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ABSTRACT

This report provides an update to the methodologies used by the National Marine Fisheries Service (NMFS) to estimate total catch in the Federal groundfish fisheries in waters off Alaska. The impetus for this update was a series of changes to the data collection and catch estimation methods, the most significant of which was a restructuring of the North Pacific Groundfish and Halibut Observer Program. A combination of industry and observer information is used by NMFS 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 provides at-sea information on total catch. The observer data are collected using a stratified hierarchical sample design where strata are defined through a combination of regulations and an annual deployment process. Within each stratum, a multi-stage sampling design is used to sample the species composition of the catch along with other catch components. The Alaska catch accounting system (CAS) uses post-stratification procedures to combine the observer and industry information to create estimates of total catch. The CAS procedures changed to complement the sampling procedures established under the restructured observer program, including changes to post-stratification in the CAS and providing catch estimation on vessels retaining Pacific halibut (*Hippoglossus stenolepis*). In this report, we update the description of the CAS procedures and discuss continued evaluation of the estimation methods including developing uncertainty measures around point estimates of catch.

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INTRODUCTION

Federal fisheries conducted in waters off Alaska are some of the largest in the world. In 2013, almost 2.4 million metric tons (t) of fish and shellfish were commercially harvested in waters off Alaska, which was just over half of the total catch in U.S. waters (NMFS 2013a). Many of these fisheries are governed by the Magnuson-Steven Fishery Management and Conservation Act (MSA), which, among other things, requires establishing fishery management plans (FMPs) that are consistent with the MSA and its National Standards. The management of Federal groundfish fisheries off Alaska is governed under FMPs that are specific to the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) regions (Fig. 1). The catch of FMP species is monitored using landing and production information that is reported by the commercial fishing industry and at-sea information collected from an extensive at-sea observer program. These data sources are integrated into a NMFS application called the Alaska Catch Accounting System (the CAS) and used to produce the total catch estimates referenced in the FMPs.

The primary purpose of the CAS is to provide estimates of total catch for FMP species in the groundfish and halibut fisheries and allow the in-season monitoring of catch against limits as required in the FMPs. 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 of fish not discarded at sea. Species that are targeted in fisheries or have biological characteristics that require them to be protected by conservation and management measures are called groundfish in the FMPs (NPFMC 2013a and 2013b). These species fall under the authority of the MSA National Standard 1 as “in the fishery” and have annual catch limits (ACL) that potentially requires in-season managers to close fisheries when a limit is reached. The FMPs also specify ecosystem components that are composed of fish species that must be avoided by vessels catching groundfish. Specifically, ecosystem components are composed of forage fish (e.g., capelin) and prohibited species (i.e., Pacific salmon (*Oncorhynchus* spp.), steelhead (*O. mykiss*), Dolly Varden (*Salvelinus malma*), Pacific herring (*Clupea pallasii*), Pacific halibut (*Hippoglossus stenolepis*), king (*Lithodes* spp. and *Paralithodes* spp.) and Tanner (*Chionoecetes* spp.) crab). Prohibited species often have complicated sector and seasonal catch limits or allocations that require in-season monitoring using the CAS.

A secondary function of the CAS is to provide catch estimates of non-FMP marine organisms caught incidentally in the groundfish and halibut fisheries. Improvement to both the CAS and at-sea data collection programs have facilitated estimation of non-FMP fish, invertebrates, and seabirds that are incidentally caught in the groundfish and halibut fisheries. Managers, scientists, and policy makers use catch information to characterize fishery impacts on habitat, marine mammals and seabirds, and to study the North Pacific ecosystems.

A comprehensive review of the history and estimation methods used for the groundfish fisheries was published in 2010 (Cahalan et al. 2010). Since that publication, there have been substantial changes to data collection programs and the estimation methods used in the CAS to warrant an update in documentation. This report updates Cahalan et al. (2010) by describing the current catch estimation methods contained in the CAS and data sources as of 2013. Readers are directed to Cahalan et al. (2010) for an in-depth treatment of the history of the CAS and further descriptions of the fisheries.

Overview of Changes Since 2010

Amendment 76 to the GOA FMP and Amendment 86 to the BSAI FMP marked a large change in the methods used to deploy observers in Federal groundfish and Pacific halibut fisheries. For this paper, these amendments are collectively referred to as the restructured program, which was implemented in the 2013 fishing year. The restructured program divides the GOA and BSAI groundfish fleet into two non-overlapping deployment categories: 1) the full coverage category that requires at least one observer to be present while a vessel is fishing and, under certain management programs, two at-sea observers; and 2) the partial coverage category that gives NMFS the discretion of placing observers on vessels and at shoreside processing plants. In general, the full coverage category consists of vessels that process catch at sea (catcher/processors and motherships), catcher vessels directed-fishing for walleye pollock (*Gadus chalcogrammus*) in the Bering Sea, vessels fishing with trawl gear for groundfish for a community development quota program entity, and vessels participating in the Central GOA Rockfish Program. In addition to the at-sea observer coverage requirements, shoreside processing plants accepting deliveries from vessels participating in the directed BSAI pollock fishery are required to have shoreside observer coverage for those pollock deliveries. The partial coverage category consists of federally permitted vessels not in the full coverage category, including catcher vessels fishing for Pacific halibut and shoreside plants not in the full coverage category.

Deployment methods for the partial coverage category are described on annual basis in the NMFS Annual Deployment Plan (ADP; NMFS 2013b, NMFS 2013c, NMFS 2014b), and reviewed annually by NMFS and the North Pacific Fishery Management Council in the North Pacific Groundfish and Halibut Observer Program annual report (Annual Report) published by NMFS (Faunce et al. 2014; NMFS 2014a). The ADP documents how the NMFS intends to assign at-sea and shoreside observers to operations fishing under the authority of the FMPs and in the partial coverage category. The ADP and Annual Report process provides methods for the random deployment of observers and allows evaluation and adjustment to deployment on an annual basis. Randomizing observer deployment and changing deployment strata are major changes from the pre-restructured program that allowed vessels without full coverage to choose when to carry an observer within a regulatory framework defined by fishery target, vessel size, and quarter of the year. In addition, the restructured program gives NMFS the authority to deploy observers on vessels fishing for halibut under the individual fishing quota (IFQ) Program. These changes in deployment methods required modification to the CAS that incorporated the new sampling strata described in the ADPs and estimation algorithms for the previously unobserved hook-and-line halibut fleet.

In response to these changes, the CAS algorithms have been adjusted to be consistent with the data collection process. Computations are carried out within each stratum, expanding catch and bycatch to the fishery for each stratum, combining strata estimates in the final step. Additional strata and post-strata have been incorporated into the CAS to improve estimation of catch and bycatch for the hook-and-line halibut fleet. Programming in the CAS also needed modification to compute discard estimates for the IFQ halibut fishery. These were not changes to the post-strata used in the CAS, but were instead technical changes associated with incorporating halibut landings into the estimation process.

Another large change to the CAS occurred in 2011 with the implementation of Amendment 91 to the BSAI FMP. This management program established transferable allocations of Chinook salmon (*Oncorhynchus tshawytscha*) for American Fisheries Act (AFA) pollock vessels participating in an Incentive Plan Agreement. The retention of salmon is prohibited under the FMPs (with the exception of salmon that may be provided to food donation program). Prior to Amendment 91, salmon bycatch in the Bering Sea was estimated by extrapolating observer-sampling data to unobserved fishing events, which mainly affected how salmon accounting was done for the AFA inshore sector. However, the management and enforcement of transferable allocations required precise accounting of Chinook salmon for each entity holding an allocation, including inshore cooperatives. Amendment 91 established regulations that facilitate enforcement of sampling methods designed to enumerate all salmon caught on catcher/processors, motherships, catcher vessels, and at shoreside plants. This amendment includes provisions requiring at-sea observers on all vessels fishing for pollock in the Bering Sea and at shoreside processors receiving Bering Sea pollock deliveries. The salmon catch numbers and other data collected by observers are used by NMFS and industry to manage and enforce Chinook salmon allocations, monitor the catch of other salmon species, and provide biological samples to researchers.

Since 2010, two other changes have been made to the data inputs for the CAS. First, the accounting of retained Pacific cod (*Gadus macrocephalus*) was changed for the Bering Sea longline catcher/processor fleet by implementing regulations requiring increased observer coverage or use of flow scales. Second, an electronic reporting method was developed for tender vessels that allows tender operators to record information electronically at the time a catcher vessel makes a delivery. These data are then transmitted to NMFS at the time of the tender offload rather than waiting for the shoreside processor to enter and submit the data, which can take a week or more.

DATA SOURCES

Data from mandatory fishing industry reports and the North Pacific Groundfish and Halibut Observer Program (Observer Program) are the two sources of information used to estimate total catch in the Federal groundfish fisheries off Alaska. Each data source is confidential under the Magnuson-Stevens Fishery Conservation and Management 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 Alaska Fisheries Science Center’s (AFSC) website: http://www.afsc.noaa.gov/FMA. Aggregated estimates of total catch are available on the NMFS Alaska Regional Office website at: http://www.alaskafisheries.noaa.gov/sustainablefisheries/catchstats.htm.

