Report to the North Pacific Fishery Management Council on the status of Pacific halibut in the Bering Sea and Aleutian Islands and the impacts of Prohibited Species Catch

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Abstract

The North Pacific Fishery Management Council (NPFMC) requested that the International Pacific halibut Commission (IPHC) provide a summary of: 1) the status of the Pacific halibut (*Hippoglossus stenolepis*) resource in the Bering Sea and Aleutian Islands (BSAI), and 2) the impact of Prohibited Species Catch (PSC, or bycatch) on halibut stock biomass, reproductive potential, and the short- and long-term yields to the directed halibut fisheries. This report summarizes a variety of analyses conducted by IPHC staff, including previous yield calculations, stock assessments, apportionment, and survey summaries, as well as new and ongoing research on tag-recoveries, abundance trends, and harvest policy.

Measures of current stock size reflecting the portion of the halibut stock available to the directed fisheries in the BSAI region (fishery and survey Weight-Per-Unit-Effort, WPUE) indicate substantial declines from biomass levels observed in the late 1990s. This is consistent with trends observed in other regulatory areas and estimated for the entire stock. The coastwide dynamics and trends for juvenile halibut, prior to their recruitment into the directed fisheries at 8-10 years old, are largely unknown. However, results of tagging of these juveniles, previously unanalyzed, indicate broad mixing from BSAI areas to the Gulf of Alaska and Area 2. Juvenile data observed in the National Marine Fisheries Service (NMFS) Bering Sea Trawl survey, particularly from 2006 to present, are investigated as to their abundance, spatial distribution and potential future contribution to the directed fisheries. Cohorts born in 2004-2006 and observed in large numbers in the trawl survey data appear to have declined rapidly in abundance in the Bering Sea, and are not evident in either the fishery WPUE, setline survey WPUE (including sublegal fish), or NMFS Gulf of Alaska (GOA) Trawl surveys. Based on historical tagging of juvenile halibut, cohorts of these ages would likely have dispersed throughout the range of the stock. It is possible that, unlike the 1987 cohort (also quite apparent in the Bering Sea trawl survey data), recent cohorts in the Bering Sea have either experienced higher mortality rates or do not represent large cohorts on the scale of the entire stock. There is uncertainty in setline survey indices in the Bering Sea due to incomplete geographic coverage in this region. Current estimates reflect calibrations with trawl data that will likely be informed through survey expansions over the next several years.

Current (2013) halibut bycatch in the BSAI is estimated to be 5.2 million pounds (net weight), representing 66% of the coastwide total from all non-target fisheries. By IPHC regulatory area, bycatch represents 89% (4A), 37% (4B) and 205% (4CDE) of the directed fishery landings. Much of this bycatch is comprised of halibut less than 26 inches in length (U26): 43% (4A), 29% (4B), and 39% (4CDE), with 22% being the average percent U26 in the most recent five years across the entire coast. Current IPHC catch limits only account for the removals of halibut over 26 inches in length (O26). This procedure sets directed Fishery Constant Exploitation Yield (FCEY) limits for each regulatory area based on apportioned

biomass estimates derived from survey catch rates, and application of fixed harvest rates (21.5% in Areas 2A-3A and 16.125% in Areas 3B-4CDE) to those estimates. Changes in O26 bycatch therefore result in equivalent changes to directed fishery yields, i.e., a 1000 pound reduction in O26 bycatch results in a 1000 pound increase in directed fishery yield. The fixed harvest rates reflect consideration of the impact of U26 removals on available yield, as a background mortality, and are lower than they would be if the U26 removals were lower or nonexistent. However, there is currently no mechanism to respond to changes in the magnitude of U26 mortality, or the ratio of U26 to O26 removals. In Area 4CDE, based on 2013 estimates, application of the harvest policy would result in no directed fishery yield if: 1) the estimated O26 bycatch were to increase by at least 30%, 2) the apportioned exploitable biomass were to decrease by the same amount, or 3) any combination of these two adding up to at least 30%. Regulatory-area specific results of application of the harvest policy under a range of increases and decreases in both coastwide and BSAI-only bycatch are presented.

The current harvest policy, consistent with the Blue Line apportionment and decision table results in 2013 has an implied total fishing intensity target which can be measured via the Spawning Potential Ratio (SPR), the relative spawning biomass per recruit under equilibrium at the current level of fishing mortality from all sources, compared to an unfished level. Because this metric includes all sources and sizes of mortality, it can be used to directly compare fishery yield associated with U26 bycatch. When FCEYs are adjusted to maintain the same SPR target, changes in bycatch result in changes to directed fishery yields that are greater than just the change in O26 mortality, because the effects of the U26 removals are also included. Results are consistent with previous analyses finding approximately a 1:1 relationship in total lost yield due to all sizes of bycatch. When translated into the current coastwide decision-making framework, there is relatively little change in risk associated with changes in bycatch (+/- 20%), and among methods of accounting for that bycatch, over the next three years. However, effects on area-specific FCEYs are pronounced: up to a 144% change in the Area 4CDE FCEY over the same set of analyses.

Introduction

The North Pacific Fishery Management Council (NPFMC or Council), at its February 2014 meeting, requested that the International Pacific halibut Commission (IPHC) provide a summary of:

> 1) The status of the Pacific halibut (*Hippoglossus stenolepis*) resource in the Bering Sea and Aleutian Islands (BSAI), and
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> 2) The impact of Prohibited Species Catch (PSC, or bycatch) in the BSAI trawl and fixed gear groundfish fisheries on halibut stock biomass, reproductive potential, and the short- and long-term yields to the directed halibut fisheries.

The report was requested for NPFMC consideration at the June, 2014 meeting in Nome, Alaska.

The request follows considerable focused discussion of similar topics during the IPHC's annual meeting: Bering Sea stock status, trends, and uncertainty, IPHC setline survey coverage and proposed expansions, commercial catch rate calculations, information about recruitment occurring in recent years and not yet present in directed fishery catches, the role of bycatch in coastwide and area-specific stock management, accounting and management of all sources of mortality including halibut less than 26 inches in length (U26) and greater than 26 inches in length (O26). In response to these discussions, the IPHC has continued investigation of alternative survey expansion plans in the next 5 years. Additionally, the IPHC's Commissioners requested that the staff prepare a discussion paper on the biological and management issues surrounding the accounting and management of all sizes of halibut removals in order to inform future discussions on this topic. This paper will be presented to the Commissioners in a preliminary form in September, 2014, with a final version included in the Interim and Annual Meeting materials for the 2015 process. Due to its direct relevance to the NPFMCs request, some ongoing analyses are included here; however, the final material available later in 2014 will also be of distinct importance for Council consideration.

The IPHC's Halibut Bycatch Working Group, is also nearing completion of a summary report, with a final report expected by mid-summer, 2014. This report describes the magnitude and impacts of bycatch on the stock and fisheries in each regulatory area. It explores options for reducing the overall level of halibut bycatch in groundfish fisheries, and for mitigating the impacts of bycatch in one area on the available harvest in other areas.

In the context of all ongoing research into stock trends and bycatch-related issues, this document attempts to summarize, in broad terms: available information for the BSAI, a variety of historical analyses conducted by IPHC staff, including previous yield calculations, stock assessments, apportionment and survey summaries, as well as new and ongoing research on tag-recoveries, abundance trends, and harvest policy. Major sources of uncertainty relating to various components of these analyses are discussed, and potential data improvements that could reduce this uncertainty are identified.

General background on halibut bycatch

Pacific halibut are caught in many fisheries other than the directed commercial, personal use, and sport fisheries. Regulations of the IPHC prohibit United States fishermen from retaining halibut captured with gear other than hook and line. IPHC and Canadian regulations allow fishers licensed to catch sablefish in waters off British Columbia, using sablefish trap gear, to retain halibut under the quota share program up to bycatch limits as defined by Canadian regulations. The allowance of sablefish trap gear is part of an integrated groundfish fishery plan where all species are under individual quota shares and fishers are responsible for the mortality of all species, retained and discarded. Regulations in both countries are designed to prevent fisheries other than the directed halibut fishery from targeting fishing effort toward halibut. However, halibut are often caught incidentally in other fisheries, and released fish may not survive injuries received during capture. Thus, the incidental catch represents a source of mortality, and resulting yield losses to the directed fishery may be substantial.

The IPHC relies largely on information collected by other agencies as the source of bycatch amounts. The most reliable information on incidental catch is from observer programs. However, observer programs are expensive to implement in a comprehensive manner. Observations on bycatch in BSAI fisheries are among the more extensive for fisheries in Alaska, but those in the Gulf of Alaska (GOA), although improving, are among the least extensive.

Total halibut removals ranged from 64 to 85 million pounds net weight (Mlb; note that the IPHC uses net weight for all calculations, this dressed, head-off weight is approximately 75% of the round weight reported in observer and other National Marine Fisheries Service (NMFS) data sources) during the 1960s, with incidental mortality estimated to have ranged from a high of 21 Mlb in 1965 decreasing to a low of 15 Mlb in 1969. Total removals subsequently declined, primarily due to the reduced quotas allowed by IPHC, which was in response to a decline in the abundance of halibut. However, incidental mortality remained high due to a lack of regulation and became an increasingly larger share of the total removals through the 1970s.

Halibut abundance stabilized during the mid-1970s and total removals from the resource ranged from 34 to 43 Mlb during 1974 to 1982. Incidental mortality declined to a low of 12 Mlb, but increased to 19 Mlb in 1980, partly as a result of increased foreign fishing effort. Incidental mortality declined as foreign fisheries operating off Alaska were curtailed and were eliminated in the GOA in 1986. However, joint-venture fishing began in the late 1970s and expanded sharply in the early 1980s, as foreign fisheries were phased out. The joint-venture and subsequent totally domestic fisheries were not initially subject to the same bycatch restrictions as the foreign fisheries and bycatch mortality increased, peaking at 20 Mlb coastwide, and over 10 Mlb in the BSAI region in the early 1990s.

Initial restrictions on bycatch mortality in the BSAI region were implemented under the auspices of the International North Pacific Fisheries Commission (INPFC) or bilateral arrangements between the U.S. and foreign fishing nations. The IPHC Bering Sea Closed Area was created by the Commission in 1967 to protect a nursery area for juvenile halibut, in response to severe declines in halibut abundance. The current Closed Area is slightly smaller than the original definition due to reductions that occurred when Areas 4C and 4E were created. The Closed Area had historically accounted for a relatively small percentage (<10%) of the directed halibut landings in the Bering Sea but was a source of significant halibut mortality from foreign vessel bottom trawling. The Commission recommended the closure to both directed halibut fishing, which was under Commission jurisdiction, and to bottom trawling, which was not under Commission jurisdiction. However, through negotiations within the INPFC and bilateral agreements with foreign governments, the Closed Area was also closed to foreign bottom trawling. Throughout the late 1960s until the early 1970s, the Closed Area provided significant protection for juvenile halibut, with bycatch mortality dropping to an estimated low of 4.2 Mlb in 1985. Coincidentally, halibut abundance improved dramatically, fuelled in part by strong year classes of the mid-1970s.

As Americanization of the Bering Sea trawl fisheries occurred in the early 1980s, following promulgation of the U.S. Extended Economic Zone, the protection to juvenile halibut afforded by the Closed Area diminished as domestic fisheries were not excluded. The NPFMC implemented control measures for bycatch mortality by instituting gear and fishery-specific limits and closures within the BSAI including the Closed Area, throughout the 1980s. However, mortality on halibut in the BSAI again increased substantially in the 1985-1991 period, reaching a peak of 10.7 Mlb in 1992. Bottom trawling within the Closed Area currently accounts for a significant proportion of the halibut mortality in the Bering Sea, and remains open to all fishing except directed halibut longline fishing.

A history of bycatch management in the BSAI region is included in the 1992 report of the joint U.S.-Canadian Halibut Bycatch Work Ground (Salveson et al. 1992). More recent history and management actions on halibut bycatch mortality are included in an update of that report by Karim et al. (2012). The following summary of bycatch management is largely extracted from the latter report.

As domestic groundfish fisheries developed and foreign fishing was phased out in the 1980s, federal regulations were implemented to limit bycatch of halibut so as to minimize impacts on the domestic halibut fisheries. Interception of juvenile halibut often occurs in trawl fisheries targeting other groundfish species such as rock sole, pollock, yellowfin sole, and Pacific cod. Incidental catch of halibut also occurs in groundfish hook and line and pot fisheries. Incidental 032 halibut within the longline sablefish fisheries can be retained if halibut quota share is held. In other groundfish hook and line or pot fisheries, regulations require that all halibut caught incidentally must be discarded, regardless of whether the fish is living or dead.

Regulations to control halibut bycatch in domestic groundfish fisheries were implemented initially as part of the BSAI groundfish Fisheries Management Plan (FMP) in 1982. These regulations reflected some of the time-area closures in effect for foreign trawl operations. Beginning in 1985, annual halibut PSC limits were implemented for the groundfish trawl fisheries, attainment of which triggered closures to bottom trawl gear. Seasonal allocations of halibut PSC limits also are authorized.

Other measures that have reduced halibut bycatch include seasonal and area allocations of groundfish quotas for selected target species, seasonal and year round area closures, gear restrictions, careful release requirements, public reporting of individual bycatch rates, and gear modifications. While the groundfish FMP's allow the NPFMC to set the season start dates to accommodate fishery interests, it has relied on the seasonal apportionments of halibut PSC limits to take advantage of seasonal differences in halibut and some groundfish fishery species distributions. Gear restrictions are specified to reduce bycatch or bycatch mortality of halibut. Restrictions include (a) requiring biodegradable panels on groundfish pots, (b) requiring halibut exclusion devices on groundfish pots, and (c) revised specifications for pelagic trawl gear that constrain the pelagic trawl fisheries for groundfish to a trawl gear configuration designed to enhance escapement of halibut.

