Fish Bycatch in the North Pacific Halibut, *Hippoglossus stenolepis,* and Groundfish Fisheries

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Introduction

Unwanted fish are taken incidentally in almost every U.S. commercial and recreational fishery. Fish are discarded because they are prohibited from being retained by regulation (for example, restrictions on the amount, size, sex, or species of the catch), or are simply not wanted due to the fish being of an unpreferable size (typically too small), or a species that may be less desirable to retain, or a lower value or unmarketable species taken in commercial fisheries. Regardless of the reason that fish are discarded, it is all considered bycatch, except for fish released alive under a recreational catch and release fishery management program. Bycatch can be a social and management issue concerning waste of natural resources or an allocation issue among different fishery sectors. Bycatch can also be a conservation issue due to impacts on biodiversity and fish populations, particularly if the bycatch is unmonitored and unregulated.

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In the United States, the primary law for management of federal marine fisheries is the Magnuson Stevens Fishery Conservation and Management Act (MSA) of 2007. The MSA establishes ten National Standards for the conservation and management of fisheries and requires that any plan or regulation developed must be consistent with these standards. However, not all of the National Standards can be met simultaneously, so each management decision must balance the tradeoffs among the standards. The overriding factor is National Standard 1, which requires that conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield (OY) from each fishery for the United States fishing industry. National Standards 2 through 10 provide further requirements for conservation and management measures.

Bycatch is addressed by National Standard 9, which requires that conservation and management measures shall, to the extent practicable, minimize bycatch. Further, the standard requires that the mortality of any bycatch that cannot be avoided must be minimized. The MSA defines bycatch as "those fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards. The term "bycatch" does not include fish released alive under a recreational catch and release fishery management program." The term "regulatory discards" means "fish harvested in a fishery which fishermen are required by regulation to discard whenever caught, or are required by regulation to retain, but not sell." The MSA further defines fish to be finfish, mollusks, crustaceans, and all other forms of marine animal and plant life other than marine mammals and birds.

The MSA also established eight regional fisheries management councils to develop fishery management plans (FMP's) and fishery regulations for their respective regions, based on the National Standards and other provisions for conserving and managing fisheries, including minimizing bycatch. The North Pacific Fishery Management Council (Council) was given the authority to develop FMP's and federal fishery regulations, subject to approval by NOAA's National Marine Fisheries Service (NMFS), for fisher-

ABSTRACT—Fish caught but not retained (i.e., fish that are discarded) during fishing operations are considered bycatch. In the commercial fisheries of the North Pacific, fish are discarded because they are either unmarketable species and unprofitable to retain or process or they are required by regulation to be discarded. Catch and bycatch in the Pacific halibut, Hippoglossus stenolepis*, and groundfish fisheries are closely monitored and recorded by observers at sea or shoreside, or by cameras onboard fishing vessels, to ensure that bycatch can be accurately estimated for individual species across the different fisheries and management areas.*

Overall North Pacific bycatch is relatively low compared to other commercial groundfish fisheries in other areas. Of the 2,058,816 t of fish caught in the North Pacific halibut and groundfish fisheries in 2021, 97,083 t (4.7%) were discarded. Bycatch accrues towards the annual catch limits for groundfish stocks, and thus has not been a conservation concern for most species.

Nevertheless, bycatch management can be a very contentious issue, given the allocative aspects for any species taken that is targeted by another gear type, and the socioeconomic and cultural concerns of Alaska Native and rural communities regarding bycatch of Chinook salmon, Oncorhynchus tshawytscha*, and chum salmon,* O. keta*. In this paper we review the data on bycatch of fish in the North Pacific halibut and groundfish fisheries and review the management measures that have been implemented to control and minimize bycatch to the extent practicable.*

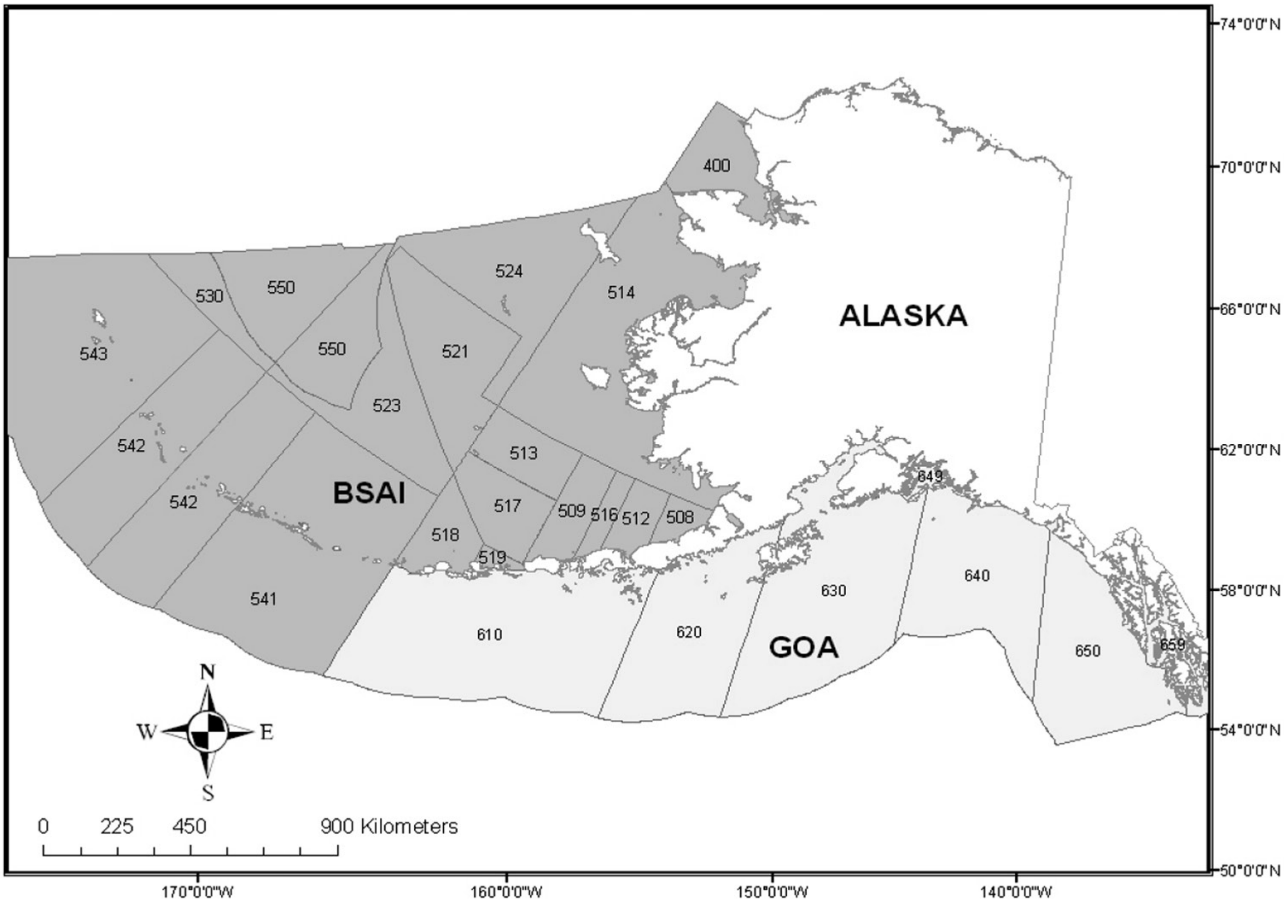

Figure 1.—Management and statistical areas for federal groundfish in the North Pacific: GOA (Gulf of Alaska areas 610-650) and BSAI (Bering Sea areas 508–530, Aleutian Islands areas 541–543).

ies in the Exclusive Economic Zone (3–200 n.mi.) off Alaska.

There are two FMP's that guide the management of groundfish fisheries in the North Pacific: the FMP for Groundfish of the Bering Sea and Aleutian Islands Management Area (BSAI Groundfish FMP), and the FMP for Groundfish of the Gulf of Alaska (GOA Groundfish FMP). These management areas, and the statistical areas within each that are used to manage catch and bycatch, are shown in Figure 1.

Pacific halibut, *Hippoglossus stenolepis*, is managed by the International Pacific Halibut Commission (IPHC) and through regulations implementing the Northern Pacific Halibut Act of 1982 (Halibut Act). The Halibut Act, at section 773c, also provides the Council with authority to develop regulations that are in addition to, and not in conflict with, approved IPHC regulations. The IPHC is authorized to conserve the halibut stocks and allocate the available catch limit between the United States and Canada. The Council has the authority to manage and regulate halibut fisheries in the Exclusive Economic Zone off Alaska, including allocating the harvest and fishing privileges among U.S. fishermen, subject to approval by the Secretary of Commerce. This authority also extends to regulating bycatch in the halibut fisheries.

In 2002, an environmental organization petitioned NMFS to count, cap, and control bycatch, and asserted that the agency was not complying with its obligations to minimize bycatch (Dobrzynski et al., 2002). In response to this petition, NMFS developed a National Bycatch Strategy, thus elevating the importance of the issue and committing the agency to expend additional effort to minimize bycatch (Benaka and Dobrzynski, 2004).

In 2011, NMFS issued its first national bycatch report in an attempt to quantify bycatch across different U.S. fisheries and regions based on 2005 data for those fisheries where information was available (Karp et al., 2011). The bycatch report has since been updated several times, with the latest report based on data through 2015 (Benaka et al., 2019).

This paper reviews the bycatch (as defined by the MSA) of fish taken in the different federally managed fisheries in the North Pacific, the management measures applied to minimize bycatch to the extent practicable, and discusses ongoing challenges in the management of bycatch in the North Pacific halibut and groundfish fisheries.

Background

North Pacific Fisheries

The federally managed groundfish fisheries in the North Pacific target an array of commercially important fish stocks including walleye pollock, *Gadus chalcogrammus;* Pacific cod, *Gadus macrophalus*; sablefish, *Anoplopoma fimbria*; yellowfin sole, *Limanda aspera*; northern rock sole, *Lepidopsetta polyxystra*; and other flatfish species; Pacific ocean perch *Sebastes alutus*; and other rockfish, *Sebastes* spp. and *Sebastolobus* spp.; and Atka mackerel, *Pleurogrammus monopterygius* (Witherell and Armstrong, 2015). The fisheries are managed using an ecosystem-based approach to achieve sustainable fisheries that provide benefits for harvesters, processors, recreational and subsistence users, and fishing communities. The fisheries 1) are maintained by healthy, productive, biodiverse, resilient marine ecosystems that support a range of services; 2) support robust populations of marine species at all trophic levels, including marine mammals and seabirds; and 3) are managed using a precautionary, transparent, and inclusive process that allows for analyses of tradeoffs, accounts for changing conditions, and mitigates threats (NPFMC, 2014a).

Management measures implemented to achieve sustainability include annual catch limits, which are established for each species or species group, and are set at conservative levels that are at or below the acceptable biological catch level and below the overfishing threshold corresponding to F_{MSY} (DiCosimo et al., 2010). In addition to catch limits, the fisheries are managed using traditional tools including: licenses and permits, allocation of catch limits among sectors, seasons and seasonal allocations, limited access privilege programs such as individual fishing quota (IFQ) and catch share cooperatives, monitoring and reporting requirements, an overall optimum yield limit on how much groundfish can be harvested annually from the ecosystem, limits on bycatch of non-target species, a prohibition on targeting forage species, gear requirements to reduce bycatch or habitat impacts, conservation areas, and measures to minimize fishery impacts on marine mammals and seabirds (Witherell et al., 2000; Witherell and Woodby, 2005; Heltzel et al., 2011; Fina, 2011).

