Fisheries Monitoring Technologies

A Project Report Submitted to

North Pacific Fishery Management Council

by

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April 2004

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1 Introduction

1.1 Background

Groundfish fisheries in the North Pacific make extensive use of observers onboard fishing vessels. Trawl and longline vessels over 124 feet in overall length have at least one observer on board at all times. Vessels between 60 and 124 feet and pot vessels longer than 124 feet in overall length carry observers for 30% of their fishing days. Vessels less than 60 feet long are not required to carry observers. Observers estimate total catch for a portion of the hauls or sets, and sample those hauls or sets for species composition. Extrapolations from these data are used to make estimates of total catch by species for observed vessels; catch estimates for unobserved catcher processors are based on weekly production reports, and on fish tickets for unobserved shoreside deliveries. Observer data are treated as if representative of all vessels, both observed and unobserved, and are used to estimate total catch of prohibited species for the entire fishery. However, National Marine Fisheries Service (NOAA Fisheries) has concerns that the observed data are not representative of unobserved vessels. Some fisheries, including most in the Gulf of Alaska, have a significant number of unobserved vessels.

A number of factors are known that could bias observer data and hence the catch estimates based on them. There is no way to deploy an observer on a commercial fishing vessel without the vessel operator being aware of the presence of the observer, and possibly changing fishing behavior as a result. This gives rise to a so-called "observer effect" (see also Section 4.3). This may occur either on unobserved vessels relative to observed vessels, or during unobserved hauls of otherwise observed vessels. To the extent that vessels fish differently when being observed, observer data provide a biased sample of the entire fishery. In addition, if the observer coverage itself is non-random with respect to the vessel fleet, the sample taken may not be representative of all vessels. For example, larger vessels may fish gear that has different catching characteristics than similar gear used by smaller vessels.

Examples of changes that are thought to occur when observers are onboard include: 1) avoiding localized areas of high bycatch; 2) rigging gear differently; 3) changing average haul duration or gear soak time; and 4) different behavior on observed and unobserved hauls. In extreme cases, vessels have been known to deploy gear in areas where commercial fishing does not normally occur or to deploy gear for very short periods of time simply to obtain credit for a day of observer coverage. Use of VMS data may provide insights into vessel behavior with and without observers, but other than this, it is difficult to quantify the bias in observer data without some form of experiment, which may itself be confounded by similar problems of non-typical vessel behavior.

1.2 Purpose of this study

The National Marine Fisheries Service (NOAA Fisheries) and the North Pacific Fishery Management Council (NPFMC) want to investigate catch and vessel monitoring technologies that can be used to augment observer programs, increase accuracy of data collected by observers, and potentially replace some observers to improve the level of confidence in catch data.

Specifically there is a desire to collect data necessary for individual quota or cooperative programs without significantly increasing observer coverage.

This report reviews applicable technologies and current examples of their use and includes information describing example technologies, the ways that each technology can be applied to the catch monitoring problem, costs, and availability. The report also considers how individual technologies could be integrated into a catch monitoring system, with emphasis on applicability to the Gulf of Alaska and Bering Sea/Aleutian Islands fisheries. The report highlights technologies suitable for filling existing data gaps – such as groundfish bycatch in the Pacific halibut fishery and bycatch in fisheries dominated by small vessels not currently subject to observer coverage.

Candidate technologies fall into two broad categories: 1) technologies to monitor catch quantity and/or composition directly; and 2) technologies to monitor characteristics of fishing activity that may provide predictors for catch quantity and/or composition. Technologies in the latter category are also expected to assist with identification and quantification of bias resulting from different behaviors of observed and unobserved vessels.

Technologies involved in direct monitoring of the catch include cameras placed at strategic locations on the vessel, and the installation of digital motion-compensated scales (Section 2). In cases where direct monitoring technologies are not an option, monitoring the characteristics of fishing activity that may provide predictors for catch quantity and/or composition provides an alternative and possibly less intrusive approach to solving the problem. For example, bycatch rates may be inferred from gear type and configuration, location (monitored through a vessel monitoring system (VMS)), depth of fishing, etc. (Section 3).

Section 4 of the report considers the computing and statistical requirements to process and conduct analyses of data collected using the technologies described in Sections 2 and 3. Section 5 considers individual or combinations of monitoring techniques with computing and analytical capabilities to make or improve determinations of fishing activities relevant to fisheries management. Section 6 draws conclusions and recommendations.

2 Monitoring catch composition and catch quantity

2.1 Cameras

2.1.1 Catch monitoring with observer analysis of video images

Archipelago Marine Research, Ltd. (AMR), based in Victoria, British Columbia, has a functioning electronic monitoring (EM) system using video recording to identify and enumerate fish by species aboard commercial fishing vessels (McElderry et al. 2003). In 2002, Fisheries and Ocean Canada (DFO) implemented 25% observer coverage of days at sea for the Canadian Pacific halibut fishery, which uses bottom longlines, primarily to monitor bycatch of rockfish and protected species. Cost, bias, and equity issues for the current program arose because of costs to individual vessels of about CDN $300 per observer day (and an additional CDN $130 per observer day funded by the Federal government) and because most vessels are less than 40 ft long. In response, AMR, which had conducted a pilot electronic halibut monitoring program in 2001, arranged with DFO and the Pacific Halibut Management Association for a voluntary expanded electronic monitoring program. Electronic monitoring equipment was placed on board observed vessels with target coverage of 10% of all trips, concurrent with required on board observers. The program was designed to evaluate the technical performance of electronic monitoring as a monitoring tool, to compare electronic monitoring and observer data for species identification and fishing effort, and to compare costs, benefits, and operational issues of observer-based and electronic monitoring programs.

The AMR video-based electronic monitoring system (Figure 1) (McElderry et al. 2003) consists of the following components:

- Operating system and data storage – A lockable, tamper-proof box contains the operating system, data storage components, and power supplies for the video camera and peripheral vessel sensors. The two primary components in the control box are the video computer and data logging computer. The video computer digitizes the incoming analog camera signal and stores the video imagery on removable computer hard disks. The data logging computer concurrently captures and records the output from the GPS, pressure sensor, and drum rotation counter. Software on the data logging computer can be set to activate the video system whenever the sensor data recognize specific fishing activities (hydraulic pressure increase or drum rotation).
- User interface – A small monitor and keyboard provide basic system status information and allow user input.
- GPS receiver – An independent GPS receiver connected to the control box delivers a digital data stream for time, vessel position, speed, and heading.
- Winch sensor – A sensor mounted on the winch detects and counts drum rotation.
- Hydraulic pressure transducer – An electronic pressure transducer mounted on the supply side of the hydraulic pump system records hydraulic pressure, and by inference, work by devices such as winches or line haulers.
- Cameras – Two closed-circuit TV cameras provide imagery of the retrieval area during longline hauling operations. The cameras are standard resolution color (350 lines per screen) with a light sensitivity of 0.8 Lux at F 2.0.

The AMR system does not transmit data in real time, although time-sensitive data (such as compliance issues) can be sent in real time. While technically feasible, transmitting the high volume of EM data in real time was deemed to be economically impractical. All EM data became available to AMR at the end of each trip.

AMR installed the EM system on vessels for specific fishing trips and removed it afterwards. Suitability of the EM equipment was demonstrated on a wide variety of halibut fishing vessels, including a few vessels not suitable for observers (McElderry et al. 2003). The EM equipment had no significant data loss for about two-thirds of the fishing trips on which it was deployed. The newness of the system for the halibut fleet, installation problems, and changes in equipment to improve the system contributed to rate of data loss. Movement of ground line out of the camera field of view, low light conditions, and loss of power resulted in data deemed not useable. AMR expects successful deployments to exceed 90% for future monitoring of the

Canadian Pacific halibut fleet, because few further changes in equipment are expected, and because of increased familiarity with installation procedures by the fishermen and the AMR technical staff. Permanent installation on vessels would likely increase the rate of successful data collection even further.

The data logging computers are retrieved following a fishing trip and returned to AMR for analysis (McElderry et al. 2003). Trained observers view the video images and enumerate catch by species by hook. Total catch estimates from the video imagery were within 2% of at-sea observer catch estimates for about 150 successfully monitored sets (about 80,000 hooks) over the 9-month fishing season. McElderry (in Cusick et al. 2003) evaluated the EM results against at-sea observers for several attributes, and scored the ability of electronic monitoring and observers for these attributes (**Table 1**) on a scale of zero (low) to five (high):

- Video-based EM reliably identifies catch to general groups with consistent morphological features. Errors were predominantly within rather than between morphological groups. The evaluation identified species as High Recognition (<5% difference of EM results from at-sea observer results), Moderate Recognition (<10% difference), and Low Recognition (>10% difference) species (**Table 2**). High recognition species accounted for 77% of the catch in the electronic monitoring study, and estimated as 92% of the catch in the overall halibut fishery. Moderate recognition species accounted for 17% of the catch in the electronic monitoring study, and estimated as 5% of the catch in the overall halibut fishery. Low recognition species accounted for 5% of the catch in the electronic monitoring study, and estimated as 3% of the catch in the overall halibut fishery. Twenty three species (2% of the catch in the study) were not encountered in sufficient numbers to compare electronic monitoring. Overall scores for species recognition: EM – 3, Observer – 5
- Video-based EM is a reliable catch and hook enumeration tool for longline vessels. Overall catch comparisons between the electronic monitoring and observers were within 3% for number of catch items, and 5% for number of hooks and catch items combined. EM provided equivalent or better results than using observers because of observer fatigue during retrieval, the possibility of observers missing discards, and the opportunity for repeat viewing of the video record. Overall scores for catch and hook enumeration: EM – 5; Observer – 4
- The AMR EM system did not address catch weight. However, counts from EM could be converted to weight estimates by obtaining average weight by species through dock-side monitoring, and applying the average weights to the counts by species. Overall scores for catch weight[1]: EM – 0; Observer – 4
- Species disposition estimates by EM and observers were in close agreement for all species except halibut and longnose skate. The EM reliably distinguished catch sorted at the rail, but could not easily distinguish catch brought onboard and sorted later. Overall scores for catch disposition: EM – 3; Observer 5
- EM provides accurate information on time and location of fishing activity. Electronic monitoring captures geo-positioning information the same way for every haul, while observers may miss the start or end of a set because of conflicting duties. Overall scores for time and location: EM – 5; Observer – 4

[1] Errors in converting counts to total weight caused by blood loss, fluid loss or parts loss should be evaluated against observer errors in estimating catch. Use of dockside weights assumes no delivery size bias or high grading.

- The AMR EM system extrapolated depth from an electronic chart database. Agreement between EM results and observers decreased at greater depths with lower sounding rates. This method would not be adequate for monitoring compliance with depth restrictive regulations. However, it will improve as the accuracy of electronic charts increases, and EM could provide depth records directly by capturing data from the echo sounder on the data logging computer (see Section 3.5). Overall scores for fishing depth: EM – 3; Observer 5

McElderry (in Cusick *et al*. 2003) also compared programmatic issues of electronic monitoring and at-sea observer programs (**Table 3**), and concluded that the fishing industry tended to support electronic monitoring over at-sea observers, but that at-sea observers had higher versatility and provided more believable data. The general public, stakeholders, and fishermen tend to have suspicions concerning technology, and prefer to believe results obtained by humans (Howard McElderry, Archipelago Marine Research, Victoria BC, pers. comm.). They see more opportunity for fishermen to avoid scrutiny from technological means than from observers, although fishermen can and do hide activities from observers.

The amount of time that a video analyst can work in a day depends on the complexity of the data analyzed (Howard McElderry, Archipelago Marine Research, Victoria BC, pers. comm.). Analysts for AMR usually worked 4 hours per day on video images, with a maximum effective time of about 6 hours per day. The time required to analyze an individual fishing trip depends on a number of days fishing, number of fishing events, fishing location (concentrated or spread out), weather, and performance of sensors (McElderry *et al*. 2003). Electronic monitoring of the Canadian Pacific halibut fishery occurred on 59 vessels that made 697 sets over 459 sea days. Time spent by observers on other duties while not at sea is not included. Thirty fishing trips accounting for 391 sets had both EM and on-board observers. Processing video records from a fishing trip required 815 hours (102 days), much less time than observers would spend aboard the vessels. EM data required about a week following a trip to be processed for subsequent analysis. The resulting per vessel cost of an EM system is substantially less than the cost of at-sea observers. The video-based EM system cost about CDN$210 per vessel per day, less than half the total cost (fishermen cost plus government cost) of at sea observers, and about two-thirds of the cost to fishermen for at-sea observers. About three-quarters of the cost for the EM system covers the labor to install and service the equipment and to analyze and produce the data from the system. Future cost reductions may be possible through strategies to improve efficiency and manage labor costs.

The Pacific halibut video monitoring that identified and enumerated individual fish was more labor intensive than most EM projects conducted by AMR (Howard McElderry, Archipelago Marine Research, Victoria BC, pers. comm.). Intensity increases with the number of fish per hook (hook population) and the species diversity. Fish occurred on about one third of the hooks in the halibut monitoring, six species accounted for about 75% of the catch, and the dominant species had mostly different morphology. Overall, analysis took about 0.75 of real time. In some pelagic longline fisheries, the hooking rate is about 5%, and therefore less-complex than in the halibut fishery. Rockfish fisheries have much higher species diversity and fish with very similar morphology, which is more complex than the halibut fishery.

EM projects that do not identify and enumerate individual fish take much less analytical time (Howard McElderry, Archipelago Marine Research, Victoria BC, pers. comm.). Analysis of video monitoring to confirm that vessels complied with full retention requirements, with species identification and biological sampling on the dock, proceeded much faster than the halibut fishery enumeration. Analysis took about 0.3-0.5 of real time. Simpler yet, video confirmation of effective deployment of seabird avoidance devices on longline vessels required about 0.05 to 0.10 of real time. Monitoring of a Canadian fishery on seamounts to confirm the location of fishing and that vessels did not offload any fish at sea required only a few hours for trips that lasted 30-40 days.

2.1.2 Catch monitoring with digital recognition of species

Since the late 1990s, attempts have been made to develop a computer system that can identify species automatically through digital recognition. Such a system would identify fish to species level *in situ* from video pictures taken by digital cameras onboard fishing vessels (Davis 2002; Mark Buckley, Digital Observers, Kodiak, AK, pers. comm.). Fish species can already be identified successfully through a combination of cameras and image recognition software, but only under controlled conditions. At present this technology does not work adequately under actual fishing conditions. Computer software cannot currently identify fish species in actual fishing operations to acceptable levels for any gear type (Mark Buckley, Digital Observers, pers. comm.). Too many lighting variables occur for the image recognition to consistently identify fish species, and shadows apparently confound the recognition (Davis 2002). As the technology develops, longline fisheries are likely to be best suited for this approach because the fish come on board one at a time. The volume and flow of fish on trawl vessels is likely to preclude automatic fish identification *in situ* for the foreseeable future.

The computer software programs that converted video images into species identification used neural nets, types of computer applications wherein a computer is configured to imitate information processing by the human brain. Data are structured not by a central processing unit but by an interlinked network of simple units called artificial neurons. The artificial neurons receive inputs, process the inputs, turn the processed inputs into outputs, and interface with other neurons. Rather than being programmed, neural nets learn to do tasks through a training regimen in which desired responses to stimuli are reinforced and unwanted ones are not. Neural nets were first proposed in the 1940s and the subject of intensive research in the '80s and early '90s[2]. However, capability of neural nets has not developed to a state that computerized recognition of fish species can perform as well as humans.

2.1.3 Work in development and application to other fisheries

Controlled lighting increases the probability that video and computer systems could provide automated species ID. Digital Observers is developing a system that provides controlled lighting conditions on board trawl catcher-processor vessels through use of a “light box” (Mark Buckley,

[2] For more information on neural nets, see http://www.shef.ac.uk/psychology/gurney/notes/index.html.

Digital Observers, Kodiak AK, pers. comm.). The digital camera will capture images as fish pass singly, in a line (not side by side) over a translucent belt with lighting that eliminates shadows. Because the camera will be a known distance from the belt, the length of fish can also be estimated. Length measurements could be converted to individual weights through a length-weight relationship. The volume and flow of fish on trawlers limits sampling to only the subsample of the catch that can through the light box. Experiments scheduled for the spring of 2004 will test the system and obtain data needs for further development. Future work is aimed at investigating the rate of fish that can be processed through the light box, whether the system can be automated, whether it can function effectively without observers, and the likely sample sizes that can be achieved. This will show whether the system is likely to be a viable sampling tool that could enhance or supplement observer coverage.

Because automated digital recognition of fish species is currently impractical, Digital Observers is also working on a system of video and human reviewers for species ID. A completed system is expected during 2004 (Mark Buckley, Digital Observers, Kodiak AK, pers. comm.). The electronic video monitoring system will be generally similar to that developed by AMR, using GPS to locate the sets, and a simple rotation sensor that detects when the block is hauling the longline. Signals to the central computer trigger the computer to begin capturing images as the longline is hauled back onto the boat, and the computer settles back to 'resting' mode when signals stop. The Digital Observer system will use digital cameras, rather than analog cameras used by AMR. Future tests will evaluate whether the digital cameras offer benefits commensurate with the additional costs compared with analog cameras.

While automated identification of fish species under fishing conditions using camera technology is problematic, sea birds and marine mammals have unique characteristics that could make the technology more applicable. The occurrence of marine mammal and seabird bycatch is relatively rare as a proportion of total fishing effort, making adequate sampling difficult. Monitoring with cameras offers a mechanism to increase the coverage of fishing effort and subsequent sampling of these animals.

The various gears used in Alaskan waters have different bycatch characteristics, including rates of bycatch, vulnerability of species to the gears, and amounts of effort by gear type. Of the marine mammal bycatch, approximately 70% occurs during trawl fishing (http://www.nmfs.noaa.gov/prot_res/readingrm/MMSARS/2002AlaskaSARs.pdf). Longlines account for about 26% and pots for about 4% of the marine mammal bycatch. Of the seabird bycatch, approximately 65% occurs during longline fishing (http://www.afsc.noaa.gov/refm/docs/2002/ecochap.pdf). Trawls account for about 34% and pots about 1% of the seabird bycatch. Therefore, in terms of total bycatch enumeration for marine mammals and seabirds, monitoring of trawl and longline vessels has a relatively higher priority than monitoring of pot vessels.

Because bird and mammal bycatches are relatively rare, crewmembers could position birds and dead mammals for a camera in a way to enhance identification without major disruption to fishing activities. However, crewmembers could also discard the animals unseen unless a camera system surveys the entire deck with sufficient coverage to prevent blind spots. A camera that surveys the deck to prevent unauthorized discarding by the crew may also be used to identify live mammals that the crew cannot position under a close up camera. Even if positioned well for the camera, digital recognition of these species may still be problematic. Animals caught on longlines or in pots are likely to experience predation by amphipods (sand fleas), crabs, and other benthic scavengers, which may destroy vital identifying characteristics. Animals caught during deployment of trawls may also suffer damage that would diminish the ability of the computer to identify them through digital recognition. Human reviewers of the digital recordings may identify these animals more successfully.