PSC limits have been used to control the bycatch of halibut in the groundfish fisheries off Alaska since the initial groundfish FMPs were developed. PSC limits are intended to optimize total groundfish harvest, taking into consideration the anticipated amounts of incidental halibut catch in each directed fishery. They are apportioned by target fishery, gear type, and season. Essentially, these bycatch limits provide an incentive for specific fisheries to operate in times and areas where the highest volume or highest value target species may be harvested with minimal halibut bycatch. Directed fishing must stop when seasonal PSC limits are reached; all other fisheries remain unaffected. Reaching a PSC limit results in closure of an area or a groundfish directed fishery, even if some of the groundfish (particularly flatfish) total allowable catch (TAC) for that fishery remains unharvested.

The BSAI halibut PSC limit is set in regulation and the GOA halibut PSC limit is set annually through the groundfish harvest specifications process; neither is tied to halibut abundance. Federal regulations also establish allocations of the BSAI halibut PSC limit between the community development quota (CDQ) and non-CDQ fisheries and a process for apportioning those limits among non-CDQ fisheries.

Halibut PSC limits in the BSAI are set in regulations at 4,526 metric tons round weight (mt). The total is allocated: a) 3,626 mt (6 Mlb net wt.) to trawl gear, and 900 mt (1.5 Mlb) to fixed gear. The Bering Sea trawl halibut PSC limit was reduced by 100 mt (0.165 Mlb) in 1999 when the NPFMC adopted a requirement that only pelagic trawls can be used in the BSAI pollock fishery. While the total has not been reduced, allocations to the trawl sector were reduced to 3,475 mt (0.3 Mlb) by 2012. The most significant recent Council action regarding halibut bycatch management was the adoption of Amendment 80, which allocated specified target species and PSC catch limits to non-AFA catcher trawl processors and facilitated the formation of fishery cooperatives.

Groundfish pot gear is exempted from halibut bycatch restrictions because the discard mortality rate and total mortality associated with this gear type is estimated to be relatively low, and existing pot gear restrictions are intended to further reduce halibut bycatch mortality. The IPHC does make estimates of this source of mortality, which are included in all analyses.

Halibut fishery management in the BSAI

Each year the IPHC sets directed fishery catch limits (FCEYs) for each of eight major Regulatory Areas: 2A, 2B, 2C, 3A, 3B, 4A, 4B, and 4CDE (Fig. 1). Halibut in the eastern Bering Sea, Area 4CDE (including the Closed Area), are considered to be a single unit in all IPHC apportionment and harvest policy analyses.

However, management subareas 4C, 4D, and 4E were created to serve the needs of the NPFMC's Catch Sharing Plan (CSP). Annually, the Commission adopts the Council's CSP to determine the specific catch limits for these subareas. The percentage share to these areas, as determined by the Council, are: Areas 4C and 4D each receive 46.43% of the Commission's adopted catch limit for Area 4CDE, and Area 4E receives 7.14%. If the total catch limit for Area 4CDE exceeds 1.6576 Mlb, Area 4E receives 0.08 Mlb off the top of the total catch limit before the percentages are applied. Within Area 4CDE, the annual available halibut yield is further allocated among CDQ and IFQ fishing within subareas. The amounts allocated to CDQ by area are: Area 4C 50%, Area 4D 30% and Area 4E 100%. There are also provisions within the CSP allowing Area 4C CDQ and IFQ to be harvested in Area 4D, and for allowing Area 4D CDQ fish to be harvested in Area 4E. Allocations among CDQ organizations in IPHC Area 4CDE are provided in Table 1. All of these allocations are outside of the Commission's jurisdiction and are governed by U.S. domestic agencies.

Commercial halibut fishery removals are delineated within Area 4 beginning in 1981 (Stewart 2014). From 1981-1984 the fishery in Area 4CDE removed from 0.3 to 1.0 Mlb (Table 2). Fisheries in Areas 4A and 4B were of a similar magnitude during this period, and all three grew rapidly as the stock increased through the 1990s (Stewart and Martell 2014), peaking at 5.2 (4A), 4.5 (4B), and 4.0 Mlb (4CDE) in 2000-2001. Directed fisheries in the BSAI, as in all other regulatory areas, have since dropped to 2013 values of 1.2 (4A and 4B) and 1.8 Mlb (4CDE). These reductions are roughly consistent with proportional declines in fishery and survey catch rates (Table 3**,** Figs. 2, 3). Bycatch mortality (and therefore total mortality) has also declined, but not in proportion to directed fishery removals (Table 1). Bycatch mortality in 2013 is estimated to be 1.10 (4A), 0.46 (4B) and 3.65 (4CDE) Mlb, which represents a majority of the coastwide mortality from non-target fisheries (Fig. 4). The proportion of this bycatch that is estimated to be comprised of U26 halibut in 4A and 4CDE has been the highest among all regulatory areas over the last five years (Fig. 5); in 4CDE this corresponds to estimates of 2.23 Mlb of O26 halibut and 1.42 Mlb of U26 halibut mortality in 2013. Recreational removals, personal use, and fishery wastage are relatively minor in BSAI areas, contributing only 0.03, 0.04 and 0.17 Mlb of removals, respectively, in 2013 (Webster and Stewart 2014).

The final adopted catch limits for 2014 resulted in FCEYs of 0.85 (4A), 1.14 (4B), and 1.29 Mlb (4CDE). These limits correspond to estimated harvest rates (based on apportionment of the coastwide exploitable biomass; Webster and Stewart 2014) of 16.125% in 4A, 20.7% in 4B, and 19.8% in 4CDE; the latter two are in excess of the current harvest policy targets (the Blue Line) for those areas (16.125%).

Status of the resources in the BSAI

There are several sources of information regarding the status, including both abundance and trend, of the Pacific halibut resource in the BSAI. Primary data sources include: catch rates reported in directed fishery logbooks, IPHC setline survey catch rates, and catch rates observed in NMFS bottom trawl surveys. Sources differ in the demographic segment of the population encountered, the geographic extent of the data, and the temporal extent over which the data are derived, both in terms of which years are available and which portions of the year are represented.

Fishery and IPHC survey abundance indices

Fishery Weight-Per-Unit-Effort (WPUE; pounds of halibut landed per standardized skate fished, lb/skate) is summarized each year from directed fishery logbook records (Stewart 2014). For the BSAI, this index includes all sets made using fixed-hook longline gear that were reported in the logbooks as specifically targeting halibut only. Effort is standardized to correct for differences in hook-spacing (Stewart 2014), and catch includes only those fish that were subsequently landed; i.e., it does not include halibut below the 32 inch legal size limit. This index of abundance represents an average of what is observed annually on the fishing grounds during the fishing season from March to November in recent years. Fishery WPUE has declined substantially across all BSAI areas from the late 1990s (after the 1995 implementation of the quota program in Alaska). In Area 4A, this decline represents a drop from catch rates of around 500 lb/skate to catch rates of 164-194 lb/skate in the last few years (Table 3, Fig. 2). In Area 4B, the decline has been from catch rates around 300 lb/skate, to catch rates of 122-165 lb/skate, and in 4C and 4D, roughly 300 and 600 to 55-88 and 151-188 lb/skate, respectively. It is clear from these data that fishery observations in the BSAI are consistent with the estimated declines in the coastwide stock, and that current catch rates are far lower than they have been in the last 20 years. In response to recent questions regarding the representativeness of these records to the fishery landings as a whole, the IPHC is conducting ongoing research into the standardization methods applied to fishery logbook records, spatial trends in the fishery over time and among gear types, as well as trends observed among all gear types. This work is planned for completion and presentation during the 2015 process; however preliminary analyses indicate that trends using all gears are very similar to currently used indices.

The IPHC conducts an annual setline survey across nearly the entire geographic range of the halibut stock, using a fixed-station design on a 10 nautical mile grid (Henry et al. 2014). Similar survey sampling has been conducted in specific geographic areas since as early as the 1960s, but comprehensive sampling began in 1997 and little change in the specific design has occurred since 1998 (Soderlund et al. 2012). The estimate of setline survey WPUE for Areas 4CDE can be divided into several geographic components, each differing in available data and temporal extent of observations (Webster 2014). These include survey stations along the Area 4D 'edge', covering depths of 75-275 fathoms which have been sampled annually since 1997, and survey stations around St. Matthew and the Pribilof Islands which have been sampled annually since 2006. The southern portion of the Bering Sea 'flats' was surveyed in 2006 using a design that paired two setline stations with NMFS bottom trawl survey stations (Fig. 6). This experiment produced a dataset of 72 comparison stations that is used to calibrate the annual NMFS Bering Sea trawl density estimates with setline survey catch rates via filtering the trawl length frequencies to include only the size-spectrum of fish consistent with those captured by the setline survey (Webster 2014). The calibrated data represent the largest size component of the halibut observed in the trawl estimates (approximated by the 80+ series in Fig. 7). In the northern portion of the Bering Sea the IPHC has never conducted a setline survey. Instead, the catch rates for all sizes of halibut observed in the NMFS trawl survey are calibrated against a NMFS/Alaska Department of Fish & Game (ADF&G) survey conducted in the Norton Sound region. A NMFS survey in 2010 covered the northern Bering Sea, and density ratios from this full survey to the region surveyed in the NMFS/ADF&G survey in Norton Sound (Fig. 8) are used to predict NMFS northern Bering Sea trawl catch rates, and therefore setline survey catch rates for this area. There are also some shallow-water coastal areas that are not currently included in any of these surveys. The density estimates from the surrounding areas are extrapolated into these unsampled areas. In this manner, available data are being used to estimate a setline survey catch rate (of varying precision) for all of the Bering Sea (Fig. 3).

When disaggregated into the constituent parts, it is clear that the majority of the 4CDE index is derived from the contributions of the 4D edge (direct IPHC sampling) and the Bering Sea flats (4S in Fig. 8). Therefore, both the proposed expansion of the setline survey sampling to include greater depths and additional stations along the 4D edge (Webster et al. 2014) as well as an updated calibration between the trawl and setline surveys would have the greatest potential effect on reducing uncertainty (and potentially bias) of trend estimates in the area. The island areas have a much higher catch rate than the flats, but the geographic extent is small, such that the contribution to the total is also small (Fig. 8). The same is true for the Norton Sound region (4N in Fig. 8).

Estimated setline survey WPUE assembled from all of these Bering Sea areas ranged from 25-41 lb/skate during the period 1997-2003 (Table 3; Stewart 2014), and has subsequently dropped to around 10 lb/skate. From 2000 (the year of peak fishery landings) to 2013 this corresponds to a 66% decline. Catch rates in Areas 4A and 4B are much higher, on average, than those in the aggregate Area 4CDE, but have shown declines of similar magnitude: from a high of around 300 and 200 lb/skate to recent levels of 40-60 lb/skate in both areas, respectively (Table 3, Fig. 3).

NMFS Bering Sea Trawl Surveys

Information available from the NMFS Bering Sea trawl survey for halibut smaller than those frequently encountered by the setline survey indicated a very large increase in abundance of the smallest fish (0-39 cm) in 2006 (Fig. 7; Sadorus et al. 2014). This appears to be consistent with subsequent observations of increasing abundance of larger fish (40-79 cm), and to a very strong decrease in abundance of the 0-39 cm numbers in the following years. Total abundance of halibut estimated in the trawl survey has been declining steeply since 2006, with a flat trend in biomass over the last four years, illustrating the trade-off between somatic growth and mortality for recent cohorts. The IPHC sends a sea sampler on NMFS trawl surveys to collect biological information, including lengths on all fish and otoliths for a random sample of these lengths (Sadorus and Lauth 2014; Sadorus and Palsson 2014b). These biological data allow a partitioning of the total estimated numbers of halibut into age classes via an age-length key. Although age data are only available for the period from 1998 to the present, the changes in size-at-age observed in the halibut stock as a whole are generally much more pronounced for older ages (i.e., 6-8+) and therefore the application of a global age-length key for data exploration purposes does not seem problematic.

In the early portion of the time-series, prior to 2006, the only cohort that is particularly evident is the 1987 year class (Fig. 10). The marked increase in the abundance estimate in 2006 can be largely attributed to two-year-old fish (the 2004 cohort); however these fish are much less abundant in the following year at three years of age. There are also relatively large numbers for the 2005, 2006, and 2007 cohorts in the years following. Examining these same data as proportions-at-age (Fig. 11) and age-specific indices (ages 2, 3, and 4; Fig. 12) gives a similar perspective, but allows direct comparison among the relative and absolute estimates for each of these cohorts. A decline in total observed abundance following these strong cohorts is consistent with natural and fishing mortality, as well as movement to other regulatory areas.

