Electronic Monitoring of the Kodiak Alaska Rockfish Fishery A Pilot Study

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December 2005

ABSTRACT

McElderry, H., R. Reidy, J. Illingworth, and M. Buckley, 2005. Electronic Monitoring for the Kodiak Rockfish Fishery - A Pilot Study. Unpublished report prepared for the Pacific States Marine Fisheries Commission by Archipelago Marine Research Ltd., Victoria British Columbia, Canada, and Digital Observer Inc., Kodiak, Alaska USA. 43 p.

Archipelago Marine Research Ltd. and Digital Observer Inc. were contracted by the Pacific States Marine Fisheries Commission to investigate the use of video-based electronic monitoring (EM) in the Kodiak rockfish trawl fishery. This pilot study involved field-testing EM systems on 10 representative fishing vessels for 100% data capture of fishing operations. EM systems, consisting of three or four closed circuit television cameras, GPS, hydraulic and winch sensors, and on-board data storage were deployed on vessels during the rockfish fishery, and opportunistically on vessels continuing in the pollock fishery. EM systems captured over 3,000 hours of vessel time at sea during the rockfish fishery, consisting of 43 trips and 433 fishing events. EM system reliability was high with Archipelago systems recording over 99% data capture. Observers were present aboard for about a third of the trips monitored by EM. EM recorded discards on over 80% of fishing events although most sets discarded less than 20 pieces. EM could not assess about 10% of the sets due to large discard quantities. EM resolved discards to species level for some (halibut, Pacific cod, sablefish, lingcod) and others to morphological groups (e.g., salmon, rockfish, flatfish) whereas observers typically resolved catch to species. About 10% of EM discards were categorized as unknown, while observers speciated everything. Using a total of 194 sets available for comparison, observers and EM were in agreement in detecting the presence or absence of discards (all species) for 86% of the fishing events. Similar results occurred for discards of just halibut. Replicate interpretations from EM fishing event imagery resulted in close agreement but few exact matches indicating the process can be complex and subjective. The authors conclude that EM could be successful in monitoring the Kodiak rockfish trawl fishery provided some changes are made to ensure that all discards pass through the discard chute in camera view in a manner that would enable proper accounting. The suitability of EM in terms of cost and logistical efficiency will depend on the specific fishery context in which it would be employed.

TABLE OF CONTENTS

INTRODUCTION

1.1 Project Background

The North Pacific Fisheries Management Council (NPFMC), a regional organization established in 1976 under the Magnuson-Stevens Fishery Conservation and Management Act, governs domestic groundfish fisheries in Alaska. The Council is in the process of developing a program to rationalize the rockfish fisheries in the Central Gulf of Alaska (NPFMC, 2005). The present Gulf of Alaska rockfish fishery opens early in July, with the vast majority of catch delivered to processing plants in Kodiak. Initially, fishing effort is directed towards Pacific Ocean Perch (POP), which closes after approximately one week, when effort shifts to the northern rockfish fishery, which normally closes after another week to ten days. Fishing activity is often intense and fast paced, with vessels wanting to offload catch as quickly as possible to facilitate prompt returns to the fishing grounds. Most fishing trips run two to three days, with boats averaging two or three trips.

Rationalization would slow the fishery, improve efficiencies, and result in higher economic yield to participants. As currently envisioned, this program would give a portion of the annual quotas for POP, northern rockfish and pelagic shelf rockfish to cooperatives built around a shore side processor and to catcher vessels that deliver to that processor. The program would also give a portion of the annual quotas for certain secondary species like Pacific cod and sablefish, as well as a portion of the halibut PSC allocation to each cooperative. Under this program, member vessels of a cooperative would be allowed to harvest their rockfish and secondary species up to the allocations that they have been issued, provided that they do not catch more halibut PSC than they were allocated.

A challenge for the fleet rationalization plan is to come up with an effective at-sea monitoring tool for ensuring full retention of catch. The fleet of catcher vessels that will harvest the majority of the cooperatives' quotas is almost entirely made up of vessels between 60 and 125 feet that currently carry observers only 30 percent of the time (NPFMC, 2006). Because increasing observer coverage may not be economically feasible for this fleet, NMFS anticipates that catch accounting will take place when catch is delivered, and that participating vessels will be required to retain all catch that they are not required to discard for regulatory reasons. In most cases, this would mean that vessels would be required to discard halibut but retain all other catch. Depending on the exact regulations developed for this program and under certain circumstances, vessels may also be required to discard other, non-allocated species such as arrowtooth flounder.

Since detailed catch information will be obtained at dockside, it was thought that the at-sea monitoring objectives become reduced to simply ensuring vessel compliance with the full retention requirement. Given the promising results of video-based electronic monitoring (EM) in the Washington/Oregon/California shore based hake fishery

(McElderry et al., 2004, McElderry et al., 2005), the hope was that a similar approach could be applied to this fishery.

The 2005 rockfish pilot included a comprehensive project to test methodologies that would be employed in the rationalized fishery. A substantial portion of the fleet volunteered to host observers and EM systems. Archipelago Marine Research Ltd. and Digital Observer Inc. were contracted to conduct a joint assessment of the use of EM technology as a tool to monitor catch retention in the Kodiak rockfish fishery. The objectives of the 2005 rockfish pilot were to place monitoring systems over a range of vessels in the fishery in order to:

- Test equipment reliability and suitability for the fleet,
- Determine how well camera systems could be used to monitor catch processing events and distinguish catch and discard species,
- Determine when discarding takes place and, if discard is sorted, determine the level of identification possible (e.g., flatfish or roundfish, or some higher level),
- Compare EM and observer assessments of discarded catch, and
- Report on the time requirements associated with deployment of EM systems and interpreting resultant EM data.

MATERIALS AND METHODS

2.1 Outreach

Outreach to the fleet initially occurred during a one day informational industry meeting held in Kodiak Alaska prior to the fishery. As part of the meeting agenda, project staff provided an overview of the technology, installation, and operational issues with EM servicing. During the fishery, outreach was continued through personal and telephone contact by project staff to all active fishing vessels. Following project completion and final report, a client meeting took place in Seattle to review the project findings and provide advice on possible next steps.

2.2 Data Collection

2.2.1 EM System Specifications

Collectively a total of three Digital Observer EM systems and seven Archipelago EM systems were provided with spare parts to keep ten vessels in the Kodiak trawl fleet fully monitored during their fishing operations. Archipelago EM systems contained the following sensor suite: GPS, hydraulic pressure transducer and drum rotation sensor. Digital Observer EM systems were equipped with only GPS, although they are capable of monitoring drum rotation and hydraulic pressure sensors. Archipelago and Digital Observer systems were all equipped with up to four closed circuit television cameras (CCTV) providing a full view of the trawl deck and closer views of the discarding areas. These systems are capable of recording motion picture imagery at selectable frame rates, ranging from one to full motion picture quality of 30 images (frames) per second. Sensors and cameras were connected to a control box, usually located in the wheelhouse. For all systems, the control box consisted of a computer that monitored sensor status and activated image recording. As well, the control box contained data storage capability for about 30 days of vessel fishing activity (see Appendices A and B). During every offload, Archipelago or Digital Observer field technicians retrieved their respective EM data for processing.

2.2.2 Digital Observer EM Data Capture Specifications

The Digital Observer EM system consists of a secured central box, which is essentially a modified, rugged PVC suitcase that varies in size depending on deployment battery requirements (see Appendix A for system details). Wires running from the box bring ship's power and peripheral data in to the computer while sending power out to recording devices. Besides a battery, the box contents include a mini computer that runs the stable operating system, a power adapter, a line conditioner that smoothes out the variances in ship's power, a data hub, and a 250 GB external hard drive. Together with GPS and other (optional) data, the Digital Observer EM computer processes video from up to eight cameras and stores accumulated records on the external drive. In the event the external drive fails, the computer is programmed to begin storing data on its internal 40 GB drive. If the entire system shuts down due to loss of power, the computer will re-start, re-connect, and begin re-capturing data as soon as power returns. Furthermore, the computer system continuously logs activity, including any failures that occur while it is active. Depending on variables such as the number of cameras connected, the physical size of each video stream, and the level of compression the video files undergo, each system is designed to run independently for between seven to thirty days before the hard drive fills with data.

In this study the EM system recorded imagery for the entire time the system was powered. The frame rates used were 2-3 per second which resulted in a data storage requirement of 0.70 GB per hour for three cameras and about 360 hours for a 250 GB storage drive.

2.2.3 Archipelago EM Data Capture Specifications

The Archipelago EM system integrates an assortment of available digital video and computer components with a proprietary software operating system to create a powerful data collection tool. The central control box contained the computer system, data storage components, and a power supply for the peripheral sensors and cameras. Image data storage was accomplished with a 120 GB hard drive. The EM data logging and control computer is set to collect and store sensor readings (GPS, hydraulic pressure and drum rotation) at specified intervals (see Appendix B for system details). The data-logging program is designed to boot up automatically whenever powered or immediately after power interruption. The computer is also equipped with a “watchdog” circuit board that re-boots the computer in the event of a program lockup. A high recording interval for sensor data results in a distinctive “signature” for various vessel behaviors including transit and net setting, hauling, and towing.

EM control box software programming activated image capture when certain fishing action is evident in the sensor data stream. The operating software monitors hydraulic pressure and winch rotations to initiate image recording. Commencement of fishing activity is sensed by hydraulic pressure and winch rotation and resulted in activation of image recording. In order to reduce the volume of unnecessary imagery, recording was disabled while the GPS position indicated the vessel was within harbor. Once at sea, image recording would commence at the start of fishing and continue until the vessel returned to harbor.

In this study, imagery was recorded at 5 frames per second and sensor data was recorded at once every ten seconds. As mentioned above, image capture commenced with the first fishing event and continued until the vessel returned to harbour. Sensor data capture was continuous while the EM system was powered. Data storage capacity with three cameras was 0.69 GB per hour, or 175 hours for a 120 GB hard drive. Sensor data storage capacity was 0.5 MB per day, inconsequential to image file sizes.

2.2.4 EM System Field Component

2.2.4.1 Installation of EM Systems

The installation procedure began with a meeting aboard each fishing vessel between an

Archipelago or Digital Observer service team manager and the vessel captain. The vessel captains were consulted regarding positioning of equipment and wiring, and onboard electrical and hydraulic systems were assessed for optimal sensor placement, system integration and power requirements (Table 2.1). Following camera and sensor suite installation, the service team performed a simulation to insure the system was functioning correctly.

Table 2.1. Archipelago and Digital Observer EM sensor suite locations on 10 pilot vessels.

Configuration Specifications for EM System Installations on 10 Pilot Vessels by Archipelago and Digital Observer (DO)					
	Archipelago	**DO**		**Archipelago**	**DO**
Power Source			**GPS Location**		
110-volt AC Generator	0	0	Cabin Top	4	2
UPS	7	3	Mast	3	0
			Gantry	0	1
Number of CCTV Cameras			**Hydraulic Sensor Location**		
1	0	0	Engine Room	1	0
2	0	0	Hyd. Control Station	0	0
3	6	2	Winch	6	0
4	1	1	Other	0	0
Winch Sensor Location					
Net Drum	0	0			
3rd Wire Winch	0	0			
Trawl Warp Winch	7	0			

During this pilot survey, power for all 10 EM boxes was backed up by an Uninterrupted Power Supply unit (UPS), which was supplied either by the vessel or by Archipelago or Digital Observer. The UPS stabilized electrical supply and minimized data loss due to brief power interruption.