Experiments conducted in Hawaii suggest that infrared cameras could be used to identify marine mammals and seabirds swimming near vessels (Scientific Fisheries Systems 2003). The warm-blooded animals provide infrared images visible against the colder seawater background. The experiments were hampered by the rarity of the target species, Hawaiian Monk seals, dolphins, and albatrosses, which did not provide enough samples. Five Monk seal images, three dolphin images, and 18 albatross images were used for the preliminary discrimination study. Preliminary results using a Principle Component Analysis did not show a clear distinction among the three species, but showed some degree of separation. Albatrosses generally occurred within a cluster, but the clusters for the other species could not be identified. Monk seals tended to separate from albatrosses, but dolphins overlapped both Monk seals and albatrosses. Further progress on this methodology would require a larger data set, especially of Monk seals and dolphins.

Any system that can identify fish could potentially be used to obtain information on the species identification of an unsorted fish bycatch. Limitations on fish identification would apply to bycatch identification. However, camera systems cannot obtain biological samples. Light boxes may not work for large species such as Pacific halibut, and rare species may require large samples for the system to make accurate and precise counts.

Due to their relatively clean catch and low discard rates, pot vessels may provide a good opportunity for electronic video monitoring of species composition of the catch. Pot vessels in Alaskan waters generally target Pacific cod, which form the main component of their catch with relatively small amounts of discards (Kent Lind, NOAA Fisheries, Juneau AK, pers. comm.). If the requirement for full retention of Pacific cod results in accurate weighing and measuring of retained catch at the processor, then a camera system could focus on the monitoring of discards. A camera to monitor the deck could check for unauthorized discards, and a camera to monitor the discard chute could collect information for subsequent analysis by humans. A belt or track, down which for discards could pass singly by the camera, would enhance species identification of discards. AMR conducted pilot programs for video monitoring of pot fisheries for British Columbia sablefish and prawns fisheries in 2002 and 2003, respectively (Howard McElderry, AMR, Victoria, BC, pers. comm.). These pilots demonstrated the necessity of a “control point” through which all fish must pass to assure that no fish miss detection. Close up views of the control point provided for monitoring and counts of the fish.

The light box in development for trawl catcher-processors would not be suitable for the open decks of most pot vessels, but could work for the several catcher-processor pot vessels.

2.2 Motion-compensated scales

2.2.1 Current Requirements

Flow scales approved by NOAA Fisheries (http://www.fakr.noaa.gov/regs/default.htm) can weigh a continuous flow of raw material and give a steady raw material throughput. Fish pass from holding tanks via conveyor belts to the flow scales, which provide fully automatic weighing. Every piece of raw material is weighed with the conveyor belt running and weighing results are added up to a total (http://www.marel.com/02000/2100_w/dwu-mpfl.asp, http://www.scanvaegt.com/Files/Filer/Extranet/Marketing/Leaflets/Processing%20Equipment/ScanFlow_Int.pdf). Depending on the model, flow scales range in size from 1450-1900 mm long by 300-900 mm wide, and can weigh 40 –100 tons per hour.

To verify that the scale performs better than the maximum permissible error (plus or minus three percent the known weight of the test material), the vessel operator must test each scale or scale system used to weigh total catch one time during each 24-hour period when use of the scale is required. A material test must be conducted by weighing at least 400 kg of fish or an alternative material supplied by the scale manufacturer on the scale under test. The known weight of the test material must be determined by weighing it on a platform scale approved for use. Vessel operators must notify observers in advance of scale tests and conduct the tests in the presence of an observer. The vessel owner must ensure that these tests are performed in an accurate and timely manner.

Although regulations allow errors up to 1% during annual testing of the scales, errors rarely exceed 0.25% (Alan Kinsolving, NOAA Fisheries Alaska Region, Juneau AK, pers. comm.). The scales drift over time as belts stretch or load cell age. Fishermen have an incentive to correct the scales if they overestimate weight, but not to fix them when they underestimate weight. Regulations allow up to 3% error during daily test. Alan Kinsolving (NOAA Fisheries Alaska Region, Juneau AK, pers. comm.) estimates that the average error found during the daily tests is on the order of 0.5% underestimate. While tampering with the scales is possible, no clear evidence exists for tampering. No cases of tampering have gone to court.

The following sections from the Alaska Region fishing regulations specify flow scale requirements (http://www.fakr.noaa.gov/regs/default.htm):

679.32(c)(4)(iv) CDQ catcher/processors using trawl gear and motherships (effective through December 31, 2007). The operator of a catcher/processor using trawl gear or of a mothership taking deliveries of unsorted codends from catcher vessels must weigh all catch on a scale that complies with Federal requirements. A valid scale inspection report must be on board the vessel at all times when a scale is required. Catch from each CDQ haul must be weighed separately. Catch must not be sorted before it is weighed, unless a provision for doing so is approved by NOAA Fisheries for the vessel in the CDQ. Each CDQ haul must be sampled by a level 2 observer for species composition and the vessel operator must allow level 2 observers to use any scale approved by NOAA Fisheries to weigh partial CDQ haul samples.

679.63(a)(1) (1) Catch weighing. All groundfish landed by listed AFA catcher/ processors or received by AFA motherships must be weighed on a NOAA Fisheries-certified scale and made available for sampling by a NOAA Fisheries certified observer. The owner and operator of a listed AFA catcher/ processor or an AFA mothership must ensure that the vessel is in compliance with the Federal scale requirements for Alaskan waters, that each groundfish haul is weighed separately, and that no sorting of catch takes place prior to weighing.

2.2.2 Work in development and application to other fisheries

Motion-compensated hopper scales may also be suitable for obtaining total weight of catch on catcher processor longline vessels. In 2003, NOAA Fisheries conducted an experiment on a Pacific cod freezer longline vessel to test observer estimates of total catch and the estimate of total catch made by the vessel compared to an actual weight (Doug Limpinsel, NOAA Fisheries, Seattle, pers. comm.). The experiment used a Marel motion-compensated hopper scale, which is a smaller version of ones used in shore plants, to weigh the catch on board the vessel. Analysis of the data comparing observer and vessel estimates are underway, and no results are yet available. However, the hopper scale performed well and provides a useful tool for measuring total weight.

The control unit for the Marel hopper scale used by NOAA Fisheries for experiments has a computer link for control of feeding fish to the scale and for storing data. For the experiment, an automatic hook stripper removed fish from the hooks, and dropped them on a conveyor belt that carried them into the hopper scale. A computer tracked the weight of fish in the hopper and stopped the conveyor at a target weight of approximately 100 kg. The computer logged the weight of fish in each hopper load, and dumped the fish onto another conveyor to continue processing. The scale was located in the factory. Marel has recently introduced a new version of the control unit, the M2200, which has an internal IP address useful for data logging.

Marel has several hopper scales of a size that could work on longline or pot catcher-processor vessels. However, the hopper scales are not suitable for use on an open deck, so their use would be limited to covered areas comparable to those found in catcher-processor factories (Birgir Johannesson, Marel Scales, Seattle WA, pers. comm.). Limitations to using hopper scales on an open deck, in descending order of concern, consist of:

- wind causes instability in the motion-compensated scales if located on open decks;
- big waves crashing on the scale could damage the load cell;
- exposure to spray and waves will increase stress on components even though the system is waterproof.

Calibration of a motion-compensating scale is only as good as the test weights used for calibration. The regulations require use of certified weights for calibrating flow scales. At present, observers must confirm the calibration of flow scales. However, available technology could substitute for the observer during calibration. Attaching a readable ID, such as a Radio Frequency Identification (RFID) chip or a bar code, on each calibration weight could ensure that the correct weights are used for calibration. A reader on the scale (which the M2200 hopper scale control unit has) could identify and log the weights used for each calibration. A camera could be used to monitor the calibration process to check whether it is completed correctly.

Discards are currently estimated for catcher processors as the total weight measured with flow scales minus the retained weight calculated with product recovery rates. Theoretically, trawl catcher processors and longline or pot catcher processors could use flow scales and hopper scales, respectively, to measure discards. Direct measurement of the discards would likely provide an improvement in accuracy. A conveyor into which flow or hopper scales could be incorporated would take discards to a chute for dumping. However, most boats have limited space, and that space is often fully utilized. Requiring additional scales to measure discards could cause financial and logistical difficulties for vessel operators.

Hopper scales are problematic for longline and pot catcher vessels, which are generally smaller than catcher-processor vessels. If the vessels do not have a protected area comparable to a factory, then the hopper scale would not work. The hopper scales require a conveyor belt for transport of fish to the hopper and from the hopper to the processing area. If a vessel does not have room for the conveyors and the hopper scale in the protected area, then a hopper scale would not work.

2.3 Codend volumetrics

Volumetric estimates of the weight of catch in trawl codends using video cameras may be technically possible (Howard McElderry, Archipelago Marine Research, Victoria Canada, pers. comm.). To our knowledge, no effort to develop this technology has yet occurred. Several cameras placed strategically to measure length, diameter, shape, and possibly other parameters could be used to calculate the volume of the net. Accuracy would improve for vessels/fisheries that have the most consistently shaped nets; therefore, camera-based volumetric measurement is likely to be most suitable for larger vessels – catcher processors and larger catcher boats. Some of these vessels currently have total weight measured by flow scales, which provide a far superior value. However, vessels without flow scales, or without observers, may be suitable candidates for camera-based codend weight estimation. If smaller boats have widely varying catches that cause irregular shape of the codend, then accuracy will likely be a problem. Camera-based codend weight estimates may provide a supplement to the self reporting of total catch weight that is currently required in groundfish logbooks. They may also provide a technological cross-check of weights recorded in logbooks, as discussed in Section 2.4.

2.4 Fisherman participation in catch and biological data collection

Use of observer data alone or observer data supplemented by electronic monitoring will not be sufficient for obtaining all the information needed by the Council and NOAA Fisheries for management of bycatch or discards in groundfish fisheries in Federal waters of Alaska. Many vessels in the Alaskan fisheries are too small to carry observers, and the cost of observers may represent a substantial portion of revenues from these vessels. Cooperative research efforts among fisheries scientists and the commercial fishing industry are receiving increased attention as a method of supplementing or replacing standard research and data collection operations and reducing the costs of obtaining fishery information (Harms and Sylvia 2000). However, for this approach to work, fishermen need to be convinced that the effort is scientifically and economically worthwhile; otherwise, they could view the research as threatening or not worth the effort, resulting in inadequate or ineffective participation. In a survey of US west coast groundfish industry and scientists, Harms and Sylvia (2000) found that industry participants favor those projects that allow them direct, and often independent, involvement and input into the scientific process, but that many scientists express concerns over bias and lack of objectivity with independent fisherman participation.

The National Marine Fisheries Service (NOAA Fisheries) Alaska Fisheries Science Center (AFSC) has a long and successful history of conducting research in cooperation with the fishing industry (Karp et al. 2000). For example, NOAA Fisheries charters commercial vessels for conducting stock assessment surveys. NOAA Fisheries has also had participating scientists on-board commercial vessels during experiments to 1) test effectiveness of a device to exclude Pacific halibut (a prohibited species) from trawl catch; 2) test different sampling methods for obtaining species composition; and 3) test flow scales for use on catcher processors. NOAA Fisheries and the fishing industry had broadly overlapping interests in reducing bycatch, better understanding the constraints to accurate catch accounting, and implementing improvements in catch accounting systems. While the fishing industry had a major role in proposing and developing the experiments, and had substantial self interest in successful completion of these experiments, NOAA Fisheries played a sufficient role to assure that the experiments complied with its scientific standards.

Expansion of the cooperative research model from joint research projects to independent fishery data collection following a prescribed NOAA Fisheries protocol, if successful, may enhance the likelihood of obtaining bycatch and discard data necessary for IFQ or co-op programs for the groundfish fishery. However, without assurance that fishermen would collect data without bias, management agencies may not want to use the data. Much self-reported data, such as for bycatch in groundfish fisheries, are not currently used for management purposes. However, the International Pacific Halibut Commission (IPHC) provides examples of using self reporting of bycatch and discards for analytic or management purposes. The IPHC interviewed halibut fishermen on

- bycatch of rockfish in Southeast Alaska, and reported the results to the Alaska Department of Fish and Game (Heather Gilroy, IPHC, Seattle WA, pers. comm.), and
- bycatch of seabirds, and reported results (and options for monitoring seabird bycatch) to NOAA Fisheries (Gilroy et al. 2000).

A pilot program to train fishermen to collect catch, discard, and location data for a small-boat tuna fishery in American Samoa is underway, under sponsorship of the University of Hawaii, Pelagic Fishery Research Program (John Kaneko, Pacific Management Resources, Inc., Honolulu HI, pers. comm.). Safety and space concerns preclude placement of at-sea observers, and no options other than self reporting were available for obtaining the data. The pilot program will qualitatively assess if the data are representative of the fishery in general.

Many government jurisdictions permit members of the public or members of a company or corporation to certify weights or measures. For example, the National Conference of Weights and Measures (NCWM) sets standards for public and corporate weighmasters (http://ts.nist.gov/ts/htdocs/230/235/h130-03/05_III_WeighmastLaw.pdf, http://www.ncwm.net/main.html). Nineteen states have weighmaster laws based on NCWM standards, 13 have weighmaster laws not based on NCWM, and 21 (including Alaska) do not have a weighmaster law (http://ts.nist.gov/ts/htdocs/230/235/stlaw.pdf).21). Weighmaster models occur in Canadian fisheries on the Atlantic and Pacific coasts. The North Pacific Fishery Management Council has explored the use of weighmasters for monitoring landings of the Pacific halibut and sablefish IFQ fisheries in Alaska (Trumble et al. 1997), but did not develop management measures for weighmasters.

Penalties and bond requirements decrease the likelihood of weighmasters falsifying records. However, weighmaster programs typically work best if enforcement agents can directly monitor weights or measures. For example, agents can confirm the weight of cargo on a selected truck by weighing the loaded truck, weighing again after unloading (assuming that unauthorized offloads did not occur), and comparing cargo weight with the weighmaster report. Similarly, agents could monitor (undercover) weights of fish in totes in a fish plant to confirm that the weight of fish from a vessel corresponds to a weighmaster's report. While data collection at sea by fishermen would not be limited to weighing, the same concept may apply. Using weighmasters to report weights at sea, such as of discards, is problematic because direct monitoring by an agent is virtually impossible. However, remote monitoring through video cameras may provide an adequate check on activities of vessel personnel to assure accurate data collection for some types of data.

In the North Pacific many vessels are too small or otherwise unsuitable for at-sea observers. Currently vessels less than 60 ft long do not carry observers and those between 60ft and 125ft carry observers for 30% of their fishing days. EM is an option to monitor these vessels when observers are not available, or not an option. However, this technology cannot currently collect biological data. The remaining options are to either expand observer coverage, or use vessel crew to obtain information about bycatch and discards. Some of the data may be useful for programs other than bycatch or discard monitoring, or may be suitable for collection by remote monitoring. However, data collection by vessel personnel in these cases may still be effective, because using technology to check on data collection by fishermen is less expensive than collecting data directly through electronic monitoring (Howard McElderry, Archipelago Marine Research, Victoria BC, pers. comm.). The following steps could determine the feasibility of data collection by vessel personnel with remote monitoring of data collection activities:

- NOAA Fisheries determines minimum data necessary for bycatch/discards
- NOAA Fisheries determines minimum activity from vessel personnel to obtain it
- NOAA Fisheries determines what training necessary for vessel crew
- Is it feasible for crew to perform minimum duties to collect data?
- Can camera monitoring or gear sensors detect violations of crew data collection duties?
- If yes, then weighmaster/self monitoring concept is worth further evaluation for data collection.

The self-reporting with electronic monitoring concept will not work if the fishermen do not consider it an advantage over the existing system and if they do not accept a responsibility for assuring data quality. The vessel crews will have to do more work than under the existing system, and the electronic monitoring will impose a cost on the vessels. The vessel operators and crews may not want management agencies to know the amount of bycatch. The incentives to misreport may be higher than the perceived benefits of accurate data. However, a change from open access to groundfish IFQ or co-op management may depend on agencies obtaining the necessary data. Vessel operators may determine that a requirement for bonded and trained weighmasters on vessels may have benefits that exceed the costs – for example, if reduced costs or increased revenues under IFQ/co-op management exceed the cost of the weighmaster, or if fishermen were willing to pay more to end open access.

Following the success of the halibut and sablefish IFQ program and the Alaska pollock AFA co-op program, many groundfish vessels operators recognize a benefit in, and support, moving toward an IFQ/co-op program. This offers an opportunity to delegate development of many details for a self-reporting bycatch data collection system to the fishermen: if they want the IFQ/co-op program, and the program is contingent on bycatch data collection, the fishermen have an incentive to develop a system that meets the standards of the Council and NOAA Fisheries.

Under this scenario, agency staff would meet with fishermen to discuss standards for bycatch data, available technologies to monitor data collection activities, and costs and benefits of vessel by vessel monitoring. Industry representatives would determine how to formulate data collection by vessel personnel combined with electronic monitoring such that fishermen would best meet the data standards. If the data collection does not follow proper protocols, then the weighmasters and vessels would be subject to penalties. Discussion points for developing standards and selecting data collection/monitoring components could include the following:

- Fishery information – check haul-by haul information with auto-logged info (GPS location, fishery sensors) to assure proper sequence of sampling hauls.
- Discarded catch– video cameras could monitor species composition for longline and possibly pot vessels; no direct methodology for estimating weight of discards.
- Biological data – weighmaster to collect bycatch samples, do species identification, and measure lengths using electronic measuring board. Check with camera to record sample collection, species identification, and length measurements techniques used on board.
- Reduce presorting or non-random samples by monitoring with camera
- Bird/mammal bycatch – monitor with camera; requires crew assistance
- Use of bycatch reduction devices – check with camera

Many fishery managers express reluctance to use self-reported data from fishermen for analyses and management decisions. Self-reported data have a direct impact on fishermen's self interest, which provides an incentive for misreporting. If fishermen can reduce the reported catch or bycatch, then seasons remain open longer, but often at the expense of exceeding quotas. The continuing issue of presorting groundfish catch before observers can sample the catch is a prime example of this problem. Using technology to monitor self reporting may not receive support from fishery managers without assurances that the program provides accurate and unbiased data.

