NOAA Technical Memorandum NMFS-AFSC-205

Catch Sampling and Estimation in the Federal Groundfish Fisheries off Alaska

by
J. Cahalan, J. Mondragon, and J. Gasper

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

February 2010

NOAA Technical Memorandum NMFS

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This document should be cited as follows:

> Cahalan, J., J. Mondragon, and J. Gasper. 2010. Catch sampling and estimation in the Federal groundfish fisheries off Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-205, 42 p.

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February 2010

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ABSTRACT

We document the methodologies used by the National Marine Fisheries Service (NMFS) to estimate total catch in the Federal groundfish fisheries in waters off Alaska. A combination of industry and onboard observer information is used to estimate total catch. Industry-reported data consists of catch and processed product amounts that are electronically recorded and submitted to NMFS. An extensive observer program is in place and provides information on catch. The observer data are collected using a stratified sample design where strata are defined by vessel size and gear fished. Within each stratum, a multi-stage sampling design is used to sample the species composition of the catch, length distribution of select species, and other catch components. We describe the current NMFS catch estimation procedures, and include formulas that would characterize the uncertainty associated with the estimates. Estimates of variance for catch and bycatch are not currently available. The equations to estimate variances are provided to guide efforts towards their eventual use.

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INTRODUCTION

Obtaining accurate total catch estimates, including retained and at-sea discarded catch, is essential for sustainable fisheries management. Underestimation of total catch can lead to underestimation of the effect of harvest, and bias in stock assessment models (NRC 1998; Punt et al. 2006). Fisheries that are managed under annual catch limits and/or catch share programs require timely and accurate total catch information to ensure that allocated harvest amounts are not exceeded.

Total catch estimates in the groundfish fisheries off Alaska are generated by National Marine Fisheries Service (NMFS) from information provided through a variety of required industry reports of harvest and at-sea discard, and data collected through an extensive fishery observer program. The methods used to estimate total catch in groundfish fisheries have evolved over time. Prior to 1990, total catch in the domestic groundfish fisheries was estimated entirely from information provided by the commercial fishing industry. The North Pacific Groundfish Observer Program (Observer Program), based at the NMFS Alaska Fisheries Science Center (AFSC), was implemented in 1990. Analysis of observer information and industry-reported catch indicated that industry reports under-represented the total catch of some species (NMFS 1993). In response to these findings, NMFS revised the total catch estimation methods in 1992 and applied a process to combine information from observers and industry for catch accounting. This process was referred as the "blend system."

Reviews of the NMFS estimation and data collection processes provided input for further improvements (Vølstad et al. 1997; MRAG Americas 2000, 2002). Recommendations included developing statistical procedures for catch estimation and providing measures of uncertainty, recording sample level observer data to inform statistical procedures, randomizing observer deployments, clarifying the use of industry and observer data, and decreasing the reliance on computations made by an observer. In 2003, a new catch accounting system was implemented to better meet the increasing information needs of fisheries scientists and managers. The 2003 improvements in catch estimation included providing more frequent data summaries at finer spatial and fleet resolution and the increased use of observer data.

More recently, estimators of total catch based only on observer data were developed by Miller (2005), Miller and Skalski (2006), and Miller et al. (2007). Recommendations made by NMFS staff and provided by Miller (2005, 2006) and other reviewers (Vølstad et al. 1997, MRAG Americas 2000, 2002) motivated changes to the methods used by observers to collect and record data. Redesigned Observer Program data collections were successfully implemented in 2008 and include recording sample-specific in lieu of pooled information, increased use of systematic sampling over simple random and opportunistic sampling, and decreased reliance on observer computations.

Past reviews of catch estimation in Alaska recommended redesign of the observer deployment model and random sample selection of sample units at the higher levels (trips or vessels) of the sample design (Vølstad 1997; MRAG Americas 2002, Miller 2005, Miller and Skalski 2006). Currently, vessels that are not required to carry an observer on all their fishing trips are responsible for obtaining observers for a portion of their trips, at a NMFS specified rate. The selection of fishing trips for observation is at the discretion of the vessel operator, and not a randomized process. This is a recognized weakness in current catch estimation processes and the North Pacific Fishery Management Council and NMFS are currently considering changes to the Observer Program that would allow NMFS to control (e.g., randomize) the deployment of observers into the fishery to rectify this weakness. In particular, some existing catch accounting methodologies described in this document rely on the assumption that the data are from a random sample that is representative of fishing activity. Gross violation of this assumption could result in biased estimates of catch.

Our intent is to document the catch estimation methods that are currently being used to estimate total catch in the Federal groundfish fisheries off Alaska. The purpose of this paper is not to develop new methods, but rather to document the catch estimation methods that are currently in place. This is part of ongoing work by NMFS to document, evaluate, and improve catch estimation methods used in the Alaskan groundfish fisheries, with a long-term goal of improving statistical estimators of catch and bycatch. We briefly discuss the groundfish fisheries and management needs before presenting the data sources available for catch estimation and the methods currently in use. Variance estimators have been included for some aspects of the estimation process. We use the term “total catch” to describe the sum of retained and at-sea discarded species and the term “retained catch” to describe quantities not discarded at sea. For our purposes , fish discarded after delivery to a shoreside processor are considered retained catch.

Fisheries Description

Fisheries conducted in waters off Alaska are some of the largest in the world. In 2008, over 2 billion pounds of fish and shellfish were harvested in waters off Alaska, which was over half of the total catch in U.S. waters (NMFS 2009). The Alaskan groundfish fisheries are diverse in respect to the species harvested, the gear types employed, and the scale of harvesting and processing operations. The major groundfish species targeted in Federal waters are walleye pollock, Pacific cod, sablefish, rockfish, flatfish, and Atka mackerel. The harvest of groundfish in Federal waters are governed under fishery management plans (FMPs) that are specific to the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) regions (Fig. 1). The groundfish FMPs describe the processes for setting and maintaining annual catch limits, and providing for optimum yield and fair resource allocation (Witherell 1997). The biological status of groundfish stocks is summarized in annual stock assessment and fishery evaluation (SAFE) reports developed by NMFS, the North Pacific Fishery Management Council (NPFMC), and the Alaska Department of Fish and Game (ADF&G). Information in the SAFE reports is used by NPFMC and NMFS to set catch limits (annual harvest specifications) that meet the management goals described in the FMPs. In addition, the FMPs describe policy for setting bycatch limits for some species, such as halibut and salmon, whose retention is prohibited in the groundfish fisheries; bycatch of these species is referred to as Prohibited Species Catch (PSC).

The NMFS estimates for total catch are specific to species and fisheries, allowing effective monitoring of catch allocations in the annual harvest specifications. Fisheries are defined in time and space for species or species groups, and management objectives require estimates of catch for fisheries at a resolution that can accommodate fishing seasons and specific spatial areas. For example, many fisheries are managed at the NMFS reporting area level, which is a geographical area defined within each FMP region (Fig. 1). In addition, inseason managers need to estimate and monitor catch and discards in multiple management programs, including individual quotas and catch shares; community cooperatives that are part of the Community Development Program (CDQ); industry-formed cooperatives that may be using a particular area; and by catch that is specific to species, gear, and processing modes. Catch estimation methods were designed to provide fast turnaround of the information so that catch and bycatch estimates are available quickly and enable managers to monitor catch and manage fisheries within prescribed limits.

Components of the total catch are discarded in the Federal groundfish fisheries for two primary reasons: either regulations require discard (prohibited species or species closed to directed fishing) or the catch has limited or no economic value. A range of management measures limit or reduce the incidental catch of non-target and prohibited species caught in Alaska groundfish fisheries (Witherell 1997, DiCosimo 2001). Regardless of the reason for discards, they are an important component of total catch and should be accounted for in estimation processes.

Generally, three types of vessels (motherships, catcher processors [CPs], and catcher vessels [CVs]) utilizing one of four gear types participate in Federal groundfish fisheries. Motherships are larger processing vessels that do not fish themselves; they process unsorted catch that is delivered from other vessels. Catcher-processor vessels (CPs) fish and process (e.g., freeze) their catch at sea. Catcher vessels (CVs) do not have processing capabilities and therefore deliver their catch either to shoreside processing plants or motherships. There are four main types of gear used by these vessels in the Alaskan commercial fisheries: trawl gear, longline (hook and line) gear, pot gear, and jig gear. The majority of the groundfish catch is taken by trawl CPs and CVs (Table 1). However, trawl CPs account for only 2.7% of the total number of vessels in 2008 Federal groundfish fisheries, while catcher vessels fishing longline gear make up the largest percentage of the vessels (61%; Table 2).

DATA SOURCES

Data from mandatory fishing industry reports and the North Pacific Observer Program are the two sources of information used to estimate total catch in the Federal groundfish fisheries off Alaska. Each of these data sources are confidential under the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (2007) and therefore can be shared only with authorized persons or in summary form for public dissemination. The unprocessed (raw) data collected by the Observer Program are available in a spatially aggregated form to the public on the AFSC website: http://www.afsc.noaa.gov/FMA. Aggregated estimates of total catch are available on the Alaska Region website at: http://www.fakr.noaa.gov/sustainablefisheries/catchstats.htm.