The groundfish fisheries are annually prosecuted by about 400 vessels, with the different fleets (i.e., sectors) categorized by gear type (trawl, pot, longline, jig) and mode of operation (vessels that catch and deliver to processing facilities or to vessels that catch and process at sea) (Witherell et al., 2012). For example, walleye pollock is targeted using pelagic trawl gear by catcher/processors operating in the BSAI and catcher vessels delivering to shoreside and vessel-based processing facilities in both the BSAI and GOA areas. Pacific cod is targeted by vessels fishing with bottom trawl, pot, and longline gears that either process at sea or deliver shoreside. Rockfish and most flatfish are targeted by catcher/processors using bottom trawls in the BSAI and western GOA, but these stocks are targeted only by catcher vessels delivering shoreside in the central GOA. A few vessels target Pacific cod (and to a lesser extent rockfish) with jig gear.

The commercial halibut fishery off Alaska targets halibut with longlines, although pot gear has recently been authorized for this species. The fishery operates through annual issuance of IFQ to quota share-holders. About 1,000 vessels participate in the commercial halibut fishery each year, and about one-third of the vessels also participate in the sablefish IFQ fishery using longlines and pots (Witherell et al., 2012; Szymkowiak et al., 2020). Commercial halibut catch limits for each IPHC management area are established annually by the IPHC, after accounting for projected removals from the subsistence, charter, and sport fish sectors, and the estimated removals of halibut bycatch mortality in the halibut and groundfish fisheries. NMFS then issues catch limits for each management area as quota (in pounds) to individual quota holders to harvest. A regulatory minimum size limit of 81.3 cm (32 in) has been in place since 1973, and all halibut under this size must be discarded in the halibut directed fishery. Keith et al. (2014) provides an overview of conservation and management measures for the halibut fishery.

Observer Program

A comprehensive observer program, combined with real time reporting and management, as well as strict enforcement of regulations and binding civil agreements among harvesters in cooperatives, ensures that conservation and management measures are effective. In the groundfish and Pacific halibut fisheries, catch and discard data are collected through the North Pacific Observer Program. The program provides the regulatory framework to deploy observers and electronic monitoring (EM) systems to collect data necessary for the conservation, management, and scientific understanding of the commercial fisheries in the BSAI and GOA management areas. In the North Pacific fisheries, EM systems use video technology to collect data on catch and discard, and provide monitoring for compliance with regulations.

Data collection through the Observer Program provides a reliable and verifiable method for NMFS to collect fishery-dependent catch data, biological information on fish, and data on seabird and marine mammal interactions with fisheries. Observers and EM systems collect information on catch and discards (including inadvertent discards such as fish that drop off hooks and fish that are bled from trawl codends) onboard fishing vessels and at onshore processing plants (AFSC, 2021). These data are used in the Catch Accounting System to extrapolate and estimate total catch and discards in the fisheries (Cahalan et al., 2014) and enable real-time catch information for in-season management of the fisheries.

The monitoring program is based on a statistically rigorous sampling design (Cahalan and Faunce, 2020). Vessels fall into two categories of coverage, a full coverage category and a partial coverage category. In the full coverage category, vessels must have one or two observers onboard on every trip, and vessels obtain observers by contracting directly with certified observer providers. Vessels in this category include catcher/processors as well as catcher vessels that are participating in specific limited access privilege program fisheries. The vast majority of the groundfish catch falls under the full coverage category, and over 93% of the trawl catch is on trips with full coverage (NMFS, 2022).

A small portion of the total groundfish catch and all directed halibut catch falls under the partial coverage category (vessels take observers when randomly selected but not on every trip), which is funded by revenue generated through an ex-vessel value-based fee (1.65% of the ex-vessel price of the landed catch for catches not landed in the full coverage category), that is split between the vessels and the processors. Vessels in the partial coverage category currently fall into four different pools that determine their monitoring coverage: the no selection pool (vessels using jig gear and vessels <12.2 m in length using pot or longline gear; these vessels have no probability of being selected for monitoring); the trawl EM pool (specific pollock catcher vessels using pelagic trawl gear); the fixed-gear EM pool (non-trawl vessels that chose to use EM and are approved by NMFS); and the observer trip selection pool (catcher vessels ≥ 12.2 m (40 ft) in length that are not in the EM pool).

To ensure that statistically reliable data collection occurs in the partial coverage category with available fee revenue, NMFS prepares an annual deployment plan to deploy at-sea and shoreside fishery observers and EM systems to processing plants and vessels participating in halibut and groundfish fisheries (NMFS, 2021). EM is a growing component of this plan. Vessels in the trawl EM pool are required to have cameras operating at all times to verify compliance with maximized retention requirements. Catch accounting for the vessel's catch and bycatch is done through industry reports and shoreside plant observers. Vessels in the fixed-gear EM pool turn on their cameras during randomly selected trips and the EM information is used for catch and bycatch estimation. In the observer pool, trips are randomly selected for onboard observer coverage.

Together, monitoring of the vessels in the full coverage and partial coverage categories provides a comprehensive data collection program from which to extrapolate and provide accurate estimates of discards. In 2021, for example, 99% of the catch (including discards) in the BSAI halibut and groundfish fisheries, and 46% of the catch in GOA was monitored by an at-sea or shoreside observer and/or by EM (NMFS, 2022). In the 2021 GOA fisheries, the percent of total discards on trips monitored by observers or by EM where some video was reviewed or sampled by observers shoreside, was as follows: 20% for pot gear, 21% for hook and line gear, 48% for pelagic trawl gear, and 91% for bottom trawl gear (NMFS, 2022). In the 2021 BSAI fisheries, 21% of the discard was on monitored trips for pot gear, 84% for hook and line gear, 100% for pelagic trawl gear, and 99% for bottom trawl gear (NMFS, 2022). Bycatch estimation for North Pacific groundfish fisheries received high scores in a classification system that considers the quality of bycatch data and the reliability of bycatch estimation methods (Benaka et al., 2021).

Types of Bycatch and Discards

Bycatch and discards are fully accounted for in the North Pacific, and bycatch can be categorized into different types based on why the fish are discarded. The categories are economic discards and regulatory discards. A summary of these types of discards in the North Pacific groundfish and Pacific halibut fisheries is provided below.

Economic discards of groundfish or other species may occur for various reasons including fish quality, fish size, and marketability of the species in general. At the current time, many species of fish and invertebrates caught in the North Pacific do not have markets and thus processors will not pay a fisherman any price to land them. Examples of unmarketable fish include sculpins, grenadiers, and sharks, as well as invertebrates such as jellies and sea stars. Additionally, fisherman may choose to discard fish due to having limited hold or freezer space, or even to prevent one species from degrading the quality of other species in the fish hold. Discarding may also occur for fish of unmarketable quality due to wounds from marine mammal bites or parasites, sand fleas, or damage that occurred during capture, or when a vessel does not deliver in sufficient time and the fish is no longer of a marketable quality. It is therefore understood that any species, regardless of its value, could end up discarded due to economic reasons.

The second type of bycatch is regulatory discards, which occur due to size limitations, attaining the catch limit within a season or year, catching more halibut or sablefish than the available IFQ held by those on the vessel, exceeding the trip limit for pollock in the western GOA, or attaining Maximum Retainable Amount (MRA) limits during a fishing trip. MRA's are established by regulation for each individual groundfish catch species or complex, as a percentage of the retained catch of a species that is open for directed fishing (i.e., the basis species). A vessel participating in directed fishing can only retain up to the MRA for species closed for directed fishing, and all catch of that species exceeding the MRA must be discarded. The intent of MRA's is to provide an incentive to avoid targeting a species that is closed to directed fishing when fishing for other species that are open to directed fishing (Ackley and Heifetz, 2001). NMFS can also require all catch of a stock to be discarded if the total catch of that stock is getting close to attaining the annual catch limit for that stock, thus removing any incentive to further target that species or stock. Size limits also create regulatory discards. While there are no size limits for any groundfish species, IPHC regulations dictate that any Pacific halibut harvested in the commercial halibut directed fishery must be at least 81.3 cm (32 in) long, so halibut smaller than this minimum size are discarded by regulation (Stewart et al., 2020).

Another type of regulatory discard that is specific to the groundfish fisheries in the North Pacific is called prohibited species catch (PSC). Prior to the passage of the MSA in 1976, the principal domestic fisheries in Alaska were for Pacific salmon, red king crab, Pacific herring, and Pacific halibut. These principal species were given special status as "prohibited species" in the BSAI and GOA Groundfish FMP's that were implemented in the early 1980's, meaning that these species could not be retained in the groundfish fisheries. Regulations require all PSC species caught in groundfish fisheries to be released immediately with a minimum of injury. Bycatch limits for PSC species (red king crab, *Paralithodes camtschaticus*; Tanner crab, *Chionoecetes bairdi*; snow crab, *C. opilio*; Pacific herring, *Clupea pallasii*; Pacific halibut; Chinook salmon, *Oncorhynchus tshawytscha*; and chum salmon *O. keta*) were established for groundfish trawl fisheries to reduce the impacts on these species that were traditionally harvested by other gear types (Witherell and Pautzke, 1997).

Halibut bycatch is typically managed in terms of total mortality of discards. To calculate total mortality, specific discard mortality rates are applied to total halibut discards in different groundfish fisheries (set by gear type) and the halibut fishery based on scientific studies of halibut survival as indicated by the viability of Pacific halibut at the time of discard (Kaimmer and Trumble, 1998; Armstrong et al., 2016). These discard mortality rates are updated every few years based on updated viability observations from at-sea observers. For 2021, for example, BSAI halibut discard mortality rates applied to specific gear types and groundfish sectors were as follows: 100% for Pacific halibut caught with pelagic trawls, 84% caught with bottom trawls on mothership and catcher processors (on hauls not subject to deck sorting), 59% caught with bottom trawls on catcher vessels, 9% with longline gear, and 32% with pot gear. The IPHC applies a 16% mortality rate to Pacific halibut discarded in the halibut longline fishery for use in stock assessment and management (Stewart and Webster, 2020).

Bycatch Management Measures

The Council works closely with NMFS to meet the objectives of the National Bycatch Strategy and standards for effective management of bycatch in the North Pacific, including monitoring and quantifying fisheries bycatch, encouraging research to minimize bycatch, assessing the effects of fishing on bycatch populations, setting operational objectives consistent with legal requirements and policies, considering the cost effectiveness of mitigation measures, considering enforcement of the management measures, evaluating the effectiveness of bycatch measures, and regular communication with stakeholders on bycatch management actions (Benaka and Dobrzynski, 2004; Kirby and Ward, 2014). This process allows management measures being developed to meet the MSA National Standards, be transparent to stakeholders, and effective. The Council, NMFS, and participants in the halibut and groundfish fisheries have utilized many of the approaches identified by Hall and Mainprize (2005) to minimize bycatch, including the use of regulations, societal pressure, encouraging the fishery sector to find solutions that do not require regulation, and technological solutions.

Regulatory approaches include establishment of bycatch limits for many PSC species to limit the incidental catch of these species in the groundfish fisheries. These PSC limits were established to address concerns of fishermen, who target a particular species, to seek limits on the amount of that species caught incidentally in the halibut and groundfish fisheries. Most of the PSC limits were established based on historical bycatch amounts and set at amounts expected to have limited impacts (1% or so) on the population of PSC species (Witherell and Pautzke, 1997).

Interest in reducing bycatch of these species increases during times when the biomass of these species declines and bycatch represents a higher portion of total removals. This is particularly the case for Pacific halibut and salmon PSC where annual PSC limits, until recently, have not been directly tied to stock abundance (Witherell et al., 2002; Stram and Ianelli, 2014; DiCosimo et al., 2015; NPFMC, 2021). Total PSC limits for BSAI groundfish trawl fisheries, using 2021 as an example, included 2,805 t of halibut mortality (and 710 t for longline fisheries), 2,723 t of herring, 80,161 Bristol Bay red king crabs, 5,990,225 snow crabs, 3,071,678 Tanner crabs, and 45,700 chinook salmon.

