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 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 data page on its website. 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. Beginning in 2019, links have been added here to existing online resources, and some material (where redundant or outdated) has been removed.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 these categories: 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 2022 stock assessment is provided as a separate document (IPHC-2023-SA-01), as are native stock assessment model input data files (IPHC-2023-SA-03, IPHC-2023-SA-04, IPHC-2023-SA-05, and IPHC-2023-SA-06). These are available through the IPHC's stock assessment web page along with historical review and assessment analyses.

FISHERY-INDEPENDENT DATA

Fishery-independent data are generated each year by the IPHC's Fishery-Independent Setline Survey (FISS), selecting annual stations from an 1890-station design (IPHC-2023-AM099-10) covering the range of Pacific halibut habitat in Convention waters from the northern Bering Sea and Aleutian Islands to California, and depths of 10-400 fathoms (Figure 1). The FISS generates catch rate information, as well as biological data from individual fish sampled randomly from the catch, including sex, weight, length, age, maturity, and the presence of prior hooking injury. 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.

The time-series of these data[1] are analyzed via space-time modelling (Webster et al. 2020) each year, in their entirety, for use in the stock assessment as new observations become available that inform the time-series. The 2022 FISS (IPHC-2023-AM099-08), was reduced from the initial design mainly due to vessel recruitment challenges, but completed sampling in all IPHC Regulatory Areas. The time-series of modelled FISS data extends from 1993-2022.

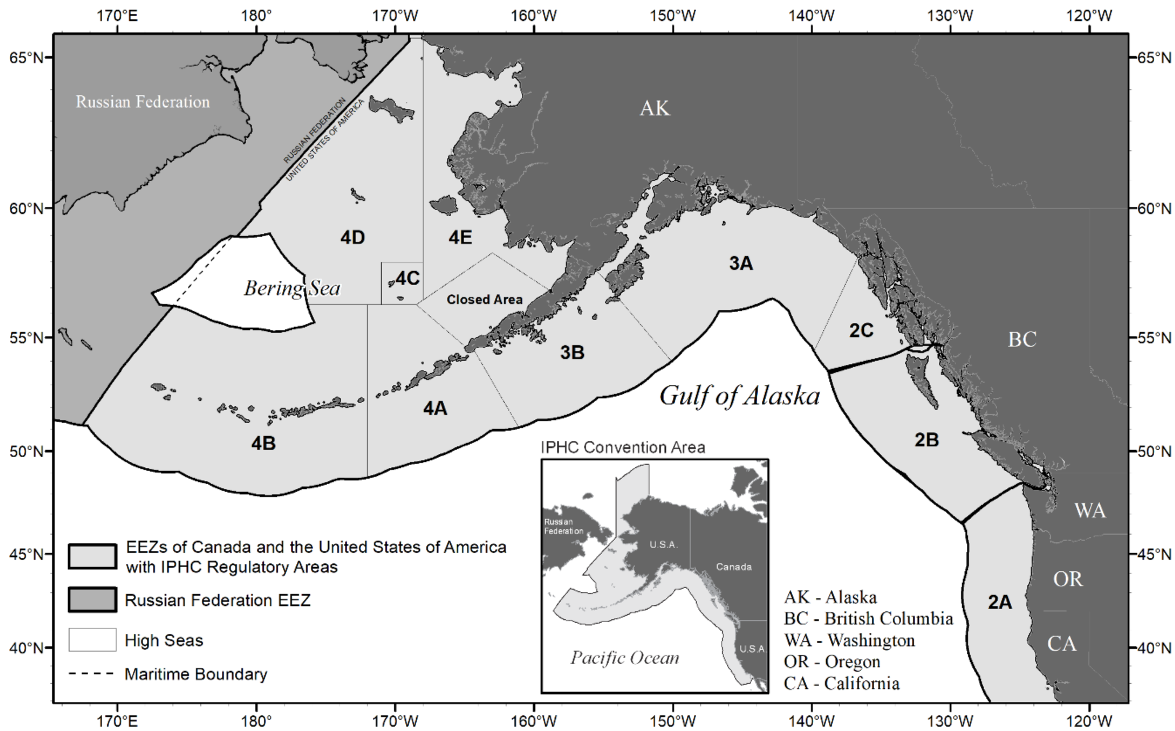

FIGURE 1. IPHC Regulatory Areas and the Pacific halibut geographical range within the territorial waters of Canada and the United States of America.

In addition to their use in supplementing the FISS data in IPHC Regulatory Areas 4A and 4CDE, bottom trawl surveys conducted by the U.S. National Marine Fisheries Service (NMFS) 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 FISS 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 IPHC's space-time modelling (IPHC-2023-AM099-09). The stock assessment models fit directly to the modelled NPUE as the data are naturally collected as numbers of fish; however, the observed weight-at-age (collected since 2019) is also used directly in the stock assessment along with other weight data from the fishery and trawl surveys (see below). Estimated coastwide survey NPUE showed an 8%

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

decrease from 2021 (Figure 2). Biological Region 3 decreased by 12%, while Biological Region 2 increased by 1%. Biological Regions 4, and 4B both showed small declines (2 and 6%) and remain at or near the lowest values in the estimated time-series, with mixed trends in individual IPHC Regulatory Areas (Figure 3).

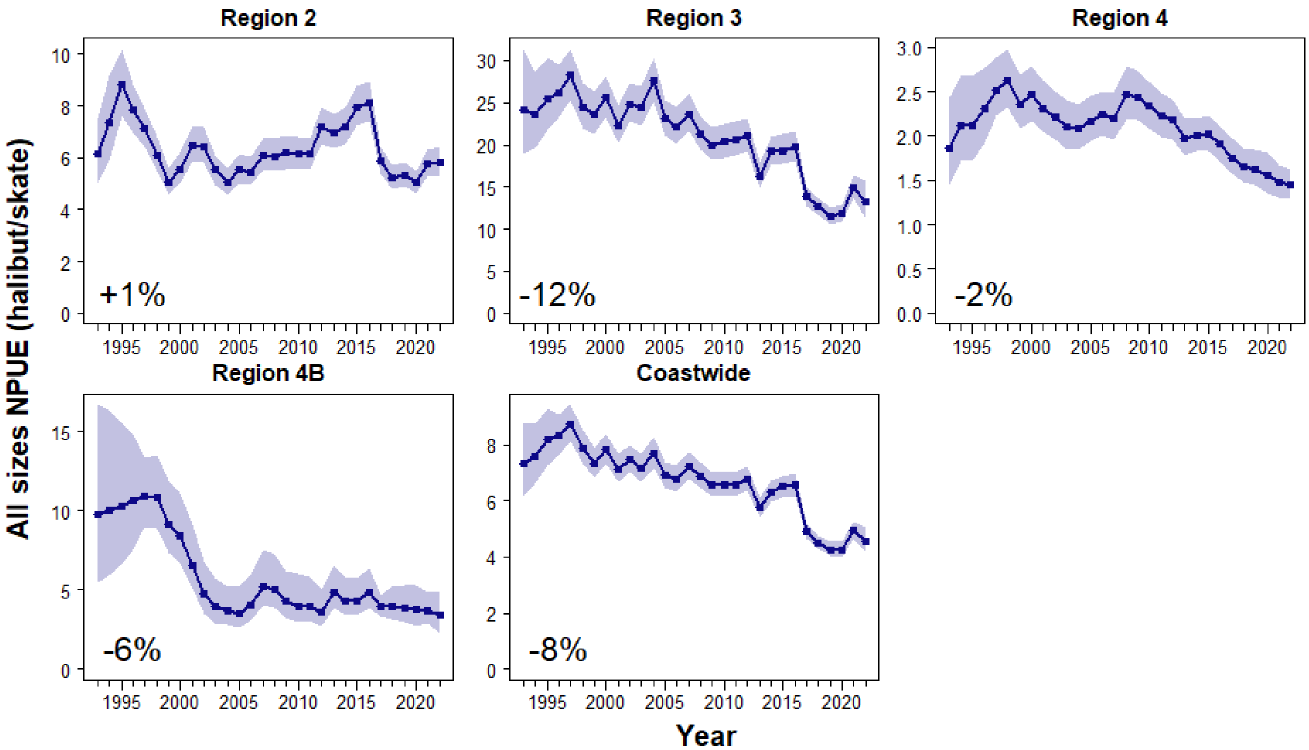

FIGURE 2. Trends in modeled survey NPUE by Biological Region, 1993-2022. Percentages indicate the change from 2021 to 2022. Shaded zones indicate 95% credible intervals.

Estimated coastwide survey WPUE (including all sizes of Pacific halibut captured by the FISS) decreased by 11% from 2021 to 2022 (Figure 4). This steeper trend relative to that for NPUE indicates that younger fish is contributing more to current stock productivity than somatic growth of larger fish. Biological Region 3 showed the largest individual estimated decrease of 19% and Biological Region 4B showed the only increase (4%) from 2021 to 2022. Individual IPHC Regulatory Areas ranged from a 10% increase in 4CDE to a 28% decrease in 3A (Figure 5). Trends in modelled legal-size (above the 32 inch, 81.3 cm, minimum size limit; O32) WPUE moved in the same direction as those for the modelled WPUE of all sizes of Pacific halibut captured by the FISS, but decreased to a greater degree in almost all IPHC Regulatory Areas (Figures 6 and 7). Time series tables of modelled survey catch rates are available online.

