Overview of data sources for the Pacific halibut stock assessment, harvest policy, and related analyses

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PURPOSE

To provide the Commission with an overview of the data sources available for the Pacific halibut (*Hippoglossus stenolepis*) stock assessment, harvest policy, Management Strategy Evaluation (MSE) and other related analyses.

INTRODUCTION

This document began as background for the 2013 stock assessment (Stewart 2014), and has served as an annually updated source for direct evaluation of the data and processing methods employed. Beginning in 2017, the IPHC has increasingly moved toward making all data sources available through the website (https://www.iphc.int/data/iphc-secretariat-data). Many of these data are now also interactive, such that they can be plotted and investigated to a far greater degree than possible in this or other static documents. It is anticipated that this document will be phased out as all data sources are moved to the website. For this year, links have been added to existing online resources, and some material (where redundant or outdated) has been removed.

For each data source reported, a brief narrative is provided which includes the primary source of information, steps taken to filter and analyze the data, and the key quantities available for subsequent analysis. Data sources are described within the categories of: fishery-independent, fishery-dependent, and auxiliary sources of information. The level of detail is adjusted annually to allow for additional description of new sources or changes in analysis methods; greater detail presented in previous versions is not repeated annually if there has been no change to the methods or results.

Also provided in this document is a brief synopsis of important changes made in the current year, as well as a list of data sources or analyses that are not directly used, but are available for comparison and/or future analysis. The 2019 stock assessment is provided as a separate document.

FISHERY-INDEPENDENT DATA

Fishery-independent data are generated each year by the IPHC's Fishery-Independent Setline Survey (FISS), covering most of the range of Pacific halibut habitat from the northern Bering Sea and Aleutian Islands to California, and depths of 20-275 fathoms (Soderlund et al. 2012; Figure 1). The setline survey generates catch rate information, as well as biological samples from individual fish sampled randomly from the catch including: sex, length, age, maturity, the presence of prior hooking injury, and recently a small subsample of individual fish weights. Data are initially compiled by IPHC Regulatory Area, aggregated to the four Biological Regions (Seitz et al. 2017): Region 2 (Areas 2A, 2B, and 2C), Region 3 (Areas 3A, 3B), Region 4 (4A, 4CDE) and Region 4B, and finally to the coastwide level.

These data[1] are re-analyzed via the space-time model each year, in their entirety, for use in the stock assessment as new observations become available that inform the time-series (**IPHC-2020-AM096-07**). In 2019, the six-year program of FISS expansions was concluded with sampling of all stations in the design in IPHC Regulatory Areas 3A and 3B (**IPHC-2020-AM096-06**). The time-series of modelled FISS data extends from 1993-2019.

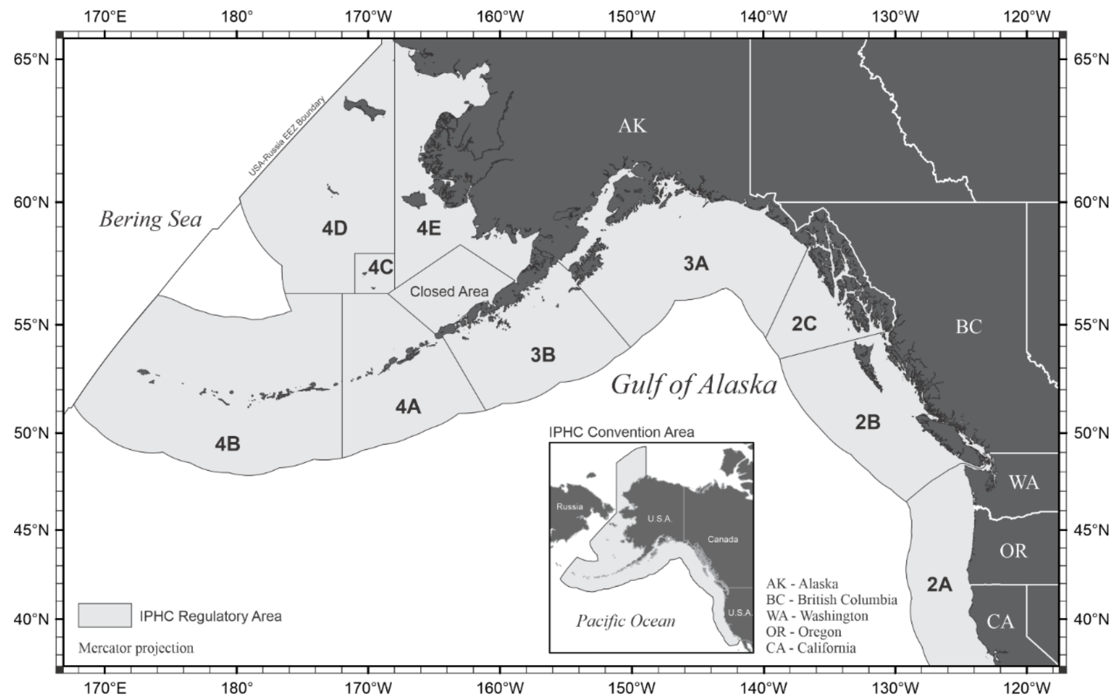

FIGURE 1. IPHC Regulatory Areas and the Pacific halibut geographical range within the territorial waters of Canada and the United States of America.

In addition to their use in supplementing the FISS data in IPHC Regulatory Area 4CDE (**IPHC-2020-AM096-07**), the NMFS trawl surveys in Alaska provide valuable information on the age, size-at-age, and abundance of Pacific halibut, particularly in the Eastern Bering Sea. These data are used to estimate size-at-age for young Pacific halibut not frequently encountered in the FISS, as well as trends in abundance and age structure of that demographic component of the overall Pacific halibut stock.

Modelled FISS WPUE (Weight-Per-Unit-Effort) and NPUE (Numbers-Per-Unit-Effort)

The modelled catch-rate information from the setline survey serves as the primary source of relative trend information (along with commercial catch-rates) for the stock assessment. This information also provides the basis for the best available estimates of the stock distribution by Biological Region.

The modelled FISS trends reported here reflect the output of the space-time model (**IPHC-2020-AM096-07**). The stock assessment models fit directly to the modelled Numbers-Per-Unit-Effort (NPUE), in order to avoid converting observed lengths to weights based on the length-weight relationship, and to provide a delineation between changes in the number of fish and changes in the size of those fish (included in the models via the mean weight-at-age; see below). Modelled survey NPUE showed a third year of decline from 2017 to 2019 (4% below 2018 coastwide),

[1] Raw catch rates and biological data from the FISS can be explored through the IPHC's website: https://www.iphc.int/data/iphc-secretariat-data

with the most pronounced decrease in Biological Region 3 (-10%; Figure 2). Other Biological Regions increased slightly, but remain near the lowest values in the modelled time-series. Individual IPHC Regulatory Areas ranged from a 16% increase (Area 2A), to a 19% decrease (Area 3A), with all Areas near historical lows (Figure 3).

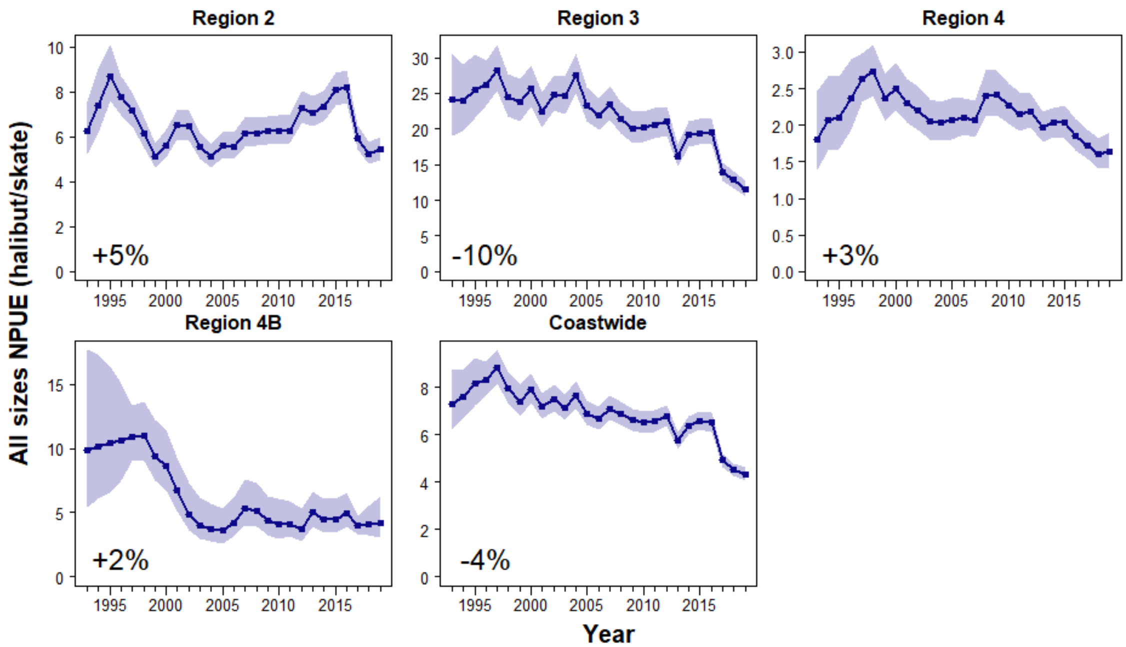

FIGURE 2. Trends in modeled survey NPUE by Biological Region, 1993-2019. Percentages indicate the change from 2018 to 2019. Shaded zones indicate 95% credible intervals.

Modelled survey WPUE (including all sizes of Pacific halibut captured by the FISS) decreased 5% from 2018 to 2019, the lowest value in the time series since 1993 (Figure 4). Biological Regions 3 and 4B showed the largest individual decreases of 10% and 12%, respectively. IPHC Regulatory Area 3A showed the largest decrease, 20% from 2018 to 2019, with IPHC Regulatory Area 3B up 18% (Figure 5). Trends in modelled legal-size, above the 32 inch (81.3 cm) minimum size limit (O32) WPUE were very similar to those for the modelled WPUE of all sizes of Pacific halibut captured by the FISS (Figures 6 and 7). Time-series tables of modelled survey catch rates are available online.

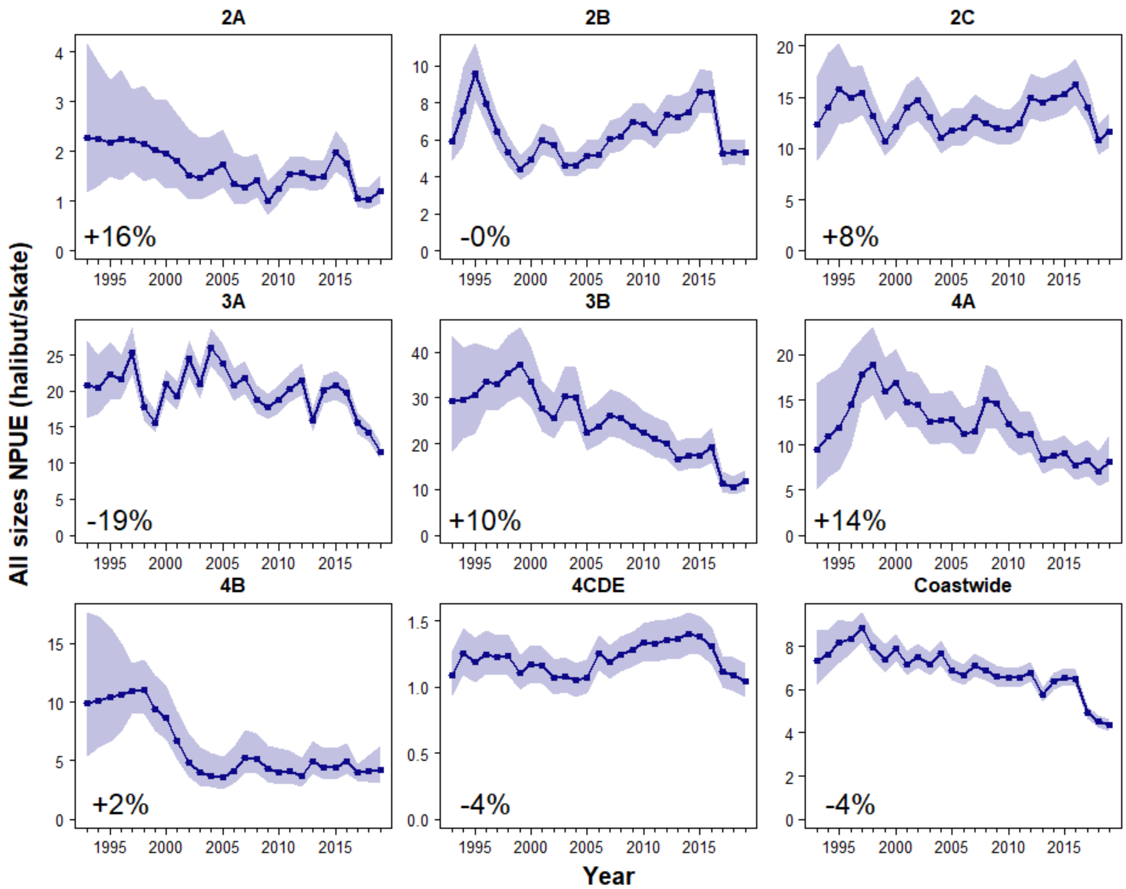

FIGURE 3. Trends in modelled survey NPUE by IPHC Regulatory Area, 1993-2019. Percentages indicate the change from 2018 to 2019. Shaded zones indicate 95% credible intervals.

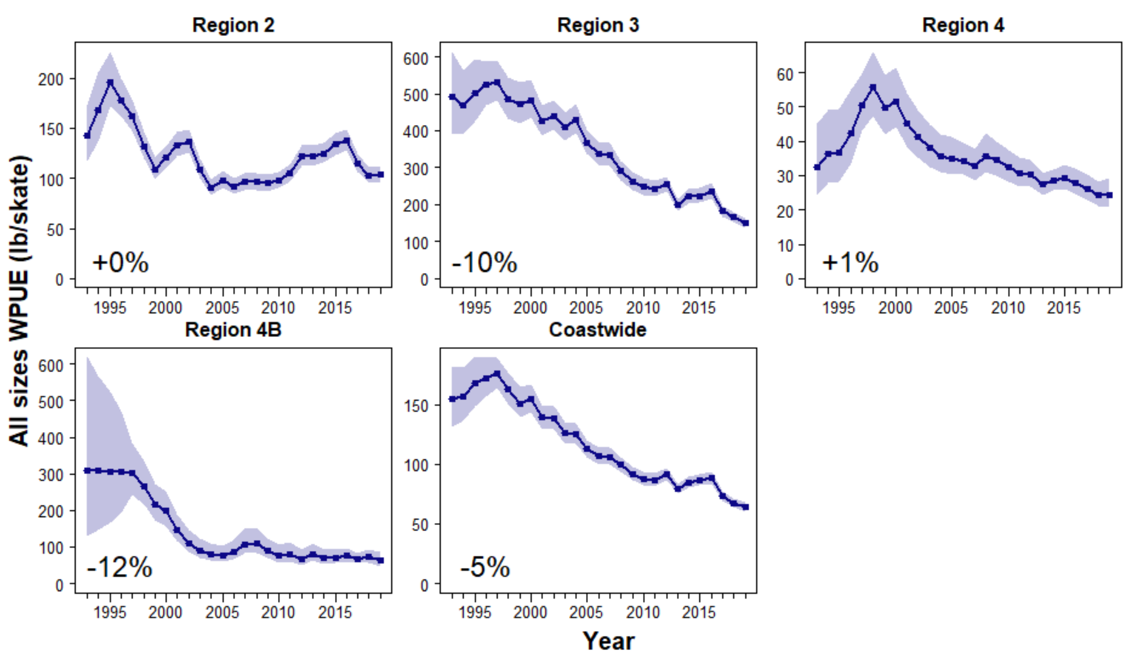

FIGURE 4. Trends in modelled survey WPUE by Biological Region, 1993-2019. Percentages indicate the change from 2018 to 2019. Shaded zones indicate 95% credible intervals.

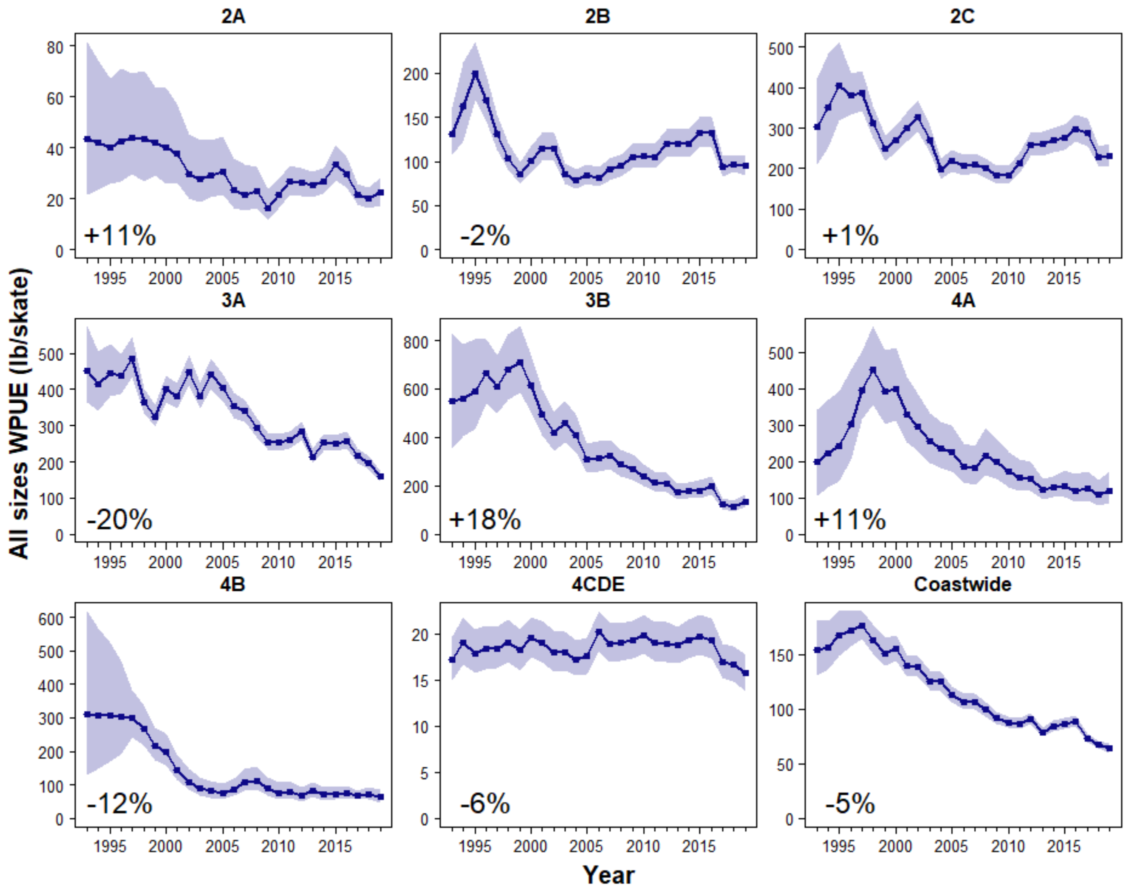

FIGURE 5. Trends in modelled survey WPUE by IPHC Regulatory Area, 1993-2019. Percentages indicate the change from 2018 to 2019. Shaded zones indicate 95% credible intervals.

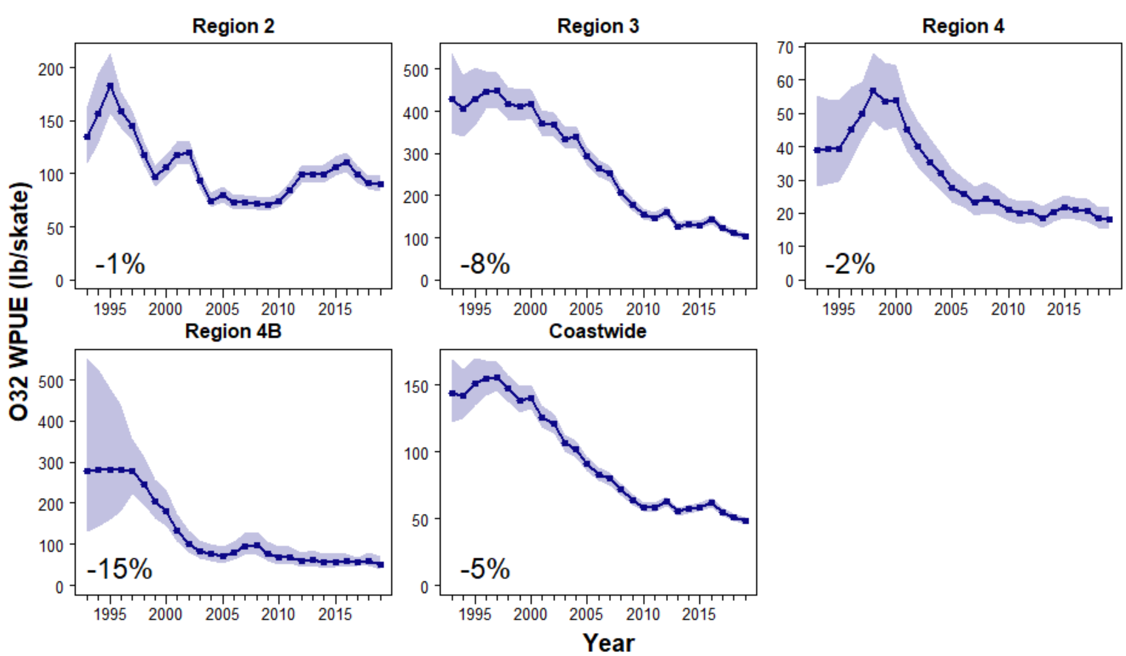

FIGURE 6. Trends in modelled survey legal (O32) WPUE by Biological Region, 1993-2019. Percentages indicate the change from 2018 to 2019. Shaded zones indicate 95% credible intervals.

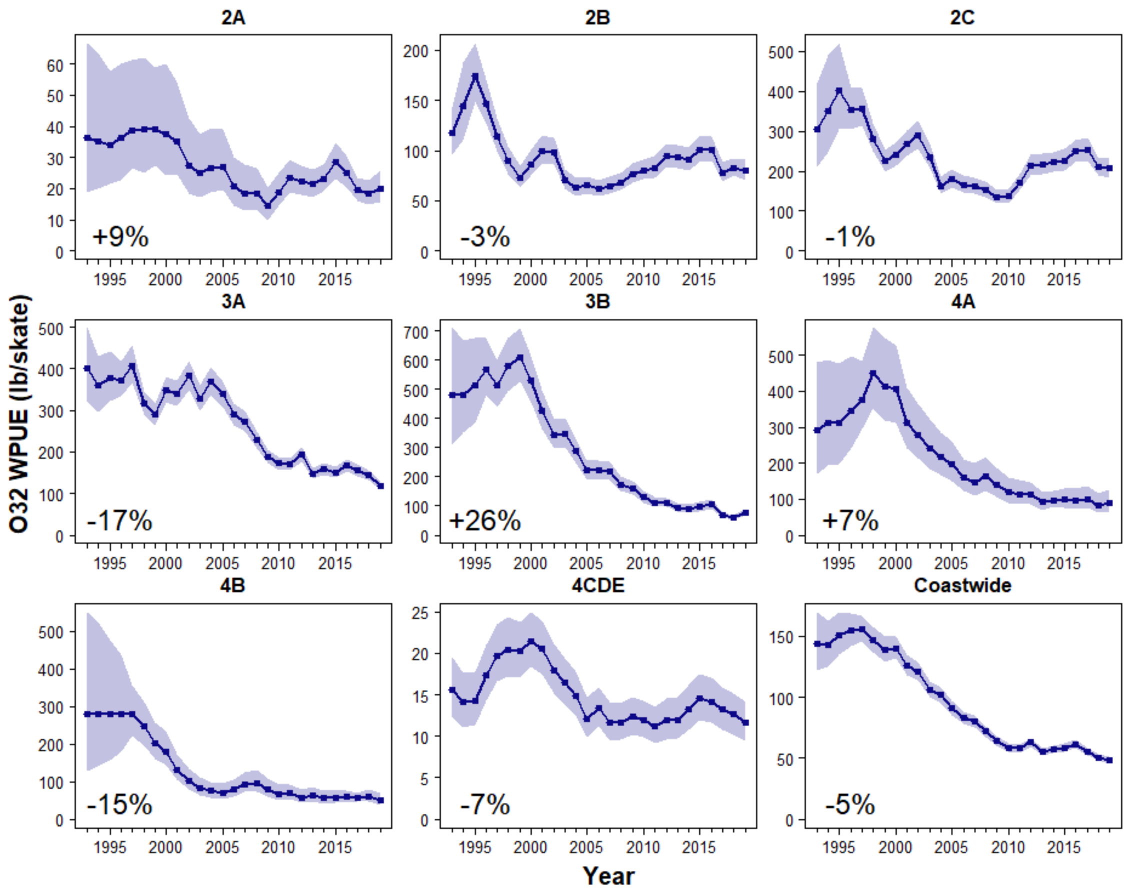

FIGURE 7. Trends in modelled survey legal (O32) WPUE by IPHC Regulatory Area, 1993-2019. Percentages indicate the change from 2018 to 2019. Shaded zones indicate 95% credible intervals.