2.2.4.2 Rockfish Fishery Monitoring

The rockfish fishery lasted for a period of about two weeks during which EM technicians made regular visits to vessels in port to service and test systems. While data storage capacity was as much as a month, regular servicing was undertaken to confirm the offshore functionality of the equipment, and gather EM data for analysis. The servicing routine by Archipelago technicians also included a preliminary analysis of sensor data to check for quality and completeness. After verifying the recorded data the technician then visually inspected all components for wear and damage.

2.2.4.3 Pollock Fishery Monitoring

The initial project plan was to remove EM systems at the conclusion of the rockfish fishery. However, owing to general support for the technology by industry and successful performance of the equipment, the project scope was expanded to also include the pollock fishery, which was slated to open about a month after the rockfish fishery was scheduled to close. Vessels with EM systems were contacted to invite their continued participation in the pollock fishery. Of the initial ten vessels, two Digital Observer and five Archipelago vessels agreed to participate and three declined. A third Archipelago EM system was removed just prior to the pollock opening when the owner decided to participate in another fishery instead. The Digital Observer vessel declined because it did not participate in the Gulf pollock fishery. The six remaining vessels with EM systems participated in a 24 hours pollock opening before coming to port when their EM systems were removed.

2.3 EM Data Interpretation

2.3.1 Sensor Data Analysis

Archipelago sensor data interpretation was facilitated using the following software tools and data presentation techniques:

- *Relational Database* – The raw ASCII sensor data was imported into a relational database application to perform a variety of tasks including reformatting and summarizing data, and examining related records for anomalies in the data series (e.g., power interruptions or poor GPS signal quality).
- *Time Series Plotting* – Selected variables from the monitoring system data were displayed in a time series graph. The sensor data presented in this format clearly distinguish vessel activities including transit, anchor, fishing, and periods when the system power was off (Figure 2.1).
- *Geographic Plotting* – Selected variables from the data set were also displayed using a geographic information system (GIS) software tool. These plots enable the geographic positioning of fishing activity with a chart and fishing boundaries (Figure 2.2).

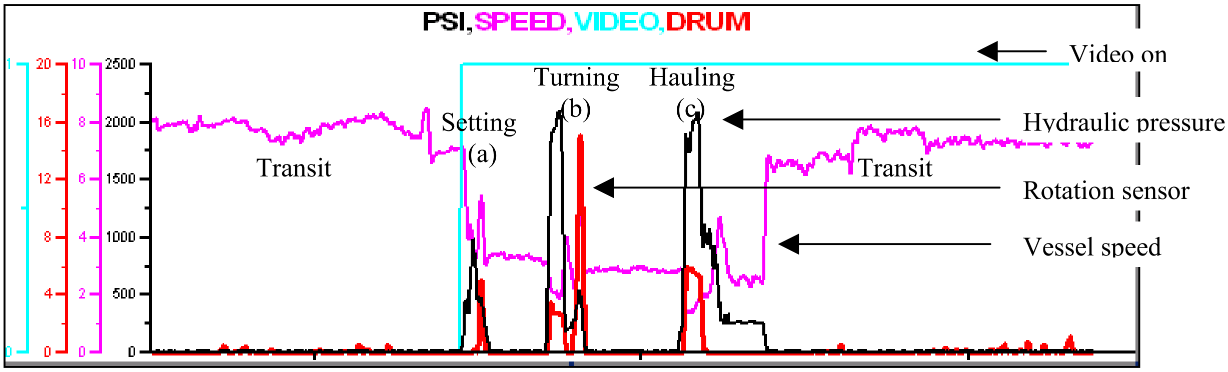

Figure 2.1. Archipelago EM times series graph of sensor values showing a typical fishing event: transit to grounds, setting gear (a), turning the vessel (b), hauling gear (c), and transit back to port. Shown are net drum rotation sensor (red), hydraulic pressure (black), vessel speed (purple), and image recording (turquoise).

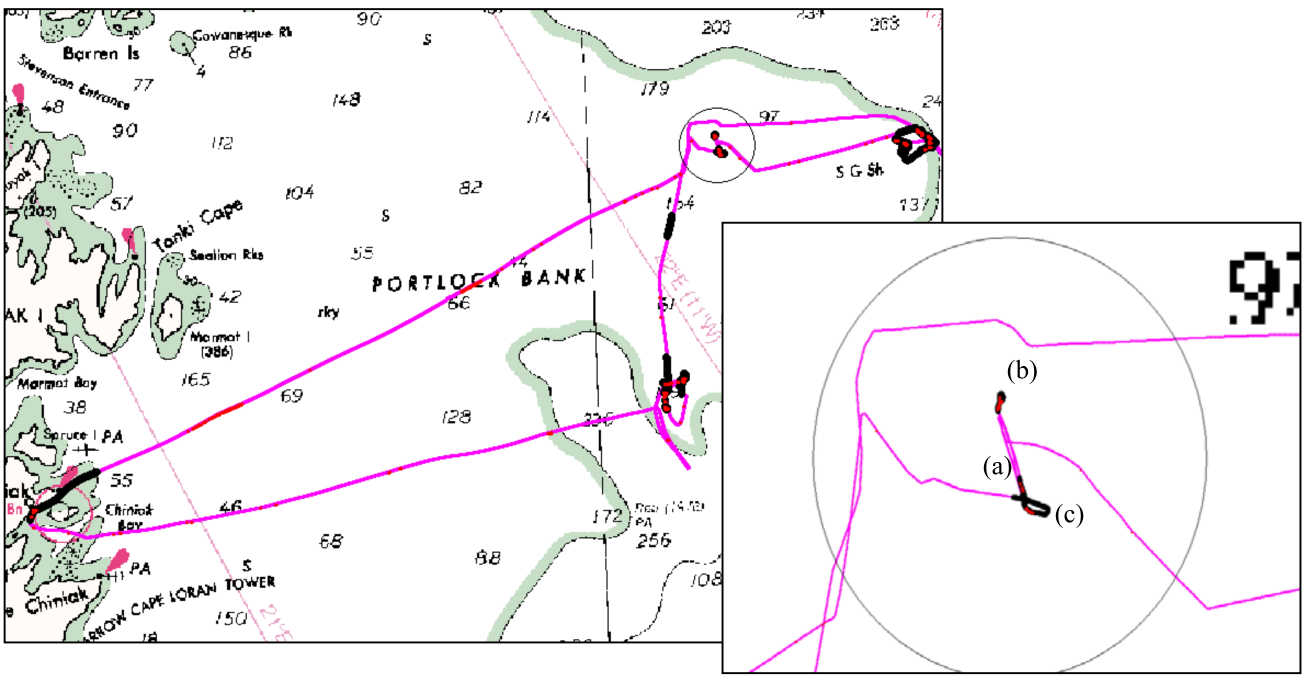

Figure 2.2. Spatial plot showing cruise track of a vessel for an entire trip with an Archipelago EM system. Insert shows cruise track for the fishing event corresponding to time series data shown in Figure 2.1. Black indicates hydraulics on for setting (a), turning (b), and hauling (c) of gear. Red indicates drum rotation during the same times.

The Archipelago analysis included an interpretation of sensor data to identify fishing events and perform an evaluation of the completeness of the data set. The relational database imported the raw data and determined fishing events using sensor signatures. A fishing event included setting, towing and hauling the net. Sensor data (GPS, hydraulic, winch rotation) of each fishing event were summarized in one-minute intervals. Trip length was determined from the time the vessel left the port until the time the vessel returned to port.

Once data were processed through the database application and the vessel's activity was summarized, anomalies in the data set were identified. Intervals greater than 60 seconds were accredited to time gaps in the data set, indicating periods when the system was not logging data.

Other data set anomalies were investigated. GPS reading lockups (position, speed and heading) indicated a temporary GPS data stream loss, and were usually caused by an intermittent GPS signal or interference from other vessel electronics. Sensor equipment, including GPS receiver, hydraulic sensor, drum counter and the CCTV cameras were evaluated for each trip as complete, incomplete, or no data. The completeness of the sensor suite was independent of any data logging time gaps. Sensor data completeness was defined as follows:

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

Digital Observer's sensors consisted of one GPS unit on each vessel, which updated vessel latitude, longitude, speed over ground, course over ground and UTC time every two seconds. Positional data were saved as text files every 90 seconds from the time the system was activated, and system servicing occurred every time a vessel returned to port. During vessel servicing GPS data were imported to a charting program that enabled review of vessel tracks, which also provided opportunity to ascertain whether the system had experienced a failure and to review the trip with the captain. In the office, GPS data were again examined and any lapses were noted, using the "Complete," "Incomplete" and "No Data" categories, as outlined above.

2.3.2 Archipelago Image Data Interpretation

The objectives of the image interpretation were to examine all fishing events and characterize non-retention events. Data were recorded in a systematic manner, and then entered into the project relational database. Imagery for each fishing trip was viewed from the start of a trip's first set until the vessel returned to port. Individual set lengths were determined from the time trawl doors left a vessel's stern gantry and entered the water until returning to its rear gantry. These times were recorded in a table in the database and linked to the fishing information identified by the sensor data. Fishing imagery was then examined to determine discarding events for each set. Figure 2.3 below is an example of the quality of imagery captured by three different cameras on one vessel.

Figure 2.3 Sample camera imagery showing simultaneous view of fishing deck overall (camera 1), and port and starboard discard chutes (cameras 2 and 3).

Only one camera in turn was utilized during image review, but switching between all three cameras for different views was also possible when the situation warranted. The speed of imagery review varied depending on deck activity and catch size, however the majority of imagery was reviewed at three to ten times faster than actual time elapsed. Upon completion of imagery review for all vessels, randomly selected imagery of fishing events were reviewed a second time to evaluate consistency of EM viewer determinations. All data and general comments were recorded in notebooks and then transferred to a database that was configured for each vessel.

Missing imagery was noted for fishing and non-fishing times and summarized on a trip level. Image quality was also assessed as an average for the entire trip, using the following scale:

- *High Quality* –camera lenses properly focused, viewing areas clearly visible, and net retrieval and catch processing easy to assess.
- *Medium Quality* - some loss of resolution, poor camera positioning, or minor obstruction of view but net retrieval and catch processing still assessable.
- *Low Quality* –reduced light, water spots on lenses, poor focus or major obstruction of view; fishing activity generally difficult to resolve.
- *No Data* –image quality low, camera views totally obstructed, or no imagery available and therefore analysis not possible.

2.3.3 Digital Observer Image Data Interpretation

Digital Observer interpreted its imagery in a similar manner. Three or more cameras were placed in positions that viewed the working deck, discarding chutes, and stern ramp/aft area of the vessel. The purpose of each placement was to enable a shore side "observer" to identify where discards took place and to categorize those discards by type. The video review process was generally efficient. In cases where fishermen sorted the haul and discarded fish through chutes, or tossed fish over rails or down the stern ramp, it was possible for an experienced viewer to enumerate individual discarding events and identify the fish. At times, though, the video viewer was limited in his observations. In cases where discards were voluminous and traveled en masse down discarding chutes, EM was unable to quantify or qualify the discards.