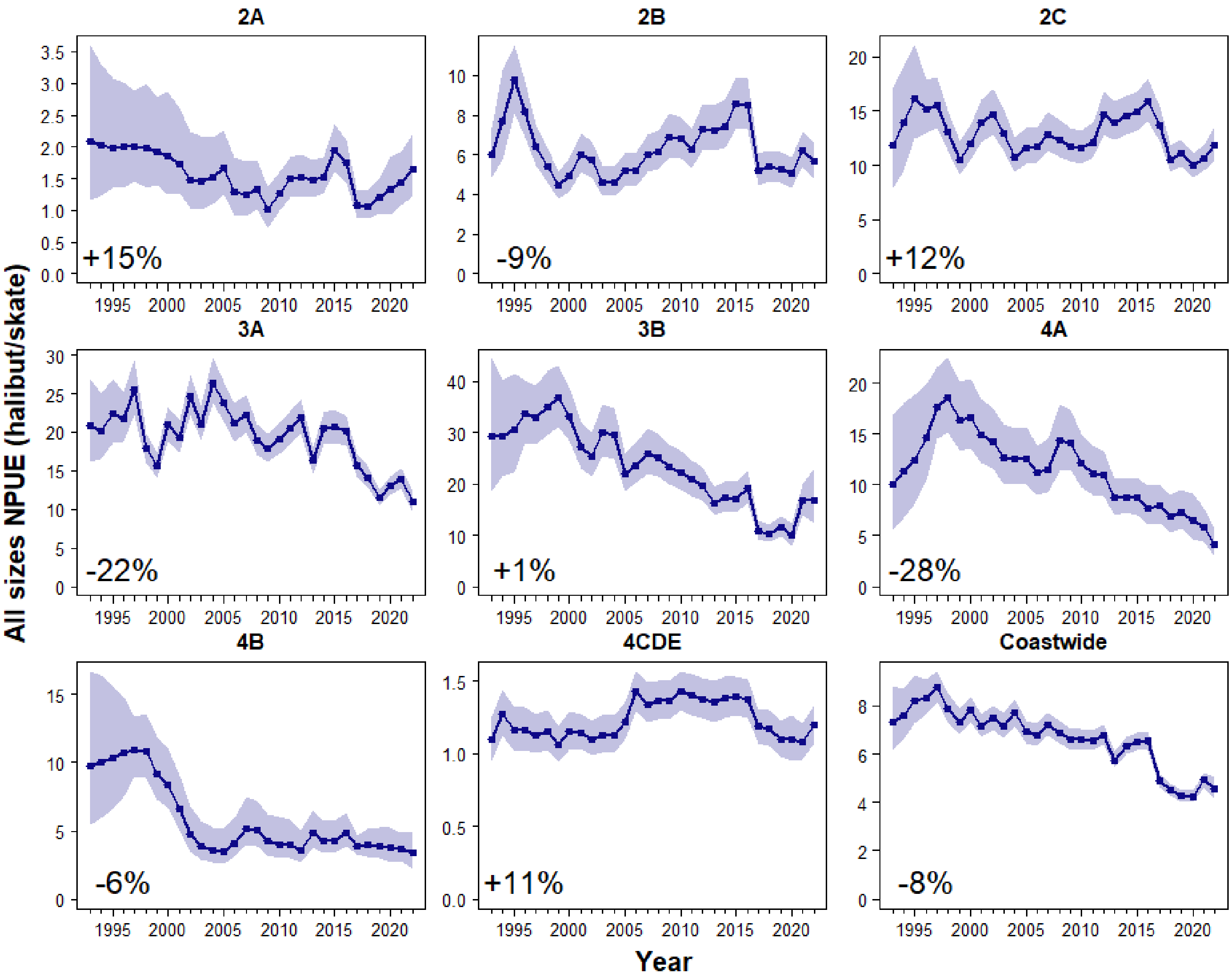

FIGURE 3. Trends in survey NPUE estimated from the space-time modelling by IPHC Regulatory Area, 1993-2022. Percentages indicate the estimated change from 2021 to 2022. Shaded zones indicate 95% credible intervals.

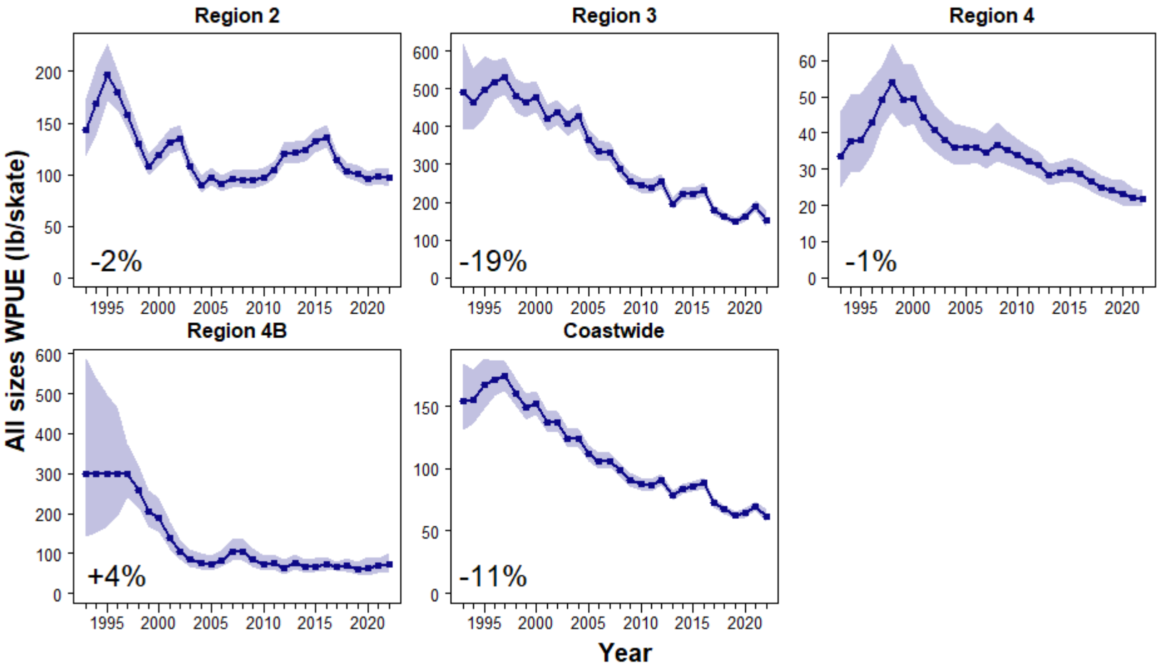

FIGURE 4. Trends in survey WPUE estimated from the space-time modelling by Biological Region, 1993-2022. Percentages indicate the estimated change from 2021 to 2022. Shaded zones indicate 95% credible intervals.