Total PSC limits for 2021 GOA groundfish trawl fisheries were 1,706 t of halibut mortality (and 257 t for longline fisheries) and 33,340 Chinook salmon. The PSC limits in the BSAI and GOA are further allocated among different fishing sectors, and in some cases, further apportioned among target fisheries, fishing seasons, or area. Attaining any of these limits closes the specific target fishery within the entire management area (for halibut and salmon PSC limits) or a specified closure area (for crab and herring PSC limits), for the remainder of the PSC period, season, or year, even if the target species catch limit has not been fully harvested.

The halibut and groundfish fisheries are also managed to allow the industry to find solutions to minimize bycatch, typically to stay within regulated bycatch limits. Numerous exempted fishing permits (permits issued by NMFS to allow fishing activities that would otherwise be prohibited under federal regulations) have been issued to provide an opportunity for fishermen to test selective fishing techniques and gears, including halibut excluders and salmon bycatch reduction devices in trawl nets, deck sorting of halibut bycatch on trawl vessels to reduce discard mortality, the use of EM for estimating catch and bycatch on vessels using longline and pot gear, the use of EM for compliance monitoring on trawl vessels, and test the effectiveness of a voluntary program for vessels to avoid high bycatch rate areas that change within the fishing season as a way to reduce salmon bycatch in trawl fisheries.

Fisheries operating under catch share programs have significantly more opportunity to implement industry solutions across an entire fishery sector than do fisheries that operate under a race for fish system where individual vessels compete to catch as much fish as possible before the catch limit is attained. Implementation of an IFQ system for halibut and sablefish fixed gear fisheries, and the formation of cooperatives (a type of catch share program) in the Bering Sea pollock and bottom trawl fisheries and the Central Gulf of Alaska rockfish fisheries, have resulted in reduced bycatch and waste (NPFMC, 2014b, 2017). The race for fish was eliminated, which then allowed for development of more selective fishing gears and fishing practices, development of additional markets for lower valued species, and significant increases in utilization rates of fish landed (Fina, 2011; Strong and Criddle, 2013).

The BSAI catcher/processor bottom trawl fleet has the potential for their catch to be constrained by the halibut PSC limits established for this sector, so this sector has strived to develop solutions to minimize the bycatch and bycatch mortality of halibut. In 2015, the Council reduced the halibut PSC limit for this sector by 25% (to 1,745 t of halibut mortality) and requested that the sector's cooperative prepare annual halibut avoidance plans. Since then, representatives from the cooperative have annually reported back to the Council on the performance of the plans, and the agreement to ensure accountability of all participants in avoiding halibut. The cooperative's current halibut agreement includes three components: implementation of best practices for avoidance on the grounds (monitoring bycatch, use of excluders, communication protocols, and captains sharing information on locations to avoid), a halibut avoidance plan that defines standards and incentives to achieve good performance, and the use of deck sorting, which by regulation allows vessels to deck sort halibut and return halibut to the water quickly, thereby reducing halibut mortality and the mortality rate applied to the bycatch (ASC, 2021). In December 2021, the Council approved a measure that links the halibut PSC limits for this sector to indices of halibut abundance. At current abundance levels, this action will further reduce this sector's halibut PSC limits by 25% (to 1,309 t of halibut mortality).

The three BSAI pollock fleet cooperatives (inshore, at-sea, and mothership cooperative) operate under regulated bycatch limits for Chinook salmon which close the fishery if reached, and these cooperatives have established incentive plan agreements which require additional actions for individual operators to effectively avoid salmon on the fishing grounds at all levels of salmon and pollock abundance (Stram and Ianelli, 2014). These incentive plan agreements typically include requirements for salmon bycatch data reporting and information sharing; identification of bycatch hotspot areas where fishing by vessels with poor bycatch performance is prohibited; several areas with historically higher bycatch rates closed to all vessels; monetary penalties for vessels with consistently higher Chinook salmon bycatch rates relative to the fleet; in some cases incentives to avoid salmon by allowing a limited number of salmon credits (i.e., uncaught portion of a salmon cap) generated by using less than a vessels annual allocation of Chinook salmon bycatch units to carry over and thus providing an insurance buffer for future years; and a requirement that all pollock trawl nets contain salmon excluder devices to allow salmon to escape from the trawl net during fishing operations (Gruver, 2022; Madsen and Haflinger, 2022).

To ensure that BSAI pollock harvesters will make every effort to avoid salmon during fishing operations, the Council developed a salmon bycatch management program that is a blend of caps and incentives. The Chinook salmon caps are "hard" caps that if reached, close the entire pollock fishery for the year. In the Bering Sea, the overall bycatch limit is either 60,000 Chinook salmon or 45,000 Chinook salmon, depending on whether the previous year's Chinook run size was above or below an abundance threshold of 250,000 salmon (in aggregate) returns to the Kuskokwim River, Unalakleet River, and Upper Yukon River system (NMFS, 2016).

A key incentive to avoid salmon is the regulation whereby if the fleet exceeds the lower performance standard cap in 3 out of 7 years, it becomes the new hard cap in perpetuity. To avoid this possibility, the fleet voluntarily operates under lower performance standard caps of 47,591 salmon, or 33,318 salmon in years below the Chinook salmon abundance threshold, as a protection against reaching the overall hard cap, which would stop pollock fishing for the remainder of the year (Gruver, 2022). Representatives from the pollock cooperatives annually report to Council on the effectiveness of their efforts to avoid salmon in the previous year, and their incentive plans for the coming year.

Technological solutions have also been implemented to reduce bycatch and unobserved mortality. Biodegradable panels made of cotton thread are required for pot gear to minimize bycatch mortality associated with lost gear. Gillnets for groundfish fishing have been prohibited to prevent ghost fishing and bycatch of non-target species. The use of bottom trawl gear for pollock fishing in the Bering Sea was prohibited to reduce crab, halibut, and other non-target bycatch. Research is currently underway to test the effectiveness of crab bycatch reduction in a variety of Pacific cod pot gear modifications, with the goal to develop a design that reduces crab bycatch while still catching target species, and then to encourage the voluntary use of those designs (BSFRF, 2022). The recent development of lightweight collapsible, "slinky pots," for sablefish, and the concomitant change in regulations to allow the use of pot gear to catch sablefish and halibut (instead of longline gear) has already reduced bycatch and further reductions are anticipated.

Regulatory approaches have also been used to limit discarding of groundfish species. Although all discards of groundfish count against the total catch quotas for each groundfish stock, discard of targeted species is considered especially wasteful as this is food that could be marketed and consumed. To address these concerns, regulations at 50 CFR 679.27 require full retention of all pollock, Pacific cod, and GOA shallow-water flatfish complex species (primarily *Lepidopsetta* sp. and *Pleuronectes* sp.), unless unfit for human consumption (i.e., decomposing fish that had previously been caught and discarded) or otherwise required to be discarded by regulation (e.g., fish caught in excess of MRA amounts). Full retention of rockfish (even if closed to directed fishing) in groundfish or halibut fisheries by catcher vessels using longlines, jigs, or pot gear is required to stop the waste of dead fish, as well as ensure accurate data collection and species identification. All sablefish caught in the IFQ fishery are required to be retained, provided there is sufficient quota share available on the vessel to cover the catch. However, due to the substantially reduced market value for smaller sablefish, participants in the sablefish fishery have requested the Council reevaluate the full retention requirement and allow fishermen to discard the smaller fish.

Methods

We evaluated the amount and composition of bycatch in the halibut and groundfish fisheries for the years 2013–21, based on the MSA definition of bycatch, using data generated by the NOAA Catch Accounting System (Cahalan et al., 2014). The Catch Accounting System uses data from observers and EM systems along with landings information to generate estimates of total groundfish catch, including at-sea discards, as well as estimates of PSC and other non-groundfish bycatch. Although bycatch data have been collected since 1991, only the data since 2013 are included in our evaluation of fishery specific bycatch amount to maintain consistency between estimation methods and data collection that have changed throughout time. Prior to 2013, for example, halibut bycatch was not reported for halibut and sablefish IFQ fisheries because there was no observer data from this fishery. Changes in estimation methodology did not impact PSC estimates relative to the PSC limits established for each year, therefore we summarized a longer time-series (1991–2021) of available PSC data to evaluate the bycatch of these species relative to PSC limits. PSC data are publicly available on the NMFS website.

We evaluated bycatch data for major fisheries in the North Pacific, with the fisheries defined based on the management area and gear used. These fishery groupings differ from those reported in the first edition of the National Bycatch Report (Karp et al., 2011), and, to a lesser extent, the updates of the report (Benaka et al., 2019). The Alaska fisheries in the National Bycatch Report updates (Benaka et al., 2019) are based on species targets (defined by the predominant species retained on a trip), management area, and gear used, but also, in some cases, the vessel type (catcher vessel or catcher/processor). The methodology results in splitting the data into specific fisheries that may not operate in a substantially different manner. For this paper, we lumped these fisheries together.

For example, in our analysis of the BSAI flatfish trawl fishery we did not distinguish between the Amendment 80 catcher/processor bottom trawl sector and the BSAI trawl limited access sector in the amount of bycatch and composition of discards, because both sectors use the same gear and fish in the same general area of the Bering Sea when fishing for yellowfin sole and other flatfish. Similarly, we examined bycatch in the Pacific cod longline fishery by area, without reporting bycatch separately for catcher vessels and catcher/processors. We also did not make a distinction based on whether or not a vessel used pelagic trawl or bottom trawl gear to harvest rockfish, as the biggest differences in fishery operations (including the rockfish species targeted) are between management areas.

For our fishery specific bycatch analysis, we treated bycatch data for Pacific halibut the same as bycatch data for groundfish and non-target species. Although halibut bycatch is typically reported in terms of bycatch mortality for PSC management, this mortality estimation is unique to halibut, therefore we did not adjust the bycatch data to account for mortality of discarded halibut in our analysis of fishery specific bycatch. This enabled an evaluation of bycatch and bycatch rates of halibut and all other species using a consistent methodology. However, in our analysis of PSC use relative to PSC limits for halibut, we did maintain the adjustment for discard mortality that is used for management purposes. Similarly, to maintain consistency with other estimations of total bycatch by fishery in this paper, we converted the bycatch data for salmon and crab from numbers of animals to total weight. Salmon and crab bycatch is typically monitored and managed by the number of animals caught, as is reported in our analysis of PSC use relative to limits. However, for the analysis of total discard weight, we applied the average observed weight of salmon