Industry Reports

In general, vessels participating in Alaska groundfish fisheries can be divided into two broad categories: vessels that catch fish versus vessels that only process or transport fish. Vessels that catch fish include catcher/processors (CPs), which catch and process fish while at sea, and catcher vessels (CVs), which deliver their catch to either a shoreside processing facility or a vessel with the ability to process fish (including CPs). The types of vessels that only process or transport fish include motherships, stationary floating processors, and tender vessels. Motherships are large processing vessels (generally greater than 200 feet in length) that, unlike a stationary floating processor, are not tied to a single geographic location. Both motherships and stationary floating processors receive and process unsorted catch from CVs. Tender vessels deliver catch received from CVs to shoreside processing facilities.

There is a variety of information, such as fishing effort and catch, that is required to be submitted by the fishing industry to NMFS and is used to manage the fisheries. The majority of these data are available electronically; however, some data sources are not yet automated. The reporting requirements vary depending on the vessel operation, fishing gear, and fisheries. Below we discuss these reporting mechanisms, which can broadly be divided into two categories: 1) landings and production information reported by shoreside processing facilities, CPs, or motherships that is used to assess catch, the location of fishing effort, species disposition, and, in the case of CPs and motherships, product type; and 2) logbook information reported by vessel operators that provides information about effort, location, and total catch.

Landings and Production

In 2005, an interagency electronic reporting system to reduce reporting redundancy and consolidate fishery landings was implemented by NMFS, the Alaska Department of Fish and Game (ADFG), and the International Pacific Halibut Commission (IPHC). Vessels fishing in Federal or state fisheries report crab, halibut, and groundfish landings and groundfish production through a web-based interface known as eLandings. Regulations specific to a shoreside processor or a vessel require fishing activity to be reported via eLandings. There are two eLandings report types used for catch estimation: landing reports and at-sea production reports. Information from these reports is stored in the eLandings database that is available to the three collaborating agencies and is integrated into the CAS.

Landing reports contain information on CV fishing activity delivering to processing facilities, including motherships, shoreside processors, and stationary floating processors. Specifically, landing reports contain important information about the fishing event (e.g., trip), including the dates and duration of fishing, gear type fished, 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 also required to report at-sea discard to the processing facility, but these data are unverified, and hence, NMFS does not use industry-reported at-sea discard for catch accounting. Catch information on landing reports is spatially aggregated to a State of Alaska statistical area (ADFG 2014) and temporally aggregated to the period between when fishing starts and when catch is offloaded. The reported date associated with the start of fishing generally corresponds to when gear is deployed for fishing; however, some fishermen report the start of fishing as the date when gear is first brought on board a vessel. This can create large differences in estimates of trip length for vessels fishing with pot or hook-and-line gear that have variable soak periods.

Reporting requirements generally specify daily reporting for mothership operations and on offload for CVs making a delivery to a processing facility. One exception is CVs delivering to a tender that offloads the catch shoreside. In general, tenders receiving deliveries from CVs complete a paper fish ticket for each delivery, and the catch is not reported through eLandings until the tender delivers to a processor. Staff from the processing facility enters data into eLandings, which can take a week or more depending on staff workload. However, an electronic reporting component of the eLandings system, called tLandings, has been developed and is voluntarily used by some tenders. Vessels using tLandings enter their landing report into a tLandings application at the time of delivery from the CV. However, these vessels do not have at-sea transmission capabilities, so this electronic information is transmitted when the tender offloads at the shoreside processing plant and is available, almost immediately, in eLandings. The use of tLandings increases timeliness of the data for management agencies and reduces the amount of data entry for processors.

At-sea production reports are mandatory for CPs and motherships that are fishing in Federal groundfish fisheries. At-sea production reports include information about the gear type used, area fished, product weight by species, and the weight or number of each species that was discarded at sea. Incidental catch of non-groundfish species other than prohibited species catch (PSC, such as economically unimportant invertebrates or fish species) are not reported. In 2009, the at-sea fishing fleet transitioned from weekly to daily reporting of production and greatly improved the temporal resolution of information. This improvement facilitates the daily management of quota since catch estimates are dependent on observer information that generally has a time lag of a few days. These daily production reports provide additional information outside of the CAS for in-season quota management.

Starting in 2013, production reports have not been regularly used in the estimation process because nearly all CPs have full observer coverage that provides verified total catch data rather than industry-reported data on production. However, as of 2014, three groundfish CPs have been exempted from full coverage requirements (see 50 CFR 679.51(a)(1)(iv))and are in the partial coverage category. For these vessels, production reports are used to assess both catch and at-sea discard. Since production is reported in product weight, the main calculation done to determine catch amounts is to convert production weight to round weight, and follows the methods documented in Cahalan et al. 2010. Production reports are also used to assess catch and at-sea discard in rare situations when observer data are not available (e.g., illness or injury prevented an observer from sampling). In addition, production repots are used in economic analysis and are consolidated into landing reports, which are submitted to Alaska Department of Fish and Game.

Logbooks

In general, logbook data are not directly used in catch estimation at this time. However, logbooks are accessed by observers while they are on board a vessel to obtain some data and electronic logbook data from CPs are used by NMFS for enforcement and verification of salmon bycatch and retained catch of Pacific cod. The logbooks are also used for other enforcement purposes; for example, catch information in logbooks is used to verify compliance with maximum retainable amounts. Haul-specific information is recorded in vessel logbooks. This information includes the date and time of haul deployment and retrieval, spatial coordinates of haul deployment and retrieval, vessel estimates of total catch and species-specific catch, the type and amount of gear used, fishing depth, vessel-specific information, management program, and species-specific discard.

Logbooks are completed either on paper or in an electronic logbook component of the eLandings program. 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. In addition, some vessels less than 60 feet that fish for sablefish voluntarily complete paper logbooks. The CVs 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 use of the electronic logbook has expanded in recent years, and there were about 50 boats using the electronic logbook in 2014. Starting in 2011, trawl CPs participating in the BSAI pollock fishery were required to submit electronic logbooks and have the additional requirement of entering their haul-specific catch of salmon in the electronic logbook. The electronic logbook requirement was also expanded to other CPs: trawl CPs participating in the Central GOA Rockfish Program began using electronic logbooks in 2012 and longline CPs fishing for Pacific cod began using the electronic logbooks in 2013. There are also other CPs and some CVs that are using the electronic logbook voluntarily instead of submitting a paper logbook. While these logbooks are not directly used for catch accounting, they provide data on fishery activity that is used for other agency activities such as stock assessment.

Issues and Constraints Associated with Industry Reports

Although landing and production reports are required for all deliveries of groundfish and halibut, the data reported by industry are not independent. 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 landed catch are assumed to be true, known values.

Electronic Monitoring and Compliance

Electronic monitoring (EM) technologies are increasingly used in a variety of fisheries settings. In Alaska, EM systems (i.e., cameras and sensors) have been implemented that monitor compliance with regulations in certain fisheries. In addition, research is underway to investigate how to best integrate these technologies into the data collection process for catch estimation and quota monitoring. The plan for further implementation and development of EM has been outlined in the North Pacific electronic reporting and EM strategic plan (Loefflad et al. 2014).

In Alaska, there are two categories of EM technologies used for compliance monitoring: the vessel monitoring system (VMS) and camera-based systems. The VMS is a satellite-based technology that remotely monitors fishing vessel locations. The VMS that has been implemented in Alaska sends data on vessel identification, location, speed, and direction at fixed 30-minute intervals. As of 2010, about one-third of the vessels that participate in the groundfish, crab, and halibut fisheries in Alaska are required to carry the VMS (NPFMC 2012). The VMS data are used for a variety of purposes including monitoring and enforcement of fishing activity relative to protected species closures and special management areas, and projecting fishing effort and locations of fishing activity within a season. For catch estimation, the VMS data are used to assign catch to specific special management areas that are usually designed to limit the bycatch of specific species.

Within the past 5 years, EM monitoring using video-based systems has become an important compliance tool to supplement observer data. Electronic monitoring is used in three BSAI CP fisheries and one GOA fishery: the BSAI non-pollock and pollock trawl fisheries, the BSAI longline fishery for Pacific cod, and the Central GOA Rockfish Program fishery. These management programs all require at least one observer be on board while the vessel is fishing. In the trawl fisheries, the imagery feed helps ensure species are not presorted or discarded before an observer is able to obtain a sample. In the CP longline fishery for Pacific cod, cameras are used to monitor compliance with regulations that require all retained Pacific cod to be weighed on a flow scale. Imagery required for compliance monitoring may be viewed in real-time by the observer and/or periodically collected and checked by NMFS staff.

Observer Program Reports

The AFSC's Fisheries Monitoring and Analysis Division (FMA) monitors groundfish and halibut fishing activities in the U.S. Exclusive Economic Zone off Alaska and conducts research associated with sampling commercial fishery catches, estimates catch and bycatch mortality, and analyzes fishery-dependent data. The AFSC is responsible for the oversight of the Observer Program, which was implemented with the passage of the MSA in the mid-1970s. The program has evolved from primarily observing foreign fleets to observing domestic fleets.

The information collected by observers is the best available scientific information for the conservation and management of the groundfish fisheries and other aquatic resources. While on board vessels, observers are tasked with many duties, including collecting information on vessel and gear 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 effort) and entering collected data. These duties are described in the Observer Sampling Manuals, which are published annually (e.g., AFSC 2014).