Distribution and movement

General understanding of Pacific halibut life history and distribution indicates that the bulk of the pelagic juvenile halibut occurs in the western GOA, Aleutian Islands and southwestern Bering Sea. Densities of 1-4 year old halibut (not frequently encountered in setline surveys or the directed fishery) are typically also very high in these areas; this has been observed in trawl surveys, directed IPHC trawl investigations, and in the length-frequencies of halibut captured as bycatch in various trawl fisheries operating in these areas. The aggregate result of historical IPHC tagging programs indicates that the Bering Sea is a net exporter of halibut of all sizes to all other regulatory areas. New analysis of historical tagging projects conducted by the IPHC in the BSAI is currently underway (Webster *in prep*). Some preliminary results of this analysis indicate that juvenile halibut tagged in the BSAI tend to remain near the area of tagging for the first year at large, but then distribute broadly to the Aleutian Islands, GOA (70-90%), and Area 2 (Fig. 13). This would imply that by the time they enter the directed fishery (and are fully selected by the setline survey) halibut spending their first few years of life in the Bering Sea could be in virtually any regulatory area. A very similar pattern of dispersal was observed for juvenile halibut tagged near Unalaska (Figs. 14, 15). At present it is not possible to correct for the spatial distribution of fishing effort in these data, which may lead to an overestimate of movement rates to areas (like the GOA) with more fishing activity.

Larger halibut are also estimated to move from 4D to 4A at a rate of 6% per year, and to the GOA and Area 2 at a rate of 1.4% per year (Valero and Webster 2012; Table 14). No adult fish from areas outside the Bering Sea are estimated to move into 4CDE, save 0.2% of fish tagged in Area 4B. Additionally, there are seasonal movements within Area 4CDE associated with changes in ice cover (fish forced out of shallow water areas in winter months), summer feeding migrations (fish moving into shallower waters), and fall/winter spawning migrations (fish moving into deeper water for spawning). The net result of these movements is widespread mixing within the eastern Bering Sea.

Summary

Given the current understanding of halibut movement patterns and absent other sources of additional mortality, above average cohorts in 2004-2006 in the Bering Sea should be evident in several other data sets. Specifically, by 2007-2013 these fish should be moving in large numbers into the GOA, where they would be encountered by the NMFS biennial bottom trawl survey (Sadorus and Palsson 2014). Although there was an increase in halibut abundance observed in the GOA in 2009 relative to 2007 and 2011 (Fig. 16), the general trend since 2003 has been a decline of around 50%. By ages 5-10 (2009-2013), these cohorts from the Bering Sea should also be visible in the setline survey, particularly when sublegal (U32) halibut are included. A series of strong cohorts would likely induce a bifurcation of U32 and legal (O32) trends, with estimates of juveniles increasing several years prior to larger and older halibut. This has not been the case for any of the BSAI or surrounding regulatory areas (3B, 3A), where survey trends for U32 and O32 halibut have declined over the last five years (Fig. 3). Although cohorts born in 2004-2006 would not be expected to be fully recruited to the directed fishery at ages 7-9 (in 2011-2013), they should be partially available, but do not appear to have altered the declining WPUE trends in BSAI and surrounding areas (Fig. 2).

These various observations lead to several hypotheses regarding 2004-2006 year-class strengths in the Bering Sea and their potential contribution to the coastwide halibut stock:

1) The year classes were large, have generally remained in the Bering Sea and, due to low size-at-age, have not yet been observed in the directed fishery.
2) The year classes were large, but have experienced higher than normal natural mortality, or unaccounted for fishing mortality, that has reduced their abundance rapidly. This has been suggested in previous analyses as a potential factor in reducing the correlation between juvenile abundance and subsequent contribution to the directed fishery (Schmitt 1985).
3) The year classes were large in the Bering Sea, but not in other regulatory areas, such that their contribution to the overall stock as they have diffused into other areas has not been above average. Aggregate bottom trawl information does suggest 2-4 year old halibut are distributed widely across the western GOA and BSAI (Fig. 17), and it is currently unknown whether coastwide recruitment strength is a function of the spatial distribution of recruits or just increased abundance in certain areas.
4) The year classes were not large, and other factors have made them appear to be above average in the trawl observations; these could include environmental, ecosystem shifts or differences in trawl survey catchability/availability due to temperature, distribution and/or other influences. The IPHC is conducting further investigations into the trends in abundance and distribution observed for other Bering Sea species and environmental factors during this time period.

Currently available information with which to clearly delineate among these hypotheses is inconclusive. Over the next several years, observations in the setline survey and commercial fishery should clearly inform the estimates of the size of these cohorts as they reach a size capable of contributing to the spawning stock and fishery yields in the BSAI and other areas. At present, trends in the adult population are all strongly indicating a BSAI stock that has declined dramatically over the last decade. Planned expansions of the setline survey and a repeated calibration experiment with the Bering Sea Trawl survey could improve future estimates of abundance for the stock assessment and apportionment calculations as well as the uncertainty about these estimates.

Impacts of bycatch on yield, stock biomass, and reproductive potential

There have been several previous IPHC analyses investigating the effects of bycatch on the halibut stock using metrics of fishery yield and lifetime spawning biomass contribution (Hare et al. 2012, Hare and Williams 2013). These analyses were conducted separately from the annual stock assessment, using equilibrium calculations based on relatively simple assumptions about growth and mortality. Results indicated that there was a 1.0 -1.14 lb loss of fishery yield per lb of bycatch (O26 and U26 combined).

For each pound of bycatch, the potential lifetime contribution to female spawning biomass was found to be somewhat larger than the fishery yield.

This analysis employs the stock assessment models (Stewart and Martell 2014), apportionment estimates, and current harvest policy calculations (Webster and Stewart 2014) to investigate the impacts of bycatch via direct comparison with the results of the 2013 IPHC process. This is done via repeating the apportionment calculations made in 2013 under different projected levels of coastwide and BSAI bycatch. It is important to note that this analysis is based on the actual bycatch estimates from each regulatory area in 2013. It does not evaluate how recent bycatch levels have or have not been affected by PSC limits, nor the effects of changing the limits on projected bycatch levels in particular fisheries. The 2013 values on which this analysis is based aggregate all halibut mortality from non-directed fishing. Detailed summaries of these estimates by fishery (Williams 2014), and the PSC limits associated with them (Williams 2014b) are available through the IPHC's website. Pacific halibut bycatch in non-target fisheries in recent years has represented a significant fraction of the total mortality of halibut due to fishing. In 2013, there was an estimated 7.9 Mlb of halibut bycatch coastwide, which represented 17% of the 46 Mlb of total fishing removals. The BSAI regulatory areas (4A, 4B, and 4CDE) contributed 5.2 Mlb, or 66% of the total.

This analysis starts from the results of apportionment and application of current harvest policy which generated the Blue Line FCEY values for 2014 (Table 4). Coastwide Total and Fishery Constant Exploitable Yield (TCEY and FCEY) values are recalculated using coastwide bycatch values that are 40, 20, and 10% above and below the estimates from 2013. This calculation integrates the changes in the distribution of halibut mortality among commercial, recreational, and subsistence catches, as well as estimates of wastage, associated with differing quantities of directed fishery landings.

With a 40% increase in bycatch (3.2 Mlb), the FCEY decreases from the 2013 value of 24.5 Mlb to 22.5 Mlb. A 40% decrease in bycatch similarly produces a 1.9 Mlb increase in coastwide FCEY (Fig. 18). Changes in bycatch of +/- 20% show an intermediate effect, but the results by specific regulatory area indicate that area 4CDE is the most sensitive. A 20% increase in bycatch results in the FCEY for 4CDE dropping from 0.64 (at the Blue Line) to 0.2 Mlb, and a decrease of 20% results in an increase in 4CDE to 1.07 (Tables 5, 6). In Area 4CDE, for all values of estimated bycatch at least 30% greater than 2013, the FCEY would be 0 for the current harvest policy. Areas 4A and 4B are much less sensitive due to a much lower ratio of bycatch to directed fishery harvest. When these changes are applied only to bycatch estimates from BSAI areas, the results are identical for those areas (Tables 7, 8).

Current IPHC harvest policy sets directed Fishery Constant Exploitation Yield (FCEY) limits for each regulatory area based on apportioned biomass estimates derived from survey catch rates, and application of fixed harvest rates (21.5% in Areas 2A-3A and 16.125% in Areas 3B-4CDE) to those estimates. The policy accounts for only O26 halibut removals from the directed and non-target fisheries in the calculation of exploitation rates and yield. Changes in O26 bycatch therefore directly translate into changes to directed fishery yields, as illustrated above, but changes in U26 mortality are not visited directly on calculations of available yield. To illustrate this gap in the current policy, it is useful to consider the hypothetical scenario where the total pounds of bycatch is reduced by 40%, but the size distribution of that bycatch is shifted, such that all of the reduction is realized on U26 halibut. The application of the current harvest policy would yield identical FCEYs, despite a large decrease in the total fishing intensity being applied to the stock. The converse would also occur: a 40% increase in the bycatch of U26 halibut would not result in any reduction to the FCEYs. These results are because the current harvest policy assumes a static level of U26 bycatch in the calculation of optimum harvest rates for the directed yield (the 21.5% and 16.125% values). The target harvest rates are lower than they would be in the absence of bycatch, but do not respond to changes in that level, or the ratio of U26 to O26 removals. The targets were developed based average age-6 recruitment levels under both positive and negative phases of the Pacific Decadal Oscillation (PDO), where U26 fish were assumed to be less than age-6.

Removals of U26 halibut are included in the stock assessment, and therefore in the estimated productivity and current status of the stock. Because the stock assessment is conducted at the coastwide level, this means that U26 mortality is implicitly assumed to have an equal effect on the productivity of all regulatory areas; these removals reduce the estimated coastwide productivity of the stock prior to the apportionment calculation and application of the harvest policy. The current harvest policy, consistent with the Blue Line apportionment and decision table results in 2013, has an implied fishing intensity target which can be easily quantified. The Spawning Potential Ratio (SPR) is the spawning biomass per recruit at equilibrium, relative to an unfished level, given the current level of fishing mortality from all sources. This metric integrates fishing intensity across multiple sources, where selectivity may differ and traditional age-range dependent fishing mortality rate (*F*) or harvest fraction calculations can be misleading. Because the SPR metric includes all sources and sizes of mortality, it can be used to directly compare potential fishery yield associated with different levels of total and U26 bycatch. This conceptual extension to the current harvest policy allows for quantification of the impacts of bycatch on the halibut stock via the yield estimates, rather than in terms of equilibrium spawning biomass units.

Calculations based on the 2013 harvest policy results were again repeated for different levels of bycatch at both the coastwide and BSAI-only levels. After the harvest policy was applied, the result was then iterated via the stock assessment to find FCEY values that resulted in no change from the SPR resulting from the 2013 tables. Where previous FCEY calculations (the traditional harvest policy) assumed a constant level of U26 bycatch, this alternative approach incorporates the impact of all sources of bycatch mortality directly in the yield calculations. Area-specific TCEYs were adjusted uniformly and in proportion to the original apportionment estimates; i.e., the harvest rates of O26 were adjusted up or down, but not differently among areas, which retains the same relative distribution as the current targets. This is the same method used in recent stock assessments to populate alternative catch levels in the decision table.

When FCEYs are adjusted to maintain the same SPR target, changes in bycatch result in changes to directed fishery yields that are greater than just the change in O26 mortality, accounting also for the effects of the U26 removals (Fig. 18). In this case, a 20% reduction in coastwide bycatch results in an FCEY of 26.0 Mlb (Table 9), compared to the Blue Line value of 24.5 and the reduction that did not account for U26 removals which resulted in an FCEY of 25.4. These results are consistent with previous analyses finding approximately a 1:1 relationship in total lost yield due to all sizes of bycatch. It is important to note that, given the current implicit assumption of U26 effects being distributed in proportion to the productivity of the stock as a whole, there are now changes in other regulatory area FCEYs as a result of changes in bycatch in only the BSAI areas (Table 10). These are more pronounced for areas that have larger apportioned biomass estimates (such as 3A), where the FCEY goes from 9.43 Mlb at the Blue Line (and for a 20% reduction in the BSAI when U26 mortality is not accounted for) to 9.59 when the same SPR is maintained. The clear difference in these calculations is that any response to changes in bycatch in the FCEY, up or down, is of greater magnitude when all sizes of mortality are accounted for. Ongoing research at the IPHC to evaluate size-limits, discard mortality rates in the directed fishery, and the interaction of bycatch with total fishing mortality is yielding very similar results.

In 2012, the IPHC adopted a revised process for providing annual catch advice. To clearly delineate between risk assessment and management, the estimated risks associated with several alternative harvest levels have been presented to the Commissioners rather than just the results of the application of the current harvest policy. These results have been in the form of a decision table, including risk metrics associated with stock trend, as well as harvest policy based metrics of stock status and fishery status. Using the Blue Line results from 2013 (Table 11) as a direct comparison, the alternative distribution and magnitude of removals for the analyses reported above can be evaluated directly in the current decision-making framework. There is relatively little change in risk associated with changes in bycatch (+/- 20%), and among two methods of accounting for that bycatch over the next three years (Table 12).

Major sources of uncertainty

There are several very important sources of uncertainty in this analysis of current halibut stock status and impacts of bycatch on yield. Some of these sources are inherent to the biology and management of Pacific halibut and are not easily addressed (e.g., specific migration pathways and rates), while others could be reduced through additional data collection and analysis.

Current uncertainty in setline survey indices in the Bering Sea is due to incomplete geographic coverage and could be improved through setline survey expansions planned over the next five years with better spatial coverage of currently sampled depths (20-275 fathoms), and a broader depth range (0-400 fathoms; the depths used for apportionment calculations), working progressively through regulatory areas (Webster et al. 2014). Pending logistical constraints, the IPHC is considering repeating the 2006 Bering Sea trawl survey calibration in 2015 (along with the Area 4D expansion). This could provide an updated estimate of the abundance in that area, particularly crucial given the current uncertainty in recent year classes.