Highly competitive fisheries, such as open access, will likely provide an environment in which fishermen will find an incentive to misreport. However, as fisheries move to more rights-based management, such as IFQs or co-ops, or co-management that actively involves fishermen in decision making, data gathering, and data sharing, fishermen may have more incentives to correctly report data they collect. Fishermen engaged in and with responsibilities for the management system will, more likely than competitive fishermen, see the advantages of accurate data. Under user pay systems, fishermen participation in data collection could reduce costs compared to at-sea observers. Monitoring the reports with electronic means provides some confirmation that fishermen participation occurs in generally appropriate ways. No measures are likely to guarantee accuracy of all fisherman data reports, but non-competitive and engaged fishermen with financial responsibility for data collection have reasons to support accurate data, especially if monitored with electronic means.

2.5 Improved technology for observers

2.5.1 North Pacific Groundfish Observer Program equipment

With the exception of CDQ and AFA fisheries, equipment used currently in the NPGOP has not changed substantially since the beginning of the observer program in the 1970s. Observers typically weigh fish in baskets using 2 and 12 kg brass and 50 kg Salter spring scales or simple Chatillon platform scales, and collect data by writing or tallying on plastic sheets (Martin Loefflad, AFSC, Seattle WA, pers. comm.). Observers may transfer data from plastic sheets to paper forms for a permanent record or may use one-time plastic sheets for a permanent record, and subsequently enter data into an electronic transfer system. Vessels that fish for CDQ or for AFA pollock, except catcher vessels that deliver unsorted catches, must supply motion compensated scales and work stations that meet NOAA Fisheries specifications. The NPGOP is aware that other technologies, such as electronic measuring boards and hand-held computers, could improve observer sampling, but has not incorporated them because of a need to evaluate the increased costs against the benefits to the observers and to the program.

2.5.2 Alternate observer equipment

Electronic data-logging

Observers in the Alaska Region currently write data on plastic sheets for transcribing to paper and subsequently entering on a computer for transmission. The multiple steps in this data-logging procedure require considerable time, and risk transcription errors at each step. Hand-held and tablet computers offer an opportunity for immediate data entry by observers and other field party staff. Outliers, or data that fall outside of normal limits, may be discarded because confirmation cannot occur after the fact, but may represent true values. Several electronic data-logging systems for use by observers may potentially reduce the potential errors resulting from the status quo. We could find no organizations that provide electronic measuring and data-logging systems for observers, although the British Centre for Environment Fisheries and Aquaculture Science (CEFAS) uses electronic measuring boards for port sampling (http://www.cefas.co.uk/news/Insight-May02.pdf).

The NEFSC is experimenting with a WalkAbout Hammerhead XRT tablet PC (http://www.walkabout-comp.com/products_specs_xrt.html) for use by observers to enter data as collected at sea (David Potter, NEFSC, pers. comm.). The tablet PC is programmed to display data entry fields that mirror the current paper forms observers use to record data. The Hammerhead has digital recognition of hand writing, so observers can fill out the forms with a stylus. The program performs an error checking to confirm all data fall within set bounds, and warns if fields are left blank. The Hammerhead is splash resistant, but not water proof, so is best suited for larger vessels with some protection from the elements. The National Observer Program tested the Juniper Systems hand-held computer, the Allegro (http://www.junipersys.com/products/products.cfm?id=9) and the Itronix tablet (http://www.itronix.com/products/tablet/gobooktablet.asp) in December 2003 aboard a fishing vessel in the Bering Sea (Teresa Turk, NOAA Fisheries Observer Program, Washington D.C., pers. comm.). As a result of the tests, NOAA Fisheries made some suggestions for improvements to the equipment. Additional tests are scheduled for early in 2004. The ruggedized tablet, handheld, notebook computers cost in the three to four thousand dollar range.

Electronic measuring boards with internal data-logging or with connections to hand-held or tablet personal computers (PS) can quickly and accurately measure fish. The data loggers typically contain error checking programs that will signal for re-measurement for lengths or weights that fall outside of a prescribed range, which eliminates outliers. The program may signal blank fields, and not allow closing out data for a set or haul until all fields are complete. A test of an electronic measuring board and a standard measuring board to obtain lengths of Atlantic herring showed that accuracy increased and time per fish decreased when using the electronic measuring board (Bourque and Cairns 1994). The electronic measuring board was linked to a computer with a real-time plausibility test that alerted the operator when outliers occurred. Real-time conformation or correction of data occurred. Automatic data entry eliminated data entry and data verification time and errors. Several research groups use electronic measuring boards on fishery survey, including NOAA Fisheries, CEFAS, and the Australia Fishery Management Authority. Electronic measuring boards cost on the order of three thousand dollars each.

Two concepts currently link electronic measuring boards with electronic data logging. Limnoterra (http://www.limnoterragroup.com/fmb/fmbhp.html) manufactures an electronic fish measuring board that performs as a data logging device, with 167 functions for user defined fields. Associated data, such as date, location, loran C start, loran C end, time start, time end, basket weight, species codes, sex, specimen weight, number of specimens, and tag number, can be logged onto the board with the length and species. The Limnoterra board currently requires a cable connection to computers for downloading data, although a prototype wireless model is in preparation (Jon Planck, Limnoterra, pers. comm.). Scantrol (http://www.scantrol.net/FishMeter.htm) also makes an electronic measuring board with internal memory that transfers data to a computer with a cable. The Scantrol board also links with electronic scales to store weights. Lat.37 manufactures a wireless fish measuring board that links to a hand-held computer (http://www.junipersys.com/files/wireless_fish_measuring_board.pdf), rather than storing data in the measuring board. The Lat.37 measuring board uses the Juniper Systems Allegro hand-held computer to store length, species, and associated data. The National Observer Program tested the Lat.37 wireless measuring board in the Bering Sea aboard a fishing vessel (Teresa Turk, NOAA Fisheries Observer Program, Washington, D.C., pers. comm.). As a result of the tests, NOAA Fisheries made some suggestions for improvements to the equipment. Additional tests are scheduled for early in 2004.

Numerous hand-held GPS units suitable for marine use are available with which an observer could independently obtain location of sets or hauls. GPS units from companies such as Garmin and Magellan allow track point storage for multiple tracks and come with computer cables to download positions to a computer. These hand-held GPS units can cost in the $250-400 range, but may range up to three thousand dollars for professional models. The Limnoterra electronic measuring board, the Allegro hand-held computer, and the Hammerhead tablet will download data from GPS.

Fishery Scientific Computing System

NOAA's Office of Marine and Aviation Operations developed a computer system, the Fishery Scientific Computing System (FSCS), to digitally collect all critical fisheries-independent data aboard research vessels (Teresa Turk, NOAA Fisheries, Washington, D.C., pers. comm.). Improvements to the system have been made by the Northeast Fishery Science Center and the Northwest Fishery Science Center (NWFSC). Four Regions currently use FSCS for research and charter vessels, and other regions are considering the system. The system uses wireless connections between various sampling devices to send data to a computer for data logging (Figure 2). The NWFSC developed a TowLogger system to automate the collection of sensor data; TowLogger collects and sends position and time data for various trawl events from GPS receivers, net mensuration and position data from Simrad's Integrated Trawl Instrumentation (ITI) equipment, and weather and sea state conditions. The NWFSC also developed an Integrator that displays temporal output data produced by FSCS, TowLogger, or other sensors.

The FSCS is currently configured for trawl data, but NOAA Fisheries is working to expand the capability to other gear types. NOAA Fisheries is also exploring the suitability of FSCS for assisting at-sea observers collect and log data.

Sampling

Considerable practical difficulties arise with obtaining a true random sample on the deck of a trawl catcher vessel. These include difficulties with access, in physically moving around on a trawl deck covered in fish, and choosing where and how to take a random sample of the catch. In mixed fisheries, the different sizes and shapes of various species may lead to vertical stratification and fore-aft presorting. Large pollock catches streaming into the hold have similar problems but with the additional problem of observer safety when trying to obtain samples. MRAG Americas (2003) recommended tests to evaluate a specially designed brailer or corer system to subsample mixed catch from the deck. Installation of a mechanical arm holding a sampling basket that could be inserted into the flow of fish at randomly determined intervals could provide safe, but possibly expensive and disruptive, sampling from large pollock catches.

Observers on factory trawlers gather samples from a moving belt by diverting fish from the belt. Development of an arm that automatically shunts fish from the belt for sampling could reduce the amount of work required of observers.

Scales

The mechanical scales used by non-CDQ or AFA observers have limited accuracy caused by vessel movement, and do not allow downloading of weights to a computer. However, the scales are robust and withstand the rigors of sea conditions in the North Pacific if properly maintained. Other mechanical scales will offer little improvements over the current scales.

The selection of electronic scales as alternatives is limited. Motion-compensated platform scales by Marel, Pols, and Scanvaegt are already certified for use as observer sampling station scales. The scales store data and can download to a computer. The scales are designed for marine application, but their suitability for use in the more extreme conditions of an open deck is not clear. Motion-compensated scales may have accuracy and reliability problems when buffeted by wind and waves (Section 2.2). These scales cost on the order of five thousand dollars each, a high cost for the number required by the observer program.

Salter Brecknell (www.salterbrecknell.com) makes the ElectroSampson electronic hanging scale with a maximum capacity of 45 kg, 5 kg less than the Salter spring scales. The ElectroSampson has a digital readout, but no capability to link to a computer. The ElectroSampson is not sealed or waterproof, which would put the scale at jeopardy when operated in the wet conditions often experienced on open decks. The scale has a minimum operating temperature of 0°C, which makes the scale suitable for observer use only during part of the year when cold weather does not occur. The ElectroSampson costs approximately $125.

3 Monitoring fishing activities

3.1 Vessel monitoring systems

A Vessel Monitoring System (VMS) enables the location of fishing vessels to be monitored remotely by external regulators, either in real time or retrospectively (MRAG 2003). Since its introduction in the 1980s, VMS has been used as an operational tool to enhance the efficiency of standard monitoring, control and surveillance (MCS) activities. A VMS complements existing MCS programs, significantly enhancing the coastal state’s resources for regulating fishing activities within its EEZ and other boundaries. By providing automated monitoring of vessels locations and activities, VMS provides cost effective and efficient support for rapid identification of potential infringements, which can then be targeted for further investigation. The position reports sent from the vessels, in quasi-real-time, give the fisheries managers a view of the current status and historical patterns of vessel activity. The term VMS has become synonymous with a satellite vessel monitoring system with a number of different satellite networks providing the position fixing and the communications functionality for the vessels. However, a VMS can obtain vessel position reports from a variety of sources including VHF radio transponders, via mobile phone short message service (SMS) messaging or at the simplest level by voice reporting. The feature of automated reporting of vessel location sets VMS apart from more traditional systems. In some systems, the management agency can poll vessels by remote control.

3.1.1 Positioning

Position fixing in a VMS can be achieved through an interface with any existing positioning system with the required accuracy. Satellite systems with this capability presently include the NAVSTAR Global Positioning System (GPS) operated by the Interagency GPS Executive Board (IGEB), the Russian GLONASS (GLObal NAvigation Satellite System) and the US Argos doppler based system (ArgoNet) operated by NOAA. Land based systems such as RADAR used in conjunction with a tagged vessel system (to uniquely identify the vessel) could also be used (MRAG 2003). In the future the European GPS project (Galileo) may provide an alternative option for geographical position determination, although at present there is some uncertainty about the future of this project.

Although there are a number of potential position fixing solutions for a VMS, the only two really potentially viable services available at present are the NAVSTAR GPS System and the Russian GLONASS. Both of these use networks of about 24 orbiting satellites in a variant of different planes. Each of the satellites transmits radio frequency timing and navigations signal. The vast majority of current VMS applications are based on the US standard positioning service.

Generally a transponder unit located on the vessel uses either an external positional data feed, or an integrated internal unit to record positional data, with associated date and time of the reading for subsequent transmission to a fishery monitoring center (FMC). The vessel's existing GPS navigational systems may provide the external feed or the transponder may have an integrated GPS receiver and antenna (internal or external). In theory, future VMS applications could use an alternative positioning system, such as a land or space based RADAR system, which forwards the vessels detected position to the on-board vessel transceiver unit (or direct to the FMC should the legislation permit).

The NAVSTAR GPS is, in the first instance, a military navigation system designed, financed, deployed and controlled by the U.S. Department of Defense. However, although the primary goal of GPS is to provide land, air and marine positioning capabilities to the U.S. armed forces and its allies, GPS is freely available to all users. It now provides an improved guarantee of 36m horizontal accuracy at a confidence level of 95% when all satellites in view (IGEB, 2001). Allowance must be made for loss of satellites, although the standard dictates this level of service for 90% of the time in any 24 hour period in the worst case location (99% average location). In effect, it is our understanding that a perfect antenna and GPS receiver would expect to receive information from the Satellite constellation that was accurate to 36m at a confidence level of 95% anywhere on the earth, for 90% of the time in any 24 hour period (MRAG 2003).

Practical issues of cost and transmission speed introduce a source of error in VMS position reports (MRAG 2003). Data transmitted from the transceiver units across the satellite network to the FMC are encoded in binary data packets. In this respect, binary data has a finite precision unlike a continuously variable analogue signal. In its current form, for example, the Inmarsat data packet assigns only enough data units to allow position to be recorded to the nearest 0.04 of a minute, which equates to about 75m at the equator. Similarly the ArgoNet system resolves positions to only 1000^{th} of a degree (~ 55 m). The resolution of reporting provided for by the EutelSat network is not yet known.

3.1.2 Communications

The general pattern of operation is similar for the several different satellite communication networks (e.g. Argos, Inmarsat and EutelSat) (MRAG 2003). A transponder on a vessel obtains its position from a GPS satellite, either directly or through the vessel's own GPS unit, and then relays this information along with an identifying code and the current date and time via a satellite communications network to a land earth station (LES). The LES then forwards this position report to the VMS, either via a direct connection or as a secure email/telex. The position report is then read into a database and displayed on a screen for a user to see. A typical VMS is shown in Error! Reference source not found. for a VMS system operating on an orbiting satellite network (a Geo Stationary satellite would however transmit directly to an LES and not between satellites as displayed). The main difference between satellite communication networks arises because of the orbital characteristics of the satellite.

Geostationary satellites (e.g. EutelSat and Inmarsat) are continuously available and have a permanent footprint within which data can be transmitted almost in real time (MRAG 2003). When a vessel moves outside the footprint area of coverage a message can be transmitted only if it is within the footprint of another satellite. Outside of the footprint of geostationary networks a vessels position cannot be monitored until it returns to a position within the footprint. The Inmarsat network covers almost the entire globe, the only exceptions being near the two poles. By contrast, orbiting satellites such as those that make up the Argos network operate in a store and forward fashion. As the satellite orbits and a vessel come into 'view' the messages are sent from the vessel to the satellite. The messages are stored into the satellite until it a ground station comes into view (typically after about 20 minutes) when the stored data are forwarded back to earth.

NOAA Fisheries has approved the following VMS service providers for US fisheries in the EEZ (http://www.nwr.noaa.gov/1sustfsh/groundfish/VMS/VMS_Type_approval_notice.pdf):

Telenor Satellite Services - http://www.telenor-usa.com
Xantic - http://www.xantic.net/ or http://www.landseasystems.com
Orbcomm – http://www.orbcomm.com
Satamatics - http://www.satamatics.com

3.1.3 Uses and limitations of VMS

The value of a VMS as a monitoring tool, to provide near-real-time information on the position and activities of vessels in the fishing fleet, is clear. The detailed effort data provided by VMS have many valuable applications in fisheries management; for example, in the evaluation of the effects of fishing on sensitive habitats. However, a major part of the value of this tool in the enforcement of fisheries regulations depends upon the extent to which the data it provides can be used as evidence in legal proceedings against vessels that are thought to have fished in an area or at a time when they should not have. The types of fisheries offense in which VMS data has been accepted as evidence before a court can be categorized as follows:

Type of offense	Value of VMS in providing evidence
Unlawful entry into a closed area	For vessels carrying the necessary equipment, VMS is the most efficient MCS tool for monitoring entry and exit into fishing zones, and controlled zones as it is operational over the whole set of zones and for 24 hours a day. However, it provides no information on the location of vessels that are not part of the system.
Failure to properly maintain a logbook	The systematic comparison of VMS data with logbook data may detect inconsistencies in the latter. The process of comparison could be greatly simplified by the introduction of electronic logbooks
Provision of false information to the relevant fisheries administration	VMS data can be cross-checked with logbook and other data reports on catch and fishing effort (e.g. days at sea)
Tampering or interfering with the transponder	These offenses are inextricably linked to the existence of the VMS
Failure to properly maintain a functioning VMS transponder	

The VMS position reports of a vessel might well suggest that at a given time it was engaged in fishing activities in a closed area or during a closed period. However, a large number of offenses (such as prohibited gear or catching undersized fish) remain that VMS cannot identify. NOAA has successfully prosecuted a scallop fishing vessel in New England for entering a totally closed area, using only VMS data as evidence (MRAG 2003). However, to date, VMS data have not been sufficient to prove evidence of illegal *fishing* in a closed area or in a closed period in US court proceedings. The need remains, therefore, for traditional methods of surveillance, including units on land, at sea and in the air, with VMS data currently providing a supporting role.

NOAA Fisheries regulations for VMS covering fishing vessels in Alaskan waters currently require only position data on a regular schedule. This requires only a one-way communication, from the vessel to the control center. Adding two-way communication greatly expands the capability of VMS systems for a variety of additional functions. A fully functional VMS component can interface with satellite systems to provide Email, Fax, pager, telephone, SMS, Internet, X.25 data packet routing (http://www.webopedia.com/TERM/X/X_25.html), and X.400 (http://www.webopedia.com/TERM/X/X_400.html) messaging protocol. The VMS component can have full vessel and system alarms, event alarms, and full chart backgrounds. A two-way communication takes advantage of the additional capabilities for such enhancements as transmitting catch and other data from vessels, polling vessels for location at unscheduled times, search and rescue and other safety issues, fishery management issues, and business and personal communications.

Catch data. Catch, effort, and other fishery data required to be reported from vessels that are logged in an electron form, such as electronic logbooks (Section 3.4), can be transmitted from vessels to shore stations. Transmitting electronic logbook data via VMS provides for availability of real-time (or near real-time) data, fine scale spatial data, position data reported independent of the operator, and catch and effort data declared prior to boarding/inspection. Properly formatted electronic logbook data can load onto catch monitoring and management data systems without transcription errors. The Alaska Region currently requires or supports electronic catch reporting (SPELR (www.fakr.noaa.gov/er/)), but not through a system tied to VMS. Data other than catch and effort, such as video

Polling VMS with one-way communication usually reports on a set schedule. However, two-way communication allows remotely controlling the reporting schedule (FAO 1998). This is a valuable tool in fisheries management as it permits the VMS operator to vary the frequency of position information as a function of the behavior and whereabouts of a vessel. While in port, for example, the position of a vessel is useful only to confirm that it is still in port. This can be accomplished with a single, daily report. During operation in fishing grounds or, particularly, near sensitive areas, the VMS operator may require much higher frequency data. Security requirements for polling are high, to prevent unauthorized access.