Observer Program Sampling Design

Since 2013, the deployment of observers into groundfish and halibut fleets is separated into two nonoverlapping deployment categories: 1) full coverage, and 2) partial coverage (Table 1). Fishing operations in the full coverage category are established in Federal regulation and can only be changed through rulemaking. Besides a few exceptions for CPs, all CPs and motherships must carry at least one observer while fishing. Most CVs are governed under the partial coverage requirements, with the exception of vessels fishing under specific fishery management programs such as the AFA pollock fishery and the Central GOA Rockfish Program. In addition, vessels in the partial coverage category and participating in the Bering Sea and Aleutian Islands Pacific cod trawl fishery entered into a compliance agreement with NMFS to carry an observer on each fishing trip, but they must still comply with the partial coverage regulatory requirements. In 2014, 37 BSAI trawl vessels fishing for Pacific cod participated in the compliance agreement.

Deployment methods and sampling strata for the partial coverage category are described annually in the ADP. The ADP specifies sampling strata in the partial coverage category based on analysis of observer deployment and sampling needs (Table 1). Under the 2013 and 2014 ADP, the partial coverage category consisted of three strata: 1) the "no selection" stratum that consisted of vessels not selected for observer coverage(i.e., no probability of being assigned an observer), 2) the "vessel selection" stratum that consisted of vessels randomly selected for at-sea observer coverage during a 2-month period, and 3) the "trip selection" stratum that was defined by observers being randomly assigned to fishing trips (NMFS 2013b, NMFS 2013c).

Under the 2015 ADP, the partial coverage category strata will be defined as 1) the "no selection" stratum (no change in definition), 2) the "small boat" stratum, and 3) the "large boat" stratum. In both observed strata (small and large boat strata) observers are randomly assigned to fishing trips using a stratum-specific rate. This replaces the stratification used in 2013 and 2014 (NMFS 2014b).

Within each of the sampled strata (e.g. full coverage, trip selection, and vessel selection), a multi-stage sampling design is used to sample trips, under which the species composition and other components of catch events are sampled (Table 2). In the full-coverage stratum, observers monitor all trips and typically sample between 50% and 100% of the individual hauls. Catch estimates from the full coverage stratum are based primarily on observer data, with industry and vessel reports comprising a small percentage of the information used to make the estimates.

For vessels in the partial coverage sampled strata (i.e., vessel selection and trip selection strata), observers are deployed onto vessels for each fishing trip, which is defined differently depending on where the vessel delivers its catch. For CVs delivering to a shoreside or stationary floating processor, a trip is the period that begins when a CV departs a port to harvest fish until all fish are offloaded or transferred from the vessel to a federally permitted stationary floating processor or shoreside processing facility. Similarly, a trip for a CV delivering to a tender begins when a vessel departs a port to harvest fish and ends when the vessel returns to a port in which a federally permitted stationary floating processor or shoreside processing facility is located and all the harvested fish has been delivered.

Within the partial coverage stratum, there are two different selection units specific to each sampled strata; the primary selection unit for the vessel selection stratum is a vessel, and the primary selection unit for vessels in the trip selection stratum is a trip. In the vessel selection stratum, vessels are randomly selected (without replacement) to have all trips observed for a 2-month period. In this stratum, the sample frame consists of vessels that fished in the same 2-month period the previous year (i.e., 2013 deployment is dependent on who fished in 2012). However, the true population of vessels may be different from the previous year, which means vessels that did not fish the previous year have no chance of selection. In addition, some vessels that are selected were also released from observer coverage. Additional details about deployment are in the ADP and the annual review (Faunce et al. 2013a, Faunce et al. 2014, NMFS 2014a).

In the trip selection stratum, individual trips are logged into the NMFS Observer Declare and Deploy System (ODDS) by the vessel operator. This list of trips forms the sample frame for the stratum; individual trips are randomly selected to be observed using Bernoulli random number generator and a pre-determined rate. In 2013, the programmed selection rate for trip selection was reduced during the year so the cost of deployment did not exceed the available funding prior to the end of the year. These changes in programmed sample rate were small, generally less than four percentage points (Faunce et al. 2014, NMFS 2014a); however, it is worth noting that for catch estimation, the data were not partitioned into additional strata.

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 the methods described in the Observer Sampling Manual (AFSC 2014). Within each observed trip, all fishing events (hauls, longline sets, or pot sets) are either sampled by the observer to obtain species composition data, or they are randomly selected to be sampled using a constrained, simple-random sample design (AFSC 2014). The sampling design follows a randomized schedule of selected hauls, while allowing for a randomly placed 6-hour break, if needed. These schedules vary by gear type, vessel type, and fishing operation (AFSC 2014).

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. For example, deck configurations on trawl CVs often limit space and fishing operations are such that fish are often quickly transferred below decks, resulting in opportunistic observer sampling. For each sampled haul and each observed trip, sample fractions vary at both levels of the hierarchy depending on the sample designs used by observers.

There are several types of sample frames generally used by observers. The sample units within each frame can be defined by time, gear, weight, or volume. In some situations, sample units are more difficult to define and the sample unit type “other” is used. For example, on a trawl CV, as a haul is being dumped into the trawl alley, an observer might randomize based on the estimated time to spill the catch into the alley and will collect a 100-kg sample at pre-selected (random) minutes during that time. Here the sample frame (composed of units of time) is defined differently than the sample unit (a weight of catch, e.g., 100 kg). Observers are trained and encouraged to use a systematic random sample whenever it is logistically feasible.

The sampling methods used by observers are also specific to the type of gear being deployed. 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. 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.

Salmon Enumeration in the BSAI and GOA Pollock Fisheries

FMP Amendment 91 to the BSAI FMP (75 FR 53026, August 30, 2010) and, to a lesser extent, Amendment 93 to the GOA FMP (77 FR 42629, July 20, 2012) changed how observers monitor salmon bycatch in the pollock fisheries. These amendments increased the ability of observers to conduct biological sampling, specifically the collection of salmon tissue samples used in genetic analysis and salmon stock identification. Sampling for and treatment of genetics data is beyond the scope of this document (see Guthrie et al. 2013 for additional details).

Amendment 91 significantly changed the management methods for salmon accounting on AFA pollock vessels to provide for complete enumeration of all salmon to support quota allocations. Some of the larger regulatory changes to catch monitoring under Amendment 91 included mandatory 100% observer coverage for all AFA inshore Bering Sea pollock fishery trips, changes to the catch monitoring and control plans (CMCPs) to improve salmon accounting at stationary and floating processors, and implementation of electronic monitoring for regulatory compliance monitoring. On CPs and motherships, vessel crews are required to monitor and retain all salmon. Compliance with the monitoring requirement is enforced with electronic (video) monitoring in the vessel factory. Salmon are placed in a secure location until the observer is available to count all the salmon and collect biological samples. On CVs, the observer samples each haul per standard haul sampling methods; however, when the vessel returns to port and offloads its catch, the observer monitors the offload and records all salmon caught during the trip. The CMCP was implemented for shoreside and stationary floating processors. These plans require that a certified observer sampling station be maintained, that the flow of fish in the processing facility not exceed certain depths, and that all set-aside salmon are stored in secure locations until the observer is available. Staff from NMFS conduct checks on CPs and motherships to ensure compliance with catch monitoring regulations, including flow scale certification, observer sampling station requirements, and video monitoring configurations. Taken together, these checks help ensure observers are able to properly sample catch, including the complete enumeration of salmon catch.

In the GOA, neither CPs nor motherships participate in the directed pollock fishery. Although Amendment 93 does not require 100% observer coverage in the GOA pollock fishery, it does require that all salmon incidentally caught in the GOA pollock fishery are retained by the vessel until an observer has had an opportunity to sample the catch (generally at a shoreside processor). Observers sample at sea following standard sampling methods described above. When the vessel returns to port, the vessel observer monitors the catch as it is offloaded and records all salmon encountered in the offload. Note that this offload monitoring occurs only on observed trips, and processing facilities in the GOA are not required to have CMCPs.

Observer Program Database

Observer data collected on vessels are transmitted electronically to a centralized database at the AFSC either while the observer is deployed at sea or once the trip has ended and the observer reaches port. While a vessel is at sea, data transmission occurs daily and generally only occurs on larger vessels with at-sea data transmission capability. In-season advisors from the AFSC provide data review and sampling guidance to observers deployed to vessels with at-sea communications. Data from observers are transferred into the AFSC database in near real time and are processed through a series of automated quality control routines. Every 3 hours, all data that have been transmitted are transferred to the AFSC database and are available for use by the NMFS CAS, fisheries managers, and AFSC staff. Any new or edited observer data are uploaded into the Alaska Regional Office database from the AFSC database every 3 hours between 6 am and 12 pm and again at 6 pm. At the end of each observer's deployment (up to 3 months), AFSC FMA quality control staff review the data, assess the sampling techniques used by interviewing each observer returning from the fishery, and conduct several quality control processes for each dataset incorporated into the database.