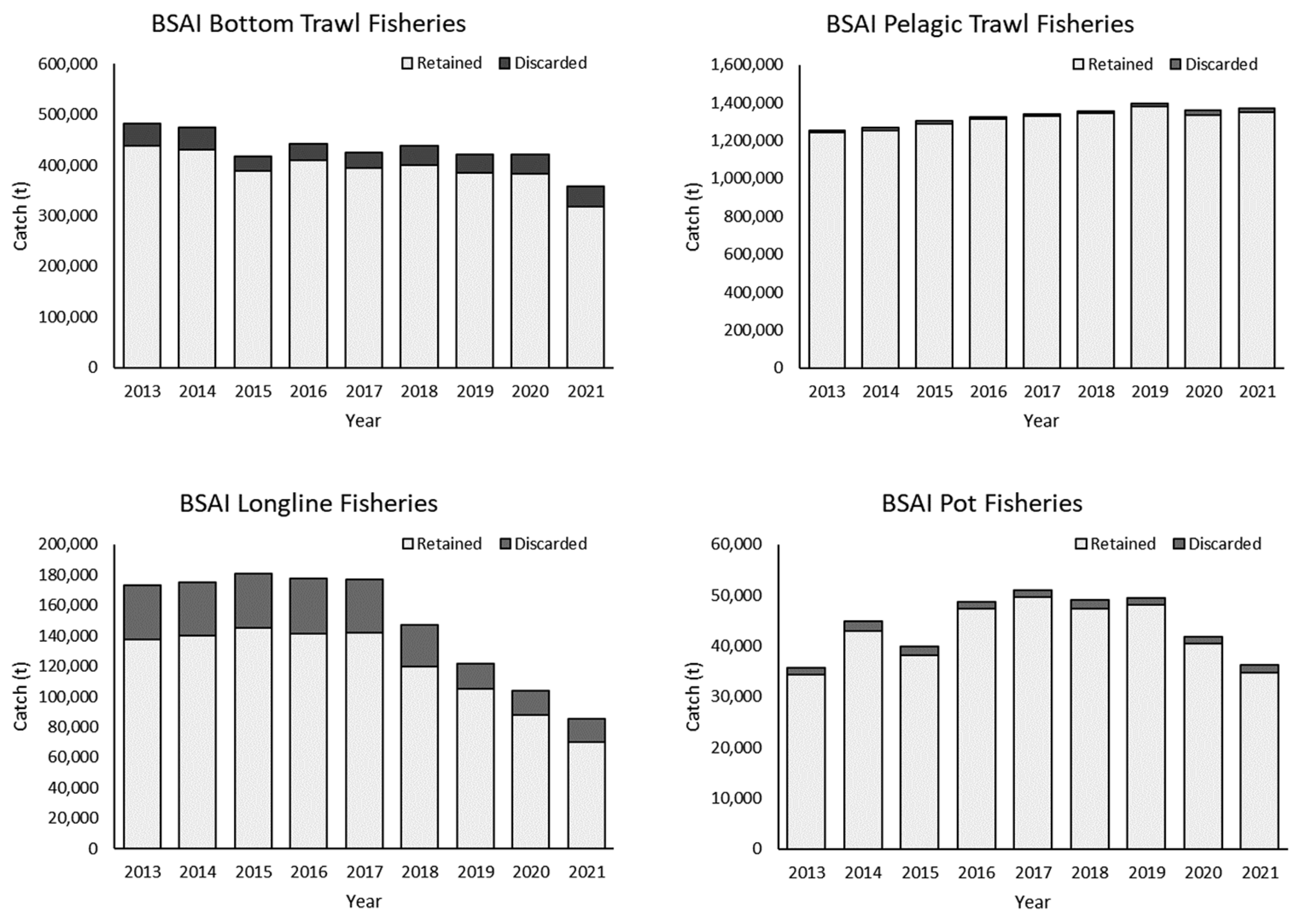

Figure 2.—Retained and discarded catch (t) in the groundfish and halibut fisheries in the Bering Sea and Aleutian Islands (BSAI) management area, by gear type.

or crab, by species, taken as bycatch in the groundfish fisheries to the total number of animals estimated to be taken as bycatch, to estimate total bycatch weight for each of these species.

Results

Total catch and discard by target gear type in the BSAI and GOA from 2013 through 2021 are shown in Figures 2 and 3. In both areas, pelagic trawl and pot fisheries had the lowest discard rates. Pelagic trawl fisheries had an average (2013–2021) discard rate of 1.1% in both the BSAI and GOA. Pelagic trawls are used to target walleye pollock, and to a lesser extent, some rockfish species in the GOA. Pot fisheries had an average discard rate of 3.4% in the BSAI and 5.0% in the GOA. There was a reduction in total catch in GOA pot fisheries starting in 2018 that was a result of reduced stock size and a corresponding closure of the directed fishery for Pacific cod. Bottom trawl fisheries had slightly higher discard rates, averaging 8.5% in the BSAI and 15.7% in the GOA. Total catch from bottom trawls has declined over the time series in both the BSAI and GOA due to reduced catches of flatfish and Pacific cod. Longline fisheries had the highest bycatch rates, averaging 18.8% in the BSAI and 46.4% in the GOA. A reduction in total catch by longline gear was due primarily to the reductions in Pacific cod catch limits over the time period. Reduced catches of sablefish in longline gear have also occurred as an increasing number of vessels have switched over to using pot gear to catch sablefish to reduce whale depredation.

The total amount of discards by species or species complex, across all groundfish fisheries (including jig gear) and the halibut fishery in the BSAI and GOA in 2021, is shown in Tables 1 and 2. In the BSAI, walleye pollock had the lowest discard rate (1.0%), but due to the high total catch of this species, it was the largest component (18.7%) of total discards across all fisheries. Discard rates for Atka mackerel, Pacific cod, Pacific ocean perch, and most flatfish species were under 10%. Higher discard rates

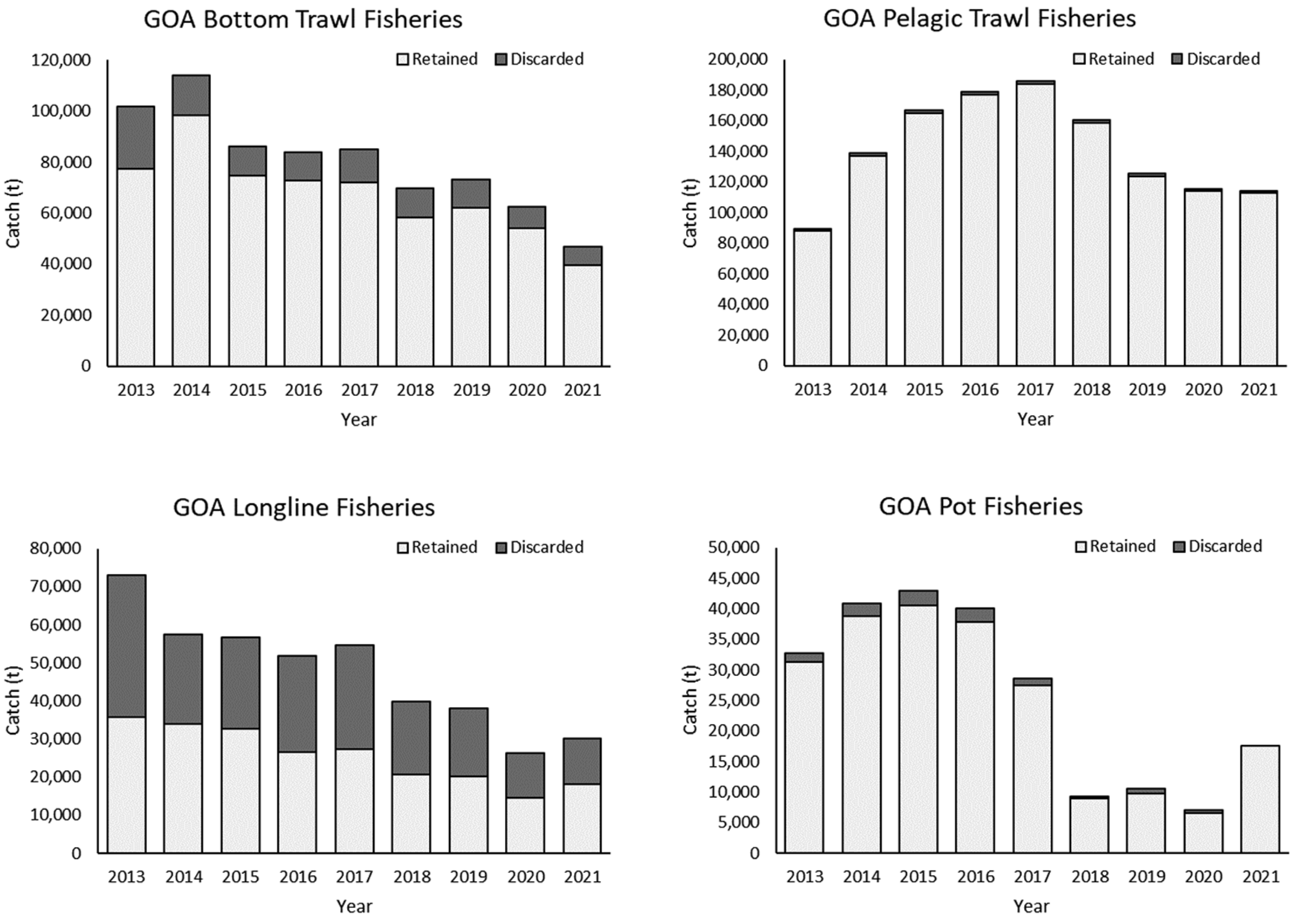

Figure 3.—Retained and discarded catch (t) in the groundfish and halibut fisheries in the Gulf of Alaska (GOA) management area, by gear type.

(30%–55%) were observed for other species, including sablefish, skates, and some rockfish species. Species that were fully accounted for and then discarded also include PSC species where retention is prohibited (salmon, crabs, Pacific herring) and unmarketable species (jellyfish, sculpins, sea stars, etc.). In the GOA, Pacific halibut was the largest component (23.4%) of the discards. Discard rates for pollock, sablefish, Pacific cod, and most rockfish were under 10%. Most flatfish had intermediate discard rates (14%–20%), and most skates were discarded (84%–97%). As with the BSAI, PSC species (salmon, crabs, Pacific herring) and unmarketable species (grenadier, sculpins, sea stars, etc.) were fully discarded in the GOA.

The 2021 catch and discard amounts, and discard amounts of the top ten species or species groups within the BSAI and GOA trawl fisheries are shown in Tables 3 and 4. Not surprisingly, the pelagic trawl fisheries primarily discarded pelagic species such as Scyphozoa jellies (primarily the northern sea nettle, *Chrysaora melanaster)*, squid (e.g., magistrate armhook squid, *Berryteuthis magister*), Pacific herring, smelt and other Osmerids (including capelin, *Mallotus villosus*, and eulachon, *Thaleichthys pacificus*), Pacific salmon, and walleye pollock. The bottom trawl fisheries tended to discard benthic species such as skates, flatfish, walleye pollock, and sculpins (including yellow Irish lord, *Hemilepidotus jordani*, in the GOA, and great sculpin, *Myoxocephalus polyacanthocephalus*, and plain sculpin, *M. jaok*, in the BSAI). Overall, walleye pollock and Scyphozoa jellyfish were the most discarded species in the BSAI trawl fisheries. Walleye pollock, arrowtooth flounder, *Atheresthes stomias*, and Pacific cod were the most discarded species in the GOA trawl fisheries. The largest total discard occurred in the BSAI flatfish fisheries (32,690 t), accounting for 34% of the total discards in the North Pacific halibut and groundfish fisheries. The BSAI pollock fishery had the second highest discard amount (19,761 t) of the trawl fisheries. Overall, the pollock fisheries had the lowest discard rates of all of the trawl fisheries, with 1.4% of the catch discarded in

Table 1.—Total discards (t) and retained catch (t) by species or species group, across all federally managed commercial halibut and groundfish fisheries in the Bering Sea and Aleutian Islands area, 2021.