Safety The Inmarsat-C system is a component of the Global Maritime Distress and Safety System (GMDSS) when configured according to rules of the International Maritime Organization (IMO) to meet Safety of Life at Sea (SOLAS) specifications (USCG 2003). Inmarsat-C is a data-only system that supports text messaging and compressed data reports. Position reports are derived from a connected or integral navigation receiver. SOLAS configurations include a distress button for emergency use, priority handling of distress and safety messages, audible alarms on the vessel, and an Enhanced Group Calling (EGC) feature enabling reception of the SafetyNET Marine Information Broadcasts. The Coast Guard has expressed concern that NOAA Fisheries VMS regulations have accepted non-GMDSS satellite systems with non-standard or one-way messaging capabilities and versions of Inmarsat-C in which a messaging unit is optional. The Inmarsat-C transceiver can provide the position reporting function either automatically or when polled but without a laptop or other messaging facility, the unit cannot send or receive messages. NMFS has made it clear that while they recognize the safety benefit of a two-way communications capability, their mandate has been limited to Law Enforcement requirements.

Fishery management One-way communication does not allow for messages to be sent to vessels from management agencies. With two-way capability, management agencies can send messages to vessels, which may prove very useful for special notifications of openings, closings, warnings of encroachments near or into restricted areas, etc. Also, vessels can provide notice or declarations when transiting the restricted area, changing from one fishery to another, and transmitting catch data in real or near-real time. An enforcement working group of the Pacific Fishery Management Council (PFMC) considered various requirements for VMS, and determined that the INMARSAT-C system flexibility to add a message terminal or a PC best met enforcement and management needs (PFMC 2002).

Business and personal communications The email, fax, pager, telephone, internet, and messaging features potentially available through VMS could enhance communications from vessel crew members with owners, family, parts and supplies services, shipyards, and others. Internet access could allow for upload of vessel data to secure website for controlled access by designated business partners of daily logs, cost allocations, safety reports, vessel positions, and other information. The fishing community has expressed significant interest in for low-cost, satellite voice communications (FAO 1998) that could become available through VMS. However, there is a concern whether the system is capable of transmitting a position report and responding to a poll, while the crew aboard a vessel is talking on the telephone. If not, telephony may be incompatible with VMS architecture.

3.1.4 Current VMS requirements for US fishing vessels

3.1.4.1 US domestic fisheries

Alaska Enforcement Division - The Alaska Enforcement Division monitors all vessels in the Atka mackerel and Cod/Pollock fisheries using VMS (http://www.nmfs.noaa.gov/ole/vms.html). Vessels provide position reports to the division seven days a week, 52 weeks per year. It is unlawful for any person to operate a vessel in any Federal reporting area when a vessel is authorized to participate in the Atka mackerel, Pacific cod or pollock directed fisheries and the vessel's authorized species and gear type is open to directed fishing, unless the vessel carries an operable NOAA Fisheries-approved VMS and complies with Federal VMS requirements (679.7(a)(18)). All vessels using pot, hook-and-line or trawl gear in the directed fisheries for pollock, Pacific cod or Atka mackerel are now required to be registered for these species. The VMS must be operable when any of these three fisheries (Atka mackerel, pollock or Pacific cod) for which the vessel is endorsed is open, regardless of the target species. If the unit malfunctions, the NOAA Fisheries Enforcement Division will determine the appropriate action on a case-by-case basis. This requirement is necessary to monitor fishing restrictions in Steller sea lion protection and forage areas (http://www.nmfs.noaa.gov/ole/Alaska/vmsfaq.html). In addition, the 2003 IPHC regulations (section 15) allow halibut fishing vessels using a transmitting VMS to obtain a waiver from clearance requirements in IPHC Area 4. The NOAA regulations require only that the VMS units are approved by NOAA Fisheries, and that the units transmit during fishing operations.

Northeast Enforcement Division - Northeast VMS regulations became mandatory in 1998 for approximately 275 limited access scallop permit holders (http://www.nmfs.noaa.gov/ole/vms.html). All vessels are required to provide at least hourly position reports, seven days per week, 52 weeks per year, primarily to monitor annual allocations of days at sea for each vessel. The VMS counts the number of days at sea, and assists in assuring that annual allocations are not exceeded. A secondary purpose of the VMS is to help determine vessel compliance with closed areas. The VMS will also provide the same services and benefits for the Northeast multispecies industry as those currently in place for the scallop industry. Participation is voluntary, however, for the Multispecies vessels. Multispecies vessels that do not use the VMS to count days at sea are subject to a call-in system.

Southwest Enforcement Division - NOAA OLE Pacific Islands Division pioneered the use of VMS in US domestic fisheries. A VMS has been operational in the Hawaii pelagic longline fishery since 1994 (http://www.nmfs.noaa.gov/ole/vms.html). Approximately 150 longline vessels are prohibited from fishing in large areas that were established to reduce localized overfishing, and to minimize conflicts with endangered species. The VMS monitors compliance with the closed areas. Since 1998, Pacific Islands Division has used the VMS to monitor, on a volunteer basis, lobster fishing vessels that operate in the Northwestern Hawaiian Islands. These vessels also use the VMS to transmit daily catch and effort information to NOAA for use in quota management. The Pacific Islands Division has also monitored the activity of 25 foreign fishing vessels. VMS installations on these foreign vessels were ordered by the US District Courts (of Hawaii and Guam) as penalty conditions for violating US fishery laws. Pacific Islands Enforcement has also studied the application of VMS in small boat fisheries, conducting a demonstration project with several "alia" fishing vessels in American Samoa. The project showed that small vessels operating in remote areas can be monitored effectively via battery powered VMS units.

Southeast Enforcement Division - The Southeast Enforcement Division is in the process of implementing the VMS requirement for the Highly Migratory Species Fishery - Atlantic and Gulf Coast (http://www.nmfs.noaa.gov/ole/vms.html). This operation will initially consist of 320 VMS equipped vessels. Additionally, Southeast Enforcement Division is preparing to launch the South Atlantic Rock Shrimp operation that will initially consist of 170 VMS equipped vessels. These programs are scheduled to begin in September and October 2003, respectively. This program will increase revenues for swordfish and shrimp fishermen while reducing enforcement costs.

3.1.4.2 Foreign and high seas fishing

International Convention for the Conservation of Atlantic Tunas (ICCAT) - ICCAT requires each member country with vessels greater than 24 meters that fish on the high seas outside the fisheries jurisdiction (Exclusive Economic Zone (EEZ)) of that country, to adopt a pilot VMS program (http://www.nmfs.noaa.gov/ole/vms.html). The 3-year ICCAT-recommended VMS pilot program was implemented October 1, 2000. Up to 300 U.S. swordfish vessels are required to carry VMS and will be monitored by the NOAA Fisheries Office for Law Enforcement.

Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) – Krill vessels may voluntarily carry a VMS unit (http://www.nmfs.noaa.gov/ole/vms.html). Vessels in all other CCAMLR fisheries are required to carry VMS as a condition of their harvesting permits. The Southwest Enforcement Division in Hawaii has been tracking one voluntary US krill vessel fishing in the convention area for the past year. The owner of the vessel also receives the vessels' position reports from NOAA Fisheries as a courtesy.

3.2 Hydraulic or engine monitoring

Remote monitoring of fishing vessel activity using directly transmitted data could assist the owners and operators of fishing vessels and companies. Monitoring equipment exists and is readily available for many key vessel activities associated with fishing operations. AMR currently uses hydraulic sensors for monitoring changes in hydraulic pressure to indicate use of fishing gear. Both AMR and Digital Observers use winch/drum counters to monitor specific equipment. Although not currently used for monitoring fishing activities, digital pyrometers are available for measuring exhaust gas temperature as an indicator of fishing activities. While many vessels operators may currently use a pyrometer to monitor exhaust temperature as an indicator of engine performance, models with an NMEA 0183 hookup would make the units suitable for electronic data logging.

More developed example applications of the necessary technology exist on land. For example, the trucking industry routinely uses sensors on engines and trailers, combined with GPS locators, to operate vehicles and manage fleets more efficiently and to meet government standards for driver working conditions. Schneider International, for example, owns 13,000 tractors (the cabs) and 42,100 trailers (the back part of the truck that carries the goods), making its fleet the largest in North America (http://www.darwinmag.com/read/090101/haul.html). Each cab is outfitted with OmniTracs, a satellite-based communications and positioning system from Qualcomm (http://www.qualcomm.com/qwbs/products/omnitracs/). A black box mounted inside all Schneider cabs has a keyboard and allows drivers to send and receive text messages to and from customer service associates. Qualcomm processes seven million data transactions every day. Schneider and Qualcomm also jointly developed a monitoring technology called SensorTracs (http://www.qualcomm.com/qwbs/products/sensortracs/), which uses electronic engine sensors to record information such as speed, rpms and idle time. SensorTracs interfaces directly with a vehicle's sensor inputs or the onboard data bus to provide RPM, speed, and idle summaries, so you can isolate vehicle operation in the driver's control. The information is delivered to dispatch at customer-defined intervals or on demand via Qualcomm's mobile communications systems. No driver intervention is necessary. The data are also displayed for drivers in real time, so they can modify driving habits immediately and meet company-set parameters. In 1990, Schneider became the first fleet to implement the technology, allowing the company to receive engine data via automatic satellite downloads. SensorTracs helps Schneider manage wear and tear on its engines and also monitors drivers. Not only can Schneider monitor the whereabouts of its trailers, a sensor unit inside the trailer can tell whether the trailer is empty or full. Another sensor mounted in the bottom of the trailer can tell whether it's hooked to a tractor.

3.3 Monitoring fishing activity using cameras

3.3.1 Canadian sablefish seamount fishery

Sablefish populations on seamounts located within between 100-200 miles offshore are generally thought to be separate from the inshore populations found along the continental slope. The Canadian Department of Fisheries has allowed a limited experimental fishery on seamount stocks under strict monitoring requirements to ensure that permitted vessels do not fish coastal stocks and that only seamount-caught fish be retained on board until the offloading. These measures were put in place to ensure clear separation between the special permit seamount fishery and the lucrative coastal quota fishery. Electronic monitoring equipment is deployed by AMR for the duration of the one-month fishing permits to provide continuous recording of GPS, hydraulic and winch activity, and imagery of the fishing deck. The electronic monitoring systems have proven to be reliable and provide monitoring at 20% the cost of an at-sea observer.

3.3.2 Canadian Dungeness crab fishery

In 2000, the Canadian DFO initiated a pot-limit control program for a Dungeness crab fishery in a specific area ("Area A"). The Canadian Government needed to monitor the number of pots deployed and the crab industry wanted to control theft of catch and gear (Howard McElderry, Archipelago Marine Research, Victoria BC, pers. comm.). An at-sea observer program could have provided the monitoring necessary to meet the requirements of both the government and the industry, but the costs of a comprehensive observer program would have been prohibitive. Monitoring with patrol boat inspections was rejected because inspections could not control fishing activities when the patrol vessels were absent. AMR worked with the industry to develop an EM system that met both demands, at a reasonable cost.

The crab EM system consists of an on-board computing system, enclosed in a locked, tamper-proof housing, and an assortment of sensors on the fishing deck and other parts of the vessel (McElderry 2003). One of the main features of the system is a time-lapse closed circuit TV (CCTV) camera system that provides a continuous record of fishing deck activities. The mast-mounted camera provides imagery of various fishing operations including, gear setting, hauling operations, retention and discard of catch, and gear identity, as revealed by vessel specific buoy colors. Computer-based digital video technology far surpasses the capabilities of the VHS tape-based predecessor, allowing rapid search and viewing of specific imagery. Also, digital imagery can be authenticated to ensure origin and integrity of data.

The crab EM system also includes radio frequency identification (RFID) for crab pots, a camera to monitor deck activity, a GPS receiver, and a hydraulic pressure transducer for the pot hauler. A small RFID chip is imbedded in the buoy of each crab pot, and the buoy is passed near an RFID scanner to generate a time-date-location stamp when set and retrieved. The hydraulic sensor also determines when hauling and setting occur. A computer program checks each hauling event for an RFID scan, and the camera can document any fishing activity that occurs during an anomalous hauling event. The GPS receiver determines location of fishing activity. The fishery consists of about 34,000 pots and 0.5 million scans per year. The system tracks deployment of all individual pot sets at an annual cost of about CDN$10 per pot, or about 20% of the cost of at-sea observers. AMR has analyzed the RFID scans, looked for anomalies, and reviewed the camera images to determine if fishermen scanned all pots. By plotting station tracks through GIS and reviewing sensors on fishing gear, analysts could determine when pots should be scanned; if scan did to appear in the data, video monitoring could determine if pots were pulled without scanning. Diverting from a normal track line or spending long periods in a location would cause an analyst to review the video to determine if a fisherman pulled pots belonging to someone else and did not scan them.

The crab EM system satisfies the requirements of both the Canadian Government and the industry. However, in spite of the success of the program and the support of the Area A fishermen, only the Area A fishermen have adopted the EM program (Howard McElderry, Archipelago Marine Research, Victoria BC, pers. comm.).

3.3.3 Work in development and application to other fisheries

3.3.3.1 Monitoring seabird avoidance devices

NOAA Fisheries contracted with IPHC to test EM on halibut vessels (Ames 2004; Ames *et al*. 2004) with a goal of monitoring 1) the use of seabird avoidance devices, and 2) the seabird bycatch. Video observers and at-sea observers had 100% agreement detecting bird avoidance devices for daytime sets.

Testing of ability to detect and identify seabirds caught on longline gear was tested by placing 63 previously caught and frozen seabirds on hooks during setting. Video observers correctly identified as birds 91% of the birds place on the longline sets, but correctly identified the birds to species in 64% of the cases. Higher-speed recording enhanced the ability of video observers to identify birds.

3.3.3.2 Longline hook counter

Digital Observers is working on a stand-alone hook-counting device for longline vessels (Mark Buckley, Digital Observers, Kodiak AK, pers. comm.). The intent is to be able to track every set during a fishing trip as a discreet event and to count every hook that goes over the stern during each set. The hook counter would indicate that fishing activity has started, and could link to camera monitoring or hydraulic sensors/revolution counters to provide information about fishing activity (e.g., soak time). Hook counts also provide a measure on effort. The prototype hook counter uses a laser beam aimed at a receiver deployed at the stern of the vessel. During setting of the longline, the gangion flies up, and breaks the laser beam. The laser is positioned to avoid counting snarls and tangles. A connection to a GPS provides date, time and location for the beginning and end of a set. A test of the prototype occurred during October 2003. The hook counter worked as expected for about half of the experimental trip, and then stopped working altogether. Digital Observers sent the prototype back to the manufacturer to determine the cause for the failure and to modify the design to improve robustness.

3.3.3.3 Presorting in the Pacific whiting fishery

The Pacific whiting fishery off Washington and Oregon was identified as needing at-sea monitoring because of concerns about accurate estimation of catch and bycatch. Short fishing trips of less than a day and departures frequently with little notice made the use of at-sea observers problematic. An experiment with EM by AMR aboard a US west coast whiting vessel in 2002 demonstrated that wide angle camera images could ensure that all catch was retained aboard as required (http://www.archipelago.ca/em-projects-whiting.htm). Based on the pilot project conducted in 2002, electronic monitoring systems are being considered as a monitoring option for the shore-based whiting vessels to verify whether all catch is retained and/or identify the frequency of catch being discarded at sea. The West Coast Groundfish Observer Program will fund electronic monitoring systems being placed on all shore-based whiting vessels during 2004 to evaluate whether these systems can be useful tool to verify full retention of catch (Carrie Nordeen, NWFSC, Seattle WA, pers. comm.).

The AMR experience with EM of the halibut longline fishery and the crab fishery also suggests that cameras have sufficient resolution and coverage to monitor fisherman activity sufficiently to detect unauthorized discards. Determining the practicality of using cameras to monitor presorting, however, will take considerable experimentation. The layout of deck and factory will vary from vessel to vessel and structures that obscure the camera's view of the flow of fish could allow fishermen to presort unobserved. These and other factors will affect the amount of coverage necessary, and will require careful consideration prior to full implementation. A subsequent discovery of a blind spot in camera coverage for a vessel could bring into question previous data collected by the camera for that vessel.

3.4 Electronic logbooks

Electronic reporting of scientific, commercial, and recreational fishery data is increasing around the world. In many cases, electronic logbooks have been designed for management use to meet statutory data reporting requirements (vessel, gear, catch, effort, location, etc.). Electronic logbooks provide for easier data entry by fishermen, with fewer transcription errors from paper copies to electronic formats, and seamless downloading directly into to management databases. These features make the data much more useable for management and scientific purposes. Electronic logbooks combined with VMS position data would enable managers to attribute landings to specific areas, in much more detail than currently available. While electronic logbooks could be formatted to incorporate data collected by observers, this function is not explicitly discussed in this report, because NPGOP observers currently enter and transmit data through the ATLAS system.

Electronic logbooks also provide fishermen and fishing companies with a way to monitor fishing operations. The commercially-oriented logbooks range from simple formats with limited information entry to complex with options for extensive data entry. In some cases, management agencies enter into agreements with fishermen, who voluntarily provide logbook data. If fishermen find the electronic logbooks useful, they will more likely agree to support them, even with a government requirement to submit them to management and regulatory agencies. A number of management- and commercially-oriented logbooks are in various stages of implementation and development around the world. Virtually all systems are in some state of continued development.

Electronic logbooks have the capacity to collect and log data from various sensors. All sensors and data export systems used for on-board computer data logging should be compatible with

NMEA standards 0183 or 2000 (http://www.nmea.org/pub/index.html). The NMEA 0183 Interface Standard defines electrical signal requirements, data transmission protocol and time, and specific sentence formats for a 4800-baud serial data bus. Each bus may have only one talker but many listeners. There is also a high-speed addendum, NMEA 0183-HS Version 1.0, to Version 3.01 of NMEA 0183. This standard operates at a 38.4K-baud rate. Specific sentence formats are common to both NMEA 0183 and NMEA 0183-HS and are defined in the NMEA 0183. The NMEA 2000 Standard contains the requirements of a serial data communications network to inter-connect marine electronic equipment on vessels. It is multi-master and self-configuring, and there is no central network controller. Equipment designed to this standard will have the ability to share data, including commands and status with other compatible equipment over a single channel.

3.4.1 Alaska Region Electronic Reporting System

The Alaska region of NOAA Fisheries has developed an Electronic Reporting (ER) System that is currently operational for the Alaskan groundfish fisheries (www.fakr.noaa.gov/er/). The ER System was developed by NOAA Fisheries to allow shoreside processors and processing vessels to submit Federal reports to NOAA Fisheries by electronic means. The Alaska ER system requires fishermen to type in all entries; no data are automatically recorded. The ER system is replacing the paper-based system of record keeping and reporting that was implemented in the late 1980s. This system required vessels and processors to maintain paper logbooks detailing fishing activity and catch. Processors summarized the logbook on a weekly basis and faxed a weekly production report (WPR) to NOAA Fisheries for entry into the database. Using the ER system processors can submit reports via e-mail or directly from their computer using a modem. The ER System is intended to help processors by making the reporting process simpler and more accurate. The ER System also helps NOAA Fisheries because the catch data reported by the processing vessels are downloaded directly into the NOAA Fisheries database. This eliminates the potential for data entry errors, which existed previously when NOAA Fisheries staff entered catch data into the database from the paper records.