Biological stock distribution

Modelled survey WPUE (a proxy for density of all sizes of Pacific halibut captured by the setline survey), and the geographical extent of Pacific halibut habitat, are used to produce the best available estimates of the stock distribution by Biological Region. With the addition of the data collected during the FISS expansion in 2019, the trend in stock distribution in Biological Region 3 has been somewhat revised, and now indicates a decline over the last five years and also extending back to 2004 (Figure 8). Biological Region 2 increased rapidly from 2004 to 2013, and has been relatively flat since then, considering the width of the credible intervals. Survey data are insufficient to estimate stock distribution prior to 1993. It is therefore unknown how historical distributions, and the average distribution likely to occur in the absence of fishing mortality may compare with recent observations. Time-series' of stock distribution estimates by Biological Region, as well as distribution estimates by Individual IPHC Regulatory Areas (for all sizes of Pacific halibut captured by the setline survey and for O32 only) are available online.

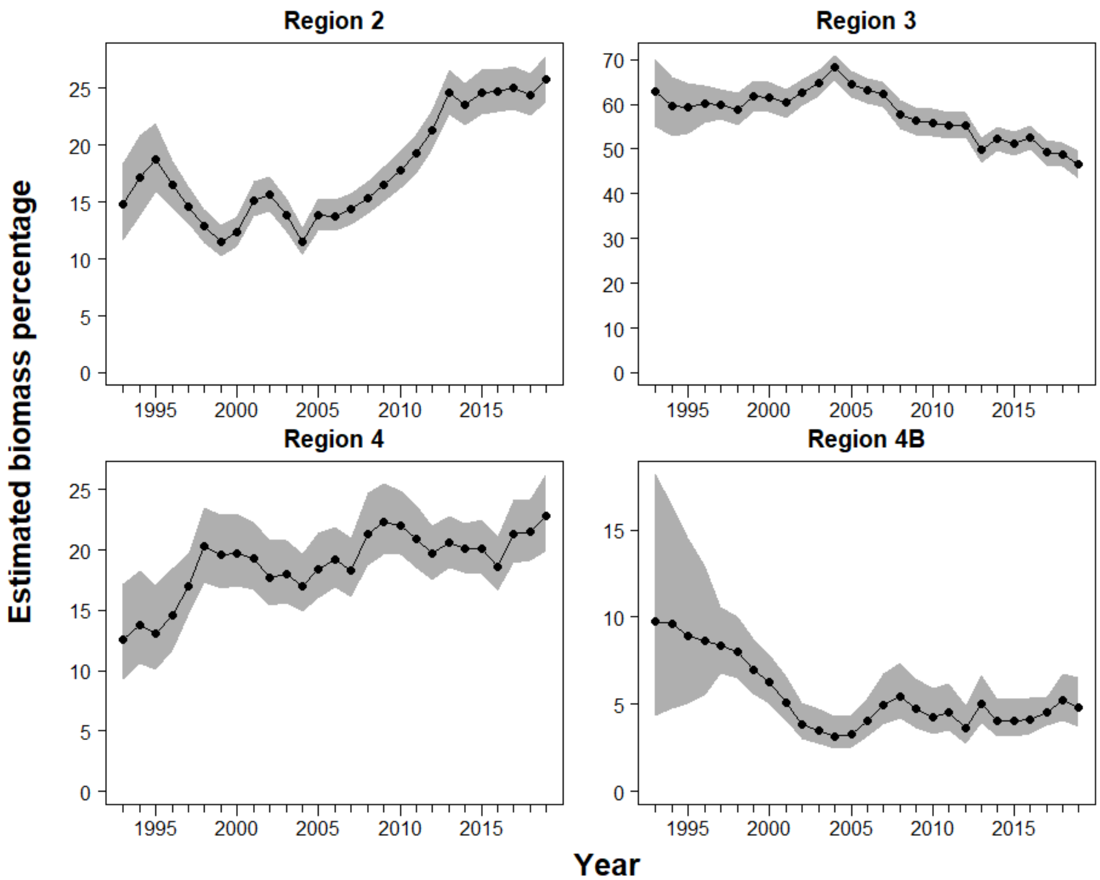

FIGURE 8. Estimated biological stock distribution (1993-2019) from modelled survey WPUE of all sizes of Pacific halibut captured by the FISS. Shaded zones indicate 95% credible intervals.

FISS age distributions

Otoliths are collected randomly from Pacific halibut captured by the FISS, with sampling rates adjusted by Individual IPHC Regulatory Area to achieve a similar number of samples from each Area in each year. All otoliths collected during FISS activities are read each year by IPHC age-readers. Because the FISS catch is sampled randomly at the same rate for all stations within an IPHC Regulatory Area and year, the raw frequency of ages is an unbiased estimate of the aggregate for the Area. Age distributions differ between male and female Pacific halibut and among IPHC Regulatory Areas, with older fish primarily males, and with males occurring in much greater numbers in the western IPHC Regulatory Areas (3B-4B, Figure 9). Age-14 Pacific halibut, corresponding to the 2005 cohort, were the most abundant coastwide in the 2019 data, although age distributions and sex ratios varied considerably among IPHC Regulatory Areas. For IPHC Regulatory Areas 3B, 4A and 4CDE, Pacific halibut from the 2011 and 2012 cohorts (age-7 and age-8 in 2019), represented the largest proportions of female in 2019. This is the second observation of these cohorts and confirms that they are stronger than other recent cohorts born from 2006-10.

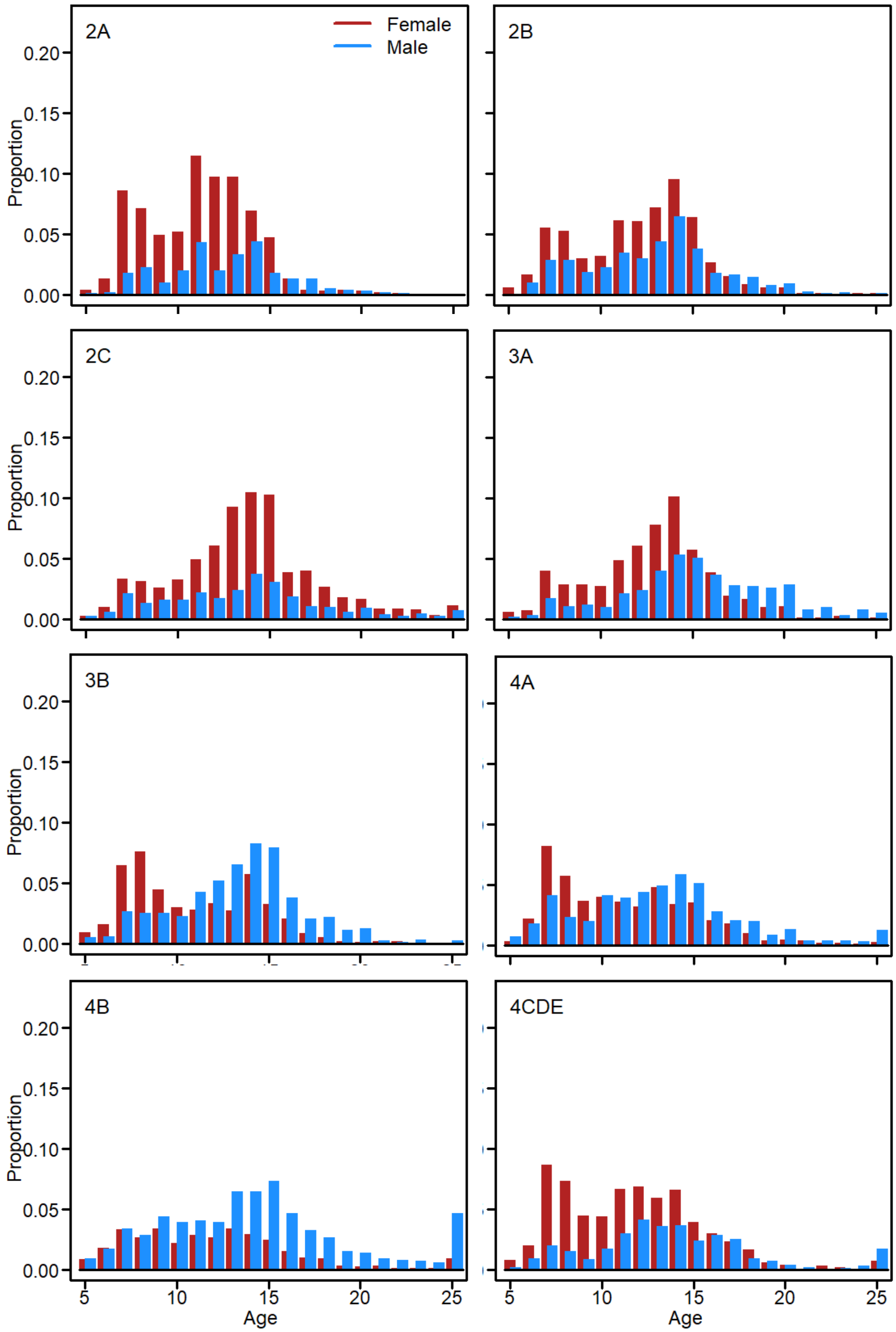

FIGURE 9. Age distributions from the 2019 FISS by IPHC Regulatory Area. Red bars indicate the proportion of females (by number) in the FISS catch, and the blue bars indicate proportions for male Pacific halibut.

In order to weight these area-specific distributions, an estimate of the number of Pacific halibut in each area is required. The modelled survey NPUE is used for consistency between the trend and biological information, as the relative numbers in each IPHC Regulatory Area provide a weighting for combining the age-frequency distributions into Biological Regions and to a coastwide aggregate (Figure 10). From the late 1990s through the mid-2000s, the strength of the 1987 year class is particularly evident in these data. The age frequencies over the last five years are relatively constant, dominated by ages 8-16, with the 2005 year-class the most numerically abundant from 2015-2019, observed to be age-14 in 2019. Following initial indications in the 2018 data of increased recruitment from the 2011-2012 cohorts (ages 6-7 in 2018), these year-classes were again observed to be larger than others from recent years (2006-2010) in the 2019 data.

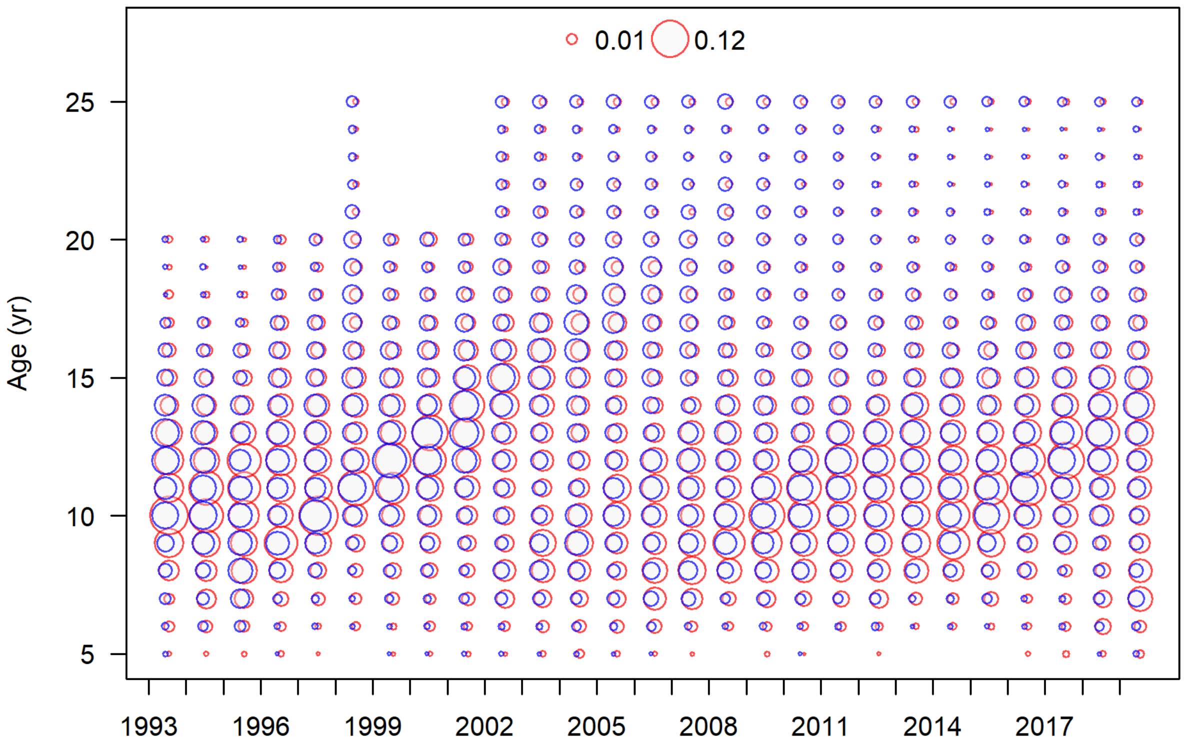

FIGURE 10. Recent coastwide proportions-at-age for females (red circles) and males (blue circles) from the FISS. Proportions sum to 1.0 across both sexes within each year.

Ages have been aggregated at age-25 for all observations using the break-and-bake ageing method. This method was adopted for all Pacific halibut age-reading by the IPHC (see section on ageing bias and imprecision below) in 2002. Ages have been aggregated at age-20 (all ages-20 and older combined) for all data (setline survey and fishery) collected prior to 2002. Most ages read prior to 2002 used surface ageing methods, except for 1998, where a randomly selected subsample of otoliths were re-aged (during 2013) and ages can now be more reliably interpreted out to age-25 (see Forsberg and Stewart 2015; Stewart 2014 for more information on these samples).

Similar to the setline survey catch-rate data, there are some sparse age data available prior to 1997. These age data represent only Areas 2B, 2C, and 3A for the years 1982-96, and only Areas 2B and 3A for the years 1980-81. These earlier data do not reveal any particularly strong cohorts, nor do the cohort strengths appear appreciably different for male and female Pacific halibut. When aggregated by Biological Region, age data reveal consistent differences in age structure and sex-ratio (Figures 11-12). Specifically, there have been very few Pacific halibut greater than age 20 of either sex observed in Region 2, but fish of those ages, and particularly males, become more common in the western and northern portions of the stock. Region 4B shows the highest proportion of male Pacific halibut, and also the greatest frequency of fish aged 25+ (Figure 12). Despite these general differences, the 2011 and 2012 cohorts can be seen across all four Biological Regions.

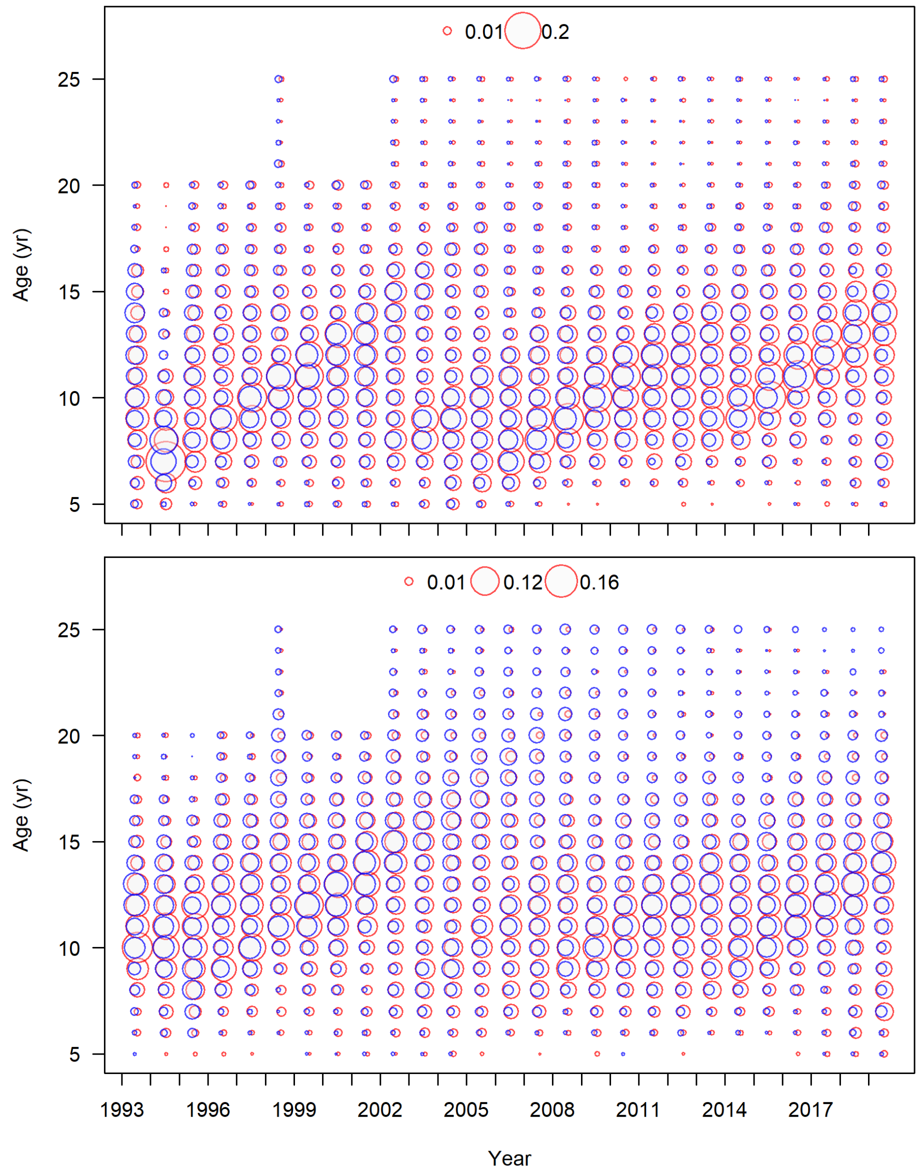

FIGURE 11. Recent proportions-at-age for female (red circles) and male (blue circles) Pacific halibut captured by the FISS from Biological Region 2 (upper panel) and Region 3 (lower panel). Proportions sum to 1.0 across both sexes within each year.

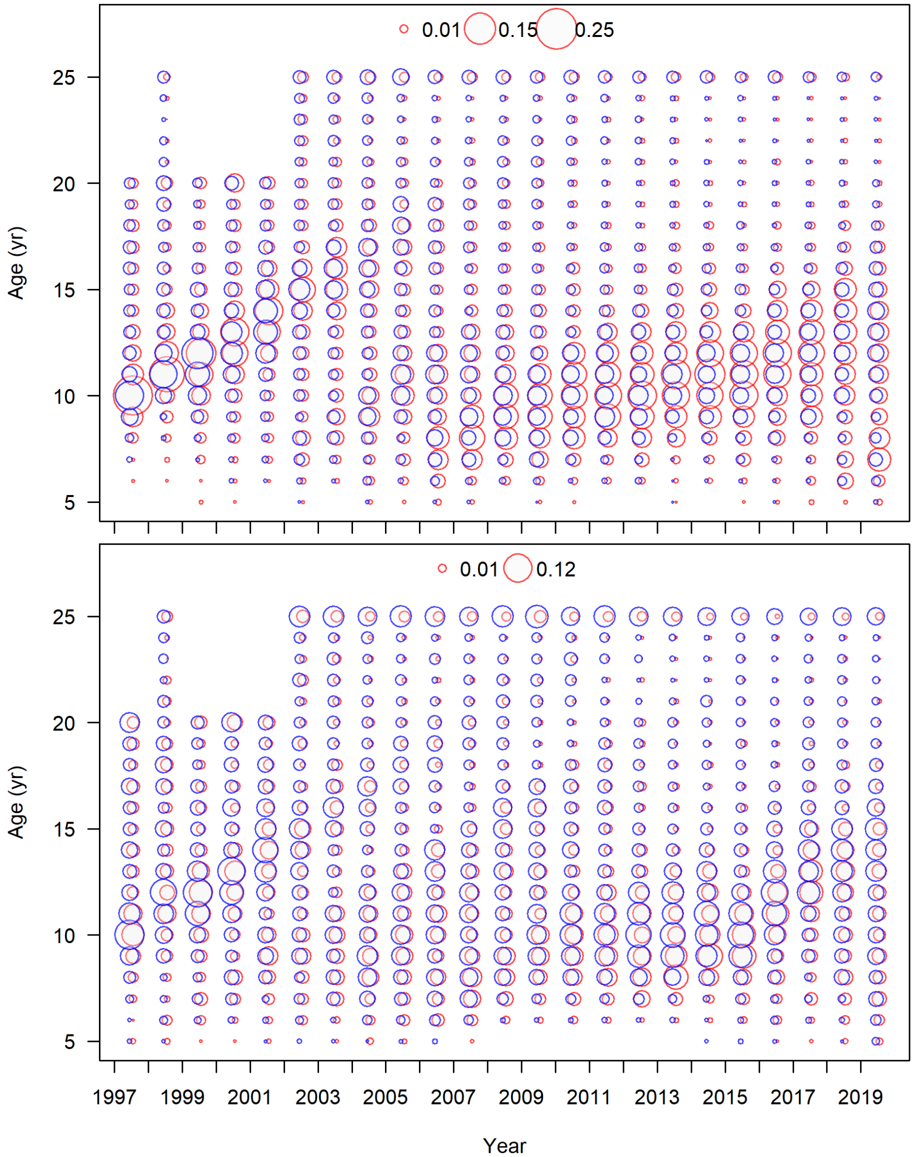

FIGURE 12. Recent proportions-at-age for female (red circles) and male (blue circles) Pacific halibut captured by the FISS from Biological Region 4 (upper panel) and Region 4B (lower panel). Proportions sum to 1.0 across both sexes within each year.

Sublegal (U32) FISS age distributions

The age-distribution of sublegal (less than 32 inches, 81.3 cm; U32) Pacific halibut captured by the FISS is used as a means to approximate the Pacific halibut comprising commercial discard mortality associated with the directed commercial fishery (Stewart and Hicks 2019). These discards occur primarily due to the minimum size limit, of which a portion are assumed to subsequently die. These FISS data show a protracted age-distribution, particularly for males in Area 3A (Figures 13-14). The age-distribution for the two sexes also differs importantly, with sublegal females present in appreciable numbers from roughly age 7 to 11, and sublegal males from 7 to well beyond age 15 in some years. The protracted age structure of fish below the 32" (81.3 cm) minimum size-limit illustrates the effects of variability in size-at-age: some fish from each cohort reaching the minimum size limit by age-6, and others (particularly males) many years later. The 2011 and 2012 year classes, at 7-8 years old in 2019 currently represent the most numerically abundance sublegal Pacific halibut.