Vessels also experienced varying levels of discarding that resulted in longer or shorter review times. In some cases the deck hands rapidly sorted the haul and simultaneously discarded bycatch through chutes, or over the rails and down the stern ramp. To get an accurate count, the reviewer would have to inventory discarding events in one area, then "rewind" the video to watch discards in another area, then repeat the process until all areas were viewed. In no way was Digital Observer able to assess weight of discards with any accuracy. However Digital Observer technicians did take volumetric measurements of deck space and tote sizes on one of its boats. These were used as an aid during review to provide some rough estimates of fish volume and weight.

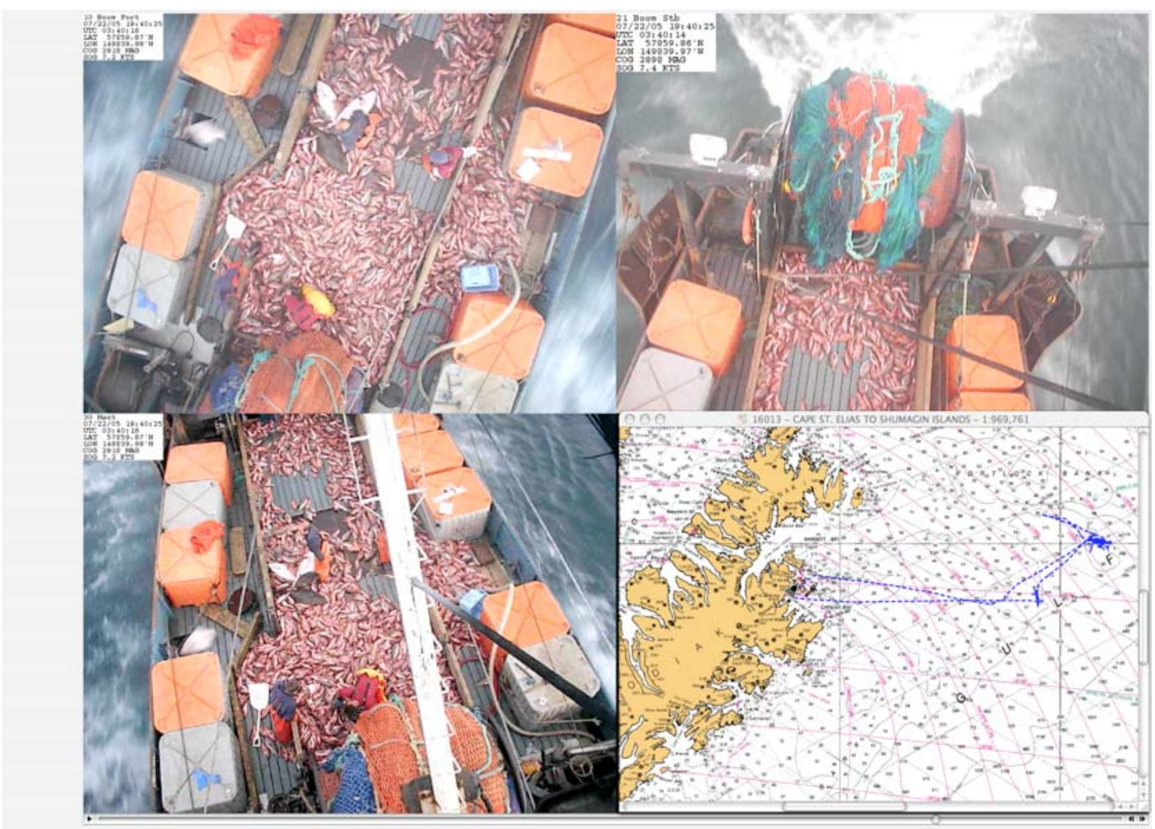

Fig 2.4 Sample Digital Observer camera and chart imagery showing three simultaneous camera views of the fishing deck plus vessel track. Clicking on any point along the vessel track sets the video to that point in time.

Vessel imagery was reviewed from all cameras simultaneously, and occasionally the video stream from one camera was expanded to allow for closer inspection. Video was typically viewed at ten times actual elapsed time, however when there were simultaneous discards from multiple places on the deck the review speed was usually slowed to three to four times normal speed. Imagery from one complete trip was reviewed twice where events with heavy discarding occurred at two or more locations. Digital Observer noted events on a notepad, and used one or more manual tally counters to keep track of fish numbers during high discard events. At the end of each set, data were transferred to an MS Excel spreadsheet that was set up for each trip.

2.4 Data Reporting

EM System raw data were fully analyzed and interpreted to provide fishing trip summary information as described below. All imagery included text overlay with vessel name, date, time, and position.

The Fishing trip summary information was provided in an MS Access database file and contained the following information:

- *EM System Deployment Details* – A concise record of installation dates, service dates, and other details of each EM installation.
- *Vessel Service Schedule* – A record of details for each EM servicing event.
- *Fishing Trip Summary* – A record of each fishing trip conducted during the fishery according to vessel, date, time and location for beginning and end of the fishing event.
- *Fishing Event Summary* – A record of each fishing event according to vessel, date, time and location for beginning and end of the event.
- *Fishing Event Detail* – A detailed record of each fishing event showing date, time, position, and sensor status at a one-minute resolution from trawl door deployment to retrieval.
- *GIS Plots* - A GIS chart plot was displayed with the vessel cruise track, and vessel fishing track.
- *EM System Data Quality* – An assessment of image quality, interruptions (time gaps) in the data record, GPS positional fix quality, and other observations relating to EM System performance (Archipelago systems only).
- *Other Comments* – Other observations pertinent to the interpretation of the data set.

2.5 At-sea Observer Data

At-sea observer coverage was directed on fishing vessels carrying EM systems to facilitate a comparison of EM and observer discard estimates. In addition to their regular duties, observers were to focus on enumerating vessel discards for subsequent comparison to EM data. At the end of the fishery and following EM video review, observer data were compiled by NMFS and delivered to Archipelago for analysis.

2.6 Archipelago and Digital Observer Project Staff Timekeeping

In order to provide estimates of the labor requirement associated with EM-based monitoring, project staff recorded work time according to various activities. Activity categories included equipment installation, servicing, equipment removal, and EM data interpretation. Project management, data analysis, and reporting were not included in this analysis. Archipelago staff recorded analysis time on the basis of individual fishing trips while Digital observer recorded analysis time on the basis of each vessel.

RESULTS

3.1 Pilot Vessels

EM equipment was installed on ten pilot trawl vessels for the rockfish fishery starting June 28th until July 29th, and were removed from four vessels at the end of the fishery but kept on board six for the pollock fishery. EM systems on these vessels were reactivated for the brief pollock fishery, and then removed. The spatial distribution of the two fisheries is shown in Figure 3.1, using fishing event detail from Archipelago EM sensor data at one-minute temporal resolution.

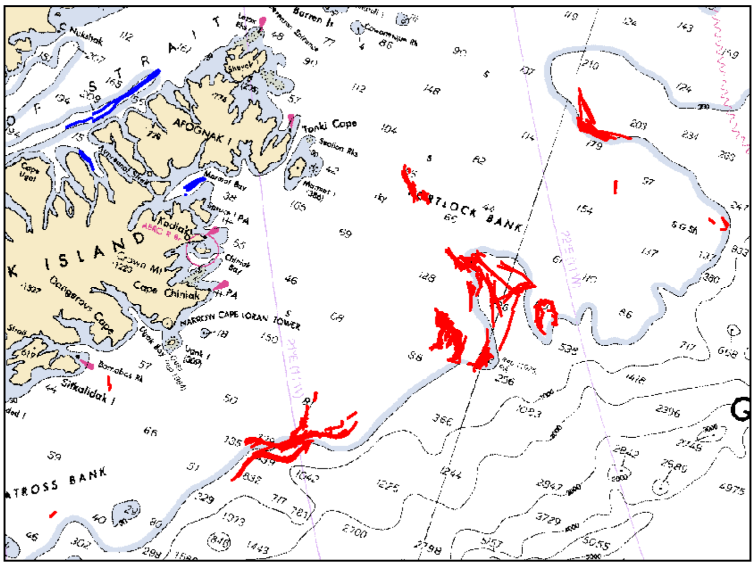

Figure 3.1. Spatial plot of fishing locations for vessels hosting Archipelago EM systems. Shows pollock (blue) and rockfish (red) fishing areas.

3.2 Fishery Data Summary

Tables 3.1 and 3.2 provide a summary of EM data collection quantity and success from the ten participating vessels for the rockfish and pollock fisheries, respectively. Taken as a whole for the two fisheries, EM systems recorded a total of 51 trips and 457 sets. Total fishing hours were thus inventoried for both fisheries, which collectively amounted to 996 hours of actual fishing activity (net deployment, towing and net haul back) and 561 hours of fish handling (landing and stowage of catch). Additionally, EM data determined varying levels of fishing intensity between vessels, which ranged from one pollock trip with two sets, to four rockfish trips with 59 sets. However, the maximum number of fishing trips completed by a vessel was seven rockfish trips with 56 sets.

During the rockfish fishery, Archipelago EM systems (Table 3.1, Vessels 1-7) collected 70% of the overall data, which accounted for 94 days, 31 fishing trips and 323 fishing events, equating to nearly 2,300 hours of monitoring at sea. The monitoring time included about 660 hours of fishing and 420 hours of time spent by crew handling fish on deck. The balance of time was transit between fishing events and to and from the fishing grounds.

Concurrently, Digital Observer's three EM systems (Table 3.1, Vessels 8-10) covered 42 days, 13 trips and 110 sets for a total of about 750 monitoring hours. EM imagery included about 250 hours of fishing and 125 hours of catch handling.

Table 3.1. Inventory of EM data by vessel for the rockfish fishery, showing the percentage of missing data for Archipelago EM systems (vessels 1-7) and Digital Observer EM systems (vessels 8-10).

Fishing Summary						Data Inventory					
Vessel	# days	# of	# of	Fishing Time (hrs)		Sensor (hrs)		Video (hrs)		Missing Data (%)	
ID	At Sea	Trips	Sets	Towing	Handling	Total	Missing	Total	Missing	Sensor	Video
1	14.2	4	48	85.2	39.4	374.0	0.0	371.3	0.0	0.0%	0.0%
2	4.8	2	17	37.6	15.2	116.3	0.0	113.3	0.0	0.0%	0.0%
3	14.9	4	59	118.7	112.2	358.1	0.1	313.8	8.5	0.0%	2.7%
4	15.6	7	56	114.1	69.6	374.1	0.0	369.2	0.6	0.0%	0.2%
5	15.8	4	51	97.5	78.5	379.3	0.0	369.1	2.5	0.0%	0.7%
6	17.1	6	54	127.1	77.4	410.2	0.0	361.7	0.1	0.0%	0.0%
7	11.6	4	38	84.8	31.7	277.9	0.1	256.4	0.1	0.0%	0.0%
Total	**94.0**	**31**	**323**	**664.9**	**424.0**	**2289.9**	**0.2**	**2154.8**	**11.9**	**0.0%**	**0.6%**
8	14*	5	42	112.8	27.9	263.2	52.0	263.2	52.0	15%	15%
9	17*	5	56	121.7	85.1	392.6	0.0	392.6	0.0	0%	0%
10	11*	3	12	15.0	12.0	264	168.8	95.2	168.8	56.30%	56.30%
Total	**42***	**13**	**110**	**249.5**	**125.0**	**919.8**	**220.8**	**751.1**	**220.8**	**24.0%**	**29.4%**

*Calendar fishing days.