The manager of a shoreside processor or stationary floating processor receiving groundfish from AFA catcher vessels or receiving pollock harvested in a directed pollock fishery is required to use the shoreside processor electronic logbook report (SPELR) or NOAA Fisheries-approved software to report every delivery from all catcher vessels (50CFR579.5(a)(4)). The owner or manager of a shoreside processor or stationary floating processor that is not required to use SPELR may use, upon approval by the Regional Administrator, SPELR or NOAA Fisheries-approved software in lieu of the shoreside processor Daily Catch Production Log (DCPL) and shoreside processor Weekly Processor Reports (WPR). Very few shoreside processors still use WPR, as most have converted to SPELR. Catcher-processors and motherships do not have requirements for ER, but may use electronic reporting for providing WPR to NOAA Fisheries.

The ER System consists of two principal components (www.fakr.noaa.gov/er/). The electronic reporting Client software is used by personnel on a vessel or at a shoreside processing facility to enter data and transmit data to NOAA Fisheries. The electronic reporting Host software runs at the NOAA Fisheries Alaska Region office in Juneau, Alaska. The electronic reporting Host system receives and logs transmitted files, validates the data, loads the data into an Oracle database, and sends a return receipt report to the vessel or processing plant informing them of the status of their submission. The client software consists of a shoreside logbook and a processor vessel logbook.

Logbook record keeping and reporting are required for fishing vessels greater than 60 feet in overall length that participate in the BSAI and Gulf of Alaska groundfish fisheries (http://www.afsc.noaa.gov/Quarterly/jfm03/divrptsREFM3.htm). OceanLogic, an information technology consulting company in Juneau, Alaska has developed an electronic logbook for catcher vessels. The logbook was specifically developed to replace the NOAA Fisheries-mandated Daily Fishing Log (DFL) for Alaskan fisheries in state and Federal waters (Robert Mikol, OceanLogic, Juneau AK, pers. comm.). The logbook collects, stores, and archives a vessel's fishing data for compliance and analysis. NOAA Fisheries has approved the OceanLogic electronic logbook system as an alternate to the DFL. The electronic logbooks are currently compliant only for trawl catcher boats, but OceanLogic is working to make them also compliant for catcher-processors and motherships. Applications for other gears may be developed in the future. Electronic logbooks are an efficient method to provide improved access to more accurate and complete information on the fishing process. In addition, electronic logbooks store data in a format that allows vessel operators to use the data more easily and more productively to monitor and improve their own fishing operations. The OceanLogic electronic logbook could also perform as a data logging system for fishing activity data by polling sensors on board the vessels (Robert Mikol, OceanLogic, Juneau AK, pers. comm.).

NOAA Fisheries purchased 50 of the OceanLogic electronic logbook systems and provided them free to vessel owners who participated in research during 2003 to test observer deployment procedures as an alternative to the current method (David Ackley, NOAA Fisheries, Juneau AK. pers. comm.). The research tested use of a protocol to distribute observers more evenly across a fishery, in this case the rockfish-flatfish trawl fishery near Kodiak. More detailed location information available from the logbooks may allow for an analysis of spatial distribution of bycatch, although no such work has as yet occurred. Approximately half of the vessels voluntarily used the OceanLogic electronic logbook. NOAA Fisheries identified two limitations on using the electronic logbook (David Ackley, NOAA Fisheries, Juneau AK. pers. comm.):

1. Some of the data entered in the electronic logbook is self-reported. The self-reported information included errors, especially in reported target fishery. Without a program to reduce errors, NOAA Fisheries would not favor self-reporting of target fishery.
2. Most of the vessels lacked the ability to transmit data directly from the boats. The data were stored, transferred to plant or NMFS personnel, and then transmitted to NOAA Fisheries. No explicit infrastructure for data transmittal has been developed, and the existing infrastructure did not run smoothly.

3.4.2 Other regions

Currently, no region of the US other than Alaska requires electronic reporting of catch or production records. However, several systems are in development or are ready for application, as described below.

3.4.2.1 NOAA Fisheries Northwest Region

The NOAA Fisheries Northwest Fisheries Science Center has developed an electronic logbook – the Electronic Fish Catch Logbook (EFCL) (http://www.nwfsc.noaa.gov/logbook/index.cfm) – through partnership with Scientific Fisheries Systems, an information technology consulting company in Anchorage Alaska (http://www.scifish.com/newWeb/productIndiv.py?11). Most of the data would be entered by fishermen, and the system also allows for entry of observer data. The system has the capability of logging environmental data, such as temperature and conductivity, collected by sensors. The EFCL electronic logbook could also perform as a data logging system by polling sensors that monitor fishing activity. Sensors may be connected directly to the system, or data may be downloaded periodically from the sensors to the logbook. GPS data are collected automatically.

However, funding for completion of the EFCL is limited; NOAA Fisheries is currently trying to finish the system development and then turn the project over to others for implementation (Linda Jones, NWFSC, Seattle, WA, pers. comm.). A write-up for documentation of the project is underway, but has been delayed by personnel changes at NWFSC. A small pilot program to test the system for processors in California is in the planning stage, but a date for the test has not been set. The NWFSC has no plans for tests on vessels.

3.4.2.2 NOAA Fisheries Northeast Region

During June-September 2002, an electronic logbook reporting system was implemented in a study fleet of commercial vessels that fished for Northern shortfin squid (*Illex illecebrosus*) in the Northeast Region (http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0307/crd0307.pdf). Project objectives included the design of an electronic logbook reporting system that would fulfill the existing regulatory requirements for logbook reporting and that would improve the resolution, quality and timeliness of fishery data for stock assessments. The data collection process involved at-sea and web-based components. Catch, effort, depth, water temperature and location data were collected in real-time by vessel operators, on a tow-by-tow basis. Data were transmitted via e-mail to the Northeast Fisheries Science Center following each tow and at the end of each day by a satellite service provider and entered into an Oracle database. Upon completion of a trip, vessel operators logged onto secure, personal web sites that were password-protected and then verified the data entered at sea, assigned tows to specific trips and entered supplemental data required to meet existing logbook reporting requirements. The web site included an interactive mapping program that allowed vessel operators to visualize the spatial distribution of their data and to query their data to produce hardcopy logbook reports. The study demonstrated that electronic logbook reporting offers an efficient, cost-effective means of collecting accurate, high resolution fisheries and oceanographic data that are useful to fishermen, stock assessment scientists and fisheries managers.

3.4.2.3 Maine

Thistle Marine of Ellsworth Maine has developed a series of simple electronic logbooks designed for specific fisheries: lobster, crab, and multipurpose (www.thistlemarine.com). The unit connects to power and an onboard GPS using cabling supplied by Thistle Marine. Fishermen manually enter the type and quantity of the catch found, including retained and discarded catch. The GPS location is recorded automatically after each haul when fishermen enter data. Data are sent by the fishermen to Thistle Marine over a phone connection. Thistle Marine analyzes the data and sends reports back to the fishermen either via US Mail or the Internet. The Maine Department of Marine Resources (DMR) considers that Thistle Marine electronic logbooks could be a valuable assessment tool, and is asking lobster fishermen to voluntarily provide electronic logbook data to the Department (http://www.state.me.us/dmr/Lobster%20Newsletter/Newsletter_feb_2002.htm#Thistle%20Marine%20Electronic%20Logbooks—Carl%20Wilson). To date, DMR has distributed approximately 75 units to fishermen from Maine to Massachusetts, and pays all costs associated with this program, including the cost of the box, installation and monthly fees, for those who volunteer data.

3.4.2.4 Science Applications International Corporation

The Automated Fishing Surveillance System (AFISS) was developed by Science Applications International Corporation (SAIC) of California to provide information on fishing activity, environmental and sea surface conditions in addition to vessel position data (http://www.saic-marinesciences.com/saic_marinesciences/pages/commercial_fisheries.htm). AFISS resides within a compact enclosure composed of an embedded microprocessor, a flash RAM memory card, several interfaces and a COTS Inmarsat transceiver. The embedded device contains the AFISS logic routines and sensor interface programs. The logic determines when the vessel is fishing by monitoring input from a winch sensor, and records the vessel's GPS position and time during trawling activities. After each haul the catch and by-catch information can be entered on a portable touch-screen device and transmitted along with the position information through the Inmarsat satellite system. The AFISS logic routines also save the position and sensor information to the memory card at sampling intervals defined within the program. The sampling intervals can be changed remotely. During trawling or long-lining activities vessel position, sea surface information like conductivity and temperature data are recorded and transmitted at pre-programmed intervals. In addition to the position data recorded by AFISS, the cumulative distance and speed-over-ground are also logged to memory during each haul. Data storage capacity within AFISS is sufficient to store two to three months of hourly records along with vessel position and sensor information. The memory cards store the data in ASCI-II format, and have a capacity of 80 megabytes. The AFISS program contains communications routines, which allow the stored data to be e-mailed when polled with the Inmarsat transceiver. Vessel position, speed, total distance, time and sensor data are transmitted after the haul with the catch information. Although SAIC has demonstrated AFISS, it currently has no users of the system (Stephen Pace, SAIC, pers. comm.).

3.4.3 Examples from outside the US

3.4.3.1 SHEEL, European Union

The European Union has begun development of a Secure and Harmonized European Electronic Logbook (SHEEL). The goal of this project is to develop and demonstrate an operational, cost-effective and secure electronic transfer system that will convey logbook information to and between authority agencies in order to facilitate improved monitoring and control (http://intelligence.jrc.cec.eu.int/fisheries/sheel/index.htm, http://intelligence.jrc.cec.eu.int/fisheries/sheel/workshops/ispra_abstracts.htm). SHEEL is intended to improve quality and accessibility of logbook data. In its final form, SHEEL is intended to encompass all the existing manually treated reports that the skipper has to fill in. At the same time, the continuation of all the existing legislation on fisheries management and enforcement has to be guaranteed. The program will evaluate and test a number of on-board software packages already developed for supporting skippers of fishing vessels on their daily catch recording. Such packages vary from very simplified to very sophisticated. Vessel owners and skippers will participate in the development as the system is designed to be useful to fishermen as well as to management and enforcement.

3.4.3.2 Australia

The Australia Fishery Management Authority (AFMA) has set standards for electronic logbooks to be compatible with its databases; however, no mandatory electronic reporting occurs in Australia. (http://www.afma.gov.au/services/data/electronic/vendor/default.php). If fishermen wish to use electronic logbooks to submit required data, they must use an electronic logbook that meets the standards. Software developers wishing to develop an electronic logbook returns system must test their software with AFMA to demonstrate that the software will send electronic logbook reports which meet the AFMA specifications. AFMA has developed a set of performance measures that a software product must meet before AFMA will accept returns from these software products. Many of the electronic logbook reporting data specifications are fishery specific. AFMA is developing specifications for each fishery progressively. Specifications are developed when there is sufficient interest from a fishery. At least two systems – the OLFISH (Section 3.4.3.3) and the ECERS (Section 3.4.3.4) – have been approved for use in Australian fisheries.

3.4.3.3 OLFISH, South Africa

OLRAC, a fishery consultant group in South Africa, has created two commercial logbook systems: OLFISH-longline and OLFISH-trawl**,** software programs for capturing, storing and summarizing fishing data (http://www.spss-sa.com/olfish/software/body1.htm). The systems can be used by fishermen, managers, and scientists for longline and trawl operations and scientific surveys. Manually entered data include

- information about the company, factory, vessel, the start date of the trip and total fuel consumption of the trip;
- general information such as gear, bait, hooks, electronics and setting co ordinates;
- setting activity records such as setting distance, fishing depth and location, bearing, time type of fishing;
- hauling activity records such as location, bearing, time, and duration of haul, environmental data and catch data;
- environmental records of sea and weather conditions, and water and sea bottom physical characteristics

- catch data sheet records of quantity of processed fish products, skippers' catch estimates and fish sizes.

The GPS software component of the software is linked continuously to the GPS readout and a facility in the relevant data screens transfers this data into the database at a time chosen by the user. Alternatively GPS coordinates, date and time information can be input manually.

OLFISH is being presently tested, intensively in Australia, New Zealand and South Africa. In Australia, OLFISH was adopted as the electronic replacement of the logbook program by South East Trawl Fishing Industry Association and it complies fully with all Australian Fisheries Management Authority reporting requirements.

3.4.3.4 ECERS, Australia

The TerraSystems Group of Western Australia developed an Electronic Catch and Effort Reporting System (ECERS) used by the vessel's skipper to comply with regulatory requirements and assist owners and skippers to plan fishing operations (http://www.sat.com.au/ecers/ecers_index.htm). Catch data are entered on forms that perform the function of a logbook, with the ability to generate graphical plots and catch and effort reports in either electronic or paper form. Different data entry forms are available for different operations and reports. The appearance of these forms and reports is consistent throughout, providing the same data form for both the vessel's skipper and the land-based computers, irrespective of the type of data sent. Both the Form designs and the data entry configurations are customizable.

ECERS will provide real-time validation of Catch Positions against VMS Positions and validation of Catch against spatial status models using the VMS route to determine the catch prediction. It will maintain a database table of computed reliability indexes against each catch report, having compared a catch report against a spatial model. ECERS contains software for the vessel, the fleet owner and the fishing authority, all connected via an Email network. This allows a report submitted by a skipper to the fishing authority to be simultaneously copied and collated to a fleet owner and the skipper's home or office. Inspection Vessels can also utilize the software whereby the fishing authority can forward incorrectly validated Catch reports to provide targeted response and reasonable cause for catch inspections. Microsoft Outlook provides a robust MAPI environment offering both email spooling and encryption features. The Satlink Email system is recommended to submit catch and effort reports via Inmarsat-C.

3.4.4 Summary of benefits of electronic logbooks

Electronic logbooks are expected to have several critical advantages over hard copy logbooks with respect to providing data for fishermen, fishery research, and management (http://www.afsc.noaa.gov/Quarterly/jfm03/divrptsREFM3.htm, http://www.nwfsc.noaa.gov/logbook/lbdraft.cfm).

- Electronic Logbooks will make it easier for vessel operators to access and use their own data because they will be in an electronic format that can be used by a variety of existing and planned software packages. Fishermen can track catches against quotas, transmit and receive marketing information, log information that affects fishing performance, and log economic information. For example, the European Union (EU) is currently finalizing the regulatory framework on labeling, food hygiene requirements and traceability (FAO 2002, http://www.fao.org/docrep/meeting/004/y3015E.htm). Traceability is defined by the International Organization for Standardization (ISO 8402:1994) as the "*ability to trace the history, application or location of an entity by means of recorded identification.*" The enforcement of traceability implies the development of systems giving information on the entire life cycle of food products, "from the farm – or the sea – to the fork." The European Commission-funded Concerted Action QLK1-2000-00164 "Traceability of Fish Products" (TRACEFISH) gathers 24 companies and research institutes from all over Europe to find common views on data which should follow fishery products from harvesting to the consumer. TRACEFISH seeks to achieve an electronic system of traceability where commercial partners transmit information on the fish they handle to a database through a unique electronic identifier applied to each package of fish (http://www.tracefish.org/). The US is also considering labeling and traceability requirements for food products. An electronic logbook compatible with traceability requirements would assist fishermen in complying with labeling requirements in the US and abroad.

- More timely data will be available to NOAA Fisheries managers and scientists because the data will be submitted more frequently and quickly and entered into a database automatically shortly after being received. With hard copy logbooks, vessel operators are required to submit copies of their logbook data to the Region within one month of the end of each quarter; therefore, timely data are not available even in a hard copy format. An end of trip transmittal could serve as a prior notification of landing to allow port samplers or enforcement officers to efficiently schedule activities.
- The quality of the data that are submitted to the Region will improve. First, the time and location for each haul set and retrieval are entered automatically using data from the vessel's GPS system. The vessel operator simply pushes a button at the beginning and end of each haul. Second, manually entered data can be validated for the use of correct codes or ranges of values. Third, the software that has been developed by the Region to receive the electronic logbook data checks for errors; and, if errors are found, the errors are flagged and sent to the vessel operator who submitted the data.
- The electronic logbook system can provide more information than is available from the hard copy logbooks. The data recording software that has been developed by OceanLogic automatically and frequently collects vessel location information during each tow. The logbook data currently includes just the set and retrieval locations, not frequent vessel location data.
- Increased timeliness, reduced errors, higher quality, and more information will improve understanding of fishing effort and CPUE and improve stock assessment.

3.5 Gear measurement

Scanmar, Simrad, Wesmar, and Northstar develop and sell systems for mobile fishing gear, primarily trawls, which allow monitoring of various sensors related to fishing activities. These systems use third wire or acoustic links to send signals from specific sensors mounted on the trawl net to a receiver that logs the information to a computer. NOAA Fisheries, other research agencies, and commercial fishermen successfully use these systems to improve performance of trawl nets. The price varies for different components and manufacturers, and can range from several thousand dollars per component to 10s of thousands of dollars. These systems are not applicable for fixed gears such as pots and longlines. However, some technologies, such as RFID, are applicable to fixed gear.

3.5.1 Scanmar trawl monitoring

The Scanmar net measurement system consists of an array of sensors that allows for measurement of trawl net configuration in great detail, and for data logging into a computer. The sensors monitor depth off bottom, time on bottom, net symmetry, record of catch per haul, foot rope-head rope distance, distance between doors, trawl speed, etc. Scanmar does not have a sensor that directly detects bottom contact, but the "trawl sounder" sensor monitors foot rope location and the degree of bottom contact.

The Scanmar system comes in three configurations (http://www.scanmar.no/): ScanMate4 monitors four of the sensors, ScanMate6 monitors 6 of the sensors, and ScanBas monitors all available sensors. Both commercial fishermen and the research community use the Scanmar systems. The NOAA Fisheries Alaska Fisheries Science Center (AFSC) uses Scanmar systems on research vessels to monitor fishing activity.

3.5.2 Simrad trawl monitoring

Simrad has three net measurement systems designed for commercial fishing (http://www.simradusa.com/index.php?sub_it=commpro&page=page&c=3); two wireless systems and one with a third wire.

The FS20/25 Series trawl sonar is the Simrad third wire system, which provides real-time images from the trawl sonar heads and data from the sensors to the bridge. This system has been around for many years, but has received periodic updates. The FS series primarily provides visual depiction of the geometry of the mouth of the net; however, the system can measure trawl depth, bottom temperature, and sense the catch in the net. It has limited capability for data logging.