The current harvest policy (and any extension to explicitly include all sizes of halibut mortality) makes the implicit assumption that the effects of this mortality are distributed across the entire stock, in proportion to the total productivity. If juveniles in some areas are less likely to disperse to other areas, or if these patterns change over time with environmental conditions or stock abundance, this assumption may not be a good one. Neither the directed fishery, nor the setline survey provides clear information on juvenile abundance distribution. Some information can be inferred from NMFS trawl survey observations, bycatch rates in non-target fisheries, and encounter rates in the directed fisheries; however, all of these are subject to incomplete spatial coverage as well as many other uncertainties. The design of a targeted survey of juvenile halibut abundance and distribution is likely to be both technically unfeasible and prohibitively expensive. An extensive tagging effort could provide a 'snap-shot' of migration rates, but these are likely to vary with stock density, environmental conditions, and other unknown factors. Again, costs would likely be prohibitive due to the extended time between tagging and recovery by the commercial fishery and the resulting low recovery rates (recovery numbers could be increased with a larger number of releases, but that also increases the costs).

Juvenile natural mortality rates are highly uncertain, but are important to any evaluation of removals to population trend and productivity. For this analysis, several alternative comparisons were made assuming juvenile natural mortality rates were 1.5 and 2 times the rates estimated for adults. The relative change in SPR was found to be similar across alternatives, but the relative importance of fishing mortality was slightly less with increasing juvenile natural mortality. Natural mortality rates are notoriously difficult to estimate, even for well-sampled/observed age ranges for highly studied species, and there are few avenues for experimental or data-collection based efforts to improve our understanding of juvenile halibut mortality. Indeed, the two-year releases of Passive Integrated Transponder (PIT) tags in the most recent tagging program were designed to examine the potential to directly estimate natural mortality but the results produced a fairly broad and uninformative estimate of natural mortality, which included the estimate currently used.

The stock assessment and application of the harvest policy relies on accurate and precise estimation of the removals from all fishing sectors, including the directed fishery, recreational and subsistence harvests, as well as discards from these fisheries and bycatch. There is a substantial amount of uncertainty in the current treatment of bycatch due to: the estimation framework (data collection), the summary of the estimates (data processing), and the forecasting of bycatch and its biological properties from one year to the next.

The first of these relates to the current North Pacific observer program. While some fisheries in the BSAI region have observer coverage of 100% of fishing trips, other fisheries have much lower coverage or no coverage at all. In these cases, data may not be representative of all fishing activity (observed and unobserved) and therefore there is no way to be certain that the estimates are unbiased, regardless of the statistical design. This situation can only be fully ameliorated via some type of monitoring on all fishing activity. In addition to the amount of bycatch, the size-distribution of these removals is also required, such that they can be accounted for accordingly. Estimates of the total bycatch are obtained by the IPHC from the catch accounting system. There is uncertainty in assigning these summarized estimates to specific regulatory areas due to the imperfect alignment of IPHC and Alaska statistical reporting areas. This means that not all bycatch may be attributed to the correct regulatory area in each year. Additionally, the size information collected by the observer program is transmitted to the IPHC in an unprocessed form, which allows no easy method for weighting among fishing sectors within IPHC regulatory areas. This would require a substantial amount of integration between the observed data and catch accounting system. Obtaining accurate size-, age-, and sex-specific estimates of the removals of halibut from all sectors via improved observation and reporting to the IPHC may be the most tractable avenue for improving our understanding of the role of bycatch in current stock trends and productivity.

The stock assessment and harvest policy calculations rely on an aggregate bycatch selectivity assumption. However, the size distribution of bycatch varies among regulatory areas, among fisheries and even annually within fisheries, in response to many extrinsic and intrinsic factors. Further, many of the tools proposed for bycatch reduction could have large effects on the potential size-distribution of future bycatch mortality through direct effects, or changes in the discard mortality estimates by fish size. These changes are difficult or impossible to predict, and therefore current practice is to use the values from the previous year for all calculations. This approach could introduce lags in response if clear trends occur. The sensitivity to some of these factors was investigated as part of this analysis: the proportions of young and old fish in the currently assumed curve were adjusted by 20% up and down and the results recalculated. This produced only modest changes in FCEYs, slightly smaller than those produced from a 10% change in the total magnitude of bycatch (~0.5 million lbs). These changes also illustrated the logical relationship between the size-distribution of the bycatch and the long-term implications for the stock productivity: if mortality is higher on small fish for the same total pounds removed (greater numbers), the harvest of larger fish would have to be reduced to offset the greater lifetime contribution of these fish that have yet to mature. More direct estimation of bycatch selectivity would require appropriately expanded and weighted length-frequency observations not currently available and would likely have to be carried out with a more spatially disaggregated assessment approach.

Conclusions and future research

Measures of the halibut stock reflecting the biomass available to the fishery and contributing to spawning output indicate substantial declines in all BSAI areas from levels observed in the late 1990s. This is consistent with trends observed in other regulatory areas and estimated for the entire stock. Cohorts born in 2004-2006 and observed in large numbers in the trawl survey data appear to have declined rapidly in abundance in the Bering Sea, and are not evident in the fishery, setline survey, or NMFS GOA trawl surveys. The strength of these year classes could remain uncertain for several more years.

Current (2013) halibut bycatch in the BSAI represents 66% of the coastwide total from all non-target fisheries. This also represents a significant portion of the total mortality in BSAI areas, especially Area 4CDE. In Area 4CDE, based on 2013 estimates, application of the harvest policy would result in no directed fishery yield if the estimated O26 bycatch were to increase by at least 30%, the apportioned exploitable biomass were to decrease by the same amount, or any combination of these two adding up to at least 30%. When FCEYs are adjusted to maintain the same SPR target, changes in bycatch result in changes to directed fishery yields that are greater than just the change in O26 mortality, accounting also for the effects of the U26 removals. This result is consistent with previous analyses finding approximately a 1:1 relationship in total lost yield due to all sizes of bycatch.

Accounting for halibut removals of all sizes represents a conceptual extension of the current harvest policy, but not a change in the implicit logic of the approach. Specifically, this does not provide an evaluation of the current harvest rate targets, but broadens their definition to provide an analog in total mortality which avoids future changes in realized SPR despite static targets. It also provides an accounting framework through which yield trade-offs can be evaluated. This may serve to elevate the discussion regarding such trade-offs, but it does not presuppose any changes to current management by the NPFMC or IPHC.

Development of a Management Strategy Evaluation (MSE) framework at the IPHC has the potential to identify alternative management procedures that may be robust to many of the uncertainties described here, and a vehicle to explore hypotheses regarding recruitment distribution, juvenile and adult migration, density dependence, spatial and temporal growth variability, and a multitude of other factors. This process is ongoing, as is the development of more spatially disaggregated assessment analyses that can also be used for future work on these topics.

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Tables

Table 1. Allocations among Community Development Quota organizations in IPHC Area 4CDE.

	CDQ Organization					
Subarea	APICDA	BBEDC	CBSFA	CVRF	NSEDC	YDFA
4C	15%	0	85%	0	0	0
4D	0	26%	0	24%	30%	20%
4E	0	30%	0	70%	0	0

Table 2. Summary of historical removals in the BSAI - IPHC regulatory Areas 4A, 4B, and 4CDE.

	Commercial landings			Estimated bycatch (PSC)			
Year	4A	4B	4CDE	4A	4B	4CDE	Combined
1981	0.49	0.39	0.31	NA	NA	NA	6.41
1982	1.17	0.01	0.25	NA	NA	NA	4.76
1983	2.50	1.34	0.58	NA	NA	NA	4.27
1984	1.05	1.10	1.01	NA	NA	NA	4.69
1985	1.72	1.24	1.33	NA	NA	NA	4.21
1986	3.38	0.26	1.95	NA	NA	NA	5.58
1987	3.69	1.50	1.69	NA	NA	NA	5.74
1988	1.93	1.59	1.17	NA	NA	NA	8.86
1989	1.03	2.65	1.26	NA	NA	NA	7.28
1990	2.50	1.33	1.59	1.99	0.94	5.65	8.58
1991	2.26	1.51	2.22	2.32	1.10	6.60	10.02
1992	2.70	2.32	1.59	2.49	1.17	7.06	10.72
1993	2.56	1.96	1.73	1.80	0.85	5.11	7.76
1994	1.80	2.02	1.55	2.20	1.04	6.24	9.47
1995	1.62	1.68	1.44	2.02	0.96	5.75	8.73
1996	1.70	2.07	1.51	1.97	0.93	5.60	8.51
1997	2.91	3.32	2.52	1.83	0.86	5.19	7.88
1998	3.42	2.90	2.75	1.79	0.85	5.09	7.72
1999	4.37	3.57	3.92	1.78	0.84	5.06	7.68
2000	5.16	4.69	4.02	1.73	0.81	4.90	7.44
2001	5.02	4.47	3.97	1.65	0.78	4.69	7.12
2002	5.09	4.08	3.52	1.69	0.80	4.79	7.27
2003	5.02	3.86	3.26	1.58	0.75	4.49	6.82
2004	3.56	2.72	2.92	1.56	0.74	4.44	6.74
2005	3.40	1.98	3.48	1.78	0.84	5.07	7.69
2006	3.33	1.59	3.23	1.74	0.82	4.94	7.49
2007	2.83	1.42	3.85	1.68	0.80	4.78	7.26
2008	3.02	1.76	3.88	1.52	0.72	4.32	6.56
2009	2.53	1.59	3.31	1.46	0.69	4.15	6.30
2010	2.33	1.83	3.32	1.41	0.67	4.01	6.08
2011	2.35	2.05	3.43	1.19	0.56	3.38	5.14
2012	1.58	1.74	2.34	1.78	0.63	3.86	6.27
2013	1.23	1.24	1.78	1.10	0.46	3.65	5.21

Table 3. Summary of fishery and survey trends in the BSAI - IPHC regulatory Areas 4A, 4B, and 4CDE.

	Fishery WPUE				Survey WPUE		
Year	4A	4B	4C	4D	4A	4B	4CDE
1984	366	161	NA	197	NA	NA	NA
1985	337	234	594	330	NA	NA	NA
1986	260	238	427	218	NA	NA	NA
1987	342	220	384	241	NA	NA	NA
1988	453	224	371	201	NA	NA	NA
1989	409	268	333	432	NA	NA	NA
1990	418	209	288	381	NA	NA	NA
1991	471	329	223	399	NA	NA	NA
1992	372	280	249	412	NA	NA	NA
1993	463	218	257	851	NA	NA	NA
1994	463	197	167	480	NA	NA	NA
1995	349	189	286	475	NA	NA	NA
1996	515	269	297	543	NA	NA	NA
1997	483	275	335	671	246	282	22
1998	525	287	287	627	307	217	41
1999	497	310	271	535	291	203	36
2000	548	320	223	556	281	217	26
2001	474	270	203	511	204	171	27
2002	402	245	148	503	173	119	27
2003	355	196	105	388	158	104	25
2004	315	202	120	445	141	73	21
2005	301	238	91	379	110	86	13
2006	241	218	72	280	87	96	14
2007	206	230	65	237	68	87	13
2008	206	193	94	247	85	104	11
2009	234	189	88	249	86	107	13
2010	182	142	82	188	75	68	11
2011	189	165	75	166	59	68	9
2012	194	149	60	155	66	49	11
2013	164	122	55	151	43	57	9

Table 4. Apportionment and harvest policy table from 2013 based on the Blue Line (current IPHC harvest policy). All biomass values are reported in millions of net pounds (From: Webster and Stewart 2014).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Exploitable bio.	4.03	26.64	25.44	56.07	23.14	9.69	7.23	18.06	170.29
Percent of total	2.4%	15.6%	14.9%	32.9%	13.6%	5.7%	4.2%	10.6%	100.0%
Harvest rate (%)	21.5%	21.5%	21.5%	21.5%	16.1%	16.1%	16.1%	16.1%	19.7%
Total CEY	0.87	5.73	5.47	12.05	3.73	1.56	1.17	2.91	33.49
Other removals	0.14	0.74	1.31	2.63	0.90	0.71	0.34	2.27	9.04
Fishery CEY	0.72	4.98	4.16	9.43	2.84	0.85	0.82	0.64	24.45

Table 5. Recalculated 2013 apportionment and harvest policy table based on a 20% increase in coastwide bycatch. All biomass values are reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Exploitable bio.	4.03	26.64	25.44	56.07	23.14	9.69	7.23	18.06	170.29
Percent of total	2.4%	15.6%	14.9%	32.9%	13.6%	5.7%	4.2%	10.6%	100.0%
Harvest rate (%)	21.6%	21.5%	21.5%	21.5%	16.1%	16.1%	16.1%	16.1%	19.7%
Total CEY	0.87	5.72	5.47	12.05	3.73	1.56	1.17	2.91	33.49
Other removals	0.16	0.78	1.31	2.81	1.01	0.83	0.41	2.71	10.02
Fishery CEY	0.71	4.95	4.16	9.24	2.72	0.73	0.76	0.20	23.46

Table 6. Recalculated 2013 apportionment and harvest policy table based on a 20% reduction in coastwide bycatch. All biomass values are reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Exploitable bio.	4.03	26.64	25.44	56.07	23.14	9.69	7.23	18.06	170.29
Percent of total	2.4%	15.6%	14.9%	32.9%	13.6%	5.7%	4.2%	10.6%	100.0%
Harvest rate (%)	21.5%	21.5%	21.5%	21.5%	16.1%	16.1%	16.1%	16.1%	19.7%
Total CEY	0.87	5.73	5.47	12.05	3.73	1.56	1.16	2.91	33.49
Other removals	0.12	0.70	1.31	2.44	0.78	0.59	0.28	1.84	8.07
Fishery CEY	0.75	5.03	4.16	9.61	2.95	0.97	0.88	1.07	25.42