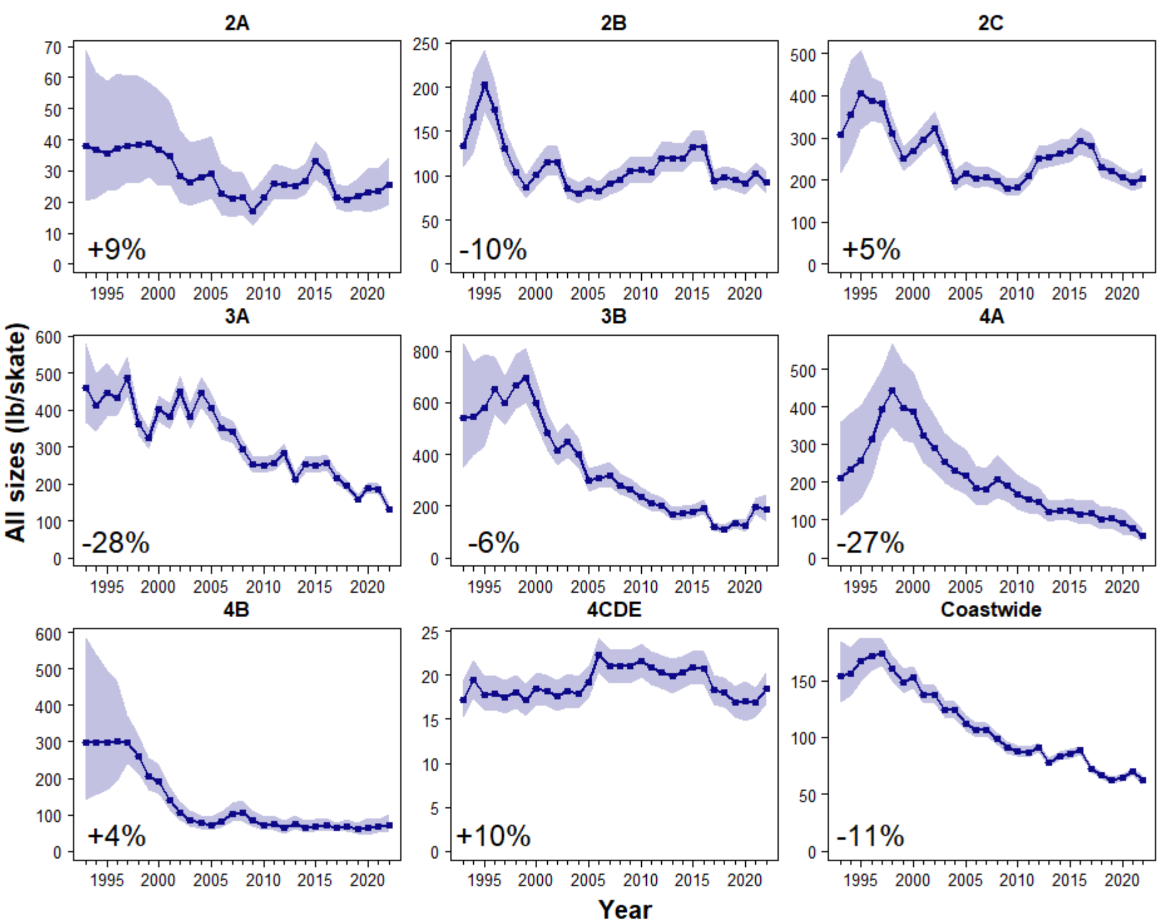

FIGURE 5. Trends in survey WPUE estimated from the space-time modelling by IPHC Regulatory Area, 1993-2022. Percentages indicate the estimated change from 2021 to 2022. Shaded zones indicate 95% credible intervals.

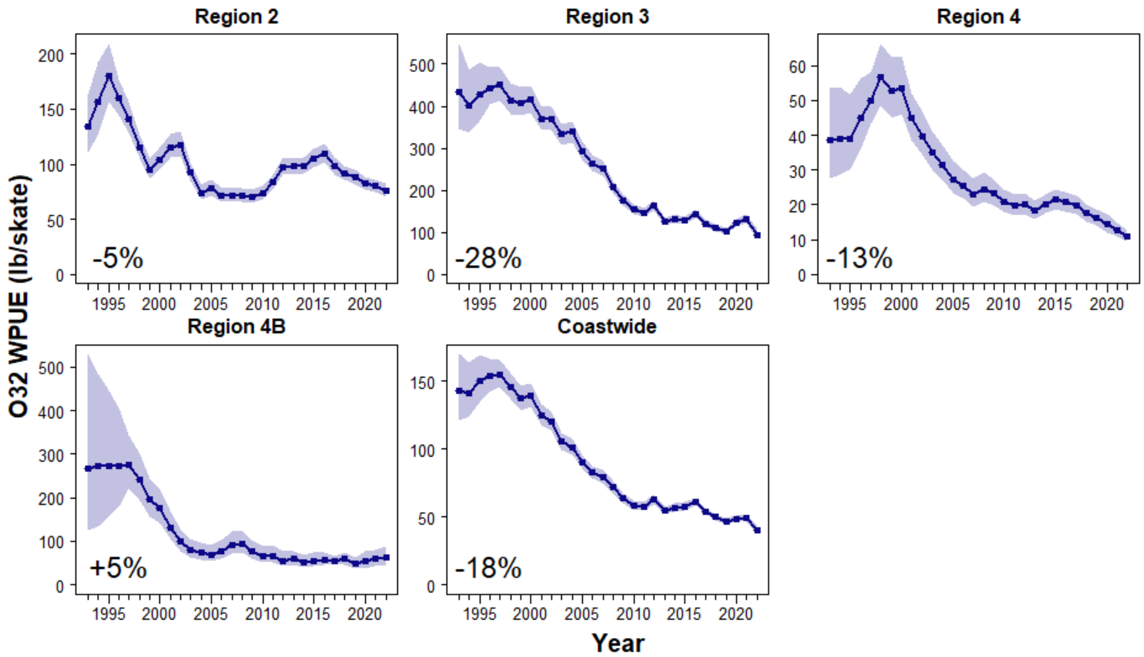

FIGURE 6. Trends in survey legal (O32) WPUE estimated from the space-time modelling by Biological Region, 1993-2022. Percentages indicate the estimated change from 2021 to 2022. Shaded zones indicate 95% credible intervals.

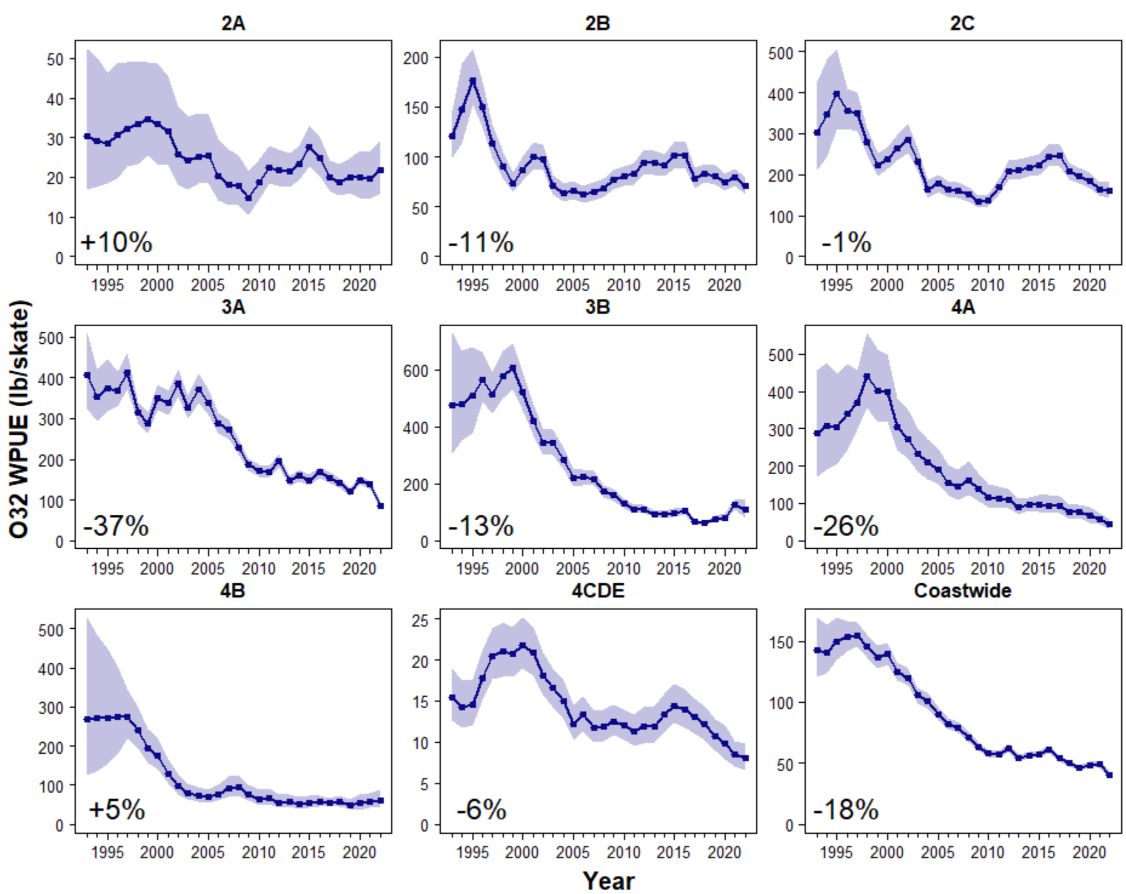

FIGURE 7. Trends in survey legal (O32) WPUE estimated from the space-time modelling by IPHC Regulatory Area, 1993-2022. Percentages indicate the estimated change from 2021 to 2022. Shaded zones indicate 95% credible intervals.

Biological stock distribution

Space-time model estimates of all-sizes 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. The 2022 stock distribution showed a sharp decrease in Biological Region 3, reversing a recent trend over 2020-21 toward increasing distribution in that Biological Region (Figure 8). All three other Biological Regions increased in 2022, with Biological Region 2 near the observed high value from 2019. 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 the estimated time series. Time series of stock distribution estimates by Biological Region, as well as distribution estimates by individual IPHC Regulatory Area (for all sizes of Pacific halibut captured by the FISS and for O32 only) are available online.