The Simrad ITI is a complete wireless trawl positioning and monitoring system designed to improve control and efficiency in pelagic and bottom trawling. Small battery powered sensors mounted on the trawl, transmit important information to the vessel on request. While the ITI system provides full visual display, data from the sensors and navigational instruments, logged in real time, gives valuable information of the trawl hauls. The ITI provides temperature, depth, distance and bearing of the sensors to the trawl, door spread or wing spread, and the catch.

The Simrad PI system is Simrad's new generation of wireless net measurement systems. It has modular sensors for net spread, headrope and footrope markers, bottom contact, depth, and temperature. The Simrad PI32 interfaces to Simrad echo sounders and sonars. One version is wireless, and another uses a third wire. The trawl measurement system has serial lines for interconnection to a data logger. Sensors use replaceable, rechargeable batteries.

The Simrad bottom contact sensor is part of the Simrad PI 32 trawl measurement system. The bottom contact sensor is attached inside the net on the bottom meshes immediately behind the middle of the footrope (http://www.simradusa.com/index.php?sub_it=docs&page=page&c=16). A heavy weight hangs through a penetration ring in the net, attached to the sensor with a detection chain and attached to the footrope with a stay. The sensor sends a signal to the receiving unit when bottom contact with the weight releases tension on the detection chain. The sensor sends a signal whenever tension is released (on bottom) and stops sending when tension occurs (off bottom). Bottom sensors can detect bottom contact with a precision of a few centimeters when correct stay and detection chain lengths are used. Optimal sensor performance requires that these lengths are configured with regard to both each other and the size of the bobbins or rock hoppers used on the trawls: bottom detection distance is relative to the diameter of the rock hoppers, bobbins or other gear in use. The computer on board that controls the PI 32 system logs the signals that indicate bottom contact.

3.5.3 Wesmar trawl monitoring

The Wesmar TCS770 is a third wire system that combines forward looking and profiling in one headrope unit (http://www.wesmar.com/trawl.html). Its split screen feature allows measurement of the net opening, profile of fishing circle, door spread, and other gear geometry. Catch sensors continuously indicate the amount of fish in the codend. A sonar component monitors the shape of the net. Wesmar does not have a sensor that directly detects bottom contact, but a down sounder sensor monitors foot rope location in relation to the bottom, and indicates when the foot rope contacts the bottom.

3.5.4 Northstar trawl monitoring

Northstar Electronics developed the NetMind trawl monitoring system with an acoustic link from the sensors to a hydrophone to measure parameters of commercial fishing nets and transmit the information back to the ship. The information is processed on a deck unit, displayed on a computer screen to enable the captain to see what activities are occurring in the net. The system has sensors for headline height, door spread, wing spread, temperature, and catch. NetMind does not have a sensor that directly detects bottom contact, but a down sounder sensor monitors foot rope location in relation to the bottom, and indicates when the foot rope contacts the bottom.

3.5.5 Other gear monitoring

RFID chips, about the size of a quarter, inserted into pot buoys can monitor the utilization of the gear (Howard McElderry, Archipelago Marine Research, Victoria BC, pers. comm. (see Section 3.3.2)). The chips largely eliminate pot robbing – a feature important to fishermen – and allow monitoring of pot numbers deployed against limits – an important feature for management. These features of the RFID chip work effectively with single pot per buoy, but would not monitor pot usage as well with multiple pots per buoy.

3.5.6 Work in development and application to other fisheries

The AFSC has developed a prototype scientific bottom sensor for use with trawl surveys to document the time of trawl contact with the bottom (Craig Rose, AFSC, Seattle WA, pers. comm.). The bottom sensor dangles from the foot rope, and tilts on contact. The sensor makes an electronic record of the time and location when tilting occurs. The data records stay within the sensor until downloaded to a wand that can transfer the data to a computer. The sensor weighs about 15 pounds and measures 3 inches by 12 inches.

Echosounders used for commercial fishing have improved substantially in quality in recent years. Some are approaching the quality of scientific echosounders (Bill Karp, NOAA Fisheries, Seattle WA, pers. comm.). Data logging of these echosounder records is routine. Acoustic data collected during normal fishing operations have been used for stock assessment and management. Approaches have ranged from extraction of subjective relative abundance and distribution information from uncalibrated echosounder displays to absolute biomass estimation from calibrated commercial or scientific sounders connected with data logging devices. As information needs expand and instruments capable of collecting scientific-quality acoustic data become more widely available, the need to evaluate the success of these approaches and consider factors which may influence data quality has become apparent. Most use of this technology will apply to providing temporal and spatial density distribution useful for stock assessment. While data logging echosounder data is likely more useful for scientific work than for fishery monitoring, it may be possible to relate fishing behavior with fish distribution.

4 Predicting bycatch for unobserved vessels

In this section of the report we discuss the various approaches that can be used to predict catch quantities for unobserved vessels. Use of various electronic monitoring and data logging systems will provide a suite of data, such as depth, precise location, fishing duration, and gear operation characteristics, for both observed and unobserved vessels. When combined with information collected from all vessels (size, gear, retained catch) and information collected from observed vessels (biological characteristics, total weight, species composition, bycatch, and discards), several approaches exist to predict the bycatch of unobserved vessels (Section 4.6). The approaches described below can be used to make estimates on a fleet-wide basis, on a co-op or other grouping basis, or on an individual vessel basis. The difference is a matter of aggregation of the data. The statistical approaches are not trivial, but are fairly well known. However, selecting the proper attributes to assure homogeneous categories for characteristics of interest is critical. For example, including attributes not related to differences in bycatch rates could result in clear, discrete groupings, but ones that don't represent similar bycatch rates. Demonstrating that attributes are applicable to the estimate required may be more difficult than developing the classification tree.

In combination, the various intensities of observer coverage – 100% (or "200%" in the case of two observers) to unobserved – present a complex array of issues to be addressed in consideration of bycatch prediction. Our goal here is to elucidate many of these issues, and then to suggest possible approaches by which these issues might be addressed. How one selects an approach for estimation depends on the quantities to be estimated (Section 4.1), and on the resolution required (Section 4.2). Clearly defining these issues is critical to determining the most appropriate methods. No approach exists that is clearly appropriate for or will adequately resolve all of the issues involved with any degree of certainty. There may, in fact, not be a way to satisfactorily reach the desired goals at the present time. It seems clear, however, that an organized description of the problems involved is needed if a coherent solution is ever to be identified.

4.1 Definition of desired predictands

Before it is possible to develop approaches for prediction of bycatch, there is a need to precisely define those quantities for which prediction is desired, namely the *predictands* of interest. Bycatch may refer to many distinct quantities, including the total weight of "non-target" catch (species or species and size), weight of non-target catch identified by species and/or size, and weight or number of "prohibited species" (weight or number possibly depending on species identity). Statistical prediction involves the prediction of unobserved random variables, which cannot be left vague in terms of definition. Prediction of the number of halibut caught in a pollock fishery may require an entirely different approach than prediction of the total weight of rockfish caught, or the total weight of non-target species, or the total weight of discarded catch. Without a clear enumeration of the desired quantities to be predicted, little additional progress can be made.

4.2 Resolution of desired predictands

Hand-in-hand with clear definition of the quantities to be predicted is the *resolution* or scale at which prediction is desired:

- for an entire fishery,
- for particular time frames within a season for an entire fishery,
- over a given geographic area for a given time frame,
- for groups of vessels over a given window in space and/or time,
- for a given vessel over a certain window in space and/or time,
- for a given vessel on a given trip,
- for a given haul on a given vessel on a given trip,

Predictions at all these levels of resolution result in the definition of different random variables. And, again, it is the values of unobserved random variables that constitute a statistical prediction problem.

The combination of quantity definition (item 1 above) and desired resolution in space, time, and vessel group or fraction (this item) allow definition of a set of random variables to be the object of prediction. Defining these issues is required to determine whether existing observer coverage is "adequate," or to make progress in improving the assessment of bycatch for unobserved situations, either for fisheries as a whole, vessels, groups of vessels, trips, groups of trips, hauls or groups of hauls. Otherwise, there will be no manner in which to answer the questions of what coverage is to be adequate for, what level of uncertainty exists in current operations, or what degree of improvement might be possible by either changing current observer deployment strategies or introducing new technologies for monitoring vessel behavior.

4.3 Relation of observed population to prediction set

Any method of prediction assumes a relationship between cases for which observations are available and those for which observations are not available (and are, hence, to be predicted). The simplest of these assumptions are those that take unobserved cases to be, in some sense, *noninformative* about the quantity of interest. That is, the lack of information on the quantity of interest provides no information about what its value might be. These assumptions are sometimes called assumptions of *missing completely at random, missing at random, or noniformative missingness*. Although there are technical differences among these three statistical assumptions, they share in common the characteristic that unobserved values of the quantity of interest constitute a subset of all or a portion of all cases in which this quantity is observed. It is difficult, if not impossible, to predict the value of a quantity if no observations are available on "like cases." The fundamental importance of this issue becomes clear if one asks whether vessels that never carry an observer can be considered a random subset of vessels that do carry an observer, or if vessels that only sometimes carry an observer behave in the same manner (relative to the quantity of interest) on observed and unobserved trips. While it is likely that, in the absence of either total observer coverage or special studies that provide observer information for cases that are in general unobserved, this issue will remain one for which unverified assumption plays a key role, there may be some avenues by which the confidence (in a non-technical sense) of assumption may be bolstered. Specifically, the approaches envisaged here take a quantity of interest for a case indexed by i, Y_i say, to be predicted on the basis of a set of covariates $\mathbf{x}_i=(x_{i1}, . . ., x_{ip})^T$ which are observed for case i. If both the relation between Y_i and $\mathbf{x}_i$ used for prediction and the Y_i itself are missing in a noninformative manner, then the methodology used for prediction of Y_i should also prove effective in the prediction of $\mathbf{x}_i$. Because the components of $\mathbf{x}_i$ have, in fact, been observed, this allows for an assessment procedure in which one or more components of $\mathbf{x}_i$ are predicted on the basis of the remaining components. The discrepancy among predicted and observed values may then be assessed as an indication of whether those quantities might be considered to reflect noninformative missingness. If all of the components of $\mathbf{x}_i$ appear to reflect this characteristic then that lends some credence to the assumption that such is also true of the quantity of interest Y_i, while if this is not true it casts doubt on any methodology used that relies on such an assumption.

4.4 Aggregation effects and prediction of ensembles

Closely related to the issue of predictand resolution (Section 4.2) are the effects of aggregation and the issue of ensemble prediction. These issues may be understood as follows. Aggregation effects concern possible differences between the prediction of an aggregated quantity and the aggregation of a set of predicted quantities. For example, there is no mathematical reason that prediction of a quantity at the fishery level should agree with the sum of predictions of the same quantity at the level of vessels. Typically, the prediction of an aggregated quantity (e.g., total bycatch of a given species in a fishery) will have less uncertainty associated with it than aggregation of predictions made at a finer scale of resolution (e.g., the sum of vessel-level bycatch predictions for a given species). The issue of ensemble prediction concerns a similar phenomenon, which is that a predictor derived to be optimal (according to some formal criterion) for prediction of an individual case may not be optimal for prediction of the sum of those cases. Our view at the current time is that aggregation effects will be more prominent in the prediction of bycatch than the issue of ensemble prediction because it is unlikely that formal prediction criteria (such as mean squared prediction error) will be available for the derivation of optimal predictors in this problem. Nevertheless, it may be prudent to identify this as a prediction issue at this point.

4.5 Static prediction versus dynamic prediction

The potential methodologies discussed briefly in Section 4.6 all constitute what may be considered *static* predictors, in that they take the relation between quantities to be predicted (i.e., predictands) and quantities on which such predictions are based (i.e., predictor covariates) to remain stable over the temporal and/or spatial window in which predications are made. This is a critical matter, particularly in the case that predictions are made in a current situation (e.g., this fishing season) on the basis of relations developed from previous situations (e.g., past fishing seasons). The alternative is to rely on dynamic methods in which the relations among various quantities of interest are allowed to vary, within certain limits imposed by model structure, over the course of time and/or space. This is a difficult issue for the development of prediction strategies, particularly if the behavior of fishing vessels may change as the result of regulatory or monitoring efforts. At the current time there appears no alternative but to assume that the past reflects the present in terms of the prediction problems formulated (which depends on the first two issues discussed previously). It may well be beneficial, however, to consider the issue of how to detect changes in the relations on which predictions are based (assuming that such relations can be identified) in the most rapid manner possible.

4.6 Prediction based on regression methodologies

One of the fundamental approaches to prediction of unobserved random variables is that of regression methodology. Consider a set of non-random indices $\{\mathbf{s}_{i\,:\,i=1,}\ldots,n\}$ which index the position of associated random variables in space, time, and definition of observational unit. For example, $\mathbf{s}_i$ may denote a combination of vessel identification, trip number, and haul number. Alternatively, $\mathbf{s}_i$ may denote a combination of vessel group, geographical area, and portion of a fishing season. Associated with these indices are random variables $\{Y(\mathbf{s}_i): i=1, \ldots,n\}$ which represent the quantity of interest, such as total weight of discards, number or weight of a particular taxonomic group, etc. Definition of $\mathbf{Y}\equiv\{Y(\mathbf{s}_i): i=1, \ldots,n\}$ must come from consideration of the first two items discussed above; without such definition progress will not be possible. Technically, $\mathbf{Y}$ denotes a *random field*, and $\mathbf{s}_i$ a *location* within that field. Now consider an additional location $\mathbf{s}_0$ at which the quantity of interest $Y(\mathbf{s}_0)$ has not been observed. The goal is to predict $Y(\mathbf{s}_0)$ on the basis of observations $\mathbf{y}\equiv\{y(\mathbf{s}_i): i=1, \ldots,n\}$. Suppose that a set of variables $\mathbf{x}\equiv\{\mathbf{x}(\mathbf{s}_i): i=1, \ldots,n\}$ has also been observed and that the value of these variables $\mathbf{x}(\mathbf{s}_0)$ is also available at location $\mathbf{s}_0$; here, $\mathbf{x}(\mathbf{s}_i)\equiv(x_1(\mathbf{s}_i), \ldots, x_p(\mathbf{s}_i))^T$ is a vector of covariates at location $\mathbf{s}_i$.

The underlying concept in regression prediction is that, for i=1,. . .,n, $Y(\mathbf{s}_i)$ is related to $\mathbf{x}(\mathbf{s}_i)$ by a regression equation, $E\{Y(\mathbf{s}_i)\} = h(\mathbf{x}(\mathbf{s}_i), \beta)$, where E is the expectation operator and β is a vector of unknown parameters. Often, the function h(.) is chosen to be linear in the parameters β, but this is not necessary if additional knowledge is available that suggests an alternative form. The observed data are used to estimate values for β, as B say, and then these estimated parameters are used in the functional form of h(.) to produce a predicted value for $Y(\mathbf{s}_0)$ as, for example, $p(\mathbf{s}_0) = h(\mathbf{x}(\mathbf{s}_0), B)$. This approach often suffers from one or more complications, even if a linear form for the response function appears adequate. Notable among these complications are linear dependencies among the component quantities that make up the $\mathbf{x}(\mathbf{s}_i)$, and the fact that various groups in the total population may contain different simple regression relations with the responses of interest (i.e., the $Y(\mathbf{s}_i)$s).

The difficulty of linear dependencies among components of the covariate vectors $\mathbf{x}(\mathbf{s}_i)$ is called the problem of *colinearity*. The problem this causes is that estimates of the parameter vector β tend to be numerically unstable, with the obvious negative implications for prediction. One standard approach to dealing with this problem is to construct new covariates as linear combinations of the original components of the $\mathbf{x}(\mathbf{s}_i)$, in such a way that the new covariates are orthogonal. Typically, this is accomplished through the use of *principal components analysis*. The principal components (i.e., linear combinations of the original covariates) are constructed in such a way as to account for a large amount of the overall variance contained in the set of original covariates. The new covariates may then be used in a regression for the attribute of interest. While often an effective approach, the potential problem with this type of principal components regression is that there is no guarantee that the principal components constructed will account for variability in the responses of primary interest.

The second potential problem identified above is caused by the presence of distinct clusters or strata within the entire population. In such situations, one approach to the prediction of $Y(\mathbf{s}_0)$ is that of *treed regression methods* (Alexander and Grimshaw 1996), which encompass methods that rely on *recursive partitioning* and, most notably, *classification and regression trees*, which are often referred to as CART methods (Breiman *et al.*1984). In this approach, binary splits are sequentially formed in the data (hence the “tree”) with each terminal “node” resulting in a simple linear regression equation for the variable of interest. This methodology has, for example, been applied to the response of blue shark catch per set in the Hawaii commercial longline fishery (Walsh and Kleiber 2001) although prediction was not the primary objective of that analysis.

In both of the above approaches, the quantification of uncertainty in predicted values becomes a complex issue. Particularly in the case of regression trees, use of linear model theory to derive standard errors of predictions at each of the terminal nodes of the tree ignores uncertainty in the process of tree development through the sequential splitting of data. Predictions are then appropriately thought of as conditional on the tree structure. The entire process then leads to an underestimate of the actual uncertainty that will exist in a set of predicted values. Cross-validation may serve as a valuable tool in assessing the degree to which this occurs, but the basic problem is not solved. An alternative is to employ a Bayesian approach, making use of either *multiple imputation* or *Gaussian process priors*. Multiple imputation makes use of multiple predictions of the same quantity, all generated from an appropriate posterior predictive distribution (e.g., Little and Rubin 2002). An immediate measure of prediction uncertainty is provided by the variability among the multiple predictions so generated. The concept of Gaussian process priors is that, rather than formulate a model in the typical manner by assigning prior distributions to model parameters, one might derive the posterior predictive by first integrating out model parameters and then assign prior distributions directly to the observable data values and covariates of the case(s) to be predicted (Neal, 1998). Both of these Bayesian approaches offer alternatives that may prove applicable to the prediction of bycatch quantities.

5 Integrated electronic monitoring system

An EM system could range from a basic VMS providing location information to a complex integrated system of video cameras and multiple sensors linked through an electronic data gathering system such as an electronic logbook. When at-sea observers ride along on vessels with EM, observer data could also link to the EM system. As described in Sections 2 and 3, a wide variety of technologies exist that can obtain and analyze information from fishing activities. Some of these technologies are currently in wide use, some are in use for limited applications, and others are in development. The most effective use of the discussed technologies for the groundfish fisheries off Alaska may be through some sort of an integrated EM program that uses at-sea observers, at-sea electronic and video monitoring, electronic logbooks, and shoreside measurement of landed catch. The FSCS system (Section 2.5.2) currently provides many of these integrated features.

EM may obtain and store more data from fishing events than can be practically analyzed. Cataloging the data as a preliminary analysis would set up the data for storage and subsequent analyses, and could examine the data for anomalous events. More detailed analyses could occur according to specific research or management questions.