Common Name	Scientific Name	Discard (t)	Retained (t)	Total (t)	% Discarded
Walleye pollock	*Gadus chalcogrammus*	14,161	1,363,936	1,378,097	1.0
Atka mackerel	*Pleurogrammus monopterygius*	706	60,647	61,354	1.2
Yellowfin sole	*Limanda aspera*	2,003	106,785	108,788	1.8
Pacific cod	*Gadus macrophalus*	3,615	132,100	135,715	2.7
Greenland turbot	*Reinhardtius hippoglossoides*	47	1,549	1,596	3.0
Kamchatka flounder	*Atheresthes evermanni*	223	6,444	6,667	3.3
Pacific ocean perch	*Sebastes alutus*	1,791	33,688	35,479	5.0
Rock soles	*Lepidopsetta polyxstra; L. bilineatus*	963	13,431	14,393	6.7
Flathead sole; Bering flounder	*Hippoglossoides elassodon; H. robustus*	774	9,485	10,259	7.5
Alaska plaice	*Pleuronectes quadrituberculatus*	1,282	14,579	15,862	8.1
Northern rockfish	*Sebastes polyspinus*	564	5,649	6,212	9.1
Arrowtooth flounder	*Atheresthes stomias*	984	8,029	9,014	10.9
Shortraker rockfish	*Sebastes borealis*	154	342	496	31.1
Other rockfish	*Sebastolobus alascanus; Sebastes* sp.	366	635	1,002	36.6
Sablefish	*Anoplopoma fimbria*	2,241	3,507	5,748	39.0
Rougheye/Blackspotted rockfish	*Sebastes aleutianus; S. melanostictus*	205	310	515	39.9
Skates	*Rajidae*	11,127	8,902	20,029	55.6
Other flatfish	*Pleuronectidae; Paralichthyidae*	1,708	930	2,638	64.8
Pacific halibut	*Hippoglossus stenolepis*	3,733	1,625	5,357	69.7
Octopus	*Octopoda*	148	22	170	87.3
Sharks	*Elasmobranchii*	352	7	359	98.0
Jellies	*Scyphozoa*	8,614	0	8,614	100.0
Sculpins	*Scorpaeniformes*	5,628	0	5,628	100.0
Squids	*Teuthoidea*	4,124	0	4,124	100.0
Giant grenadier	*Albatrossia pectoralis*	2,677	0	2,677	100.0
Sea stars	*Asteroidea*	2,401	0	2,401	100.0
Pacific herring	*Clupea pallasii*	1,878	0	1,878	100.0
Non-Chinook salmon	*Oncorhynchus keta;* other *O.* sp.	1,222	0	1,222	100.0
Misc. fish sp.	*Teleostomi*	315	0	315	100.0
Red king crab	*Paralithodes camtschaticus*	309	0	309	100.0
Tunicates	*Tunicata*	220	0	220	100.0
Sponge unidentified	*Porifera*	170	0	170	100.0
Tanner crab	*Chionoecetes bairdi*	151	0	151	100.0
Sea anemones	*Actinaria*	142	0	142	100.0
Snails	*Gastropoda*	126	0	126	100.0
Snow crab	*Chionoecetes opilio*	84	0	84	100.0
Eelpouts	*Zoarcidae*	55	0	55	100.0
Invertebrates (unident.)	*Invertebrata*	50	0	50	100.0
Chinook salmon	*Oncorhynchus tshawytscha*	49	0	49	100.0
Golden king crab	*Lithodes aequispina*	44	0	44	100.0
Corals/Bryozoans	*Bryozoa*	28	0	28	100.0
Urchins/dollars/cucumbers	*Echinodermata*	19	0	19	100.0
Misc. crabs (unident.)	*Decapoda*	19	0	19	100.0
Brittle stars	*Ophiurodea*	15	0	15	100.0
Grenadiers (unident.)	*Macrouridae*	13	0	13	100.0
Bivalves	*Bivalvia*	10	0	10	100.0
Sea pens/sea whips	*Octocoralia*	8.7	0.0	8.7	100.0
Hermit crabs	*Paguroidae*	8.3	0.0	8.3	100.0
Black/blue/dark rockfish	*Sebastes melanops; S. ciliatus; S. mystinus*	5.7	0.0	5.7	100.0
Pandalid shrimp	*Pandalus* sp.	4.7	0.0	4.7	100.0
Greenlings	*Hexagammidae*	3.1	0.0	3.1	100.0
Misc. crustaceans (unident.)	*Crustaceamorpha*	1.7	0.0	1.7	100.0
Other osmerids	*Osmeridae*	1.4	0.0	1.4	100.0
Lanternfishes	*Myctophidae*	0.7	0.0	0.7	100.0
Saffron cod	*Eleginus gracilis*	0.6	0.0	0.6	100.0
Misc. invertebrates	*Invertebrata*	0.5	0.0	0.5	100.0
Polychaete worms	*Polychaeta*	0.4	0.0	0.4	100.0
Pacific sandfish	*Trichodon trichodon*	0.3	0.0	0.3	100.0
Pricklebacks	*Stichaeidae*	0.2	0.0	0.2	100.0
Pacific sand lance	*Ammodytes hexapterus*	0.2	0.0	0.2	100.0
Misc. deepwater fish	*Teleostomi*	0.1	0.0	0.1	100.0
Smelts	*Osmeridae*	0.1	0.0	0.1	100.0
Gunnels	*Pholidae*	0.0	0.0	0.0	100.0
Total BSAI		75,553	1,772,602	1,848,155	4.1

Table 2.—Total discards (t) and retained catch (t) by species or species group, across all federally managed commercial halibut and groundfish fisheries in the Gulf of Alaska area, 2021.

Species Group Name	Scientific Name	Discard (t)	Retained (t)	Total (t)	% Discarded
Walleye pollock	*Gadus chalcogrammus*	1,347	99,814	101,160	1.3
Northern rockfish	*Sebastes polyspinus*	38	2,339	2,376	1.6
Pacific ocean perch	*Sebastes alutus*	517	28,383	28,900	1.8
Dusky rockfish	*Sebastes variabilis*	106	2,822	2,929	3.6
Sablefish	*Anoplopoma fimbria*	1,206	15,295	16,501	7.3
Pacific cod	*Gadus macrophalus*	1,407	17,769	19,176	7.3
Thornyhead rockfish	*Sebastolobus* sp.	23	284	306	7.4
Demersal shelf rockfish	*Sebastes ruberrimus; other Sebastes* sp.	14	122	136	10.3
Atka mackerel	*Pleurogrammus monopterygius*	107	832	939	11.4
Rex sole	*Glyptocephalus zachirus*	44	257	301	14.5
Rougheye/blackspotted rockfish	*Sebastes aleutianus; S. melanostictus*	79	342	421	18.7
Arrowtooth flounder	*Atheresthes stomias*	1,885	8,144	10,029	18.8
Shallow water flatfish	*Pleuronectidae*	379	1,478	1,858	20.4
Flathead sole	*Hippoglossoides elassodon*	145	562	708	20.5
Shortraker rockfish	*Sebastes borealis*	198	372	571	34.7
Pacific halibut	*Hippoglossus stenolepis*	5,041	9,235	14,276	35.3
Other rockfish	*Sebastes* sp.	487	753	1,240	39.2
Octopus	*Octopoda*	29	27	55	51.7
Deep water flatfish	*Pleuronectidae*	79	17	96	82.4
Big skate	*Beringraja binoculata*	664	122	786	84.5
Longnose skate	*Raja rhina*	1,198	105	1,303	92.0
Skates	*Rajidae*	859	27	886	96.9
Sharks	*Elasmobranchii*	2,091	24	2,114	98.9
Giant grenadier	*Albatrossia pectoralis*	931	0	931	100.0
Sculpins	*Scorpaeniformes*	903	0	903	100.0
Misc. fish sp.	*Teleostomi*	634	0	634	100.0
Squids	*Teuthoidea*	276	0	276	100.0
Smelts	*Osmeridae*	241	0	241	100.0
Grenadier (unident.)	*Macrouridae*	236	0	236	100.0
Sea stars	*Asteroidea*	94	0	94	100.0
Other osmerids	*Osmeridae*	89	0	89	100.0
Chinook salmon	*Oncorhynchus tshawytscha*	53	0	53	100.0
Black/blue/dark rockfish	*Sebastes* sp.	30	0	30	100.0
Pacific herring	*Clupea pallasii*	19	0	19	100.0
Tanner crab	*Chionoecetes bairdi*	19	0	19	100.0
Jellyfish	*Scyphozoa*	15	0	15	100.0
Corals/bryozoans	*Bryozoa*	8.7	0.0	8.7	100.0
Non-Chinook salmon	*Oncorhynchus* sp.	8.3	0.0	8.3	100.0
Snails	*Gastropoda*	6.8	0.0	6.8	100.0
Sea anemones	*Actinaria*	6.3	0.0	6.3	100.0
Greenlings	*Hexagammidae*	4.6	0.0	4.6	100.0
Sponge unidentified	*Porifera*	2.7	0.0	2.7	100.0
Misc. crabs (unident.)	*Decapoda*	2.5	0.0	2.5	100.0
Pricklebacks	*Stichaeidae*	2.0	0.0	2.0	100.0
Urchins/dollars/cucumbers	*Echinodermata*	2.0	0.0	2.0	100.0
Saffron cod	*Eleginus gracilis*	1.8	0.0	1.8	100.0
Eelpouts	*Zoarcidae*	0.9	0.0	0.9	100.0
Golden king crab	*Lithodes aequispina*	0.7	0.0	0.7	100.0
Invertebrates (unident.)	*Invertebrata*	0.4	0.0	0.4	100.0
Pandalid shrimp	*Pandalus* sp.	0.4	0.0	0.4	100.0
Sea pens/sea whips	*Octocoralia*	0.4	0.0	0.4	100.0
Brittle stars	*Ophiurodea*	0.2	0.0	0.2	100.0
Hermit crabs	*Paguroidae*	0.1	0.0	0.1	100.0
Bivalves	*Bivalvia*	0.1	0.0	0.1	100.0
Pacific sand lance	*Ammodytes hexapterus*	0.1	0.0	0.1	100.0
Red king crab	*Paralithodes camtschaticus*	0.1	0.0	0.1	100.0
Tunicates	*Tunicata*	0.1	0.0	0.1	100.0
Pacific sandfish	*Trichodon trichodon*	0.1	0.0	0.1	100.0
Pacific hake	*Merluccius productus*	0.1	0.0	0.1	100.0
Misc. crustaceans (unident.)	*Crustaceamorpha*	0.1	0.0	0.1	100.0
Lanternfishes	*Myctophidae*	0.0	0.0	0.0	100.0
Gunnels	*Pholidae*	0.0	0.0	0.0	100.0
Misc. invertebrates	*Invertebrata*	0.0	0.0	0.0	100.0
Misc. deepwater fish	*Teleostomi*	0.0	0.0	0.0	100.0
Snow crab	*Chionoecetes opilio*	0.0	0.0	0.0	100.0
Total GOA		21,531	189,126	210,658	10.2

Table 3.—Amount (t) and composition of discards in the 2021 BSAI trawl fisheries.

Pollock trawl		Flatfish trawl		Rockfish/mackerel trawl		Pacific cod trawl	
Scyphozoa jellies	7,817	Pollock	11,944	Pacific o. perch	819	Pollock	289
Squid sp.	3,822	Skate sp.	3,037	Atka mackerel	541	Pacific halibut	125
Pacific herring	1,708	Sculpin sp.	2,453	Northern rockfish	451	Skate sp.	102
Pacific cod	1,477	Sea star sp.	2,151	Pollock	440	Other flatfish sp.	89
Chum salmon	1,212	Giant grenadier	1,977	Sculpin sp.	425	Pacific cod	80
Pollock	968	Pacific halibut	1,862	Giant grenadier	407	Rock sole	63
Sablefish	662	Other flatfish sp.	1,374	Skate sp.	348	Atka mackerel	57
Pacific o. perch	652	Alaska plaice	1,281	Sablefish	309	Sculpin sp.	51
Skate sp.	341	Yellowfin sole	1,249	Other rockfish	252	Scyphozoa jellies	51
Shark sp.	300	Sablefish	874	Misc. fish sp.	174	Arrowtooth fl..	44
Other species	802	Other species	4,490	Other species	1,167	Other species	92
Total discard	19,761	Total discard	32,690	Total discard	5,335	Total discard	1,043
Total catch	1,368,493	Total catch	227,565	Total catch	109,891	Total catch	20,303
% Discard	1.4	% Discard	14.4	% Discard	4.9	% Discard	5.1

Table 4.—Amount (t) and composition of discards in the 2021 GOA trawl fisheries.