More than half of the estimates of retained catch and groundfish discarded at sea are derived exclusively from observer data (Table 3). In 2008, approximately 63% of the retained catch was pollock, which is harvested by vessels that generally have high levels of observer coverage. For some vessels, at-sea discard rates based on observer data are multiplied by industry harvest reports to generate discard estimates. Only 6% of the estimated at sea discards of groundfish species is based on industry data alone. Estimates of at-sea discard of prohibited species catch (PSC) are based either entirely on observer data, or if observer data are not available for a specific trip, on at-sea discard rates from observer data that are applied to industry reports of retained catch. With the exception of Pacific halibut PSC, all estimated at-sea discard is assumed to have 100% mortality. The halibut mortality rates are determined periodically by the International Pacific Halibut Commission (IPHC) and are specific to the condition of the halibut (estimated viability of discarded halibut). These rates are applied to the total estimated halibut discard (for a gear type, FMP area (GOA or BSAI), fishery, and year) based on the estimated condition of halibut sampled by observers (Williams 2010).

Industry Reports of Catch and Production

In 2005, NMFS, ADF&G, and the IPHC implemented an interagency electronic reporting system to reduce reporting redundancy and consolidate fishery landing. Vessels in Federal or state fisheries report groundfish landing and production through a web-based interface known as eLandings. There is also a stand-alone application available for the vessels fishing and processing catch at sea (the at-sea fleet). The at-sea fleet submits eLandings files via email. Each industry report submitted via eLandings undergoes error checking by NMFS. Data are then stored in a database and are made available to the three collaborating agencies. There are two basic eLandings report types used for catch estimation: production reports and landing reports.

Production Reports

At-sea production reports are mandatory for CPs and motherships that are issued a Federal Fishing Permit. At-sea production reports include information about the gear type used, area fished, product weights (post-processed) by species, and the weight or number of each species that was discarded at sea. Incidental catch of non-groundfish species other than PSC (such as economically unimportant invertebrates or fish species) are not reported. As of 2009, the at-sea fishing fleet has submitted these reports daily. Prior to 2009, these reports were submitted weekly.

Production reports are required for all shoreside processing facilities that receive groundfish from Federally permitted CVs. These reports are much simpler than at-sea production reports because they only require product weights (post-processed) of each species by FMP region (GOA or BSAI). Shoreside production reports are not specific to a vessel, nor do they contain information on species that were discarded at sea. Shoreside processors must submit these reports to NMFS on a daily basis.

On production reports, both the weight of product and the weight of whole fish are computed values. Product weight (PW) is typically computed as the daily number of cases produced (CN) multiplied by the estimated case weight (Q) by product and species. Some processors report actual case weights while others report the estimated weight, which is based on a standard size of a case of product and is therefore a nominal weight (not measured). The product weight is converted to a pre-processed (round) weight of fish by expanding the product weight by the ratio of pre-processed fish weight (PRFW) to post-processed fish weight (PSTFW). This ratio of pre-processed to post-processed fish weight is the inverse product recovery weight (PRR). Hence, the round (RW) weight can be computed as

$$RW = \frac{\left(CN * \hat{Q}\right)}{PRR} \text{ where the PRR is defined as } PRR = \frac{PSTFW}{PRFW}.$$

Standardized PRRs are published in Federal regulations for product types and species combinations (50 CFR 679 Table 3, 2008). The standardized PRRs are defined in Federal regulations as single point estimates, but they were derived from observer data, industry records, and sample data (see Berger and Hare 1988; Loh et al. 1989). For the most part, these PRRs have not been verified or updated recently. Variance estimates are not available for the PRR point estimates in Federal regulation.

Landing Reports

Landing reports are required when a CV makes a delivery to a shoreside plant or a mothership. Upon making a landing, a representative of the shoreside plant or mothership submits the landing report into eLandings and a paper “fish ticket” is printed for both the processor and the CV representative to sign. The collection period for a landing report is a trip for shoreside processors and a day for each CV that delivers to a mothership. A trip for CVs delivering to a shoreside processor is defined as the time period between when fishing gear is first deployed and the day the vessel offloads groundfish (50 CFR 679.2). Landing reports are mandatory for all processors required to have a Federal processing permit, including motherships who receive groundfish from Federally permitted CVs.

Landing reports include the fishing start date, the delivery date, gear type, area fished, a breakdown of the weight and condition of each species delivered, and weights of any species that were discarded at the plant before processing. Delivering vessels are required to report at-sea discard to the processing facility, but these data are not verified. As a result, NMFS does not use these landing reports to estimate at-sea discard rates. Information for specific hauls within a trip is not available from the landing reports because data are aggregated to delivery level; specifically, landing reports are aggregated to a trip if the catch was delivered to a shoreside processing plant or aggregated to the day if the catch was delivered to a mothership.

Logbooks

Paper logbooks are required to be completed and submitted for Federally permitted vessels over 60 feet in length that are fishing for groundfish and for vessels that are 25 feet and over in length fishing for IFQ halibut. Catcher vessels and CPs that participate in both the groundfish fishery and sablefish or halibut IFQ fishery during the same fishing year are allowed to submit a single combined NMFS/IPHC logbook. The NMFS logbook program has been in place since 1991 and has largely been used for enforcement purposes. For example, catch information in logbooks is used to verify compliance with maximum retainable amounts and to document observer coverage. This information is submitted as hard copy and the information is not routinely entered into a database.

Haul-specific information, including date and time, location, vessel estimates of total catch and species-specific catch, fishing gear, fishing depth, and at-sea discard are recorded in the logbook. These data are not available electronically and thus are not used in catch estimation. For unobserved trips, the logbook data would be extremely useful to determine spatial and temporal trends in fishing effort. There have been some past efforts to keypunch data from subsets of paper logbooks into electronic format; however, the cost and logistics of this effort prohibit wholesale implementation of data entry efforts. A small number of vessels are currently participating in an electronic logbook program. This program was implemented in 2003 and involves 12 voluntary participants. Expansion of electronic logbooks would provide haul-specific effort information on unobserved vessels and the information could be useful to total catch estimation or observer deployment processes in the future.

Issues and Constraints Associated with Industry Reports

Although landing and production reports are legally mandated for all deliveries of groundfish and are enforceable documents, these data are reported by industry and therefore are not independent reports of catch. These data may be subject to the usual suite of reporting errors (e.g., unintentional and intentional reporting errors, transcription errors, scale and other measurement errors). The variance and bias associated with industry reports of harvest and at-sea discard is not known or accounted for in the estimation process, and hence, industry reports of harvest are assumed to be true, known values.

The use of industry-reported information to describe spatially-explicit fishing activities is limited. The data provided by industry are generally not recorded at the haul level, and as such can only be used in the estimation of catch at the spatial resolution of the report. The smallest spatial scale on industry reports containing catch amounts that are electronically available within NMFS is the state statistical area (http://www.cf.adfg.state.ak.us/geninfo/statmaps/statcharts.php). These areas are approximately $30nm^2$.

Observer Program Reports

The AFSC's Fisheries Monitoring and Analysis Division (FMA) monitors groundfish fishing activities in the U.S. Exclusive Economic Zone (EEZ) off Alaska and conducts research associated with sampling commercial fishery catches, estimating catch and bycatch mortality, and analyzing fishery-dependent data. The AFSC is responsible for the oversight of the Observer Program, which was implemented on the domestic fleet in early 1990 for vessels harvesting groundfish under the FMPs. While onboard vessels, observers are tasked with many duties, including monitoring compliance and interactions with endangered species as well as the collection of data used in fisheries management. The majority of an observer's time is spent on data collection, which includes collecting biological samples, recording fishing information (e.g., catch) and entering collected data.

Federal regulations (50 CFR 679.50) require certain levels of observer coverage that are generally defined by the size of a vessel participating in a fishery and, in some instances, the fishery in which a vessel is participating. Observer coverage is defined as the percentage of days a vessel is at sea and fishing (or percentage of fishing effort) for which an observer is onboard. Coverage levels are divided into three general categories: (1) vessels that are 125 feet or greater length overall (LOA) and are not fishing pot gear are required to carry an observer for 100% of their trips; (2) vessels that are between 60 feet and 125 feet LOA or are fishing pot gear are required to carry an observer for 30% of their fishing days for each calendar quarter during which they fish more than 10 days; and (3) vessels less than 60 feet LOA are not required to have any observer coverage. Shoreside processing plants that process 1,000 metric tons (t) or more of groundfish in a month are required to have observer coverage each day they process groundfish while those that process between 500 and 1,000 t of groundfish in a month are required to have observer coverage on 30% of their processing days.

Vessels participating in certain management programs have additional observer coverage requirements. For example, vessels participating in the Rockfish Pilot Program (50 CFR 679.80) require at least 100% observer coverage, regardless of the length of the vessel. Motherships and CPs that participate in either the American Fisheries Act (AFA) directed Pollock fishery) (50 CFR 679.60) or the Amendment 80 (50 CFR 679.90) management program, are required to have

200% observer coverage, which means that two observers are on board for every fishing trip and every haul is sampled.

Vessels that are required to have 30% observer coverage are responsible for obtaining observers to meet their coverage rate requirements. Hence, the vessel operator determines which trips will be observed. As a result, the selection of observed trips is not randomized and observers are deployed into the fishery in areas and at times that are determined by the fishing industry.