Table 7. Recalculated 2013 apportionment and harvest policy table based on a 20% increase in bycatch in Areas 4A, 4B, and 4CDE. All biomass values are reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Exploitable bio.	4.03	26.64	25.44	56.07	23.14	9.69	7.23	18.06	170.29
Percent of total	2.4%	15.6%	14.9%	32.9%	13.6%	5.7%	4.2%	10.6%	100.0%
Harvest rate (%)	21.5%	21.5%	21.5%	21.5%	16.1%	16.1%	16.2%	16.1%	19.7%
Total CEY	0.87	5.72	5.47	12.06	3.73	1.56	1.17	2.91	33.49
Other removals	0.14	0.74	1.31	2.63	0.90	0.83	0.41	2.71	9.66
Fishery CEY	0.72	4.98	4.16	9.43	2.84	0.73	0.76	0.20	23.83

Table 8. Recalculated 2013 apportionment and harvest policy table based on a 20% reduction in bycatch in Areas 4A, 4B, and 4CDE. All biomass values are reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Exploitable bio.	4.03	26.64	25.44	56.07	23.14	9.69	7.23	18.06	170.29
Percent of total	2.4%	15.6%	14.9%	32.9%	13.6%	5.7%	4.2%	10.6%	100.0%
Harvest rate (%)	21.5%	21.5%	21.5%	21.5%	16.1%	16.1%	16.1%	16.1%	19.7%
Total CEY	0.87	5.72	5.47	12.06	3.73	1.56	1.16	2.91	33.49
Other removals	0.14	0.74	1.31	2.63	0.90	0.59	0.28	1.84	8.43
Fishery CEY	0.72	4.98	4.16	9.43	2.84	0.97	0.88	1.07	25.06

Table 9. Recalculated 2013 apportionment and harvest policy table based on a 20% reduction in coastwide bycatch, and accounting for U26 mortality by maintaining the same fishing intensity (SPR). All biomass values are reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Exploitable bio.	4.03	26.64	25.44	56.07	23.14	9.69	7.23	18.06	170.29
Percent of total	2.4%	15.6%	14.9%	32.9%	13.6%	5.7%	4.2%	10.6%	100.0%
Harvest rate (%)	22.0%	21.9%	21.9%	21.9%	16.4%	16.5%	16.4%	16.4%	20.0%
Total CEY	0.89	5.83	5.57	12.27	3.80	1.59	1.18	2.96	34.09
Other removals	0.12	0.71	1.31	2.44	0.79	0.59	0.28	1.84	8.08
Fishery CEY	0.77	5.13	4.26	9.83	3.01	1.00	0.90	1.12	26.01

Table 10. Recalculated 2013 apportionment and harvest policy table based on a 20% reduction in bycatch in Areas 4A, 4B, and 4CDE, and accounting for U26 mortality by maintaining the same fishing intensity (SPR). All biomass values are reported in millions of net pounds.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Exploitable bio.	4.03	26.64	25.44	56.07	23.14	9.69	7.23	18.06	170.29
Percent of total	2.4%	15.6%	14.9%	32.9%	13.6%	5.7%	4.2%	10.6%	100.0%
Harvest rate (%)	21.5%	21.8%	21.8%	21.8%	16.3%	16.3%	16.3%	16.4%	19.9%
Total CEY	0.88	5.80	5.55	12.22	3.78	1.58	1.18	2.95	33.94
Other removals	0.14	0.74	1.31	2.63	0.90	0.59	0.28	1.84	8.44
Fishery CEY	0.73	5.06	4.24	9.59	2.88	0.99	0.90	1.11	25.50

Table 11. Final 2013 decision table results.

				Stock Trend				Stock Status				Fishery Trend				Fishery Status
				Spawning biomass				Spawning biomass				Fishery CEY from the harvest policy				Harvest rate
				in 2015		in 2017		in 2015		in 2017		in 2015		in 2017		in 2014
2014 Alternative	Total removals (M lb)	Fishery CEY (M lb)	Harvest rate	is less than 2014	is 5% less than 2014	is less than 2014	is 5% less than 2014	is less than 30%	is less than 20%	is less than 30%	is less than 20%	is less than 2014	is 10% less than 2014	is less than 2014	is 10% less than 2014	is above target
No removals	0.0	0.0	0.0%	5/100	<1/100	23/100	4/100	3/100	<1/100	1/100	<1/100	0/100	0/100	0/100	0/100	0/100
FCEY = 0	11.4	0.0	5.0%	31/100	<1/100	32/100	18/100	3/100	<1/100	2/100	<1/100	0/100	0/100	0/100	0/100	<1/100
	20.0	8.5	10.1%	33/100	<1/100	37/100	24/100	4/100	<1/100	3/100	<1/100	<1/100	<1/100	<1/100	<1/100	<1/100
	30.0	18.2	15.9%	39/100	<1/100	66/100	41/100	4/100	<1/100	5/100	<1/100	5/100	2/100	8/100	4/100	7/100
Blue Line	36.4	24.5	19.7%	56/100	1/100	82/100	63/100	5/100	<1/100	6/100	1/100	43/100	20/100	74/100	47/100	50/100
Final adopted	39.6	27.5	21.5%	67/100	1/100	87/100	72/100	5/100	<1/100	8/100	1/100	80/100	46/100	95/100	81/100	89/100
	40.0	28.0	21.8%	68/100	1/100	87/100	73/100	5/100	<1/100	8/100	1/100	85/100	52/100	96/100	84/100	92/100
	45.0	32.8	24.7%	82/100	4/100	93/100	83/100	6/100	1/100	10/100	1/100	>99/100	95/100	>99/100	99/100	>99/100
status quo	48.5	36.1	26.7%	88/100	8/100	95/100	87/100	6/100	1/100	13/100	1/100	>99/100	>99/100	>99/100	>99/100	>99/100
	55.0	42.6	30.5%	95/100	23/100	98/100	94/100	6/100	1/100	19/100	2/100	>99/100	>99/100	>99/100	>99/100	>99/100
	60.0	47.5	33.5%	98/100	38/100	99/100	97/100	7/100	1/100	26/100	2/100	>99/100	>99/100	>99/100	>99/100	>99/100
				a	b	c	d	e	f	g	h	i	j	k	l	m

Table 12. Comparison of alternative 2013 decision table results based on changes in bycatch and U26 mortality accounting: row a) 2013 Blue Line, b) 20% reduction in coastwide bycatch in 2014, c) 20% reduction in coastwide bycatch in 2014 maintaining target SPR, d) 20% reduction in 2014 bycatch in areas 4A, 4B, and 4CDE, and e) 20% reduction in 2014 bycatch in areas 4A, 4B, and 4CDE maintaining target SPR. Rows correspond to apportionment and harvest policy tables above and are ordered by increasing total mortality.

				Stock Trend				Stock Status				Fishery Trend				Fishery Status
				Spawning biomass				Spawning biomass				Fishery CEY from the harvest policy				Harvest rate
				in 2015		in 2017		in 2015		in 2017		in 2015		in 2017		in 2014
2014 Alternative	Total removals (M lb)	Fishery CEY (M lb)	Harvest rate	is less than 2014	is 5% less than 2014	is less than 2014	is 5% less than 2014	is less than 30%	is less than 20%	is less than 30%	is less than 20%	is less than 2014	is 10% less than 2014	is less than 2014	is 10% less than 2014	is above target
b	35.8	25.4	19.7%	55/100	1/100	82/100	63/100	5/100	<1/100	6/100	1/100	55/100	26/100	81/100	57/100	49/100
d	36.0	25.1	19.7%	55/100	1/100	82/100	63/100	5/100	<1/100	6/100	1/100	50/100	23/100	78/100	53/100	49/100
a	36.4	24.5	19.7%	56/100	1/100	82/100	63/100	5/100	<1/100	6/100	1/100	43/100	20/100	74/100	47/100	50/100
e	36.5	25.5	19.9%	57/100	1/100	83/100	64/100	5/100	<1/100	6/100	1/100	52/100	24/100	80/100	55/100	51/100
c	36.5	26.0	20.0%	58/100	1/100	83/100	65/100	5/100	<1/100	6/100	1/100	57/100	27/100	83/100	59/100	50/100

Figures

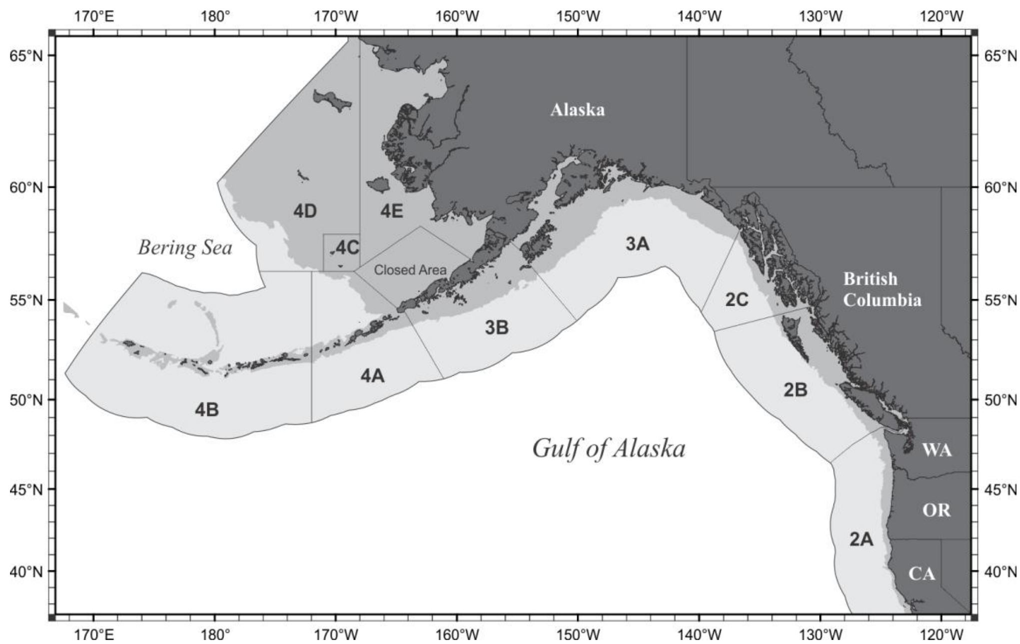

Figure 1. IPHC Regulatory Areas. Shaded region indicates the Exclusive Economic Zone (EEZ) of the United States and Canada.

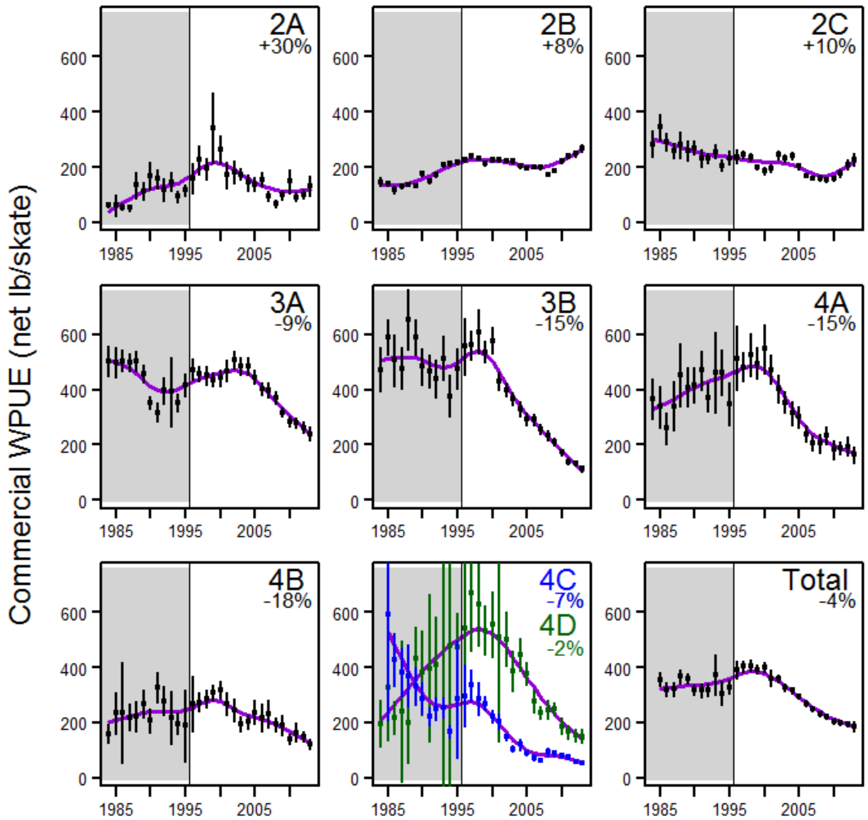

Figure 2. Directed commercial halibut fishery WPUE summarized by regulatory area and year. Percentages for each Area indicate the change from 2012 to 2013; lines represent a smoother for visualization purposes only (From: Stewart, 2014).