These technologies may provide the most practical supplement or alternative to at-sea observers in the Alaska groundfish fisheries. Many at-sea processors currently weigh fish with motion-compensated flow scales and have one or two observers for all fishing days. NOAA Fisheries receives detailed information from shoreside processors, which weigh fish on certified scales. Large improvements in data quality for catcher vessels delivering to shore-based plants will come from more precise at-sea monitoring for location information, from improved estimates of bycatch and discards, and from monitoring fishing activity.

Currently, NMFS receives landings reports by NMFS management area and ADF&G statistical area, which are broad areas. Data from observed vessels are extrapolated to unobserved vessels by gear type and management area. However, if an electronic logbook provides exact fishing locations and durations, the catch can be attributed to areas at a much finer resolution. This should enable managers to better identify areas of high bycatch and provide managers with better ability to extrapolate catch from observed to unobserved areas. NMFS would also be better equipped to quantify the observer effect. For example, patterns of observed vessels consistently fishing in different times and areas than unobserved vessels could be investigated. Bycatch and discards from the unobserved vessels can be estimated through the data processing and data analysis procedures that use and compare fishing information from unobserved vessels with that of observed vessels (Section 4.6). Data analysis could take two predominant forms: 1) using patterns in fishing practices of observed and unobserved vessels to make fleet wide estimates of bycatch and discards, and 2) using information from observed vessels to build a bycatch prediction model using groundfish species composition, gear, area, time, depth, etc. for use in calculating bycatch for individual vessels.

5.1 Components of integrated electronic monitoring

The composite EM system is an integrated system, using a variety of components discussed individually in earlier sections to collect a series of data. In some cases, data could be automatically logged in a format ready for downloading to a database (e.g., GPS locations, gear sensors). In other cases, data could be stored on a computer for later processing (e.g., camera images). In still others, data would be input manually (e.g., catch data). Depending on management needs and transmission costs and capabilities, some data elements could be reported directly to management agencies with VMS on a real-time, regularly scheduled, or interrogation basis. For after-the-fact monitoring, data could be stored in computers for transmission at the end of a fishing trip. Electronic logbook systems could poll the various sensors and log them with the VMS location data. All data would have date, time, and location stamps confirmed with a verification system to facilitate linking haul-by-haul information (Robert Mikol, OceanLogic, Juneau AK, pers. comm.).

In general, transmission costs would likely limit the amount of data transmitted directly through a VMS. Therefore, a composite EM with a variety of data sources would likely require computers for logging, processing, and transmitting data: one computer that receives and stores information on the fishing activities, and another that receives and stores video from cameras that monitor fishing operations.

Electronic logbooks have been developed around the world, largely with benefits to the fisher as the driving force. Many of the electronic logbooks have the capacity to automatically log in a variety of fishery data, and as such, are an important component of a composite electronic monitoring system. An electronic logbook designed to assist – and accepted by – fishermen, with a capacity to log fishery data required by fishery management programs, would have the highest likelihood of succeeding in practice as the data logging format. Two electronic logbooks designed for northeast Pacific fisheries – the OceanLogic electronic logbook produced for Alaskan fisheries and the EFCL produced by Scientific Fisheries Systems for the NWFSC – could fit this description.

VMS are in use around the world for a variety of monitoring and surveillance purposes. VMS data have been used to successfully prosecute vessel operators for entry into a closed area, but at present, VMS alone cannot categorically demonstrate, sufficiently for prosecution in a US court of law, that a vessel has fished. Other information is required to demonstrate when a vessel actually fishes.

Various types of sensors can be used to record the use of fishing equipment. Rotation counters on winches or line pullers and pressure monitors on hydraulic systems will indicate when and to what extent fishing gear has been activated. However, fishermen may activate this equipment without actually fishing. For example, trawlers may tow a net with the codend open to remove fish residue. Pot fishermen may set pots to store them at sea. Although such activities make up a small proportion of gear sets, some mechanism is required to distinguish between gear operation for fishing and gear operation for other activities. For vessels that increase engine speed during setting or retrieving operations, a pyrometer would supplement VMS and fishing gear sensors and help to confirm whether fishing is occurring. Trawl vessels would generate much higher exhaust temperatures during fishing than during net cleaning because towing a closed codend, particularly with fish, would require much greater engine power than dragging an open codend (Robert Mikol, OceanLogic, Juneau AK, pers. comm.). Pot and trawl vessels do not need to increase engine speed during gear setting, but the fishing gear goes over the side in a sequence. The laser-based hook counter under development by Digital Observers could determine when hooks and pots go over the side. Catch data entered in electronic logbooks would indicate that fishing occurred, and video monitoring of the deck could provide confirmation that fishing occurred when no catch data are indicated.

Camera images could add a powerful component to EM through monitoring catch and discards and through monitoring fishing activities. However, fishermen may resist use of cameras because of confidentiality issues. Fishermen are concerned that someone (e.g., an environmental group or a plaintiff's attorney), through the Freedom of Information Act (FOIA) and/or subpoena, will obtain video images collected by a government management agency and use them for unintended purposes (Paul MacGregor, Mundt MacGregor, Seattle WA; Mark Buckley, Digital Observers, Kodiak AK, pers. comm). At this time, the only sure way to avoid FOIA for video images is to have the vessels own the camera system and the images, and loan the images to the government for analysis.

5.2 Mechanisms for enhanced electronic monitoring

Two possible mechanisms are considered for implementing a composite electronic monitoring: A *Regulatory Mechanism* and a *Standards Mechanism*.

Regulatory mechanism – The Council/NOAA Fisheries would develop the composite electronic monitoring, in partnership with a vendor, and specify through regulations all of the detailed procedures that vessels would have to follow to participate in the enhanced EM program. This process would closely follow the approach used to define the requirements for SPELR or the model development for the EFCL. Under a system fully defined in regulations, all fishermen would operate under the same system with equal treatment. But fishermen and vendors would have minimal opportunity for innovation to improve the system.

Standards mechanism – The Council/NOAA Fisheries would specify performance standards for the composite electronic monitoring. Vendors would develop an integrated EM and demonstrate that it meets the standards following a successful trial of hardware and software. NOAA fisheries has used this approach to define the requirements for scales in processing plants for weighing groundfish, in which each plant established its own program that met or exceeded the standards, unique for the plant. AFMA currently uses this approach for approving electronic logbooks.

Whichever mechanism is used, the Council and NOAA Fisheries need to agree on what constitutes a satisfactory implementation for an integrated electronic monitoring, so that this can be used to define the regulation, or in the evaluation of plans proposed to meet the performance standards. The Standards Mechanism will provide greater flexibility, reduce the administrative burden on NOAA Fisheries, and place some of that burden on the participating industry. However, NOAA Fisheries would have to monitor the EM systems to assure they continue to meet standards. Under this approach, NOAA Fisheries and the Council would determine which aspects require regulatory management, while the participating vessels would prepare implementation plans describing how participants will achieve the performance standards for other aspects (defined in regulations).

6 Conclusions and recommendations

6.1 Conclusions

Because NOAA Fisheries currently obtains adequate data on weight, species composition, and biological samples from landed catch, the main emphasis of improved at-sea data collection is on obtaining data on species discarded at sea. Many more options are available for larger vessels than for smaller vessels and larger vessels often have significant requirements for data collection, especially those vessels participating in CDQ or AFA fisheries. Larger vessels already have one or two observers on board for all fishing activities, and have more space and protection for motion-compensated scales, conveyors, etc. Large trawl vessels often have net measurement systems that could supply data to an electronic logbook on many fishing activities. The technology available for larger vessels is often unsuitable for smaller vessels because of space limitations and cost. It does not, therefore, provide viable solutions for improving bycatch estimation for smaller vessels. Some combinations of technology suitable for smaller vessels have been described in this report, and may lead to feasible electronic monitoring for these vessels.

6.1.1 Management measures and electronic monitoring

Fisheries management measures often require or presume that fishermen operate their gear in a particular way (e.g. regulations designed to eliminate or reduce undesirable behavior that might increase bycatch or fishing off-bottom when pelagic trawls are required). However, substantial latitude remains within which fishermen can decide how and where they go to fish. Fishermen still have widely varying bycatch (and catch) rates, which may be the result, to a greater or lesser extent, from the way in which they fish. New technology might be used in conjunction with various types of controls on the operation of vessels and gear in the North Pacific**. Table 4** contains a description of electronic monitoring activities that may apply to general management measures.

6.1.2 Catch composition and quantity

Table 5 presents a summary of the technologies applicable to monitoring catch composition and quantity. For the foreseeable future, observers are likely to be the best source of biological information from vessels at sea. Using crewmembers from a vessel to collect biological data from unobserved vessels is possible, but many scientists and managers will not trust, and therefore not use, the data. However, developing incentives for fishermen participation and monitoring data collection with video cameras may provide for data of sufficient quality to improve estimates compared to estimates made with no data from unobserved vessels.

Video cameras are not likely to provide automatic identification of fish, seabirds, or protected species for the foreseeable future. Remote observers are used to identify and enumerate fish from video images in cases where fish pass by the camera as non-overlapping single images. Improvements are expected for video and remote observer capabilities. Remote observers can also count numbers of hooks or number of pots set by a vessel. They can also identify many species with accuracy comparable to at-sea observers, but some difficult-to-identify species must be grouped. Low light levels, specimens not in focus or out of the field of vision, and obscured subjects reduce the ability of remote observers to identify fish. Adequate lighting and proper placement and protection of the cameras will require some experimentation before they can be deployed effectively.

Video images may provide for remote observer counts of bycatch of seabirds, marine mammals, or other protected species. Insufficient experience exists to determine the capability of remote observers to identify protected specimens to species. Accuracy could improve if crew members placed this bycatch in the view field of a close up camera, but such a requirement could increase time and cost of fishing operations.

Motion-compensated flow scales work well for weighing total catch on many catcher-processor trawler vessels, although some smaller vessels have configuration problems. Motion-compensated hopper scales could estimate total weight for catcher-processor longline and pot vessels, but may cause a space problem for smaller vessels. Motion-compensated scales will be problematic on vessels without shelter to protect the scales from the wind and waves, i.e., all catcher vessels. Motion-compensated flow or hopper scales could also weigh discarded catch, but the space required for a second scale could cause severe disruptions and expense for the vessels.

Technological methods can only partially monitor bycatch and discards from unobserved vessels. Regression methods can improve the estimates of unobserved bycatch and discards by using fishing attributes of observed and unobserved vessels obtained with technological means. Fishing attributes used in a regression model must relate to bycatch or spurious correlations may occur.

Several technological improvements to observer sampling equipment are currently available, but have high costs. Electronic measuring boards, electronic scales, and hand-held or tablet computers currently used for scientific surveys would allow for easy and accurate data collection by observers. Direct entry of data to a computer by observers or from electronic measuring devices will result in reduced transcription errors, faster data collection, fewer errors, and less need for data entry staff to enter data from paper forms (North Pacific observers enter data at sea with electronic transmission to the Observer Program). Feedback to observers from automatic error checks will also provide a learning experience for the observers likely to reduce similar errors in the future. These pieces of gear cost from three to five thousand dollars each, and a single observer could require $10,000 or more worth of equipment. Most observer programs do not have a budget that allows for purchase of all this equipment at a level to supply all observers. Tests of the electronic equipment in field situations comparable to observer conditions in the North Pacific have resulted in some equipment failure. Observer program managers may selectively purchase electronic devices for a particular need, but will unlikely take full advantage of technological improvements until costs decline and managers have confidence in reliability.

6.1.3 Fishing activity

Table 6 presents a summary of the technologies applicable to monitoring fishing activities. VMS (Section 3.1) can provide accurate, frequent position fixes for fishing vessels, but is not sufficient for monitoring fishing activity. Other technology, such as sensors that monitor fishing gears (hydraulics, rotation counters, exhaust temperature, bottom sensors, etc.), can help to confirm when fishing is occurring (Section 3.2, 3.5). Recording the VMS and sensor data automatically in a computerized data logging system, such as an electronic logbook (Section 3.4), will be a key for making the data accessible. The amount of data collected under such a program maybe too large for economic transmission of an entire dataset via the VMS, but secure data storage on a computer makes the data available for downloading to a management system upon return to land.

Future developments or applications of signal processing to the integrated sensor data may allow for identifying signatures of fishing behavior, e.g., fishing events. Summaries of the data that identify specific events, such as hauls/sets or transiting, could be sent via VMS to management agencies for monitoring of activities. Agencies could monitor summaries of specific fishing activities in near-real time, while a full data set of all activities resides on an on-board computer for periodic download to the agencies.

Remote observers viewing digital video images can monitor many fishing activities: presorting, use of bird scaring devices, marine mammals in trawl chute, etc. The monitoring will have direct enforcement implications, by documenting illegal actions or confirming compliance. However, any features (shadows, stacks of gear) or activities (standing in front of the camera) on vessel that obscure the view of the point of interest could jeopardize the integrity of the video. NOAA Fisheries must assure that placement of cameras maintains clear lines of sight.

Fishermen will likely find an EM system that requires VMS, sensors, an electronic logbook, and video cameras intrusive and costly. Opposition will arise unless the fishermen recognize a personal benefit that exceeds the costs. Some fishermen in Alaska voluntarily use an electronic system to comply with mandatory reporting requirements. Some Alaskan fishermen have also voluntarily used an electronic logbook. These voluntary activities represent a small proportion of the overall groundfish fleet. It is not clear what inducements would convince fishermen to support such an EM system. However, management measures implemented with the support of the fishermen seems vital for the system to prove effective. Support could come from addressing two key factors: 1) basing management measures on reliable scientific advice that fully justifies the need for the measures, and 2) understanding the socio-economic circumstances of the fishermen, to avoid measures which cause unacceptable hardship and to promote cooperation between the fishing communities and the regulatory authorities. In this spirit, management measures to enhance the observer program will gain the greatest support if the requirements are helpful to fishermen. If they provide a value, the fishermen will have less of a problem using the system. Potential benefits to fishermen could come from:

- Web-based data retrieval of data by owners, operators, and partners. The Thistle logbook was designed for fishermen, and has web-based access to data. Qualcomm (http://www.qualcomm.com/qwbs/products/viaweb/index.html) has developed several products that allow web-based information tracking and exchange.

- Fish sales prior to a vessel landing fish currently occurs for many fisheries in the North Pacific region. Sales often occur by ship-to-shore radio or mobile phone. In Europe, direct sales of fish from vessels at sea through on line auctions bring an opportunity for increased profits (http://www.intrafish.com/intrafish-analysis/UK_2000_48_eng/index.php3?thepage=5).

- Fleet or vessel managers could make better business decisions using information in an integrated EM system just as Schneider Trucking has improved management of its fleet of trucks through an online tracking system that monitors location, engine sensors and trailers.

- Recently approved legislation to require country-of-origin labeling for wild fish (http://thomas.loc.gov/cgi-bin/cpquery/?&dbname=cp108&maxdocs=100&report=hr401.108&sel=TOC_88536&) will require fishermen to meet documentation standards. Electronic logbooks can be formatted to provide the documentation needed for full traceability.

- Development of an EM system that includes sufficient information to categorize unobserved vessels with observed vessels for bycatch and discard estimation may allow for increased levels of monitoring without substantial increases in the number of on-board observers. Redistribution of on-board observers to currently unobserved vessels and use of EM more widely than the current distribution of on-board observers could increase the overall level of monitoring and data collection. Some redistribution of observer coverage may be contingent on a program as part of the EM system for biological data collection by fishermen that meets the needs of managers/scientists and fishermen.

6.2 Recommendations

Three key components of a system to enhance monitoring of bycatch and discards emerge from this paper: an electronic logbook linked with VMS and key sensors; video camera coverage; and estimation of bycatch through a regression model analysis. In addition, electronic equipment for observers could reduce errors and reduce time required for data collection. These technologies are not yet mature to the point that readily-available applications exist that completely meet the needs of NOAA Fisheries and the Council. However, experience in the northeast Pacific and around the world suggests significant potential for these technologies to contribute to fishery management in Alaskan waters. More detail on the application of these technologies is presented below, but more analysis, pilot programs, and consultation with stakeholders by NOAA Fisheries and the Council is likely necessary before implementation of any of these methods could occur. Some technologies are suitable for specific monitoring purposes, and care must be taken to ensure that a technology is suitable for the problem addressed. The details of these components will differ by gear type and by the types of information most critically needed for management. Observers in the North Pacific use data collection and logging methods that take several steps. Each step takes time from other possible activities and is a potential source of error. Cost effective electronic measuring and logging will enhance the observers' capabilities.

1. Evaluate an electronic logbook (Section 3.4) linked with VMS (Section 3.1) and key sensors (Section 3.2, 3.5) to provide detailed information on location and fishing characteristics. Many of the attributes captured in an electronic logbook would provide input to the regression model (below); a comprehensive analysis of the contribution of these attributes to variation in bycatch rates or quantities (or to other topics of interest) will increase the probability of choosing the correct attributes. The attributes obtained automatically without input from fishermen – location, depth, winch or engine sensors, etc. – would have higher reliability than attributes that fishermen may collect – species composition, catch weights, biological data, etc, although EM can help monitor if fishermen follow proper protocols. Further evaluation of fishermen participation in data collection under a bonding-type program comparable to weighmasters would determine advantages and disadvantages of the concept.

2. Evaluate video camera coverage (Section 2.1, 3.3) to increase compliance with regulations (such as unsorted samples for observers) and to provide counts and identification of species. The confidentiality issues for video monitoring may limit acceptance by fishermen, and require further analysis.

   A test on the Pacific whiting fishery demonstrated the potential for cameras to greatly reduce and possibly prevent unauthorized discarding of fish from shore-based trawlers, and the whiting fishery will use electronic monitoring in 2004. Remote observers identified presence of seabirds caught on halibut longlines and obtained moderate accuracy for species identification. Cameras demonstrated use of required gear or gear modifications, as in a test of compliance with bird avoidance devices in the halibut fishery. Remote observers for the Canadian Pacific halibut fishery identified many fish species from video images at accuracy rates similar to at-sea observers. Use of video monitoring for the US Pacific halibut fishery also seems feasible.

   Random checks of video records from all vessels and checks of video records of vessels with anomalous VMS/sensor/electronic logbook data would increase efficiency in monitoring the large quantity of video that would result. Cameras could also help check and confirm that fishermen correctly collect data should they participate in data collection programs.

3. Evaluate a regression model analysis (Section 4.6) to compare observed and unobserved vessels to improve estimates of unobserved bycatch. Conduct research to determine which attributes contribute the most information to bycatch estimation. While Section 4.6 describes several regression techniques, no testing or evaluation of them has occurred for application to fishery bycatch estimation in Alaskan waters. The methodology has been applied to Hawaiian blue shark fisheries, but not for purposes of prediction.