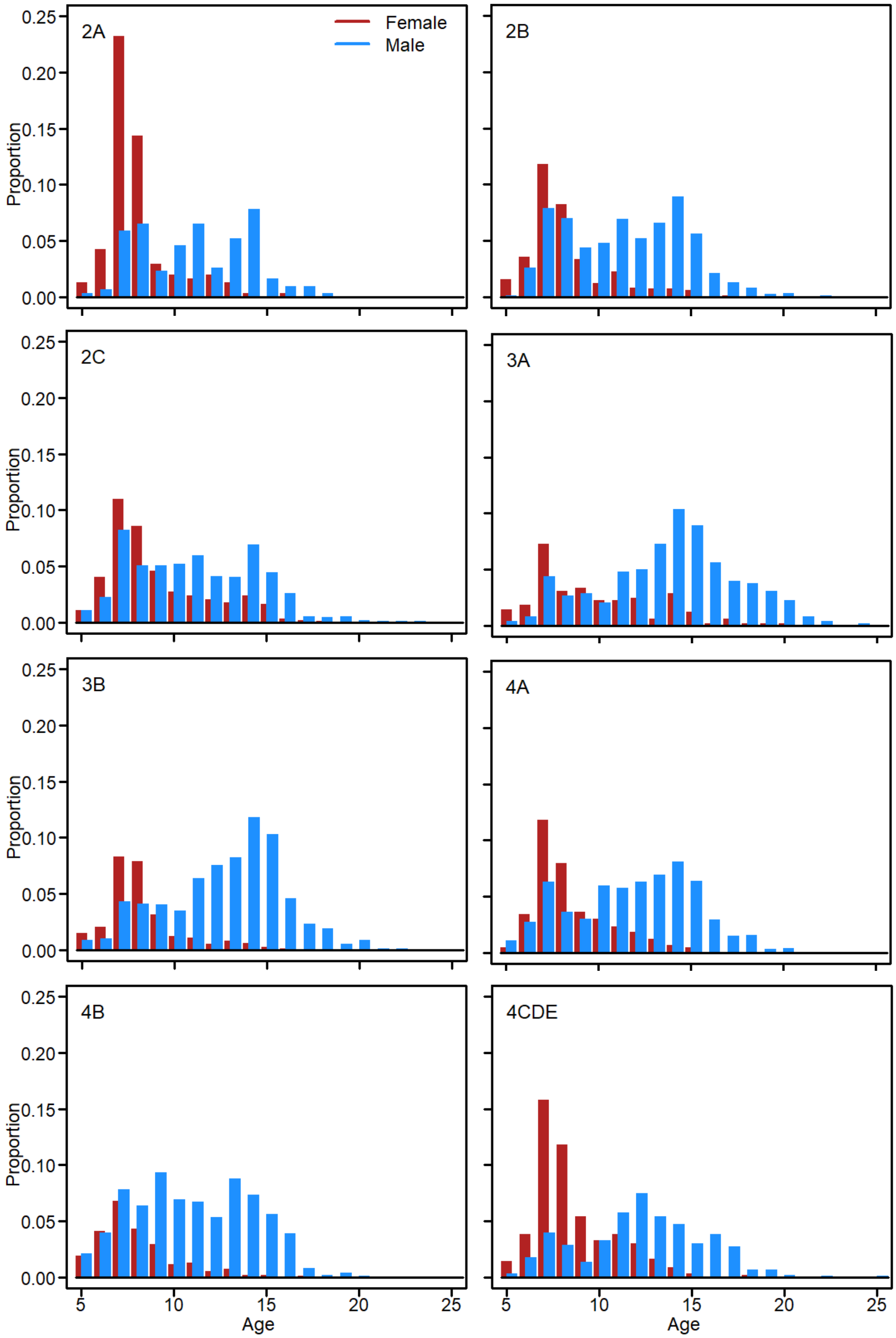

FIGURE 13. Sub-legal (U32) age distributions from the 2018 FISS by IPHC Regulatory Area.

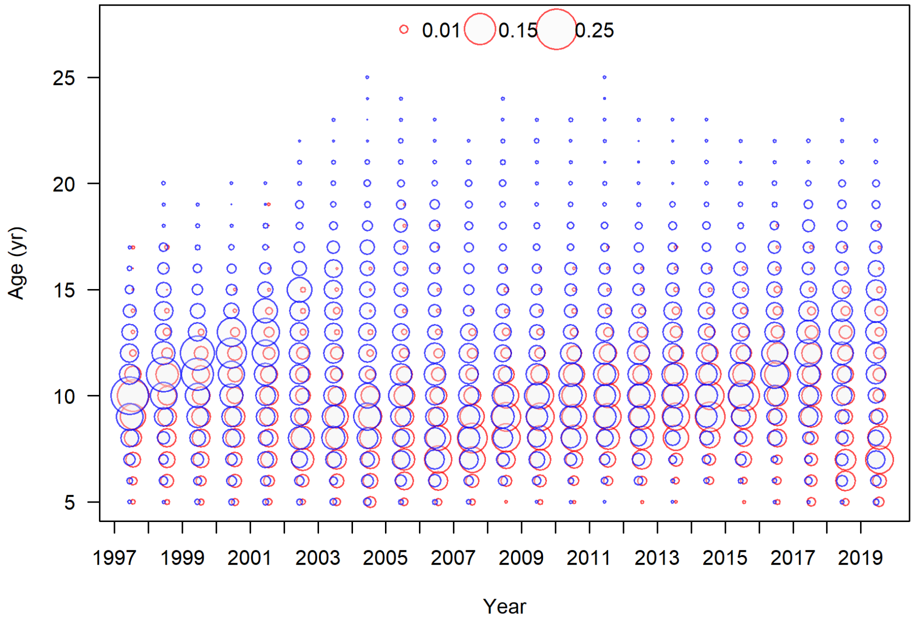

FIGURE 14. Recent coastwide proportions-at-age for sublegal (U32) female (red circles) and male (blue circles) Pacific halibut captured by the FISS. Proportions sum to 1.0 across both sexes within each year.

FISS weight-at-age

The FISS collects individual length observations on all Pacific halibut captured, which are then converted to estimated weights via the length-weight relationship (see section below). Age estimates are also available for a random subsample of these lengths.

Ages consist of primarily surface ages prior to 2002, and exclusively break-and-bake ages from 2002 to the present. Prior analyses of weight-at-age attempted to correct for the potential bias of surface ages by converting the weights corresponding to surface ages to the 'true' weight at age given an estimated level of bias (and some assumption of the underlying age structure). Investigation of the data prior to 2002 revealed that many of the surface ages also had corresponding break-and-bake ages that were not being included in the analysis (see summary of ageing bias and precision below). Replacing all surface ages with break-and-bake ages (where available) in the weight-at-age calculations appears to adequately address the differences in the ageing methods for the recent data.

Because the sampling of ages is random within the FISS catches for an area each year, the average weight-at-age by area, sex, and year can be calculated directly. Where there are very few individuals in the population of a particular age, the number of FISS age samples is also small (the age samples are not length-stratified). This pattern, in combination with incomplete FISS sampling for some areas and years, results in a small number of missing weights-at-age within area and year combinations. These are simply interpolated from adjacent years. Because the FISS captures few fish younger than age 7 or older than age 25, all fish outside this range are aggregated to these 'minus' and 'plus' groups (but see NMFS trawl survey section below). Although there has been a very strong trend of declining weight-at-age in recent decades, there are marked differences in the magnitude of this decline among Regulatory Areas (an interactive tool to view detailed weight-at-age information is available on the IPHC's website: https://iphc.int/data/iphc-secretariat-data). There also appear to be some patterns associated with specific cohorts; e.g. females in Area 2C born in the late-1990s and mid-2000s. These different trends among IPHC Regulatory Areas require appropriate weighting to create a coastwide time-series that represents the entire stock. The estimates of numbers of fish generated from modelled survey NPUE are used to weight the individual IPHC Regulatory Areas. At the coastwide level, there appear to be small increases in size-at-age for both males and females over many ages (Figure 15); however, this is also consistent with year-to-year variability observed in the past. When the weighted coastwide observations are smoothed across years, there appears to be little consistent change since 2015 with younger ages increasing, and older ages decreasing (Figure 16). A broader comparison of historical observations predicted from a mix of fishery and FISS data (See Fishery weight-at-age section below) indicates that the declines in size-at-age for female Pacific halibut were even more pronounced from the mid-1970s to the mid-1990s than in the recent period covered by the FISS. Current size-at-age is estimated to be at or near historical lows with some indication of increases for younger ages coastwide (Figure 17).

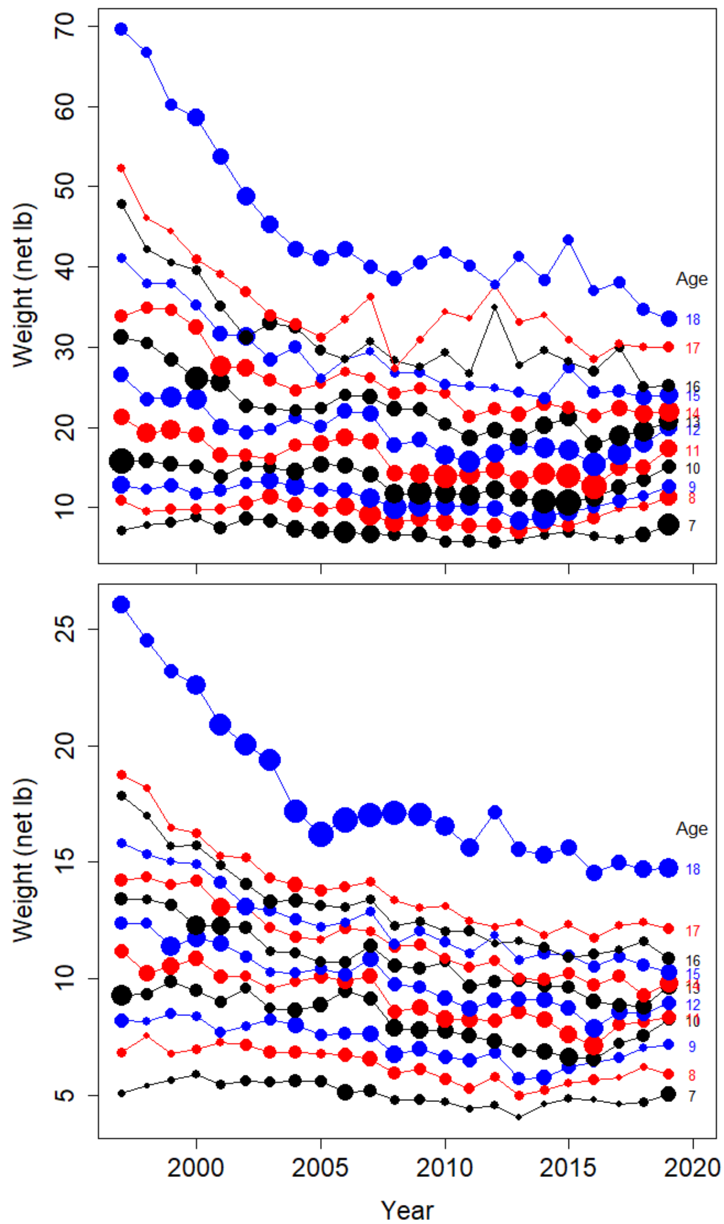

FIGURE 15. Weighted coastwide trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the FISS. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and older, and ages 7 and younger have been aggregated for clarity.

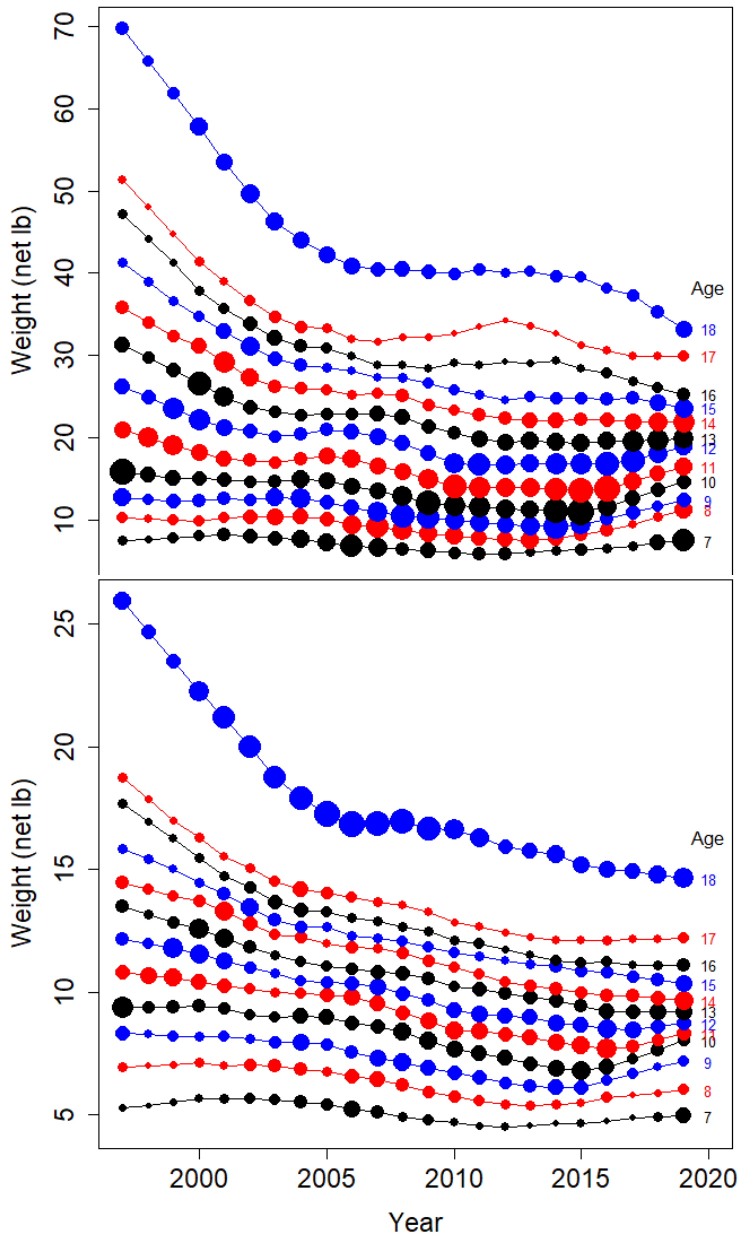

FIGURE 16. Weighted and smoothed recent coastwide trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the FISS. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and older, and ages 7 and younger have been aggregated for clarity.

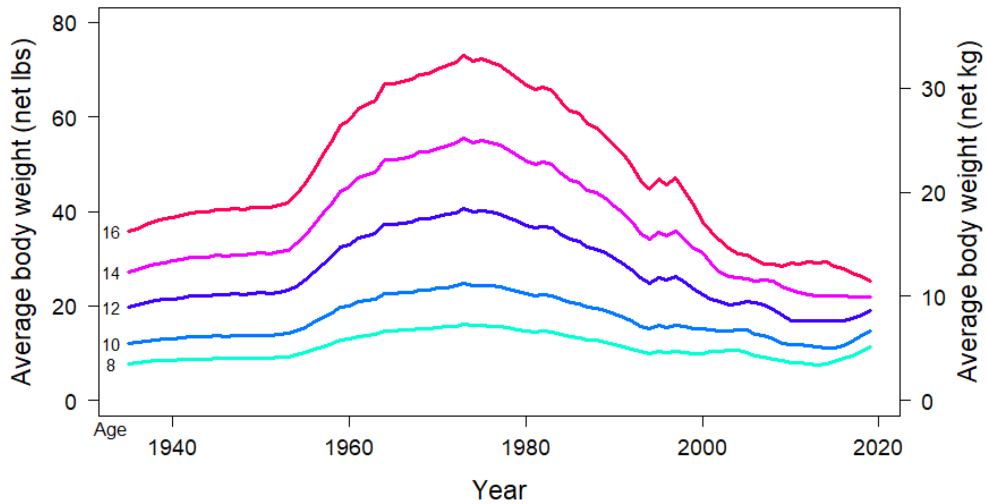

FIGURE 17. Estimated average female weight-at-ages 8, 10, 12, 14 and 16 trends from FISS and fishery data since 1935.

Spawning output-at-age

FISS data are also used to define the population-level weight-at-age and spawning biomass. Unlike the FISS index calculation, where inter-annual sampling variability is logically included, the true population level quantities should be smoother than the raw observations. Applying a smoother across years within each age produces results more consistent with those expected for population level values; these summaries most clearly show the population-level decline in weight-at-age observed for both male and female Pacific halibut over the period from the late 1990s to around 2010 (Figure 16). FISS observations of weight-at-age might include some bias relative to the population if size-based selectivity is operating on the distribution of lengths within each age. However, the matrix of population-level weight-at-age is most important in the assessment for those ages that are mature, for Pacific halibut mainly ages 11 and higher (see Maturity section below) which are less likely to experience significant bias. Collection of direct measurements of individual weight during FISS operations began in 2019, and will replace the historical use of a static weight-length relationship for future analyses.

NMFS Trawl surveys in Alaska

Pacific halibut stock analyses have used various extrapolation and smoothing methods to assign weight-at-age to fish that are younger than those observed in the FISS, which provides the most detailed source of sex-length-age information. These calculations are not critically important to the treatment of commercial fishery or FISS information, as few very young fish are observed in those data sets; however, accurate depiction of the mortality from other sources, such as recreational fisheries and bycatch in non-target fisheries requires a representative estimate of weight-at-age for all fish captured, particularly ages 2-6.

Otoliths are collected by IPHC samplers on board NMFS trawl surveys in Alaska each year. The average weight-at-age by year and sex was summarized from the NMFS trawl surveys; age and length data were available for all years since 1997, although mean values were somewhat variable for ages greater than 10 due to limited sample sizes (Figure 18). To reduce the effect of sampling variability (there is no easy way to account for observation error in the treatment of weight-at-age), raw values were smoothed across years within age (Figure 19). These trawl survey weights-at-age were used to augment the weight-at-age inputs calculated from ages 7+ in the setline survey and commercial fishery. For the plus group in the stock assessment input data (25+), the average age is calculated; this average age is then used to extrapolate the weight-at-age for ages 25-30. This is necessary because the average weight-at-age for all 25+ Pacific halibut combined should not be attributed to exactly age 25: the average age must be >25 unless all fish are exactly 25.

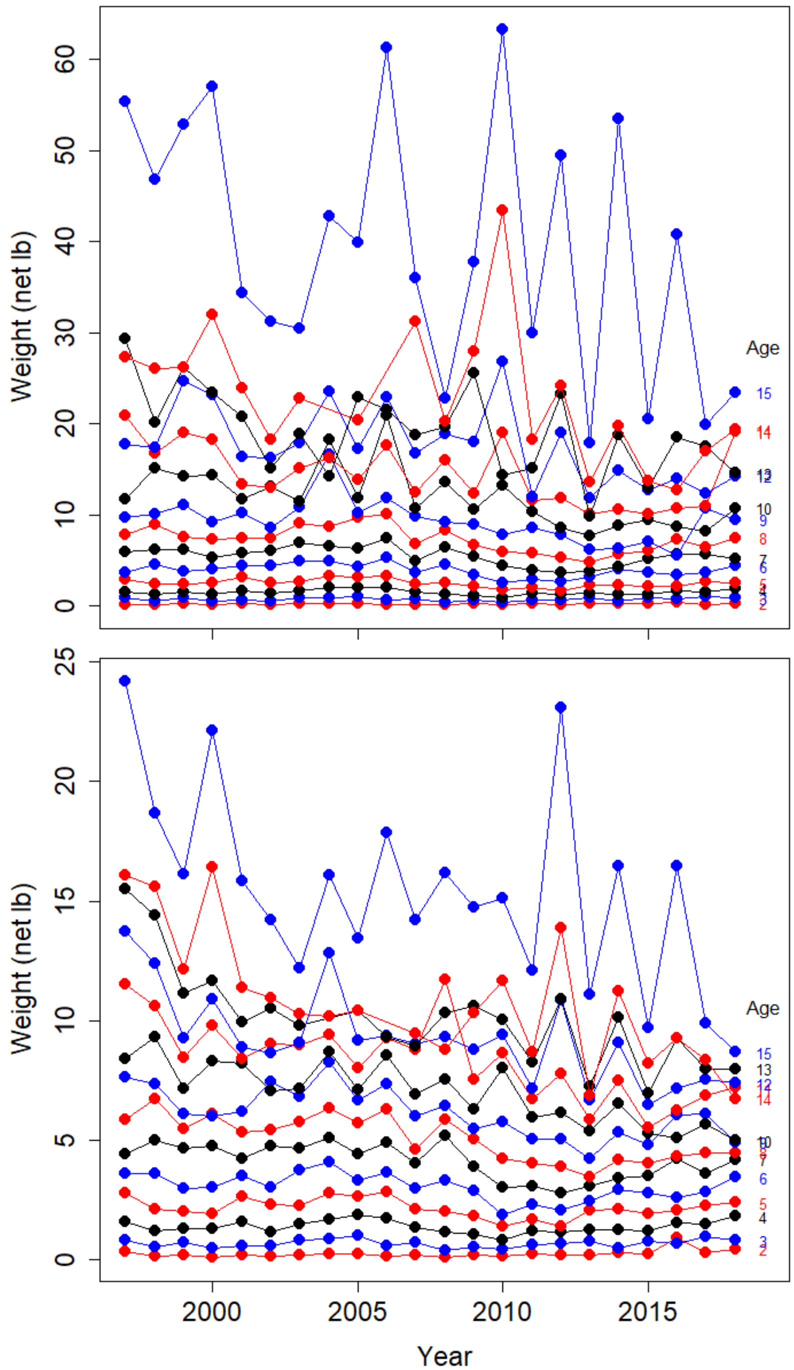

FIGURE 18. Raw trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the NMFS Bering Sea trawl survey. Ages 15 and greater have been aggregated.

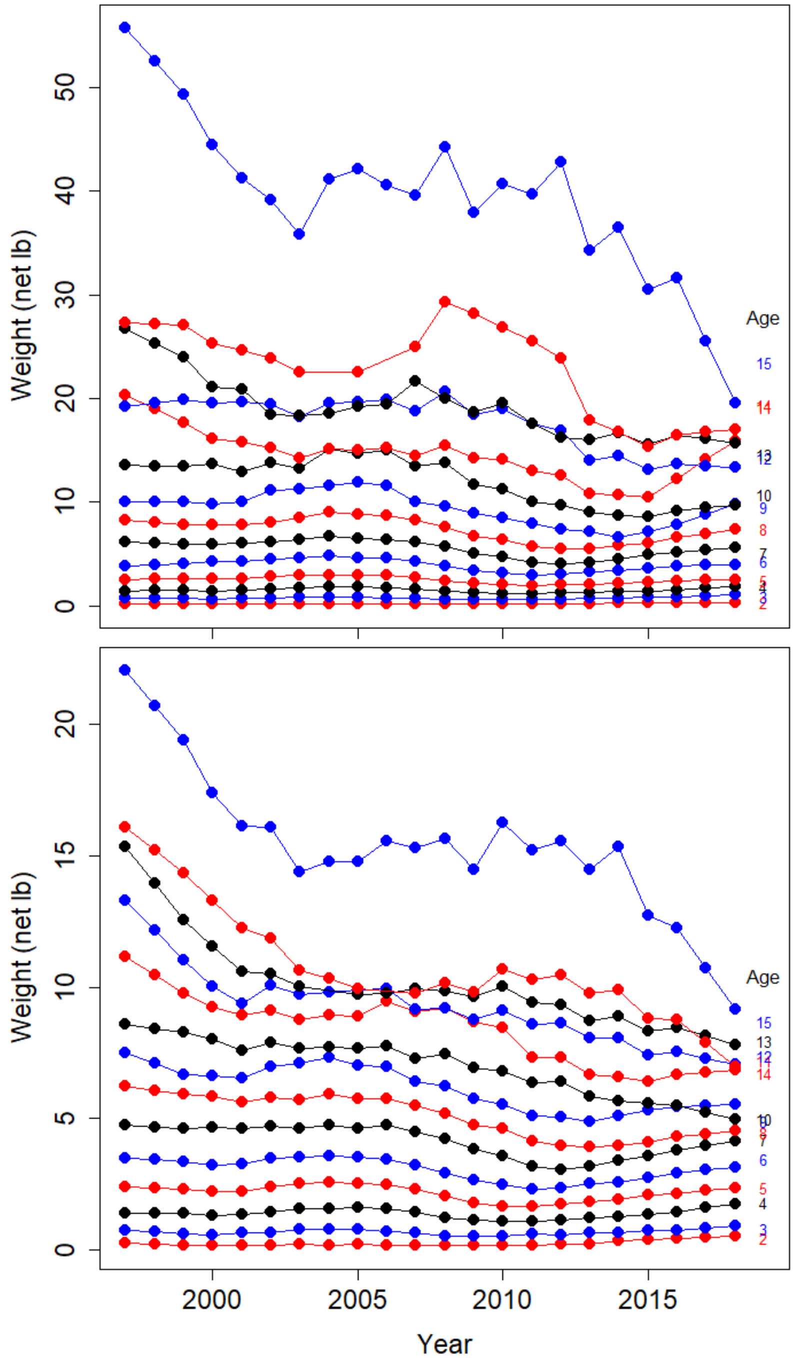

FIGURE 19. Smoothed trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the NMFS Bering Sea trawl survey. Ages 15 and greater have been aggregated.

The ages observed on the NMFS trawl surveys provide year-specific information with which to estimate age distributions from that trawl survey as well as other sources that report only length frequency information but encounter Pacific halibut of similar ages, such as bycatch. However, there are no age data available from the NMFS trawl surveys before 1997, so a global (all-years) relationship (Figure 20) must be used to interpret lengths collected in earlier years and sometimes the terminal year when samples have not yet been aged (as is the case for 2019) as well as other sources of length data (see age distribution of bycatch removals below). When this key is applied to the earlier years of the NMFS Bering Sea Trawl survey, several strong cohorts emerge (Figure 21). The 1987 year class is prominent in the age distributions observed by this survey through the late 1990s. Strong 2004 and 2005 Bering Sea cohorts can also be observed graduating through the age distribution. These year classes are consistent with the catch rates of numbers of Pacific halibut observed in that survey (Figure 22), although the relative magnitude of the 1987 and 2005 cohorts differ more appreciably in the index than in the age data. There appears to be a large proportion of 3-6 year old Pacific halibut present in the 2016-2018 data, thus the indications of the 2011 and 2012 cohorts from the FISS ages and other sources appear consistent with these trawl ages.