Issues and Constraints Associated with Observer Program Data Collection

The ability of an observer to safely obtain random samples of catch is sometimes limited by the logistical realities of sampling on board commercial fishing vessels. Although difficult sampling situations can arise on any vessel, they are particularly common on smaller CVs, particularly those fishing trawl gear. Fishing vessel crews are required to provide observers with access to unsorted catch, and to provide reasonable assistance. However, an observer's ability to sample on CVs is constrained by many factors including limited unobstructed access to unsorted catch in the trawl alley, limited time that fish are available before being placed below deck, weather and other environmental factors that restrict some deck activities, and other safety concerns such as handling large species. Despite these issues, observers are able to obtain random samples for the majority of sampled hauls. On fixed gear vessels and trawl CP vessels, over 85% of observers sample catch using systematic random or simple random methods. Conversely, observers on trawl CVs use a systematic or simple random sample design on 20% of the sampled hauls (Cahalan 2013).

Departures from intended sampling can arise when observers are limited in available tools, space, energy, or working conditions. For example, when the catch composition unexpectedly increases in species diversity during a sample collection period, the observer may need to reduce sample size due to limits in space and time. Observers reduce the size of the sample, mid-sample collection, in response to the sample outcome (e.g., species diversity). This situation was rare; however, occurring on less than 5%

of all sampled hauls, and has decreased from 7.4% in 2010 to 4.3% in 2012, presumably in response to increased training and feedback to observers.

CATCH AND BYCATCH ESTIMATION METHODS

Retained catch and discard catch estimates for groundfish, halibut, and PSC are based on either observer-collected sample data, industry reports of catch, or a combination of the data types (Table 3). Estimation methods within each stratum follow a post-stratification of hauls and deliveries based on gear and area fished, target species (as defined by the prominent groundfish species or halibut in the catch), and vessel type (i.e., CP or CV). Fishery-level estimates of total catch (retained catch and at-sea discard) are then obtained by summing all estimates within the domain (fishery, time, and area) of interest across all strata. Retained catch and at-sea discard estimates for vessels in the no selection stratum are based, in part, on industry and vessel reports of harvest and observer data collected from other sampling strata.

Estimates of retained and discarded catch obtained from observer information are derived for each haul on observed trips based on the sampling design. On trawl vessels, total catch for hauls that were not sampled is based on the vessel record of total catch size, while on fixed gear vessels the total catch estimates for these sets are based on the amount of gear fished and average catch per unit gear from sampled hauls on the trip. Species-specific catch estimates for hauls that were not sampled are generated using a nearest neighbor imputation process during which the species composition from sampled hauls is applied to the total catch weight of hauls that were not sampled.

Estimates of retained catch from industry are taken from landing and occasionally production reports (for CPs exempted from full coverage or in rare circumstances when observer data are deleted due to quality concerns), and are assumed to be precisely known quantities (without variance or bias). Catch reported from these two 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 use 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. Symbols used throughout the next sections are listed in the Appendix.

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 trawl CPs, the total weight of fish in a haul is measured directly by a flow or hopper scale. On non-pollock trawl CVs fishing outside the BSAI, the total weight of fish in a haul is estimated from the haul volume (measured by the observer) and the density of the unsorted catch. On trawl CVs fishing (AFA) BSAI pollock, the total haul weight is based on the total delivery weight apportioned to each haul based on the vessel estimate of catch. Although the total haul weight is estimated on these vessels, variance estimates are not available and the total weight is assumed known (not estimated). On trawl vessel hauls where the observer has not independently assessed the total weight of catch, the vessel's estimate of catch is taken to be the total haul weight.

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* ($i = 1, \ldots I_j$) over all samples, *j* ($j= 1\ldots J$), and divided by the sum of the total sample weight (Equation 1):

$$\hat{W}_i = W \frac{\sum_{j=1}^{J} w_{ij}}{\sum_{j}^{J} \sum_{i=1}^{I_J} w_{ij}} = W \frac{\bar{w}_i}{\bar{w}} \quad . \qquad \text{Eq. 1}$$

In order to maximize the sample fraction for the majority of species on CPs and motherships where the factory flow scale is used to weight the observer's sample, 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 2, where there are K_j subsamples in sample *j*, w_{ij} is the weight of fish of species *i* in sample *j*, 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*:

$$\hat{w}_{ij} = S_j \frac{\sum_{k=1}^{K_j} w_{ijk}}{\sum_{i=1}^{I_j}\sum_{k=1}^{K_j} w_{ijk}} = S_j \frac{\sum_{k=1}^{K_j} w_{ijk}}{\sum_{k=1}^{K_j} w_{jk}} = S_j \frac{\overline{w}_{ij}}{\overline{w}_j} \quad . \qquad \text{Eq. 2}$$

This estimated weight is then combined with the other sample weights to estimate the catch of species *i* in the haul (Equation 3). In the GOA pollock fisheries only, the haul weight is adjusted so that the sum of the retained portion of the hauls on each trip is equal to the delivered weight (see Equation 9):

$$\hat{W}_i = W \frac{\sum_{j=1}^{J} \hat{w}_{ij}}{\sum_{j=1}^{J} w_j} = W \frac{\overline{\hat{w}}_i}{\overline{w}} \quad . \qquad \text{Eq. 3}$$

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 (hook or pot), whereas on trawl vessels the units are measured in terms of volume or weight. Fixed gear vessels fish longline sets, consisting of segments of line with baited hooks that are often referred to as skates or magazines, or pot gear where a set consists of individual pots fished as a group. Overall, estimates of the number of fish within a species are based on the mean-number-per-hook or mean-number-per-pot from the observer sample data expanded by the total number of hooks or pots retrieved in a set. The total number of a species in a set is converted to weight using the mean weight per fish that is derived from data collected during observer sampling. The same estimation process is followed for both pot and longline gear.

In general, the amount of gear fished and sampled (hooks or pots) is estimated from observer-collected data. The few exceptions occur when the number of pots set is known (i.e., not estimated from sample data) and for Pacific cod on longline CPs with flowscales; the weight of retained Pacific cod is the flowscale weight. Recognizing that estimation for both pot gear and longline gear follows the same basic, gear-based estimation methods, the following sections provide details (equations and associated subscripting) for estimation of catch for longline gear.

In order to estimate the total amount of gear fished (number of hooks fished) and sampled (number of hooks sampled) on longline vessels, the number of hooks per segment of gear is computed based on observer sampling of the gear (hooks per segment). Twice per week, the observer (opportunistically) selects an amount of gear equal to 20% of an average set, and records the number of hooks on each selected segment. The mean number of hooks per gear segment, $\bar{h}$, is the average of these gear counts. The estimated total number of hooks sampled, $\hat{h}$, is the mean number of hooks per gear segment (skate or magazine) multiplied by the total number of segments in the sample, *m*: $\hat{h} = m\bar{h}$, where $\bar{h}$ is the mean number of hooks per segment and where *m* is the number of segments of gear sampled on that haul. Similarly, the total hooks fished, $\hat{H}$, is the expansion of the mean hooks per segment over all segments fished (*M*: $\hat{H} = M\bar{h}$).

The mean weight per (individual) fish is computed over all fish of the species of interest with a minimum of 15 fish in the haul where weight and count are recorded. These fish are taken from the gear segments adjacent to the randomly selected sampled segments for the predominant species and from both within the sample and adjacent to the sample for all non-predominant fish. Observers are trained to weigh 60 fish of the predominant species -- 30 to 40 shortraker / rougheye, and 15 of all other fish species on each haul. There are hauls where this goal is not possible and fewer fish are weighed. If 15 fish of the species are not counted and weighed in the haul, the mean weight per fish is based on all the fish of that species weighed on the trip. If 15 fish of that species were not weighed during the trip, the mean is based on weights of fish for that species for that observer on that same vessel. In the very rare instance that in all the hauls for a trip there are not 15 of a specific species weighed, then the mean weight is based on the number of those fish that were weighed the previous year. Hence, that although the mean weight per fish specified in Equation 2 is indicated to be the haul-mean weight per fish ($\bar{w}_i$), the mean may be based on data from the entire trip or all the trips an observer took on a given vessel.

The total number of a given fish species for the haul, $\hat{N}_i$, is the mean number of fish of species *i* tallied per sampled gear (hooks or pots) expanded by the amount of gear retrieved (Equation 4):

$$\hat{N}_i = \hat{H}\bar{n}_i = \hat{H}\frac{\sum_{j=1}^{J} n_{ij}}{\hat{h}} \quad . \qquad \text{Eq. 4}$$

The weight per fish, $\overline{w}_i$, is estimated as the average weight over all samples (and subsamples) of the species-specific fish weights, where the number of samples (f_i) of fish species (i) are weighed by the observer (Equation 5). Note that this includes all fish for which a weight is available in the samples and any subsamples for that haul, and that mean weight per fish is based on aggregate fish weights and numbers:

$$\overline{w}_i = \frac{\sum_{k=1}^{f_i} w_{ik}}{f_i} \quad . \qquad \text{Eq. 5}$$

The total species-specific catch weight for the haul is the total number of fish, multiplied by the average weight per fish for that species (Equation 6):

$$\hat{W}_i = \hat{N}_i \overline{w}_i \quad . \qquad \text{Eq. 6}$$

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

Speciation of Data Collected for Species Groups

There are fish species that cannot be differentiated beyond their species group unless the observer has the fish in-hand (see Table 4 for species listings). This situation arises most often on longline vessels where the observer is tallying fish on the longline but does not have the fish on board and available for closer inspection. This situation is occasionally encountered by observers on trawl or pot vessels where although the fish are available to the observer, there are too many individuals of a species group (morphometrically similar species) for the observer to speciate all individuals. In all cases, however, the observer will use a subsample of fish randomly selected from within a species group to identify and quantify the species. From this subsample, the proportions of each species are determined and applied to the un-speciated (species group) catch.