Pollock trawl		Flatfish trawl		Rockfish trawl		Pacific cod trawl	
Pollock	583	Arrowtooth fl.	700	Arrowtooth fl.	648	Pollock	249
Squid sp.	226	Pacific cod	596	Giant grenadier	388	Arrowtooth fl.	122
Smelt sp.	218	S.W. flatfish sp.	320	Other rockfish sp.	345	Giant grenadier	78
Other osmerid sp.	89	Pacific halibut	308	Pacific cod	309	Pacific halibut	43
Shark sp.	63	Sablefish	285	Pollock	248	Big skate	22
Grenadier sp.	46	Pacific o. perch	253	Pacific o. perch	242	Sculpin sp.	20
Pacific halibut	40	Pollock	241	Pacific halibut	199	S.W. flatfish sp.	17
Chinook salmon	34	Sculpin sp.	152	Sablefish	175	Chinook salmon	12
Misc. fish sp.	22	Flathead sole	85	Misc. fish sp.	169	Pacific cod	11
Pacific o. perch	21	Misc. fish sp.	81	Atka mackerel	89	Misc. fish sp.	10
Other species	43	Other species	342	Other species	408	Other species	28
Total discard	1,386	Total discard	3,361	Total discard	3,220	Total discard	612
Total catch	114,099	Total catch	16,133	Total catch	28,142	Total catch	2,417
% Discard	1.2	% Discard	20.8	% Discard	11.4	% Discard	25.3

the BSAI, and 1.2% in the GOA. The highest bycatch rates among the trawl fisheries were those targeting flatfish, with 14.4% of the catch discarded in the BSAI, and 20.8% in the GOA, and for the trawl fishery targeting Pacific cod in the GOA (25.3%).

Total catch and discards from BSAI and GOA longline and pot fisheries, and the discard amounts of the top ten species or species groups in these fisheries, are shown in Tables 5 and 6. The highest amounts of total discard in the fixed gear fisheries were in the BSAI Pacific cod longline fishery (12,767 t) and the GOA halibut longline fishery (8,711 t). The BSAI and GOA Pacific cod and sablefish pot fisheries had very low amounts of discard, totaling 2,426 t, and low discard rates, ranging from 2.6% to 6.1%. Sculpins and yellowfin sole in the BSAI, and sculpins and Pacific halibut in the GOA comprised the highest weight of bycatch in the Pacific cod pot fisheries. The majority of bycatch in the sablefish pot fisheries consisted of arrowtooth flounder, sablefish, Pacific halibut, and giant grenadier, *Albatrossia pectoralis*. The highest bycatch rates for fixed gear were in the halibut and sablefish longline fisheries, with 55.0%–63.3% of the catch discarded in the BSAI, and 28.5%–48.2% in the GOA. Giant grenadier, shark species (including Pacific spiny dogfish, *Squalus suckleyi*, and Pacific sleeper shark, *Somniosus pacificus*) and sablefish comprise the highest bycatch amount in the sablefish longline fisheries. Pacific halibut, sharks, skates, and Pacific cod comprised the largest bycatch by weight in the halibut longline fishery. The Pacific cod longline fisheries had more intermediate discard rates (15.7%–27.0%) with skates, Pacific halibut, and sculpins accounting for much of the bycatch.

Table 7 shows the total catch and discards from all 2021 halibut and groundfish fisheries the BSAI and GOA. Of the 2,058,806 t of fish (including PSC and non-target species) caught in the BSAI and GOA halibut and groundfish fisheries, 97,083 t (4.7%) were discarded as bycatch. Overall, discard rates were low in the trawl fisheries (3.6%) and pot fisheries (4.4%), and higher in the longline fisheries (23.5%). The rates for trawl and pot fisheries were similar in the BSAI and GOA. Discard rates in the GOA longline fisheries (40.0%) were higher than the BSAI longline fisheries (17.7%), due to differences in scale of the Pacific cod and Pacific halibut fisheries in each area. No bycatch rate estimates were made for other gears (jig and halibut pots) as bycatch information is incomplete for these small fisheries. Data from the jig fishery include catch and discards of groundfish, but do not include PSC or bycatch of other non-target species, which are not estimated for the jig fishery.

Table 5.—Amount (t) and composition of discards in the 2021 BSAI longline and pot fisheries.

Pacific cod longline		Pacific cod pot		Sablefish longline		Sablefish pot		Halibut longline	
Skate sp.	6,557	Sculpin sp.	404	Giant grenadier	226	Arrowtooth fl.	34	Skate sp.	726
Sculpin sp.	2,138	Yellowfin sole	370	Skate sp.	16	Giant grenadier	24	Pacific cod	587
Pacific halibut	1,086	Red king crab	221	Pacific halibut	11	Golden king crab	16	Pacific halibut	333
Pacific cod	897	Octopus sp.	117	Sculpin sp.	1	Pacific halibut	10	Sablefish	236
Pollock	482	Sea star sp.	92	Arrowtooth fl.	1	Sablefish	6	Sculpin sp.	113
Yellowfin sole	358	Snail sp.	51	Sablefish	1	Pacific cod	5	Pollock	34
Flathead sole	241	Sablefish	43	Rougheye rockf.	1	Kamchatka fl.	3	Other rockfish sp.	19
Arrowtooth fl.	203	Pacific cod	36	Other flatfish sp.	1	Misc. crab sp.	2	Sea star sp.	17
Other flatfish sp.	118	Pacific halibut	25	Sea anemone sp.	1	Greenland turbot	2	Giant grenadier	13
Sea star sp.	112	Snow crab	23	Kamchatka fl.	0	Shark sp.	0	Arrowtooth fl.	8
Other species	576	Other species	97	Other species	2	Other species	3	Other species	25
Total discard	12,767	Total discard	1,479	Total discard	260	Total discard	106	Total discard	2,112
Total catch	81,296	Total catch	34,346	Total catch	411	Total catch	1,982	Total catch	3,840
% Discard	15.7	% Discard	4.3	% Discard	63.3	% Discard	5.3	% Discard	55.0

Table 6.—Amount (t) and composition of discards in the 2021 GOA longline and pot fisheries.

Pacific cod longline		Pacific cod pot		Sablefish longline		Sablefish pot		Halibut longline	
Pacific halibut	527	Sculpin sp.	55	Shark sp.	499	Arrowtooth fl.	246	Pacific halibut	3,673
Skate sp.	280	Pacific halibut	45	Giant grenadier	387	Sablefish	186	Shark sp.	1,266
Shark sp.	168	Pacific cod	25	Sablefish	236	Pacific halibut	75	Longnose skate	932
Big skate	141	Tanner crab	15	Grenadier sp.	170	Giant grenadier	64	Sculpin sp.	602
Longnose skate	88	Sea star sp.	15	Longnose skate	134	Rougheye rockf.	11	Skate sp.	473
Sablefish	55	Octopus sp.	13	Pacific halibut	128	Shark sp.	10	Big skate	449
Sculpin sp.	47	Sablefish	9	Shortraker rockf.	112	Grenadier sp.	9	Pacific cod	408
Pacific cod	46	Misc. fish sp.	9	Skate sp.	68	D. W. flatfish sp.	8	Misc. fish sp.	302
Pollock	24	S.W. flatfish sp.	4	Rougheye rockf.	52	S.W. flatfish sp.	6	Sablefish	260
Arrowtooth fl.	24	Other rockfish sp.	3	Arrowtooth fl.	44	Pacific cod	6	Arrowtooth fl.	98
Other species	53	Other species	8	Other species	113	Other species	17	Other species	248
Total discard	1,452	Total discard	204	Total discard	1,943	Total discard	637	Total discard	8,711
Total catch	5,385	Total catch	7,852	Total catch	6,809	Total catch	10,482	Total catch	18,057
% Discard	27.0	% Discard	2.6	% Discard	28.5	% Discard	6.1	% Discard	48.2

Table 7.—Total catch (t) and discard (t) in the 2021 GOA and BSAI halibut and groundfish fisheries.

Area	Gear	Catch (t)	Discard (t)	% Discard
BSAI	Trawl	1,726,252	58,829	3.4%
	Longline	85,547	15,139	17.7%
	Pot	36,328	1,585	4.4%
	Other gears	31	0	n/a
	Total BSAI	1,848,158	75,553	4.1%
GOA	Trawl	160,791	8,579	5.3%
	Longline	30,251	12,106	40.0%
	Pot	18,344	841	4.6%
	Other gears	1,272	4	n/a
	Total GOA	210,658	21,530	10.2%
Total	Trawl	1,887,043	67,408	3.6%
	Longline	115,818	27,245	23.5%
	Pot	54,662	2,426	4.4%
	Other gears	1,303	4	n/a
	Total all areas	2,058,816	97,083	4.7%

Figures 4–6 show the time series of PSC relative to overall PSC limits. Overall, the bycatch of crabs in the BSAI and Pacific halibut in both the BSAI and GOA have been substantially reduced since the early 1990's. In recent years in BSAI fisheries, bycatch of Pacific herring and chum salmon was higher than average, whereas Chinook salmon bycatch was relatively lower. Bycatch of all PSC species has been well below total PSC limits. There was only one recent instance where a PSC amount was exceeded (BSAI Pacific herring PSC in 2020). Chinook salmon bycatch in the GOA has been variable without a clear trend. Note that the increased PSC limit for Chinook salmon in the GOA occurred when new PSC limits were implemented for the non-pollock trawl fisheries in 2015, in addition to the Chinook PSC limits previously implemented for the pollock fisheries.

Discussion

Our results indicate that management of bycatch in the North Pacific halibut and groundfish fisheries has been effective at minimizing bycatch to the extent practicable, as measured by the low bycatch amounts relative to total catch in recent years. In 2021 for example, only 4.7% (97,083 t) of the catch was discarded as bycatch, which was similar to the 2017–2021 average of 4.8% (106,291 t/year). This relatively low bycatch and bycatch rate reflects the rationalization of many fisheries through implementation of catch share systems, as well as changes in regulations, capital investment, ex-

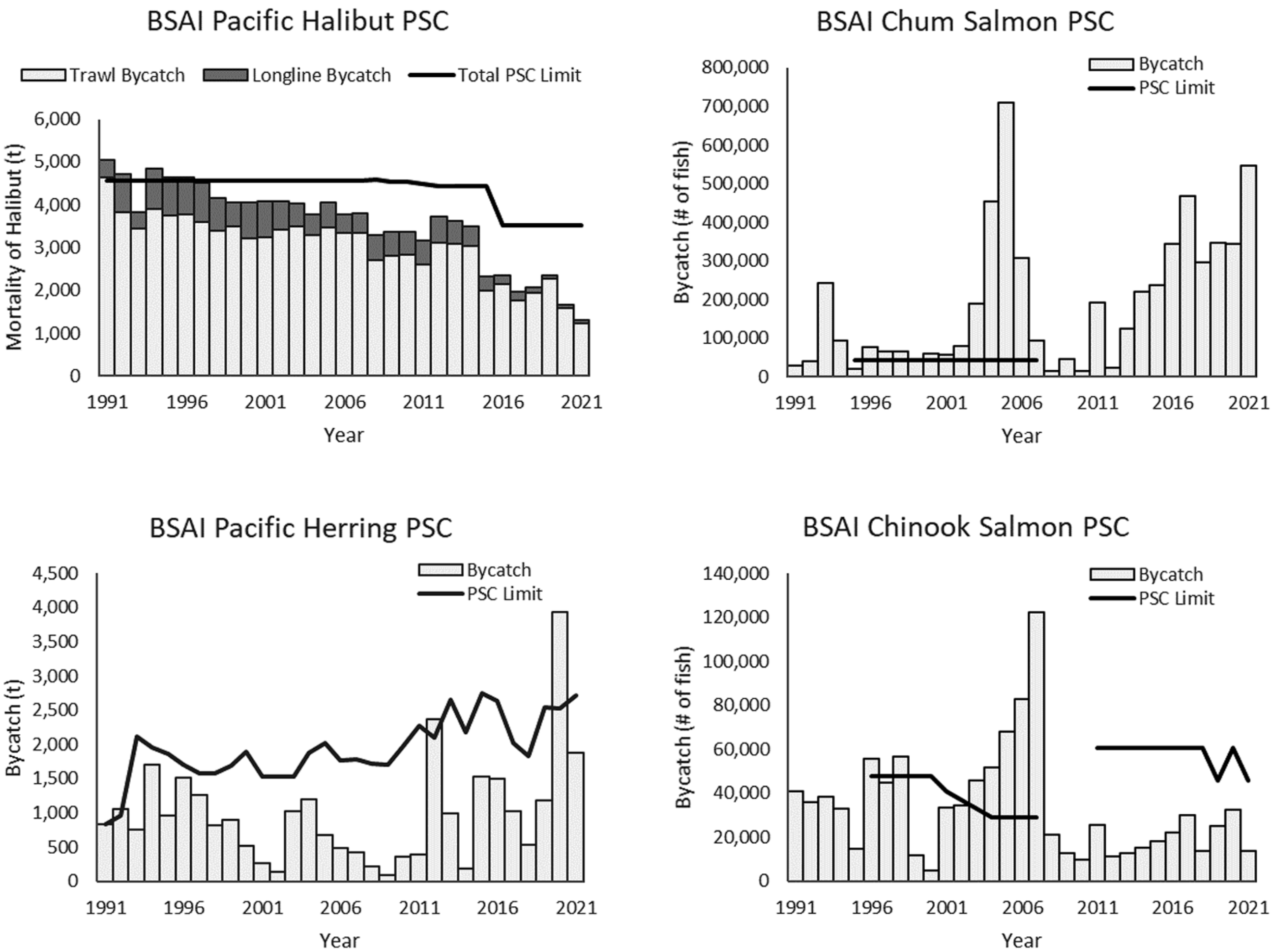

Figure 4.—PSC limits and bycatch of Pacific halibut (t of mortality) by gear type, Pacific herring (t), Chinook salmon (# of fish), and chum salmon in BSAI groundfish fisheries, 1991–2021.