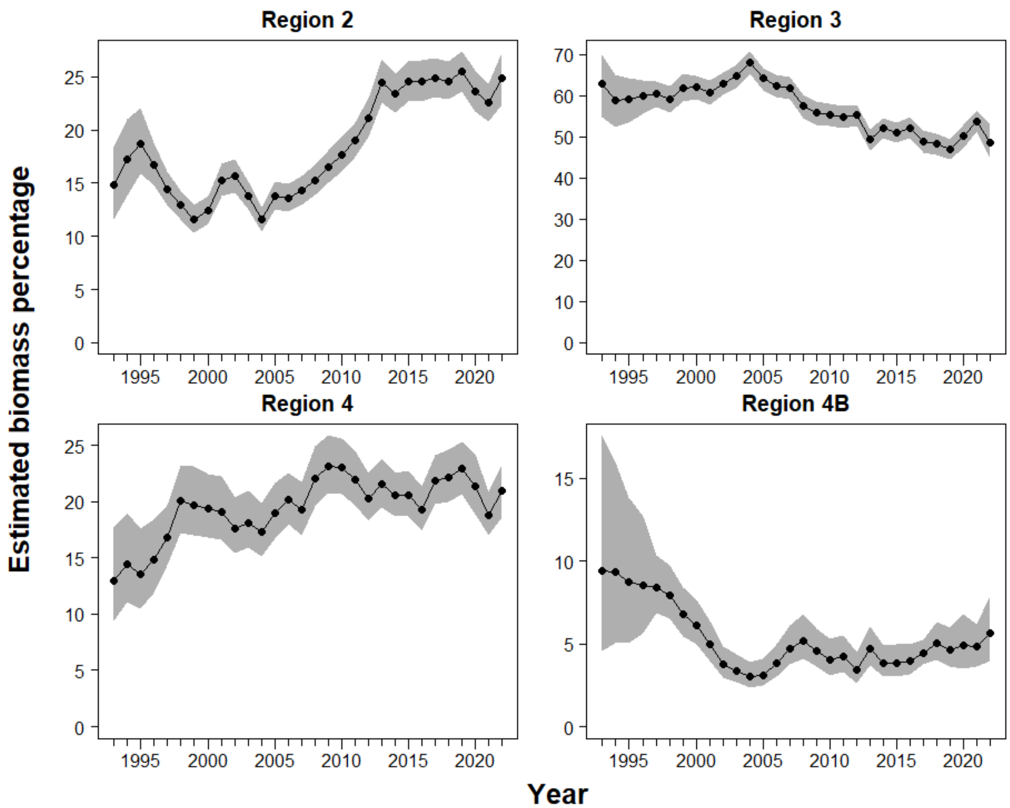

FIGURE 8. Estimated biological stock distribution (1993-2022) calculated from model output of survey WPUE of all sizes of Pacific halibut captured by the FISS. Shaded zones indicate 95% credible intervals.

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 by IPHC age-readers, and the ages provided for use in that year's stock assessment. 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 (e.g., 4B, Figure 9). The 2012 year-class was the most numerous of any age in 5 of the 8 IPHC Regulatory Areas in 2022.

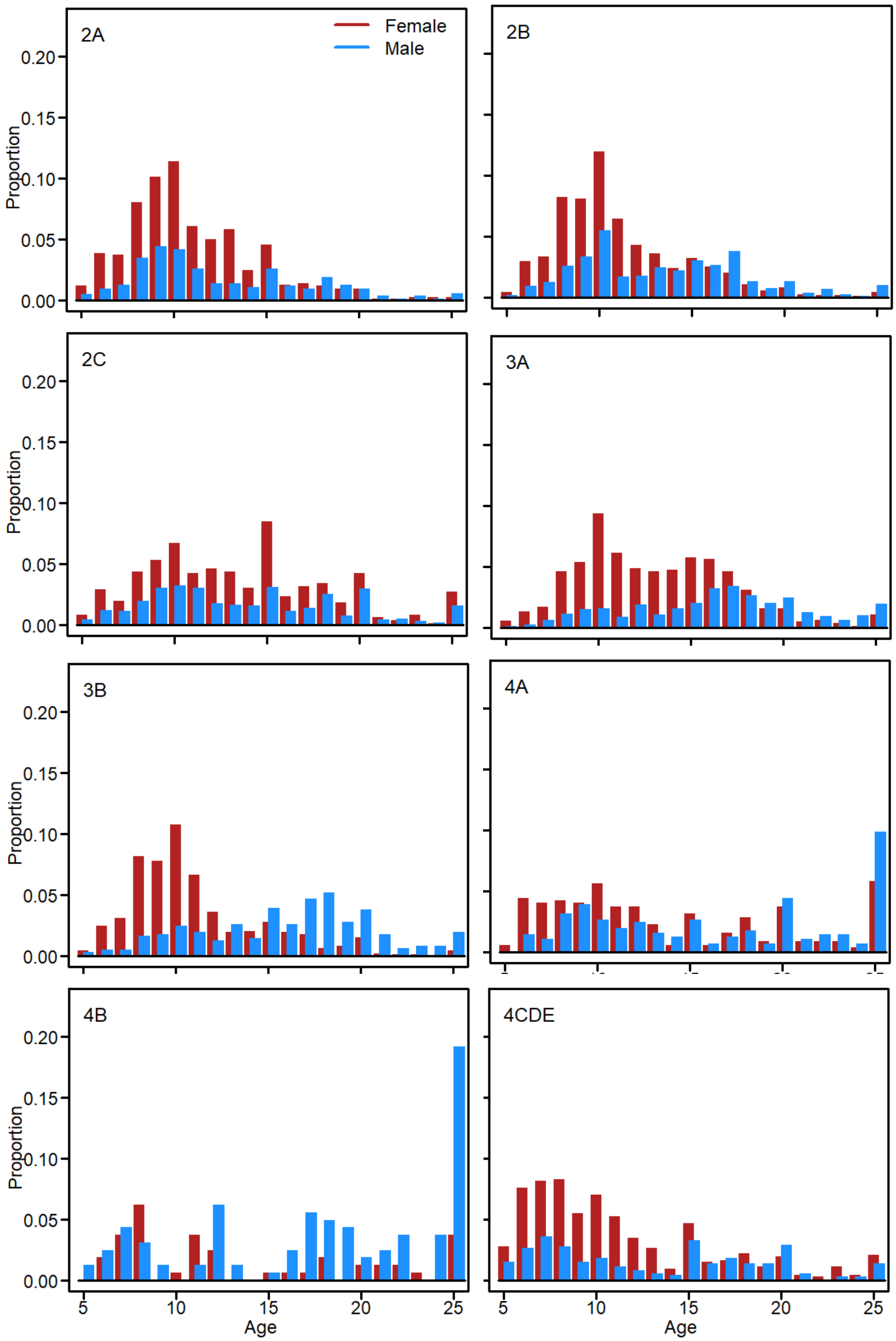

FIGURE 9. Age distributions from the 2022 FISS by IPHC Regulatory Area. Red bars indicate the proportion of females (by number) in the FISS catch, and the blue bars indicate proportions for male Pacific halibut.

In order to weight these area-specific distributions, an estimate of the number of Pacific halibut in each area is required. The survey NPUE estimated from space-time modelling 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 as a strong diagonal pattern in these data. Beginning in 2014 the 2005 year-class was most numerically abundant, through age 15 in 2020. The 2021-22 coastwide FISS data show an increasing number of younger Pacific halibut, the most numerous at age 10 in 2022, corresponding to the 2012 cohort.