Observer Program Sampling Design

Sampling of groundfish fisheries employs a stratified sample design that has three strata, defined by regulation (50 CFR 679.50), that are generally based on vessel size, gear fished, and management program. Vessels in two of the three strata (vessels > than 60 feet LOA and those in special management programs) are required to carry observers for some percentage of their fishing activities. Within each of the two sampled strata, a multi-stage sampling design is used to sample the species composition of the catch, length distribution of select species, and other catch components (Table 4). Detailed descriptions of the sampling methods can be found in the Observer Sampling Manual, prepared each year by AFSC (http://www.afsc.noaa.gov/FMA/default.htm).

The three strata are defined by vessel size, gear type, and fishery. The vessel size stratum is composed of the following: (1) vessels less than 60 feet, (2) vessels 60 to 124 feet and all vessels fishing pot gear, and (3) vessels 125 feet and greater or participating in particular fisheries. Each of these strata is sampled at different rates. The 0 to 60 foot vessel stratum is not sampled by observers (0% sampling rate). Retained catch and at-sea discard estimates for these vessels are based, in part, on industry and vessel reports of harvest as well as on observer data. In the large-vessel stratum (vessels 125 feet and longer, and not fishing pot gear), observers generally monitor 100% of the trips, typically sampling between 50% and 100% of the individual fishing events (hauls). Catch estimates from the 125-foot-and-longer vessel stratum are based primarily on observer data, with industry and vessel reports comprising a smaller percentage of the information used to make the estimates. The medium-sized vessels (between 60 feet and 125 feet), and all vessels fishing pot gear, are sampled at a rate of 30% of fishing days. Trips in the 30% stratum are not selected randomly. Vessels are responsible for obtaining observer coverage for the correct portion of their fishing days as defined in regulation. Since vessels choose when and where they fish with an observer onboard, there is non-random deployment of observers, and for some fisheries the observed fishing may not represent the fishing behavior of the entire fleet.

Once an observer is deployed on a vessel, they are responsible for assessing the fishing activities on the vessel and determining how to sample the unsorted catch using methodology described in the Observer Program Sampling Manual (AFSC 2009). Within each observed trip, either all fishing events (hauls, longline sets, or pot sets) are sampled by the observer to obtain species composition data, or fishing events are randomly selected to be sampled using a constrained simple random sample design (AFSC 2009). The randomization design allows for a randomly placed 6-hour break, if needed, and sampling of no more than four consecutive fishing events (e.g., a trawl haul or longline set).

For each sampled haul or set, a random sample of the total catch is obtained. The observer establishes a sampling frame, defines the sampling units (potential samples), and randomly selects sample units to be collected. Sample frames and units are defined differently depending on the vessel type and configuration, the size of the haul, and the gear used. For example, sampling options that are available to observers on large CPs are often very different from those available on small CVs. In some cases, opportunistically selected samples are taken because the vessel configuration or catch handling practices prevent observers from randomly sampling the catch. Opportunistic sampling usually occurs on trawl CVs.

There are three types of sample frames generally used by observers: temporal (sample units defined by time), spatial (sample units defined by location or space), and a combined temporal-spatial frame. Observers are trained and encouraged to use a systematic sample whenever it is logistically feasible. Systematic samples are generally treated as simple random samples during data analysis. Variance estimates based on this assumption will tend to be high (Thompson 1992).

On trawl vessels, the entire weight of the catch taken on observed hauls is either estimated by the observer or directly measured when onboard flow scales are available. For trawl vessels, a portion of the total haul is selected randomly and the weight of each species in the sample is recorded. The species-specific weight is expanded by the sampling fraction (size of sample divided by size of haul) to estimate the total catch of that species.

For pot and longline vessels, the catch weight for the set is estimated from a randomly selected sample, generally resulting in a third of the set being sampled. All fish on the selected portion of the gear (hooks or pots) are enumerated. This tally of fish is expanded by the sampling fraction (the fraction of total hooks sampled) to estimate the total number of fish caught. The number of fish is further expanded by the mean weight per fish to estimate the total set weight. Estimates of mean weight per fish are obtained from samples of fish randomly selected from both within and outside the enumerated portion of the gear.

In addition to sampling at sea during fishing operations, groundfish observers also sample vessel deliveries to shoreside plants and floating processors. Observers assigned to plants or stationary floating processors are responsible for verifying as many delivery weights as possible, collecting delivery information, assisting vessel observers in their sampling duties, and collecting length data and fish age structures from randomly selected fish (AFSC 2009).

Observer Program Database Structure

Observer data collected on vessels are transmitted electronically to a centralized database. AFSC quality control staff review the data, interview each observer returning from the fishery, and conduct several quality control processes for each dataset incorporated into the database. This database contains all data collected by observers at processing plants and onboard vessels, including marine mammal interaction data, groundfish and non-target catch, and seabird sightings. The data tables are generally nested and configured to complement the observer sampling methods. Data are organized in the database to reflect where and how the data are collected. Observer data are merged with industry reports nightly and are available to fishery managers the following day.

Issues and Constraints Associated with Observer Program Data Collection

The sampling scheme chosen by an observer is often based on expected catch composition, the estimated size of the haul or set, and the processing methods used on the vessel. Based on this information (size, stratification, diversity), the observer decides upon a sampling strategy. However, situations arise where an observer's best assessment of a fishing situation is not accurate, and the sampling scheme implemented is not suitable for the haul. An observer might encounter unexpected degrees of stratification, pockets of higher or lower species diversity, or changes in vessel operations (e.g., due to weather or emergency) that prevent him or her from adhering to a selected sampling scheme throughout the sampled haul.

The ability of an observer to safely obtain random samples of catch is limited on some of the smaller CVs, particularly those fishing trawl gear. Fishing vessel crew are required to give observers access to unsorted catch, and to provide reasonable assistance. However, on CVs observer access to unsorted catch is limited and sampling often occurs when the crew is busy with their own duties. An observer's ability to sample on a CVs is constrained by the speed at which catch is brought onto the vessel's deck, sorted, and placed below deck level. For example, fish are dumped from the trawl net onto the deck, immediately sorted by the crew, and transferred to the fish holds through trawl alley hatches. To accommodate safety concerns, observers often have access to fish at only one or two locations on the deck, and the entire catch is not available to be sampled by observers. In these situations, opportunistic samples are taken because random sampling is not possible or is unsafe. Opportunistic samples are taken by allowing a target sample weight of fish to flow into a checker bin or by collecting a basket of fish from the trawl alley. Despite these issues, observers are generally able to obtain random samples that are based on appropriate sampling.

Due to constraints on sample storage space and access to fish, observers are rarely able to sample more hauls within a trip by decreasing the average sampling fraction per haul. Observers generally do not have the space to store samples or time between hauls to process samples. As a result, all fish included in the observer's samples must be processed before the next haul comes onboard. Thus, sampling fewer hauls will not allow larger samples to be taken, and likewise, taking smaller samples generally does not result in more hauls being sampled.

CATCH AND BYCATCH ESTIMATION METHODS

Estimates of retained catch and at-sea discarded groundfish and PSC are generated for each fishery described in the FMPs (e.g. Fixed Gear Sablefish fishery in the Aleutian Islands).

Retained and discard catch estimates are based on both observer sample data and industry reports of catch (Table 5). Estimation methods follow a post-stratification of hauls and deliveries based on gear and area fished, target species (as defined by realized catch), and vessel type. Fishery-level estimates of total catch (retained catch and at-sea discard) are then obtained by summing all hauls or deliveries within the domain (fishery, time, and area) of interest.

Estimates of retained and discarded catch obtained from observer information are derived for each haul on observed trips based on the sampling design for sampled hauls. On trawl vessels, this is followed by a nearest-neighbor type of imputation of species composition from sampled to unsampled hauls on sampled trips; on fixed-gear vessels catch estimates for unsampled sets are based on the amount of gear fished and average catch per unit gear from sampled hauls on the trip. Estimates of retained catch from industry are taken from landing and production reports, and are assumed to be accurate. Catch reported from these two main data sources, observer data and industry reports, provides a complete accounting of all harvest and at-sea discard in the Federal groundfish fisheries off Alaska.

Haul-level Estimates

The analytical methods that are used to generate point estimates of catch utilize ratio estimators that take into account the underlying sample design used to collect the data. The methods presented here have been used since 2008 to generate point estimates of catch for sampled hauls on observed trips, based on data collected by the Observer Program. Variance estimates are not currently computed. Symbols used throughout the next sections are listed in the Appendix.

All the estimators assume simple random selection of samples, although in most cases systematic sample selection with a single random starting point is used. The assumption of simple random sampling when systematic random sampling has been used will tend to result in an overestimation of variance (Thompson, 1992). In some situations on small CVs, conditions at sea prevent safe collection of random samples and opportunistic samples are taken instead. When samples are selected opportunistically, estimation is based on the assumption of random sampling.

Species-Specific Haul Weight: Trawl Vessels

Generally, several samples are taken from each haul to determine the species proportions of the haul. The size of these species composition samples may be based on units of time, space, or weight. For each sample, the total weight of fish and the weight of fish of each species are recorded. A ratio of means estimator is used to estimate the proportion of the haul that is a given species. The estimated weight of a species in a haul is the estimated proportion of the haul of that species applied to the total weight of the haul. On most CPs (all trawl CPs operating in the BSAI), the total weight of fish in a haul is measured directly by a flow (or other type) scale.