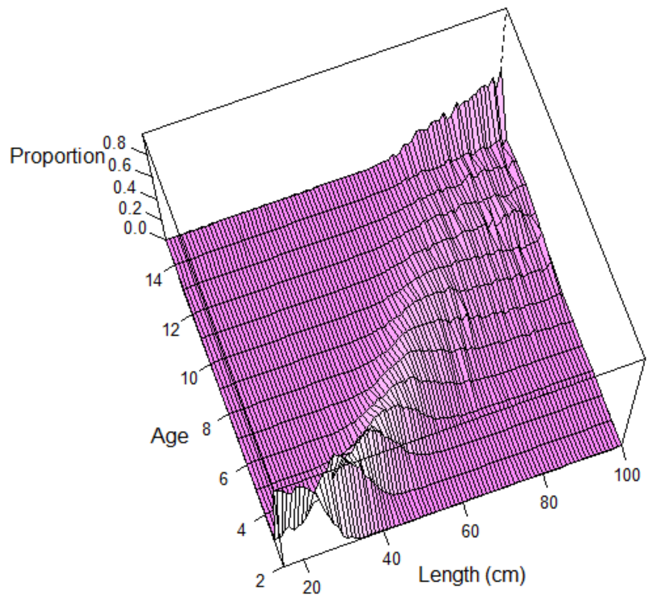

FIGURE 20. Global age-length key created from Pacific halibut captured by NMFS trawl surveys in Alaska. Proportions-at-age sum to 1.0 within each length.

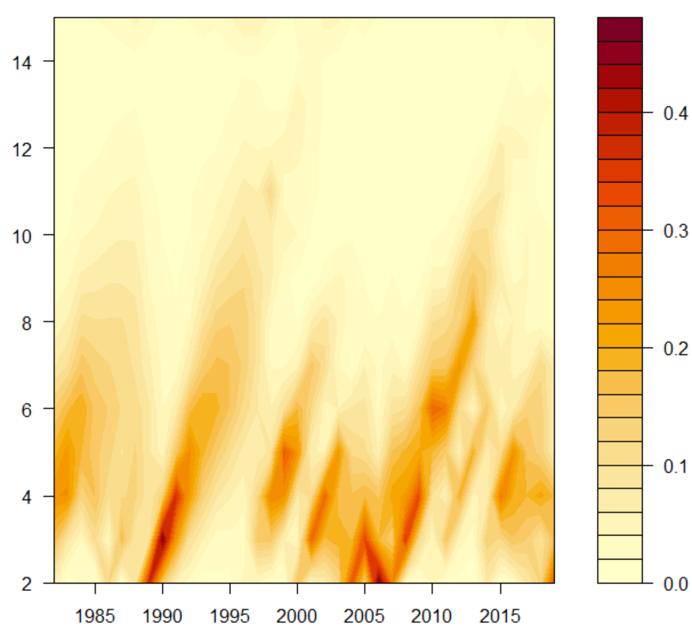

FIGURE 21. Heat map of proportions-at-age from the NMFS Bering Sea trawl survey. Ages 15 and greater have been aggregated; proportions sum to 1.0 within each year.

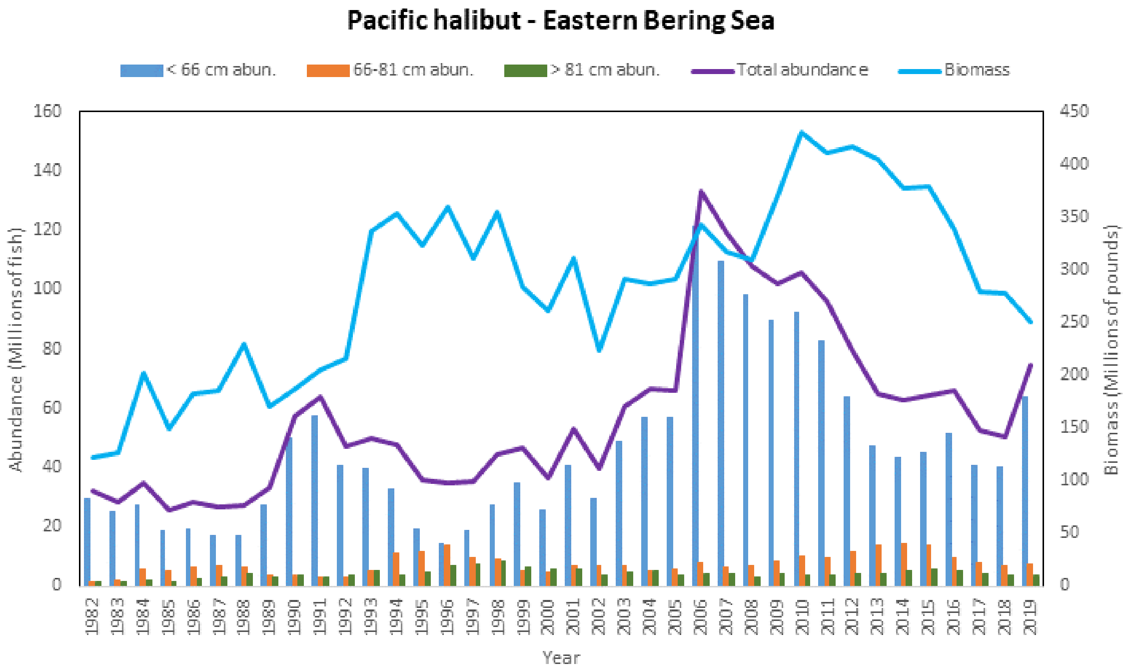

FIGURE 22. Index of abundance (millions; purple line) and biomass (millions of pounds; blue line) of Pacific halibut from the NMFS Bering Sea trawl survey, 1982-2019. Bars indicate abundance of size categories noted in the legend.

FISHERY-INDEPENDENT DATA

Commercial fishery landings

An annual estimate of mortality of Pacific halibut from all sources is required for all stock assessment and related analyses. Mortality can be categorized into five major components: commercial fishery landings, directed commercial fishery discards (a combination of mainly sub-legal and some legal-sized fish), recreational, subsistence, and non-directed commercial discard mortality ('bycatch') of Pacific halibut in fisheries targeting other species.

Landings of Pacific halibut from the directed fishery are documented through the use of commercial fish tickets, reported to the IPHC (**IPHC-2020-AM096-05**). From 1981 to the present, these landings are fully delineated by IPHC Regulatory Area (including all of Areas 4A-4CDE; Figure 23). Coastwide fishery landings increased from 2014-17, the first increases since 2003, then decreased in 2018 in response to reduced mortality limits, increasing again slightly in 2019. Prior to 1981, landings are available only in aggregated form for IPHC Regulatory Areas 4A-4CDE. Landings from 1935-80 are not currently included in the IPHC's database; however, previous analysts have left a number of 'flat files' which appear to correspond well with tables published in technical reports, and other IPHC documents. Because the raw data are not able to be reprocessed directly, the landings estimates prior to 1981 are more uncertain than those after 1981. Historical landings prior to 1935 were reconstructed within current regulatory areas from summaries by historical statistical areas (Bell et al. 1952). Reported industrial landings of Pacific halibut begin in 1888; however, already over one million pounds were being landed per year at that time, and historical records of tribal fisheries prior to this time also exist. The reconstruction by IPHC Regulatory Area of total landings included some use of ratios between Areas 2A and 2B among adjacent years for ambiguous records (both nations were fishing the same fishing grounds), therefore the area-specific distributions are therefore more uncertain than the corresponding totals. Reconstructed landings estimates as well as other historical time-series are available on the IPHC's website. Several patterns emerge from the longer time series of landings including: the period of substantially reduced fishing in the 1970s in all areas, and the sequential exploitation of biological Regions 2, 3, and 4 over the entire time series (Figure 24).

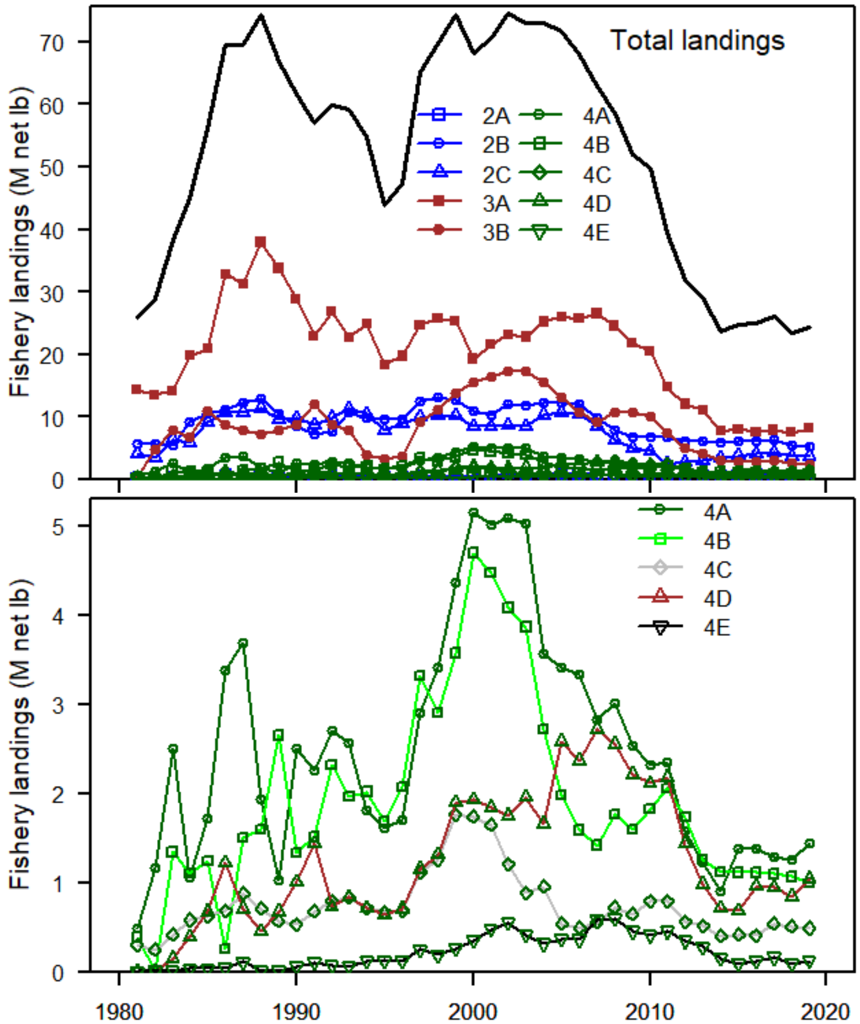

FIGURE 23. Recent landings of Pacific halibut by the directed commercial fishery by IPHC Regulatory Area (upper panel), and among Areas 4A to 4E for better resolution of the trends (lower panel).

Recreational mortality

Recreational mortality is reported to the IPHC by the various agencies in charge of managing these fisheries, including Alaska Department of Fish and Game, the Department of Fisheries and Oceans Canada, and the states of Washington, Oregon, and California. The scientific basis for data collection programs, analyses, and the quality of the subsequent estimates vary considerably by year and source. Since 2014, the IPHC has included estimates of the mortality of released fish in the total recreational mortality. It is generally assumed that there was little recreational fishing for Pacific halibut prior to the mid-1970s. Recreational mortality has grown rapidly since that time, with peak harvests estimated at over 10 million pounds annually during the mid-2000s. These fisheries were reduced after that peak, along with other sources of mortality, but have been relatively stable since about 2010 (Figure 25). Catch sharing plans tie the recreational mortality limits in Areas 2A and 2B, and the charter limits in 2C and 3A to mortality limits set by the IPHC. Among IPHC Regulatory Areas, Area 3A represents over half of the total recreational mortality, with Areas 2C, 2B, and 2A each contributing somewhat less (in declining order).

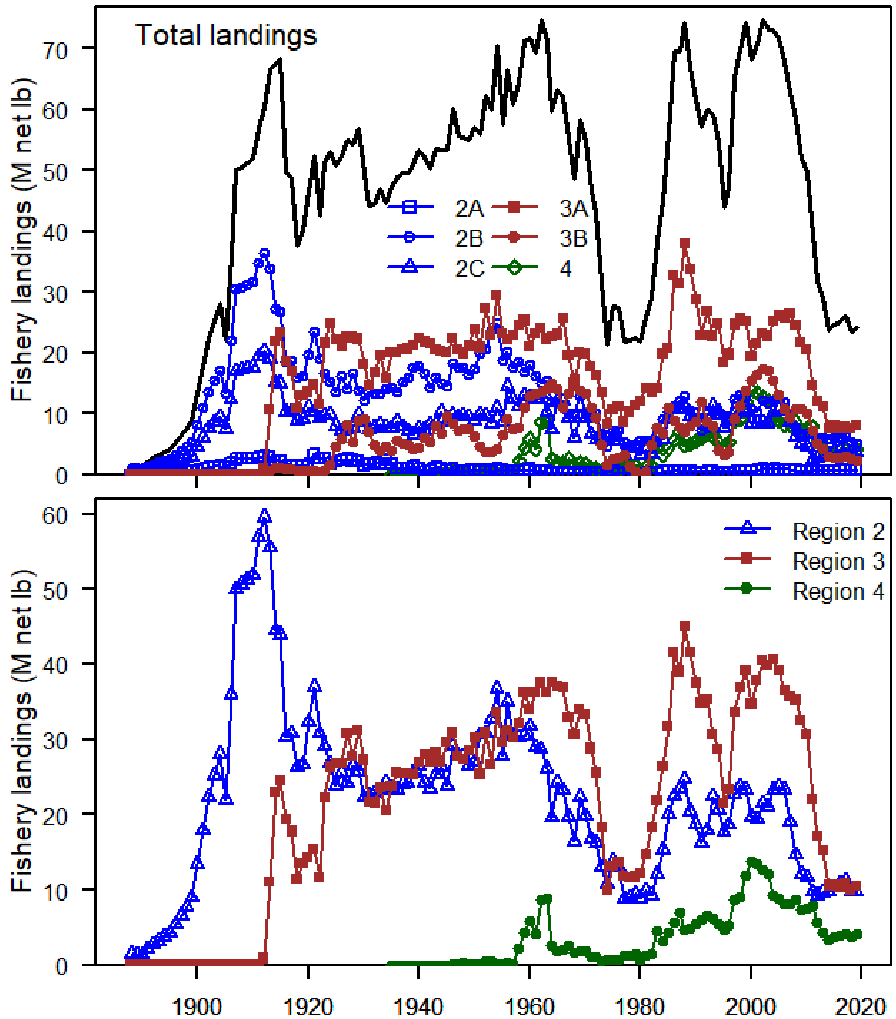

FIGURE 24. Historical landings of Pacific halibut by the directed commercial fishery by IPHC Regulatory Area (upper panel) and Biological Region (lower panel; Regions 4 and 4B are combined due to historical data aggregation).

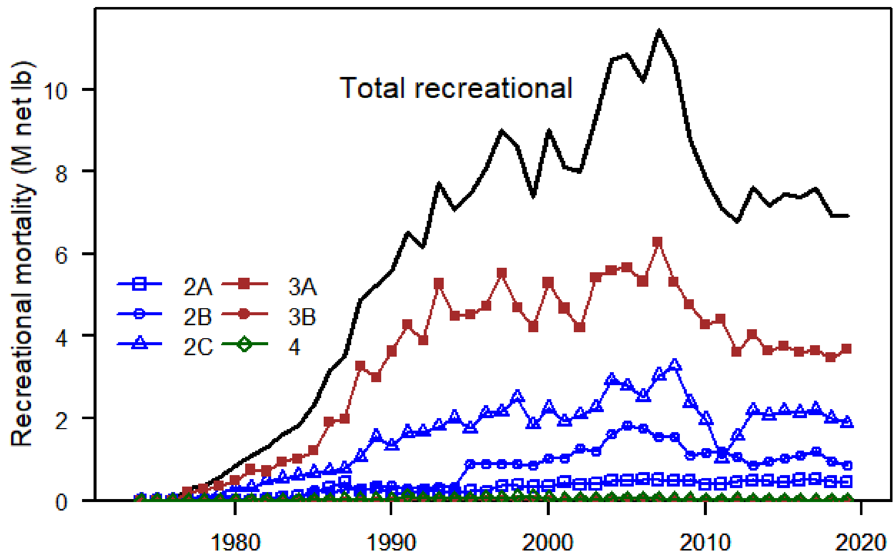

FIGURE 25. Recreational mortality of Pacific halibut by IPHC Regulatory Area.

Subsistence mortality

Subsistence harvest estimates are provided to the IPHC by the DFO and NMFS. Estimates are not generated annually in all cases, and therefore some values are applied through intervening years until the next estimate is made available. This has frequently been the case in recent years. There are currently no estimates available prior to 1991. The time-series created from these estimates is relatively noisy, but occurs on a scale much smaller (< 2 million lbs; ~900 t) than other critical inputs to the analyses (Figure 26).

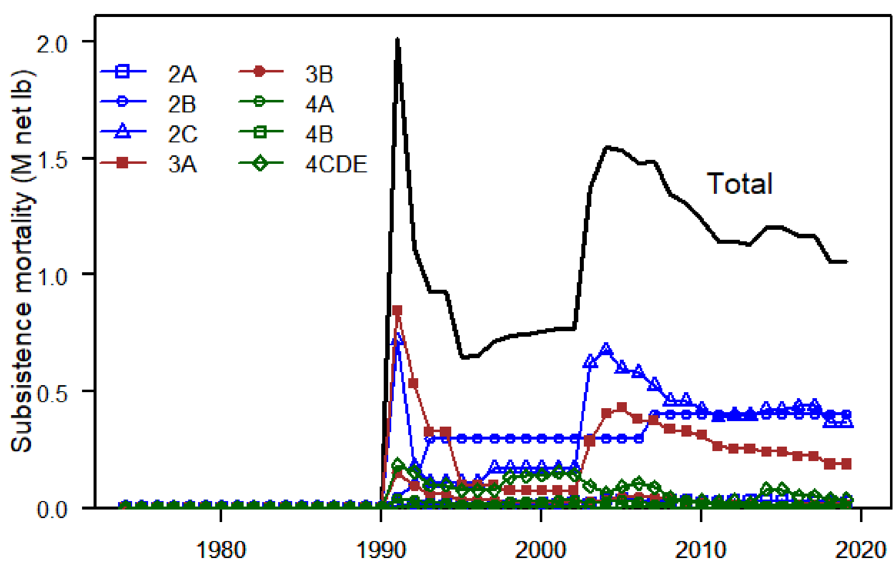

FIGURE 26. Reported subsistence mortality by IPHC Regulatory Area.

Commercial fishery discard mortality

Discard mortality includes all Pacific halibut that are captured during the directed commercial fishery, are subsequently estimated to die, but that do not become part of the landed catch. There are three main sources of discard mortality:

1) fish that are estimated to have been captured by fishing gear that was lost during fishing operations,

2) fish that are discarded for regulatory reasons (e.g., the vessel's trip limit or harvester's IFQ limit have been exceeded), and
3) fish that are captured and discarded because they are below the legal size limit of 32 inches (81.3 cm).

The methods applied to produce each of these estimates differ due to the amount and quality of information available (**IPHC-2020-AM096-05**). New for 2019 is the inclusion of discards of legal (O32) Pacific halibut reported in logbooks from IPHC Regulatory Areas 2C-4CDE (Alaska) that occur when the last trip of the season captures fish in excess of available quota. Historically these values were assumed to be small, possibly incomplete, and had been omitted.

Based on these methods, discard mortality in the commercial fishery is estimated to have been highest in the late 1980s, subsequently declining (particularly in Area 3A in 1995 when the derby fishery was converted to a quota system), and then increasing from 1995 to 2010 as the size-at-age of Pacific halibut declined and more fish at older ages remained below the minimum size limit (Figure 27, upper panel). The estimates of discard mortality cannot be delineated among IPHC Regulatory Areas 4A-4CDE prior to 1981, but there the magnitude is estimated to be very small prior to that time (Figure 27, lower panel).

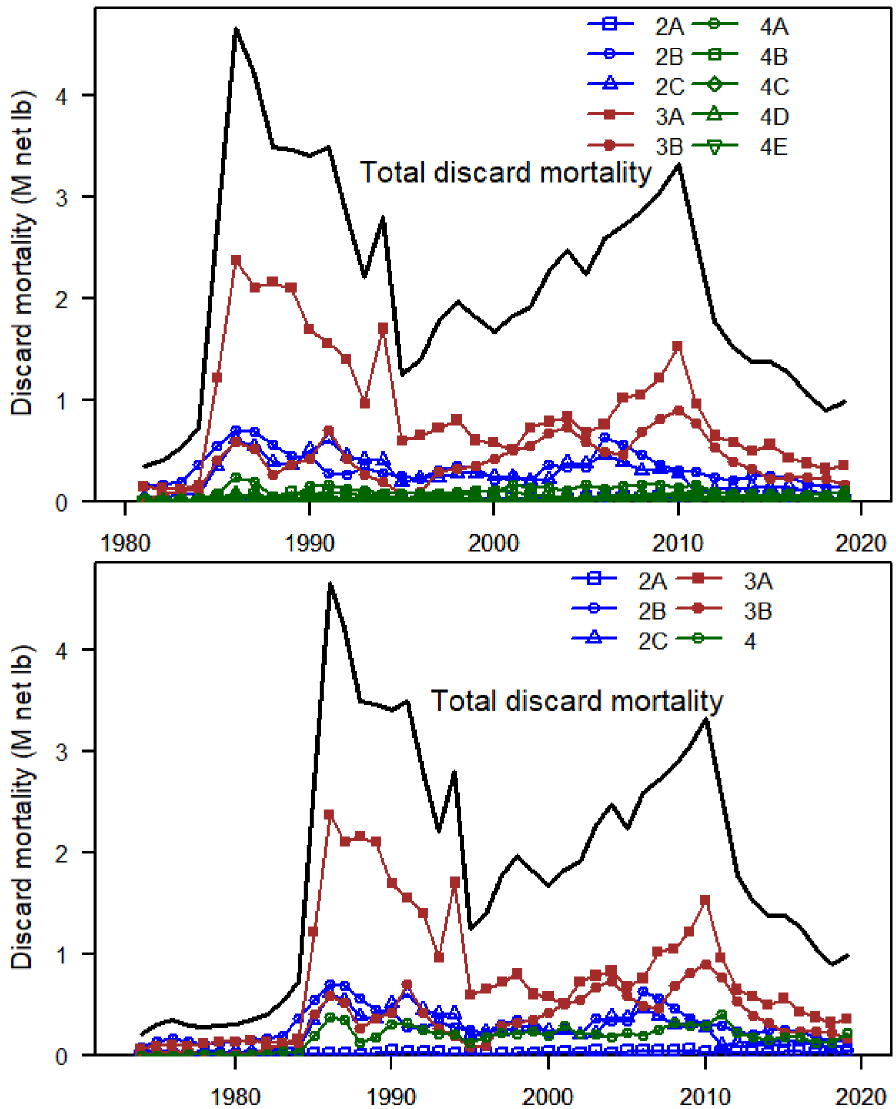

FIGURE 27. Discard mortality in the commercial fishery by IPHC Regulatory Area, 1981+ (upper panel), and 1974+, with Areas 4A-4CDE combined (lower panel).

Discard mortality in non-directed commercial fisheries ('bycatch')

Mortality from fisheries where the retention of Pacific halibut is prohibited, or non-directed commercial fisheries ('bycatch') is reported to the IPHC by the NMFS and DFO on an annual basis by IPHC Regulatory Area. These estimates vary greatly in quality and precision depending upon year, fishery, type of estimation method, and many other factors. Non-directed commercial fishery discard mortality has been delineated among Areas 4A, 4B, and 4CDE only from 1990 to the present, during which time it has declined from a peak of over 20 million lbs (~9,070 t) to a projected value of approximately 6.4 million pounds (~2,920 t) in 2019 (Figure 28, upper panel). The 2019 estimate represents a 5% increase from 2018, almost all of which occurred in IPHC Regulatory Area 4CDE, which also increased from 2017 to 2018. Prior to 1991, available estimates are aggregated for IPHC Regulatory Areas 4A-4CDE. From the 1960s to 1990s, annual values were variable with a peak in the early 1960s corresponding to the peak of foreign fishing in (currently) Alaska waters, primarily Areas 3A and 3B. There was likely less non-directed discard mortality prior to the development of the foreign fishery in U.S. waters in the early 1960s; however, estimates are only available from 1962 to the present.

