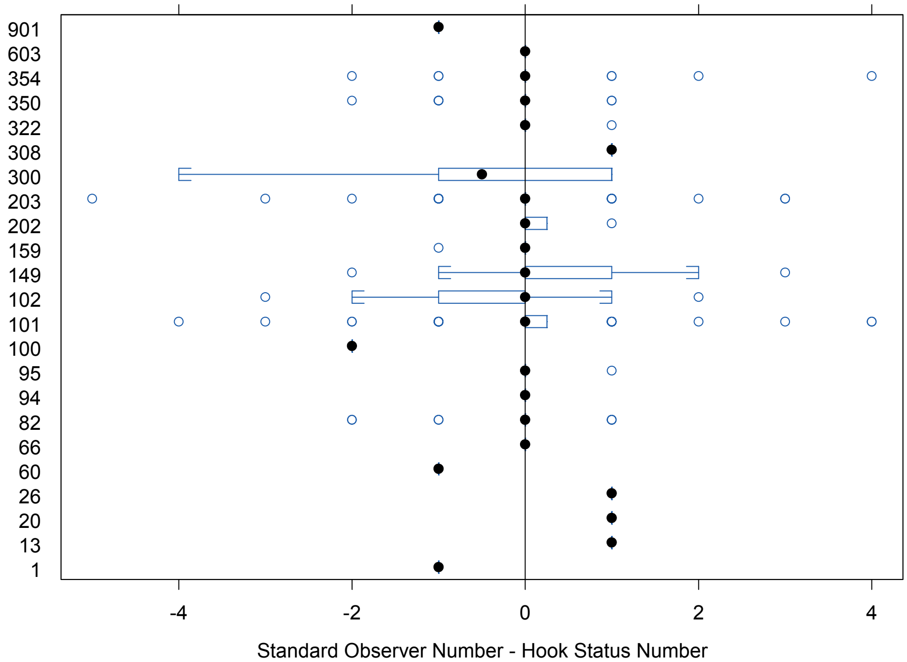


Figure 8. -- Skate-specific difference (standard observer methods – hook-status methods) in number of fish for each species (y-axis). The dot indicates the median difference, the boxes represent the center half of the data (25^{th} and 75^{th} quartiles), and the whiskers extend to the largest data point that is within 1.5 times the inter-quartile range. Species codes are provided in the Appendix.

Two tests were conducted to examine whether the observed differences between the skate-specific totals were significant. For each gear segment (skate) where both observers documented the catch, the results of a paired t-test showed no significant difference between the numbers of fish documented using the standard-sampling methods and the hook-status sampling methods ($p = 0.9641$, $df = 358$, $t = 0.0451$, two-tailed). Although inspection of the data did not show large deviations from normality (using qq plot), a Wilcoxon signed rank test was also used to test whether the median of the differences between the two methods was equal to zero. This test also showed no differences between the two methods of determining catch ($p = 0.8798$, $Z = 0.1513$, two-tailed).

In addition, for these same 20 sets, the data collected using the standard sample methods were expanded to estimate the total catch for each species and set. The expanded catch estimates were similar to counts of fish collected using hook-status methods (Fig. 9). Neither method appeared to generate catch estimates that were consistently larger than the other, and the differences between the methods did not appear to increase substantially with the total amount of fish; deviations from the diagonal 1:1 relationship did not appear larger for larger numbers of fish (upper right of plots).

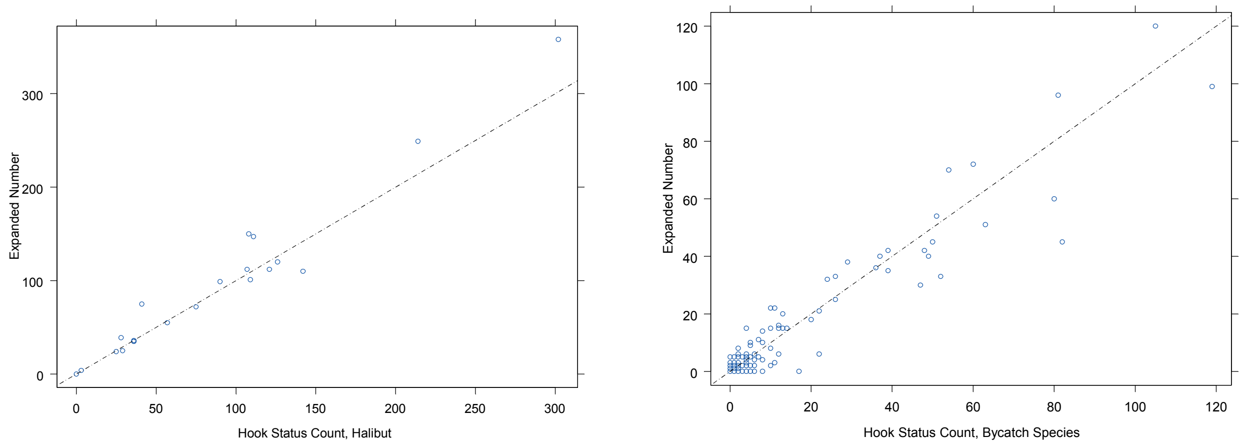


Figure 9. -- Relationship between catch estimates based on data collected using standard methods and hook-status methods for Pacific halibut (left) and non-halibut species (right).

For each set, the differences in catch were generally less than 20 fish (Fig. 10). The largest differences were for Pacific halibut (species 101) and sablefish (species 203), the two predominant species in the catch, although the differences were centered close to zero.

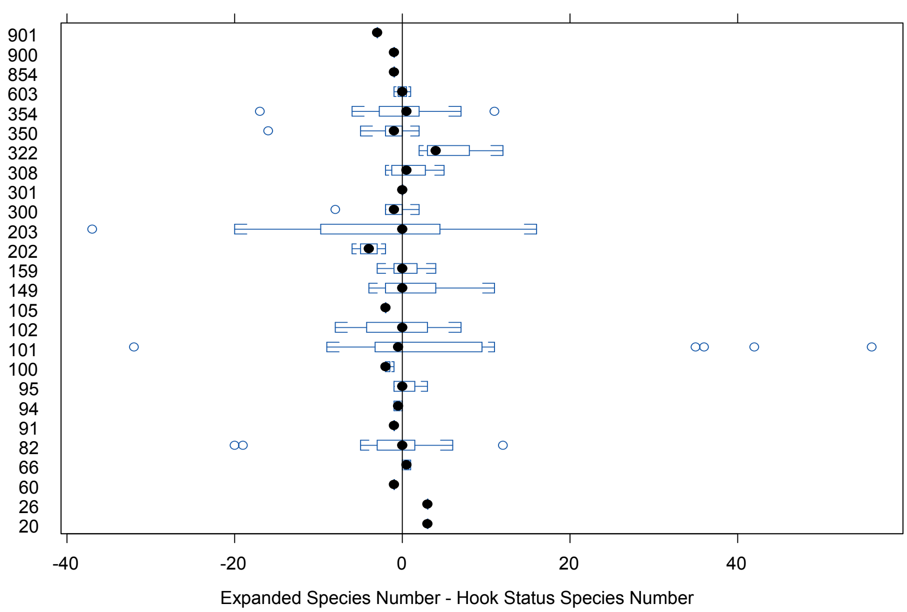


Figure 10. -- Box and whisker plot of differences in number of fish by species for each set. The dot indicates the median difference, the boxes represent the center half of the data (25th and 75th quartiles), and the whiskers extend to the largest data point that is within 1.5 times the inter-quartile range. Species codes are provided in the Appendix.

Assuming that the catches are distributed normally, the confidence intervals for each catch estimate were estimated. There were 86 estimates of catch (17 sets and several species per set) for which 95% confidence intervals could be computed. In each case, the hook-status species specific count of fish was within the 95% confidence interval of the estimated number of fish generated from the standard-method data.

There were three sets where the standard-method observer monitored the entire set (16 species-specific estimates). Five of the species-specific hook-status counts were greater than, and five of the species-specific hook-status counts were less than, the estimate from the standard observer data. The remaining 10 species specific hook-status counts were equal to the estimates from the standard methods. Under the assumption of normally distributed catch estimates, we would expect five hook-status observations to be outside the 95% CI. The assumption of normality may not be appropriate for these data, especially for less common species, and hence these confidence coverage levels may not be 95%.

Lastly, the CV of both the hook-status and standard sampling methods was compared (Table 11). The CV is defined here as the variability among skates in species-specific number of fish, and does not include sampling variability. Instead it compares the measured variability between gear sections for the two methods of sampling.

Table 11. -- Comparison of the among-skate variances for each species and set (Vessel A, trip 1).

	Minimum	1^{st} Quantile	Median	Mean	3rd Quantile	Maximum
Standard Sampling	16.8%	66.6%	104.3%	116.1%	187.3%	223.6%
Hook-status Sampling	27.4%	57.1%	109.0%	130.6%	162.8%	387.3%

The range, mean, and median of the among-skate variance (CV) estimated from data collected using standard sampling methods was smaller than that of the hook-status sampling methods.

The among-skate variance (CVs) did not appear to vary with the observer (Fig. 11, left) or the type of species (Fig. 11, right).