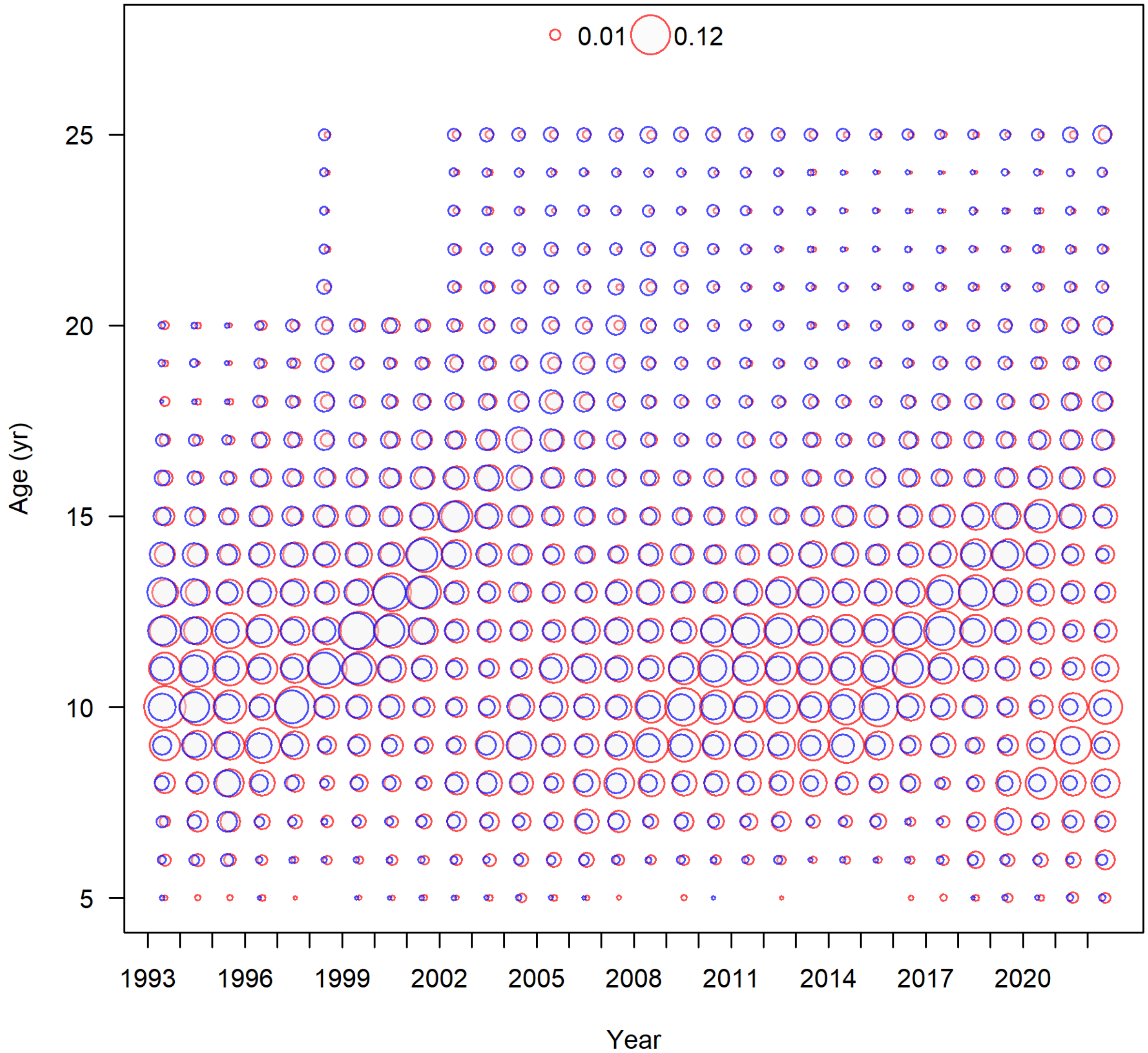

FIGURE 10. Recent coastwide proportions-at-age for females (red circles) and males (blue circles) from the FISS. Proportions sum to 1.0 across both sexes within each year.

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 (FISS 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 has been 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).

The FISS age data represent only IPHC Regulatory Areas 2B, 2C, and 3A for the years prior to 1997, only Areas 2B and 3A for the years 1980-81, and only Areas 2B, 2C, 3A and eastern 3B in 2020. The data prior to 1993 do not reveal any particularly strong cohorts, nor are cohort strengths appreciably different for male and female Pacific halibut. When aggregated by Biological Region, age data reveal consistent differences in both age structure and sex-ratio (Figures 11-12). Specifically, there have been few Pacific halibut greater than age 20 of either sex observed in Biological 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 the greatest frequency of fish aged 25+, especially pronounced in 2022 (Figure 12). The 2012 cohort can be clearly seen in Biological Regions 2 and 3 in the 2018-2022 observations but is much less evident in Biological Regions 4 and 4B.

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, of which a portion are assumed to subsequently die, occur primarily due to the minimum size limit. The 2022 FISS data show a protracted age distribution, particularly for males (Figures 13-14). Sublegal females are present in appreciable numbers from roughly age 5 to 10, and sublegal males from 7 to well beyond age 15 in some years. An increase in sublegal males of ages 5-7 over 2018-2022 may be related to the strength of the 2012 year-class as well as increased size at age for younger fish over this period. The protracted age structure of fish below the 32” (81.3 cm) minimum size limit illustrates the effects of wide 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 2014 year-class (at age 8) currently represents the most numerically abundant sublegal Pacific halibut.

FISS weight-at-age

The FISS collects individual length observations on all Pacific halibut captured, which were historically converted to estimated weights via the length-weight relationship (see section below). Beginning in 2019, individual fish weights have been collected for all fish randomly sampled for age. 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 available 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. 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.

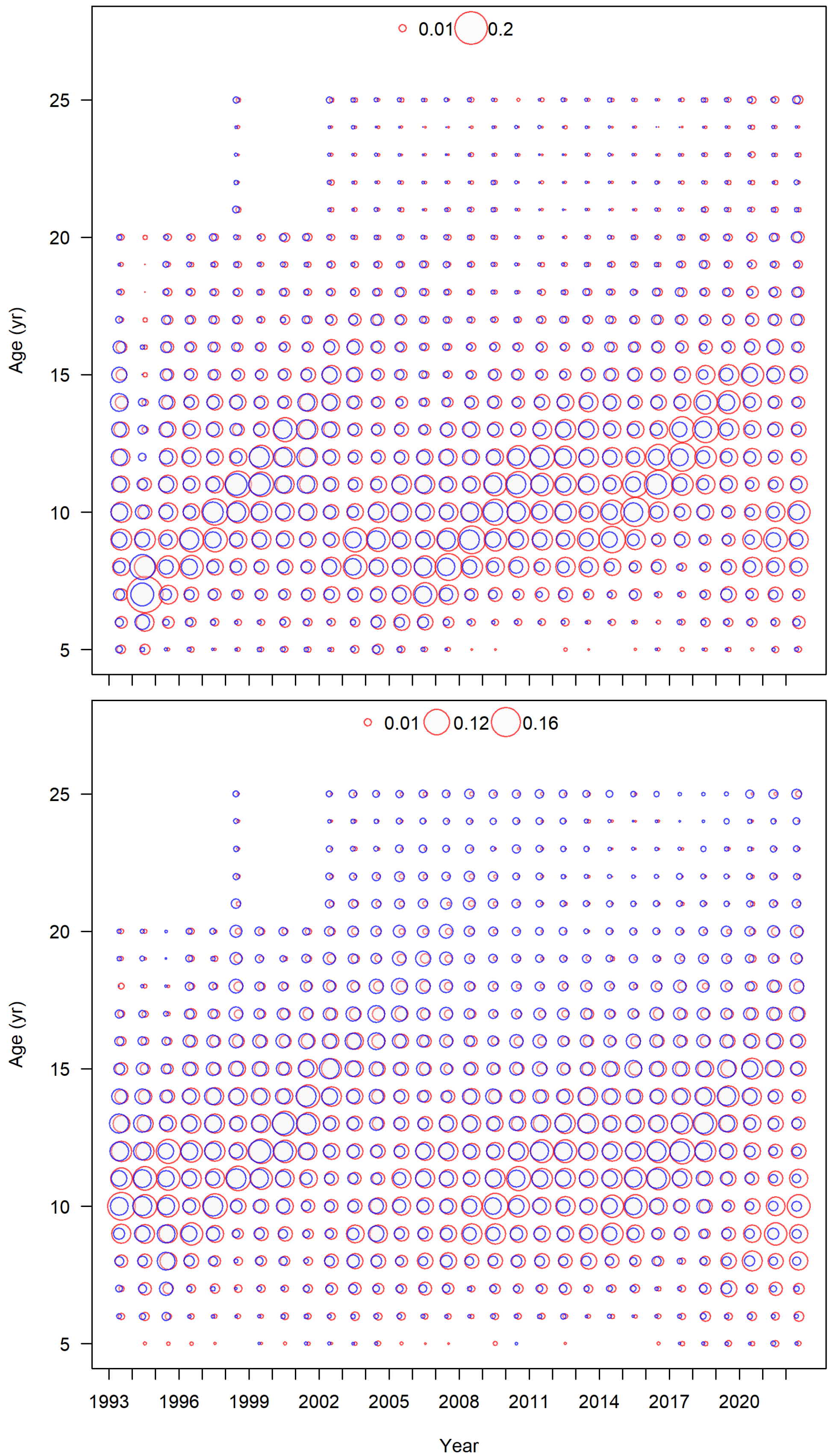

FIGURE 11. Recent proportions-at-age for female (red circles) and male (blue circles) Pacific halibut captured by the FISS from Biological Region 2 (upper panel) and Region 3 (lower panel). Proportions sum to 1.0 across both sexes within each year.