In situations where we have a known total weight of fish in the haul (e.g., from a flow scale), the estimated weight of species *i* in a haul, $\hat{W}_i$, is the total weight of fish (*W*) multiplied by the sum of weight of species *i, i = 1, … I_j*, over all samples, *j*, *j= 1… J,* and divided by the sum of the total sample weight, Equation (1):

$$\hat{W}_i = W \frac{\sum_{j=1}^{J} w_{i,j}}{\sum_{j}^{J} \sum_{i=1}^{I_J} w_{i,j}} = W \frac{\overline{w}_i}{\overline{w}} \qquad (1)$$

The variance of $\hat{W}_i$ is

$$V\hat{a}r(\hat{W}_i) \cong W^2(1-p_w)\left[\overline{w}_i^2 \overline{w}^{-4} V\hat{a}r(\overline{w}) + \overline{w}^{-2} V\hat{a}r(\overline{w}_i) - 2\overline{w}_i \overline{w}^{-3} C\hat{o}v(\overline{w}_i, \overline{w})\right] \qquad (2)$$

where p_w is the sampling fraction based on weight of fish, and the variances of $\overline{w}_i$ and $\overline{w}$ are computed using the usual formulas. Estimation of the last variance term, $2\overline{w}_i \overline{w}^{-3} C\hat{o}v(\overline{w}_i, \overline{w})$, may not be possible since observers generally only randomly select three samples. Omitting the covariance term will lead to conservative estimates (overestimates) of the variance.

This approximate variance, Equation (2), is derived from the Taylor expansion of $\overline{w}_i / \overline{w}$. The above estimator uses size-of-sample as a weighting factor, hence samples that weigh more contribute more to the estimate than smaller samples that weigh less.

In order to maximize the sample fraction for the majority of species in cases where there are only two predominant species in the haul, the predominant species are not enumerated in the sample; however, subsamples are selected from within the sample and every species in the subsample is weighed. Not all samples within a haul will necessarily have two predominant species (and subsamples). Hence, in order to estimate the weight of the predominant species in the catch, the sub-sample data are first expanded to the sample for the predominant species. The samples are combined to generate haul-level estimates of catch.

The weight of one of the two predominant species, *i*, in sample *j* is estimated by Equation (3) where there are K_j subsamples in sample *j*, *k*=1, … *K* subsamples in sample *j*, and w_{ij} is the weight of fish of species *i* in sample *j* where *j* = 1, …, *J* and S_j is the total weight of predominant species in the sample, and w_{ijk} is the weight of fish of species *i* in sample *j*, sub-sample *k* where *k* = 1, …., K_j,

$$\hat{w}_{ij} = S_j \frac{\sum_{k=1}^{K_j} w_{ijk}}{\sum_{i=1}^{I_j}\sum_{k=1}^{K_j} w_{ijk}} = S_j \frac{\sum_{k=1}^{K_j} w_{ijk}}{\sum_{k=1}^{K_j} w_{jk}} = S_j \frac{\overline{w}_{ij}}{\overline{w}_j} \qquad (3)$$

with variance

$$V\hat{a}r(\hat{w}_{ij}) \cong S_j^2(1-p_{w_j})\left[\overline{w}_{ij}^2\overline{w}_j^{-4}V\hat{a}r(\overline{w}_j) + \overline{w}_j^{-2}V\hat{a}r(\overline{w}_{ij}) - 2\overline{w}_{ij}\overline{w}_j^{-3}C\hat{o}v(\overline{w}_{ij},\overline{w}_j)\right] \quad (4)$$

Since most samples that are subsampled (containing two predominant species) have a single subsample taken, estimates of uncertainly cannot be developed. However, we can model the within-sample variance using the assumption of a binomial distribution of predominant species within the subsample. In this case, we have $V\hat{a}r(\hat{w}_{ij}) = S_j^2 p_j(1-p_j) = S_j^2 \frac{w_{ij}}{w_j}(1-\frac{w_{ij}}{w_j})$, where p_j is the proportion of the j^{th} sample that is species *i*, based on weight of fish.

This estimated weight is then combined with the other sample weights to estimate the catch of species *i* in the haul as

$$\hat{W}_i = W \frac{\sum_{j=1}^{J} \hat{w}_{ij}}{\sum_{j=1}^{J} w_j} = W \frac{\hat{\overline{w}}_i}{\overline{w}} \qquad (5)$$

with variance

$$V\hat{a}r(\hat{W}_i) = W^2(1-p_w)\left[\hat{\bar{w}}_i^2\bar{w}^{-4}V\hat{a}r(\bar{w}) + \bar{w}^{-2}V\hat{a}r(\hat{\bar{w}}_i) - 2\bar{w}_i\bar{w}^{-3}C\hat{o}v(\hat{\bar{w}}_i,\bar{w})\right] \quad (6)$$

where $V\hat{a}r(\hat{\bar{w}}_i) = \frac{\sum_{j=1}^{J}(w_{ij}-\hat{\bar{w}}_i)^2}{J-1} + \frac{\sum_{j=1}^{J}V\hat{a}r(\hat{w}_{ij})}{J}$ and $V\hat{a}r(\bar{w}) = \frac{\sum_{j=1}^{J}\left(w_j-\bar{w}\right)^2}{J}$.

Species-Specific Haul Weight: Longline and Pot Vessels

Estimation methods for the longline and pot fisheries are similar to the trawl estimation methods. The major difference is that the unit of measure used on longline and pot vessels is a unit of gear (hooks or pots), whereas on trawl vessels the units are measured in terms of volume or weight. Overall, observer estimates of species-specific weights are based on the mean-weight-per-hook or mean-weight-per-pot statistic expanded by the total number of hooks or pots retrieved in a set. The mean weight per hook or pot is the estimated weight of fish sampled (number of fish in sample multiplied by mean weight per fish), divided by the total number of hooks or pots sampled. The total number of hooks retrieved is the total number of gear segments set expanded by the mean number of hooks per gear segment.

For a given sample, the estimated weight of fish of a given species, $\hat{w}_{ij}$, is the mean weight per fish expanded by the number of fish in the sample, N_{ij},

$$\hat{w}_{ij} = N_{ij}\left[\frac{\sum_{k=1}^{K} w_{ijk}}{f_{ij}}\right] = N_{ij}\bar{w}_{ij}, \quad (7)$$

where f_{ij}, is the number of fish weighed of species i in sample j. This estimated variance, Equation (8), is the usual variance estimator:

$$V\hat{a}r(\hat{w}_{ij}) = N_{ij}^2 V\hat{a}r(\bar{w}_{ij}) = N_{ij}^2\left[\frac{\sum_{k=1}^{K}(w_{ijk}-\bar{w}_{ij})^2}{f_{ij}(f_{ij}-1)}\right]. \quad (8)$$

Longline sets consist of segments of line with baited hooks. Each segment is called a skate or magazine of gear. The estimated number of hooks sampled, $\hat{h}_j$, is the mean number of hooks per gear segment (skate or magazine) multiplied by the total number of segments in the sample, m_j: $\hat{h}_j = m_j \bar{h}$, where $\bar{h}$ is the mean number of hooks per segment determined through an independent sample of gear taken weekly and where m_j is the number of segments of gear in sample *j*. Each week the observer (non-randomly) selects 20% of the gear and records the number of hooks on each selected sample. The variance is estimated as $V\hat{a}r(\hat{h}_j) = m_j^2 V\hat{a}r(\bar{h})$ where $V\hat{a}r(\bar{h})$ is computed in the usual manner under the assumption of a simple random sample.

The weight per hook, $\hat{w}_{i,h}$, is estimated as the sum over all samples of the species-specific sample weights divided by the sum of the sampled hooks, Equation (9):

$$\hat{w}_{i,h} = \frac{\sum_{j=1}^{J} \hat{w}_{ij}}{\sum_{j=1}^{J} \hat{h}_j} \tag{9}$$

The variance for this estimator is presented in Equation (10):

$$V\hat{a}r(\hat{w}_{i,h}) = (\sum_{j=1}^{J} \hat{w}_{ij})^2 (\sum_{j=1}^{J} \hat{h}_j)^{-4} V\hat{a}r(\sum_{j=1}^{J} \hat{h}_j) + (\sum_{j=1}^{J} \hat{h}_j)^{-2} V\hat{a}r(\sum_{j=1}^{J} \hat{w}_{ij}) - V\hat{a}r(\sum_{j=1}^{J} \hat{w}_{ij})(\sum_{j=1}^{J} \hat{h}_j)^{-4} V\hat{a}r(\sum_{j=1}^{J} \hat{h}_j) . \tag{10}$$

Assuming independence between the number of hooks and the mean weight per hook, this is the exact variance of the ratio (Goodman 1960). The total number of hooks fished ($\hat{H}$) is the mean number of hooks per unit of gear ($\bar{h}$) expanded by the known total number of units of gear fished (*M*) or $\hat{H} = M\bar{h}$ with variance $V\hat{a}r(\hat{H}) = M^2 V\hat{a}r(\bar{h})$.