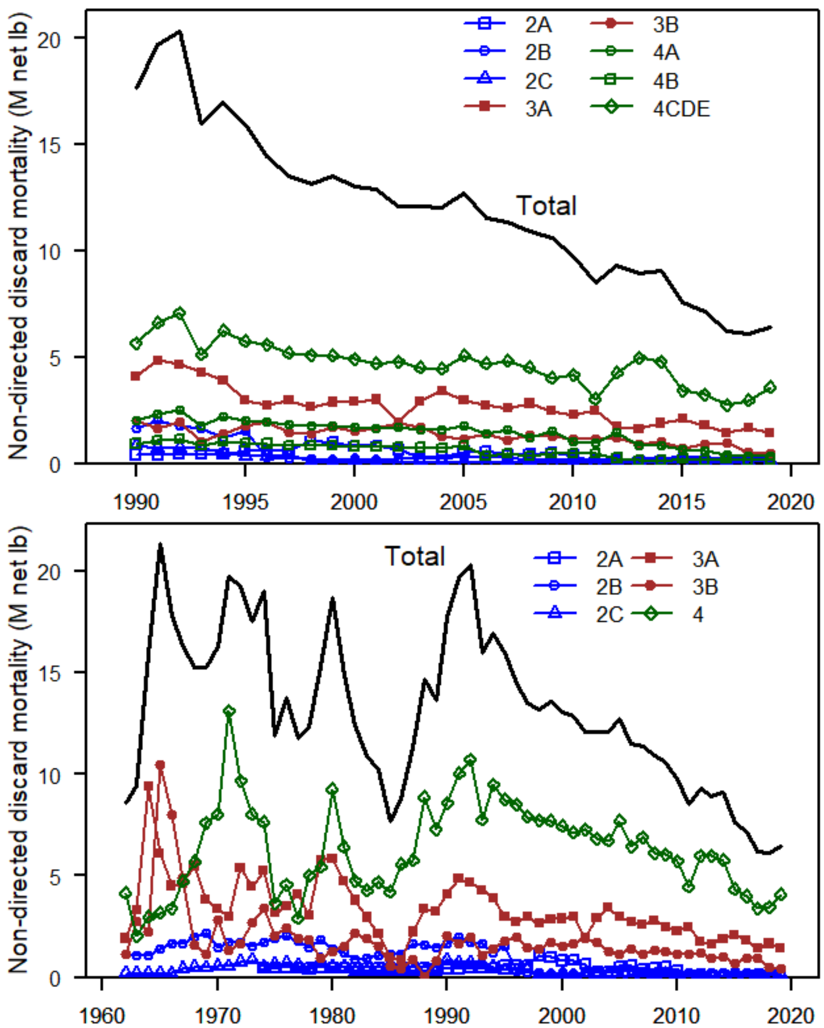

FIGURE 28. Pacific halibut discard mortality estimates from non-directed fisheries by IPHC Regulatory Area, 1990+ (upper panel), and 1962+, with Areas 4A-4CDE combined (lower panel).

Summary of Pacific halibut mortality from all sources

Recent aggregate mortality estimates from all sources show that the directed commercial fishery represents the majority of the fishing mortality (Figure 29). Mortality from all sources in 2019 was estimated to be 39.7 million pounds (~18,000 t), up 3% from 2018. Over the period 1920-2019 mortality has totaled 7.2 billion pounds (~3.2 million t), ranging annually from 34 to 100 million pounds (16,000-45,000 t) with an annual average of 63 million pounds (~29,000 t; Figure 30). Time-series tables of annual estimates by source are now available on the IPHC's website. Annual mortality was above this long-term average from 1985 through 2010 and was relatively stable near 42 million pounds (~19,000 t) from 2014-2017. Recent mortality estimates from all sources by individual IPHC Regulatory Area reveal that Area 3A has been the largest single source throughout the last five decades, but that Area 3A and 3B represent a smaller fraction of the total in recent years than in previous decades (Figures 31-32; time-series tables online). When mortality by source is compared among IPHC Regulatory areas, there are differing patterns in both the magnitude and distribution.

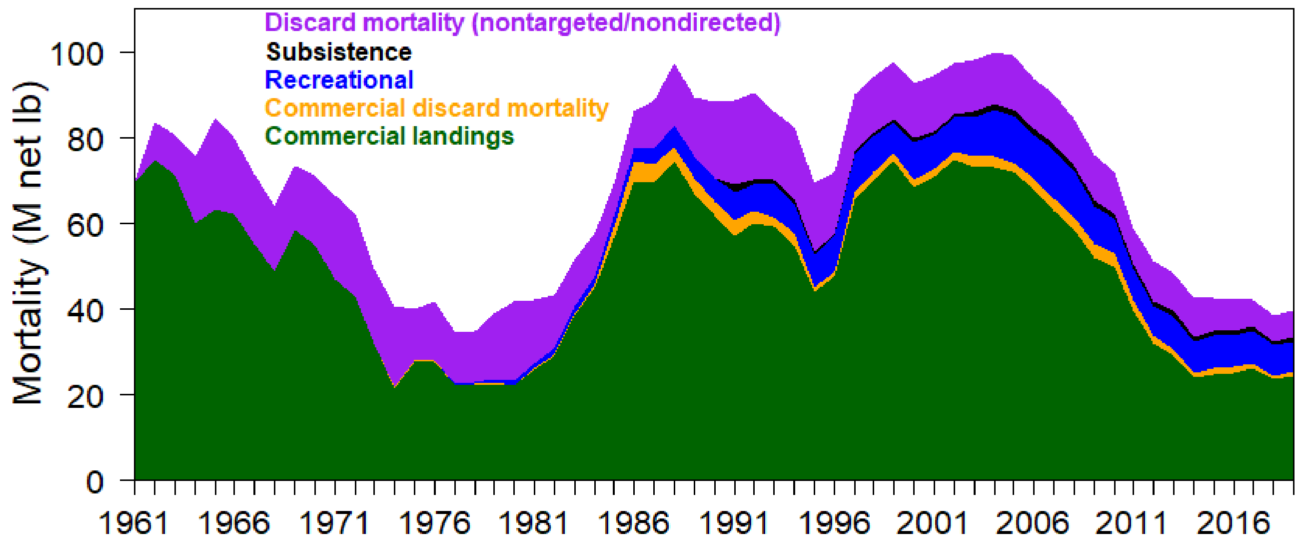

FIGURE 29. Pacific halibut mortality estimates from all sources since 1961.

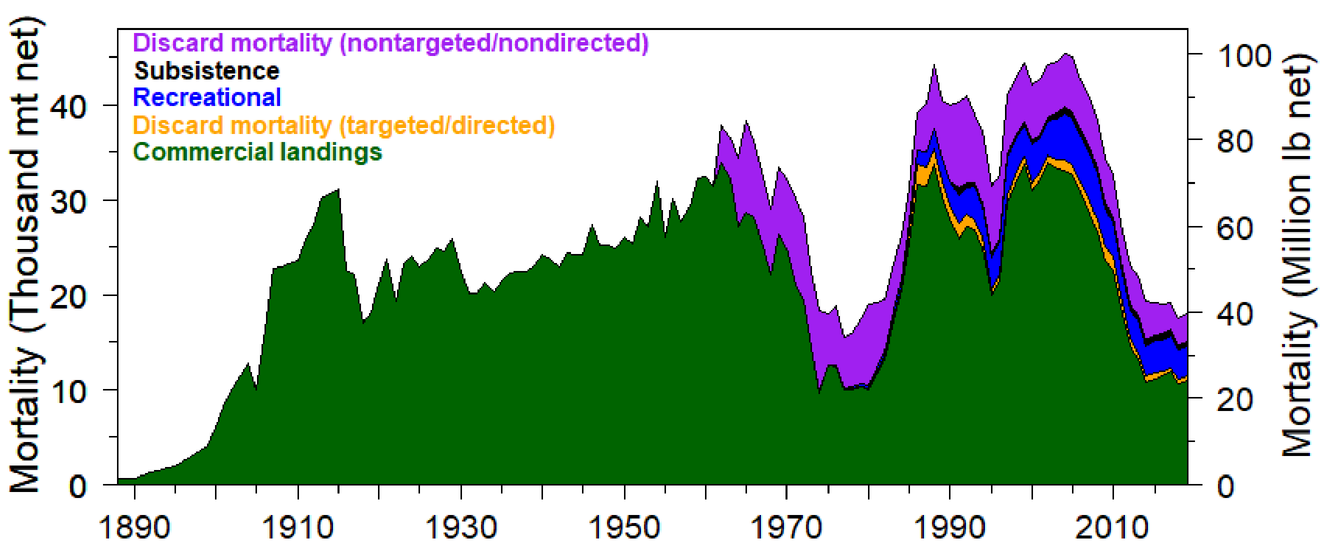

FIGURE 30. Summary of estimated historical mortality by source (colors), 1888-2019.

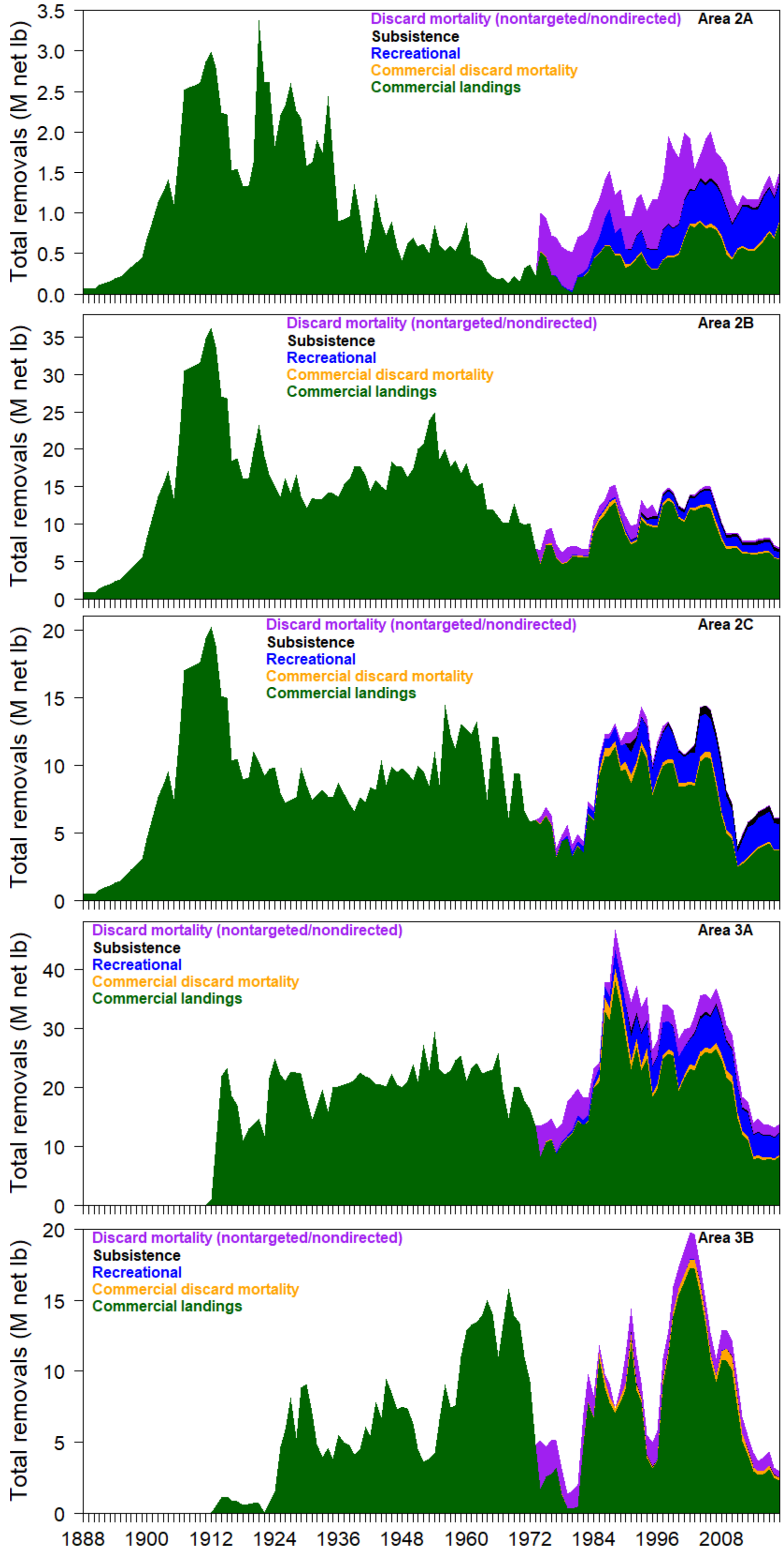

FIGURE 31. Estimated Pacific halibut mortality by source in IPHC Regulatory Areas 2A-3B since 1888. Note that the y-axes differ in scale.

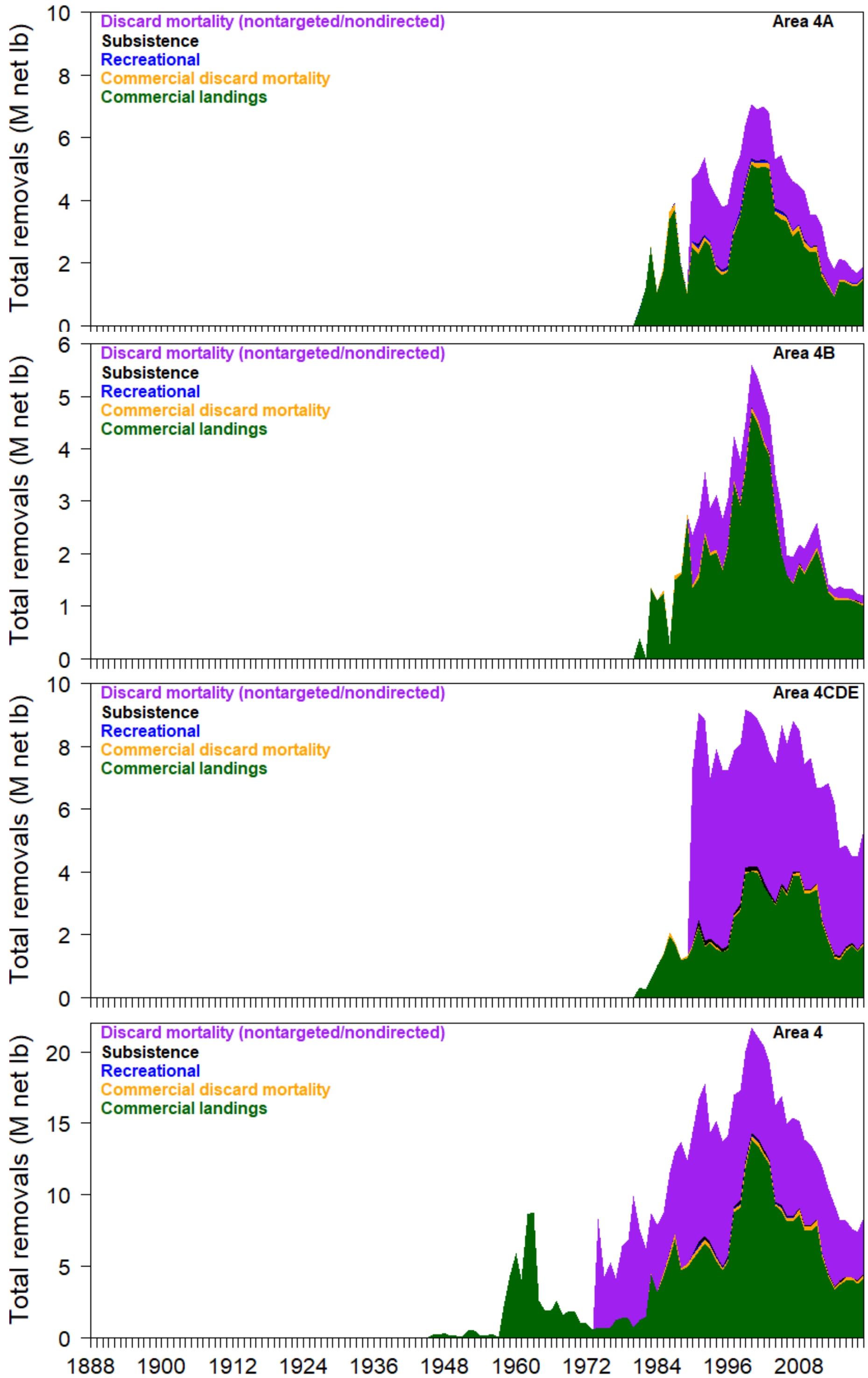

FIGURE 32. Estimated Pacific halibut mortality by source in IPHC Regulatory Areas 4A, 4B, 4CDE, and for Areas 4A-4CDE combined since 1888. Note that the y-axes differ in scale.

Commercial Pacific halibut fishery WPUE and biological data

A relatively simple approach is employed to calculate the annual index of fishery WPUE and to summarize fishery-dependent biological information. The most important addition to the fishery-dependent data in 2019 was sex-specific age frequency distributions from the 2017-18 directed commercial Pacific halibut fishery. These provided the first direct information on the sex-ratio of the landings, and the beginning of a critically important improvement to the IPHC's fishery monitoring program.

Commercial Pacific halibut fishery WPUE

Commercial fishery logbook data is collected by port samplers, and reported directly to the IPHC by fishermen (**IPHC-2020-AM096-05**). This dataset represents a valuable source of information about many aspects of the commercial fishery, including seasonal and spatial patterns, gear usage, and other details. The data that are included in the current fishery WPUE standardization are:

- the IPHC Regulatory Area of fishing (regardless of the port of delivery),
- the type of fishing gear used (only fixed-hook data are included in Areas 2C, 3A, 3B, 4A, 4B, 4C, 4D; both fixed-hook and snap gear are used in Areas 2A and 2B),
- the year of fishing (some logbooks are not obtained by port samplers until the following year),
- the number of skates fished (excluding any gear that was lost),
- the spacing of the hooks,
- the number of hooks on each skate,
- the pounds of legal-sized Pacific halibut captured and landed, and
- the reported target of the set (only sets specifically targeting Pacific halibut are included in the analysis, and all sets with hook-spacing of less than four feet are assumed to be non-Pacific halibut targeting, except in IPHC Regulatory Area 2A).

The fishery catch-rates are calculated based on the catch (in weight) relative to the amount of gear deployed at each location (a set). Effort for each set is standardized to an effective skate (*ES*) that is 1,800 feet long, with 100 hooks (and therefore an 18-foot average spacing), based on the number of skates fished (*S*), the average number of hooks fished per skate (N_h), and the hook-spacing (H_s; Figure 33) based on the relationship given by Hamley and Skud (1978):

$$ES = S \cdot \left(\frac{N_h}{100}\right) \cdot 1.52 \cdot (1 - e^{-0.06 \cdot H_s})$$

This effective skate relationship has recently been reevaluated (Monnahan and Stewart 2018) and the results of that investigation suggest a slightly different relationship than that estimated historically. The IPHC will be considering an update to its data processing methods to reflect that revised relationship in the near future. The sum of the catch weight (*C*) for all sets (*s*) reported from a Regulatory Area (*a*) each year (*y*) is divided by the sum of the effective skates to obtain the total WPUE, or index (*I*):

$$\bar{I}_{a,y} = \frac{\sum_{s=1}^{Nsets} C_{s,a,y}}{\sum_{s=1}^{Nsets} ES_{s,a,y}}$$

Due to the small number of fixed-hook sets in IPHC Regulatory Areas 2A, 2B and 4C (4C represents a change for 2019 due to continued decrease in fixed-hook effort in that area), snap gear is included in the calculation for these areas. This is done by dividing the snap gear effort by a factor of 1.35 (Clark 2002). A detailed exploratory analysis of the logbook standardization data and methods was completed during 2014 (Monnahan and Stewart 2015), which suggested future analyses would be able to include all logbook records in all Regulatory Areas regardless of gear type if a model-based estimator were used. However, discussions with the IPHC's Scientific Review Board did not result in a recommendation to change the simple method employed historically. There are too few logs available on an annual basis from Area 4E to include that regulatory area in the WPUE calculations.

These annual area-specific mean catch-rates are then weighted by the geographic extent of suitable depths occupied by Pacific halibut within each IPHC Regulatory Area (g_a, 0-400 fathoms; 0-732 m) relative to the entire coast (Figure 34). The weighted values are then summed to generate a coast-wide index of abundance:

$$I_y = \sum_{a=1}^{Areas} \bar{I}_{a,y} * \frac{g_a}{\sum_{a=1}^{Areas} g_a}$$

This approach is consistent with the concept that the commercial WPUE is also a 'survey' of the stock and therefore the estimates are a proxy for density, but diverges from the common approach of weighting the commercial WPUE from each area by the catch (in weight) in that area relative to the total. It may be preferable in the future to explore the use of catch- instead of geographic-weighting.

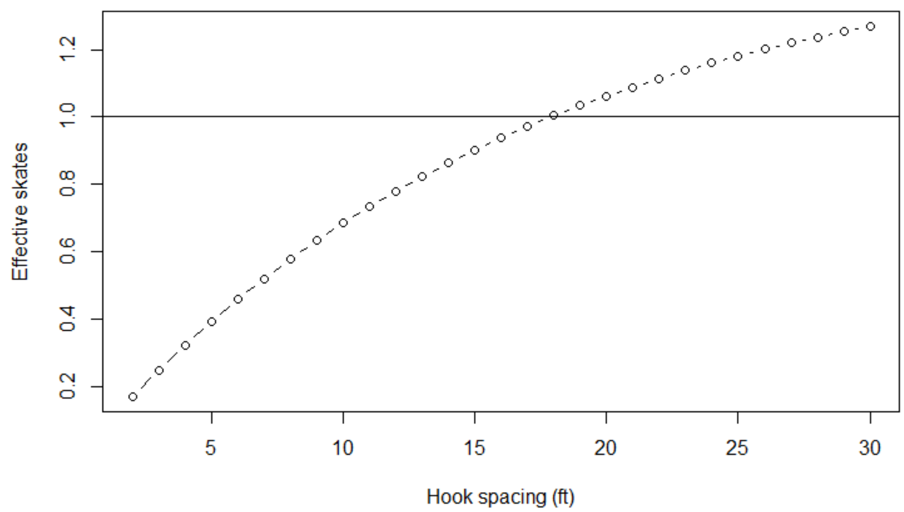

FIGURE 33. Relationship between hook spacing and the number of effective skates for setline survey and commercial fishery WPUE calculations (From: Hamley and Skud 1978).

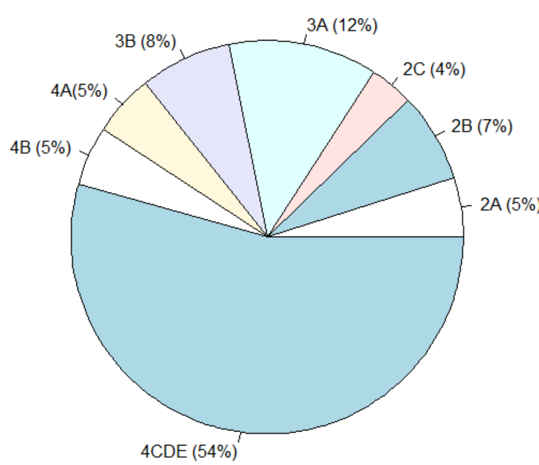

FIGURE 34. Relative spatial extent of each regulatory area.

All available information was finalized on 31 October 2019 in order to provide adequate time for analysis and modeling. As has been the case in all years, commercial fishery WPUE for 2019 remains incomplete. The final verified record of logbooks available approximately 10-12 months after the end of the annual fishing season differ from the preliminary data available in November and used in the stock assessment each year. Differences reflect: 1) the inclusion of logbooks that were not collected by port samplers during the year of fishing (and subsequently mailed in to the IPHC, or collected by port samplers during the following fishing season), and 2) logbooks that had been collected, but were not available for analysis (the fishing season extends beyond the cutoff date for the stock assessment data). In previous years, these changes have generally led to a reduction in the index from preliminary values. Because the data are always incomplete at the time of the assessment, the variance of the terminal year of the WPUE series is inflated for use in the stock assessment by a factor of two. Based on review by the IPHC's Scientific Review Board (SRB), a bias correction for each Regulatory Area was developed using the most recent seven years (2012-2018) of post-assessment revisions resulting from additional logbooks available after the assessment deadline. By calculating the average revision to the terminal year's value, a prediction of the corrected trend is provided along with the currently observed trend (Figure 35).