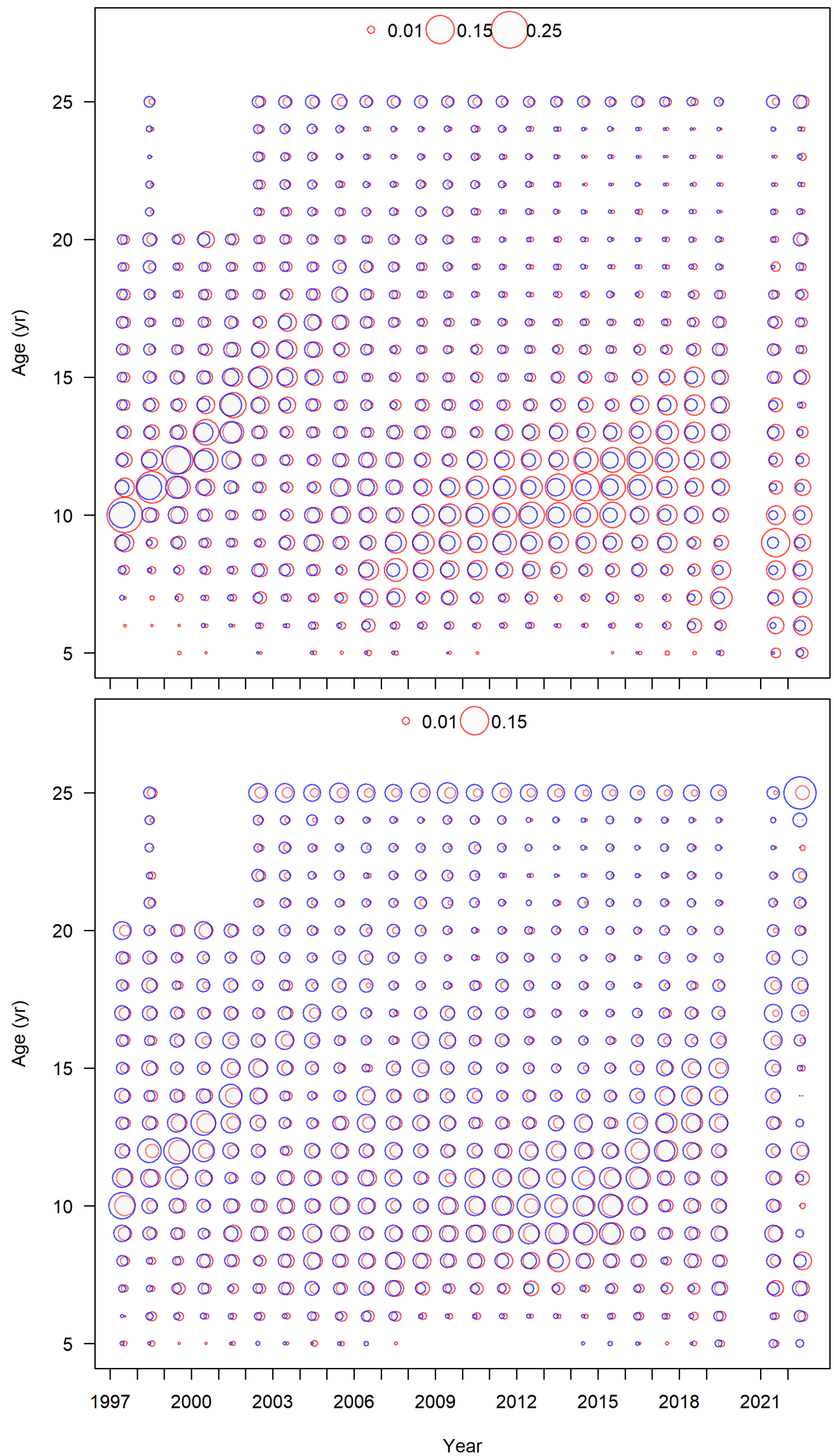

FIGURE 12. Recent proportions-at-age for female (red circles) and male (blue circles) Pacific halibut captured by the FISS from Biological Region 4 (upper panel) and Region 4B (lower panel). Proportions sum to 1.0 across both sexes within each year. Note that there was no FISS sampling in these Regions in 2020.

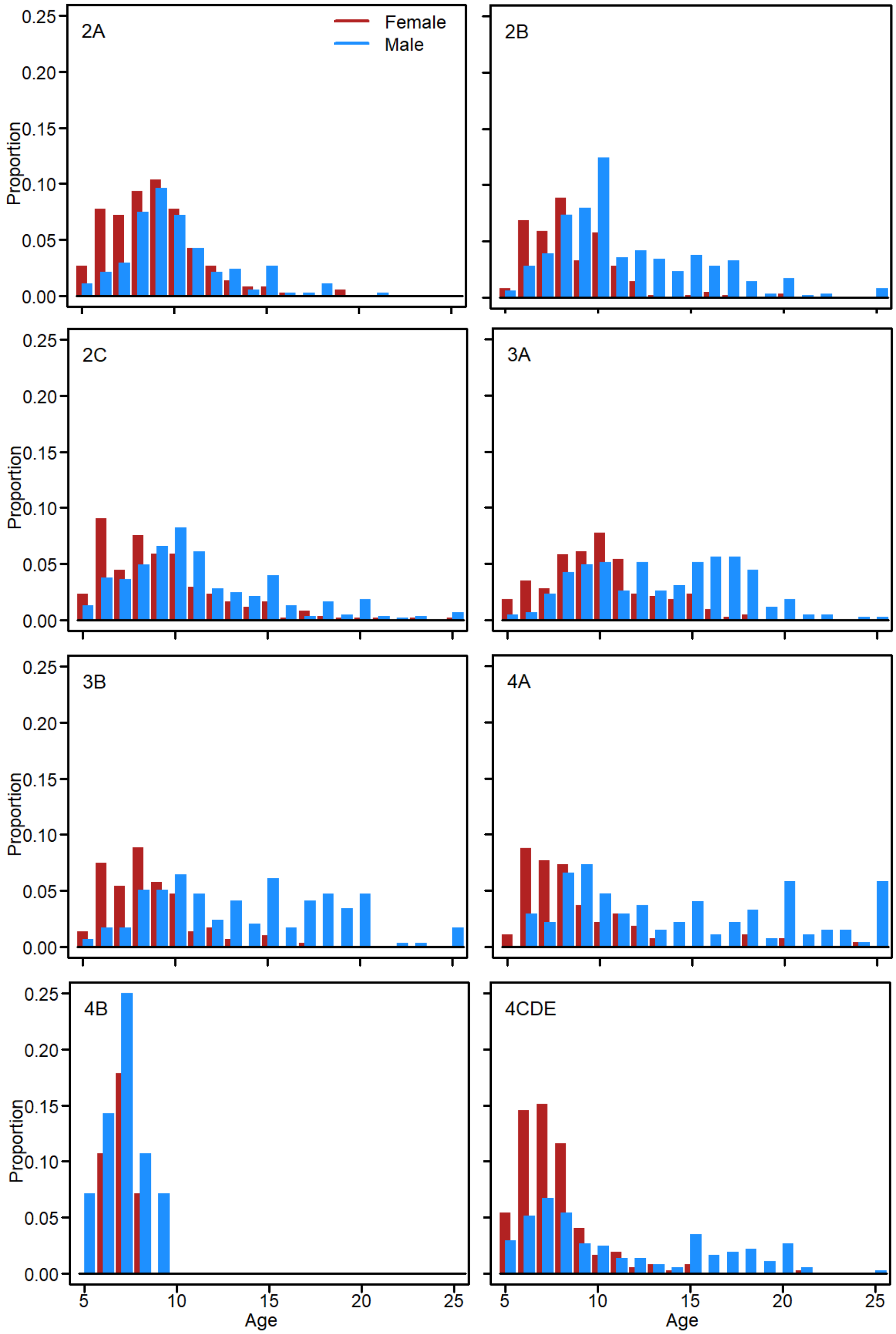

FIGURE 13. Sub-legal (U32) age distributions from the 2022 FISS by IPHC Regulatory Area.