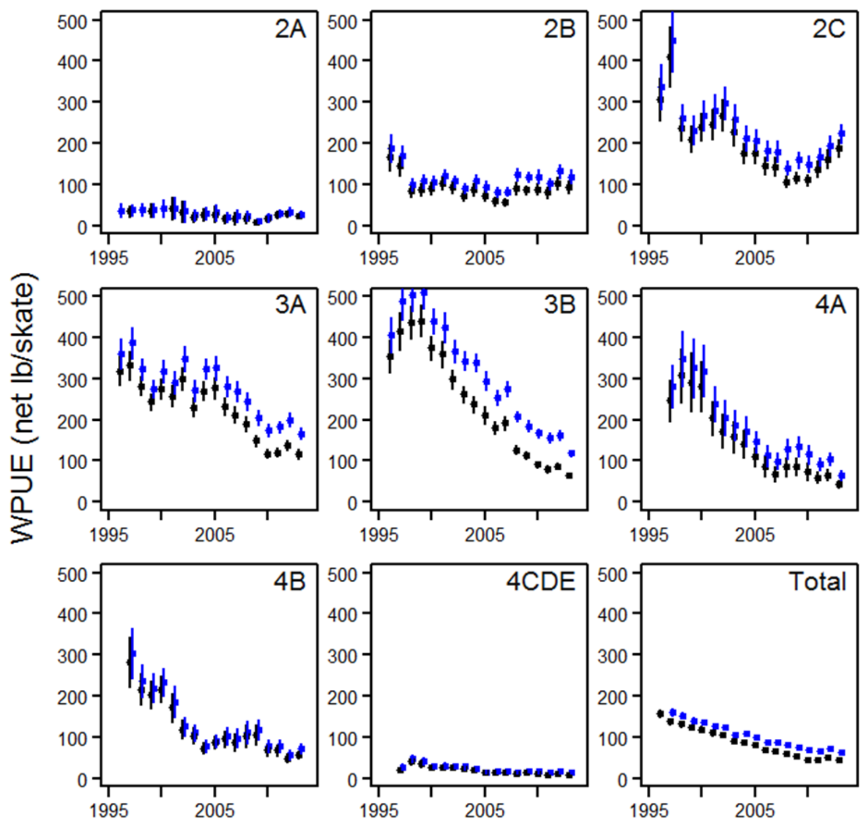

Figure 3. IPHC setline survey indices for all (blue upper series in each panel), and only O32 (black lower series) halibut (From: Stewart, 2014).

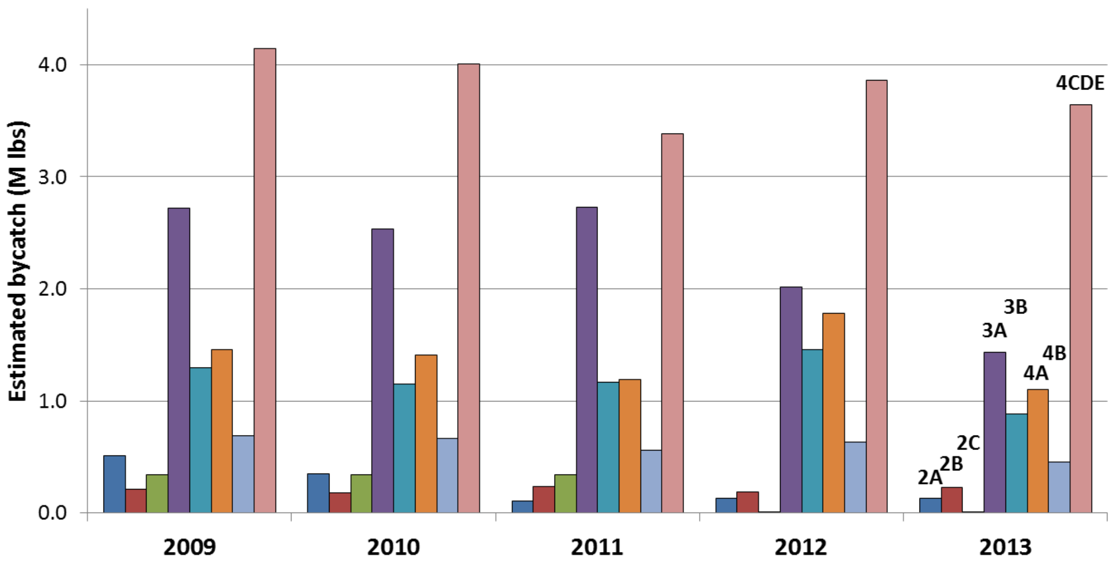

Figure 4. Bycatch estimates by IPHC regulatory area over the period 2009-2013.

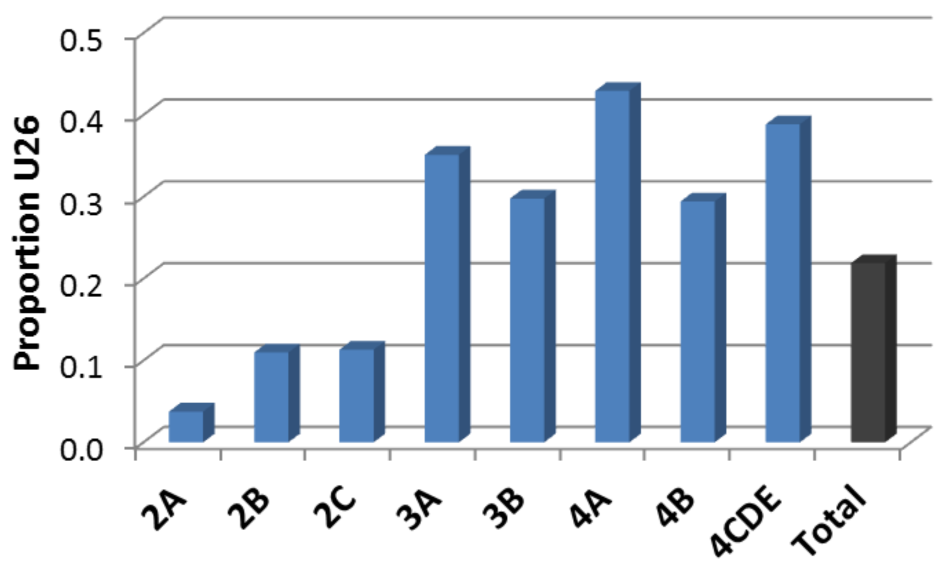

Figure 5. Estimated proportion of U26 halibut bycatch by regulatory area averaged over the period 2009-2013.

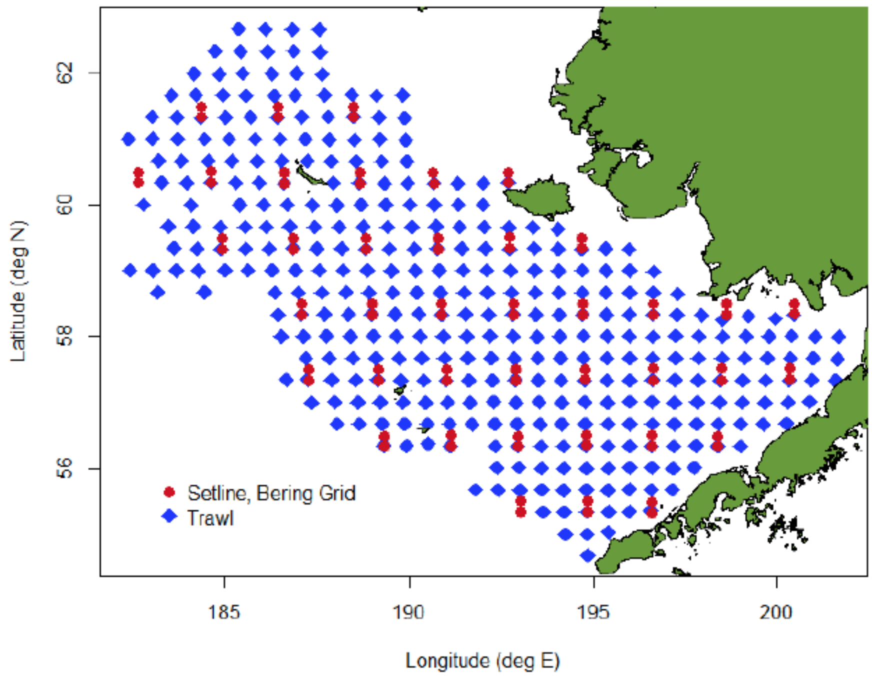

Figure 6. NMFS 20 nmi annual trawl grid stations and IPHC Bering setline survey grid stations used in the estimation of a calibration curve for the two surveys conducted in 2006 (from Webster 2014).

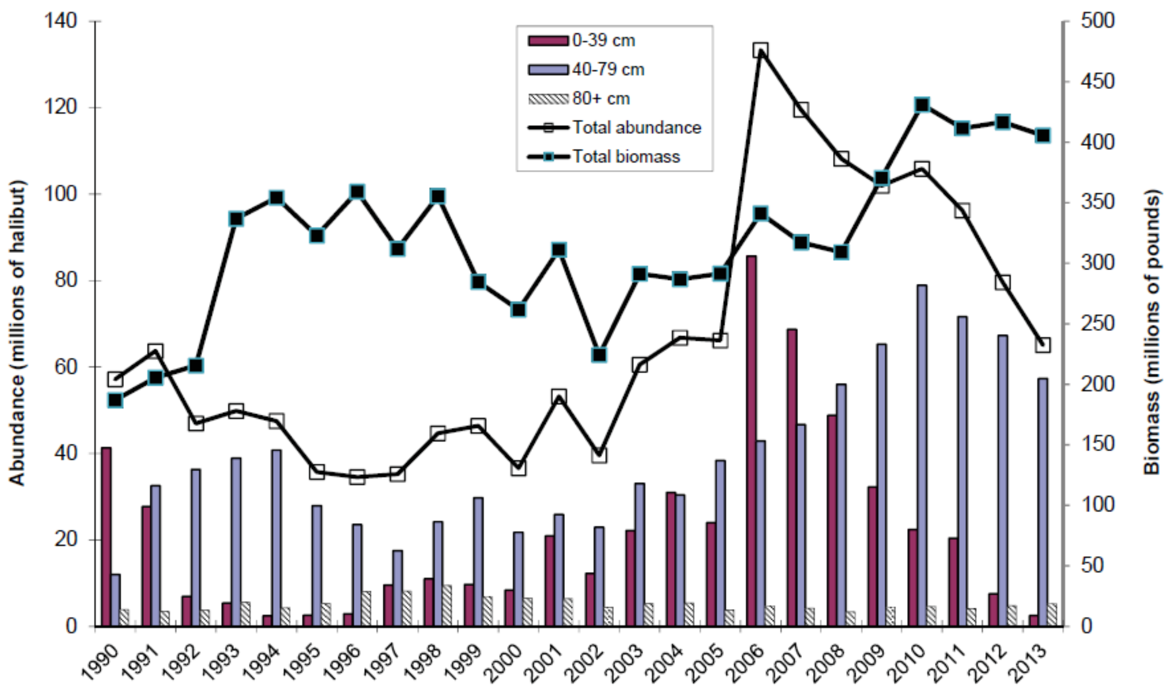

Figure 7. Estimated abundance (number) of Pacific halibut by length category and total biomass (pounds round weight) as estimated by the NMFS Bering Sea trawl survey from 1990-2013 (from Sadorus et al. 2014).

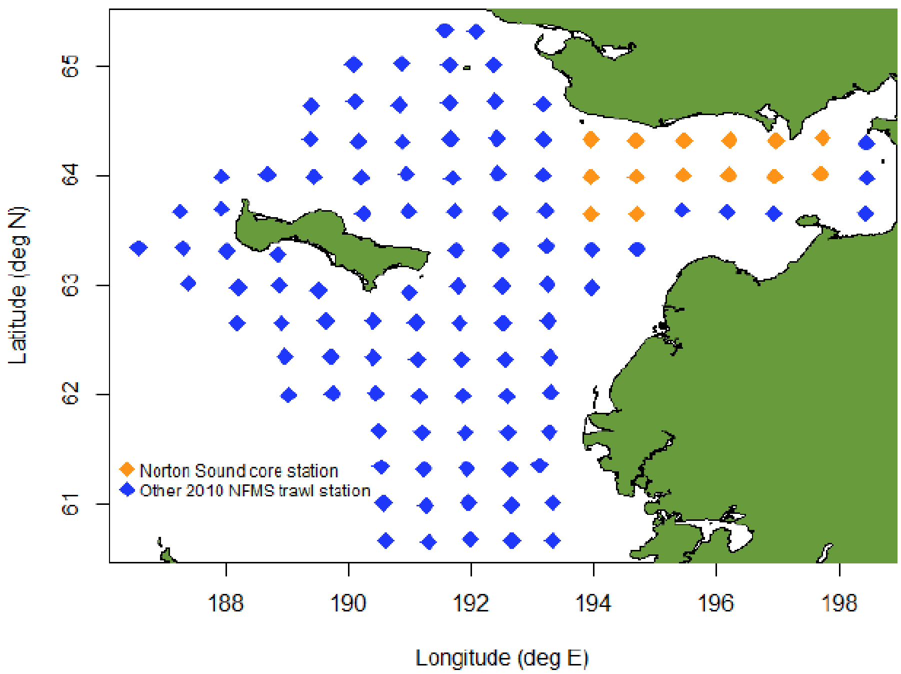

Figure 8. NMFS 2010 northern Bering Sea trawl survey stations. Those located in the Norton Sound region are highlighted (from Webster 2014).