The sampling procedures used to speciate fish differs depending on whether the observer is on board a fixed gear or trawl vessel. Since on fixed gear vessels the observer does not always obtain individual fish for weight and species identification from all samples they collect, the species proportions are estimated from all subsample data for that species groups for the haul. On trawl vessels, these species identity data are collected for each sample, and hence the species proportions for each species group are sample-specific. In all situations regardless of gear type, the species proportion is based on the weight of fish. A similar process is used to estimate prohibited species-specific crab counts where the crab have been broken in the trawl net and therefore cannot be identified to species, but only to species group. This process first uses identified crab species within the observer sample to speciate broken crab; however, if no crab are available within a sample, crab species composition are taken from across samples and within a haul or trip, depending on available information. This process for crab and fish species is described more specifically below.

For a species where during the sample period some fish are identified to species and some are identified to species group, the proportion of individuals in the group that are species *i* is taken from within the sample and any subsamples. On trawl vessels, the species group is split into species for each sample. The species-specific sample weight is then extrapolated along with other trawl sample data. On fixed gear vessels, the sample data are expanded to the haul and then the species group is split into its component species. This difference is the result of differential sampling methods for the two gear types.

Letting g_{ij} indicate the weight on trawl vessels (number on fixed gear vessels) of individuals in the species group to which species *i* belongs and f_{ij} be the weight (number on fixed gear vessels) of fish identified to species *i*, the weight (or number) of species *i* in the group is the species proportion, p_{ij}, multiplied by the total weight (or number) of the group (Equation 7 for trawl and Equation 8 for fixed gear). Use of Equations 7 and 8 assumes the species proportionality does not change within a haul (i.e., the relationship is the same for all samples on the same haul):

$$\hat{w}_{ij} = g_{ij} \frac{f_{ij}}{\sum_{i \in g} f_{ij}} = g_{ij} p_{ij} \quad , \qquad \text{Eq. 7}$$

$$\hat{n}_{i} = g_{i} \frac{f_{i}}{\sum_{i \in g} f_{i}} = g_{i} p_{i} \quad . \qquad \text{Eq. 8}$$

On trawl gears where fish are identified to species only in the subsample (with the mean-weight fish), the proportion of the group that is species *i* is taken from the subsample and applied to the sample. If there are no species-group fish in the sample or associated subsample that are identified to species, then the species proportion is taken across samples from within a haul and applied to the sample count of species-group fish, under the assumption that the species proportionality is constant across the entire haul.

Note the differential subscripting for the two gear types. The species-specific weight of a species group on trawl vessels is computed for the individual sample (*j*), and those sample data are combined with other samples for the haul in the extrapolation process. On fixed gear vessels, the number of individuals of a species within a species group is computed for the haul and then converted to weight using the species-specific mean weight per fish (see Equation 6).

Salmon Estimation

Pollock CV deliveries are monitored for salmon by an observer. The number of salmon from the delivery and at-sea discard combined with salmon contained within the observer's at-sea sample is the total salmon catch for that trip. Since all trips are observed in the directed Bering Sea pollock fishery, the final catch estimates are based on the total salmon counts from all trips (CP/motherships and all shoreside deliveries by CVs). These estimates are not rate-based.

In the GOA directed pollock fishery, all catch is taken by CVs; however, not all trips are observed. On observed trips, the salmon catch from the delivery (inclusive of the at-sea samples and discard) is assigned to a specific haul in proportion to the vessel's catch estimates for those hauls. The total catch estimates are based on the prohibited species estimation methods that include using the apportioned salmon catches for observed trips and a rate-based estimator derived from observed hauls (apportioned salmon) that is applied to unobserved trips.

Since bycatch rates rely on post-stratification of haul data, salmon catches on observed trips are back apportioned to individual hauls. This is accomplished in two steps. First, the haul weight for all hauls in the trip is adjusted so that the total of at-sea retained catch is equal to the delivery weight (Equation 9) where $\hat{W}_h$ is the estimated weight of haul *h* (generally the vessel estimate of total catch), $\hat{D}_h$ is the estimated at-sea discard and presorted organisms of all species for haul *h*, and *O* is the total offload weight (scale weight). This calculation results in an adjusted haul size, which is the retained portion of the catch for a haul:

$$\hat{W}_h^* = \frac{\hat{W}_h - \hat{D}_h}{\sum_{h=1}^{H} \hat{W}_h - \hat{D}_h} O \quad . \qquad \text{Eq. 9}$$

The salmon catch predicted for haul *h* is the apportionment of salmon from the offload monitoring to each haul in the trip. The apportioned catch is proportional to the adjusted haul size (Equation 10), where *S* is the number of salmon monitored in the CV offload, including any at-sea discards and sampled salmon:

$$\hat{W}_{salmon,h} = \frac{\hat{W}_h^*}{\sum_{h=1}^{H} \hat{W}_h^*} S \quad . \qquad \text{Eq. 10}$$

The apportioning of catch occurs only when all the hauls contributing to a delivery can be identified. In cases where there are fish in the vessel's hold prior to the start of fishing on a given trip, these apportioning methods cannot be applied and haul-specific salmon estimation follows the standard methods used for other species. The adjustment of haul weight and subsequent apportioning of salmon catch from the delivery to the haul assumes that the ratio of the haul weight 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(e.g., the amount of salmon is proportional to the amount of groundfish for every haul.)

Observer Estimates of Percentage of Catch Retained

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 species-specific proportion of catch that is retained by the vessel 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 of a vessel, estimates of the numbers of fish that drop-off 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.

The method used by onboard observers to assess at-sea discard varies depending on the type of gear being fished. At-sea discards on trawl vessels include any discarded catch, including factory discards. On trawl vessels catch sorting by the crew and the observer sampling generally occurs in the same general area; hence, the observer has direct knowledge of crew sorting and retention practices. On fixed gear vessels, all crew sorting generally occurs on deck; on CPs, sorted catch is delivered to the factory. Hence, the estimated percent retained (1 minus the percent discarded) for a given species is determined using data on catch that drops off or is removed from the line at the roller as it is retrieved (with the exception of *Bathyraja* skates). Since *Bathyraja* skates are sorted by size and species in the factory as well as at the rail, factory discards are taken into account for those species. Similarly, the percent retained for a species harvested on vessels fishing pot gear is determined using only data on catch that is discarded from the deck (sorting tables).

The weight of at-sea discarded catch for species *i*, $\hat{D}_i$, is computed by applying the estimated at-sea discard rate (1 minus the percent retained), $\hat{d}_i$, to the total estimated haul weight, $\hat{W}_i$ (Equation 11):

$$\hat{D}_i = \hat{d}_i \hat{W}_i \quad . \qquad \text{Eq. 11}$$

Imputation Process

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 only some 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 haul that was not sampled is selected in the following order:

1. the sampled haul occurred on same day, but prior to the non-sampled haul;
2. the sampled haul occurred on same day, but after the non-sampled haul;

3. the sampled haul occurred on different day, but prior to and within 7 days of the non-sampled haul; and
4. the sampled haul occurred on different day, but no more than 7 days after the non-sampled haul.

Once a matching (similar) haul is identified, the species composition from the selected haul is multiplied by the total haul weight of the non-sampled haul. This process is defined in Equation 12 where $\hat{W}_i^A$ is the adjusted estimated total weight of species *i* for the non-sampled haul (indexed by superscript *A*), W_{h_u} is the total weight of the non-sampled haul, W_h is the total weight of the sampled haul (*h*), and $\hat{W}_{i,h}$ is the estimated catch for species i̲ in the sampled haul:

$$\hat{W}_{h_u i}^A = W_{h_u} \frac{\hat{W}_{ih}}{W_h} \quad . \qquad \text{Eq. 12}$$

On longline trips where all the longline sets are not 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 non-sampled haul. This adjustment factor is applied to the estimated species weight, estimated species number, and sampled species weight and number.

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 in the full coverage stratum, then observer data are used to determine the trip target. For all other vessels, a landing report or processing report (rarely used) is used to determine trip target. 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 pelagic 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 (inclusive of bottom pollock target).

Retained Catch

Estimates of retained catch (groundfish and Pacific halibut) are generated from both observer estimates (CPs and CVs delivering to motherships) and industry reports (CVs delivering shoreside) of catch (Table 3). 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 all strata: full coverage (subscripted by *F*), trip (subscripted by *T*) and vessel (subscripted by *V*) partial coverage, and no selection strata (subscripted by *Z*) of the estimates of catch for a given species for all hauls within the domain (Equation 13) where $\hat{W}_{ih}$ is the observer estimate of harvest for species *i* and haul *h* on a vessel in the fully covered stratum, and W_{id} is the delivered weight of species *i* in delivery *d* from vessels in the partial and no selection strata (industry report of retained catch):

$$\hat{C}_{ia} = \sum_{h \in a} \hat{W}_{ihF} + \sum_{d \in a} W_{id(T,V,Z)} \quad . \qquad \text{Eq. 13}$$

Note that there are no trips without either observer or industry catch reports. Trips that have unsampled hauls impute the species composition data from sampled hauls to derive a total catch estimate for that trip. In addition, the retained weight of Pacific cod caught on longline CPs in the Bering Sea are obtained from flow scale weights and are, thus, not estimated from observer information. Pacific halibut is not a prohibited species if there is a halibut IFQ permit holder on board the vessel and that permit holder has quota remaining to be harvested. In those cases, Pacific halibut greater than or equal to 32 inches must be retained and those less than 32 inches must be discarded.