4. Nationally coordinate a cost effective, integrated electronic data collection and logging system for observers. Evaluate which systems provide benefits that exceed costs for the Alaska and other regions. Work with manufacturers to develop electronic measuring boards (Section 2.5.2) and electronic scales (Section 2.5.2) at low enough cost to distribute to observers. The observer boards would not need all the features of a board used for scientific surveys. Observer boards and scales should be robust enough to withstand the rigors of traveling with observers, operate in extreme conditions at sea, and have a standardized (preferably wireless) link to a hand-held or tablet PC. Eliminate data recording on plastic sheets, and convert to direct entry on tablet or hand-held PCs that have adequate readability and reliability.

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Tables

Table 1 Comparison of EM with observer programs: Data Quality Issues (Archipelago Marine Research Ltd.)

Data Quality Issue	EM	Observers
Fishing Location	+++	++
Fishing Depth	++	+++
Time/Date of Fishing	+++	++
Number of Hooks/Traps	+++	++
Catch - Pieces	+++	++
Catch - Disposition	+++	+++
Species Recognition	++	+++
Catch - Species Category	+++	+++
Catch - Weight	-	+++

Table 2 EM species recognition capability (Archipelago Marine Research Ltd.)

Performance	Proportion of the catch and number of species
Excellent (<5% mistakes)	92% of catch; 8 species
Good (<10% mistakes)	97% of catch; 13 species
Poor (>10% mistakes)	3% of catch; 12 species
Unknown	0.6% of catch; 23 species

Table 3 Comparison of EM with observer programs: Programmatic Issues (Archipelago Marine Research Ltd.)

Program Issues	EM	Observers
Technological Complexity	higher	lower
Versatility	lower	higher
Sampling Complexity	lower	higher
24/7 Coverage capability	higher	lower
Providing believable data	lower	higher
Intrusiveness	lower	higher
Cost	lower	higher
Industry "Buy In"	higher	lower
Industry Involvement	higher	lower

Table 4. Management measures and applicable electronic monitoring.

Management measure	Application of electronic monitoring
TAC, harvest guidelines, and allocation	Expansion of electronic reporting by individual processors or vessels, such as current Alaskan SPELR and IFQ requirements, to all catches will increase the accuracy and speed of obtaining the data.
Closed areas and time-area closures	Vessel monitoring systems can determine if vessels enter closed zones, as currently applied in Alaska for Steller sea lion closed areas. Sensors on fishing equipment, such as on winches, can determine if fishing occurs.
Trip limits and trip frequency limits	Electronic reporting, as for TAC above, can quickly and accurately track trip limits. VMS can track the number of trips a vessel makes.
At-sea discards	Diverting catcher-processors discards to motion-compensated (hopper or flow) scales could provide total weight of discards; space requirements and cost may limit applicability. Remote observing with cameras may provide counts by species for discards from pot and longline vessels.
Pre-sorting	Remote observing with cameras as planned for the Pacific whiting fishery.
Bycatch on halibut vessels	Remote observers using camera images linked to fishing gear sensors are currently used aboard halibut longline vessels in Canada to provide counts of hooks and catch (numbers) by species or species group.
Marine mammals and seabirds	Remote observing with cameras can determine if longline fishermen use seabird scaring techniques. Remote observing with cameras may identify and count seabirds and marine mammals brought on board. Comprehensive coverage is unlikely without on-board observers.
Prohibited species and bycatch limits	Remote observing with cameras may identify and count some discards and prohibited fish species using remote observers to process images on land. Weights of bycatch and discards are problematic. Regression models could improve estimates of bycatch and discards from unobserved vessels through comparison with observed vessels.
Size limits and sex restrictions	Determination of these limits is unlikely without on-board observers.
Effort control, permits, endorsements	VMS linked to a list of permits, endorsements, or registrations authorized for a vessel.
Gear size (dimensions, mesh size, hook size or spacing, pot opening)	Use of electronic monitoring is unlikely for these types of measures.
Fishing time (soak or haul time, days at sea)	Bottom contract sensors, sensors on winches can track fishing time. Radio frequency identification (RFID) can track the amount of time gear (e.g., pots) is off the vessel. VMS can track days at sea. Automatic hook counter combined with GPS, camera monitoring, hydraulic sensors, or rotation counters.
Gear prohibitions	Remote observing with cameras may identify basic gear types. Bottom contact sensors can monitor for pelagic trawls.
Gear construction (mesh type, chafing gear, roller/rock hopper, buoys and buoy identification, biodegradable panels, TEDs and BRDs, seabird avoidance devices)	Of these, RFID and other electronic identification can uniquely identify individual gears. Remote observing with cameras may detect some gear construction details and can confirm use of required components.
Limits on amount of gear – pot limits	RFID can identify and count individual pots.

Table 5. Monitoring needs and available technologies for determining weight and species composition of groundfish catch

Monitoring needs	Available technologies	Suitability
Species composition – Groundfish	Video camera – Human review, after the fact (Section 2.1)	Total catch enumeration and identification on longliners, does not require at-sea observers
	Video camera – Human review, after the fact (Section 2.1)	Discards enumeration and identification on pot vessels, does not require at-sea observers
	Video camera – Human review, after the fact (Section 2.1)	Not suitable on trawlers
	Video camera – Automatic identification (Section 2.1.2)	Not suitable, software limitations
	Brailer, corer (in development) (Section 3.5.2)	More representative sample for trawl catcher vessels, requires at-sea observers
Species composition – Protected species	Video camera – Human review, after the fact (Section 2.1)	Enumeration and identification; does not require at-sea observers, but moderate success rate in species ID
	Data collection by crew, with video camera confirmation (Section 2.4)	Incentive for misreporting, does not require at-sea observer
Biological samples	Electronic measuring boards (Section 2.5.2)	Expensive; reduce errors, speed up data collection
	Tablet or hand-held PC (Section 2.5.2)	Expensive; reduce errors, speed up data collection
	GIS (Section 2.5.2)	Independent check of location
	Portable, digital, motion-compensated scales (Section 2.5.2)	Used in AFA/CDQ at-sea processors, expensive for catcher vessels
	Digital readout electronic hanging scale (Section 2.5.2)	Not water proof; not suitable for observer work
	Data collection by trained and certified crew, with video camera confirmation (Section 2.4)	Requires buy-in from fishermen, assurance of quality data for researchers and managers
Total catch weight	Motion-compensated flow scales (Section 2.2.1)	Used on AFA/CDQ trawl catcher processors; not suitable on deck
	Motion-compensated hopper scales (Section 2.2.2)	Potential use on pot or longline catcher processors; not suitable on deck
	Video camera – codend volumetrics (Section 2.3)	Potential, not developed
Bycatch estimates from unobserved vessels	Regression estimation – combine observer data with electronic monitoring of unobserved vessels – rates or absolute (Section 4.6)	Need to monitor suitable attributes that relate to bycatch; estimate vessel-specific or group rates or amounts

Table 6. Monitoring needs and available technologies for determining fishing activities by groundfish vessels

Monitoring needs	Available technologies	Suitability
Vessel position	One-way VMS (Section 3.1.1)	Real time or "batch" reporting
Communication with vessels	Two-way VMS (Section 3.1.2, 3.1.3)	Poll vessels for location, transmit management messages to fleet; more expensive than one-way
Vessel reporting of information	Two-way VMS (Section 3.1.2, 3.1.3)	Transmit catch, sensor, or logbook data, transmit emergency information; volume of data may limit use
Determining fishing activity	Sensors on fishing equipment or engines (Section 3.2)	Available for hydraulics, winch-reel rotation, pyrometer
	Video camera – Human review, after the fact (Section 3.3)	Monitor deck activities to verify fishing, discarding/retention
	Longline hook counter (Section 3.5.6)	Longline vessels, verify setting, count hooks; under development
	Radio Frequency Identification (Section 3.5.5)	Identifying, counting, soak time for pots
	Gear measurement (bottom sensor) (Section 3.5)	Commercial sensor packages, mainly for trawl vessels; expensive for smaller vessels
Data logging, electronic reporting	Electronic logbook (Section 3.4, 5)	Gear/equipment sensors, location, catch, biological data.

Figures

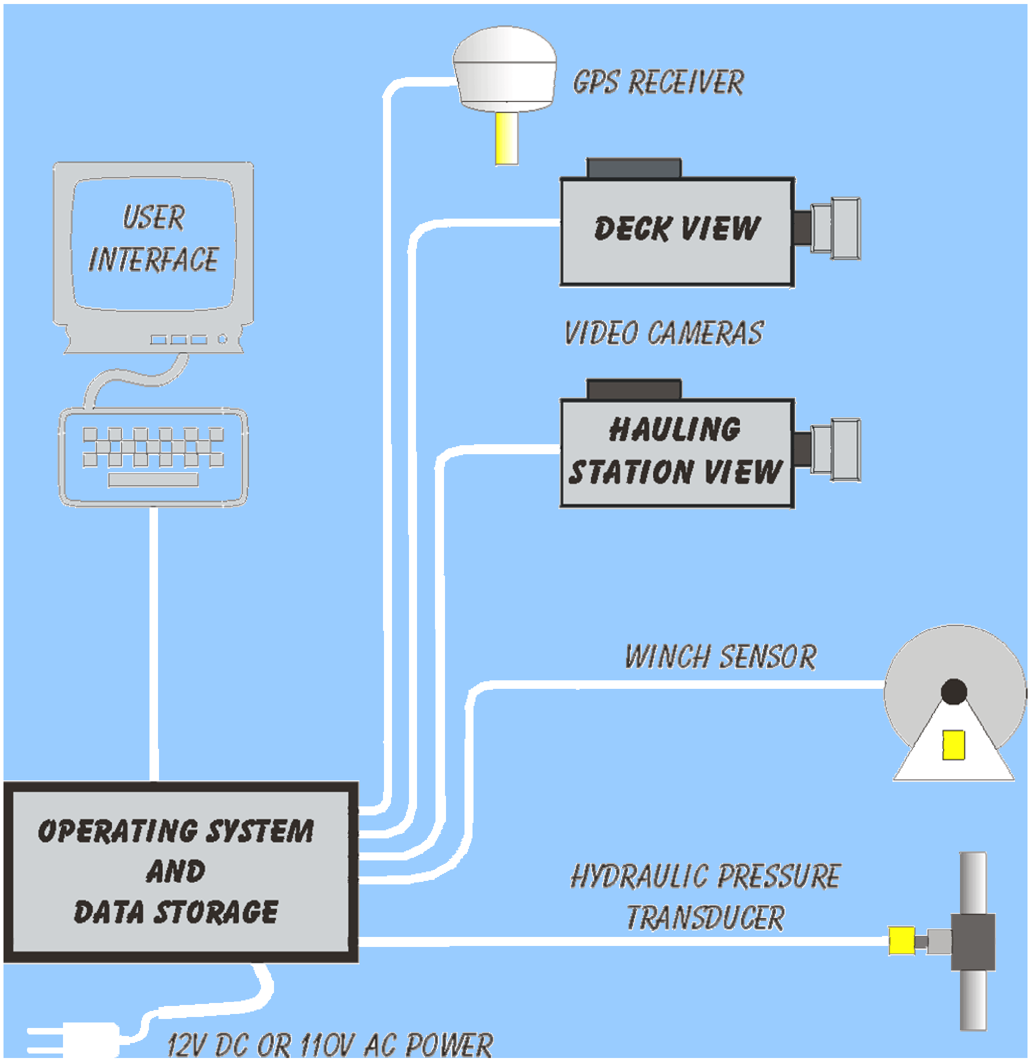

Figure 1 Schematic of a typical electronic monitoring (EM) setup, Archipelago Marine Research Ltd.

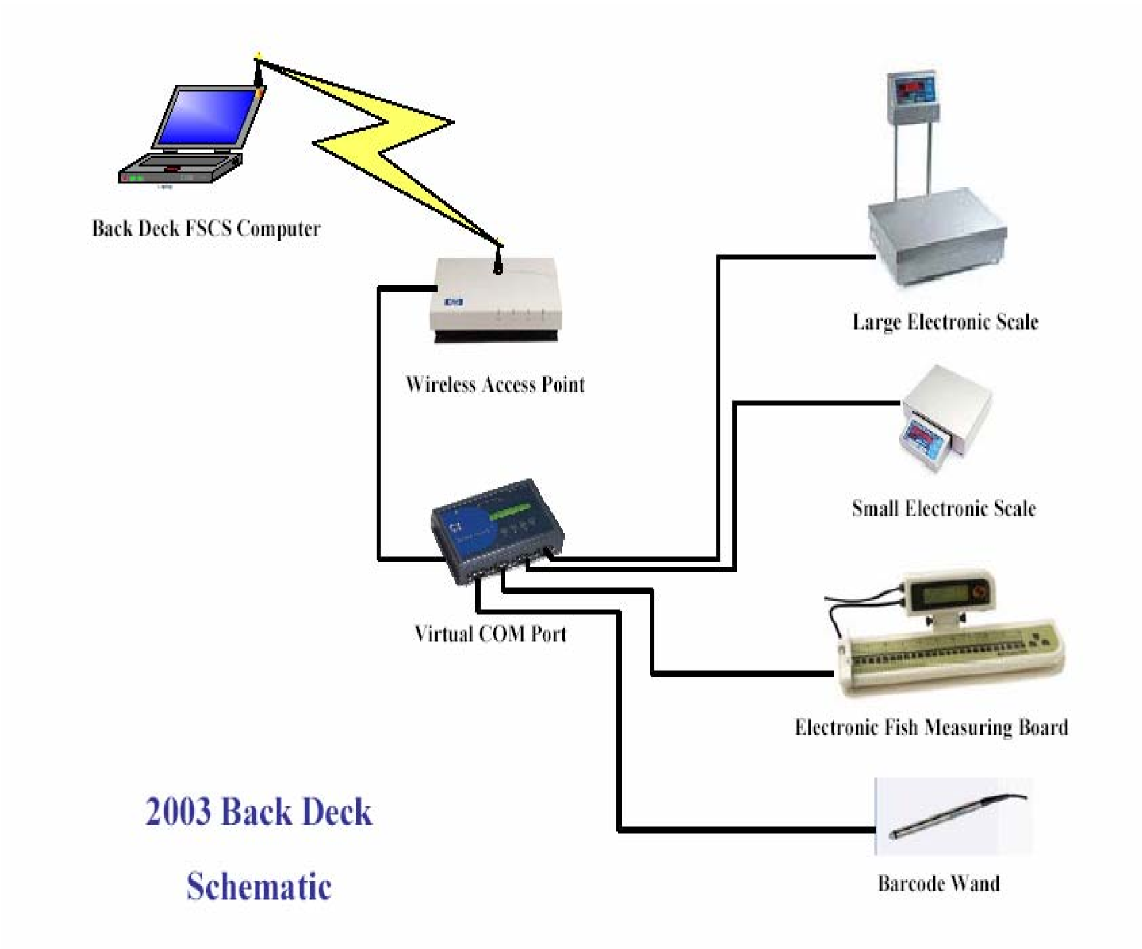

Figure 2 Schematic fish sampling equipment used during 2003 linked to the FSCS (NOAA Fisheries)

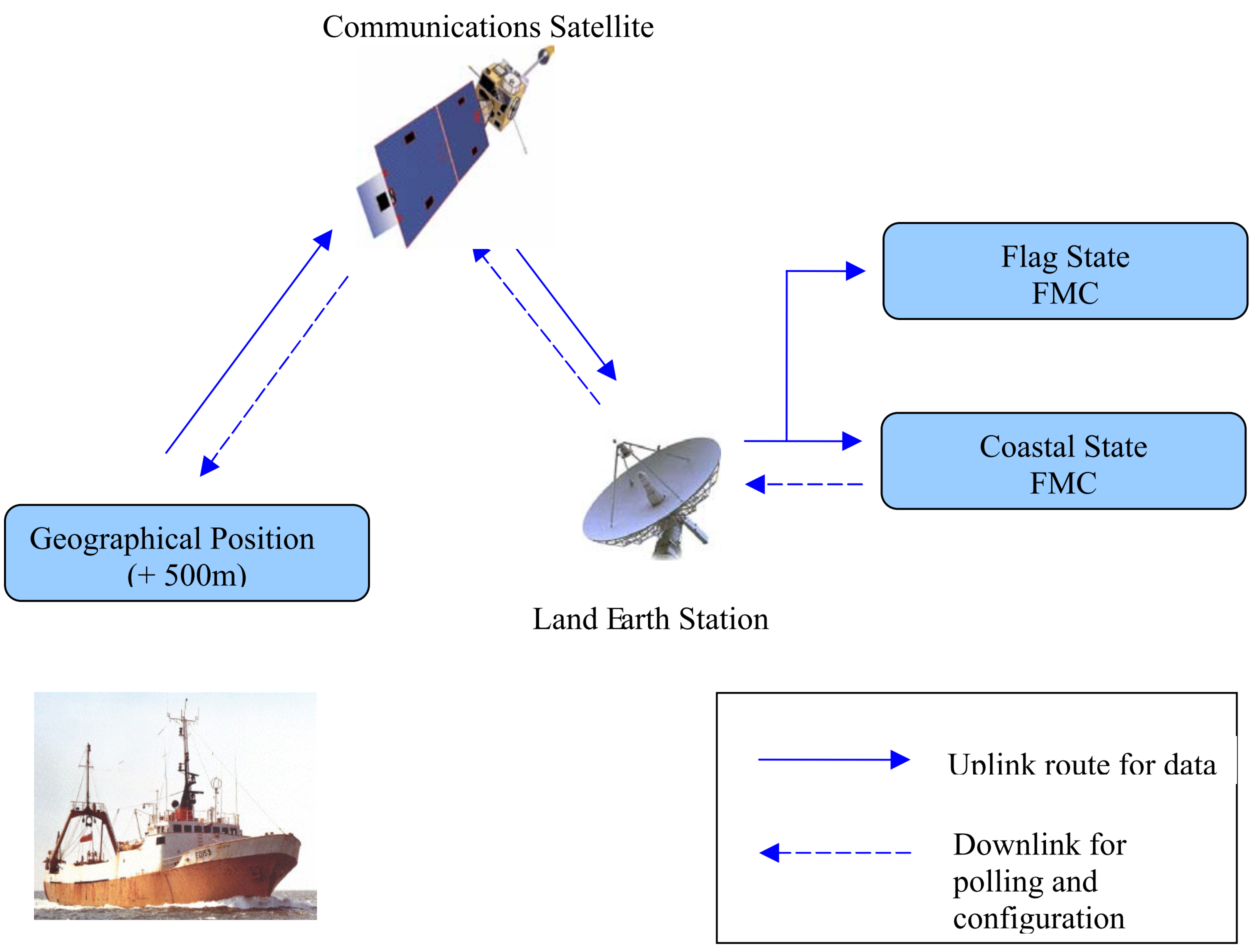

Figure 3 Basic components of a VMS (from MRAG 2003)