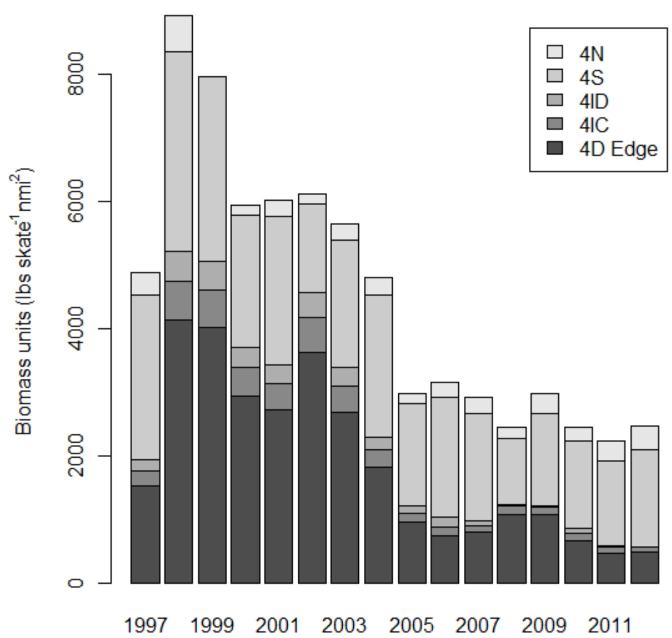

Figure 9. Distribution of estimated setline survey biomass within Area 4CDE (from Webster 2014). The region indicated by 4S is currently estimated from the 2006 calibration between the setline and trawl surveys. Area 4N is currently estimated via the calibration between NMFS and ADF&G trawl surveys. Areas 4ID, 4IC, and 4D are directly sampled by the IPHC survey.

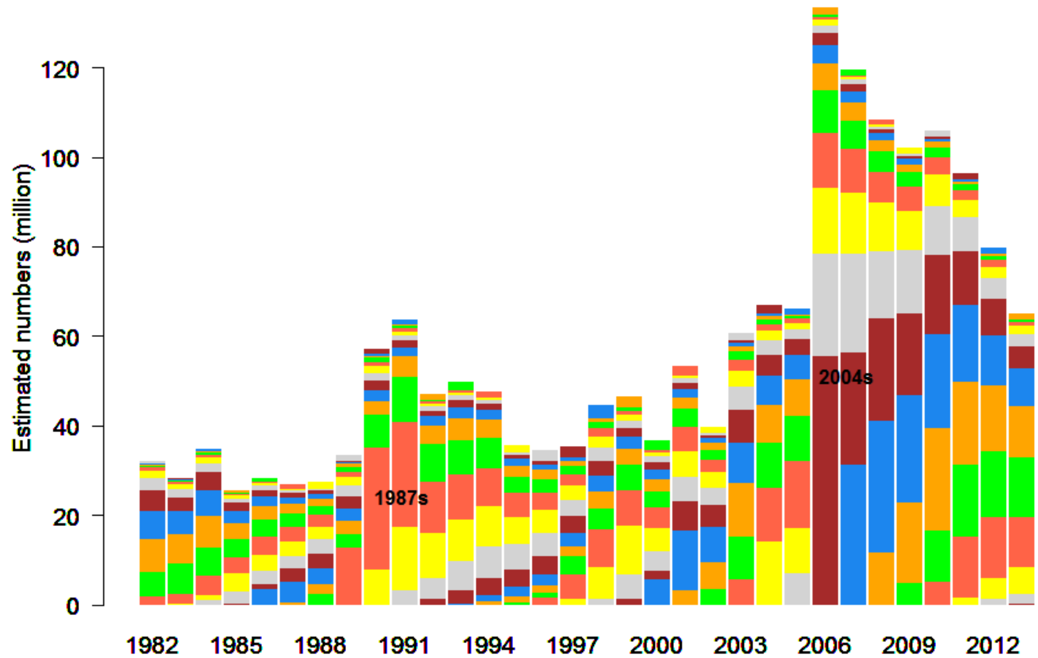

Figure 10. Proportions-at-age estimated from the NMFS Bering Sea trawl survey 1982-2013, via a global age-length key. Cohorts are coded by color, the sum of numbers-at-age for all cohorts adds to the estimated total from the trawl survey. The 1987 and 2004 cohorts are labelled for reference.

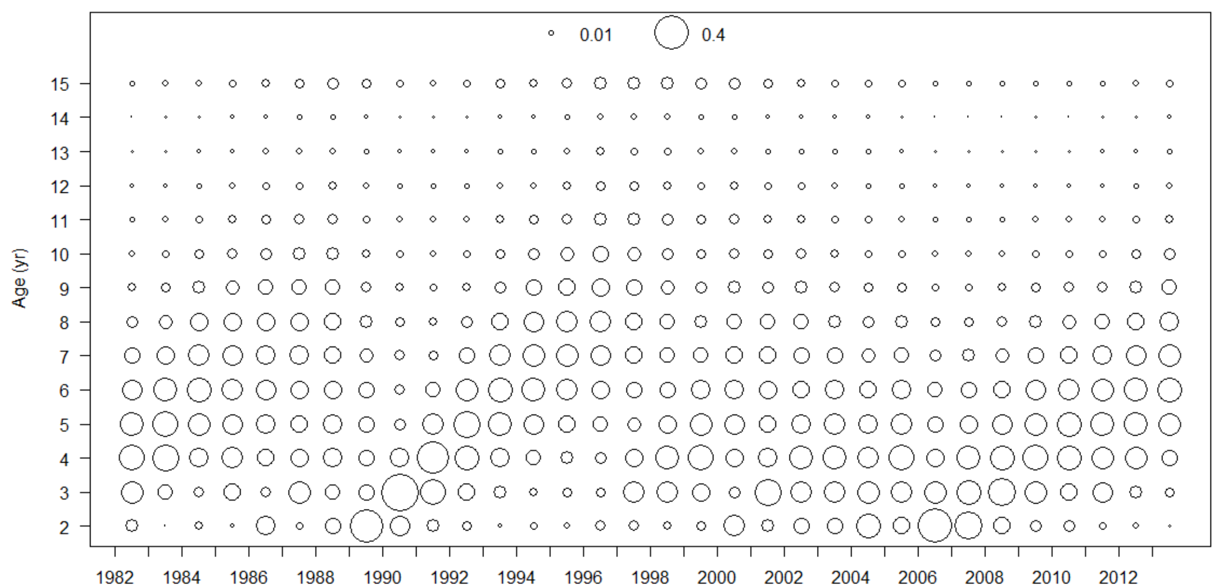

Figure 11. Proportions-at-age estimated from the NMFS Bering Sea trawl survey 1982-2013 via a global age-length key.

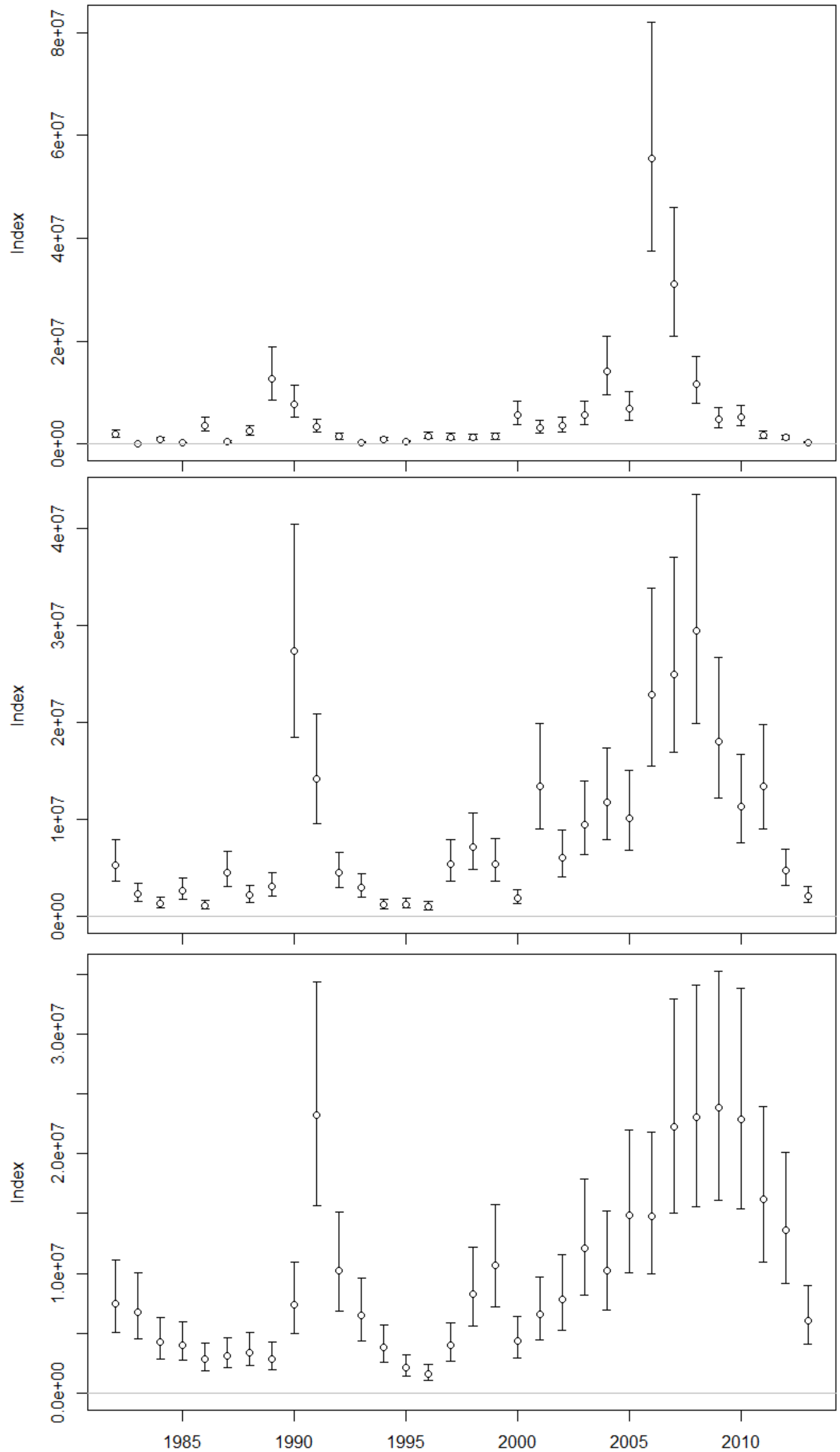

Figure 12. Age-specific indices of abundance for age-2 (top panel), age-3 (middle panel) and age-4 (lower panel) estimated from the NMFS Bering Sea trawl survey 1982-2013 via a global age-length key.

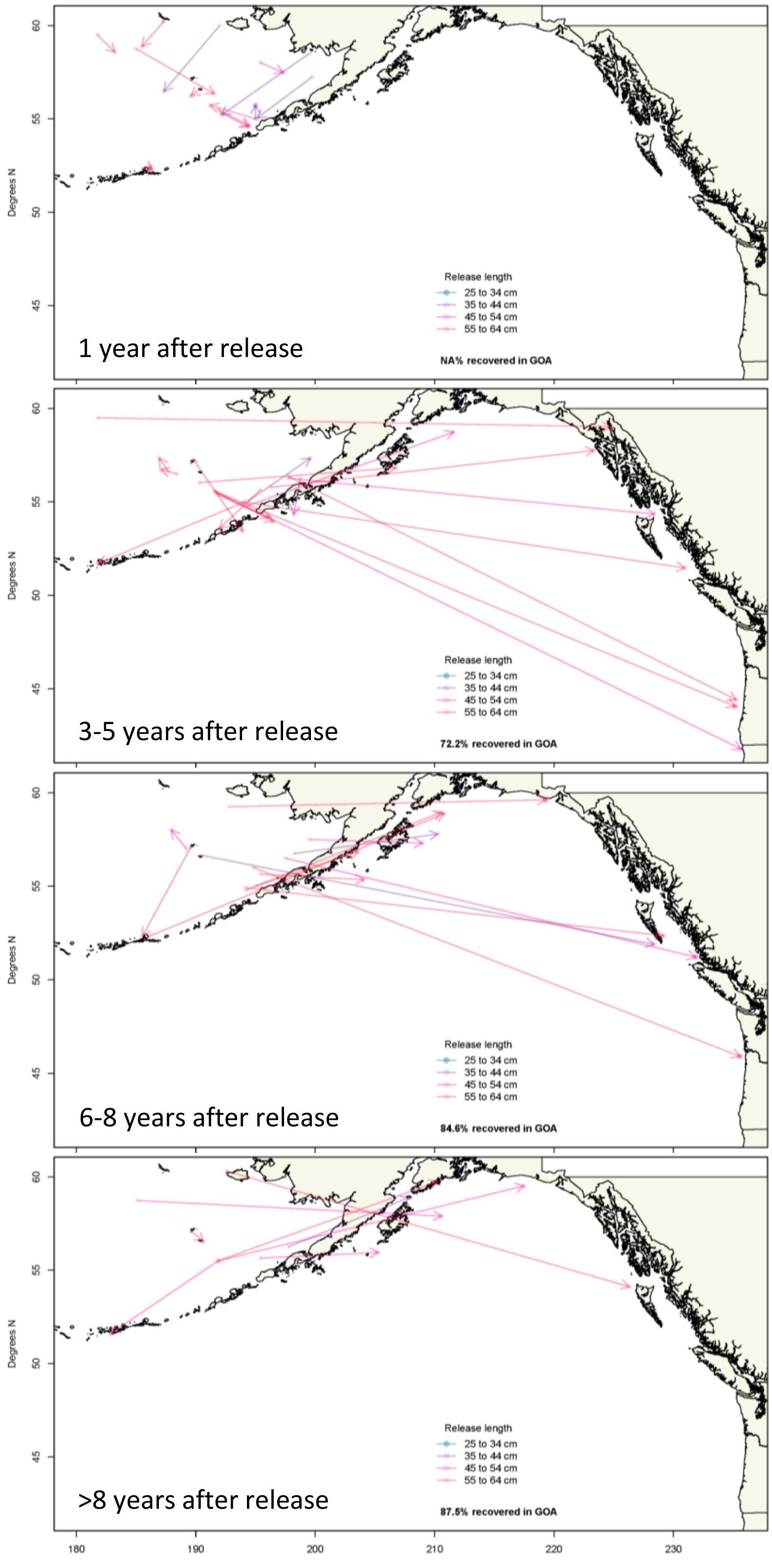

Figure 13. Release and recovery locations for juvenile halibut tagged in the Bering Sea, grouped by time at large (From: Webster, *in prep.*)