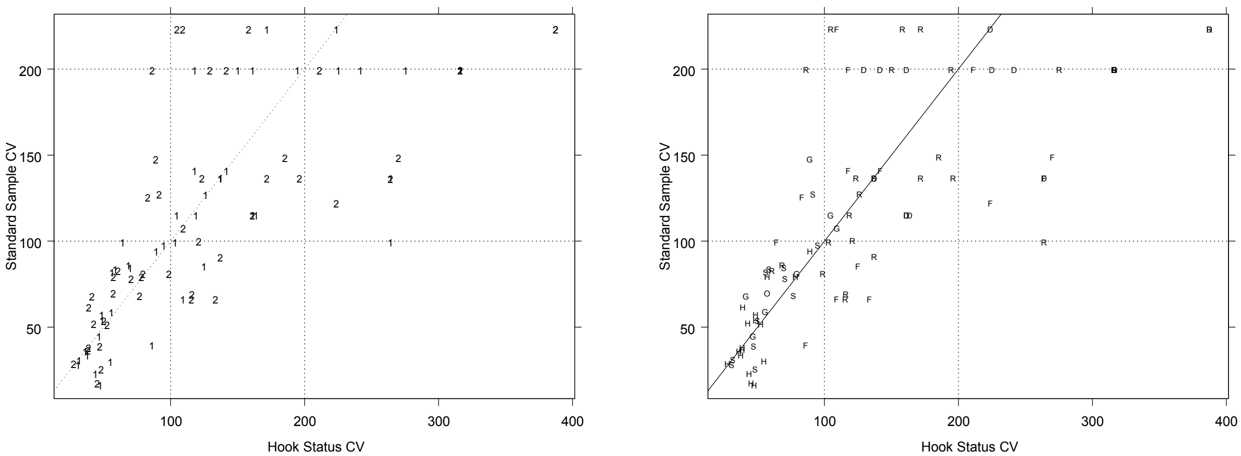
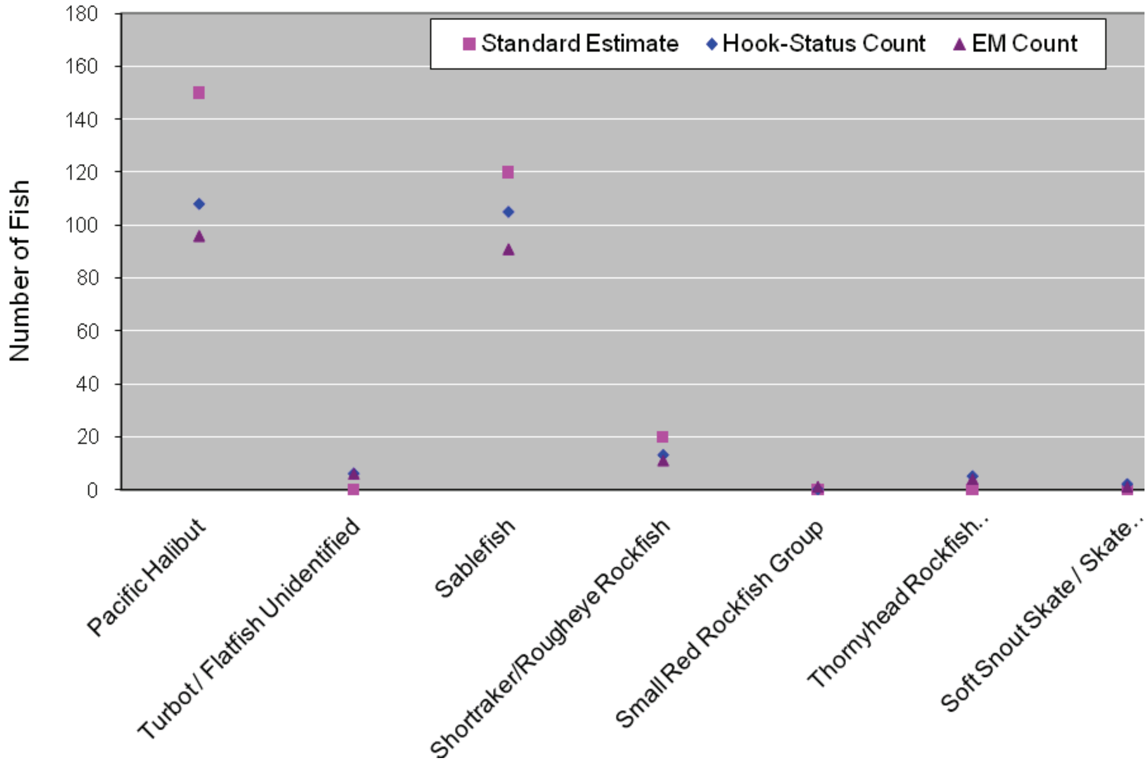


Figure 11. -- Comparison of CVs between two data collection methods, identifying observer (left) and species type (right). Letters indicate species type of an observation: H=halibut, S=sablefish, L=lingcod, R=rockfish, G=grenadier, F=flatfish, D=skates and rays, O=other fish species and I=invertebrates and other miscellaneous items.

Comparison 3: Agreement between Observer (Standard /Hook-status) Catch Estimates and EM Catch Estimates

The intent of Comparison 3 was to assess the agreement between the estimates generated using standard sampling methods and the estimates from the EM methods. When using the EM method, the catch of the set was not sampled, so there is no sampling variability associated with that method. Unfortunately, due to space limitations on the vessels and deployment of single observers, standard sampling methods were used on only a single trip, during which the EM equipment was unable to collect catch data for the majority of sets.

There were two sets on Vessel A for which both standard sampling and EM review data were available. Both of these sets occurred on the first trip during which technical difficulties resulted in much of the EM data collection to be intermittent for other sampled sets. The estimates of total catch for each species are similar using each of the estimation methods (Fig. 12). On the first set (Set ID 22; 10% sample fraction), the standard sample observer was able to take a single sample only, and hence, variance and percent standard error estimates are not available. On the second set (Set ID 26), the observer was able to take four samples (40% sample fraction).



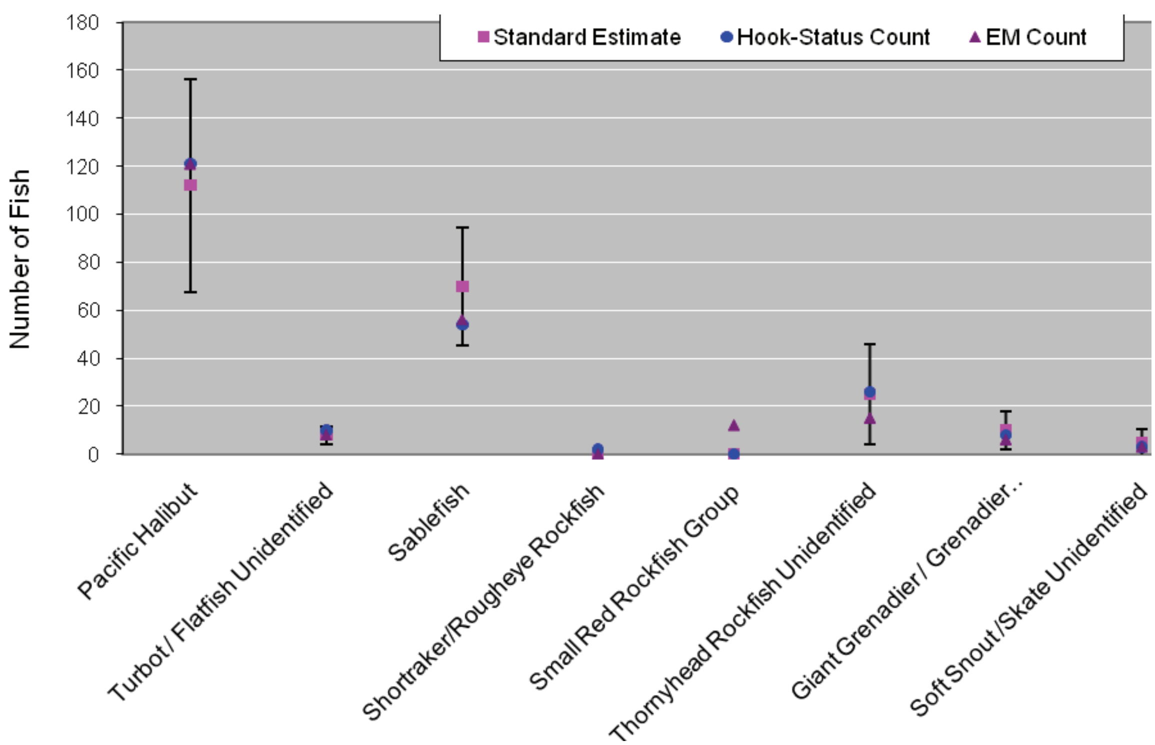


Figure 12. -- Comparison of catch totals between three sampling methods. for two sets: Set ID 22 upper and Set ID 26 lower. Error bars are 1 standard error around the standard method estimate.

Although data collected using the standard sampling method are not available for other sets that have EM monitoring, we compared ‘observer’ methods and EM methods by estimating variances for the hook-status estimates of catch (by species) and using these to construct hypothetical confidence intervals which could then be compared with the catch estimates from the EM review. Again, the required observer species groupings were used, and turbot and arrowtooth flounder species were grouped. This analysis used all 150 sets for which both EM and hook-status data were available.

First, to assess species-specific estimates of catch for each set, the total number of fish of each species was determined using data from each data collection method (EM and hook-status). Since monitoring was complete using both methods, there is no sampling error involved, only measurement (non-sampling) error. The difference, defined as the observer-based hook-status method total minus the EM-based total was computed (positive numbers indicate the observer-based number of fish was higher). The mean difference, by species, is shown in Figure 13. The height of each bar indicates the magnitude and direction of the mean difference; the numbers indicate the number of sets included in the average. Since not all species were present (detected) on all sets, the number of sets contributing to the average varies with species, and was less than or equal to the total number of sets fished by the vessel. This applies only to cases where both the EM reviewer and the hook-status observer failed to document any of that species for the set. If one or the other data collector identified a species that the other data collector did not, then a zero was assigned to the data set where the data collector did not detect the species.

Figure 13 highlights the differential use of species group codes by one or the other data collector. For example, on Vessel A, the observer reported more shortspine thornyhead rockfish (species code 350) while the EM recorded more thornyhead rockfish group (species code 349) and red rockfish species (species code 348). Similarly, on Vessel D the observer reported more rockfish species group (species code 300) while the EM recorder reported more species-specific rockfish (species codes 322, 327, 329, 343, 345, and 346). Reported numbers of *Bathyraja* skates (species code 159) and skate group (species code 90) also appear to potentially be negatively associated.