In general, Archipelago's EM systems provided a very high rate of reliability for collecting both sensor and image data. For instance, out of nearly 2,300 total monitoring hours the quantity of missing sensor data was 0.01%, or about 12 minutes. Sensor interruption resulted most often from either a GPS signal loss or problems with the EM control box. Total imagery recorded was lower than sensor (cameras turned off during outbound portion of trip) but similar performance results were recorded. The quantity of missing imagery accounted for 0.6% (about 12 hours) and was the result of two faulty cameras. Only one vessel significantly contributed to this result with a video loss of 8.5 hours (see Table 3.1, vessel 3). A second vessel lost 2.5 hours of imagery, accounting for the majority of remaining lost imagery.

As a final point on equipment performance, EM system problems identified during servicing were addressed, thereby ensuring high performance for following trips. For example, during their first trip in the rockfish fishery one Archipelago EM system had poor camera focus while a second had poor camera location. The latter camera tangled with a net and was removed by the vessel captain for the remainder of that trip. This incident was largely responsible for the 8.5 hours of missing imagery for vessel 3. Both EM cameras were repaired during their first servicing in port, and performed well for the balance of the season.

Digital Observer EM systems experienced several equipment failures during the rockfish fishery that resulted in lost data. Missing data for the three vessels combined was 24% and 29% for sensors and video, with individual vessel results varying from no data loss to significant data loss on vessel 10. For this particular vessel the ship's 110-volt AC electrical supply was apparently mismatched with Digital Observer's equipment, which caused significant data loss for the first two rockfish trips. For its third trip, however, Digital Observer deployed a different in-line electrical filter, which corrected the problem. Operator error resulted in the complete loss of data from one trip during the rockfish fishery (vessel 8). In this case the system administrator did not activate the image capture function and no video was saved for that trip.

At the start of this project Digital Observer deployed ten new surveillance cameras, four of which turned out to have identical factory defects. Under specific lighting conditions, the defective cameras were unable to regulate the iris, which caused the cameras to cycle from a totally black view through to a normal view, and then to a totally white view every 30 seconds. Fortunately, the cameras were randomly installed between two of the three vessels, meaning that some data sets were incomplete as opposed to missing one vessel's entire data set. Digital Observer replaced the defective units in-season and no more data were lost as a result of defective equipment.

In the pollock fishery, EM systems recorded much smaller quantities of data as compared with the rockfish fishery (Table 3.2). The systems captured a total of 12 days, seven trips and 24 fishing events, or a total of about 175 hours of monitoring. Equipment performance results were similar as observed in the rockfish fishery. While there were six vessels volunteering to participate, one forgot to power the EM system and resulted in no data. Results from this vessel were not included in Table 3.2 as the failure was not considered a function of EM equipment performance. Digital Observer system on one vessel experienced a hard drive that failure, the consequence of which was the loss of GPS data and some at-sea video for the first part of a fishing trip before the system began saving to its backup 40 GB drive.

Table 3.2. Inventory of EM data by vessel for the pollock fishery, showing the percentage of missing data for Archipelago EM systems (vessels 1, 4 and 5) and Digital Observer EM systems (vessels 8 and 9).

Fishing Summary						Data Inventory					
Vessel ID	# Days At Sea	# of Trips	# of Sets	Fishing Time (hrs) Towing	Handling	Sensor (hrs) Total	Missing	Video (hrs) Total	Missing	Missing Data (%) Sensor	Video
1	1.4	1	2	17.0	0.8	34.2	0.0	34.1	0.1	0.0%	0.4%
4	1.4	1	5	12.0	1.3	34.1	0.3	34.0	0.0	0.8%	0.0%
5	2.3	1	2	10.7	0.9	55.6	0.0	55.0	0.0	0.0%	0.0%
Total	**5.1**	**3**	**9**	**39.7**	**2.9**	**123.9**	**0.3**	**123.1**	**0.1**	**0.2%**	**0.1%**
8	2*	1	4	8.5	1.1	48.5	0.0	48.0	0.0	0.0	0.0%
9	5*	3	11**	33.2**	8.9	156.0	30.0	180.0	6.0	19.0	3.3%
Total	**7***	**4**	**15**	**41.7**	**10.0**	**204.5**	**30.0**	**228.0**	**6.0**	**19.0**	**2.6%**

*Calendar fishing days. ** One fishing event missing; total Fishing Time based on 10 events.

3.2.1 EM Discard Summary

Fishing event imagery was examined to assess the ability to estimate fish discards during catch sorting operations. Other than the aforementioned periods of no image data the majority of imagery from all ten vessels was considered to be high quality. Table 3.3 provides an overview of fishing events where discarding was observed for all 10 vessels for the two fisheries combined. The overall average of sets with discards amounted to

84% and 71% for the rockfish and pollock fisheries respectively. In the rockfish fishery, pilot vessels fished a total of 44 trips that encompassed 433 sets, of which 362 sets had discards. The frequency of discarding for each boat ranged from 68% to 100% of their sets. In the same way, the pollock fishery totaled 7 pilot trips with 24 sets, where 17 sets had discards. The frequency of discarding for these vessels ranged between 40% (2 sets) and 100% (2 sets).

Table 3.3. Summary of discard occurrence by vessel for the rockfish and pollock fisheries.

	Rockfish Fishery				Pollock Fishery			
Vessel ID	Total Trips	Total Sets	Sets With Discards	Percent of Total	Total Trips	Total Sets	Sets with Discards	Percent of Total
1	4	48	45	93.8%	1	2	2	100.0%
2	2	17	17	100.0%				
3	4	59	40	67.8%				
4	7	56	48	85.7%	1	5	2	40.0%
5	4	51	50	98.0%	1	2	2	100.0%
6	6	54	43	79.6%				
7	4	38	35	92.1%				
8	5	42	33	78.6%	1	4	2	50.0%
9	5	56	41	73.2%	3	11	9	81.8%
10	3	12	10	83.3%				
Totals	**44**	**433**	**362**	**83.6%**	**7**	**24**	**17**	**70.8%**

The quantity of discarded catch on monitored sets ranged from none to quantities too numerous to count (denoted as N/C, Figure 3.2). Among the monitored sets with discards (362 or 84%), the majority (65%) consisted of 20 pieces or less.

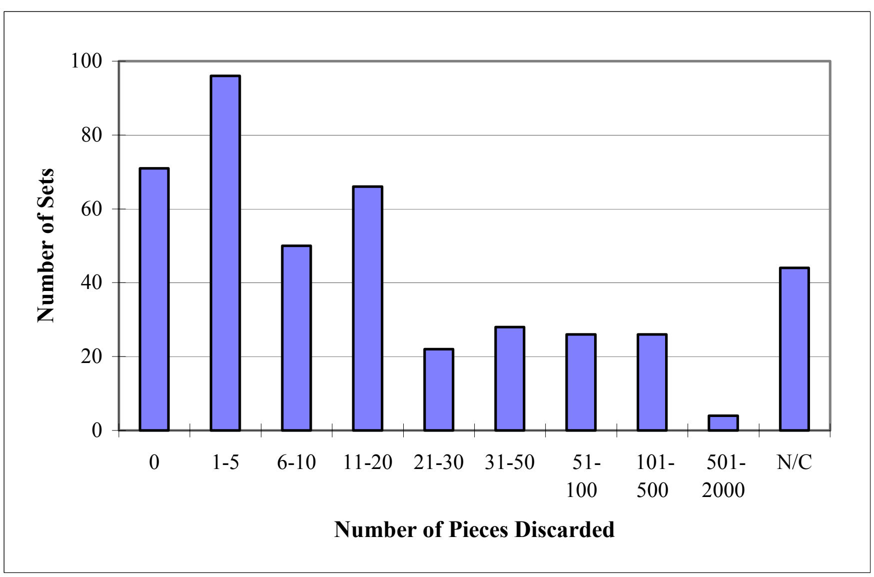

Figure 3.2 Histogram showing the number of sets associated with varying levels of discarding in the rockfish fishery (n=433 sets). N/C = discards not countable due to large volume.

The type of discarding common to these vessels generally involved the disposition of individual fish, usually flatfish, through discard chutes, or less frequently over vessel rails. Instances of net bleeding or dumping were not evident from EM imagery and reference to EM sets also monitored by observers confirmed that discarding generally occurs after the net had been emptied on deck (observers noted one instance of net bleeding that was not detected by EM). Crew regularly passed halibut and other discard fish to an area adjacent the discard chute where, upon completion of catch stowage, they were discharged through the discard chute. On a few occasions, observers collected halibut from the discard chute area and carried elsewhere on the fishing deck out of camera view, presumably for sampling. About 10% of all sets comprised large quantities of mixed species discards that were simultaneously washed by hose through discard chutes on both sides of the vessel. It was thus impossible for EM to enumerate small flatfish and most roundfish during unsorted discards, although EM could easily count large halibut as they moved en mass within the discard wash.

More detailed results of discarding are summarized in Table 3.4, showing discard categories to species or group level, frequency of encounter on fishing events, and total pieces enumerated. Out of the 379 sets with discards, 44 sets contained large quantities of discarded catch too numerous to count (N/C = not counted), although it was usually possible to distinguish a wide assortment of species including rockfish, halibut, grenadiers, Pacific Ocean Perch, skates, sablefish, Atka mackerel or arrowtooth flounder. As a result, for fishing events with large discard quantities, catch items could be included in the frequency but not enumerated for an estimate of quantity.