At-Sea Discard of Groundfish Species and IFQ Pacific Halibut

For vessels in the full coverage stratum, observer data are used entirely to estimate the amount of groundfish that was discarded at sea. These at-sea discards are quantified by the observer on the vessels and are based, in part, on the observer’s best professional judgment as to how much catch is retained. The at-sea discard weight for any given domain (fishery) is the sum of the haul estimates of the at-sea discard weight for the domain (fishery).

For CVs delivering their catch to plants on shore (the partial and no selection strata), observer-based at-sea discard rates are applied to the total retained catch recorded on industry reports, which include the shoreside discards reported by the plant. The at-sea discard rates (ratio estimator) are based on two post-stratification groupings of hauls within each sampling stratum:

1. aggregated on a 5-week period, centered on week 3, and defined by week end-date, gear type, trip target code, and reporting area; and
2. aggregated across reporting areas and by a 5-week period, centered on week 3, and defined by weekend 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 (using the post-strata defined above) 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, $\hat{D}$, and observer-based estimates of total retained catch for groundfish species, $\hat{C}$, within the post-stratum. The ratio is applied to the retained landed weight, C^*, within the same post-strata. The domain estimates for these post-strata are the sum of the hauls within the domain of interest. The at-sea discards of groundfish species *i* for a fishery (or domain), *a*, is estimated as the sum of the estimated at-sea discard of groundfish for each sampling stratum (Equation 14) where *h* indexes hauls, *l* indexes landings, and $\hat{C} = \sum_{i \in groundfish} \hat{W}_i$:

$$\hat{D}_{ia} = \sum_{h \in F} \hat{D}_{iha} + \sum_{r \in T} \sum_{l \in r} C^*_{lra} \frac{\sum_{h \in T} \hat{D}_{ihra}}{\sum_{h \in T} \hat{C}_{hra}} + \sum_{r \in (Z,V)} \sum_{l \in r} C^*_{lra} \frac{\sum_{h \in V} \hat{D}_{ihra}}{\sum_{h \in V} \hat{C}_{hra}} \quad . \qquad \text{Eq. 14}$$

The indexes used in Equation 14 are as follows: the full coverage stratum is indexed by *F*; the partial coverage, trip selection vessels, and exempted CPs are indexed by *T*; the vessel selection stratum is indexed by *V*; and the no selection stratum is indexed by *Z.*

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

At-sea discard of prohibited species is estimated in numbers for salmon and crab species, and in weight (metric tons, t) for herring, halibut, and groundfish species where the quota has been harvested and additional catch of that species cannot be retained (prohibited species status). Prohibited species cannot be legally retained except for salmon bycatch donated to food donation programs. 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 species and observer coverage strata. For vessels in the full coverage stratum, the observer estimate of prohibited species discarded catch is the observer-based estimate of at-sea discard for a particular species, with the exception of salmon caught in the Bering Sea (AFA) pollock fishery. For salmon taken in the Bering Sea (AFA) pollock fishery, a complete enumeration of the catch occurs under Amendment 91 to the BSAI FMP. The total catch is the sum over all trips of the salmon counts reported by observers; note, however, that in the GOA pollock fishery the methods described below apply.

For vessels in the partial and no selection stratum, 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 groundfish discard calculated using the methods described in the preceding section). The catch rate (ratio of estimated prohibited species to estimated total catch in sampled hauls) is based on varying levels of post-stratification (Table 5). 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 (Equation 15). This includes the haul-specific estimates for not-sampled hauls (on observed trips) that are generated through the imputation process:

$$\hat{G}_h = \sum_{i \in \{Groundfish\}} \hat{W}_{ih} \quad . \qquad \text{Eq. 15}$$

For unobserved trips, the total groundfish for a given trip, G_l, is the sum over all groundfish species of the harvest and the at-sea discarded catch, as reported by industry for each landing (Equation 16):

$$G_l = \sum_{i \in \{Groundfish\}} \left(C_{il} + D_{il} \right) \quad . \qquad \text{Eq. 16}$$

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) in each sampling stratum, summed over the strata. This is computed using Equation 17, where *h* indexes sampled hauls and *l* indexes landings:

$$\hat{D}_{a,pro_i} = \sum_{r \in T} \left[\frac{\sum_{h \in T} \hat{W}_{hra,pro_i}}{\sum_{h \in T} \hat{G}_{hra}} \sum_{l \in T} G_{lra} \right] + \sum_{r \in (V,Z)} \left[\frac{\sum_{h \in (V,Z)} \hat{W}_{hra,pro_i}}{\sum_{h \in (V,Z)} \hat{G}_{hra}} \sum_{l \in (V,Z)} G_{lra} \right] + \sum_{r \in F} \sum_{l \in F} W_{lra,pro_i} \quad . \qquad \text{Eq. 17}$$

In the Equation 17, the index of post-strata, *r*, defines the covariates used to define observed hauls that are used to estimate the bycatch rate. For observed trips on vessels with less than full coverage, the set of covariates always includes the specific trip and FMP area. For observed trips on full coverage vessels, 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.

FUTURE DIRECTIONS

The catch estimation method in this paper is the current method used to quantify catch for in-season management of Alaska groundfish fisheries. 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 will consider statistical and implementation issues within the estimation hierarchy.

One important evaluation goal is to characterize the variation associated with the final estimates arising at each level of the sampling and estimation process (Figure 2), including statistical variance due to post-stratification and the type of estimator being used. Hence, the next steps for this work focus on how to characterize the uncertainty in the estimates and develop methods for generating variance estimates for catch. In addition, the evaluation will consider whether alternate estimators of catch are available and when appropriate, these will be assessed using performance measures specific to the catch estimation process.

Several performance measures have been developed that focus on both the estimation methods used to generate catch and bycatch estimates and the sampling methods from which the data arise. Throughout the sampling and estimation hierarchy, variance accumulates due to the estimation process and the sampling process. This variance (error) can be categorized into two main types: sampling errors and non-sampling errors. Sampling errors include selection bias and variance arising from the random sample. Selection bias is introduced to the analysis when the actual probability of a sample unit being selected differs from that assumed in the analysis. Sample variance is directly related to sample size and the definition of a sample unit. Non-sampling errors include sample frame inconsistencies (under and over coverage), non-response errors (fishing activities selected for observation that are not observed), and measurement and processing errors. In addition, statistical variability and bias are introduced through the choice of estimator, definition of post-strata, and sample size. While the focus here is on the estimation process, sampling methods and variances will be briefly discussed because they influence the estimates.

In 2013, NMFS and the NPFMC changed the deployment model used to place observers into the fishery (NMFS 2013b) in response to criticism and known biases that had been identified previously (MRAG 2000, Faunce and Barbeaux 2011). Two of the changes that have implications for the estimation process are the redefinition of strata and the randomization of deployments (Fig. 2 at numbers 1, 2, 8, and 11). Data within each sampled stratum are summarized under the assumption that the sample is representative of the underlying population; hence, behavioral changes that affect the proportion of trips that are observed may introduce bias to the estimates through the sampling process. Both the deployment methods and the sample rate will influence the representativeness of the sample. Performance measures that address these components of the sampling plan are described in the 2014 ADP (NMFS 2013c) and include measures of spatial and temporal representation of the sample, size of the sample (potential detection issues), sample frame inconsistencies (under and over coverage), and non-response issues (selected trips that are cancelled or selected vessels that do not take observers).

Several evaluations of observer sampling methods have been conducted to evaluate the effectiveness of, and alternatives to, current sampling methods used on CVs. For example, work has been completed that evaluates sampling methods used on the deck of the vessel against alternative methods that might be more efficient. In cooperation with commercial trawlers homeported in Kodiak, AK, NMFS conducted a side-by-side comparison of catch and discard estimates generated from current and alternative observer sampling methods that targeted sampling to the portion of the catch that would be discarded at sea (Faunce et al. 2013b). The alternative at-sea sampling method was easily implemented when there was a smaller amount of discard of only a few species; however, it could not be properly implemented in all fishing situations. The detection of at-sea discards of rare species was higher using alternative sampling methods. The resulting discard estimates tended to have less uncertainty than standard methods in low discard situations where the alternative methods could be implemented without logistical limitation. While these alternative methods show promise, they cannot currently be implemented across all fisheries due to the logistical constraints associated with sampling at sea under the current management setting.

In addition to performance measures that focus on the data collection process, performance of the catch estimators and the catch estimation process is also important. Statistical catch estimators are evaluated based on statistical bias and efficiency. These are often evaluated using measures such as the mean square error (a combination of variance and bias) and the variance of the estimator, particularly variance relative to the variance of alternative estimators. Since catch and bycatch estimation is a hierarchical process, there are several estimators involved and each of these should be evaluated both individually and in conjunction with other estimators.