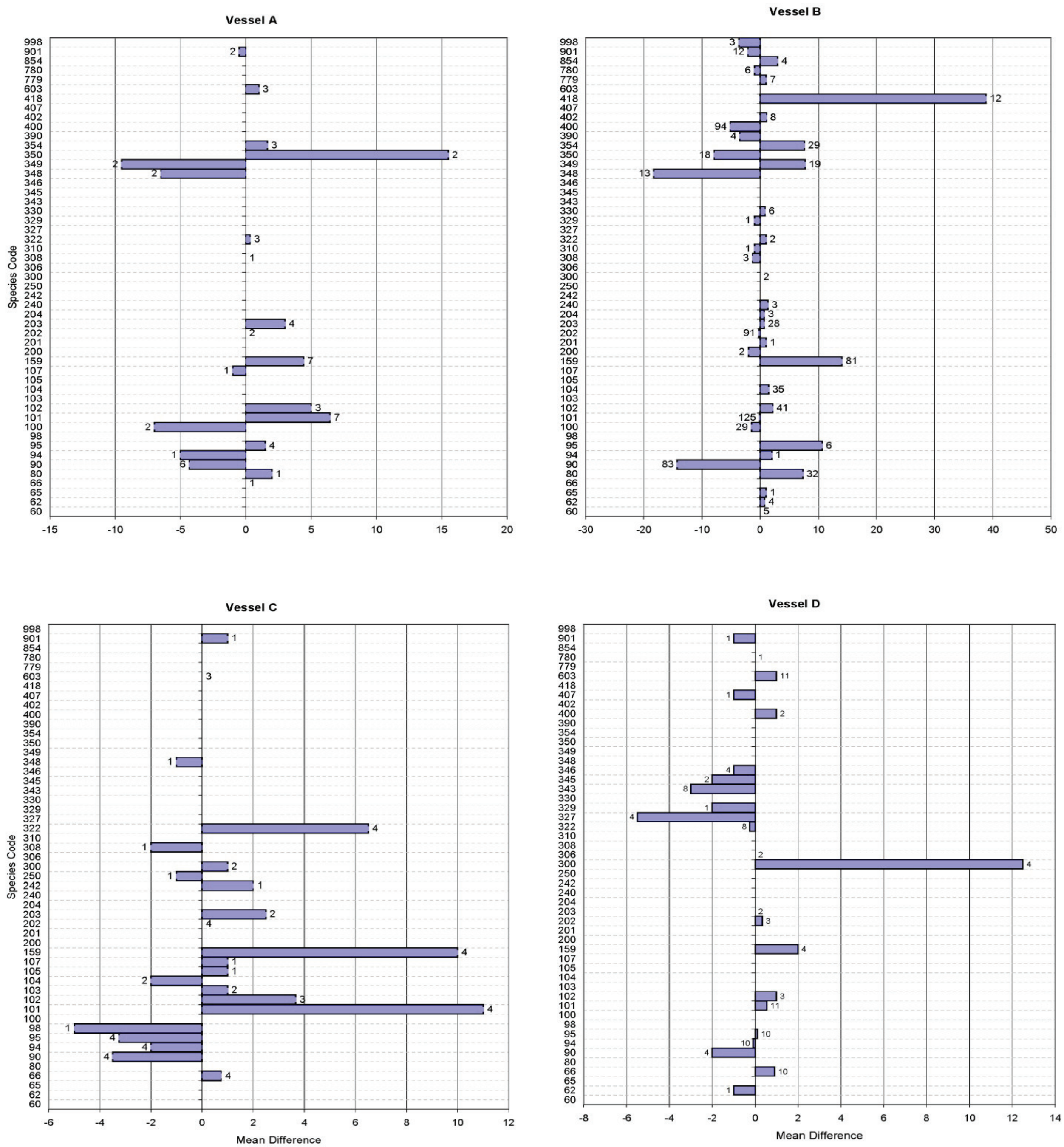


Figure 13 --Mean species-specific differences in number of fish estimated from data collected using EM and standard observer methods. Positive differences indicate that the observer-based estimate was higher than the EM-based estimate. Number of sets included in the mean is indicated next to the species bar. Numbers of sets without a species-specific difference indicate mean differences of zero. Mean includes positive sets only; sets where the organism was identified by either the EM, the observer, or both. Since in some cases, organisms were not present in a set, the number of set-specific differences within a vessel varied with species code. Species codes are provided in the Appendix.

The differences between numbers of fish documented by the two methods may be due to fish dropping off the line before being landed. To assess this, the species-specific number of fish per set that dropped off the line, either before or after the line left the water (before the hook was brought on board), was also computed for these same 150 sets, based on the hook –status observer counts of dropped fish. The number of drop-offs documented by the hook-status observer was compared with the difference in the species specific number of fish documented by the two data collection methods (Fig. 14, left).

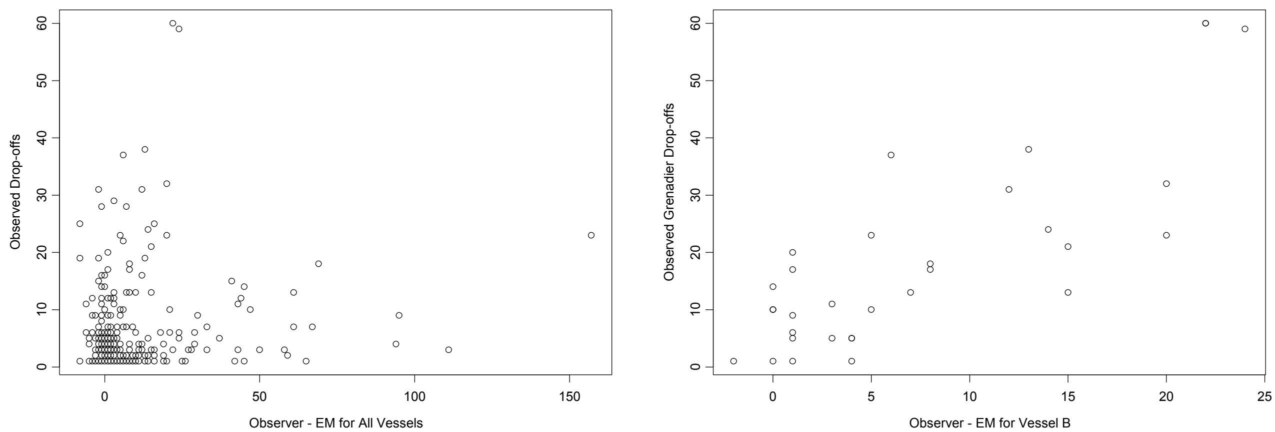


Figure 14 -- Relationship between the number of fish observed to drop off the line by the hook-status observers (y axis) and the difference between the number of fish estimated by the two methods (x-axis) for all vessels and species (left) and for grenadiers on Vessel B (right).

This was of particular interest for Vessel B, where the difference between the hook-status observer counts and the EM counts of grenadiers appeared to be large (Fig. 14, right). Additionally, the biology of the fish (relatively soft-mouthed) may increase its propensity to fall off the hook before the hook is retrieved. This is the only species-specific comparison that showed (visually) a relationship between the dropped fish and the difference in number of fish documented by the two methods (Fig. 14, right). The other comparison of interest was for halibut on Vessels A and C, where the difference in the number of halibut documented appeared to be relatively large. In these cases however, the dropped fish did not appear to be related to the magnitude of the differences between the two methods for vessels A and C (Fig. 15). Both the EM data recorder and the observer were instructed to record all fish that were captured by the gear, regardless of whether they were retrieved by the vessel.

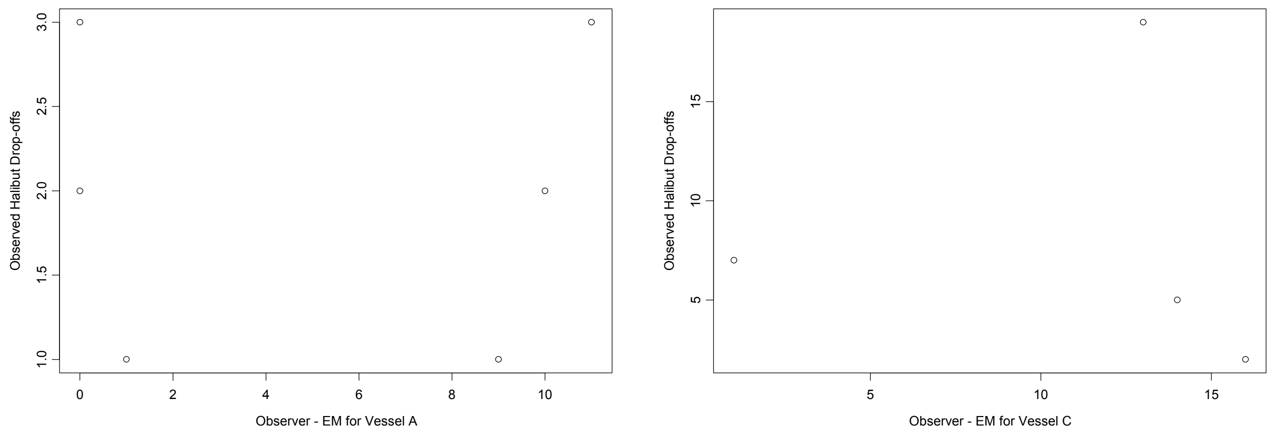


Figure 15. -- Relationship between the number of fish observed to drop off the line by the hook-status observers (y-axis) and the difference between the number of fish estimated by the two methods (x-axis) for Pacific halibut on Vessels A (left) and C (right).

A simple box and whisker plot comparing the estimates shows that differences between the two methods in estimating the number of fish are small (Fig. 16), especially in cases where species groupings are used (Fig. 17). Species-specific comparisons were conducted using the combined turbot-arrowtooth-Kamchatka flounder group and the observer required species groups as defined previously. Species groups are listed in the Appendix.