panded markets, and other factors that have changed since the 1990's. Bycatch in BSAI groundfish fisheries during the period 1990–1994 ranged from 198,000 t to 315,000 t annually, with corresponding bycatch rates of 12% to 16%. In the GOA, bycatch ranged from 41,000 t to 61,000 t annually with bycatch rates of 17% to 21% during this time period (Queirolo et al., 1995). By the 1998–2000 period, total bycatch in the BSAI and GOA groundfish fisheries had been reduced to 149,000 t to 151,000 t (8.4%–9.8% of the total catch) (Smoker, 2010). Our results indicate that further reductions in total bycatch and bycatch rates have occurred over the past 20 years.

The current bycatch rate for the North Pacific halibut and groundfish fisheries is among the lowest in the world. Recent global bycatch estimates range from 4.1%–4.5% in the Southeast Pacific and Eastern Indian Ocean to 23%–29% in the western Central Atlantic and Southwest Atlantic (Pérez Roda et al., 2019). Overall, about 10% of the global catch is discarded based on recent estimates (Zeller et al., 2017; Pérez Roda et al., 2019; Gilman et al., 2020). Global bycatch estimates from the 1990's and early 2000's had estimated global bycatch at 35% to 40% of the catch (Alverson et al., 1996; Davies et al., 2009).

Our results show relatively low bycatch rates occur across most North Pacific fisheries gear types. Average global discard rates (including North Pacific bycatch data) were 12% for pelagic otter trawls, 31% for bottom otter trawls, and 24% for bottom longlines (Pérez Roda et al., 2019). For comparison, the 2021 North Pacific discard rates were 1% for pelagic otter trawls (BSAI and GOA pollock trawl fisheries), 11% for bottom trawls (sum of BSAI and GOA flatfish, rockfish, and Pacific cod trawl fisheries), 24% for bottom longlines (sum of BSAI and GOA Pacific cod, sablefish, and halibut longline fisheries), and 4% for pot gear (sum of BSAI and GOA Pacific cod and sablefish pot fisheries). A global comparison with pot gear was not made because global discard rates for pot gear include fisheries for crus-

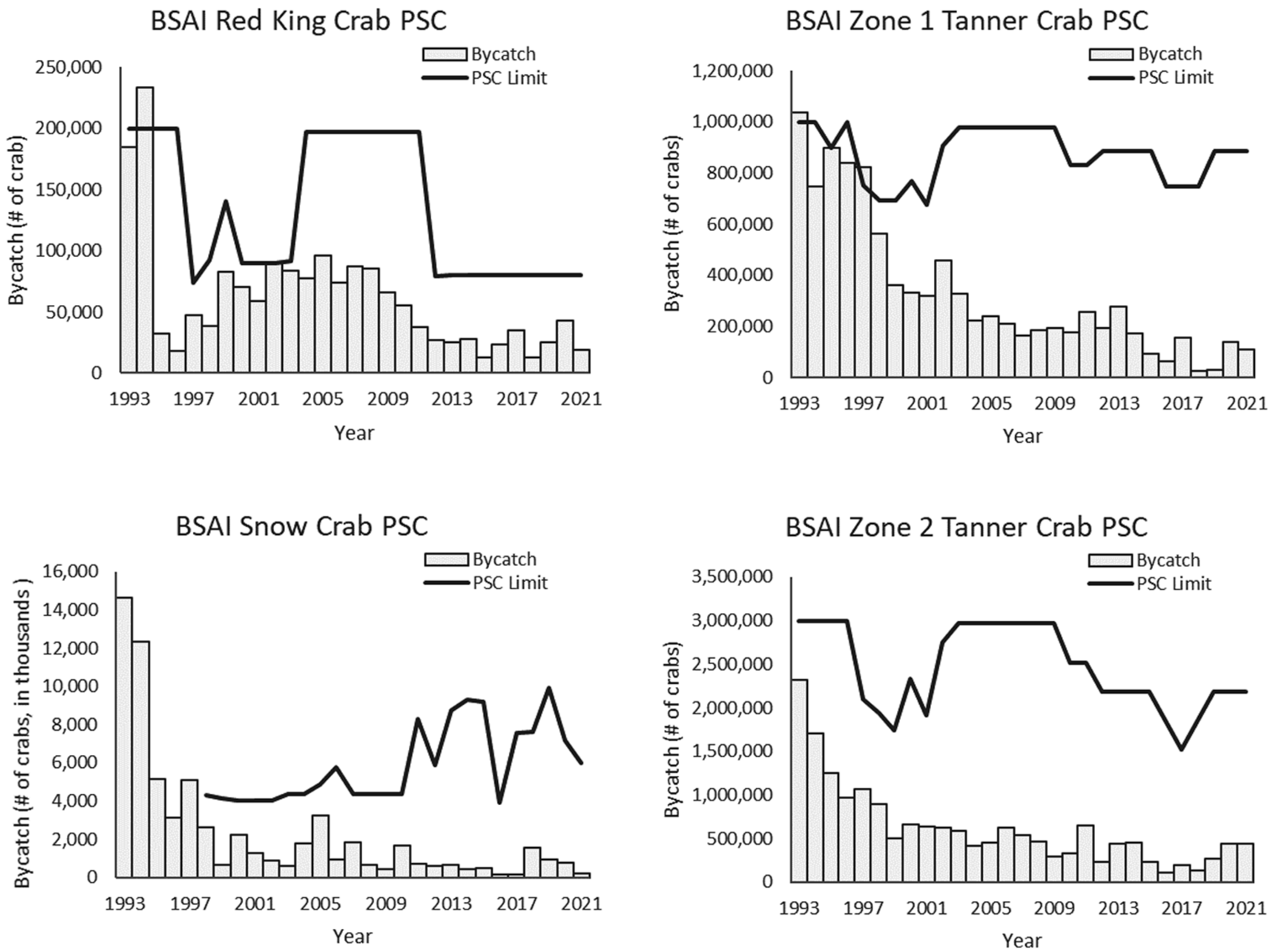

Figure 5.—PSC limits (# of crab) and bycatch (# of crab) of red king crab, snow crab, and Zone 1 (Bering Sea statistical areas 508, 509, 512, and 516) and Zone 2 (Bering Sea statistical areas 513, 517, and 521) Tanner crab in BSAI groundfish fisheries, 1993–2021.

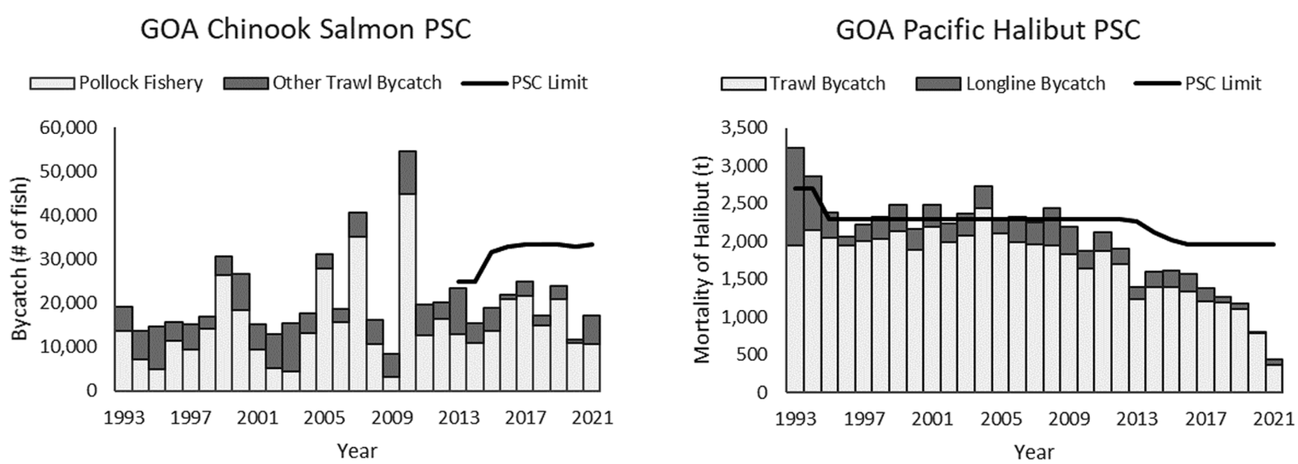

Figure 6.—PSC limits and bycatch of Chinook salmon (# of fish) by trawl target fishery and Pacific halibut (t of mortality) by gear type in GOA groundfish fisheries, 1993–2021.

taceans, which have higher discard rates than demersal fish (Gilman et al., 2020).

The total amount of bycatch, the composition of the bycatch, and the bycatch rate differ greatly among the fisheries and gear type used in those fisheries (Tables 3–6), and this information can be used to focus management efforts on minimizing total bycatch or minimizing bycatch rates. The 2021 Bering Sea pollock trawl fishery had a very low bycatch rate (1.4% discarded), but because it is a high-volume fishery, had a high amount of bycatch (19,761 t), consisting mostly of Scyphozoa jellies (40%), followed by squid (19%) and herring (9%) (Table 3). Although these jellyfish are not marketable, squid can be retained and processed into food or bait, and management could provide additional incentives to retain squid and other species. On the other end of the range, the sablefish longline fisheries and the halibut fishery off Alaska (BSAI and GOA combined) had relatively high bycatch rates (30.5% and 49.4%, respectively) but since these fisheries were lower in volume, had lower total bycatch amounts (2,203 t and 10,823 t, respectively). The rapid conversion of the sablefish fishery from longlines to pots to avoid depredation by sperm whales, *Physeter macrocephalus*, in the GOA and orcas, *Orcinus orca*, in the BSAI, has likely reduced bycatch rates and total bycatch in the sablefish fishery after pot gear was authorized in 2017, based on our data. Our results indicate that the use of pot gear in the sablefish fisheries reduces bycatch of sharks and skates in particular compared to longline gear. Recent authorization for the use of pot gear to target Pacific halibut (also to avoid whale depredation) could result in similar reductions in bycatch should an effective and acceptable pot gear be developed for this species.

Total bycatch of PSC species has been well below the established PSC limits in recent years. The PSC limits for Chinook salmon and Pacific halibut can be very restrictive for trawl fisheries in the GOA and BSAI, and the fleet expends substantial effort and added cost to minimize bycatch, avoid attaining the limits and thus avoid shutting down the fishery (Stram and Ianelli, 2014). As a result, Pacific halibut bycatch in the GOA and BSAI groundfish fisheries is currently about one-third of what it was in the early 1990's (Fig. 4, 6). The original PSC limits for BSAI Chinook salmon (implemented in 1996) and chum salmon (implemented in 1995) were seasonal triggers which closed specified fixed areas despite where salmon were located. These salmon PSC limits failed to constrain total salmon bycatch in the Bering Sea, so they were replaced with caps on Chinook salmon PSC that if reached would close the pollock fishery, a system of inseason closure areas dependent on real-time PSC rates, and other avoidance requirements by industry contract, which proved more successful at minimizing Chinook salmon bycatch.