The imputation process (Fig. 2, number 5) that is currently being used has recently been evaluated relative to both bias and efficiency (Cahalan et al. in review). The authors evaluated several statistical proprieties of the estimators in context with the underlying data: bias of the estimators, variability of the estimators, the performance of the estimators in relation species proportion (rarity), and the performance of the variance estimators. Results show that the simple mean estimator had the best performance for vessels landing catch at shoreside processors. The choice of estimator was less clear for vessels processing catch at sea, due to sensitivity associated with species composition (e.g., rare species) and implementation issues for the simple mean and ratio estimators. Results from Cahalan et al. (in review) suggest the simple mean estimator generally has better performance than imputation methods and has the added advantage of being able to generate estimates of variance. Based on these analyses, we anticipate changing the imputation process used in the CAS to that of a simple mean estimator.

The next phase of this evaluation will be to produce variance estimates at the trip level for all full coverage fisheries and test these estimates using simulation (Fig. 2; numbers 3 through 5). This is an analytic process incorporating the variance from at-sea sampling to the trip-level, a three-level sampling hierarchy. The existing post-stratification scheme (Fig. 2, numbers 6 through 8) will be evaluated. This work is expected to be complete by the end of 2015. Algorithms for estimating variance of trip-level catches will be developed and programmed.

Expansion of the trip-level data to the final fishery (quota) level will be dependent on the previous work and the definition of post-strata. The suite of variables used to define the current post-strata will be assessed to determine whether these are the most appropriate post-strata given the underlying fisheries and sampling programs. In addition, the performance of design-based or ratio estimators will be compared to assess the most appropriate method for this portion of the estimation process. Based on (and incorporating) results from the previous phase, the expansion of catch from the trip to the fishery will be assessed (Fig. 2, numbers 8 through 11) and estimation algorithms for catch and bycatch and its associated variance will be developed. Incorporation of these algorithms into the CAS is expected to begin in mid-2016 or early 2017.

It is important to recognize that these evaluations are dependent on having a reasonable expectation that the deployment of observers (randomization of the primary sample units; Fig. 2, numbers 1 and 2) is representative of fishing activity across fisheries. The analytic methods used to estimate catch all assume that the sample process is randomized and therefore sampling bias is minimized. If this assumption is not valid, both the estimates of catch and bycatch and variance will be biased; however, the magnitude and the direction of this bias will likely not be estimable. These evaluations are useful only in the context of an unbiased sample program.

The methods that we describe are a detailed account of current estimation techniques. 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 in-season 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 continuing to meet management needs.

In addition to the work evaluating estimation, video technology has been proposed as a potential way to supplement existing observer coverage, enhance the value of the data NMFS receives, and/or fill data gaps that have proven difficult to fill with human observers. NMFS, working with the NPFMC and industry, continues work on developing this video technology. NMFS and the NPFMC have identified fixed gear (hook and line, pot) vessels under 58 feet in length overall as the first priority for developing an

EM data collection program for catch estimation (Loefflad et al. 2014). Research is currently underway investigating challenges such as logistics on small boats, data transmission, species identification, and quantification of weight We anticipate that future EM-derived data collections will compliment current observer data in the catch estimation process.

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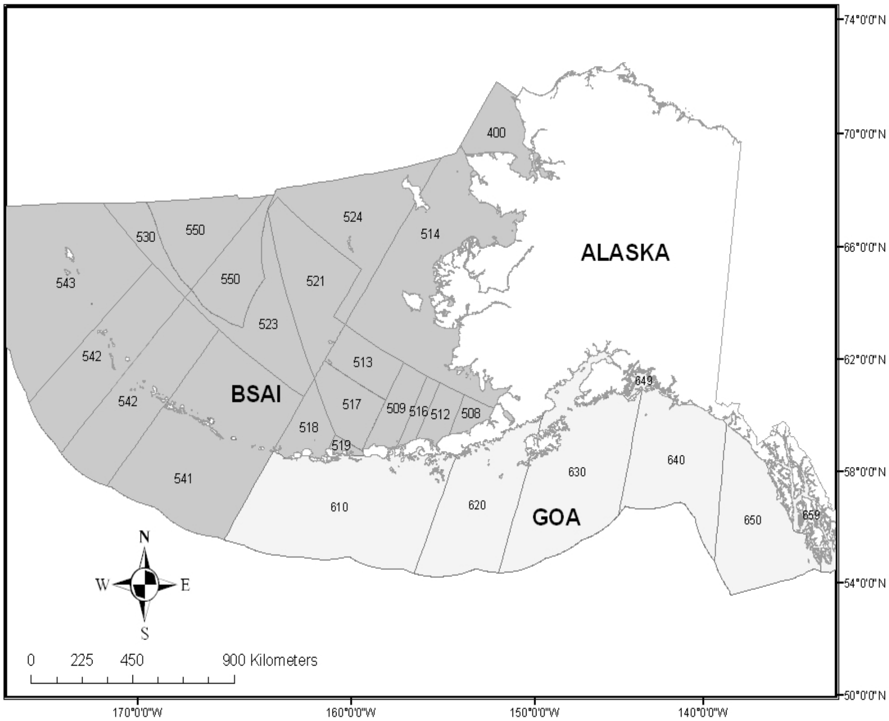

Figure 1. -- Fishery management plan regions and Federal reporting areas in Alaska. The Bering Sea and Aleutian Island (BSAI) region is shown in dark grey shading; the Gulf of Alaska (GOA) is shown in light grey shading; and NMFS reporting areas are identified with numbers.

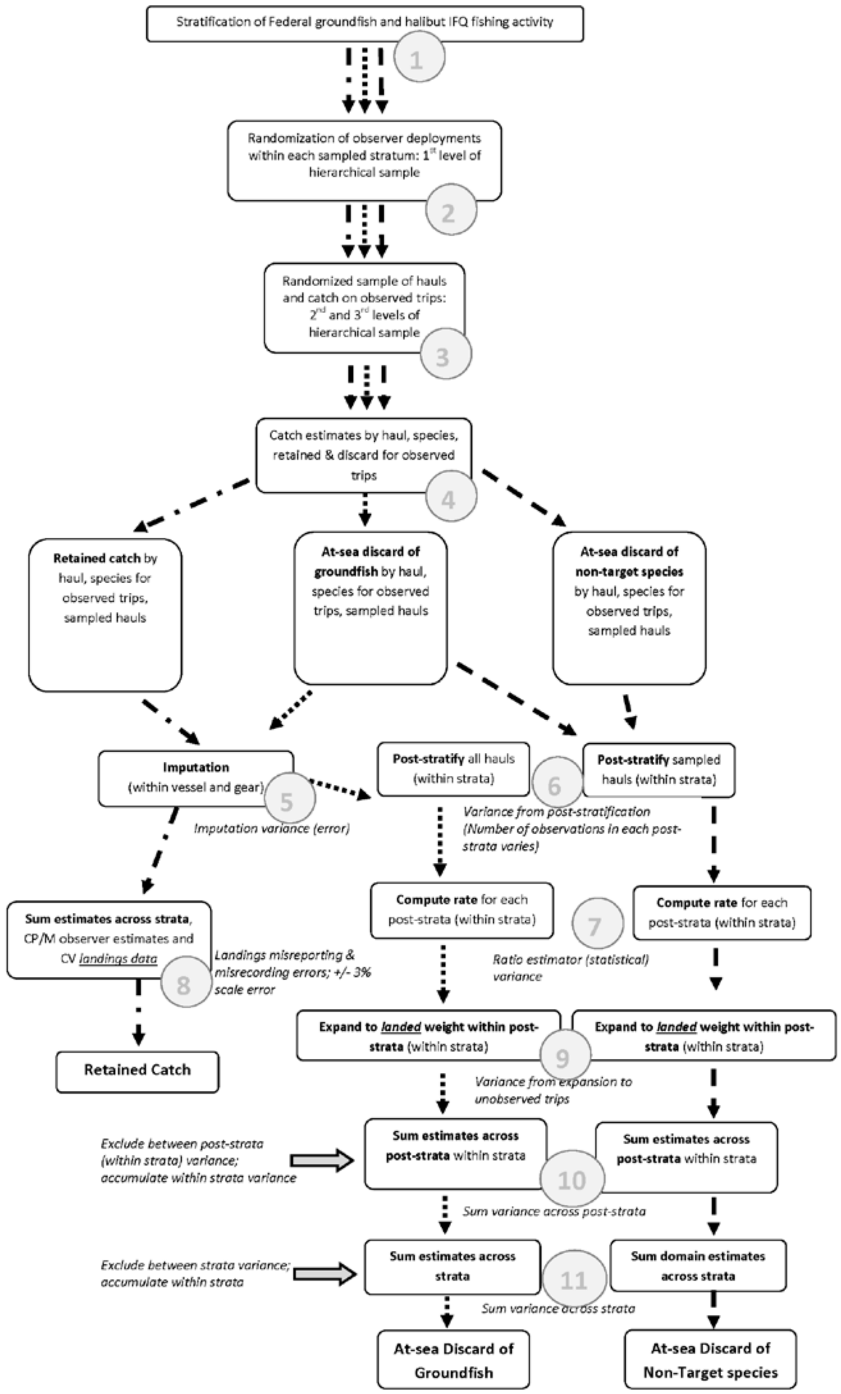

Figure 2: --Diagram of the Catch Accounting System process. Circled numbers indicate major computational processes where variance terms are accumulated.