Table 3.4 Overall summary discarding by species category for all vessels combined. Shown are the by set frequency (discard occurrence as % of total sets monitored) and the percentage of total pieces discarded by species category. (N/C = discards not counted due to large volume).

					equency	**Total Pieces**	**Percentage**
Prohibited	Halibut	71.59%	9,482	56.75%	29.17%	9	10.23%
	Salmon	6.93%	56	0.34%	25.00%	12	13.64%
	Crab	1.39%	11	0.07%			
Non Prohibited	Grenadier	3.00%	1,764	10.56%			
	Atka Mackerel	0.46%	N/C				
	Sablefish	1.15%	977	5.85%			
	Pacific Cod	0.69%	856	5.12%			
	Arrowtooth	2.77%	729	4.36%			
	Flatfish	5.54%	625	3.74%			
	Skate	25.40%	391	2.34%	4.17%	1	1.14%
	Roundfish	3.00%	72	0.43%			
	Invertebrate	1.15%	47	0.28%			
	Rockfish	1.85%	37	0.22%			
	Shark				25.00%	17	19.32%
	Lingcod	0.69%	13	0.08%			
	Sculpin	1.62%	7	0.04%			
	Spiny Dogfish	0.23%	2	0.01%	4.17%	1	1.14%
Undetermined	Unknown	38.57%	1,640	9.82%	50.00%	48	54.55%
	Total all Species		**16,709**			**88**	

Identification of discarded catch by EM could resolve morphological categories and easily distinguish groups such as flatfish, roundfish and rockfish. Further, image viewers felt that species like halibut, Pacific cod, and sablefish were generally distinctive and easy to identify. Halibut had the highest frequency of occurrence for prohibited species discarded in the rockfish fishery (99%), and, together with grenadiers, represented the most common enumerated discards overall (67%). Unidentified fish constituted 10% of total pieces discarded, where 167 rockfish sets contained fish that could be counted but were difficult to identify. Additionally, Atka mackerel were detected for two sets in quantities too numerous to count and were thus recorded by frequency only. The remaining species all had relatively low frequencies of occurrence, and collectively represented less than 23% of discards in the rockfish fishery.

Discard species for the pollock fishery are also summarized in Table 3.4; however, the number of fishing events monitored was low (only 6% of the rockfish sample size), and therefore was not likely descriptive of the fishery. Nevertheless, salmon was the most common prohibited species discarded (12 pieces), but constituted only 14% overall. Unidentified fish encompassed more than half (55%) of all species discarded in this fishery, followed by shark (20%) and halibut (10%).

3.2.2 Repeatability of EM Video Interpretation

In order to assess the consistency of discard determinations from EM imagery interpretations, selected image data was re-examined for comparison with the initial determinations. Digital Observer imagery was examined by repeat viewing of one complete rockfish fishing trip. Imagery from the Archipelago data set was examined by random selection of 31 (9%) fishing events from the total pool of 332 rockfish sets. The different methodology was a reflection of both groups working independently in evaluating viewer consistency. Table 3.5 shows the results of this comparison with catch summarized by general categories.

Table 3.5. Summary of catch discards compared between a primary (V1) and a second video viewer (V2). Individual blank spaces in the table indicate that no discards were evident. (N/C = discards not counted due to large volume).

	Trip	Halibut		Skate		Unknown		Salmon		Crab		Other		Total	
	SetID	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
AMR	16	1	11				2						1	1	14
AMR	18	5	6	1	1	2								8	7
AMR	43	4	6	1	1	9	11				1			14	19
AMR	44	1	2	4	7	50	46					100	57	155	112
AMR	54	12	13	1	1									13	14
AMR	62	7	4				1							7	5
AMR	77	15	15	1	1	84	88							100	104
AMR	100	14	14			1								15	14
AMR	102											N/C	N/C	N/C	N/C
AMR	110	15	15				1							15	16
AMR	124	6	6	2	2	11	2					2	2	21	12
AMR	133	2	2	5	6		2							7	10
AMR	136	1	1	1		2	3							4	4
AMR	152	3	2						3					3	5
AMR	162														
AMR	163	2	2	1	1						1			3	4
AMR	169	1	2		1									1	3
AMR	177											N/C	N/C	N/C	N/C
AMR	187	21	20			1	1							22	21
AMR	194	2	2					5	5					7	7
AMR	199						1	5	2					5	3
AMR	209	41	37				1							41	38
AMR	211	6	5											6	5
AMR	231	5	7	1	1	11	12							17	20
AMR	237	1	1	1	1	1	5							3	7
AMR	249	8	6			1								9	6
AMR	258	44	42	6	5	8	15	1					2	59	64
AMR	275	4	5			1	2							5	7
AMR	281		1												1
AMR	298	1	1				1							1	2
AMR	308														
DO	352	24	26	3	4	10	6		3				4	37	43
DO	353	1					1							1	1
DO	354	11	13		1	1	2							12	16
DO	355														
DO	356	4	4	1	1									5	5
DO	357	2	4											2	4
DO	358														
DO	359											N/C	N/C	N/C	N/C
DO	360		1	1			1					14	18	15	20
DO	361	1	1											1	1
	Total	**265**	**277**	**30**	**34**	**193**	**204**	**11**	**13**	**0**	**2**	**116**	**84**	**615**	**614**

Overall totals for halibut, salmon, unknown, and total pieces were in close agreement, but the individual tallies almost never exactly matched. Out of 181 numeric entries in the Table, only 13% of totals (24 records) matched. Although the majority of discards were small, the resultant totals between viewers for all species combined (Table 3.5, 'Total' column) were in very close agreement (615 versus 614 pieces) and most counts between viewers were either the same or within a few pieces.

By and large, the level of viewer agreement for halibut was quite high as totals differed by less than 5% (265 versus 277 pieces). Both viewers detected halibut for 30 out of 41 sets, and counts for 12 fishing events (36%) exactly matching. In contrast, the results for salmon were not especially good; both viewers detected salmon on only two of the five sets and enumerations matched for only one set. Digital Observer viewer comparison results were generally consistent with Archipelago's 31 reviewed sets, suggesting no obvious bias between groups.

Although the majority of second reviews did not exhibit any significant differences, sets such as 16, 44 and 124 revealed noteworthy differences (Table 3.5). Upon closer examination of these fishing events the difference was attributed to both the subjective nature for some discard assessments and viewer error resulting from the competing needs of trying to process imagery efficiently and the complex pattern in which discarding can occur. As previously mentioned, when discarding occurred from multiple locations it was often difficult to detect. In all cases discard was not always passed through the discard chutes in camera view. On two of the vessels crew simultaneously discarded over the rails on both sides, and sometimes just out of camera range. For these vessels some halibut and unknown flatfish were seen but it was unclear if they were discarded, which one viewer likely recorded as discarded while another did not. Additionally, crew infrequently grabbed at fish just to the side of camera view, or crew discarded other fish and objects very quickly. In some cases EM discard detection becomes subjective and complicated in situations where there is variation in catch handling, and uniform accounting methods become inhibited.

3.2.3 Comparison of EM and Observer Discard Catch Data

EM discard data was compared for overall agreement with at-sea observer data to further evaluate the catch monitoring capability of EM technology. Observers were present for some of the EM monitored fishing trips resulting in 194 fishing events (45% of EM fishing events) where both EM and observer estimates of discard were made.

EM and Observer data structures were differently normalized lacked a common fishing event identifier. A preliminary join between the data sets was established by vessel date and time, and fishing event was compared to ensure that the number of sets per fishing trip matched properly. While most sets were easily aligned, a common problem was with 'water hauls' (net deployed with no catch) that were inconsistently handled by both EM and observers. EM failed to detect one water haul recorded by an observer, and observers failed to detect three water hauls that were detected by EM. EM also erroneously recorded a very short fishing set that was not recorded by the observer and was subsequently removed.

The first level of discard comparison was with detection of discarding events. Using the total of 194 sets available for comparison, observers and EM were in agreement in detecting the presence or absence of discards for 86% of the fishing events (Table 3.6); both recorded discards on 146 sets while neither recorded discards on 20 sets (10%). We assume the observer data are correct for instances where observers recorded discarding and the EM not, indicating failed to detect discarding for 15% of sets where observers recorded discards. The reverse situation (i.e., where EM recorded discarding and the observer not) is more problematic and, depending upon the method the observer used to measure discard, could be the result of a false positive on the part of the EM system, or the result of discard not noted by the observer or reported to the observer by the vessel. In this case the observer did not record discarding for 4% of the instances where EM detected discarding.

Table 3.6 EM and Observer detection comparison showing observed fishing events and the presence and absence of discards (all species combined).

		EM Sets with Discards		
		Yes	**No**	**Total**
Observer sets with Discards	**Yes**	146	22	**168**
	No	6	20	**26**
	Total	**152**	**42**	**194**

Imagery was reexamined for the 22 sets where EM failed to detect discarding noted by observers. The majority (86%) of these fishing events were during daylight hours, and 62% of sets consisted of less than 5 pieces of fish recorded by observers. All 22 sets were carefully reviewed and discarding was evident in 9 of the 22 sets (41%), indicating that EM had missed discarding during the initial review. Much of this discrepancy was attributable to a single viewer. As well, observer sampling in vessel 4 and 6 occurred too far from camera view where detailed imagery was not available, likely the cause for overlooked discard events. Among the remaining 13 fishing events where EM failed to detect discards, 6 were with vessel 3 where, despite clear camera imagery, observer sampling occurred under the forward net drum out of the camera view. In two instances a crewmen carried single large halibut out of view and it was undetermined if these fish were discarded. Similarly, vessel 9 had 4 missed discard events, apparently the result of camera placement, where chute cameras had been re-aimed to rail views according to the crew's handling of discards on a previous trip. However, on the following trip crew discarded fish through discard chutes that effectively eliminated EM discard detection.

The next level of comparison between observer and EM discard results was for two common species, halibut and salmon (Table 3.7). Among the 194 sets, EM and observers were in agreement in detecting the presence or absence of halibut in 78% of the fishing events (i.e., 152 out of 194). Following the same approach as before, EM failed to detect halibut discarding in 19% of fishing events where observers recorded discards. Imagery was reexamined for the 28 fishing events where EM failed to detect observer halibut discards. The majority (64%) of these events consisted of less than five halibut recorded per set, and six sets consisted of large mixed fish discards. Upon reexamination of imagery, halibut discards were easily detected on 13 of the 28 sets (46%), the likely cause being viewer error. Of the remaining 16 sets where EM failed to detect halibut discarding, 12 sets overlapped with those in Table 3.6 (22 sets) with detection failure due to camera positions and observer or crew activities occurring outside the field of view.

Table 3.7 EM and Observer detection comparison showing observed fishing events and the presence and absence of discards of halibut (left) and salmon (right).

Observer sets with Halibut	EM Sets with Halibut			
		Yes	No	Total
	Yes	116	28	**144**
	No	14	36	**50**
	Total	**130**	**64**	**194**

Observer sets with Salmon	EM Sets with Salmon			
		Yes	No	Total
	Yes	11	13	**24**
	No	5	165	**170**
	Total	**16**	**178**	**194**

Similarly for salmon, EM and observers were in agreement in detecting presence or absence of salmon for 90% of the events, although the low incidence of occurrence of salmon in generally infers a higher level of agreement that actually occurred. Among the 24 fishing events where observers recorded salmon, EM did not detect salmon in 54% instances. Salmon are usually given to the observer for sampling as opposed to placing them in the discard chute for overboard discharge. Hence, detection of salmon by EM would be low unless the observer sampling occurred at the discard chute.

The correlation between discard quantities of salmon and halibut were also examined, with correlation results summarized in Table 3.8 and plotted in Figure 3.3. Of the 158 sets where one or both EM and observers recorded the presence of halibut, 141 fishing events were usable for comparison. Through a similar deduction, 20 sets were available for a comparison of salmon discards. There was a strong correlation between EM and observers for halibut, and the regression slope suggests a bias toward observer method (i.e., observers tended to have higher counts than EM). The correlation between methods for salmon was much weaker, as a result of EM not detecting salmon to the same degree as the observer.