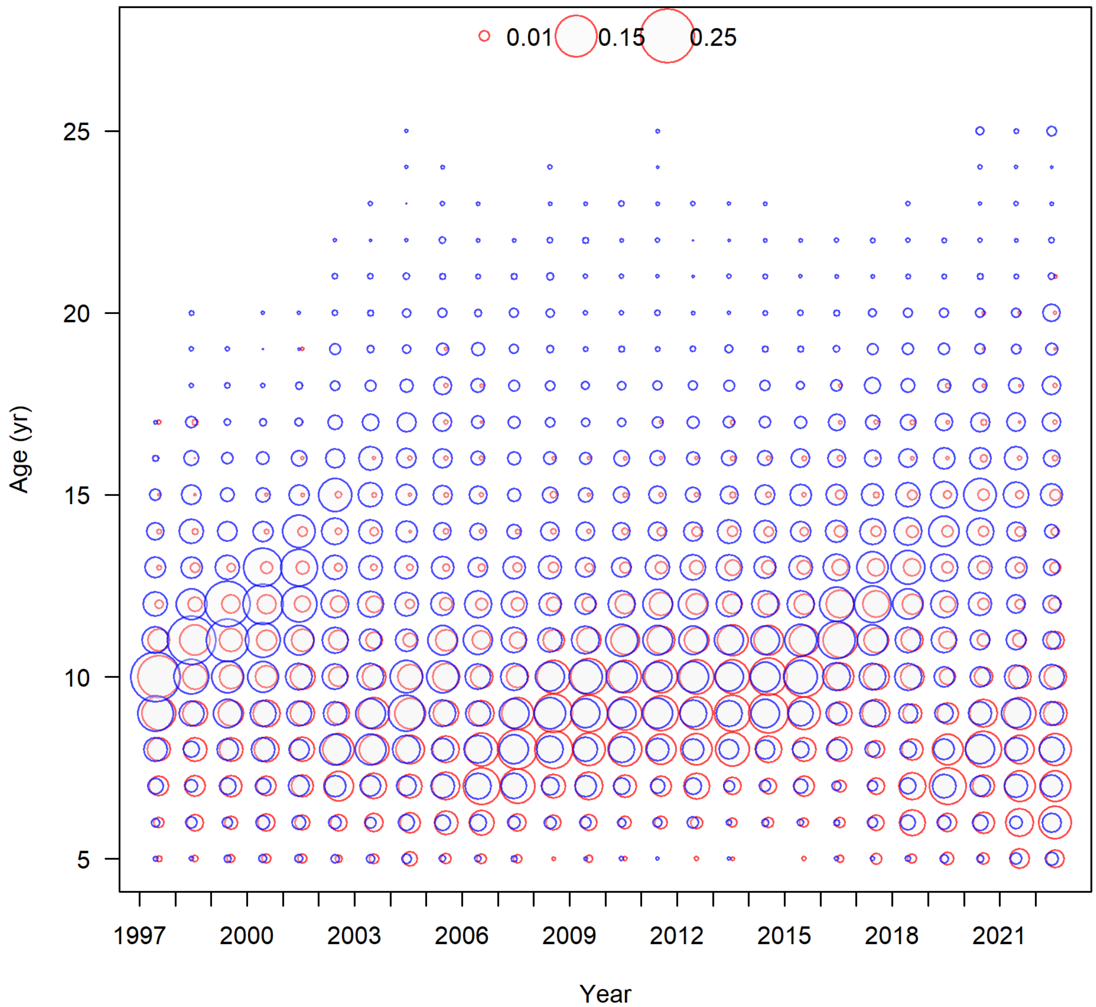

FIGURE 14. Recent coastwide proportions-at-age for sublegal (U32) female (red circles) and male (blue circles) Pacific halibut captured by the FISS. Proportions sum to 1.0 across both sexes within each year.

Because the FISS sampling of ages is random at sampled stations within each IPHC Regulatory Area, 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 was a very strong trend of declining weight-at-age up until around 2010, there are marked differences in the magnitude of this decline among Regulatory Areas (an interactive tool to view detailed FISS weight-at-age information is available on the IPHC's website). There also appear to be positive trends associated with recent cohorts, e.g., beginning around 2012 weight-at-age appears to be increasing for the younger year classes across the entire coastwide distribution (Figure 15). When the weighted coastwide observations are smoothed across years, these trends are even more pronounced (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 size-at-age for Pacific halibut increased from the 1950s to the late 1970s, subsequently declining to the recent period covered by the FISS.

Current females coastwide size-at-age is estimated above historical lows for younger ages and increasing, but below for older ages (Figure 17).

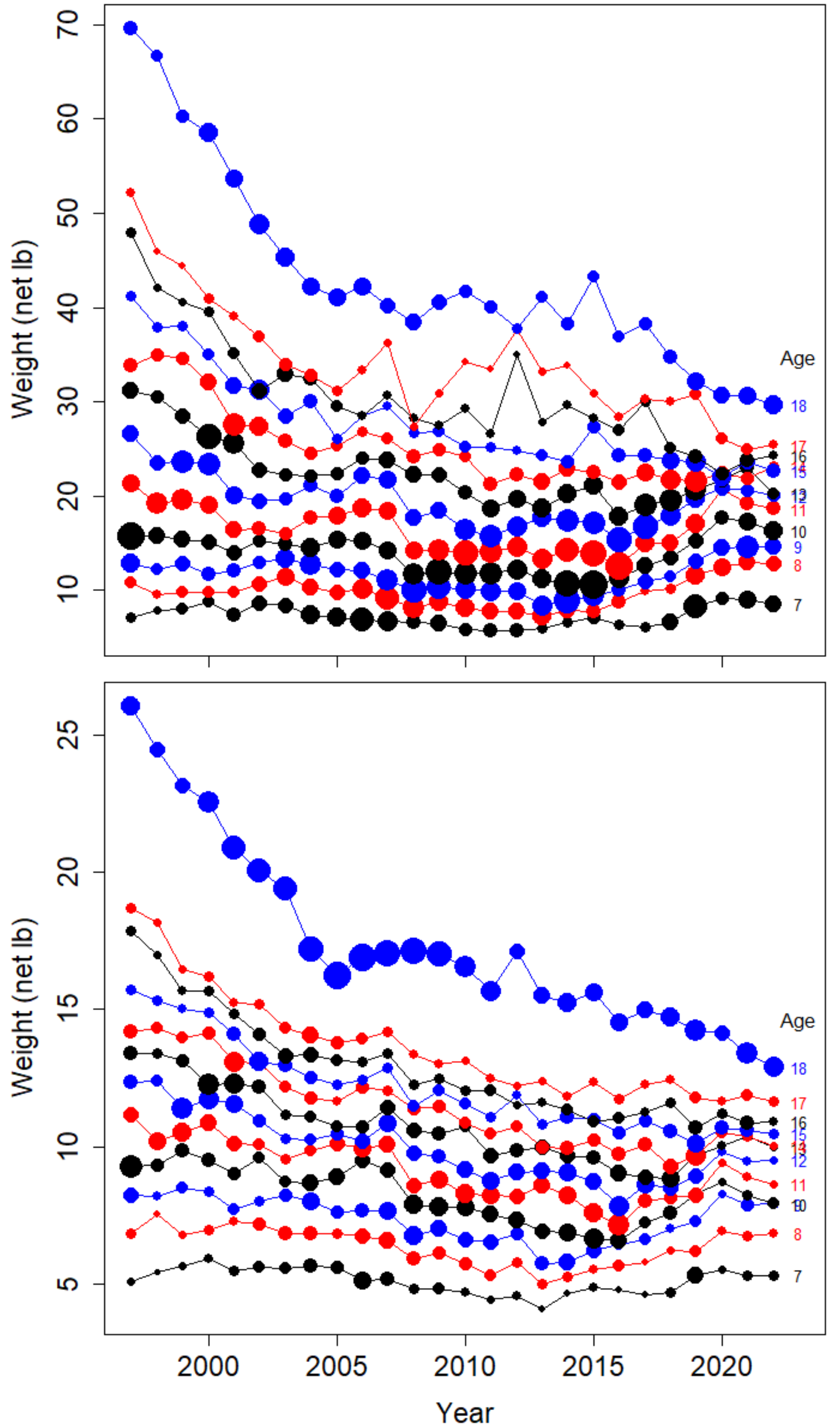

FIGURE 15. Weighted coastwide trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the FISS. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and older, and ages 7 and younger have been aggregated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