Finally, the total weight of a given fish species for the haul, $\hat{W}_i$, is given by Equation (11) with variance given by Equation(12):

$$\hat{W}_i = \hat{H}\hat{w}_{i,h} \tag{11}$$

$$V\hat{a}r(\hat{W}_i) = \hat{H}^2 V\hat{a}r(\hat{w}_{i,h}) + \hat{w}_{i,h}^2 V\hat{a}r(\hat{H}) - V\hat{a}r(\hat{w}_{i,h}) V\hat{a}r(\hat{H}) . \tag{12}$$

On trips where not all the longline sets are sampled, the total haul weight ($\hat{W}$) is computed as the mean weight per hook for all sets in the trip multiplied by the number of hooks set on the unsampled haul.

The preceding section described the estimation for longline gear; however, the same estimation process is followed for pot gear. The single exception is that the number of pots set is a known constant, not estimated from sampling. Hence, $\hat{W}_i = H\hat{w}_{i,h}$, where H is the known number of pots fished. The variance then simplifies to $V\hat{a}r(\hat{W}_i) = H^2 V\hat{a}r(\hat{w}_{i,h})$.

Observer Estimates of At-Sea Discard

The catch of groundfish that is discarded at sea is estimated using the same general computations for all gear types (longline, pot, and trawl). The observer assesses the amount of catch that is discarded at sea for each species encountered in the haul. This estimate is based on the observer's best professional judgment and may include observations of at-sea discard from the deck, estimates of the numbers of fish that dropoff longline gear as it is retrieved, estimates of at-sea discard from the factory (made by the vessel or by the observer), and estimated differences between total catch and final product. Discard is challenging because it can occur at many places in a fishing and processing operation.

The weight of at-sea discarded fish of species *i*, $\hat{D}_i$,can be computed by applying the estimated at-sea discard rate, $\hat{d}_i$, to the total estimated haul weight, $\hat{W}$, for species *i*, Equation (13). The variance of at-sea discards is estimated by Equation (14).

$$\hat{D}_i = \hat{d}_i \hat{W}_i \quad (13)$$

$$V\hat{a}r(\hat{D}_i) = \hat{d}_i^2 V\hat{a}r(\hat{W}_i) + \hat{W}_i^2 V\hat{a}r(\hat{d}_i) - V\hat{a}r(\hat{W}_i) V\hat{a}r(\hat{d}_i) \quad (14)$$

Unfortunately, since the estimates of at-sea discard rate are not based on sampling, the variance ($V\hat{a}r(\hat{d}_i)$) is not available. The magnitude of bias (if any) associated with these estimates is not known at this time. However, if we are willing to assume that the at-sea discard rate is a binomial proportion (the probability of at-sea discard) and the amount of at-sea discard is binomially distributed, then the variance for discards is $V\hat{a}r(\hat{d}_i) = \hat{d}_i(1-\hat{d}_i)$.

Calibration of Haul-Level Estimates to Landed (Delivery) Weight

Catcher vessels in the AFA pollock fishery generally deliver a large amount of their prohibited species catch (PSC) to shoreside processing plants. These prohibited species individuals are counted by observers at the dockside plant as the CV offloads. However, the Alaska Region database and estimation process is currently configured to accept observer data only at the haul level, not at the offload level at which PSC data are collected. PSC information collected by observers requires data collected at the shoreside plant to be apportioned back to those hauls that contributed to that delivery. Thus, for CVs where the delivery weight of relatively unsorted catch exists, the observer estimates are adjusted so that the sum of the species catch weight equals the delivery weight and at-sea discard weight. Vessel logbook information is used to determine the total number of hauls made in a trip.

The basic adjustment ratio for a delivery where the total delivery weight as measured by the plant (*O*) is available and the delivery is monitored is the proportion of the retained weight of the haul of interest (*h*) to the total retained weight over all sampled hauls in the delivery. This ratio, $\hat{R}_h$, is computed for the total catch , Equation (15), and for an individual species in the catch, Equation (16), as the ratio of retained catch for an individual haul divided by the total retained catch in the delivery, where *i* indexed species, *h* indexed hauls, *H* is the total number of hauls in the delivery as reported by the vessel, $h=1, \ldots, H$, S_{ih} is the weight of prohibited species *i* contained in observer's samples from haul *h*, X_{ih} is the pre-sorted catch of species *i* from haul *h*, and $\hat{D}_{ih}$ is the estimated at-sea discard of species *i* (observer or vessel estimate) for haul *h*:

$$\hat{R}_h = \frac{\hat{W}_h - (\hat{D}_h + S_h + X_h)}{\sum_{h=1}^{H} \left[\hat{W}_h - (\hat{D}_h + S_h + X_h) \right]} \tag{15}$$

$$\hat{R}_{ih} = \frac{\hat{W}_{ih} - (\hat{D}_{ih} + S_{ih} + X_{ih})}{\sum_{h=1}^{H} \left[\hat{W}_{ih} - (\hat{D}_{ih} + S_{ih} + X_{ih}) \right]} . \tag{16}$$

The adjusted total haul weight is $\hat{W}_h^* = \hat{R}_h O$, and the prohibited species catch predicted for haul *h* is given by Equation (17), where D_{pro_i} is the delivered weight of prohibited species *i*.

$$\hat{D}_{pro_i,h} = \hat{R}_{ih} D_{pro_i} + S_{ih} + \hat{D}_{ih} + X_{ih} . \tag{17}$$

The total catch of monitored species for all hauls in the delivery is the sum of the estimated catch of monitored species over all monitored species: $\hat{D}_h = \sum_{i \in M} \hat{D}_{ih}$, where M is the set of monitored species.

This apportioning of catch of a single species from the delivery to the haul assumes that the ratio of the weight of a haul to the total delivery weight is the same as the ratio of the weight of a single species within the haul to the total species weight over all hauls (i.e. all hauls have the same species composition). Further, this apportioning of PSC results in PSC only being attributed to sampled hauls for that trip (delivery). However, the species composition of unsampled hauls within an observed trip are imputed for retained catch and at-sea discard of groundfish using the methods described in the next section. For PSC species, the total PSC bycatch for the trip is based on expanding the PSC bycatch rate of the sampled hauls on the observed trip to the total trip catch of groundfish (retained and discarded at-sea). The NMFS is in the process of changing programming in the catch accounting system to eliminate the apportioning of offload data to individual hauls. Programming changes would allow PSC census data at the trip level to be used to estimate overall PSC catch.

Imputation Process for Unsampled Hauls

A deterministic imputation method, based on matching hauls within the data collected for that calendar year and using a set of covariates, is used to estimate species catch rate for un-sampled hauls in observed trips. This imputation method is used to estimate the species catch rate for groundfish species only (both retained and at-sea discard) on observed trips. Methods of estimation for PSC and other non-groundfish species are covered in a separate section. On observed trips where not all the hauls are sampled, the species composition data from the next nearest haul (in time and area) within the same vessel and gear type is substituted for the missing data. Additionally, when hauls are within the same FMP area, a spatial match takes precedence over a temporal match. Once the set of hauls matching the vessel, gear type, and area criteria is identified, the haul closest in time to the unsampled haul is selected in the following order:

1. Sampled haul occurred on same day as the unsampled haul, but prior.

2. Sampled haul occurred on same day as the unsampled haul, but later.
3. Sampled haul occurred on different day than the unsampled haul, but prior to it within 7 days.
4. Sampled haul occurred on different day than the unsampled haul, but no more than 7 days later.

Once a matching (similar) haul is identified, the species composition from the selected sampled haul is multiplied by the total haul weight of the unsampled haul. On trips where not all the longline sets are sampled, the total haul weight ($\hat{W}$) is computed as the mean weight per hook for all sets in the trip multiplied by the number of hooks set on the unsampled haul. For the unsampled haul, Equation (18), where $\hat{W}_i^A$ is the adjusted estimated total weight of species *i* for the unsampled haul, W_{h_u} is the total weight of the unsampled haul, W_h is the total weight of the sampled haul, and $\hat{W}_{i,h}$ is the estimated catch for species *i* in the sampled haul:

$$\hat{W}_i^A = \frac{W_{h_u}}{W_h}\hat{W}_{i,h} \; . \tag{18}$$

This adjustment factor is applied to the estimated species weight, estimated species number, and sampled species weight and number. If we consider that the total haul weight is a constant, the variance of the adjusted catch can be estimated by scaling the variance of the sampled haul by Equation (19) where the variance is defined by Equation (12):

$$V\hat{a}r(\hat{W}_i^A) = \frac{W_{h_u}^2}{W_h^2} V\hat{a}r(\hat{W}_{i,h}) \, . \tag{19}$$

Fishery-Level Estimates

Estimates of retained and at-sea discarded catch for each fishery are generated by combining haul-level estimates (or reported catch) for all hauls within a defined fishery (domain). The domains are defined largely by area, gear, vessel type, and the predominant species retained during the trip (i.e., trip target).

The data that are used to determine the predominant species retained during a trip depends on the amount of observer coverage and the type of vessel (mothership, CP, or CV). If the vessel is a CP or mothership with at least 100% observer coverage, then observer data is used to determine the trip target. For all other vessels, either a production or landing report is used. Determining the trip target is a three-step process that is implemented in the catch accounting system: (1) if 95% or more of the retained catch is pollock, then a pollock target is assigned; (2) if the sum of all flatfish is greater than the amount of any other species, then flatfish is assigned as the trip target; 3) if neither pollock nor flatfish is determined as the target, then the groundfish species that has the highest proportion of the retained catch is assigned as the target.