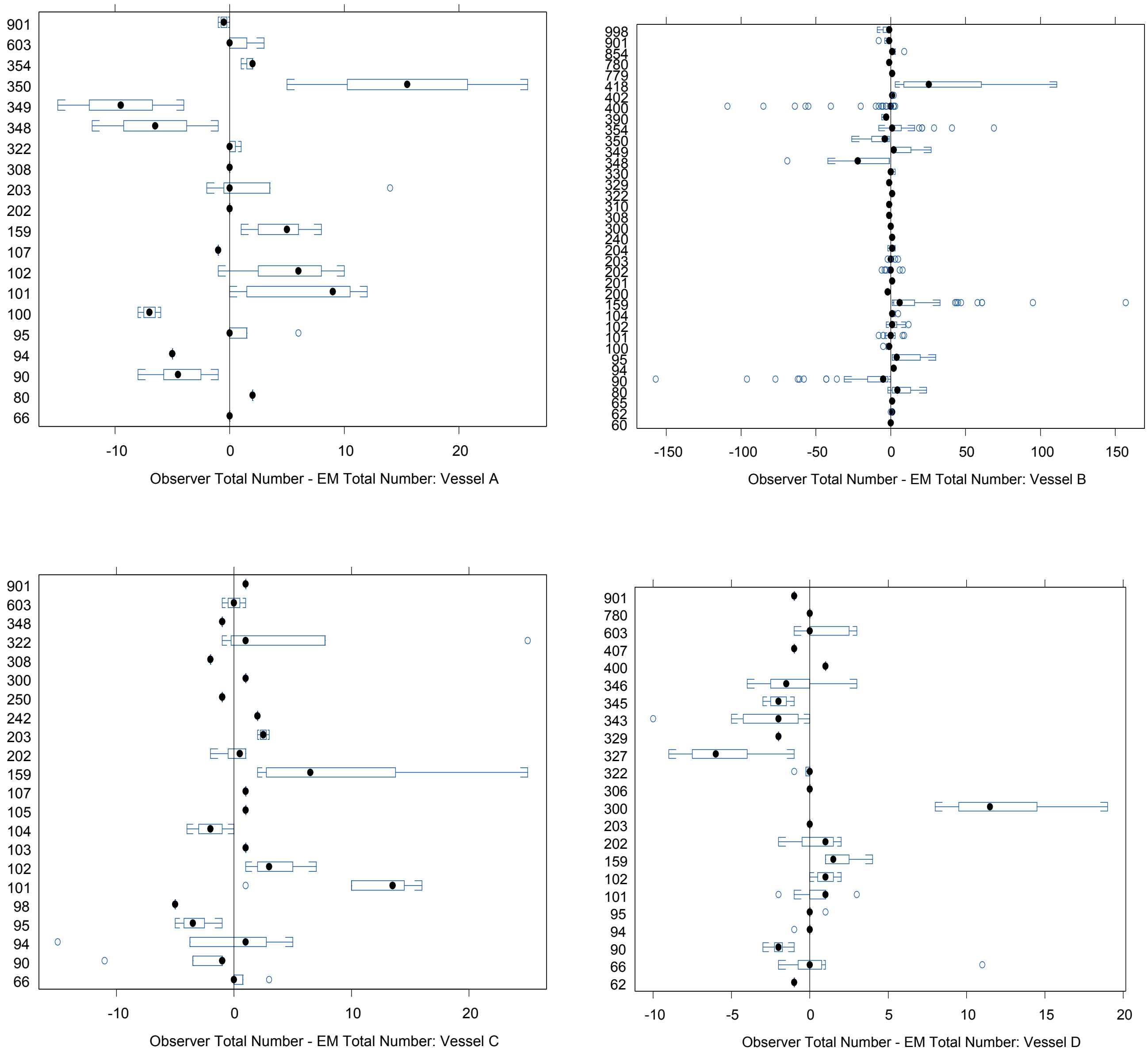


Figure 16. -- Box and whisker plot of set-specific differences in estimated total catch by species for each participating vessel. Species codes are provided in the Appendix.

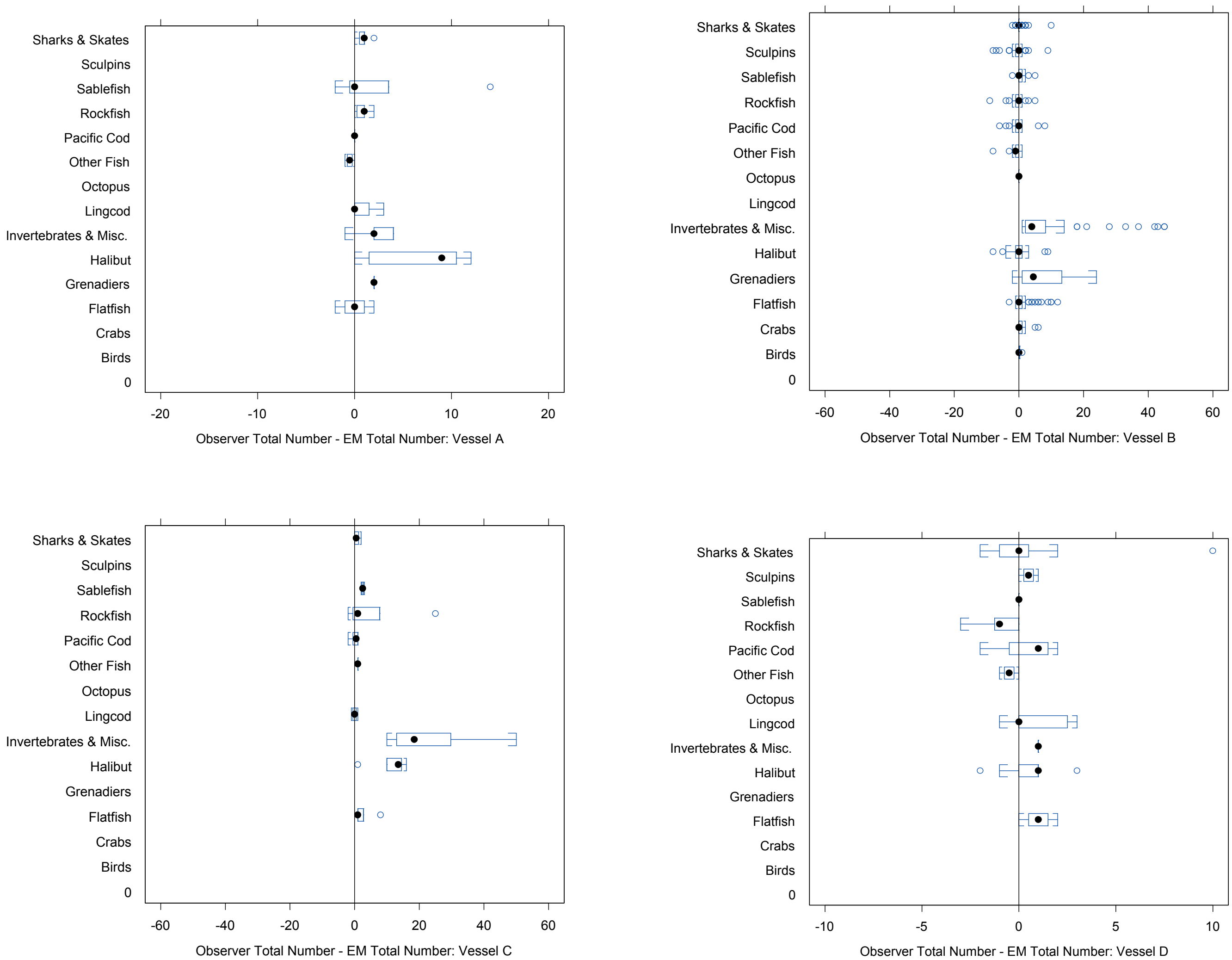


Figure 17. -- Box and whisker plot of set-specific differences in estimated total catch by species group for each participating vessel.

The correlation between the catch estimates generated from observer hook-status and EM data was computed for the species specific comparisons as well as the species groupings for each vessel (Table 12). While this high correlation does not necessarily indicate a perfect match between the two data sources, it does indicate that any discrepancies between the data are consistent regardless of the total number of fish caught. Larger sets do not appear to have disproportionately larger mean differences between the numbers of fish documented by each data recorder (EM and observer).

Table 12. -- Correlation between catch estimates generated from hook-status monitoring and EM monitoring.

	Species-specific Correlation		Species-groups Correlations	
Vessel	All Species	Non-Halibut Species	All Species	Non-Halibut Species
A	0.987	0.932	0.997	0.995
B	0.924	0.761	0.997	0.994
C	0.999	0.960	0.999	0.982
D	0.997	0.995	0.999	0.999

For each set where both the hook-status observer and EM documented the entire catch, the results of a Wilcoxon signed rank test was used to test whether the median of the differences between the two methods was equal to zero. The results of this test are presented in Table 13. Since inspection of the data showed large deviations from normality (using qq plot), a t-test was not used on these data.

Table 13. -- Results of Wilcoxon signed rank test of the differences between catch estimates using two methods of data collection. Values presented are p-values (Z-statistics).

Vessel	Species-specific Test	Species-groups Test
A	0.1309 (0.151)	0.0008 (3.363)
B	0.05 (1.957)	0.0137 (2.465)
C	0.09 (1.696)	0.0013 (3.212)
D	0.90 (0.1245)	0.233 (1.193)

On Vessel C, several sets occurred at night and the lighting was such that empty hooks could not be enumerated and these hooks were removed from the EM data set. One of the four sets from Vessel C included in the Wilcoxon testing was a night set with some hooks removed from the data set. Repeating the analysis with the remaining three sets increased the p-value associated with the species-specific test from 0.09 to 0.217 ($Z = 1.234$). The p-value for the species group test increased from 0.0013 to 0.0066 ($Z = 2.717$), still showing the median to be significantly different from zero.

Similarly, on Vessel A, three of the seven sets included in the aligned data had some slight intermittent EM recording. Once those sets were removed the p-value for the species group analysis increased to 0.097 ($Z = 1.659$). The p-value of the species-specific test conducted without the sets with intermittent data collection increased from 0.13 ($Z = 0.151$) to 0.71 ($Z = 0.368$).

On Vessel B, the ‘grenadier’ species group appeared to be generating the largest differences, and hence to assess the groups impact, the Wilcoxon test was conducted with and without this species group. The p-value of the species-group test without the grenadier group was 0.386 (Z = 0.868).

Second, to construct hypothetical confidence intervals, the among-skate variance from the hook-status data collection was used to estimate the sample variance for each set in the aligned data set (150 completely monitored sets). There were 702 species-specific estimates over the four vessels and 150 sets. Of these, on 47 occasions the EM count fell below the hypothetical lower 95% CI and on five occasions the EM count was above the hypothetical 95% CI. On all but five instances, the EM count for the species was zero while the observer count was greater than zero (and the lower confidence bound was greater than zero).

The five instances where the EM count was greater than zero and outside the CI appear to be the result of differential use of species groups. On three sets on Vessel B, the observer used the Irish lord species group code (species code 418; 65, 59, and 94 fish) while the EM reviewer used the sculpin species group code (species code 400; 65, 59, and 86 fish, respectively). On vessel C (one set) the observer recorded an observation of *Bathyraja* skates (25 fish using species code 159) while the EM recorded 20 fish identified as big skates (*Raja binoculata*, species code 94). This may be a case of species misidentification by either the observer or the EM reviewer. Lastly, on Vessel C, the observer counted one rock sole species group (species code 104) while the EM recorded identified five fish to the same species. We would expect, based on random chance and the assumption of normality being valid, that 5% of the observations fall outside the CI (35 observations). While our results were higher than expected, it may be the result of either species groupings increasing the “misidentifications” of fish or a failure of the assumption of normality. The assumption of normality was particularly problematic for species that tend to be clustered within the set (e.g., travel in schools) or species that were less common in the catch. Of the 702 hypothetical confidence intervals, 356 had lower bounds that were less than zero, indicating a potential failure of normality assumptions.