Bycatch amounts of crab PSC in the BSAI trawl fisheries are a small fraction of what they were in the 1990's due to a number of regulatory and non-regulatory changes, including more modernized trawl fishing gear, a requirement that bottom trawls must use elevated sweeps (Rose et al., 2012), establishment of static closure areas to protect crab (Witherell and Woodby, 2005; Kruse et al., 2010), changes in the abundance of crab stocks, reduced PSC limits, and implementation of catch share cooperatives for trawl fisheries which serve to slow down fishing effort and allow for sector-wide efforts to minimize bycatch. Crab industry representatives have recently requested the Council further reduce PSC limits for crab and take other actions to rebuild depleted BSAI crab stocks. Because crab and other PSC species are mobile and move in response to environmental or other variables, further reduction in PSC for bottom trawl fisheries could potentially be attained with expanded use of dynamic temporary closures based on real-time data, similar to how the BSAI pollock fleet avoids areas of high Chinook salmon bycatch (Pons et al., 2021).

In the North Pacific, conservation concerns regarding bycatch are limited. All Pacific halibut and groundfish caught, whether taken in a target fishery or as bycatch in another fishery, accrue towards the annual catch limits and are also factored into the stock assessment and specification of annual catch limits (Witherell et al., 2000; Stewart and Webster, 2020; Kong et al., 2021). From a biological perspective, so long as bycatch is considered a subset of catch, it makes no difference to the fish population whether the catch is targeted or caught incidentally, or whether the catch is retained or discarded (Tagart, 2004). Additionally, all discards in the groundfish fishery are assumed dead for accounting purposes, even though some proportion of fish and invertebrates discarded survive capture and release from commercial fishing gears (Benoit, 2013; Conners and Levine, 2016) with survival rates depending on environmental and other factors (Davis, 2002). Bycatch of non-target species, which are not managed with annual catch limits but which have the potential to be impacted by the halibut and groundfish fisheries, is also monitored to the extent data are available. Some non-target species commonly taken as bycatch such as grenadier, sculpins, and forage fish, are assessed regularly to ensure that stocks are not being overfished (Reuter et al., 2010; Rodgveller and Siwicke, 2020, Ormseth and Yasumiishi, 2021). Other ecosystem components, including bycatch species, are monitored to the extent data are available and reported annually in ecosystem status reports (Ferriss and Zador, 2021; Ortiz and Zador, 2021; Sidden, 2021). Clearly, bycatch can be a major conservation issue in regions where bycatch is uncontrolled, unquantified, unassessed, or not included in the total removals prior to setting an annual catch limit (Harrington et al., 2005; Komoroske and Lewison, 2015), but that is not the case for federally managed fisheries in the North Pacific.

There are social and conservation concerns with the bycatch of Chinook salmon and chum salmon off Alaska. Scientific data indicate that Chinook salmon and chum salmon population trends in this region are driven by environmental factors such as marine heatwaves and the prey quantity and quality that occur in the first few months after outmigration of smolts (Howard et al., 2019; Murphy et al., 2021). Nevertheless, salmon bycatch has been a particularly challenging issue for the Council given the economic and cultural importance and subsistence value of these species to Alaska Natives and people living in remote areas of the State of Alaska.

Social concerns are heightened when subsistence salmon fisheries managed by the State of Alaska are limited or prohibited. For example, closures of subsistence salmon fishing in the Yukon River and Kuskokwim River regions in coastal western Alaska in 2021 and 2022 has put an intense focus on the bycatch of salmon in groundfish fisheries. In 2021, a total of 15,827 Chinook salmon and 535,282 chum salmon were taken as bycatch in Bering Sea groundfish fisheries, most of which were in the pollock fishery. Because Chinook salmon and chum salmon from other countries in the Pacific region intermingle in the ocean and are caught as bycatch, NMFS annually conducts extensive and statistically reliable genetic sampling of salmon taken as bycatch in the pollock trawl fisheries so that the impacts of bycatch on spawning stocks in different regions can be estimated (Ianelli and Stram, 2014; Faunce, 2015). Genetic analysis of salmon taken in the 2020 Bering Sea pollock fishery showed that about 52% of the Chinook salmon bycatch was estimated to have originated from coastal western Alaska and about 9% of the chum salmon caught as bycatch originated from coastal western Alaska (Guthrie et al., 2022; Barry et al., 2022). Overall, since 2011, Chinook salmon bycatch has reduced the runs by an average of 1.9% for the aggregate coastal western Alaska stocks and 0.6% for the Upper Yukon River stock (NMFS et al., 2022). Chum salmon bycatch is roughly estimated to have affected aggregate western Alaska stocks by about 1.1%; the average impact rate (2004 through 2011) for coastal western Alaska was 0.46% and 1.16% impact rate on the Upper Yukon fall chum salmon run (NPFMC, 2012). Although these impacts appear to be small, conservation concerns about western Alaska salmon stocks and lack of subsistence harvest opportunities have prompted the Council to continue evaluating ways to further minimize bycatch of salmon consistent with the MSA.

Regulatory discards are difficult to address but could be a focus for future management action. In the North Pacific, regulatory discards typically result from prohibitions on retaining PSC, discarding any amount of fish of a species closed for directed fishing that exceeds the MRA specified for that species in that fishery, or mandatory discarding of a target species if the total allowable catch (TAC) limit is reached to eliminate incentives to catch the species. Development of an alternative tool to MRA's, such as implementation of procedures by cooperatives, could reduce the need for MRA's in these catch share fisheries. Further reductions in regulatory discards could result with implementation of fully rationalized trawl fisheries in the GOA whereby all TAC is allocated and can be redistributed among participants during the season. While there are no regulatory discards of groundfish due to size limits, the minimum size limit for Pacific halibut creates regulatory discards in the halibut IFQ fishery, which results in halibut being the prominent discarded species in that fishery in the GOA (Table 6). Eliminating the size limit could reduce bycatch, but this action may have impacts on long term yield of the halibut fishery (Martell et al., 2015; Stewart et al., 2020).

Regulatory discards could be reduced by authorizing the retention of PSC species, particularly for those fish that are dead or likely to die if discarded. Current regulations do authorize some voluntary retention of salmon and halibut taken as bycatch, but only for donation to hunger relief organizations. Although not all the halibut and salmon PSC are retained for donation, the non-profit organization SeaShare has worked with the Alaska seafood industry to distribute 2,660 t of donated salmon and halibut to foodbanks throughout the U.S. (Watson et al., 2020). Discards could be further reduced if regulations allowed the retention of all salmon, Pacific halibut, and Pacific herring, in the groundfish fisheries. While potentially challenging from a policy perspective, allowing for the sale of these species would provide some incentive to retain and process the incidental catch. Increasing retention of bycaught crabs; however, would be more difficult for most vessels participating in the groundfish fisheries, in that vessels would need circulating seawater tanks onboard to keep the crabs alive until processing.

Economic discards can be further reduced or even eliminated by development of new regulations. Several different management tools have been used to minimize economic discards in North Pacific groundfish fisheries. Economic discards have been reduced by establishing catch share programs that allocate the TAC—minus the amount allocated to other fisheries or needed to cover incidental catch in other fisheries (the incidental catch allowance) where applicable—to individual permit holders as IFQ (sablefish and halibut fisheries), to community development quota entities, or to cooperatives (the BSAI pollock cooperatives, bottom trawl catcher/processor cooperatives, GOA rockfish program cooperatives, and a pending program for trawl catcher vessels targeting Pacific cod). These catch share-based programs eliminated the race for fish, allowing operators to be more selective in the size and species of fish being targeted and retained, resulting in lower bycatch (Fina, 2011; Grimm et al., 2012; NPFMC, 2014b, 2017). For example, implementation of the cooperative catch share program for the BSAI bottom trawl catcher/processor fleet reduced discards from about 22% to less than 10% (NPFMC, 2014b). Implementation of catch share programs in unrationalized fisheries could further reduce discarding. Another way to eliminate economic discards is to simply require that all fish are retained. This has been the goal for the European Union as an approach to eliminate waste of edible protein (Karp et al., 2019). In the North Pacific, 50 CFR 679.27 regulations require that all walleye pollock, Pacific cod, and GOA shallow water flatfish caught be retained unless otherwise regulated (e.g., retention only up to MRA allowance, or if the species is on PSC status) or dead or decomposing fish previously caught and discarded and thus unfit for human consumption. Although bycatch is just one component of the waste of edible seafood in the U.S., waste reduction is needed for food security with a growing global population living under the stress of climate change (Love et al., 2015). In the North Pacific, the waste of fish from bycatch (97,083 t in 2021) is considerably less than the amount of groundfish quota that goes unharvested (422,791 t in 2021) due to PSC limits and other regulatory impediments, and economic factors, as well as the amount of walleye pollock that remains unharvested in some years due to the 2 million t OY limit in the BSAI.

In taking any action to minimize bycatch, the Council must make policy decisions relative to balancing trade-offs between National Standard 1 (achieve Optimum Yield) and other National Standards, including National Standard 9 (minimize bycatch to the extent practicable). To date, these decisions balancing National Standards have considered the ability of the fleet to catch the TAC and achieve OY while minimizing bycatch to the extent practicable, taking into account the biological and/or socio-economic impacts of any bycatch. The Council must decide at what level bycatch has been practically minimized to meet the requirements of the MSA.

Recent legislation introduced in the 117th Congress proposed to revise MSA National Standard 9 by eliminating the words "to the extent practicable" (Huffman, 2021). The word "practicable" includes consideration of social and economic tradeoffs in deciding how much additional regulatory burden and cost the fishery should bear to minimize bycatch or further reduce the amount of bycatch in the fishery while achieving OY. Without the phrase "to the extent practicable," the Council could be under pressure to minimize bycatch regardless of the net costs to the nation in terms of food security, economic activity, fishing community health, or jobs. Eliminating the phrase "to the extent practicable" could also increase litigation risk for actions taken to minimize bycatch, given it is impossible to completely eliminate bycatch unless all catch is required to be retained (Tagart, 2004).

Climate change is affecting stock size, composition, productivity, and distribution of groundfish in the North Pacific (Mueter et al., 2021; Hollowed et al., 2022), which will impact the amount and composition of bycatch in future years. Some fish populations (e.g., pollock, Pacific cod) and crab populations are expanding into the northern Bering Sea and the high Arctic in response to warmer water on the Bering Sea shelf and loss of sea ice and a reduced cold pool. These environmental conditions are further projected to substantially reduce the pollock and Pacific cod stocks over the long term (Holsman et al., 2020) and are having significant effects on current crab stocks. Environmental monitoring and modeling revealed that marine heatwaves in the GOA during 2014–16 drastically reduced the forage base available and increased metabolism of Pacific cod, resulting in a drastic reduction in stock size and recruitment (Barbeaux et al., 2020). These same conditions appear to have been favorable for sablefish, with historically large year-classes of sablefish produced during 2016–18 period (Goethel et al., 2021). The abundance of these large year-classes has resulted in substantially higher trawl discards of sablefish, which raises management and allocation issues. Additional marine heatwaves appear likely to be more common, and future changes in ocean conditions in the North Pacific will impact the magnitude and species composition of catch and discards in ways that are difficult to predict. Fishery managers must develop climate resilient fishery management plans and regulations using ecosystem-based approaches to take into account this uncertainty. As noted by Holsman et al. (2020), the current ecosystem-based management approach used in the North Pacific can ameliorate climate change impacts on fisheries in the near-term, but the long-term benefits of this approach are limited by the magnitude of anticipated change. Revised management approaches, including those taken to minimize bycatch to the extent practicable, will be required.

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