Table 3.8 Summary of regression results between discard estimates by EM viewers and Observers for halibut and salmon.

Species	Number Of Sets	*r2* (correlation)	*m* (slope)	*b* (y-intercept)
Halibut	141	0.974	0.795	1.367
Salmon	20	0.422	0.379	0.453

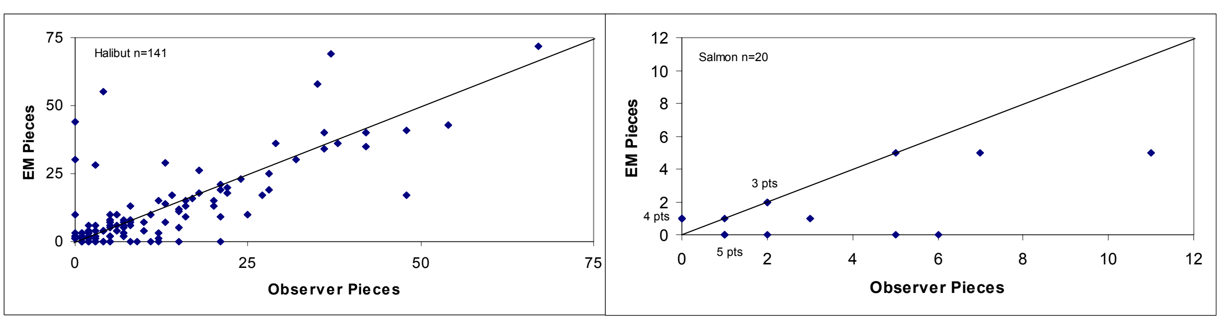

Figure 3.3. Scatterplots of EM and Observer discard quantities (pieces) for halibut and salmon sets. The line (m=1) depicts the expected correlation where EM and Observer estimates are equal. (Six fishing events with very large halibut discards are not shown).

Imagery was re-examined for obvious outliers in the scatter plot. This consisted of 4 fishing events for halibut and one fishing event for salmon. The four halibut sets came from two vessels (4 and 6) and the salmon set came from vessel 6.

Among the four halibut sets, there was one where an observer noted 48 pieces while EM recorded 17. The difference was due to inconsistent handling of discards with crew tossing fish over the rail as well as into discard areas on both sides of the vessel. Two baskets of halibut were dumped in the discard chute area on top of existing halibut that were sloshing around in rough seas. Although EM likely saw more halibut than was recorded, an accurate count was unattainable. Among the other three fishing events, EM estimates of halibut were larger than that recorded by the observer. In all cases, halibut discarding was occurring on both sides of a vessel, often opposite the observer. Two crew were discarding large halibut before the net was fully emptied. In one set where observer noted 4 halibut and EM 55, imagery showed the observer handle more than 4 halibut. Perhaps some of the smaller pieces were arrowtooth flounder, however imagery showed the observer handling more than 4 large halibut.

The salmon outlier furthest to the right of the regression line represents a haul that was handled further astern and out of view of discard cameras. Potential discards were difficult to detect since the deck camera did not provide detailed imagery of stern activity. The only salmon detected by EM in this haul were placed on top of a tote by the observer.

The following issues limited further quantitative comparison of EM and Observer discard data:

- *Catch Estimation Units* – Observers generally recorded catch quantities as an estimated weight in kilograms, while EM viewers recorded discards in pieces.
- *Catch Quantities* – Camera-based discard census methodology was most accurate for small quantities of fish that could be easily distinguished. Large volumes were either estimated or considered not counted. Observer discard estimation methods similarly changed with increasing quantities, and very large quantities were simply recorded as ‘mixed fish’. As a consequence, there were 20 fishing events with high levels of discards that could not be directly compared.
- *Species Identifications*: Species identifications by observers were more comprehensive than was possible by EM viewers. Observers identified catch to 25 species categories, not including general categories for skate, salmon and mixed groundfish. In contrast, EM viewers distinguished 8 species with general categories for an additional 10. Comparison of specific catch involves rolling up to common groupings (e.g. dover sole, flathead sole, rex sole and arrowtooth flounder were combined into a general ‘flatfish’ category)

3.2.4 Project Time Analysis

In an effort to characterize labor requirements associated with various project components, the time requirements for the Archipelago work component have been summarized in Table 3.9. Included are project activities associated with placing equipment on vessels and with interpreting data. Not included in this presentation are the time associated with overall project management, data analysis (summarizing interpreted data) and project reporting. These have not been included as they are unique to pilot projects and not representative of the labor effort required to carry out an EM program. The majority (44%) of the 605 total hours involved EM system installations where a concentrated labor effort was made to get all seven vessels equipped in a short period of time. Next most time consuming was image interpretation (22%), requiring about 4.3 hours per fishing trip. Vessel servicing was twice as time-consuming as sensor interpretation and system removal. Sensor data interpretation averaged 1.6 hours per trip.

Table 3.9 Summary of project labor hours for individual project components.

	Activity Category					
	System Install	**Vessel Servicing**	**System Removal**	**Sensor Interpretation**	**Image Interpretation**	**Total Hours**
Hours	264	100	57	50	134	605
Percentage	43.6%	16.5%	9.4%	8.3%	22.1%	

3.2.5 Image Analysis Time

Image analysis time was evaluated by comparing the total time for fish stowage in relation to the time required to review imagery. The analysis to real time ratio represents the proportion of actual time required to process imagery. These vessel level data are summarized in Table 3.10.

Table 3.10 Summary of image processing time requirements for the Kodiak rockfish and pollock fisheries. Vessels 1-7 monitored by Archipelago and vessels 8-10 by Digital Observer.

	Rockfish Fishery				Pollock Fishery			
Vessel	**Total Trips**	**Fish Stowage All Trips (hrs)**	**Total EM Review Time (hrs)**	**Analysis to Real Time Ratio**	**Total Trips**	**Fish Stowage All Trips (hrs)**	**Total EM Review Time (hrs)**	**Analysis to Real Time Ratio**
1	4	39.4	14.3	0.36	1	0.8	0.4	0.44
2	2	15.2	7.1	0.47				
3	4	112.2	27.2	0.24				
4	7	69.6	18.7	0.27	1	1.3	0.3	0.19
5	4	78.5	20.3	0.26	1	0.9	0.3	0.28
6	6	77.4	22.9	0.30				
7	4	31.7	14.3	0.45				
Totals	**31**	**424.0**	**124.8**	**0.29**	**3**	**3.0**	**0.9**	**0.28**
8	4	27.9	13.2	0.47	1	1.10	1.8	1.59
9	5	85.1	47.3	0.56	3	8.90	2.5	0.28
10	2	12.0	8.5	0.71				
Totals	**11**	**125.0**	**69.0**	**0.55**	**4**	**10.0**	**4.3**	**0.43**

The seven vessels with Archipelago EM systems, with 31 rockfish fishing trips and 422 hours of rockfish catch processing imagery (Table 3.1), required about 125 hours for image processing. This equates to analysis being completed at approximately 29% of real time. Analysis ratio averages for the seven vessels ranged from approximately 0.25 to 0.5, indicating that image analysis could be performed in one quarter to half the actual elapsed fish stowage time.

Digital Observer review times for individual trips were slightly higher, although review times remained less than one hour per trip overall for the rockfish fishery. In all, Digital Observer spent 69 hours physically reviewing rockfish video that covered 13 trips with a total elapsed time of 751 hours at sea. Out of the 751 hours crews spent 125 hours sorting the catch, and most of the EM review time focused on this activity with an analysis to real time ratio of 55%.

Similar to Archipelago's variability in analytical time, a major source of variance for Digital Observer review times included multiple discards in different locations that slowed imagery analysis. In addition, vessel 10 in the rockfish fishery had 4 cameras (all others had 3) resulting in a longer review time for that vessel. For vessel 8 in the pollock fishery, analysis time included setting up the EM system and reviewing 44 hours of actual time at sea, which included the one-hour of fish stowage time.

The results for the seven vessels monitored by Archipelago EM systems are shown by trip in Table 3.11. The analysis ratio ranged from 0.01 (i.e., one hour in 40 seconds) to 0.74 (one hour in 44 minutes) and half the trips were between 0.2 and 0.4. Three viewers completed the image analysis with each vessel by a single viewer. Differences in viewer efficiency probably explain some of the variation (e.g., vessel 6 generally in the mid range), however vessels such as 7 and 4 had wide variation in values, likely due to trip specific catch patterns.

Table 3.11 Summary of imagery review times by vessel and trip for vessels with Archipelago EM systems doing the rockfish fishery.

Vessel	Trip Number	Number of Sets	Fish Stowage All Trips (hrs)	Analysis to Real Time Ratio
5	1	10	16.5	0.01
4	3	3	2.3	0.09
4	2	5	9.2	0.10
6	6	2	1.1	0.12
7	1	5	9.7	0.15
4	1	7	12.1	0.16
5	4	17	21.5	0.18
2	1	9	7.6	0.19
4	4	9	10.9	0.19
4	6	15	14.0	0.20
3	3	19	49.5	0.20
3	1	12	10.4	0.20
6	1	8	14.6	0.24
3	4	16	23.0	0.26
6	5	15	19.8	0.29
6	4	11	14.5	0.32
3	2	12	29.3	0.32
6	3	8	11.3	0.32
1	2	12	14.5	0.33
6	2	10	16.1	0.34
4	5	9	10.9	0.34
5	3	13	25.4	0.36
1	4	18	12.7	0.37
1	1	11	9.8	0.38
1	3	7	2.4	0.43
5	2	11	15.1	0.48
7	4	18	11.2	0.54
7	3	4	2.2	0.56
7	2	11	8.6	0.66
4	7	8	10.2	0.69
2	2	8	7.6	0.74
Total			**423.7**	**0.29**

DISCUSSION

4.1 Technical Assessment of EM System

On the basis of overall equipment performance, EM systems achieved a very high level of reliability. EM equipment was deployed on ten fishing vessels for a collective total of 44 fishing trips, 434 fishing events, or about 3,100 hours of monitoring time at sea. Accurate measurements of equipment performance could be determined from Archipelago EM systems, with virtually complete sensor data capture (0.2 hours missing) and 99.4% image capture (Table 3.1). Sensor data loss was usually related to power loss while image loss was due to camera failures. Performance of Digital Observer EM systems was more variable with results ranging from 100% to less than 50% data capture. Data loss was primarily the result of an incompatible power supply on one vessel, technician error, and faulty cameras. All these issues were easily corrected when identified and do not present serious performance limitations of the equipment.

The suitability of EM technology for monitoring the Kodiak rockfish trawl lies primarily with an assessment of its' efficacy in addressing fishery monitoring objectives. Sensor data from GPS, winch and hydraulics provided an effective means to evaluate the overall fishing trip in terms of duration, when and where fishing events took place, and overall completeness of the data set. Track plots showed the vessel position throughout the fishing trip and additional sensors provided a high level of temporal and spatial definition of fishing events in terms of net setting, towing, haul back and catch stowage. The matching of 194 fishing sets from EM and observer data sets support this conclusion and, for the small number of sets that did not align, the chief reason was the inconsistent manner in which 'water hauls' were handled.