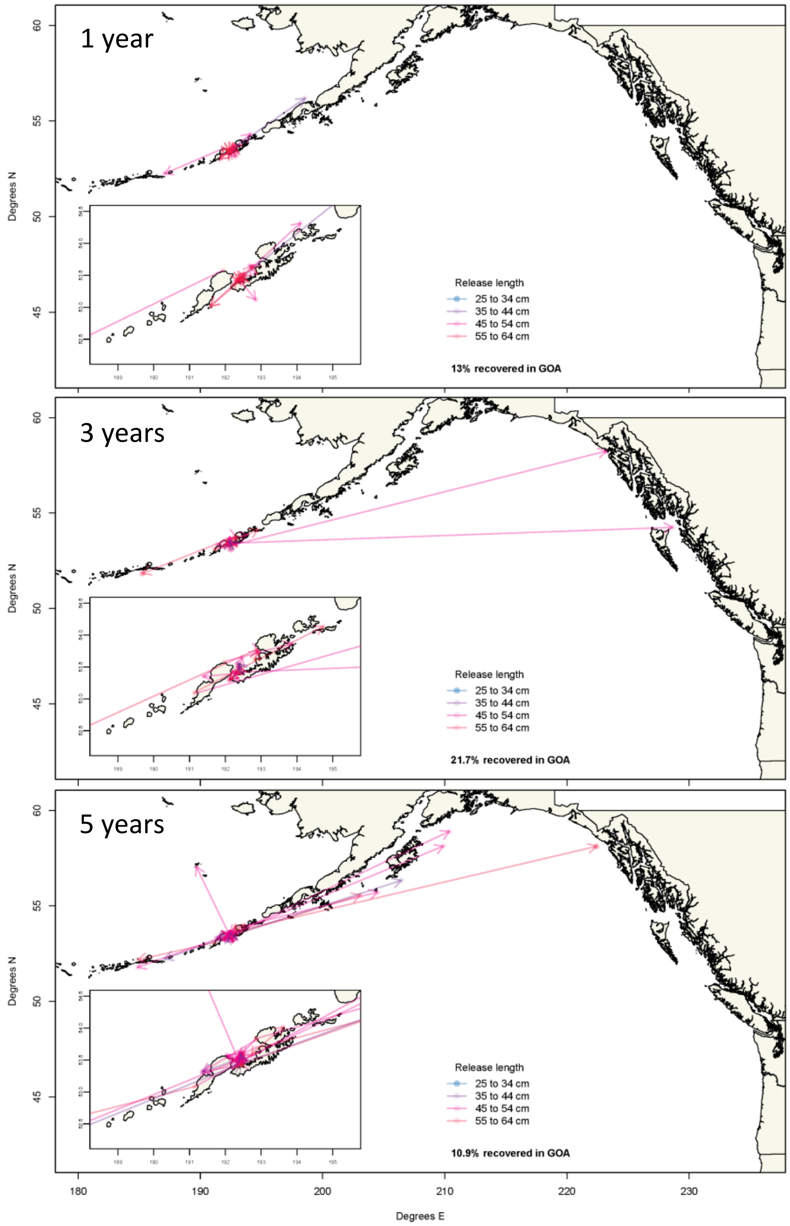

Figure 14. Release and recovery locations for juvenile halibut tagged near Unalaska, grouped by time at large (also see next figure; From: Webster, *in prep.*).

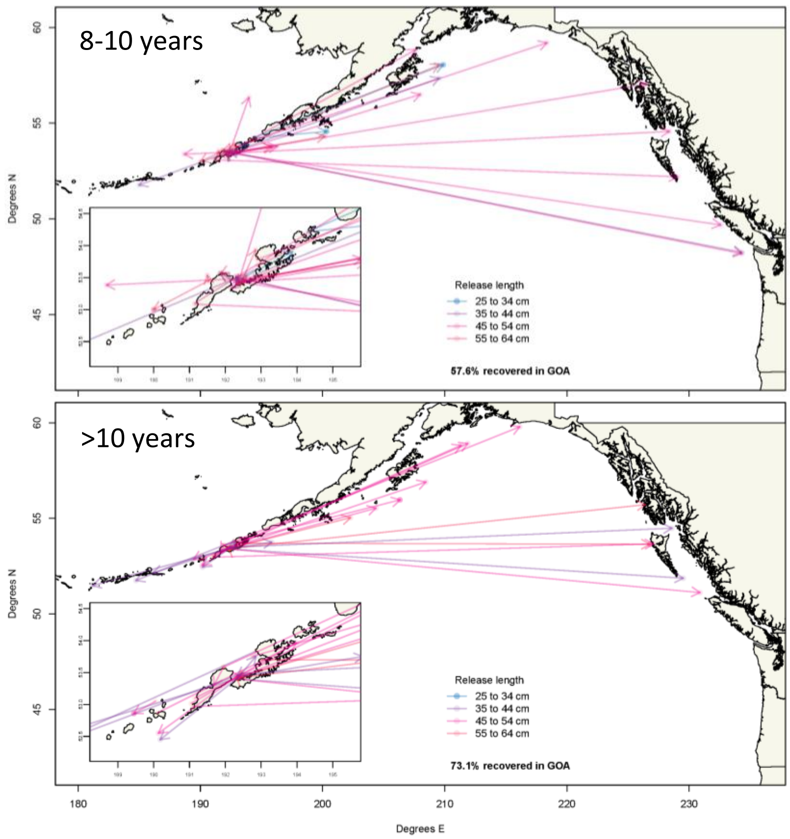

Figure 15. Release and recovery locations for juvenile halibut tagged near Unalaska, grouped by time at large (also see previous figure; From: Webster, *in prep.*).

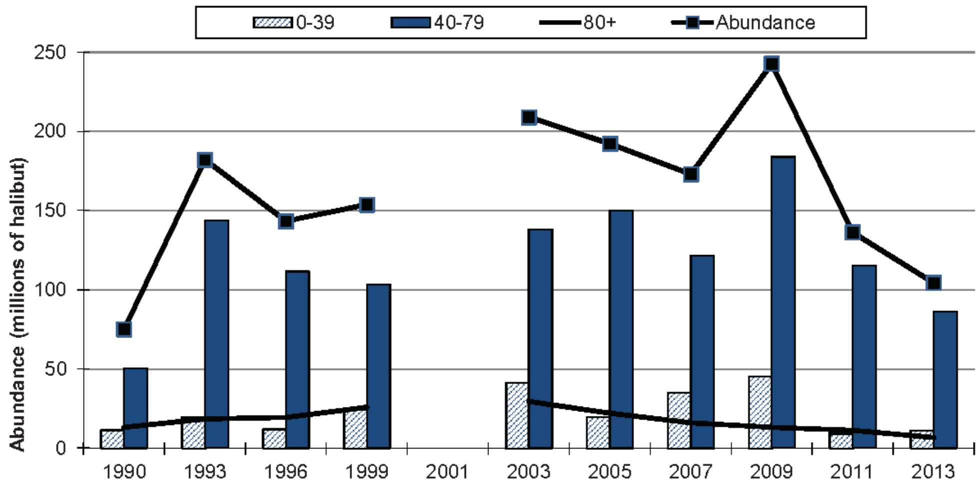

Figure 16. Total estimated halibut abundance (millions) by size category from the NMFS Gulf of Alaska bottom trawl survey for the years 1990-2013. There is no total estimate for 2001 due to incomplete survey coverage in the Eastern Gulf.

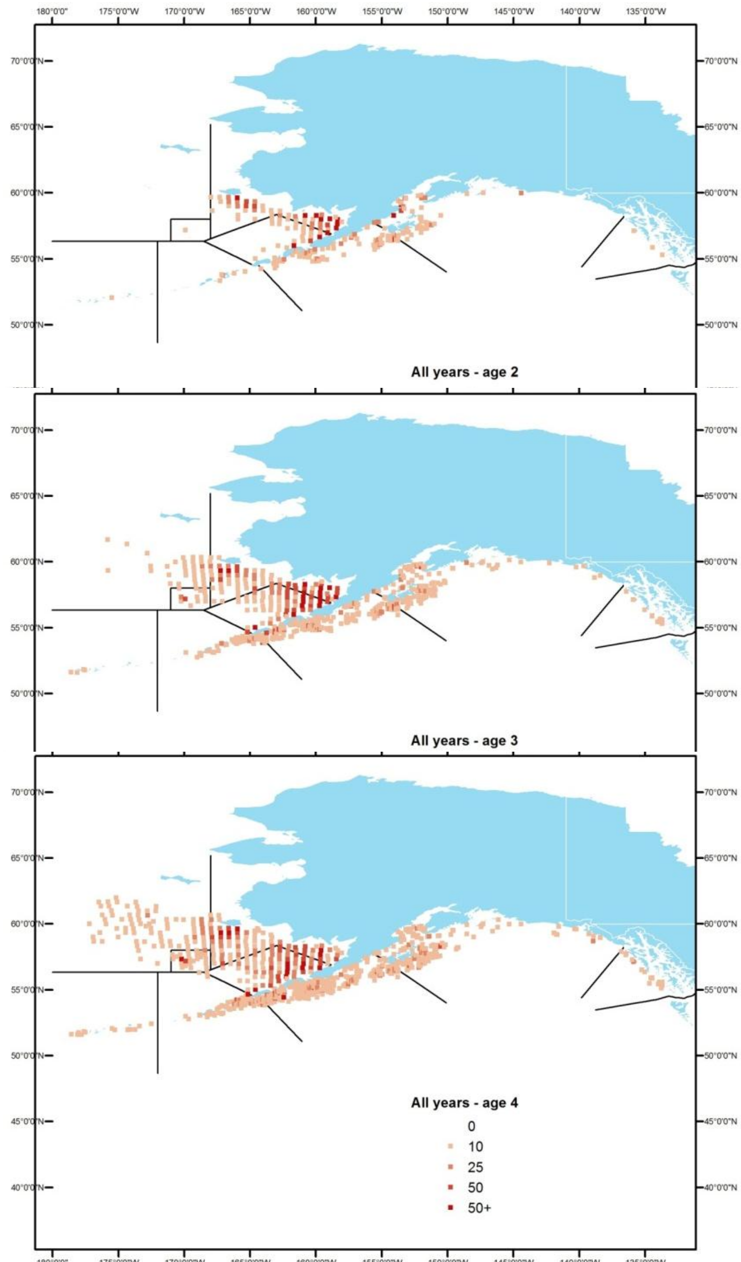

Figure 17. Distribution of aggregate halibut catch by age from all available NMFS Bering Sea, Aleutian Islands, and Gulf of Alaska trawl surveys.

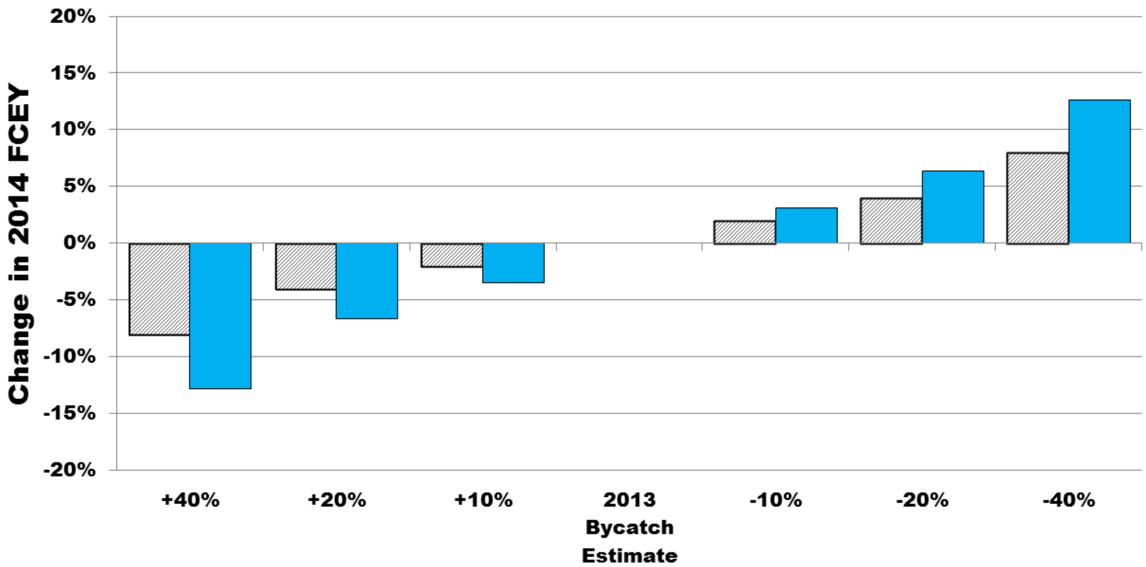

Figure 18. Change in projected coastwide 2014 FCEY in response to changes in coastwide halibut bycatch. Gray bars (left) indicate the application of current harvest policy directly accounting for only O26 mortality, darker blue bars (right) indicate an extension of this policy explicitly accounting for all mortality by maintaining the same level of fishing intensity (SPR) for all scenarios.