When catch estimates were made at the species group level, 669 catch estimates were available for the analysis. Of these, the EM estimates fell within the hook-status hypothetical CI on all instances (excluding invertebrate and miscellaneous species). We would expect approximately 33 observations to fall outside the CIs. This may indicate that the normality assumption is not valid and the CIs used are too large. This may be the case since approximately half (325) of the hypothetical lower confidence intervals were less than zero.

Comparison 4: Proportion Matching Species Identifications between two Independent EM Reviewers

A sample of 17 sets (10% of sets) from the study were selected for a second review by Archipelago Marine Research staff. These were distributed within each of the vessels that participated in the study (Table 14). There were six primary reviewers of the video data, two of whom also provided a secondary review of the selected video. None of the sets were documented by the same person for both reviews. On Vessel A, two of the reviewed sets were not useable due to the intermittent quality of the data; neither of these sets received a second review.

Table 14 -- Summary of EM video review.

Vessel	Total Number of Reviewed Sets	Single Reviewer (Number of sets)	Primary Reviewer (Number of sets)	Secondary Reviewer (Number of sets)
A	8	D (4); B (2); E (1)	D (1)	**C**
B	140	A (67); C (59)	C (7); A (7)	**F**
C	14	F (3); A (10)	A (1)	**C**
D	**13**	**D (12)**	**D (1)**	**C**

For those sets that received a secondary review, the determination of image quality was consistent between the two reviewers for 65% of the sets (Table 15). No sets were determined to have low image quality by the primary reviewer and only one set was determined to have low image quality by the secondary reviewer.

Table 15. -- Determination of image quality by independent video reviewers

Primary Reviewer	Secondary Reviewer			
	High	Medium	Low	**Total**
High	**8 (47%)**	3 (18%)	0 (0%)	**11 (65%)**
Medium	2 (12%)	**3 (18%)**	1 (6%)	**6 (35%)**
Low	0 (0%)	0 (0%)	**0 (0%)**	**0 (0%)**
Total	**10 (59%)**	**6 (35%)**	**1 (6%)**	**17 (100%)**

For four sets, the image quality assigned by the second reviewer was lower than that assigned by the primary reviewer while on two sets this was reversed (i.e., the secondary reviewer assigned a higher image quality). The secondary video reviewer tended to spend longer reviewing imagery for a set than the primary reviewer (Fig. 18). All three sets with shorter secondary review times had high quality imagery (as determined by primary reviewer).

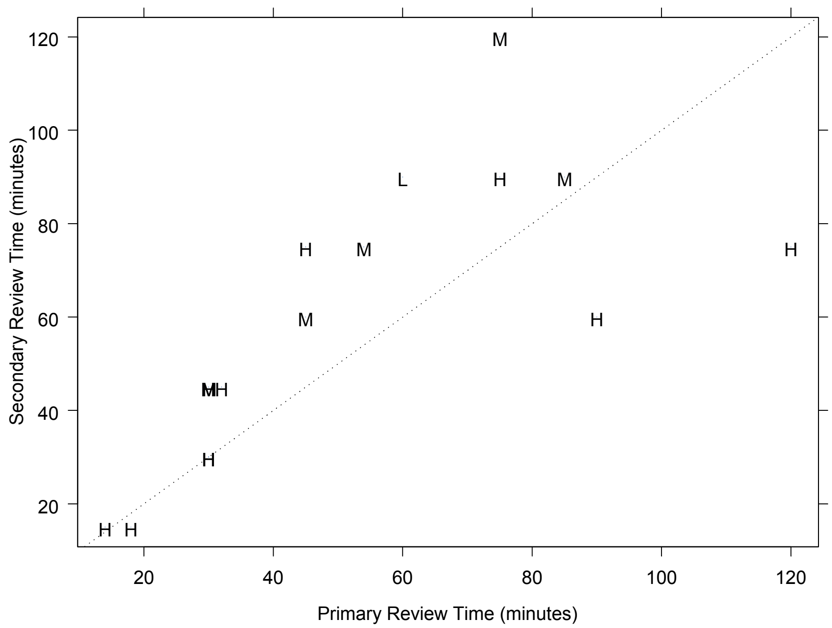


Figure 18. -- Comparison of primary and secondary review times. Image quality determined by primary reviewer is indicated as H=high image quality, M=Medium image quality, and L=low image quality.

As with the observer and EM datasets, the data collected by the primary and secondary review were aligned by AMR staff, matching hook numbers and notable species. The proportion of matching species identifications, inclusive of missing and empty hooks, was generally greater than 80% (Table 16). The proportion was lowest for Vessel C, which had some night fishing and had some empty hooks removed from the analysis.

Table 16. -- Summary of proportion of species identification agreement for each study vessel. Empty and 'missed' hooks are not included. Image quality is determined by the primary reviewer.

	Proportion of Species-specific Identification in Agreement (variance, number of hooks) ALL HOOKS		
Vessel	**High Image Quality**	**Medium Image Quality**	**Total**
A	---	0.905 (0.086; 1,529)	0.904 (0.086; 1,529)
B	0.908 (0.084; 9,430)	0.843 (0.132; 4,946)	0.885 (0.101; 14,376)
C	0.804 (0.157; 1,579)	---	0.804 (0.157; 1,579)
D	---	0.891 (0.097; 441)	0.891 (0.097; 441)
Total	0.893 (0.096; 11,009)	0.860 (0.121; 6,916)	0.881 (0.106; 17,925)

The analysis was repeated including only those hooks where both reviewers identified catch, omitting empty and missing hooks. The proportion of hooks with matching species-specific identifications are presented in Table 17. The proportion of fish identifications that were identified as the same species was in excess of 90% in all cases.

Table 17. -- Summary of proportion of species identification agreement for each study vessel. Empty and 'missed' hooks are not included. Image quality is determined by the primary reviewer.

	Proportion of Species-specific Identification in Agreement (variance, number of hooks) FISH ONLY		
Vessel	**High Image Quality**	**Medium Image Quality**	**Total**
A	---	0.977 (0.023; 172)	0.977 (0.023; 172)
B	0.991 (0.009; 1,267)	0.936 (0.060; 737)	0.971 (0.028; 2,004)
C	0.984 (0.016; 311)	---	0.959 (0.016; 311)
D	---	0.959 (0.040; 218)	0.959 (0.040; 218)
Total	0.990 (0.010; 1,578)	0.947 (0.050; 1,217)	0.972 (0.027; 2,705)

Similar to analyses presented in Comparison 1, halibut observations were removed from the data and the proportion of species identifications in agreement was recalculated (Table 18). As in Comparison 1, the proportion of hooks with the same species identified decreased when halibut were omitted from the analysis.

The proportion of hooks in agreement was over 84% for all combinations of vessel and image quality. The small sample sizes and numbers of sets from each vessel prohibit a more comprehensive analysis of the similarity between reviewers in species identification.

Table 18. -- Summary of proportion of species identification agreement for each study vessel. Empty, 'missed' hooks, and halibut observations are not included.

	Proportion of Species-specific Identification in Agreement (variance, number of hooks) BYCATCH ONLY		
Vessel	**Primary Reviewer High Image Quality**	**Primary Reviewer Medium Image Quality**	**Total**
A	---	0.846 (0.135; 26)	0.846 (0.135; 26)
B	0.983 (0.016; 478)	0.887 (0.101; 335)	0.943 (0.053; 813)
C	0.970 (0.030; 33)	---	0.97 (0.030; 33)
D	---	0.855 (0.126; 62)	0.855 (0.126; 62)
Total	0.982 (0.017; 511)	0.879 (0.106; 423)	0.936 (0.060; 934)

A second metric for comparison is the total numbers of fish recorded by each EM reviewer. The total numbers of fish, of each species, was computed for each set with two complete reviews. The between EM reviewer differences in the species-specific numbers of fish were generally less than 10 fish regardless of species (Fig. 19). The largest differences occurred in the rockfish species, and may be the result of the primary reviewer using the 'small red rockfish' grouping while the secondary reviewer used the 'shortraker/rougheye rockfish' grouping.