Retained Catch

Estimates of retained catch are generated from both observer estimates (on ≥100% observed CPs and CVs delivering to motherships) and industry reports (on <100% observed CPs and motherships, CVs delivering shoreside) of retained catch (Table 5). Note that observer estimates and industry reports include all retained catch; discards of catch that occur at the processing plant are included in these estimates. Since all hauls have either estimated or known catch, the estimator of total catch is the sum across strata of the estimates of catch for a given species for all hauls within the domain, Equation (20), where $\hat{W}_{ih}$ is the observer estimate of harvest for species *i* and haul *h* on a CP with 100 or 200% observer coverage or a CV delivering to a mothership, and W_{id} is the delivered weight of species *i* in delivery *d* from CPs or motherships with less than 100% observer coverage and CVs delivering shoreside (industry report of retained catch):

$$\hat{C}_i = \sum_{h \in a} \hat{W}_{ih} + \sum_{d \in a} W_{id} \ . \quad (20)$$

On observed trips, the harvest for each species in each haul is either estimated from observer sample data or generated through the imputation process. Hence, there is no sampling variance within strata, except the variance associated with expansions of observer sample data. Thus, assuming industry reports are known constants with no error, Equation (21) is an appropriate variance estimator, where $V\hat{a}r(\hat{W}_{ih})$ is defined in Equation (12):

$$V\hat{a}r(\hat{C}_i) = \sum_{h \in a} V\hat{a}r(\hat{W}_{ih}) \quad (21)$$

The variance in Equation (21) will tend to underestimate the actual variance in retained catch since the $V\hat{a}r(\hat{W}_{ih})$ associated with unsampled hauls does not include the variance associated with the imputation process, simply the scaled variance in total catch from the selected nearest-neighbor haul.

At-Sea Discard of Groundfish Species

For catcher-processors that have 100% (one observer, random selection of hauls are sampled) and 200% (two observers, all hauls are sampled) observer coverage and CVs delivering to motherships (all have ≥100% coverage), observer data is used entirely to estimate the amount of groundfish that was discarded at sea. These at-sea discards are quantified (observed) by the observer on the vessels; estimates are based, in part, on the observer's best professional judgment, and haul-level variances are largely unknown (see previous at-sea discard discussion). Since each haul is accounted for, either through sampling or the imputation process, there is no between-haul sample variance. The total at-sea discard for this post-stratum of a fishery (domain) is the sum of estimated at sea-discards for those hauls within a domain.

For CPs in the 0% and 30% observer coverage portions of the fishery, at-sea discards are reported by the industry and are assumed to be known. In this case, the total at sea discard for this post-stratum is the sum of reported at-sea discards for all landings.

For CVs delivering their catch to plants on shore, observer-based at-sea discard rates are applied to the total retained catch recorded on industry reports (including the shoreside discards reported by the plant). The at-sea discard rates are based on a post-stratification of hauls based on two covariate groupings:

1. aggregated on week end date, gear type, trip target code, and reporting area; and
2. aggregated across reporting areas; by week end date, gear type, trip target code, and FMP area.

The ratio estimator of at-sea discard rate is the at-sea discard for a given species divided by the total retained groundfish of all species. This ratio is computed for each post-stratum, *r*, using all the observer-based estimates of at sea discard, $\hat{D}$, within the post-stratum. The ratio is applied to the retained landed weight within the same post-strata. The domain estimates for these post-strata are then the sum of the hauls within the domain of interest. Letting

i	= index the species of interest
a	= index the domain of interest (small area=fishery)
r	= index the post-strata (rate computation)
h_{op}	= index hauls on observed trips on >100% observed CPs, M
h_i	= index all hauls on <100% CPs
h_{ov}	= index observed hauls on CVs
h_v	= index hauls on CVs
H_r	= total hauls in post-strata
$\hat{C}$	= estimated total retained groundfish based on observer sample; $\hat{C} = \sum_{i \in groundfish} \hat{W}_i$
C^*	= total industry reported retained groundfish (all species)
$\hat{D}$	= estimated total at sea discarded groundfish based on observer sample and,
D^*	= total industry reported at-sea discards on 30% CPs,

then the at-sea discard of groundfish species i for a fishery (or domain) a is estimated using Equation (22):

$$\hat{D}_{i,a} = \sum_{r \in a} \left(\frac{\sum_{h_{ov} \in H_r} \hat{D}_{i,h_{ov},r,a}}{\sum_{h_{ov} \in H_r} \hat{C}_{h_{ov},r,a}} \sum_{h \in H_r} C^*_{h_v,r,a} \right) + \sum_{h_{op} \in H_a} \hat{D}_{i,h_{op},a} + \sum_{h_i \in H_a} D^*_{i,h_i,a} \,. \qquad (22)$$

The summations in the above equation are not within sampling strata, but rather are pooled by vessel type. As a result, variance estimators for at-sea discard of groundfish species cannot be developed.

At-sea Discard of Non-groundfish Species Including Prohibited Species (PSC)

At-sea discard of prohibited species is estimated in numbers of individuals for salmon and crab (Tanner, red king, and snow), and in weight (t) for herring and halibut. Since no catch of prohibited species can be legally retained for sale (with exception of food donation programs), all catch is assumed to be discarded at sea. At-sea discard of any other non-groundfish species is estimated in the same manner and is calculated as weight (t) of incidental catch. These non-target species include invertebrates, forage fish, and other non-groundfish species that are not retained.

The estimation method for at-sea discard of prohibited and non-groundfish species differs based on the observer coverage strata. For CPs with 100% observer coverage or greater and CVs delivering to motherships, the observer estimate of prohibited species discarded catch is the observer-based estimate of at-sea discard for that species. For vessels with less than 100% observer coverage and CVs delivering to shoreside processors, an observer-based rate is applied to the total groundfish catch (the sum of a landing or production report of total groundfish catch and the at-sea discard calculated using the methods described in the preceding section).

The catch rate (ratio of estimated prohibited species to total estimated total catch in sampled hauls) is based on varying levels of post-stratification (Table 6). For all rates except the vessel-specific and the FMP-level rates, a minimum of three observed hauls is required for the rate to be generated. The vessel-specific and the FMP-level rates can be generated if data from one or more hauls are available in the observer data.

For each landing report, the mean value based on the closest match of aggregating variables (level of detail) is applied to landing amounts (numbers or weights). As with the estimation of retained and incidental catch, prohibited species incidental catch is the sum over all landings within a domain of estimated prohibited species incidental catch. For observed trips, the total groundfish is the species-specific estimates of catch summed over all groundfish species, Equations (23) and (24):

$$\hat{G}_{h_o} = \sum_{i \in \{Groundfish\}} \hat{W}_{i,h_o} \tag{23}$$

$$V\hat{a}r(\hat{G}_{h_o}) = \sum_{i \in \{Groundfish\}} V\hat{a}r(\hat{W}_{i,h_o}) . \tag{24}$$

This includes the haul-specific estimates for unsampled hauls (on observed trips) that are generated through the imputation process. For unobserved trips, the total groundfish for a given haul (*h*), G_h, is the sum over all groundfish species of the harvest and the at-sea discarded catch, as reported by industry, Equation (25):

$$G_h = \sum_{i \in \{Groundfish\}} \left(C_{i,h} + D_{i,h} \right) . \tag{25}$$

The at-sea discard of prohibited and non-groundfish species catch, $\hat{D}_{a,pro_i}$, is the ratio estimate of at-sea discard rate applied to total groundfish catch (landing report) for CVs and vessels with less than 100% coverage plus the observed at-sea discards on vessels with 100% or greater coverage. This is computed using Equation (26), where t_o indexes observed trips, h_o indexes sampled hauls, h indexes of all hauls on CVs and vessels in the <100% observed strata, and h^* indexes all hauls on CPs and motherships in the >=100% observed strata,

$$\hat{D}_{a,pro_i} = \sum_{r \in a} \frac{\sum_{h_o \in H_r} \hat{W}_{h_o,r,a,pro_i}}{\sum_{h_o \in H_r} \hat{G}_{h_o,r,a}} \sum_{h \in H_r} G_{h,r,a} + \sum_{t_o \in a} \frac{\sum_{h_o \in t_o} \hat{W}_{h_o \in t_o,a,pro_i}}{\sum_{h_o \in t_o} \hat{G}_{h_o \in t_o,a}} \sum_{h^* \in t_o} \hat{G}_{h^* \in t_o,a} \quad (26)$$

In the above equation, the index of sub-domain, *r*, defines the covariates used to define observed hauls that are used to estimate the bycatch rate. For observed trips on CVs the set of covariates always includes the specific trip and FMP area. For observed trips on CPs the set of covariates always includes the specific trip (defined as week), gear type, and NMFS reporting area. Hence, for all vessels with 100% or greater observer coverage (second term in the above equation), the set of covariates is always trip-specific. For vessels with less than 100% coverage, the set of covariates used to define the at-sea discard rate for observed trips is trip-specific.

DISCUSSION

The catch and bycatch estimators that we present are not an attempt to develop new statistical estimators, but rather to document the methods used to quantify catch for inseason management of Alaska groundfish fisheries. Variance estimators are provided in some cases, especially where sampling is randomized.