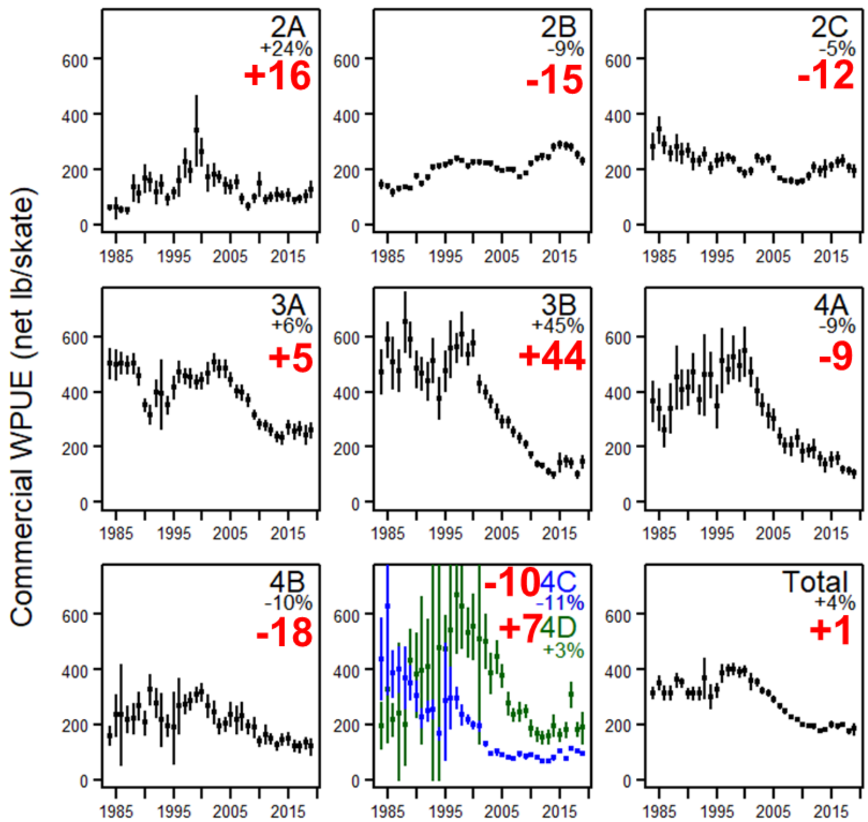

FIGURE 35. Trends in commercial fishery WPUE by IPHC Regulatory Area, 1984-2019. Percentages reported below the Regulatory Area label indicate the uncorrected change from 2018 to 2019 (see text above). Larger font percentages in each panel reflect the bias corrected percentage change anticipated when the remainder of the available logbook information is included. Vertical lines indicate approximate 95% confidence intervals.

Uncorrected commercial fishery WPUE in 2018 increased 4% from 2018 at the coastwide level. Applying the bias correction resulted in a smaller estimated increase of 1% for the coastwide commercial fishery WPUE with a mix of negative and positive trends among IPHC Regulatory Areas. Tribal and non-tribal commercial fishery trends in Area 2A were reported separately for the first time in 2017 in order to better illustrate the effects of important differences in the timing and spatial extent of the two components. For 2018, additional detail in the commercial fishery

WPUE was provided through separating the time-series of catch rates by gear type (snap and fixed-hook) for most IPHC Regulatory Areas (Figure 36). A notable difference in scale reflects the historically lower catch-per-effort estimated for snap vs. fixed-hook longline gear. This difference may reflect individual fishing practices among fishermen, spatial patterns, and other differences among the gears beyond the gear itself. Regardless, the relative trend of the time-series' for the two gear types within most IPHC Regulatory Areas is similar.

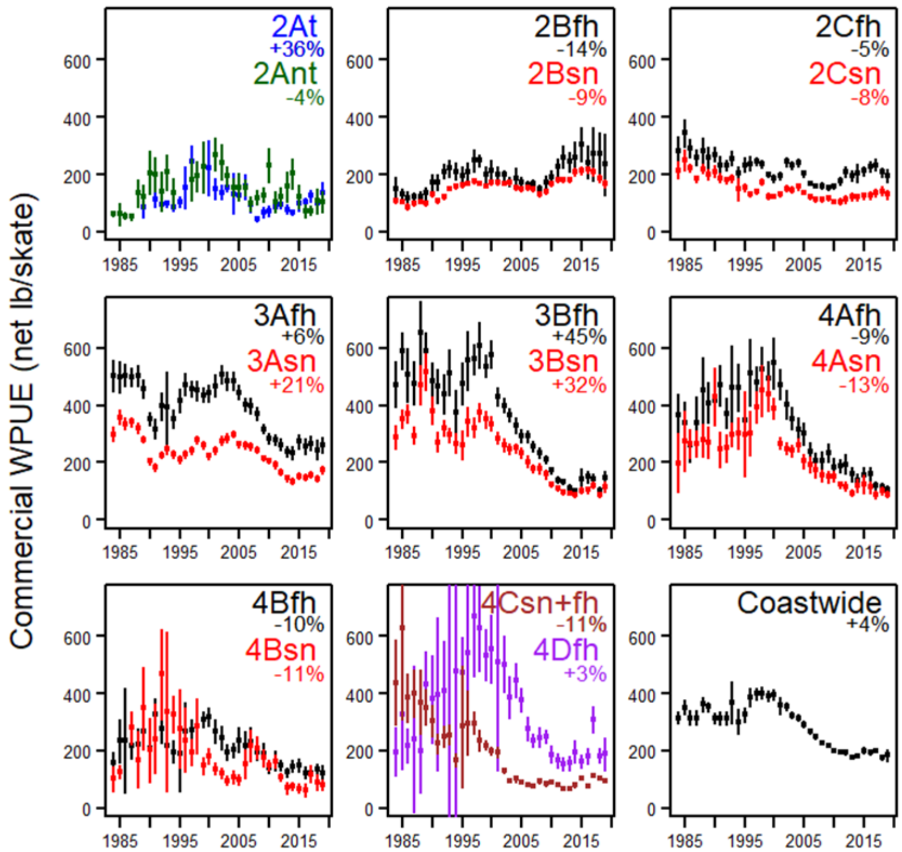

FIGURE 36. Trends in commercial fishery WPUE by Regulatory Area and gear, sector or area, 1984-2019. Percentages reported below the Regulatory Area label indicate the uncorrected change from 2018 to 2019 (see text above). In IPHC Regulatory Area 2A "t" denotes tribal and "nt" denotes non-tribal fisheries. In IPHC Regulatory Areas 2B-4B "fh" denotes fixed-hook gear and "sn" denotes snap gear. Vertical lines indicate approximate 95% confidence intervals.

Effort data for years prior to 1981 do not currently exist in the IPHC's database. For historical data, as is the case for other sources of information, there exist flat files from previous analysts that include effort and landed catch by regulatory area. These data have been used for other analyses, and date back to 1907. Prior to 1935, records of effort are reported in various technical and other IPHC reports, and there are a number of differing time-series available. Total catch and total effort were tabulated from Chapman et al. (1962) for the years 1921-1934, and from Thompson et al. (1931), although there are slightly differing series in at least Skud (1975) and several others. The oldest historical records do include even earlier years, but have not been included here pending more detailed investigation. It would be preferable to access and process the historical log data directly from data stored in a database with meta-data, but this is not currently possible.

The most dramatic change in the commercial WPUE time series corresponds to the transition from "J" to circle hooks in 1984 (online time-series data sets; Figure 37), although there have been many other changes in the definition of effort over the time series (see synopsis in Leaman et al. 2012). Changes in catch rates prior to the 1980s also reflect the historical progression of the fishery from south to north over much of the time-series (Figure 24). Despite these caveats, it is clear that catch rates were quite low around the time of the formation of the IPHC (the motivation for the original convention), and again in the late 1970s (Figure 37). Additional uncertainty throughout the historical series is reflected by increased coefficients of variation (fixed at 0.1) for all years prior to 1984.

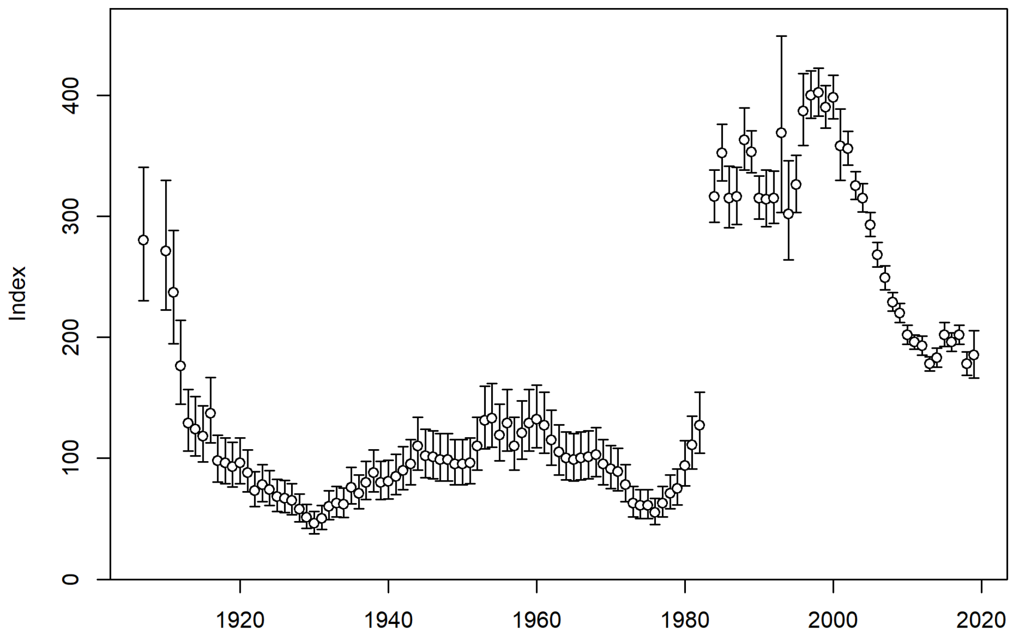

FIGURE 37. Coastwide commercial WPUE from historical records of effort and catch, as well as more recent direct logbook processing. The large change between 1982 and 1984 coincides with the adoption of circle hooks.

Commercial fishery age distributions

Recent fishery age distributions are created from otoliths collected by port samplers. These otoliths are collected in proportion to the landings (in all ports that are annually staffed by the IPHC). Because of this sampling method, the raw ages can be simply aggregated within each IPHC Regulatory Area and year to estimate the age composition of the catch. Beginning in 2017, port samplers have collected a fin-clip from each sampled Pacific halibut, which are subsequently analyzed via a genetic assay to determine the sex. For 2019, sex-specific information was available for 2017-2018, with collection and analysis of subsequent samples ongoing. The aggregate sex-ratios in the commercial landings indicate that the fishery has comprised mainly female Pacific halibut in recent years, ranging from 65% in Biological Region 4B to 92% in Region 4 and 82% coastwide in 2017 (Figure 38). Patterns were similar for individual IPHC Regulatory Areas within each Biological Region (Figure 39). Sex-ratios by age indicted that for Pacific halibut less than 14 years old 90% or greater are female (figure 40).

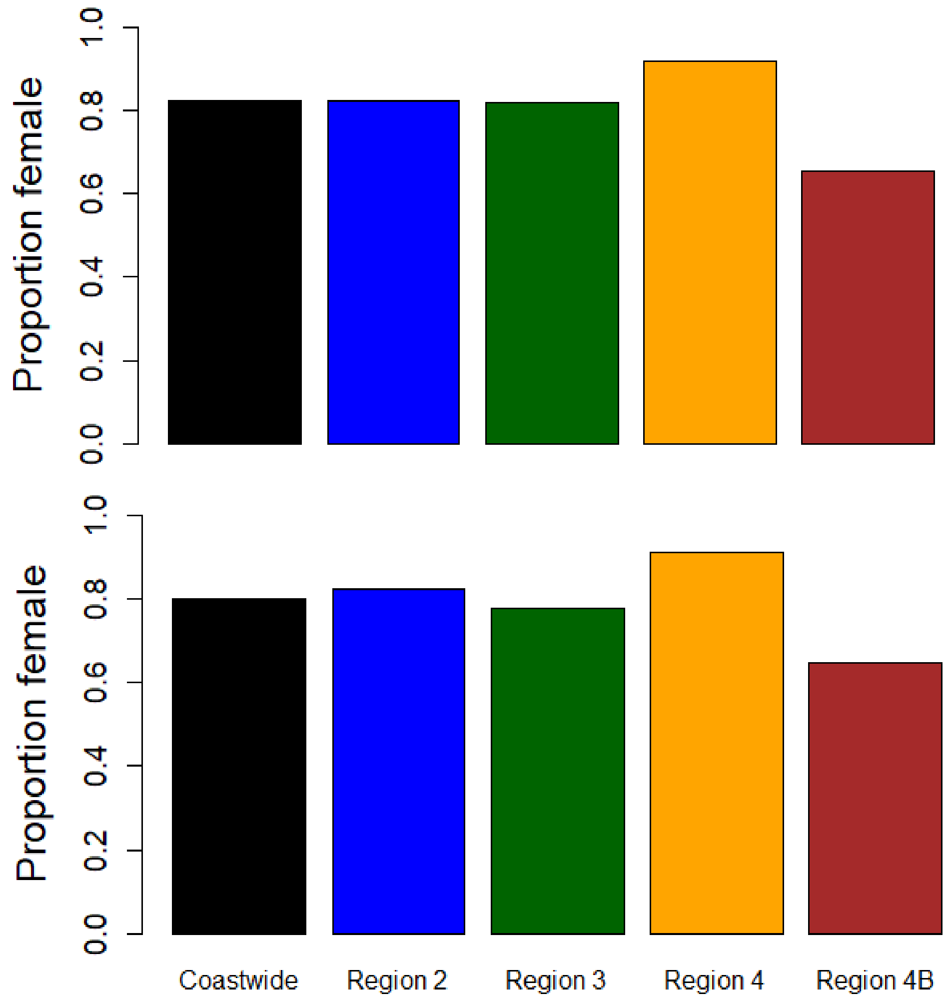

FIGURE 38. Estimates of the sex-ratio of the commercial fishery landings by Biological Region from 2017 (upper panel) and 2018 (lower panel).

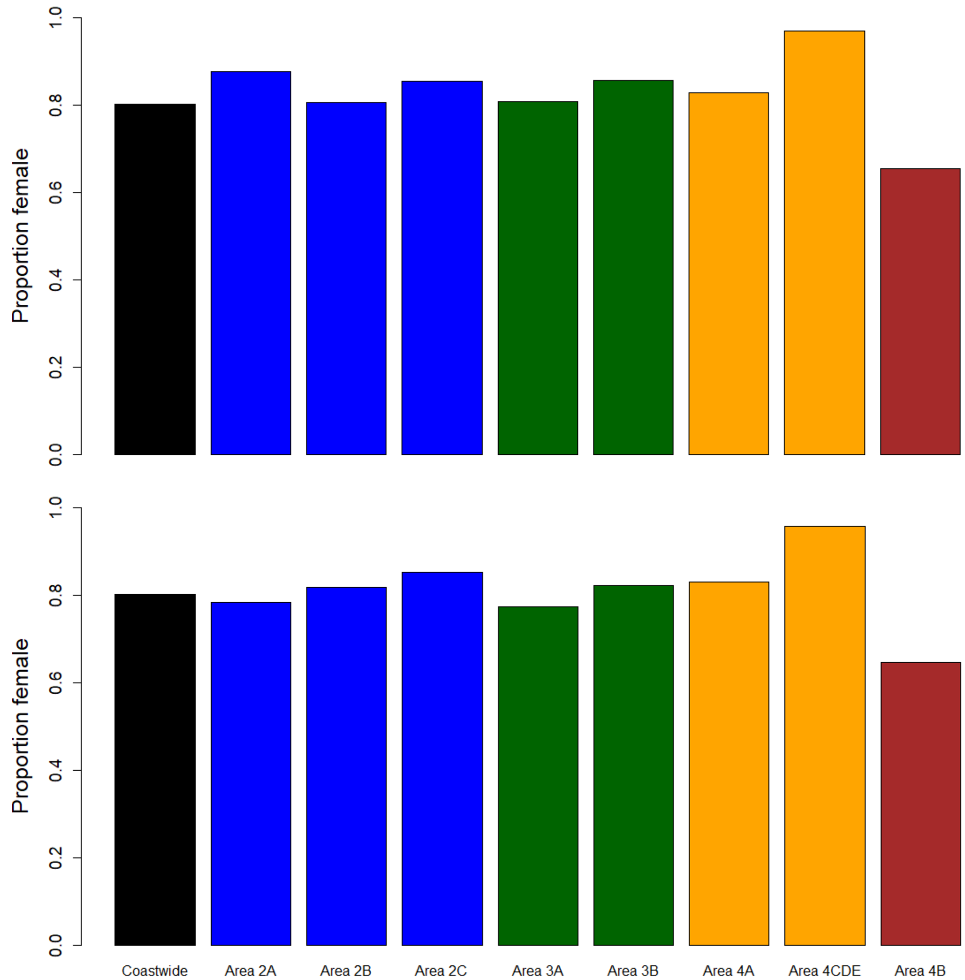

FIGURE 39. Estimates of the sex-ratio of the commercial fishery landings by IPHC Regulatory Area from 2017 (upper panel) and 2018 (lower panel).

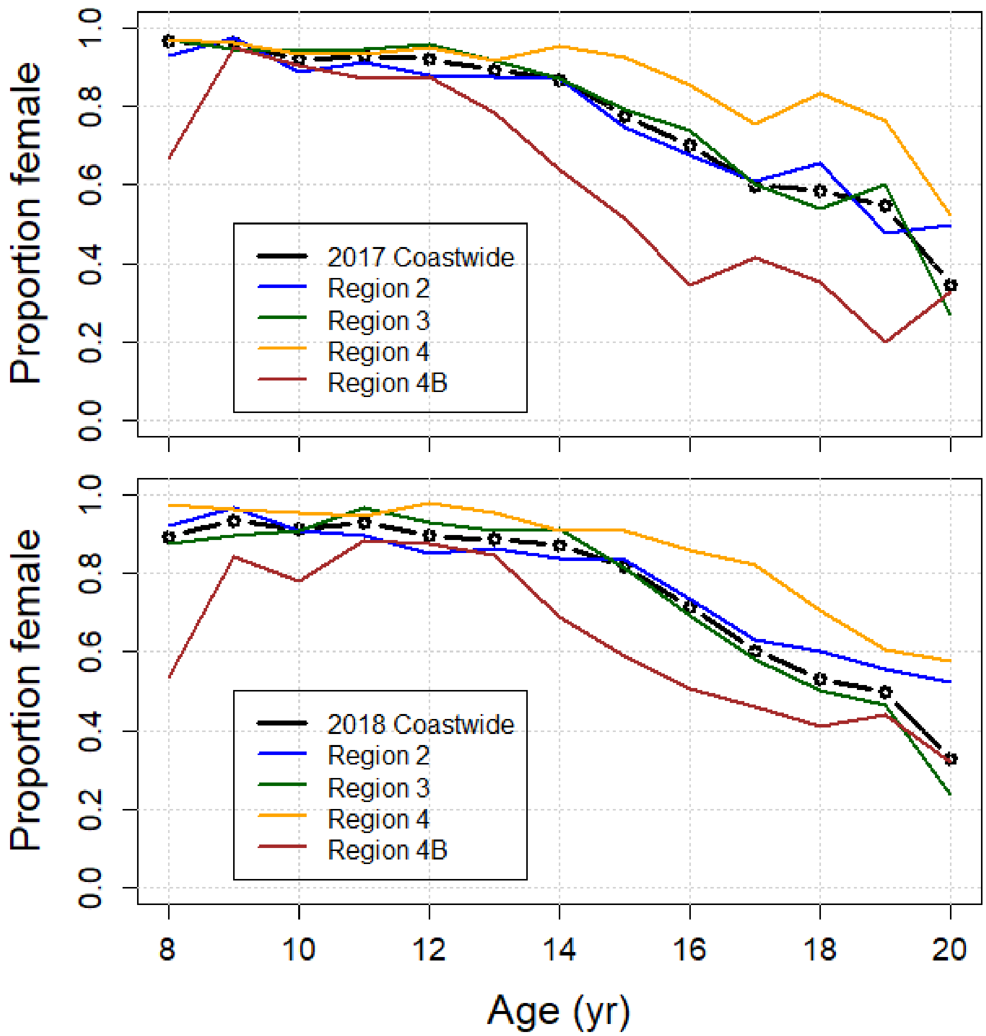

FIGURE 40. Estimates of the sex-ratio of the commercial fishery landings by Biological Region and age from 2017 (upper panel) and 2018 (lower panel).

Port samplers also collect individual lengths, and the historical average weight within each area can be estimated via the length-weight relationship. Beginning with a pilot project in 2015 and expanding to include all port samples in 2017, individual weights are now measured for each fish sampled for length and age from the commercial fishery. These measured weights are included in all data analysis for the stock assessment. Dividing the total commercial catch for each IPHC Regulatory Area and year by the average fish weight gives an estimate of the number of fish captured. To aggregate the proportions-at-age from each area into a total by Biological Region or coastwide, each IPHC Regulatory Area is weighted by the estimated number of fish in the catch relative to the total number of fish captured over all IPHC Regulatory Areas. For the period included in recent stock assessments, the coastwide age distribution displays a very similar pattern to that of the setline survey ages: a very strong 1987 cohort moving through the stock (Figure 41), followed by catches comprised primarily of 9 to 18 year-old Pacific halibut. Age distributions in 2018 show a 2005 cohort, and weak recruitments from 2006-10. Although few fish are sampled in the commercial catch below ages 8-9 the 2011 and 2012 year-classes are apparent as the largest proportions at these ages since the mid-2000s.

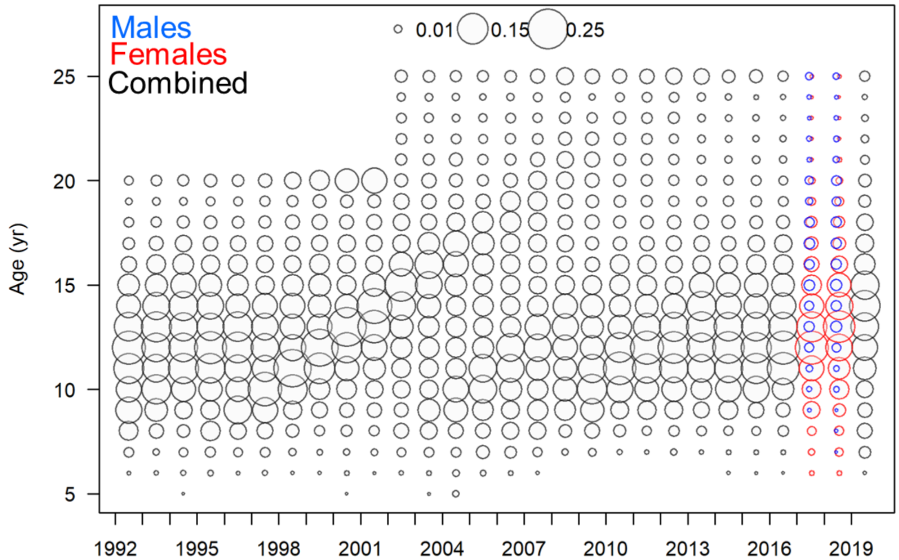

FIGURE 41. Estimates of recent commercial fishery numbers-at-age. Circles represent proportions that sum to 1.0 within each year. For 2017 and 2018, males are delineated by the blue circles and females by red at each age.

Commercial fishery ages prior to 1991 have been summarized by several previous analysts, in some cases processed originally by one analyst and then subsequently by another (Clark et al. 2000). For this summary, a file produced for the analysis by Clark et al. (2000) was obtained, which included proportions at age by IPHC Regulatory Area from 1935 to 1990. Additional work could be done to recreated some of these summaries from the current IPHC database, but not all of the raw data is currently available. Weighting of the IPHC Regulatory Area-specific proportions followed the method applied to the more recent data, first obtaining an average individual weight (in this case by multiplying the proportions-at-age by the estimated average weight-at-age from the historical records), and then dividing the total landings by that weight to get an estimate of the number of fish in the landings by year and IPHC Regulatory Area. Again following the FISS analysis methodology, the estimated numbers in the landings by IPHC Regulatory Area were used to weight the proportions-at-age for totals by Biological Region and coastwide.

The resultant fishery age-frequency distributions reveal that Pacific halibut in the commercial landings from the 1930s to 1973 (when the current minimum size limit was implemented) were predominantly age 6 to 15 (Figure 42). Several strong cohorts can be observed in the data, but none more conspicuous or persisting longer than the 1987 year-class. When the fishery age data are aggregated by Biological Region, a similar pattern emerges to that seen in the FISS data: a greater proportion of older Pacific halibut in Biological Regions 4 and 4B than in Regions 2 and 3. However, much of the historical catch has been taken over a very similar age range regardless of year or location, and clear evidence that the strong 1987 cohort was present across the entire range of the population (Figures 43-45).