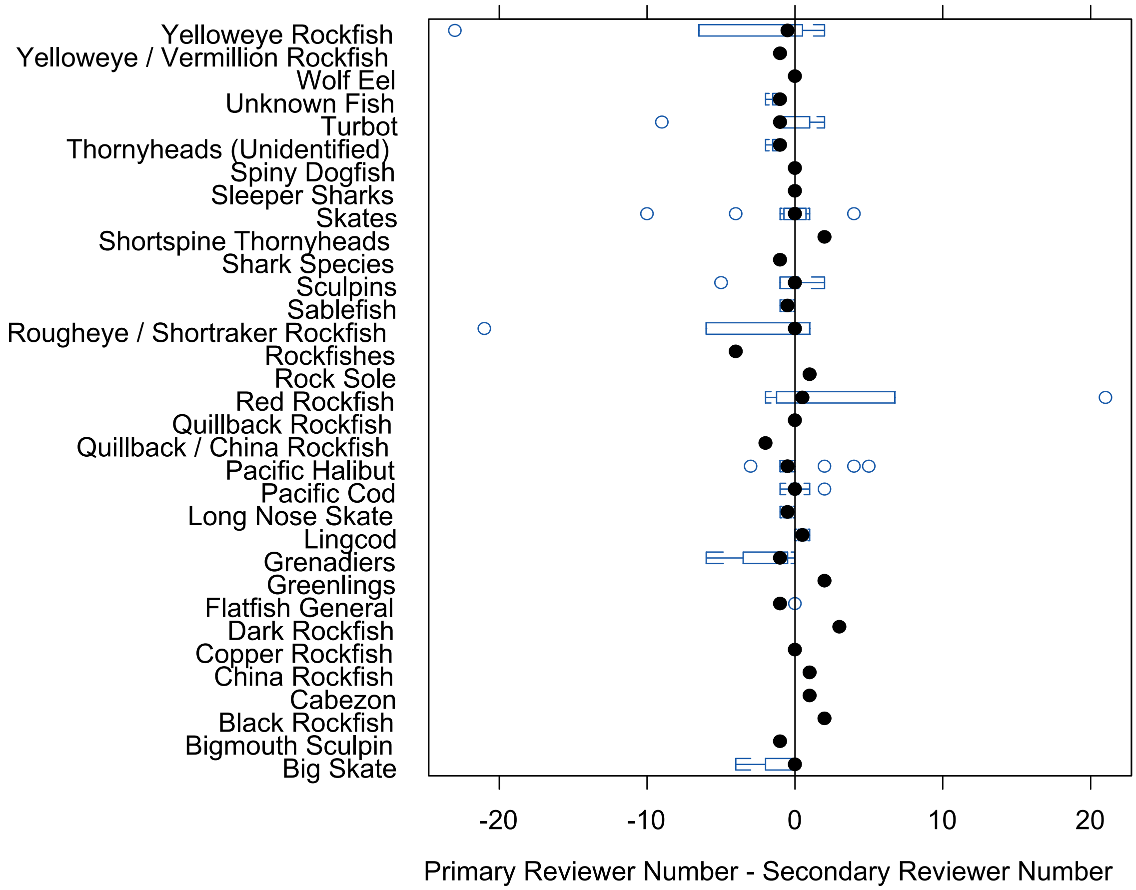


Figure 19. -- EM reviewer species-specific differences in total number of fish per set. Invertebrates and empty hooks are not included. Species groupings are not used. The dot indicates the median difference, the boxes represent the center half of the data (25^{th} and 75^{th} quartiles), and the whiskers extend to the largest data point that is within the 1.5 times inter-quartile range.

Results of a Wilcoxon signed rank test did not result in significant differences in numbers of fish recorded between the two reviewers (p-value = 0.059, Z = -1.888, not inclusive of empty and missed hooks), however, the p-value is marginal. When halibut were removed from the analysis, the differences were still not significantly different from zero (p-value = 0.105, Z = -1.621). T-tests were not attempted due to non-normality of the differences.

The total number of hooks fished and the total number of fish (all species) recorded for each set was similar for both reviewers (Fig. 20).

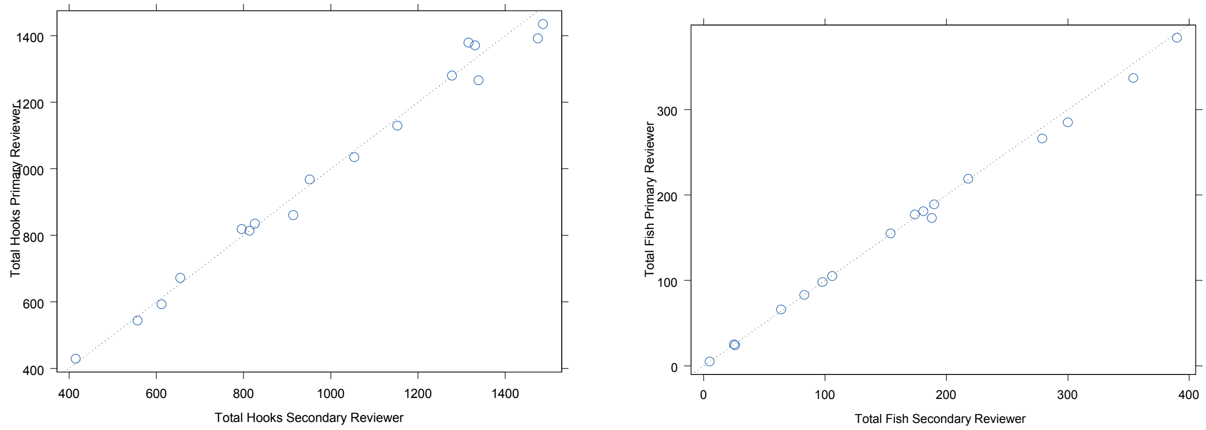


Figure 20. -- Comparison between EM reviewers of total hooks fished (left) and total number of fish recorded (right).

The number of fish of each species did not appear to vary between the two reviewers with increasing magnitude of the species-specific catch, regardless of whether halibut were included in the analysis (Fig. 21). While the magnitude of the differences did not appear to vary with the type of species, the largest differences were for rockfish species (Fig. 21). The primary reviewer tended to have lower estimates of numbers of fish than the secondary EM reviewer.

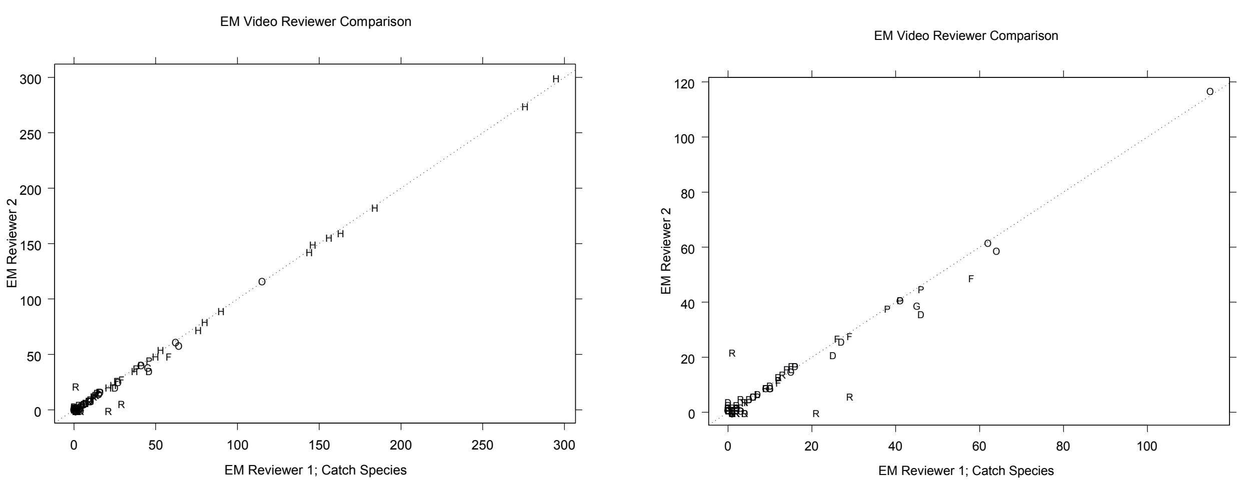


Figure 21. -- Comparison of number of fish, by species, documented by the two video reviewers. All fish species (left) and non-halibut fish species (right) are indicated by the following letters: H=halibut, S=sablefish, L=lingcod, R=rockfish, G=grenadier, F=flatfish, D=skates and rays, and O=other fish species.

The correlation between the two data sources' total number of fish documented per set (each set as an independent replicate) for each species (not including empty hooks) was high (0.99, 116 df). The correlation between the two data sources for each species-specific total numbers of fish caught per set, excluding empty hooks and halibut was slightly lower (0.97, 100 df).

DISCUSSION

The lack of observations on catch for most components of the Pacific halibut fishery off Alaska is an area of concern for both fishery management agencies (relative to characterization of bycatch in the fishery), and the commercial fishing industry (relative to its need to satisfy conditions for continued eco-certification of the fishery). The largely small-boat nature of the commercial halibut fleet renders it less suitable for traditional observer coverage and more conducive to alternative monitoring methods in the likely event of regulatory requirements for catch monitoring. Our objectives were to evaluate a pilot EM implementation in the halibut fleet and to provide a comparison of catch monitoring capabilities using traditional observer coverage to that of an EM system. The bycatch estimates presented here are based on observations from four vessels and may not represent the bycatch rates or composition of vessels participating in the halibut fishery. However, the comparisons made between methods and the resulting inferences are likely representative of the similarities and differences between the data collection methods.

Implementation Issues

Vessel solicitation was a greater problem for the study than was anticipated. Many vessel operators, while sympathetic to the research, declined to participate in the absence of a regulatory requirement for catch monitoring. In this sense, they did not distinguish between EM and traditional observer coverage and were simply disinclined to carry out catch monitoring without an incentive. They also did not appear to give significant weight to the needs for additional catch monitoring that were identified in the eco-certification of this fishery.

The EM system chosen for the project has a relatively long history of successful implementation in fisheries elsewhere in the world (Dalskov and Kindt-Larsen 2009, McElderry 2008, Pria et al. 2008). The reliability of these systems has been extremely high. For example, deployment on 50 vessels in a British Columbia crab fishery resulted in only 200 hours of lost coverage from a total of about 55,000 hours of operation, or, 99% reliability (McElderry 2008). Similarly, deployment of the same EM system on seven vessels in a Danish fishery resulted in 97.9% successful coverage of over 8,900 hours of fishing (Dalskov and Kindt-Larsen 2009).

Nonetheless, we experienced two types of problems with EM system operations during this project: system/ equipment issues and installation issues. The first problem occurred on our first two vessel deployments and concerned incompatibilities of system components arising from a change in the software operating system of the control unit (Windows XP to Vista). This resulted in communication problems between the computers resulting in poor or no data capture. These problems were resolved on the subsequent deployments following installation of software patches and did not recur. In another case, a hard drive failure resulted in a system shut-down and no further monitoring for that trip. Replacing the hard drive provided for EM data collection on the subsequent trips on that vessel.

The second problem was installation-specific and resulted from both improper setting of a hydraulic sensor and power supply issues on the vessel. The former issue meant that the EM cameras were not consistently activated when vessel hydraulics were engaged, and the latter issue resulted in intermittent re-booting of the EM system. The EM systems are sensitive to power supply issues, particularly with vessels using inverted DC power to derive AC power, or where dedicated AC power generators do not function continuously. Power supply issues could be a significant factor concerning EM deployment on the smallest vessels (< 30 ft) within the halibut fleet. While technical problems with EM systems can be expected, it appears that these problems can be resolved fairly rapidly.

Although observers are typically not required to sample every set during a fishing trip and are never required to completely monitor a set, this study also served to highlight some of the potential shortcomings in observer coverage. For example, on one vessel, adverse weather prevented the observer from working on deck due to safety concerns, resulting in a coverage rate of approximately 84% of the sets. Additionally, observers were unable to monitor all sets completely (without breaks) on two vessels, resulting in hook-status monitoring of (randomly selected) portions of some sets. Data from sets where observers sample the catch can be expanded to the entire set (based on the sampling fraction obtained). Note that a similar process potentially could be used to select portions of the EM video record to be reviewed, and data from that review could be expanded to the entire set (under the assumption that the sample fraction can be obtained). In cases where the sample variance was higher than desired, EM provides the unique additional capability to allow more portions of the video record to be reviewed, thus increasing the sample fraction and decreasing the sample variance.