The catch and associated variance estimators for haul-level estimates are based on the sample design currently employed by the NMFS. There are sources of variance associated with the haul-level catch estimates that are not included in the equations. These include situations where observers are not able to collect multiple samples, are not able to randomize their sample collection, or where total haul weight is not known (estimated). In addition, some parameters are considered to be known (without variance), when in fact there is likely to be some associated error. For example, observer estimates often use vessel (flow) scale weights of catch. However, allowed scale tolerances (±3%) are not included in the estimation of variance nor is possible bias to this tolerance examined. As a result, equations provide a minimum estimate of the variance associated with catch; actual variances for these catch estimates are expected to be larger.

An evaluation of observer sampling methods could be conducted to evaluate the effectiveness of, and alternatives to, current sampling methods used on catcher-only vessels and the methods used to assess the species-specific discard rates obtained by observers to further improve quality of observer data. There are currently no formal sampling procedures for observers to estimate discard of each species for a given haul. Due to logistical constraints that arise from sampling in a factory setting, it is unlikely that a well- defined sampling design can be developed. As a result, the estimation of variance associated with at-sea discard of groundfish and non-groundfish species is limited.

As described earlier, the fishery-level catch estimators have been developed over time to meet the fishery management needs. Variance estimation at the fishery level for the catch and bycatch estimators presented is complicated by many factors including the lack of randomization in observer deployments, use of industry and PRR based reports, the use of imputation and apportioning methods, and post-stratification of data.

Currently, the process used to deploy observers in fisheries with less than 100% coverage is problematic. For this portion of the fleet, vessel operators determine when (and where) observers are deployed under the requirement that 30% of the fishing effort is observed. Of particular concern under this deployment model is the non-representativeness of observed trips and vessels that arises from the non-random selection of trips to be observed. This leads to potential non-representativeness of the spatial and temporal distribution of observed catch relative to total catch, which in turn, could result in biased catch estimation.

NMFS and NPFMC are currently considering options for changing the deployment model used to place observers into the fishery. Several alternatives for restructuring and funding the Observer Program are being analyzed. Each action alternative being considered would provide NMFS control over the placement of observers for those vessels and fishing trips currently subject to less than 100% observer coverage. This would greatly increase NMFS' ability to assess uncertainty associated with catch and bycatch estimates by allowing valid statistical estimators to be developed.

In addition, the NMFS Alaska Regional Office, NMFS AFSC, and the Pacific States Marine Fisheries Commission are currently working to evaluate the procedures used to estimate total catch and discard for Alaskan groundfish fisheries. This evaluation is expected to assess alternate estimators of total catch and bycatch as well as to develop and incorporate statistically valid variance estimates. Specifically, we will be investigating methods of estimation that minimize the use of non-statistical methods such as the nearest-neighbor imputation used to predict catch of unsampled hauls and the apportioning of catch from the delivery back to the individual hauls.

Imputation methods that incorporate stochasticity have been developed (see Nordholt, 1998) and may be useful if imputation to unsampled hauls is necessary to the estimation process. These methods preserve the variance structure of the estimates, use data from the same dataset for imputation, and are well documented. Alternately, imputation of the mean will not add any imputation variance, and in the case of randomly selected hauls, the estimates will not be biased (Nordholt 1998).

The post-stratification of observer data for the determination of discard rates currently does not take into account the differential sampling rates caused by stratification of observer coverage and by the vessel-specific nature of observer coverage requirements. As a result the discard rates developed may be biased. An analysis of the post-stratification of observer data needs to be conducted, inclusive of an evaluation of the choice of covariates used to define post-strata and an overall sample size analysis.

The current methodology makes use of ratio estimators to estimate catch at the fishery-level. Ratio estimators are potentially biased, however, and the bias increases with decreasing relationship between the numerator and denominator of the ratio, and with decreasing sample size (Cochran 1977, Thompson 1992). Use of a ratio estimator when there is no relationship between numerator and denominator can result in 1) large variance in predictions and 2) potential bias (Cochran 1977). While the use of entirely design-based methods seems attractive (e.g., Miller 2005), there are advantages to continued use of ratio estimators in generating catch estimates. Ultimately, ratio methods will be evaluated along with the completely design-based estimators recommended by Miller (2005). Increased use of design-based estimators that rely only on observer data will also be assessed in terms of relative bias and variance associated with the final fishery-level total catch and discard estimates.

Lastly, we recognize that the actual PRRs experienced by processors may differ from those published in Federal regulation due to different factory configurations, processing staff, and size of fish, and that potential bias has not been assessed. In addition, estimates of variance associated with the published PRR point estimates are not available. Hence, these published PRRs are nominal values and may not reflect differences in technology, or spatial and seasonal differences in the efficiency of processing operations.

The methodology that we describe is a detailed account of current estimation techniques and provides examples of the formulas and associated assumptions that could be used to characterize uncertainty. We provide an important foundation from which to evaluate the statistical limitations and make improvements to the estimation procedures. The continuing challenge is to implement rigorous methods while at the same time meeting the need for near real-time information for quota monitoring and inseason management. Certain statistical methods that might provide very robust estimates may not lend themselves to near real-time use without a large increase in staff resources. These issues are being considered as part of ongoing effort by NMFS to evaluate and make improvements to the catch estimation procedures, and we expect that this evaluation will result in estimators, with measures of uncertainty, that are more robust while meeting management needs.

ACKNOWLEDGEMENTS

We gratefully acknowledge Dr. Martin Dorn (AFSC), Dr. Craig Faunce (AFSC), Dr. William Karp (AFSC), Martin Loefflad (AFSC), Pam Mason (AKRO), and Susan Salveson (AKRO) who provided useful comments and review.

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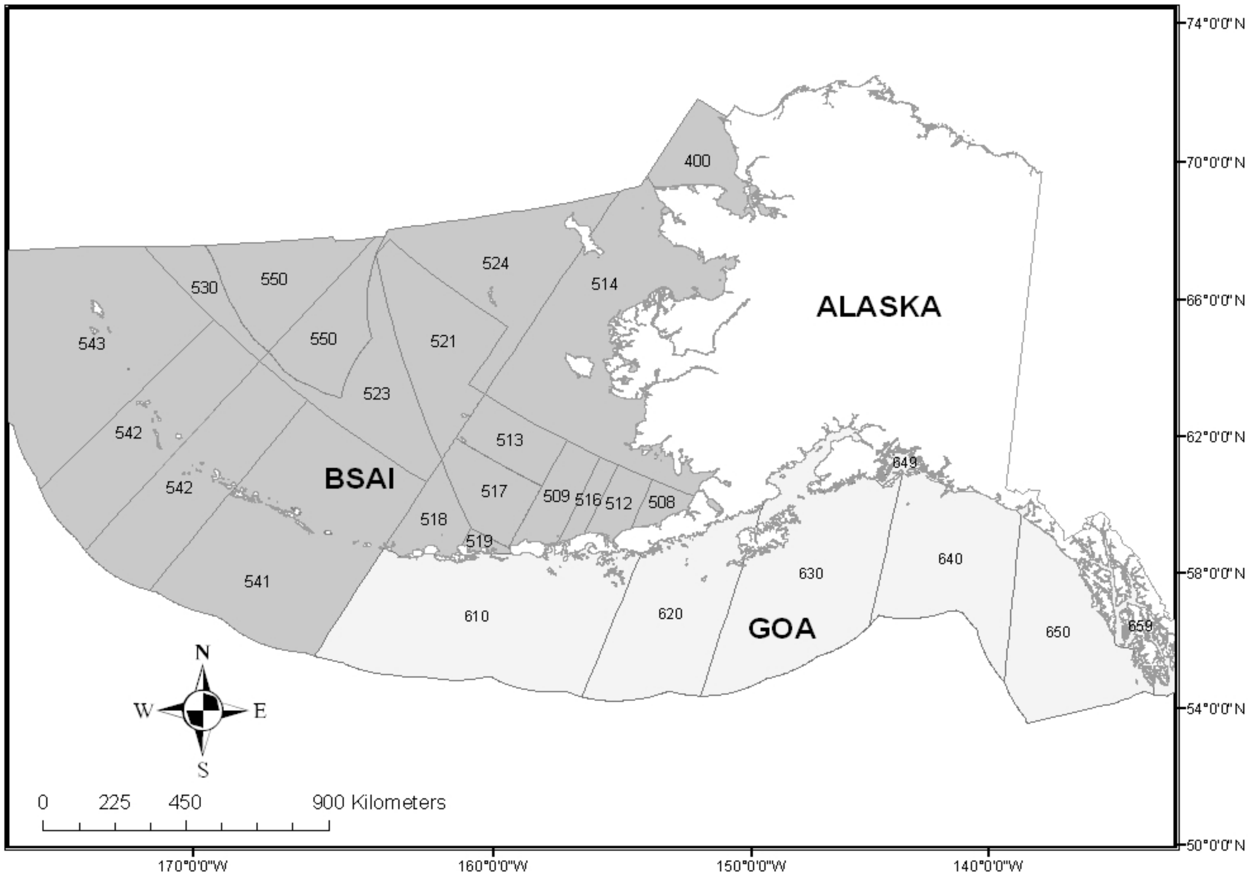

Figure 1. -- Fisheries management plan regions and Federal reporting areas in Alaska. The Bering Sea and Aleutian Island (BSAI) region is shown in dark grey shading; the Gulf of Alaska (GOA) is shown in light grey shading; and NMFS Federal reporting areas are identified with numbers.