The assessment of EM in monitoring discard activities is more complex. EM systems reliably recorded imagery and regular servicing ensured that image quality was high for most fishing trips. EM imagery could successfully monitor fishing deck operations and monitor the type and quantity of fish discarded, so long as discards countable visible within discard chute cameras.

The intent of the multiple CCTV cameras was to create a camera view mosaic that included a complete overall view of the fishing deck and close up views of chutes where discarding was to occur. The opportunistic camera placements could result in 'blind spots' not covered by any of the cameras. The fishing deck view was very useful in determining trawl net handling operations and processes for bringing catch aboard and stowing. However, this wide-angle deck view poorly resolved specific catch items for identification and counting purposes. The discard chute cameras provided the best image resolution, enabling close up view for counting and identification of most discard items. Discard chute imagery can provide accurate discard estimates if countable quantities of discarded fish pass through the camera field of view. This was not always the case as catch sorting is a busy process and discarded fish are removed in the most direct manner possible in order to stow retained catch quickly. Even though many fish are discarded through the chute, in practice they follow the most convenient means for discharge over the side, which includes the discard chute, over bulwarks, into stern ramp or being set aside for later disposition. Some fish such as salmon are regularly set aside for the observer sampling and may not come within the discard chute camera view at all.

Among all the sets monitored by EM, about 16% had more than 100 pieces which were either not countable or roughly estimated. About half the sets had less than 100 pieces of discarded catch and while replicate viewer assessments were close but they seldom agreed exactly (Table 3.5), indicating that assessing imagery for discarding is subject to interpretation and variable between viewers. This process is more difficult when fish are piled or when several discard activities occur simultaneously. These problems are compounded the competing needs of viewers trying to processing imagery as quickly as possible and trying to discern discard practices that may vary from vessel to vessel or even set to set.

The image analysis tool used by Archipelago viewers was limited in providing only a single camera view on the display screen with the ability to toggle between cameras. This single view approach made it more difficult to keep track of all discarding activities on the trawl deck. A simultaneous multiple camera view would have reduced viewer error in making determinations. The Digital Observer image viewing tool provided all camera views on the screen at the same time with each scalable by size. This simplified interpretation of more complex discarding events.

EM imagery could distinguish species such as halibut, sablefish, Pacific cod and lingcod provided that they occur within the discard chute camera. Other discard items such as salmon, flatfish, sculpin, and crab were discernable at a group level. About 10% of discarded catch was categorized as unidentified although this category was misleading since it generally reflected a large quantity of mixed species among which morphological groups such as flatfish, rockfish, and roundfish were readily distinguishable. Application of more however consistent species coding standards tailored to these categories should be considered in future studies.

4.2 Comparison Between EM and Observer Discard Estimates

Comparing EM and observer data from the same fishing events permitted the assessment of how well EM could detect discarding and secondarily, how well EM could quantify discarding. The assumption in this comparison was that observer data are currently the accepted standard in at-sea monitoring so the evaluation consisted of determining how well EM results would match observer data. However, observer data are not without error and, consequently, differences between these data sets are not solely due to EM error.

On the basis of discard detection, results from this study show that EM could reliably detect discarding, particularly when discarding occurred at the discard chutes. EM and observer estimates were in close agreement (86%) in detecting the presence and absence of discarding for all species. Similar results occurred with the detection of halibut discarding. EM was less able to detect salmon discarding and we believe this is primarily the result of salmon being set aside rather than discharged through the discard chute. As well, salmon were recorded on only 6% of sets, illustrating the sampling issues encountered with the detection of rare species. Subsequent review of cases where observers noted discards and EM not showed that the principal reasons were viewer error and difficulty detecting discarding when it took place away from the discard chute areas.

The inability to compare discarding on a more quantitative basis was more due to methodological issues of the test than the technology itself. As previously mentioned, EM and observers speciate and quantify discards differently making it difficult to compare data from similar sets. Observers also carried out other duties other than just collecting data to support the EM pilot project.

4.3 Potential for EM-based Monitoring of the Kodiak Rockfish Fishery

Based on the results in this study, the potential for an EM technology approach in monitoring the Kodiak rockfish fishery would be high if some critical design issues were addressed. There is no reason to doubt that, in a more permanent application, virtually complete data capture could be achieved with EM systems on this fleet. The vessels are large with very stable electrical power systems. Once sensors and camera placements are established their persistent reliability could be expected. In pilot studies the placement of peripheral sensor and camera devices is usually opportunistic and sometimes not ideal. In a long-term application, the placement of these devices should be specifically established to ensure the best chance of success. This would result in sensor placements where they are less prone to damage and camera placements where they provide ideal views of the desired locations.

We assume that identification of all species in not a monitoring requirement for EM. Rather, identification to species level is required for some (e.g., halibut, sablefish, etc.) and to group level is adequate for others (e.g., flatfish, salmon, etc.). Species coding practices should be developed along these lines to improve image interpretation data quality. We believe that EM could resolve species at this level from discard chute camera imagery.

One of the larger problems limiting EM discard estimations relates to catch handling practices aboard the vessel. We are confident EM would achieve an accurate census provided that all discarded fish pass through the discard chute camera views. Embedding this as a requirement with crew would be essential and consultation with industry should occur to determine the best way for this to occur.

This study showed that discard estimation by EM is limited when catch quantities are high. This issue would not be easily resolved although under the rationalized fishery, these events are thought to be extremely rare (Kinsolving, Pers. Comm.). One possible approach would be for discards to be transferred to checker or totes to enable volumetric estimate prior to discarding.

As a final issue, it is important to consider if EM would be a more practical option than monitoring the fishery by at-sea observers. On the basis of cost per day in this study, observers would likely be a less expensive option. However, pilot programs are often more costly than developed programs. The Archipelago project staff labor in this project indicates that basic data collection and interpretation from installed systems is a considerable labor savings over having an observer at sea. We estimate an average three-day fishing trip requires about nine hours to produce fully interpreted EM data, less than a third of the observer time requirement. The EM time requirement doubles when equipment installation and removal are included. With EM equipment and other project costs it is not likely that EM would be a less expensive option for the Kodiak rockfish fishery. Under a rationalized fishery where effort is less intense and spread out over a longer time period, an EM-based approach makes less sense unless the equipment were a permanent fixture on the vessel and used for a broader suite of fisheries than just rockfish.

Another cost component with an EM program is with data storage. While the data storage requirements for interpreted EM data are minimal (<10 GB), raw EM data are considerable. At data capture rates of 0.7 GB per hour of imagery, about 2 TB (1 terabyte = 1,000 GB) of imagery was collected for this study, indicating that the seasonal requirement for the rockfish fishery would be about 5 TB. Data storage costs could be considerable if there is a requirement to save all raw data from each fishery year for a number of years.

Logistical issues also factor into the assessment of practicality of EM. Given the intense nature of the 2005 Kodiak rockfish fishery, developing an observer program to deliver large numbers of observers for pulse intervals is very problematic. Indeed, elevated coverage levels in Alaskan fisheries in general are a strain to observer programs. EM more easily addresses this requirement as a handful of people can keep equipment in operation on a large number of vessels. Under a rationalized fishery, where fleet activity at any point in time is lower, fleet activity levels may not justify the EM infrastructure requirements. The specific fishery context needs to be more fully defined to determine the overall viability of addressing the fishery monitoring issues through EM.

RECOMMENDATIONS

The use of EM in the Kodiak rockfish trawl fishery will depend on the support and involvement of the vessels carrying these systems. The results of this study should be shared with industry and a process should be set up to discuss the areas of required cooperation should EM be considered in this fishery.

Future studies involving EM and observers on the same vessels would achieve better comparative data by controlling data formats, catch handling procedures, observer sampling methods, and required areas of crew involvement. A certain level of control may only be achievable on a research cruise.

In order to further consider on the suitability of EM for the Kodiak rockfish trawl fishery, the specific context of the monitoring requirements need to be defined.   More generally, an overall strategy for EM should be considered to identify fisheries that would benefit from this type of monitoring and the benefits afforded by a more comprehensive implementation of the technology.

Perhaps not well presented in this report was the high level of support and interest in EM based monitoring approaches by the fishing industry. Continuing the development of EM and implementing its use where appropriate is needed to foster this interest.

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ACKNOWLEDGMENTS

The Pacific States Marine Fisheries Commission funded this project, and we thank Dave Copol for his advice and assistance during the study. We are grateful for the co-operation and support of Kodiak vessel owners and crew who carried EM equipment aboard their vessels and provided feedback throughout the field season. We are also appreciative of the advice and support from groundfish industry representatives including Julie Bonnie, Al Birch, and Jay Stinson. Several staff of the National Marine Fisheries service were helpful in the design of the project and assisting in the field implementation. This included Alan Kinsolving, Todd Loomis, Ken Hanson, Jennifer Watson, and Rob Swanson. Several Archipelago staff participated in this project including: Steve Oh, Joe Laferte, Ben Denslow, Robert Wright, and Andrea Crumpacker.

APPENDIX A

Overview of Digital Observer EM System

The Digital Observer system comprises both shipboard data acquisition and shore side data review components.

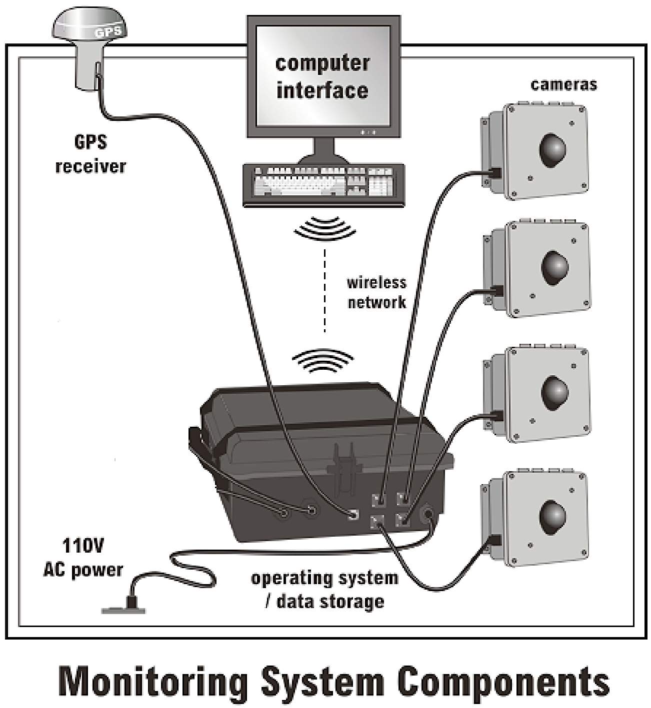

Figure 1 Schematic diagram of Digital Observer electronic monitoring system.