Implementation of both observer-based monitoring and EM-based monitoring did not achieve the coverage rates of fishing events that we expected. EM monitoring achieved higher levels of coverage under adverse weather conditions and functioned continuously throughout the entire time of vessel fishing compared with observer-based monitoring. However, EM systems failed to collect data for both technical and non-technical reasons and, in this study, had a higher than expected rate of operational failures.

When the EM equipment was unable to capture data, the percentage of sets without data for a trip was relatively high. Conversely, when the observer was not sampling, either because they were operating under normal sampling conditions or because they were prevented from sampling by weather or illness, other sets during the trip were monitored by EM.

Relative to the goals of this study observers and EM systems can collect similar types of data. Observers are also able to collect biological data and samples, and they are able to weigh fish as individuals or on aggregate. Furthermore, observer duties and priorities can be changed in a relatively straightforward manner. Each of these approaches provides a set of tools which can be used to configure monitoring systems relative to specific management and science goals.

Study Costs

Costs of this study are likely not indicative of a typical fishery application for several reasons. Primarily, the study's limited deployment meant that no efficiencies in size could be used to control project costs. For example, we did not deploy observers to specific ports, and we did need to pay for observers to remain with study vessels during periods when the vessels were not fishing. Hence, travel costs for observers and EM technicians were likely higher than typical costs would be in an active fishery. Airline schedules were also disrupted by volcanic eruptions in 2008. All observers were deployed from Seattle or Anchorage, rather than other coastal ports, compounding delays in deployment of observers. AMR technicians also flew up to the ports from Victoria, B.C. as needed, instead of being stationed in local ports.

The additional training costs for this study were likely less than those generally required of observers. Since the observers that participated in the study were already certified and had experience, we did not pay for the initial 3-week training required for new observers nor the annual 4-day training required of returning observers. Hence the training costs for this study potentially would be less per observer (annually) than normal in the Alaska groundfish fisheries.

In addition, we had higher levels of video review than might be used in a typical fishery monitoring program, including hook-specific data recording and a secondary review of some sets. This additional review was necessitated by the study design, specifically the hook-specific catch comparisons, and such high levels of review are not typically used to meet monitoring goals (McElderry 2008). Agency staff costs are also not included but should be considered a part of the overall monitoring program. Thus, we would expect a different financial picture and probably more program efficiencies in a fishery monitoring program.

Internal Consistency of Monitoring Methods

Both monitoring methods showed reassuringly high levels of internal consistency in species counts and hook-status monitoring. For skates where two observers monitored the same skates, the comparison of data collected using between standard observer sampling methods (AFSC Observer Program extrapolation) and hook-status methods (census) showed no significant difference in numbers of fish documented and no significant differences in median differences in catch estimation by skate between the two observation methods. While subject to measurement-type errors, these errors are small in magnitude. The correlation between the observations made by the two observers was high (0.98, 333 df). Comparisons at the set level also showed consistent results. We did not find evidence of bias in the catch estimates based on data collected using standard observer methods. The species-specific hook-status count fell within the 95% confidence interval for all sets that the standard observer sampled. For the three sets that the standard observer completely monitored, the estimates were either equal to the hook-status counts, or in cases where the estimates were not equal they were evenly divided above and below the hook-status counts. This was not unexpected since a mechanism that might produce bias in the expansion process has not been identified.

For the EM observations, we examined a similar number of randomly selected sets using independent video reviewers. For review of all hooks, agreement on species occupancy or hook-status between video reviewers averaged 88% (range 84-91%). For fish only, agreement averaged 97% (range 95-99%), and for bycatch species only the agreement averaged 94% (range 85-98%). For those same sets neither the estimates of total numbers of fish nor those for total numbers of non-halibut species were significantly different between reviewers. For those sets, the correlation between observations by the two reviewers in total numbers of fish of each species, by set, was very high (0.99, 116 df).

Although not directly comparable due to inherent differences in sampling methodologies, both the between-reviewer and the between-observer comparisons yielded similarly consistent results. Both the EM methods and the observer methods show some internal variation (measurement error), but the inferences (catch estimates) are the same.

Comparability of Observer and EM Monitoring

The key question we posed for the study was whether observers and an EM system can produce comparable data for catch monitoring. This question has two components: are data for direct observations and EM observations of the same hook or skate (gear unit) comparable; and, are estimates of total catch in numbers of fish from standard observer estimations (i.e., extrapolation from samples to total catch) comparable to EM observations of total catch?

Very high levels of agreement on species identification and hook status between the two methods were achieved. The percentage of hooks for which there was agreement averaged 96.5% (range 94.5-98.3%) across all vessels and viewing conditions. Agreement was lower when only fish were considered (i.e., no empty/missing hooks or invertebrates), and did not change appreciably whether fish were grouped according to management/observer categories. Comparability dropped further when only bycatch species were considered, averaging 80.7% agreement (range 55.5-97.3%). Lower agreements are associated with differences in species-level identifications between the two methods and, to a lesser extent, viewing conditions and the pace of fishing. The pace of fishing was slowest and weather conditions best on Vessel D and it is on this vessel where agreement of the two methods at the species level was highest, and where the video observer identified more species than the observers. Agreement of results from both methods at higher levels of grouping (e.g., rockfish, flatfish) was essentially unanimous over all observations.

There are a number of factors that diminished agreement on bycatch species identification between the two monitoring methods. The tendency of the video reviewers to categorize more species into broader categories on two of the vessels can indicate either poorer visual resolution of the EM or better species recognition ability by observers. Both effects were likely to have influenced our data, since the video reviewers were not regular Alaskan fishery observers and known species misidentifications occurred. For example, cabezon and bocaccio were recorded by video reviewers. These species are common in British Columbia, where the video review was conducted, but have not been recorded in the areas where vessels were operating. Similarly, we found it necessary to group arrowtooth flounder (*Atheresthes stomias*) and turbot (*Reinhardtius hippoglossoides*) observations because of the common designation of these species as ‘turbot’ in British Columbia and but not in Alaska. These types of problems may be resolved though improved training and experience of video reviewers.

Also, for some of the larger differences between observer-based number and EM-based total number, the occurrence of fish dropping off the line may be a contributing factor. This was recognized by Ames (2005), and may explain, in part, the discrepancy on Vessel B for grenadiers. This does not appear to be generally the case for other species, however. Since these fish may be dropping off the line before the hook comes into view of the EM cameras (e.g., below the water surface), there is no opportunity for the observer to collect specimens to confirm species identification or to obtain biological data.

Percentage agreements in species identification between the two observation methods should also be interpreted cautiously because both methods are subject to error and no absolute standard of reference exists, with which either observations can be compared. No consistent trend in numbers of species identified by observers or EM reviewers on different vessels occurred. Both methods resulted in fewer or greater numbers of species identified, depending on vessel. While there were deviations in estimated numbers of fish by species between the two methods, the mean deviations tended to be small in absolute magnitude (< 10 fish).

Our interpretation of these results is that EM can be a valuable addition to the suite of monitoring options for Alaskan halibut fisheries but that higher levels of training for identification of enigmatic bycatch species, additional sampling methods for collection of biological specimens and weight per fish data, and contingencies to accommodate technical and equipment malfunctions would be required for large-scale EM implementation in Alaskan waters.

CONCLUSIONS

The primary conclusions from this field test of EM and observer monitoring of commercial halibut fishing in Alaskan waters are:

1. Neither observers nor EM achieved complete monitoring of all fishing events. It is a reasonable expectation that a fully developed EM implementation would achieve close to complete coverage of fishing events but could be subject to occasional technical failures. While we experienced unanticipated technical problems, these issues were resolved and were not persistent during the study; however, data capture was less than planned. In large scale implementation, contingency plans that address unexpected technical malfunction should be part of the overall program design. Existing observer programs would be expected to achieve coverage to design guidelines (i.e., representative random sampling) in most instances but would experience coverage failure due to adverse weather or observer shortfalls.
2. Both EM and observer monitoring are subject to errors and no standard for comparison and determination of the absolute accuracy of either method exists.
3. EM coverage was not subject to any scale dependency, that is, adequacy of monitoring was not dependent on magnitude of catch for a given set.
4. Comparison of species identification of catch between standard observer estimation, complete hook-status observer coverage, and EM coverage showed statistically unbiased and acceptable comparability for almost all species however some cryptic species could not be monitored beyond the species grouping levels used in management. Enhanced training of video reviewers on identification of cryptic species would improve comparability. Identification of one species group (grenadiers) was

not comparable between observer and EM coverage, possibly due to observers being able to detect drop-offs below the waterline at the hauling point.

5. EM could be an additional tool for catch monitoring in the commercial halibut fishery. Its potential use would be determined by the specific monitoring requirements of each management application. Estimation of bycatch species composition (numbers of fish) in this fishery could be achieved with a high degree of accuracy using EM. In general, EM is not an alternative to observers for the collection of certain biological specimens (e.g., otoliths, scales, etc.) from the catch. Note that in this study, fish weight (either as individual fish or an aggregate of several fish) could not be obtained within our EM system configuration.

6. EM could provide viable catch monitoring capability for the smaller-boat component of the commercial halibut fleet, a large portion of which may be unsuitable for observer coverage.

ACKNOWLEDGMENTS

This research was funded in part by the North Pacific Research Board, Project # 712 (NPRB No. 281).

The project would not have been possible without the cooperation of the participating vessels and their crews of vessels: Captain Jay Hebert, FV *Lisa Marie*; Captain Dan Hull, FV *Gretchen S*; Captain Norm Pillen, FV *Sherrie Marie*; Captain Bill Sauer, FV *Kristiana*.

Our subcontractors provided invaluable field assistance and data collection. Bryan Belay at MRAG Americas was responsible for getting observers where they needed to be according to schedule. Our project observers (Mike Cox, Melanie Haggard, Suzie Hanlan, Paula Hartzell, and Mel Kahn) collected data using atypical methods that required motivation and dedication beyond typical deployments.

Morgan Dyas, Jessica Schrader, Greg Morgan, and Howard McElderry at Archipelago Marine Research Inc. provided EM equipment and data collection and processing, and critical on-site technical support.