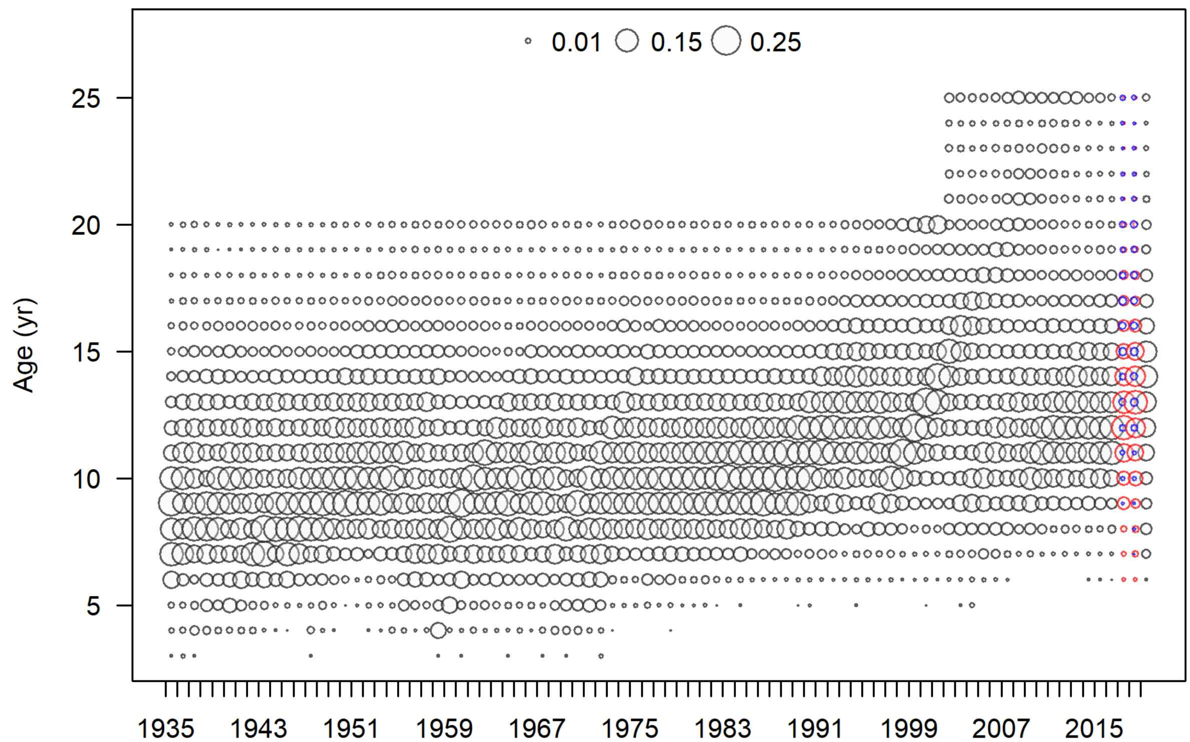

FIGURE 42. Coastwide commercial fishery proportions-at-age from the retained catch. Note that the current 32 inch (82.3 cm) minimum size limit was implemented in 1973. Circles represent proportions that sum to 1.0 within each year. For 2017 and 2018, males are delineated by the blue circles and females by red at each age, for all other years males and females are aggregated as the sex is unknown.

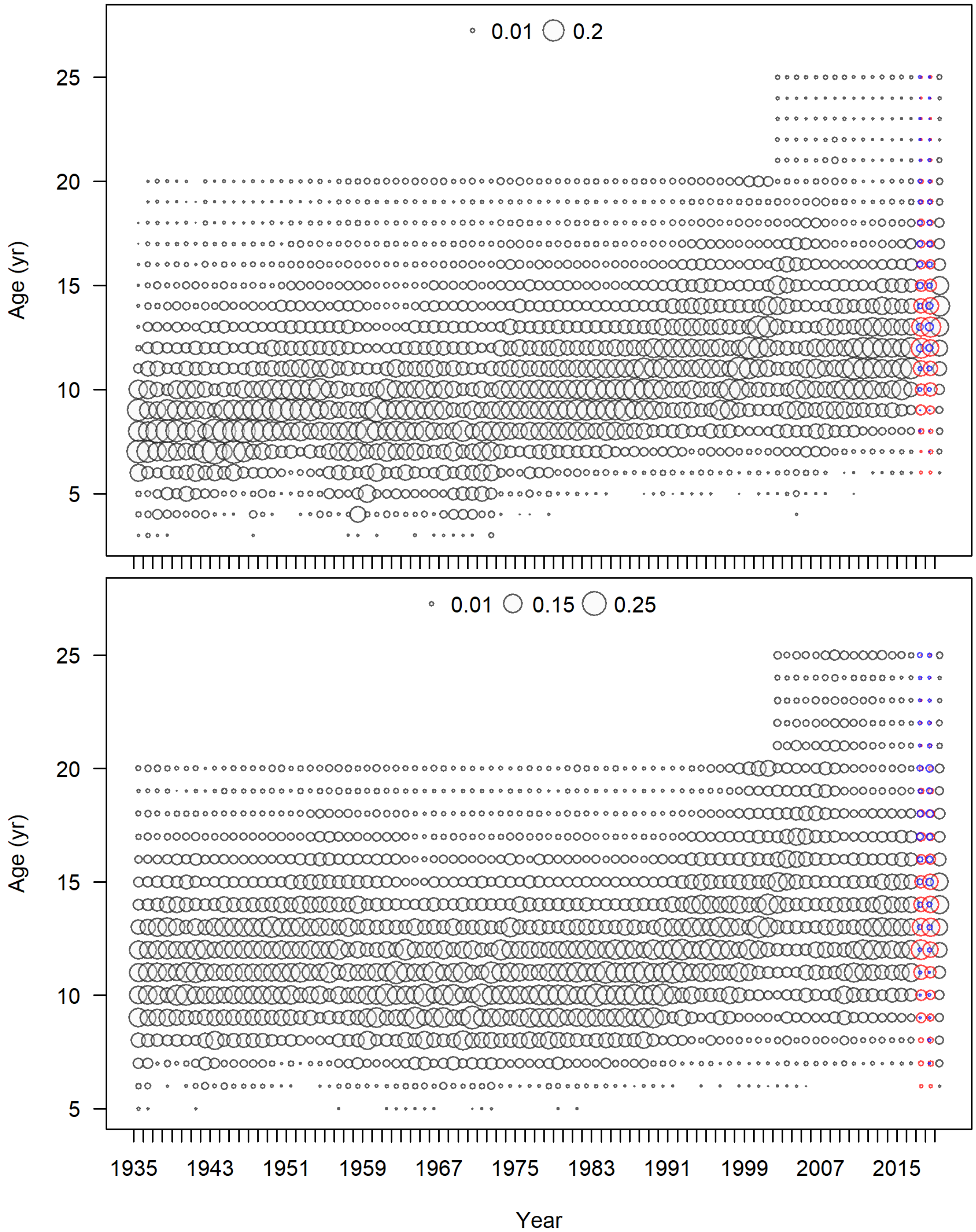

FIGURE 43. Commercial fishery proportions-at-age in the retained catch (male and female Pacific halibut combined) for Biological Region 2 (top panel), and Region 3 (bottom panel). Circles represent proportions that sum to 1.0 within each year. For 2017 and 2018, males are delineated by the blue circles and females by red at each age, for all other years males and females are aggregated as the sex is unknown.

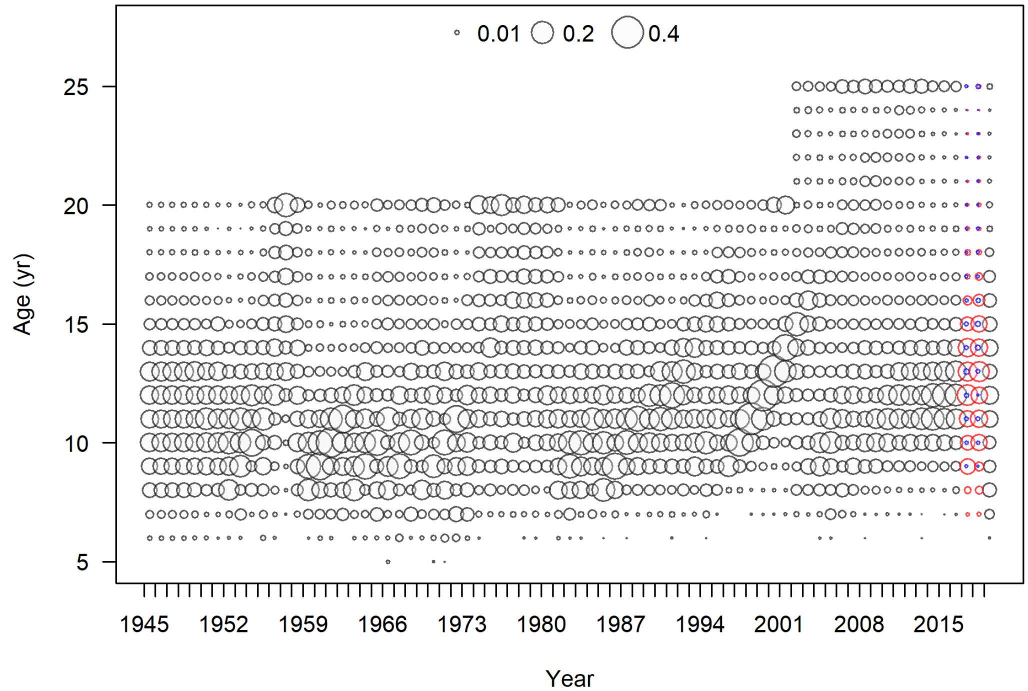

FIGURE 44. Commercial fishery proportions-at-age in the retained catch (male and female Pacific halibut combined) for Biological Region 4. Circles represent proportions that sum to 1.0 within each year. For 2017 and 2018, males are delineated by the blue circles and females by red at each age, for all other years males and females are aggregated as the sex is unknown.

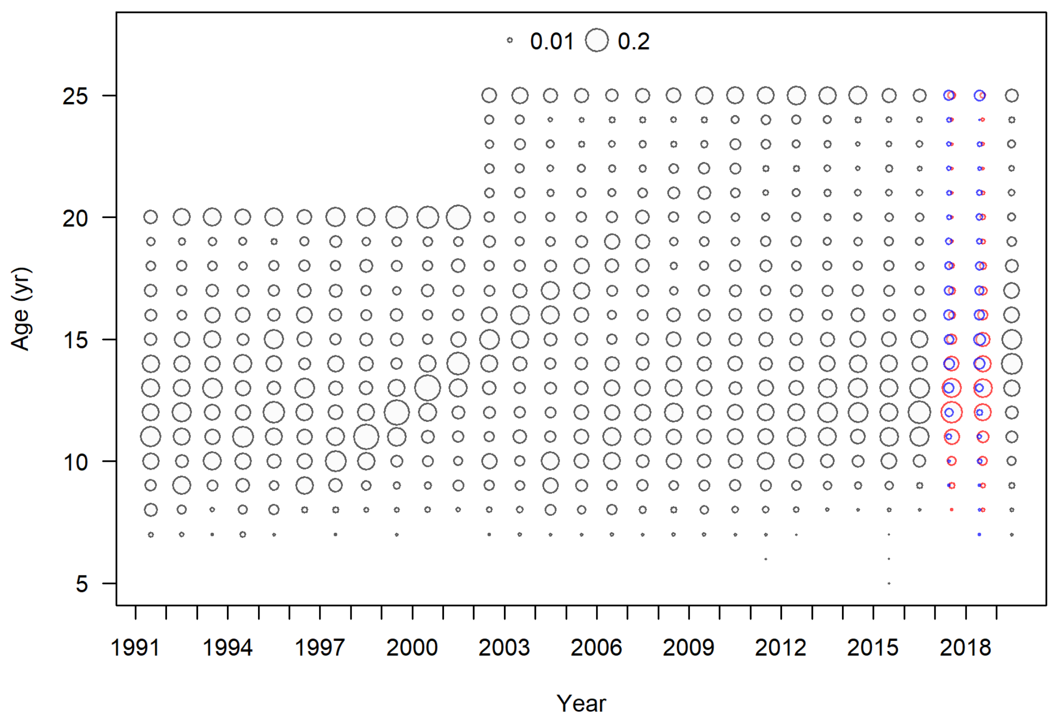

FIGURE 45. Commercial fishery proportions-at-age in the retained catch (male and female Pacific halibut combined) for Biological Region 4B. Circles represent proportions that sum to 1.0 within each year. For 2017 and 2018, males are delineated by the blue circles and females by red at each age, for all other years males and females are aggregated as the sex is unknown.

Commercial fishery weight-at-age

Individual fish weights, and otoliths are collected from the landed catch by port samplers each year. The recent average weight of a landed Pacific halibut has been the highest (around 30+ lbs, 13.6 kg) in IPHC Regulatory Area 2C. The trends in average weight have been reasonably flat since 2011, with some differences among IPHC Regulatory Areas (Figure 46). The coastwide trend remains lower than the last several decades but stable since around 2010. These observations accurately reflect the fishery landings, but include the relative influences of weight-at-age, age- and sex-structure, as well as selectivity and fishery behavior relative to the underlying population.

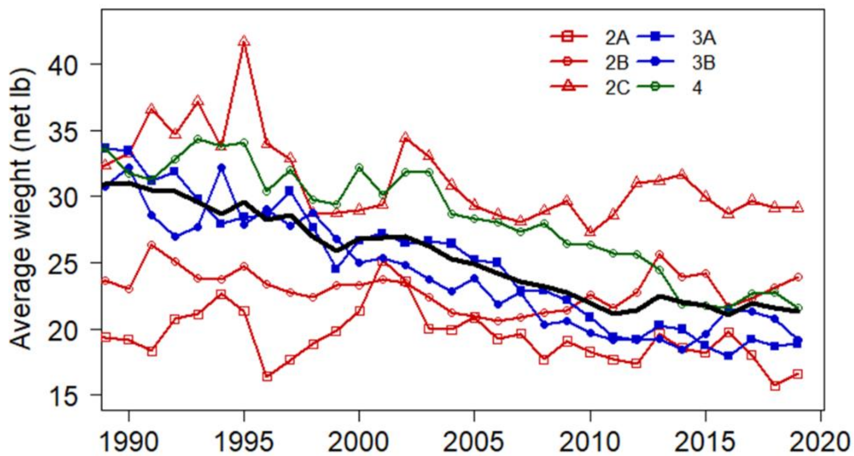

FIGURE 46. Recent average Pacific halibut weight by IPHC Regulatory Area in the directed commercial fishery landings; thick black line indicates the coastwide average.

Historical observations of average weight are more problematic. Specifically, from 1963-1990 the IPHC did not collect individual lengths from the commercial landings. It was thought at the time that otoliths measurements could be used to accurately estimate the length of the fish (Southward 1962), and therefore the weight. Subsequent investigation of the relationship between otolith measurements and individual length (Clark 1992) resulted in the resumption of length sampling in 1991. For this reason, the weights-at-age for most of the historical period should be considered much more uncertain than recent observations. Despite these considerations, there is a clear pattern of increasing fish size in the landings estimated from the 1930s through the 1970s, followed by a subsequent decline to the present (Figure 47). Also clearly visible is the effect of the implementation of the 32 inch (82.3 cm) minimum size limit in 1973.

Following the same method applied to the age-composition data (weighting the historical weight-at-age for each regulatory area by the number of fish in the landings for that IPHC Regulatory Area), weight-at-age by Biological Region and coastwide can be constructed for the entire time-series. Unfortunately, this historical series is not sex-specific due to the dressing of fish at sea prior to sampling in port. However, there are very similar trends for the best represented ages (8-16) over the historical period. One way to investigate these patterns is to divide the time series of weight-at-age for each age by the value observed in the first year in which we have a coastwide estimate from setline survey data (1997). Only legal-sized fish from the setline survey catch are included in these weights-at-age in order to make them comparable to fishery landings. These deviations show very similar temporal patterns, despite expected differences on an absolute scale (Figure 48). As a proxy for sex-specific weights-at-age for the entire time-series, the FISS weights-at-age from 1997 are scaled by the time series of annual deviations calculated from the fishery data. This implicitly assumes that male and female Pacific halibut have experienced similar trends in size-at-age; recent sex-specific data support this assumption. The resulting reconstructed coastwide mean weights-at-age clearly show an increase in the late 1970s and subsequent decrease toward present estimates (Figure 49).

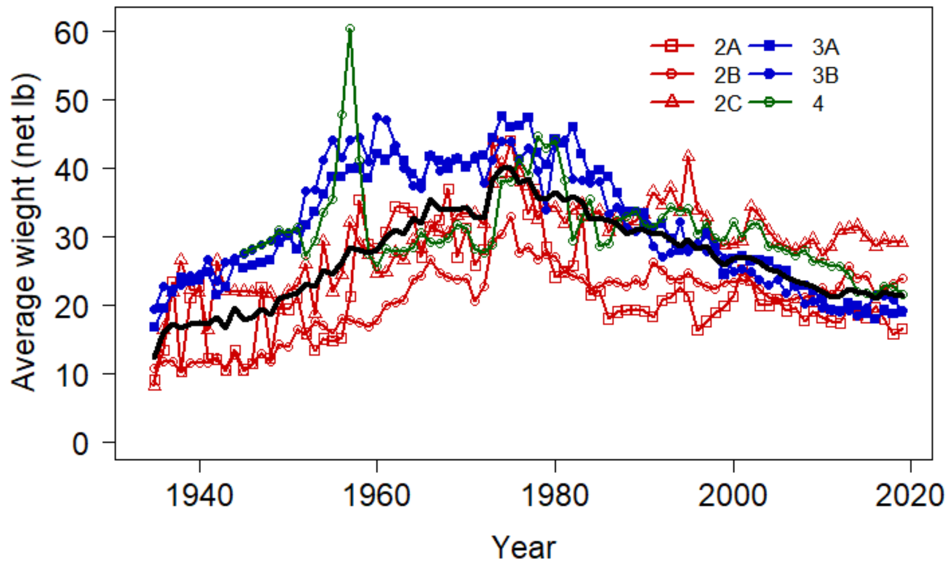

FIGURE 47. Historical trends in average individual Pacific halibut weight in the commercial fishery landings; thick black line indicates the coastwide average. The current 32 inch (81.3 cm) minimum size limit went into effect in 1974.

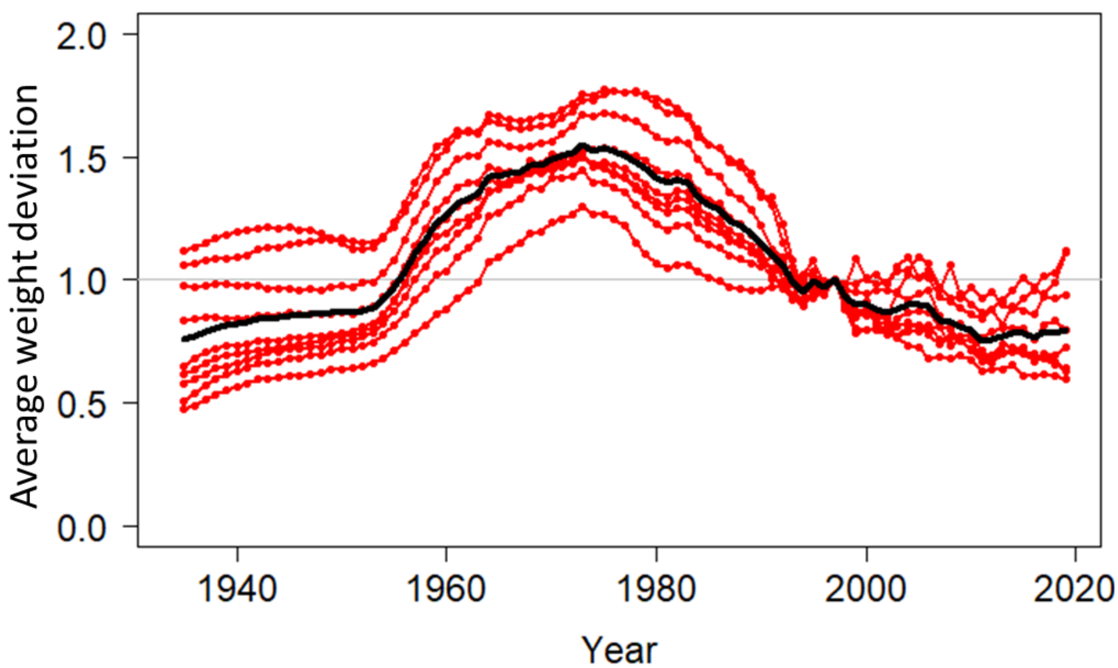

FIGURE 48. Trends in coastwide average individual Pacific halibut weight as deviations from 1997 in the commercial fishery landings for Pacific halibut aged 8-16 years old (red lines). The black line represents the average trend among the nine ages included.

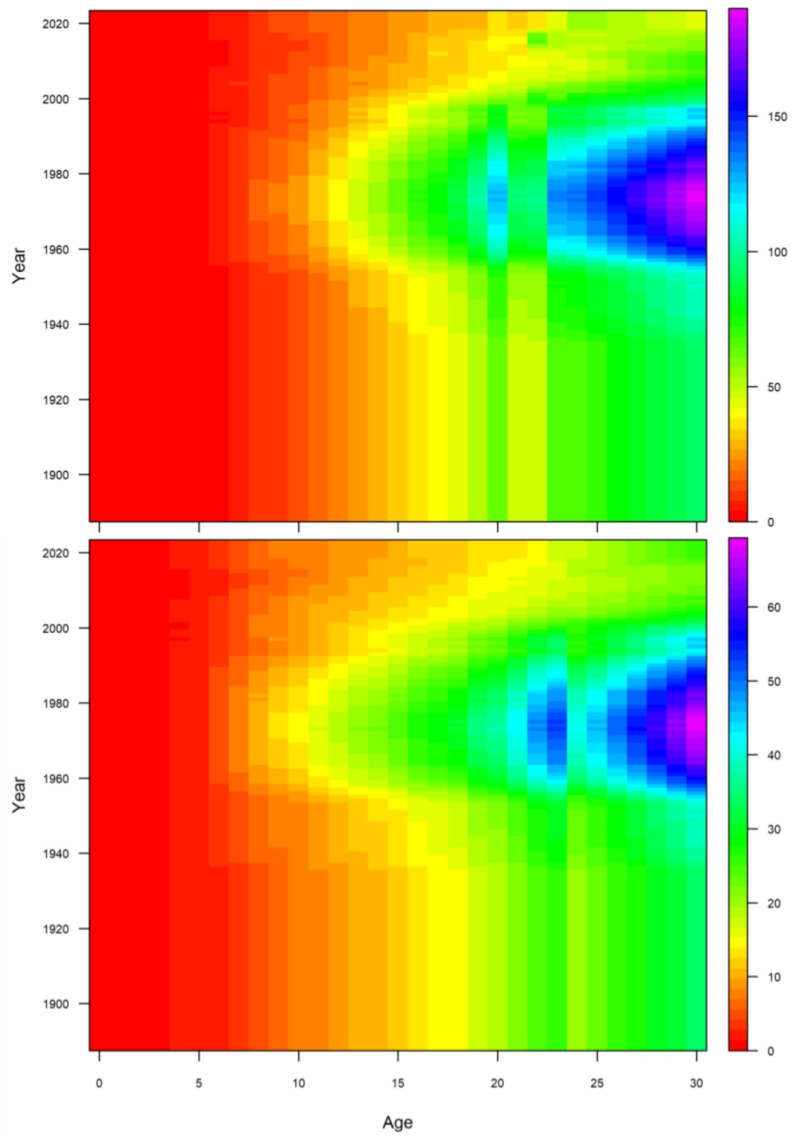

FIGURE 49. Time series of coastwide weight-at-age (net lb) for female (upper panel), and male (lower panel) Pacific halibut from all IPHC Regulatory Areas (note that the scale differs between panels).

The same methods were also used to estimate trends in weight-at-age by Biological Region. The results indicate that changes in Region 2 have been less pronounced than the very large decrease in fish size observed for Region 3 from the 1950s through the 1990s and that Region 4 has shown a much more muted historical pattern (Figure 50). The relative scalar for Region 4 is only slightly above a value of one for most of the historical period, and the smallest values occur in the most recent years. Trends in recent years show increased deviations for some ages, but continued declines for others. No historical data predating the FISS were available from the commercial fishery in Region 4B. The historical Region 4 weight-at-age arrays were therefore used as input for both Region 4 and Region 4B.