Table 1. -- The amount, in metric tons (t), and the percent of total groundfish catch by vessel type in the 2008 Alaskan federally managed commercial fishery (from 2008 NMFS Regional Office catch accounting system). Percentages reflect the total within-category amount compared to the total for all vessel and gear categories.

	Catch (percent total)			
Gear	Total catch	Catcher-vessels delivering to motherships	At-sea catcher-processors	Catcher-vessels delivering to shore
Trawl	1,546,139.4 (88.6%)	104,484.9 (6.0%)	858,130.5 (49.2%)	583,524.1 (33.4%)
Longline	149,814.5 (8.6%)	4.8 (<0.01%)	125,767.3 (7.2%)	24,042.4 (1.4%)
Pot	47,660.8 (2.7%)	1,586.8 (0.1%)	4,730.2 (0.3%)	41,343.8 (2.4%)
Jig	1,865.0 (0.1%)	0.0 (0%)	0.0 (0%)	1,865.0 (0.1%)
Total Catch	1,745,479.8 (100%)	106,076.5 (6.1%)	988,627.9 (56.6%)	650,775.3 (37.3%)

Table 2. -- The number and percent of vessels by gear and vessel type in the Alaskan groundfish fishery in 2008 (NMFS Alaska Regional Office catch accounting system). Percentages reflect the total within-category amount compared to the total for all vessel and gear categories. There are 1,350 unique vessels; 173 vessels fished in multiple capacities.

	Number of vessels (percent)			
Gear	Total vessels	Catcher-vessels delivering to motherships	At-sea catcher processors	Catcher-vessels delivering to shore
Trawl	193 (12.7%)	8 (0.5%)	41 (2.7%)	144 (9.5%)
Longline	969 (63.6%)	1 (0.07%)	41 (2.7%)	927 (60.9%)
Pot	207 (13.6%)	11 (0.7%)	7 (0.5%)	189 (12.4%)
Jig	154 (10.1%)	0 (0.0%)	0 (0%)	154 (10%)
Total Vessels	1,523 (100%)	20 (1.3%)	89 (5.8%)	1,414 (92.8%)

Table 3.-- Percentage of the 2008 catch estimates that were derived from different data source categories. The data type 'Mixed Observer and Industry' refers to catch estimates generated from application of an at sea discard rate from observer data to an industry report of total catch. Prohibited species catch (PSC) is the catch of specific species, such as salmon, that have economic value in non-groundfish fisheries and therefore cannot be retained in groundfish fisheries. Salmon and crab PSC is estimated as number of individuals caught; halibut and herring PSC is estimated as weight in metric tons (t). Column percentages add to 100%.

Data type	Retained catch (Percent)	At-sea Discard of groundfish (Percent)	At-sea discard of PSC (#) salmon, crab (Percent)	At-sea discard of PSC (t) halibut, herring (Percent)
Observer	989,933 (60.6%)	62,300 (67.0%)	1,625,888 (36.0%)	7,607 (31.0%)
Industry	642,510 (39.4%)	5,596 (6.0%)	0.0	0.0
Mixed Observer and Industry	0.0	25,138 (27.0%)	2,888,428 (64.0%)	16,851 (68.9%)
Total	1,632,443	93,034	4,514,316	24,458

Table 4. -- Sampling design description for the North Pacific Groundfish Observer Program.

Sample Level	Sample Frame	Sample Unit	Sample Selection	Data / Observation
1^o Unit: Trips	Set of all trips within a fishery and quarter	Fishing trips (deliveries)	All trips (100%) or Non-random (30%)	Departure and delivery ports, trip dates, *etc*
2^o Unit: Hauls	Set of all hauls on trip	Fishing event (haul, longline set)	Constrained Simple Random Sample (SRS) of set of all hauls	Effort data (total catch size, gear deployed, fishing location, *etc*)
3^o Unit: Sample	Set of all sample units in the haul	Predefined weight, volume, or gear segment	Systematic Random Sample (SYS) / SRS / opportunistic from haul	Species composition data
4^o Unit: Length Sample	All fish (by species) within a sample	Individual fish	SRS from 3^o sample	Sex, length, and weight
5^o Unit: Otolith Sample	All fish (by species) from length (SLW) sample	Individual fish	SRS from 4^o sampled fish	Otoliths

Table 5. -- Data sources used in retained catch and at-sea discard estimation. Prohibited species catch (PSC) is composed of salmon, herring, several crab species, and halibut. These are species that have economic value in non-groundfish fisheries and therefore cannot be retained in groundfish fisheries.

Fishing Sector	Observer Coverage Level	Retained Catch	At-sea discard of Groundfish	At-sea discard of non-FMP species and PSC
Catcher Vessel delivering to shore	Based on vessel size	Landing report	At-sea discard rate from observer data is applied to a landing report	At-sea discard rate from observer data is applied to a landing report
Catcher Vessel delivering to Mothership	Vessels with ≥ 100% observer coverage	Observer data	Observer data	Observer data
	Vessels with 0-30% observer coverage	Landing report	At-sea discard rate from observer data is applied to a landing report	At-sea discard rate from observer data is applied to a landing report
At-sea Catcher Processors	Vessels with ≥ 100% observer coverage	Observer data	Observer data	Observer data
	Vessels with 0-30% observer coverage	At-sea production report	At-sea production report	At-sea discard rate from observer data is applied to an at-sea production report

Table 6. -- Post-strata used in estimating at-sea discard rate of prohibited species.

Rate Description	Fishing Cooperative	Processing Sector	Week	Trip Target	Gear	FMP Area	NMFS Reporting Area	Special Area
Coop level	Yes		Yes	Yes	Yes		Yes	Yes
Processing Sector Level		Yes	Yes	Yes	Yes		Yes	Yes
3 week moving average			Yes	Yes	Yes		Yes	Yes
3 month moving average			Yes	Yes	Yes	Yes		
FMP Level				Yes	Yes	Yes		

APPENDIX: LIST OF SYMBOLS USED

Haul Level Estimates

i = index of the species of interest

J = the number of samples taken from a haul j=1, … J

N_{ij} = the number of fish of species i in sample j

$f_{i,}$ = the number of fish weighed of species i

W = the total weight of fish in the haul

$\hat{W}_i$ = the estimated total weight of species i in the haul

w_j = the weight of fish in sample j

w_{ij} = the weight of fish of species i in sample j where j = 1, …, J

w_{ijk} = the weight of fish of species i in sample j, sub-sample k where k = 1, …., K_j

K_j = the number of subsamples in sample j, k=1, … K subsamples in sample j

p_w = the sampling fraction based on weight of fish

S_j = the total weight of predominant species in the sample

h_i = the number of hooks on the i^{th} sampled section of longline gear

m_j = the number of sampled longline segments in sample j

M = the total number of longline segments fished

H = the total known number of pots set; $\hat{H}$ the estimated total number of hooks set

$\hat{d}_i$ = the estimated at-sea discard rate for species i

$\hat{D}_i$ = the estimated total at-sea discard for species i

Calibration of Haul-Level Estimates to Fishery

D_{pro_i} = the catch of (prohibited) species i monitored at the plant and the total at-sea discard

$\hat{D}_{ih}$ = the estimated at-sea discard of species i (observer or vessel estimate) for haul h

H = the total number of hauls in the delivery as reported by the vessel, $h=1, …, H$

O = the total offload weight of groundfish as measured by the plant (scale weight)

$\hat{R}_{ih}$ = the adjustment ratio for species i, haul h

$\hat{R}_h$ = the adjustment ratio for haul h (all species)

S_{ih} = the catch weight of prohibited species i contained in observer's samples from haul h.

$\hat{W}_{ih}^{*}$ = the adjusted estimate of catch for species *i* haul *h*

X_{ih} = the pre-sorted catch of species *i* from haul *h*.

At-Sea Discard of Groundfish Species

a = index of the domain of interest (small area=fishery)

r = index of the post-strata (rate computation)

h_{op} = index of hauls on observed trips on >=100% observed CPs, M

h_{i} = index of all hauls on <100% CPs

h_{ov} = index of observed hauls on CVs

h_{v} = index of hauls on CVs

H_{r} = total hauls in post-strata

$\hat{C}$ = estimated total retained groundfish based on observer sample; $\hat{C} = \sum_{i \in groundfish} \hat{W}_i$

C^{*} = total industry reported retained groundfish (all species)

$\hat{D}$ = estimated total at-sea discarded groundfish based on observer sample

D^{*} = total industry reported at sea discards on 30% CPs

At-Sea Discard on Non-groundfish Species

a = index of the domain of interest (small area)

r = index of the sub-domain (rate computation), includes trip for all observed trips

t_{o} = index of observed trips

h_{o} = index of sampled hauls

h = index of all hauls on CVs and vessels in the <100% observed strata

h^{*} = index of all hauls on CPs and Motherships in the >=100% observed strata

H_{r} = total hauls in sub-domain on CVs and vessels with <100% observer coverage

$\hat{G}$ = observer estimated total (retained plus at-sea discard) groundfish

G = total industry reported groundfish (retained plus at-sea discard)

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