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APPENDIX: SPECIES CODES, NAMES, AND GROUPINGS

Species Code	Species Name	Scientific Name	Observer Group Code	Species Type Group Code
1	CRAB UNIDENTIFIED	NON TAXONOMIC GROUPING		Crabs
2	KING CRAB UNIDENTIFIED	NON TAXONOMIC GROUPING		Crabs
20	STARFISH UNIDENTIFIED	ASTEROIDEA	Invertebrates and Misc. (900)	Invertebrates and Misc.
21	BASKET STARFISH	GORGONOCEPHALUS	Invertebrates and Misc. (900)	Invertebrates and Misc.
24	SUNSTAR STARFISH/SUNFLOWER STARFISH	SOLASTERIDAE	Invertebrates and Misc. (900)	Invertebrates and Misc.
26	SPONGE UNIDENTIFIED	PORIFERA	Invertebrates and Misc. (900)	Invertebrates and Misc.
29	MUSSELS OYSTERS SCALLOPS CLAMS	PELECYPODA	Invertebrates and Misc. (900)	Invertebrates and Misc.
30	SNAIL UNIDENTIFIED	GASTROPODA	Invertebrates and Misc. (900)	Invertebrates and Misc.
32	CORALS BRYOZOANS UNIDENTIFIED	SCLERACTINIA, BRYOZOA	Invertebrates and Misc. (900)	Invertebrates and Misc.
36	SNAIL SHELL UNIDENTIFIED	GASTROPOD	Invertebrates and Misc. (900)	Invertebrates and Misc.
40	SEA URCHINS OR SAND DOLLARS UNIDENT	ECHINOIDEA	Invertebrates and Misc. (900)	Invertebrates and Misc.
43	ASCIDIAN SEA SQUIRT TUNICATE	UROCHORDATA	Invertebrates and Misc. (900)	Invertebrates and Misc.
48	BARNACLES UNIDENTIFIED	CIRRIPEDIA	Invertebrates and Misc. (900)	Invertebrates and Misc.
55	SEA ANEMONE UNIDENTIFIED	ACTINIARIA	Invertebrates and Misc. (900)	Invertebrates and Misc.
57	SEA POTATO UNIDENTIFIED	HALOCYNTHIA SPP	Invertebrates and Misc. (900)	Invertebrates and Misc.
58	SEA PEN SEA WHIP UNIDENTIFIED	PENNATULA	Invertebrates and Misc. (900)	Invertebrates and Misc.
60	OCTOPUS UNIDENTIFIED	OCTOPODA		Octopus
62	PACIFIC SLEEPER SHARK	SOMNIOSUS PACIFICUS		Sharks and Skates
65	SHARK UNIDENTIFIED	SQUALIFORMES		Sharks and Skates
66	SPINY DOGFISH SHARK	SQUALUS ACANTHIAS		Sharks and Skates

Species Code	Species Name	Scientific Name	Observer Group Code	Species Type Group Code
70	SHRIMP UNIDENTIFIED	NON TAXONOMIC GROUPING	Invertebrates and Misc. (900)	Invertebrates and Misc.
80	RATTAIL (GRENADIER) UNIDENTIFIED	MACROURIDAE	Grenadiers (80)	Grenadiers
82	GIANT GRENADIER	ALBATROSSIA PECTORALIS	Grenadiers (80)	Grenadiers
85	ALEUTIAN SKATE	BATHYRAJA ALEUTICA	Bathyraja Skates (159)	Sharks and Skates
90	SKATE UNIDENTIFIED	RAJIFORMES		Sharks and Skates
91	SKATE EGG CASE UNIDENTIFIED	RAJIFORMIES	Invertebrates and Misc. (900)	Invertebrates and Misc.
94	BIG SKATE	RAJA BINOCULATA		Sharks and Skates
95	LONGNOSE SKATE	RAJA RHINA		Sharks and Skates
98	SANDPAPER SKATE	BATHYRAJA KINCAIDI		Sharks and Skates
100	FLATFISH UNIDENTIFIED	PLEURONECTIFORMES		Flatfish
101	PACIFIC HALIBUT	HIPPOGLOSSUS STENOLEPIS		Halibut
102	TURBOT	REINHARDTIUS HIPPOGLOSSOIDES	Turbot/ Kamchatka/ Arrowtooth (102)	Flatfish
103	FLATHEAD SOLE	HIPPOGLOSSOIDES ELASSODON		Flatfish
104	ROCK SOLE UNIDENTIFIED	LEPIDOPSETTA SPP		Flatfish
105	REX SOLE	GLYPTOCEPHALUS ZACHIRUS		Flatfish
107	DOVER SOLE	MICROSTOMUS PACIFICUS		Flatfish
141	ARROWTOOTH FLOUNDER	ATHERESTHES STOMIAS	Turbot/ Kamchatka/ Arrowtooth (102)	Flatfish
143	GR TURBOT/KAMCHATCA FL/ARROWTOOTH-UNIDENT	NON TAXONOMIC GROUPING	Turbot/ Kamchatka/ Arrowtooth (102)	Flatfish
149	KAMCHATKA FL./ARROWTOOTH FL. UNIDENTIFIED	NON TAXONOMIC GROUPING	Turbot/ Kamchatka/ Arrowtooth (102)	Flatfish
159	SOFT SNOUT SKATE	BATHYRAJA SPP	Bathyraja Skates (159)	Sharks and Skates
200	ROUNDFISH	NON TAXONOMIC		Other Fish

Species Code	Species Name	Scientific Name	Observer Group Code	Species Type Group Code
	UNIDENTIFIED	GROUPING		
201	POLLOCK	THERAGRA CHALCOGRAMMA		Other Fish
202	PACIFIC COD	GADUS MACROCEPHALUS		Pacific Cod
203	SABLEFISH (BLACK COD)	ANOPLOPOMA FIMBRIA		Sablefish
204	ATKA MACKEREL	PLEUROGRAMMUS MONOPTERYGIUS		Other Fish
220	SALMON UNIDENTIFIED	ONCORHYNCHUS SPP		Salmon
240	RONQUIL UNIDENTIFIED	BATHYMASTERIDAE		Other Fish
242	SEARCHER	BATHYMASTER SIGNATUS		Other Fish
250	EELPOUT UNIDENTIFIED	ZOARCIDAE		Other Fish
300	ROCKFISH UNIDENTIFIED	SCORPAENIDAE		Rockfish
302	BOCACCIO /LONGJAW ROCKFISH	SEBASTES PAUCISPINIS	Rockfish Unident (300)	Rockfish
306	BLACK ROCKFISH	SEBASTES MELANOPS		Rockfish
307	ROUGHEYE ROCKFISH	SEBASTES ALEUTIANUS	Shortraker/Rougheye (354)	Rockfish
308	RED BANDED ROCKFISH	SEBASTES BABCOCKI		Rockfish
309	ROSETHORN ROCKFISH	SEBASTES HELVOMACULATUS		Rockfish
310	SILVERGRAY ROCKFISH	SEBASTES BREVISPINIS		Rockfish
314	CANARY ROCKFISH	SEBASTES PINNIGER		Rockfish
322	YELLOWEYE ROCKFISH	SEBASTES RUBERRIMUS		Rockfish
326	SHORTRAKER ROCKFISH	SEBASTES BOREALIS	Shortraker/Rougheye (354)	Rockfish
327	COPPER ROCKFISH	SEBASTES CAURINUS		Rockfish
329	TIGER ROCKFISH	SEBASTES NIGROCINCTUS		Rockfish
330	DUSKY ROCKFISH	SEBASTES VARIABILIS		Rockfish
332	BROWN ROCKFISH	SEBASTES AURICULATUS		Rockfish
343	QUILLBACK ROCKFISH	SEBASTES MALIGER		Rockfish
345	DARK ROCKFISH	SEBASTES CILIATUS		Rockfish
346	CHINA ROCKFISH	SEBASTES NEBULOSUS		Rockfish
348	RED ROCKFISH	NON TAXONOMIC		Rockfish

Species Code	Species Name	Scientific Name	Observer Group Code	Species Type Group Code
	UNIDENT	GROUPING		
349	THORNYHEAD ROCKFISH UNIDENT	NON TAXONOMIC GROUPING		Rockfish
350	SHORTSPINE THORNYHEAD	SEBASTOLOBUS ALASCANUS		Rockfish
354	SHORTRAKER/ROUGHEYE ROCKFISH	NON TAXONOMIC GROUPING	Shortraker/Rougheye (354)	Rockfish
356	SQUARESPOT ROCKFISH	SEBASTES HOPKINSI		Rockfish
390	GREENLING UNIDENTIFIED	HEXAGRAMMIDAE		Other Fish
400	SCULPIN UNIDENTIFIED	COTTIDAE	Sculpins (400)	Sculpins
402	BIGMOUTH SCULPIN	HEMITRIPTERUS BOLINI		Sculpins
407	RED IRISH LORD	HEMILEPIDOTUS HEMILEPIDOTUS	Irish Lords (418)	Sculpins
418	IRISH LORD UNIDENTIFIED	HEMILEPIDOTUS SPP	Irish Lords (418)	Sculpins
603	LINGCOD	OPHIODON ELONGATUS		Lingcod
779	WOLFFISH UNIDENTIFIED	ANARHICHADIDAE		Other Fish
780	WOLF-EEL	ANARRHICHTHYS OCELLATUS		Other Fish
840	LYRE CRAB UNIDENTIFIED	HYAS SPP		Crabs
854	NORTHERN FULMAR	FULMARUS GLACIALIS		Birds
899	FISH WASTE/UNIDENTIFIED ORGANIC MATTER	NON TAXONOMIC GROUPING	Invertebrates and Misc. (900)	Invertebrates and Misc.
900	MISCELLANEOUS UNIDENTIFIED	NON TAXONOMIC GROUPING	Invertebrates and Misc. (900)	Invertebrates and Misc.
901	FISH UNIDENTIFIED	OSTEICHTHYES		Other Fish
902	INVERTEBRATE UNIDENTIFIED	NON TAXONOMIC GROUPING	Invertebrates and Misc. (900)	Invertebrates and Misc.
998	BIRD UNIDENTIFIED	AVES		Birds
99999	CABEZON	SCORPAENICHTHYS MARMORATUS	Sculpins (400)	Sculpins

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