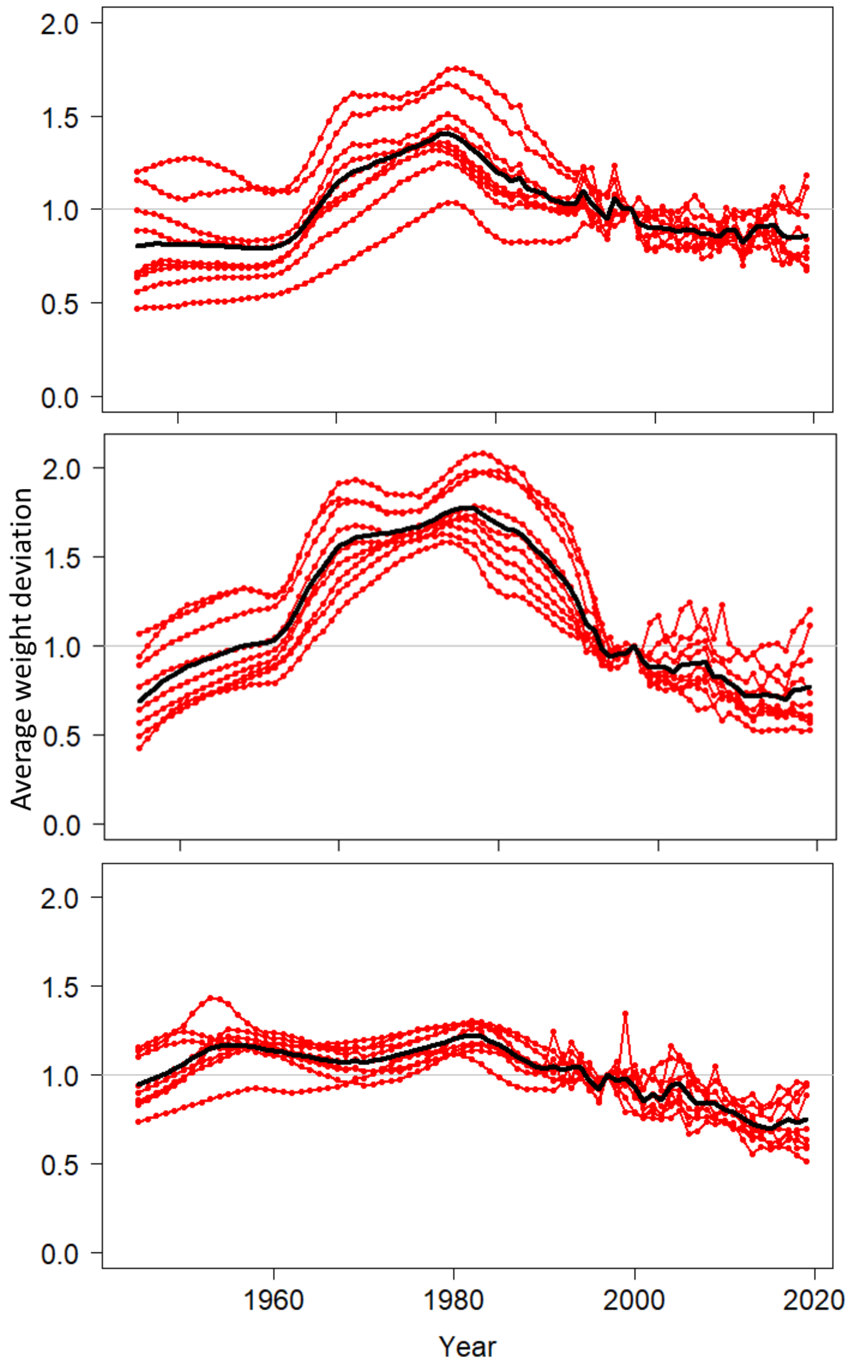

FIGURE 50. Trends in average individual Pacific halibut weight as deviations from 1997 in the commercial fishery landings for Pacific halibut aged 8-16 years old (red lines) from Biological Region 2 (upper panel), Region 3 (middle panel), and Region 4 (lower panel). The black lines represent the average trend among the nine ages included.

Recreational fishery age distributions

Otoliths sampled from the recreational catch of Pacific halibut in IPHC Regulatory Area 3A have been routinely collected by ADF&G, and the ages read by IPHC staff. These samples are weighted by port-specific harvest and provided to the IPHC for use in the stock assessment. (S. Webster, ADFG, pers. comm.). These data showed a variable but generally larger proportion at ages younger than age 5, and smaller proportion greater than age 15 (Figure 51) compared to the coastwide FISS over a similar time-period (Figure 10). The recreational data also contained a few Pacific halibut below age 4 which is younger than any observed in the setline survey. The observation of extremely young Pacific halibut differs from the FISS, as trends in size-at-age indicate that some of the smallest fish for their age across the coast are currently observed in Area 3A, so that area might be expected to have fewer very young fish in the recreational harvest if selectivity were similar to that of the setline survey. Of note in the 2017-18 distributions are the increased abundance of Pacific halibut at ages 6-7 representing the 2011 and 2012 year-classes. These observations are consistent with other data suggesting slightly larger year classes than observed from 2006-10. These data are not geographically comprehensive; however, recreational removals from Area 3A represent around half of the coastwide recreational total in recent years. Currently, there are no additional age data from the recreational fisheries in other Regulatory Areas, but such data could be included with those from Area 3A if they become available (or are created via age-length keys from creel sampling) in the future. It may also be possible in the future to partition these ages by male and female Pacific halibut to better understand the effects of these removals on the Pacific halibut stock.

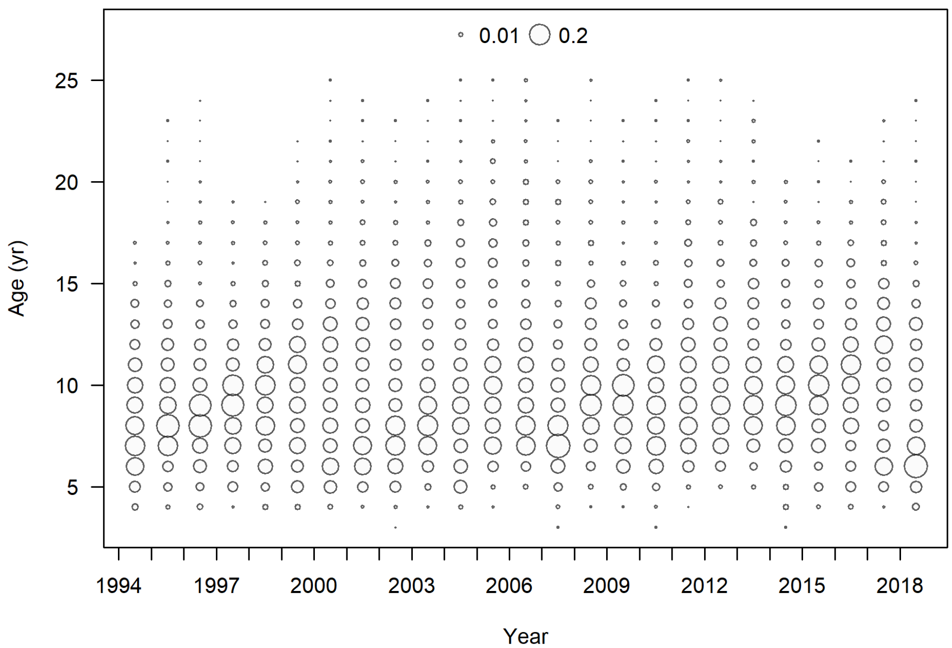

FIGURE 51. Proportions-at-age from the recreational fishery in IPHC Regulatory Area 3A (male and female Pacific halibut combined). Circles represent proportions that sum to 1.0 within each year.

Age distributions from Pacific halibut captured in non-directed commercial fisheries

The length-distribution of Pacific halibut caught in commercial fisheries targeting other species (i.e., non-directed; 'bycatch') is reported to the IPHC each year by the National Marine Fisheries Service (NMFS; for Alaska and Washington-Oregon-California) and Fisheries and Oceans Canada (DFO; for British Columbia). Historically, the raw length frequencies are summarized by target fishery within gear type (i.e., trawl, hook-and-line, and pot), then aggregated in order to better represent the differing contributions and sampling rates for each fishery. Weighted length-frequencies are used in the annual interim management procedure calculations where mortality tables specifically to delineate O26 and U26 non-directed commercial fisheries discard mortality. In order to evaluate these data directly in the context of the stock assessment, they first need to be converted to age-distributions. Annual age-length keys were produced from the NMFS survey data for the years 1998-2018, and the global key used for prior years and 2019. Coastwide aggregate non-directed commercial fishery lengths were summarized into predicted ages via these annual age-length keys. Estimated age distributions showed a mode (or modes) between age-3 and age-10, with up to one-third of the total age distributions represented by Pacific halibut age-4 or less in some years (Figure 52). Consistent with the NMFS Bering Sea trawl survey data, both the 1987 cohort and the strong 2004-05 year classes are also present in the estimated distributions for the coastwide discard mortality. Increased proportions corresponding to the 2011 and 2012 year-classes are also clearly present in this data set, and may become more pronounced in the 2019 observations when actual 2019 length and age data become available.

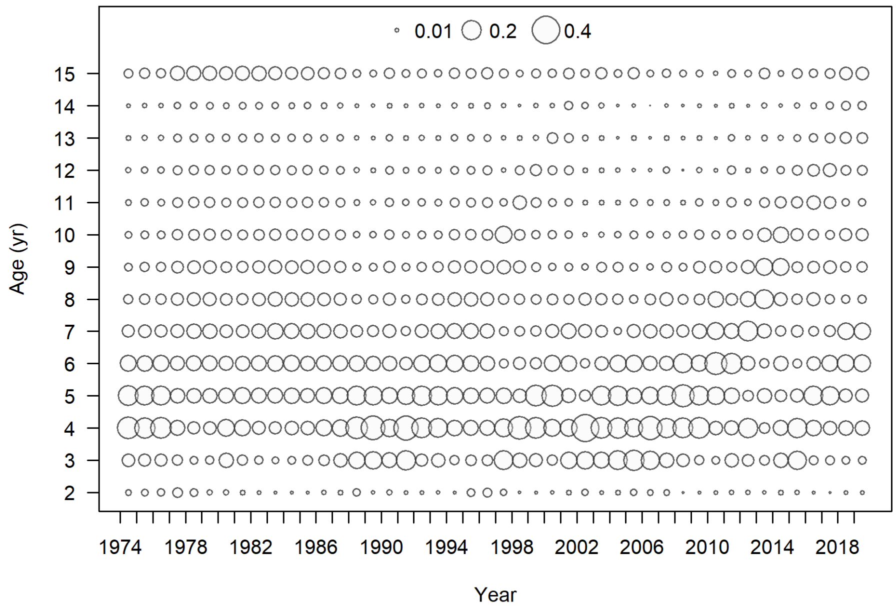

FIGURE 52. Coastwide proportions-at-age from the aggregate non-directed commercial fisheries (male and female Pacific halibut combined). Circles represent proportions that sum to 1.0 within each year.

AUXILIARY SOURCES OF INFORMATION

Several additional sources of information are evaluated directly, included in the stock assessment or related analyses and treated as data, even though they represent the products of analyses themselves. These are briefly summarized here but considerable additional background material exists.

Weight-length relationship

The weight-length relationship for Pacific halibut was developed in 1926, re-evaluated in 1991 (Clark), and has been applied as standard practice for al years of IPHC management. The relationship between fork length (L_f), and individual net (headed and gutted) weights (W_n) is given by:

$$W_n = 0.00000692 \cdot {L_f}^{3.24}$$

This relationship reflects the slightly greater than cubic increase in weight with increasing length (Figure 53). In 2013, the IPHC staff initiated a program to begin sampling individual weights during port sampling. Since 2015 this program has included data collection on survey vessels and during routine port sampling in almost all ports. In addition, beginning in 2019 individual Pacific halibut weights have been collected during FISS sampling (**IPHC-2020-AM096-06**). These direct observations have reduced the use of the weight-length relationship in IPHC analyses, and over the next several years these data should allow for exploration of the length-weight relationship, as well as an improved understanding of the differences in measurements collected on freshly dead fish, fish that have been stored on ice, as well as the relative contributions of head-weights, ice and slime on standardization to net weight. Such analyses may result in revised and potentially geographically-explicit weight-length relationships in the future.

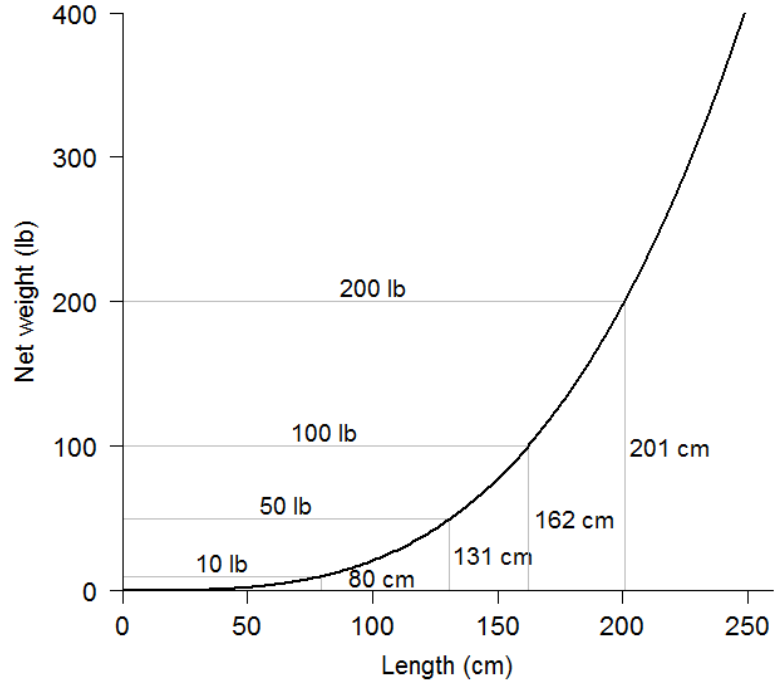

FIGURE 53. The conversion relationship for length in centimeters to net weight in pounds.

Maturity schedule

The maturity schedule for Pacific halibut has been investigated several times historically, and maturity-at-age found to be very stable despite long-term changes in length- and weight-at-age (Clark and Hare 2006). Estimates of the age at which 50% of female Pacific halibut are sexually mature average 11.6 years among regulatory areas, with very few fish mature at ages less than five and nearly all fish mature by about age 17. The maturity schedule used for stock assessment has not been updated in recent years, and it is represented by a logistic fit that is truncated below age 8 (Figure 54). A research program to evaluate the current maturity schedule has been ongoing since 2017 (**IPHC-2020-AM096-11**).

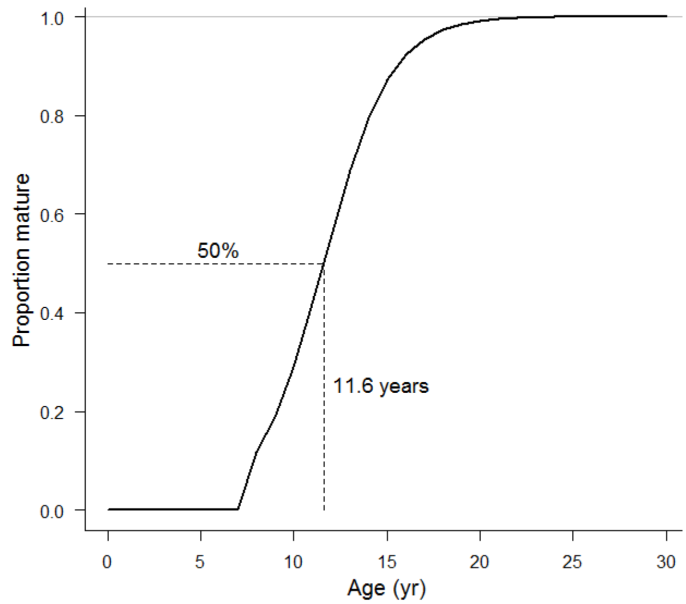

FIGURE 54. The maturity ogive used in recent Pacific halibut assessments. Note that this is a logistic curve, trimmed to be equal to zero below age-8.

Ageing bias and imprecision

Ages are often treated and referred to as 'data', however they represent estimates of age based (most commonly) on the counting the rings formed annually on otoliths. These estimates are therefore subject to both bias and imprecision depending on the method employed to obtain them. Pacific halibut tend to be relatively easy to age (compared to longer-lived groundfish), and historical estimates of the imprecision of the standard method of 'break-and-bake' ageing showed that the method was very precise (Clark 2004a, 2004b; Clark and Hare 2006). Validation of the method relative to actual age has been performed via analysis of radiocarbon levels observed in known-age otoliths, and the relationship has since been used as the standard for North Pacific groundfish species (Piner and Wischnioski 2004).

Prior to 2002, surface ageing was employed as the primary tool for ageing Pacific halibut, and this method is known to be biased for older individuals and less precise than other methods when applied to many marine species. Estimates of bias and imprecision for break-and-bake and surface ages were updated in 2013 based on re-aging of setline survey samples from 1998 (Stewart 2014). Analysis of surface ages from each decade back to the 1920s also corroborated those results (Forsberg and Stewart 2015).

Movement rates among Biological Regions

Development of spatially explicit stock assessment and Management Strategy Evaluation (MSE) operating models requires an understanding of the rates of movement among geographic regions. A review of historical studies and more recent tagging by the IPHC is ongoing, with a summary and interactive tool planned for the Biological and Ecosystem Science Research section of the IPHC's website. This review will update and replace previous summaries contained in this document.

Ecosystem conditions

Previous research identified a strong correlation between the environmental conditions in the northeast Pacific Ocean, specifically the Pacific Decadal Oscillation (PDO; Mantua et al. 1997) and recruitment of Pacific halibut to the commercial fishery during the 1900s. The time-series of estimates has recently been moved and can now be found at: https://oceanview.pfeg.noaa.gov/erddap/tabledap/cciea_OC_PDO.htmlTable?time,PDO. For Pacific halibut, the positive 'phase' of the PDO (years up to and including 1947, 1977-2006, and 2014+) and concurrent recruitment appears to be correlated (Clark and Hare 2002; Clark et al. 1999). Continued evaluation of this correlation indicates that it still appears strong using data through 2019 (Stewart and Hicks 2019). Therefore, the most recent PDO observations comprise the only information available related to Pacific halibut abundance prior to their observation in the survey and fisheries, generally a lag of 6 to 8 years. PDO values from 2006-2013 were negative, representing the longest period of negative annual values observed since the late 1970s. Positive values have been observed over 2014-19 (Figure 55); however, these values should be interpreted cautiously, as many other environmental indicators were highly anomalous, and it is very unclear whether these years represent comparable conditions to previous PDO observations. The correlation between the PDO and average recruitment strength is re-estimated in each year's stock assessment (**IPHC-2020-AM096-09**).

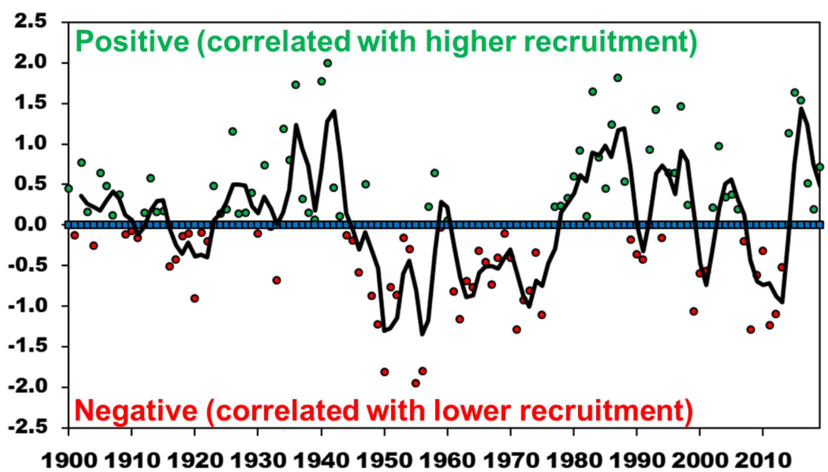

FIGURE 55. Time series of annual average PDO conditions (deviations from the long-term mean).

The Gulf of Alaska and Bering Sea have exhibited warmer than average temperatures over the period 2014-2019, with repeated marine 'heat waves' in the Gulf of Alaska, and very little sea ice for two consecutive seasons in the Bering Sea (Siddon and Zador 2019; Zador et al. 2019). These conditions have been associated with seabird, marine mammal and Pacific cod (*Gadus macrocephalus*) mortality events in the Gulf of Alaska (Barbeaux et al. 2019). However, this same time period also appears to have produced very large 2014 and 2016 year classes for the sablefish (*Anoplopoma fimbria*) stock (Hanselman et al. 2019). It remains unknown whether historical correlations related to the PDO will be relevant to this period, and it will be several more years until the Pacific halibut recruitment from the 2014 and subsequent year-classes is observed in the FISS and then subsequently in the directed fisheries.

Empirical harvest rates

This section provides an empirical approach for evaluating relative harvest rates based solely on data (rather than stock assessment output). A measure of exploitation (U) in each year (y)

and Biological Region (*r*) can be based on the O26 mortality (or 'catch'; *C*) and some measure of the biomass (*B*):

$$U_{y,r} \sim \frac{C_{y,r}}{B_{y,r}}$$

The biomass is a function of the modelled survey index (*I*) and an unknown catchability parameter (*q*):

$$B_{y,r} = q_{y,r} \cdot I_{y,r}$$

Finally, the survey index is a function of the modelled survey WPUE of all sizes of Pacific halibut (primarily O26), and the geographic extent (*A*) of each Biological Region:

$$I_{y,r} = WPUE_{y,r} \cdot A_r$$

In this calculation, it is assumed that the catchability parameter is constant (or at least non-trending) across years and among Biological Regions (note that the FISS timing and station-specific hook competition are already accounted for in the space-time modelling of WPUE; **IPHC-2020-AM096-07**). Given this approach, with an unknown constant value for catchability, the absolute scale of the exploitation intensity is unknown. Therefore, to compare across years all *U*s were scaled relative to the average over the period 2014-2016, providing a relative metric of exploitation rates. Much higher *U*s are estimated historically for Biological Region 2, than in other Regions; however, all Regions experienced peak harvest rates between 2003 and 2009 (Figure 56). The harvest rates in all Regions were generally lower than most historical values over the period 2012 -2014, but increased in Regions 2 and 3 during 2017-19.

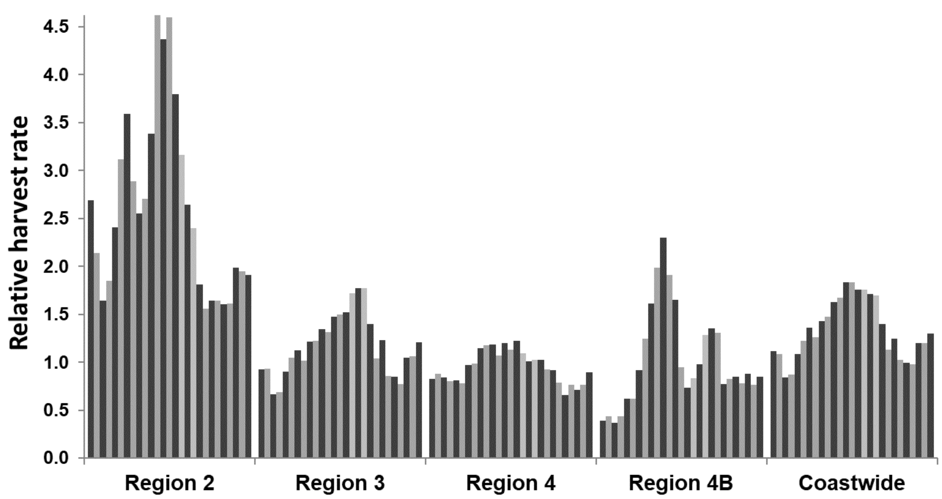

FIGURE 56. Empirical harvest rates from 1993-2019. All rates are relative to the coastwide average over the period 2014-2016, which is arbitrarily set equal to 1.0.

CONCLUSIONS

Despite the heterogeneous nature of the various datasets, there is a considerable quantity of historical data available for Pacific halibut, perhaps more than for any other single groundfish species in the region. The IPHC has the benefit of an extremely long time-series of data collection, a high degree of cooperation from the commercial fleet, and therefore a unique resource for historical fishery and biological patterns in the northeast Pacific Ocean. The data themselves, after accounting for important known changes in fishery and survey activities, are highly informative for stock assessment, harvest policy, and MSE analyses.

Summary of improvements for 2019

This document does not attempt to describe all relevant detail in processing data for use in the stock assessment, MSE and harvest policy analyses. It is intended to provide an overview of what might be considered current IPHC 'best practices', relying on previous documents to identify the development of sources and methods. Important changes or additions are noted each year; for 2019 these included:

- Results of the FISS expansion in Biological Region 3 (**IPHC-2020-AM096-06** and **IPHC-2020-AM096-07**).
- Sex-ratio information from the 2017 and 2018 directed commercial Pacific halibut fishery landings.
- Standard updating of preliminary values from 2018 including mortality estimates, commercial logbooks and commercial age distributions.
- All current-year data available at the end of October 2019.

Research priorities

Research priorities for the stock assessment and related analyses have been consolidated with those for the IPHC's MSE and the Biological Research program. These ranked and categorized priorities will soon be available on the IPHC's website.

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