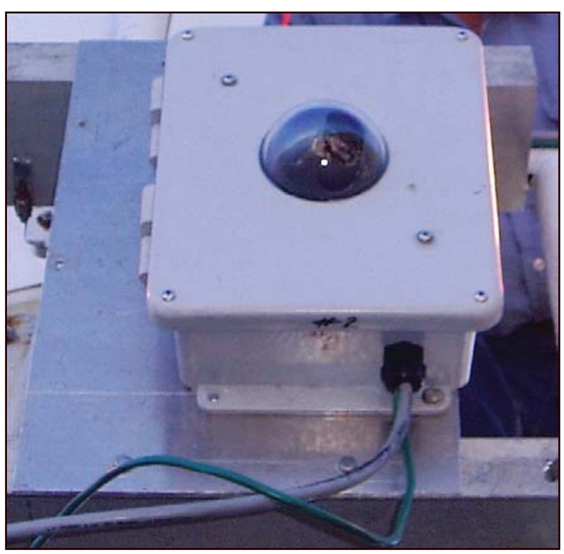

Figure 2 Camera in its housing, affixed to vessel.

Hardware and Software

Digital Observer Inc.'s electronic monitoring system combines state of the art video technologies with custom data acquisition and review software. The result is high quality video that is quick and easy to review. The shipboard system incorporated up to four cameras and one GPS receiver linked by wires to a central control box. The water-resistant box contained a power supply, a computer and various peripheral devices, and the vessel supplied 110-volt AC power. The computer captured and processed video and GPS data and saved the information to external hard drives, which were replaced with "fresh" drives when the vessel returned to port.

For shipboard data acquisition Digital Observer Inc. used Macintosh Mac Minis. Each computer had G4 CPUs from IBM that ran at no less than 1 GHz. Digital video cameras were Toshiba IKWB -11a progressive scan network units. The GPS units were Model 17N by Garmin. Ethernet hubs were Netgear Gigabit Switches, Model GS605. The Uninterruptible Power Supplies were APC Back-UPS-ES 725s. External hard drives were LaCie Porsche Design 250 GB drives that were connected to the computers by FireWire (IEEE 1394) cables. The control box housings were Pelican model 1600 cases. (Fig. 3).

All computers ran Apple Macintosh System 10.3 and higher. Data acquisition software was a custom product that saved digital video at 2-3 frames per second at screen resolutions of up to 1280 X 960 pixels. Typical resolutions were 800 X 600 pixels and 640 X 480 pixels. Video was saved in MPEG-4, format digitally compressed to 75 percent original size. Each frame was imprinted with the specific camera name, local date and time, GMT date and time, latitude, longitude, vessel speed over ground and course over ground. The data acquisition systems ran 24 hours per day from the time they were activated until the time a technician shut the system down.

Figure 3 Open control box aboard ship: 4-camera installation. Rear right is Mac Mini, rear left is Ethernet hub. Other equipment includes uninterruptible power supply and external hard drive. When in use the closed, locked box is tucked away in a niche to the left.

Once the external hard drives were in our Kodiak office, they were connected to a Macintosh computer with 4 GB of DRAM and running dual G5 chips at 2 GHz each. Data review was performed using custom software. Data were recorded in Microsoft Excel spreadsheets that could then be imported into Microsoft Access databases.

APPENDIX B

Overview of Archipelago EM System

The EM system supplied by Archipelago integrated an assortment of available digital video and computer components with a proprietary software operating system to create a unique and powerful data collection tool. The system operated on either DC or AC voltage to record imagery and sensor data during the fishing trip. The software was set to automatically activate image recording based on preset sensor indicators (e.g. net deployments, mitigation devices). The EM system automatically restarted and resumed program functions following power interruption. The system components are schematically depicted in Figure 1 and described in the following sections.

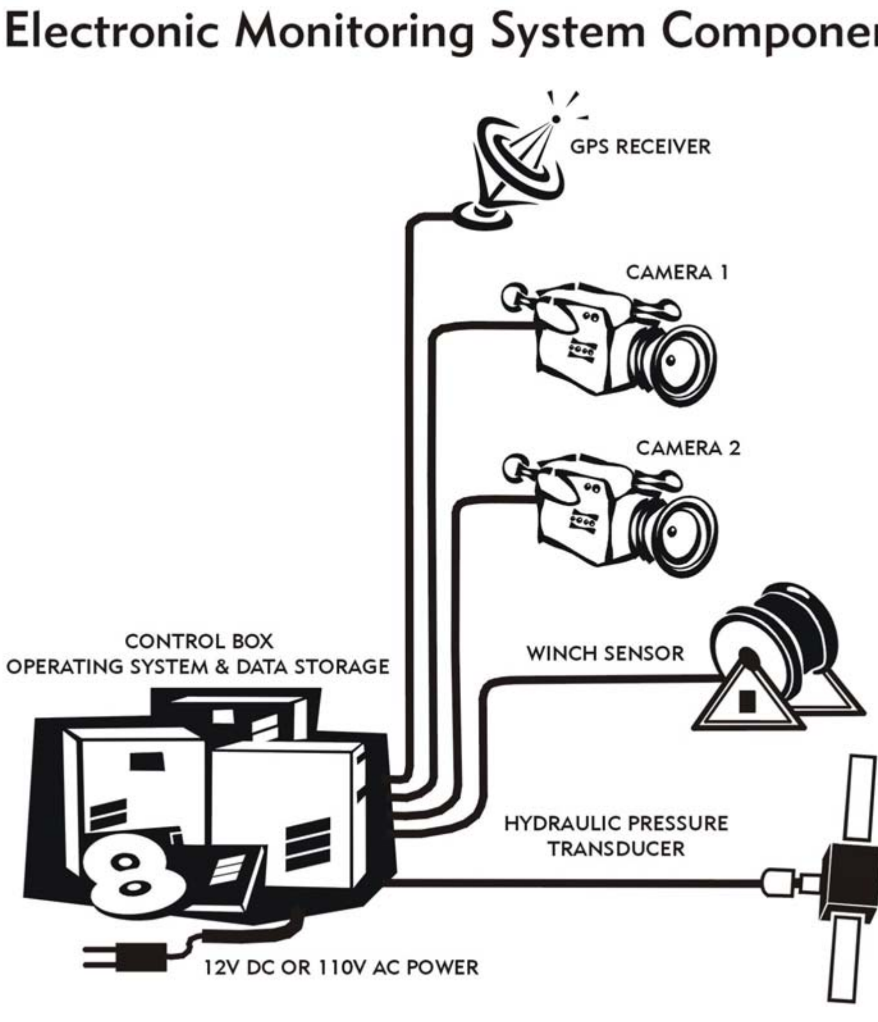

Figure 1 Schematic diagram of Archipelago's electronic monitoring system

Control Box

The heart of Archipelago's electronic monitoring system was a metal tamper-proof control box (approx. 15x10x8" = 0.7 cubic feet) that housed the digital data logger and video computer circuitry. The control boxes were mounted in cool, dry internal locations and continuously powered with 110 volts AC. Sources of AC power varied from vessel to vessel.

Video and Digital Data Storage

Each vessel had a pair of 120-gigabyte video hard drives that were used for video data collection. Drives were swapped on the vessel at each service interval to allow video processing to take place on shore. When the review process was complete for each drive, the disk was reformatted to remove old imagery and to prepare it for re-installation on the vessel. GPS and sensor data were recorded on removable compact flashcard media that could be downloaded to the service technician's laptop. At each service visit to the vessel, the sensor data was transferred from flashcard to laptop where it was mapped and graphed to check the operational status of the EM system. When the data checking was complete, the files were erased from the flashcard and the card was replaced in the EM control box.

CCTV Cameras

Waterproof closed circuit television (CCTV) cameras were chosen for installation on these fishing vessels. The armored dome camera design has proven reliable in extreme environmental conditions on long-term deployments on vessels in other fisheries. A choice of lenses from fisheye to telephoto enabled the service technician to optimally adjust the field of view and image resolution on each vessel. Color cameras with 480 TV lines of resolution (high resolution) and low light capability were chosen for deployment in this program.

GPS Receiver

An independent GPS receiver was installed with each EM system. The GPS receiver and antenna were packaged together in a plastic dome and mounted on the vessel rigging. When powered, the GPS delivered a digital data stream to the data-logging computer that provided an accurate time base as well as vessel position, speed, heading and positional error (measures the accuracy of the GPS position data). The GPS receivers were attached to temporary mounts in the vessel rigging or on top of the cabin, away from other antennae and radars. Archipelago used Garmin GPS products that contained Wide Area Augmentation System (WAAS) receivers. WAAS provides real time GPS signal correction that, according to the manufacturer, results in positional errors of less than 3m for 95 percent of the position fixes.

Hydraulic Pressure Transducer

An electronic pressure transducer was mounted on the hydraulic systems of each vessel. The EM control software compared the hydraulic pressure reading to a preset pressure threshold. The pressure threshold was determined by a hydraulic test and was generally set to a point above the system idle pressure. An increase in system pressure signaled the start of fishing operations such as trawl door handling or net setting. When pressure readings exceeded threshold the control box software initiated video data collection. The majority of sensor installations were made on the operating hydraulics such as the supply lines and valves connected to the net drums and warp or third wire winches. On a few vessels the sensors were attached to the vessel "pilot" hydraulics, a low pressure system (<300 psi) that controls the valves of the high pressure supply. Pilot hydraulic systems were typically found on the larger vessels and usually provided the advantage of sensor placement in a protected position inside the wheelhouse where the pilot controls are located.

Drum Rotation Sensor

A photoelectric drum rotation sensor was mounted on each vessel. The rotation of a net drum or warp winch when the vessel was at sea generally indicated that fishing operations had commenced. The rotation sensor, like the pressure sensor, was configured in the software as a video trigger device. A single rotation of the monitored winch would initiate the video data collection thus providing a backup to the pressure sensor. The waterproof sensors were usually mounted in protected locations on net drums. Alternate locations used were on the stationary frames of third wire and warp winches. One or more reflectors were mounted on a rotational component of each winch. Variations in rotation speed were used to distinguish setting, towing and hauling events.

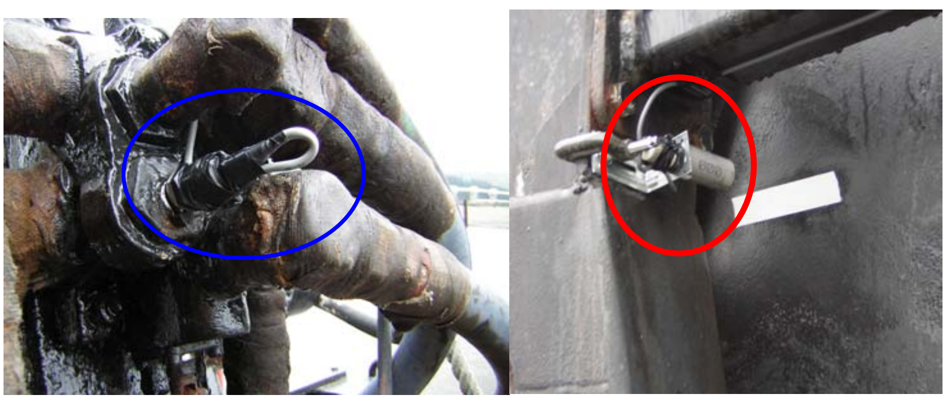

Figure 3 Hydraulic and drum sensor installations on a trawl vessel. The photo sensor and reflector (red circle, right photograph) provide counts of winch drum rotations and the hydraulic pressure sensor (blue circle, left photograph), installed on the supply line, monitors power at the winch.