Table 1. -- The deployment categories and sampling strata as defined by regulation and the 2013 through 2015 Annual Deployment Plan (ADP) for the North Pacific Groundfish and Halibut Observer Program.

Deployment category	Strata	Sampled?	Sampling unit (2013 and 2014)	Sampling unit (starting in 2015)	Sampling design defined by
Partial coverage	No selection	No	n/a	n/a	ADP
	Vessel selection	Yes	Vessel	Trip	ADP
	Trip selection	Yes	Trip	Trip	ADP
Full coverage	Full coverage	Yes	Trip	Trip	Regulations

Table 2. -- General sampling design description for the North Pacific Groundfish and Halibut Observer Program.

Sample level	Sample frame	Sample unit	Sample selection	Data / Observation
1° Unit: trips	Set of all trips taken by CVs outside of state and catch share fisheries	Fishing trip	Bernoulli sample	Trip data (e.g., Departure and delivery ports, trip dates)
1° Unit: vessels	Set of all vessels that fished the previous year in the same 2-month period	Two months of fishing activity (all trips taken by the selected vessel)	Simple random sample (SRS)	Trip data (e.g., Departure and delivery ports, trip dates)
2° Unit: hauls	Set of all fishing events on trip	Fishing event (haul, set)	Constrained SRS of set of all hauls	Effort data (e.g., total catch size, gear deployed, fishing location)
3° Unit: sample	Set of all sample units in the haul	Predefined weight, volume, or gear segment	Systematic random sample / SRS / opportunistic from haul	Species composition data
4° Unit: length sample	All fish of given species within a sample	Individual fish	SRS generally from 3° sample	Sex, length, and weight
5° Unit: otolith sample	All fish in length sample	Individual fish	SRS, generally from 4° sampled fish	Otoliths

Table 3. -- Data sources used in retained catch and at-sea discard estimation in each stratum as defined Annual Deployment Plan for 2013 through 2015. Prohibited species catch (PSC) is composed of salmon, herring, several crab species, and halibut. Note that the abbreviations are as follows: CP = Catcher/Processor; CV = Catcher Vessel.

Coverage stratum	Fishing sector	Retained catch	At-sea discard of groundfish	At-sea discard of non-FMP species and PSC
No selection	Fixed gear CVs under 40 ft length overall and CVs fishing jig gear	Landing report	At-sea discard rate from observer data in the small vessel selection strata is applied to a landing report.	At-sea discard rate from observer data in the small vessel selection strata is applied to a landing report.
Vessel selection (partial coverage)	Fixed gear CVs > 40 ft and < 57.5 ft and not fishing jig gear	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.
Trip selection (partial coverage)	All trawl CVs delivering shoreside and fixed gear CVs ≥ 57.5 ft delivering shoreside	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.
	Exempted CPs	Production report	Production report	At-sea discard rate from observer data is applied to a production report.
Full coverage	At-sea CPs and motherships, and vessels participating in certain fisheries (e.g., AFA, Rockfish Program)	Observer data	Observer data	Observer data

Table 4. – Species group codes and species codes used in the estimation of average weight per fish.

Group code	Species-group name	Species-specific code	Species name
159	Soft Snout Skate Group	85	Aleutian Skate
		88	Alaska Skate
		97	Bering Skate
		92	Deepsea Skate
		161	Okhotsk Skate
		162	Whitebrow Skate
		163	Commander Skate
		164	Whiteblotched Skate
		165	Mud Skate
		166	Roughshoulder Skate
		168	Butterfly Skate
167	Stiff Snout Skate Group	94	Big Skate
		95	Longnose Skate
354	Shortraker / Rougheye Rockfish Group	307	Rougheye Rockfish
		326	Shortraker Rockfish
104	Rock Sole Unidentified Group	120	Northern Rock Sole
		121	Southern Rock Sole
418	Irish Lord Unidentified Group	415	Butterfly Sculpin
		410	Brown Irish Lord
		407	Red Irish Lord
		414	Yellow Irish Lord
		434	Longfin Irish Lord Sculpin
149	Kamchatka / Arrowtooth Flounder Unidentified Group	141	Arrowtooth Flounder
		147	Kamchatka Flounder
440	Myoxocephalus Unidentified Group	398	Warty sculpin
		399	Plain sculpin
		405	Great sculpin
2	King Crab Unidentified Group	6	Blue king crab
		8	Brown king crab
		13	Red king crab
		16	Cousi king crab
3	Tanner Crab Unidentified Group	18	Tanneri tanner crab
		19	Angulatus tanner crab
		4	Bairdi tanner crab
		5	Opilio tanner crab
		47	Bairdi/opilio hybrid crab

Table 5. -- Post-strata used in estimating at-sea discard rate of prohibited species. These post-strata are applied within each sampling strata (e.g. full, partial trip, partial vessel selection), gear type, and trip target. Note that the abbreviations are as follows: CP = Catcher/Processor, M = Mothership, and CV=Catcher Vessel.

Rate label	Fishing entity	Time period	Area
50	Fishing Trip	CP/M: Week CV: time between first gear deployment and offload of catch	NMFS Reporting / Special Management Area
45	Fishing Cooperative	3-week	NMFS Reporting / Special Management Area
40	Processing Sector (i.e., CP, M, or CV)	3-week	NMFS Reporting / Special Management Area
30	All Landings	3-week	NMFS Reporting / Special Management Area
25	All Landings	3-month	Fishery Management Plan Area
20	All Landings	Year to Date	Fishery Management Plan Area

APPENDIX: LIST OF SYMBOLS USED

Introduced in Haul-Level Estimates Section

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

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

$f_{ij,}$ = the weight of fish identified to species i in sample j, used with species groups

g_{ij} = the weight of the species group in sample (and subsample) j to which species i belongs

$\bar{h}$ = the mean number of hooks per segment of longline gear

$\hat{h}$ = the total number of hooks sampled

i = index of the species of interest

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

k = the number of subsamples taken from a sample k=1, … Kj

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

m_j = the number of sampled longline segments in sample j

p_{ij} = the proportion of a species group that is species i

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_{ik} = the weight of fish of species i in subsample k where k = 1, …, K_j

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

$\bar{w}_i$ = the mean weight per fish for species i

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

$\hat{D}_h$ = the estimated total weight of at-sea discard for ALL species on haul h

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

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

S = the number of salmon in a CV offload including at-sea salmon discards

S_j = the total weight of predominant species in the sample

M = the total number of longline segments fished

$\hat{N}_i$ = the number of fish of species i for a haul

O = the total weight of an offload (CV delivery)

W = the total weight of fish in the haul

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

$\hat{W}_i^A$ = the adjusted estimated total weight of species *i* for a not-sampled haul (used in imputation)

$\hat{W}_h^*$ = the estimated total weight of haul *h*, generally the vessel estimate

Introduced in Fishery-Level Estimates Section

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

$\hat{C}_{ia}$ = estimated total retained groundfish based on observer sample for species *i*

F = indicator of full coverage stratum, excluding exempted CPs

T = indicator of partial coverage, trip selection stratum, including exempted CPs

V = indicator of partial coverage, vessel selection stratum

$\hat{W}_{ihF}$ = the estimated total weight of species *i* in haul *h* in the full coverage stratum

$\hat{W}_{id(T,V,Z)}$ = the estimated total weight of species *i* in delivery *d* in partial and no coverage strata

Z = indicator of no coverage stratum

h = index of sampled hauls

l = index of landings

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

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

$\hat{C}_{hra}$ = estimated total retained groundfish based on observer sample for haul *h*, post-stratum *r*, and domain *a*

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

C^*_{lra} = total industry reported retained groundfish (all species) for landing *l*, post-stratum *r*, and domain *a*

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

$\hat{D}_{hra}$ = estimated total at-sea discard of groundfish based on observer sample for haul *h*, post-stratum *r*, and domain *a*

At-Sea Discard on Non-groundfish Species

C_{il} = total industry reported retained catch of all groundfish species for landing *l* (unobserved trips)

$\hat{D}_{a,pro_i}$ = estimated at-sea discard of prohibited species *i* in domain *a*

$\hat{G}_h$ = observer estimated total (retained plus at-sea discard) groundfish for haul *h*

$\hat{G}_{hra}$ = observer estimated total (retained plus at-sea discard) groundfish for haul *h*, post-stratum *r*, domain *a*

G_l = total industry reported groundfish (retained plus at-sea discard) for landing *l* (unobserved trips)

G_{lra} = observer estimated total (retained plus at-sea discard) groundfish for landing *l*, post-stratum *r*, domain *a*

D_{il} = total industry reported at-sea discard of all groundfish species for landing *l* (unobserved trips)

$\hat{W}_{hra,pro_i}$ = estimated weight at-sea discard of prohibited species *i* in haul *h*, post-stratum *r*, domain *a*

W_{lra,pro_i} = industry reported weight at-sea discard of prohibited species *i* in landing *l*, post-stratum *r*, domain *a*

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