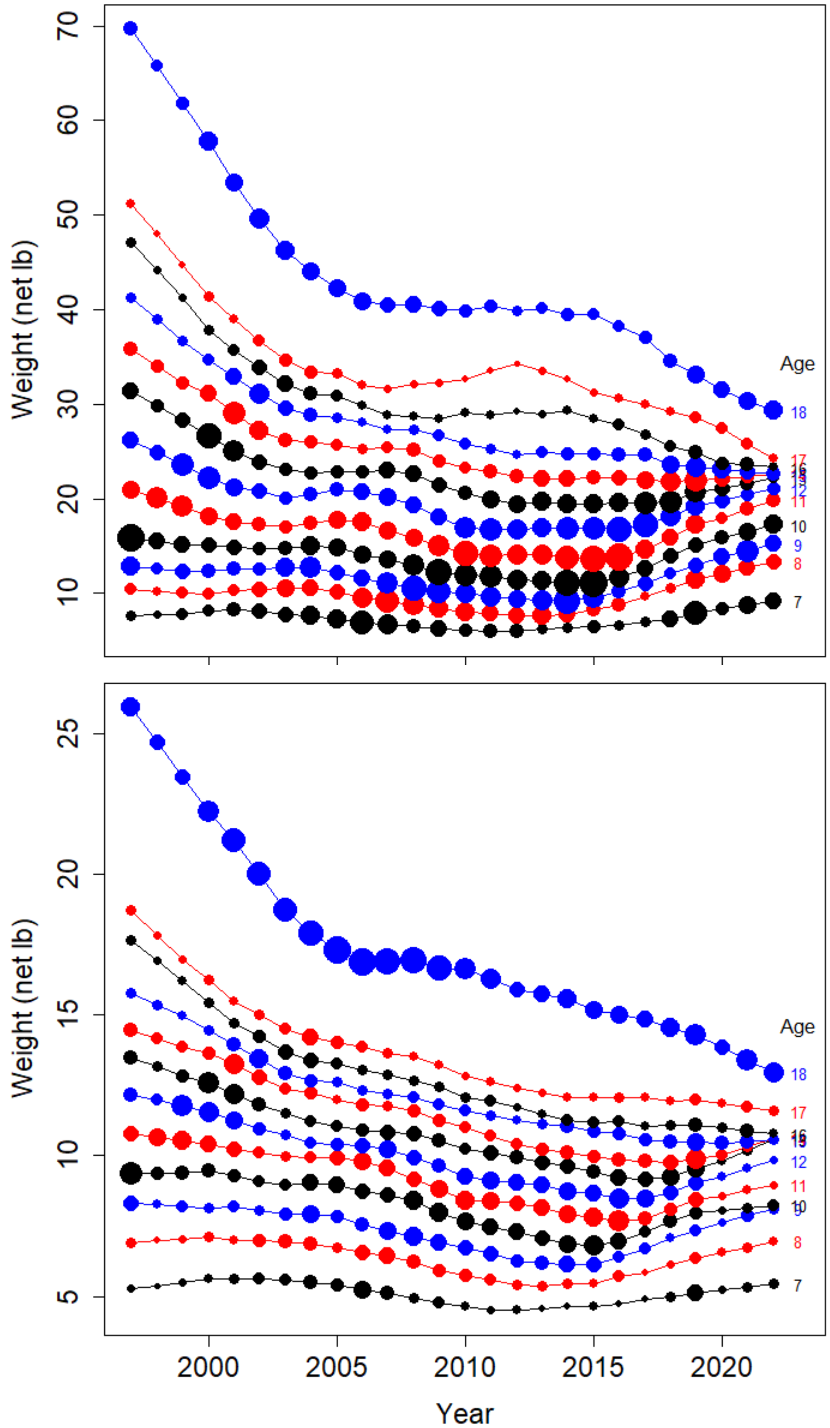

FIGURE 16. Weighted and smoothed recent coastwide trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the FISS. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and older, and ages 7 and younger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

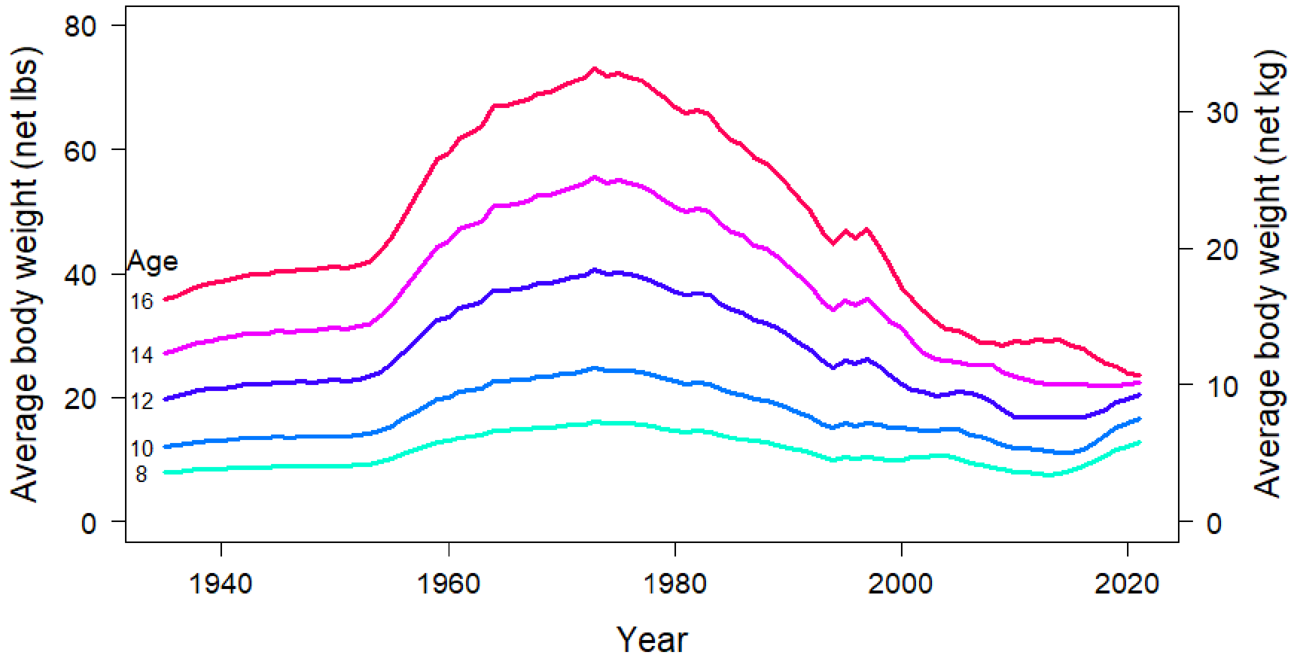

FIGURE 17. Estimated average female weight-at-ages 8, 10, 12, 14 and 16 trends from FISS and fishery data since 1935.

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 interannual 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 (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.

NMFS Trawl surveys in Alaska

Estimating weight-at-age for fish that are younger than those observed in the FISS is not as critically important in the treatment of directed 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 non-directed discard mortality in fisheries that cannot retain Pacific halibut requires a representative estimate of weight-at-age for all fish captured, particularly ages 2-6.

Otoliths are collected on board NMFS trawl surveys in Alaska each year. The average weight-at-age by year and sex is summarized from the NMFS trawl surveys; mean values are 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 are smoothed across years within age (Figure 19). These smoothed trawl survey weights-at-age are used to augment the weight-at-age inputs calculated from ages 7+ in the setline survey and commercial fishery. Slightly increasing trends at the end of the time-series appear consistent with those from the FISS data but are less pronounced.

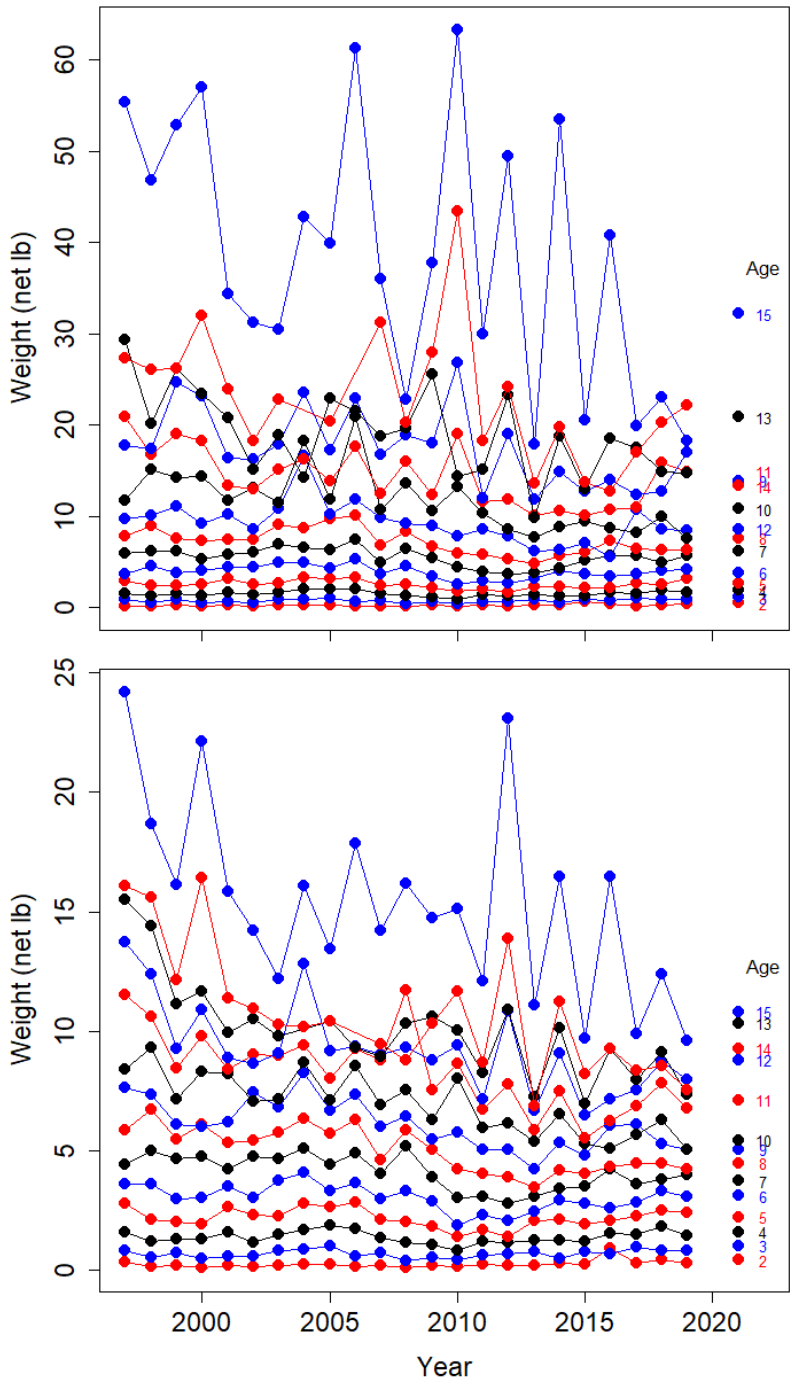

FIGURE 18. Raw trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the NMFS Bering Sea trawl survey. Ages 15 and greater have been aggregated. Note that no trawl survey was conducted in 2020 and weights were not yet available for 2022 at the time this document was produced.

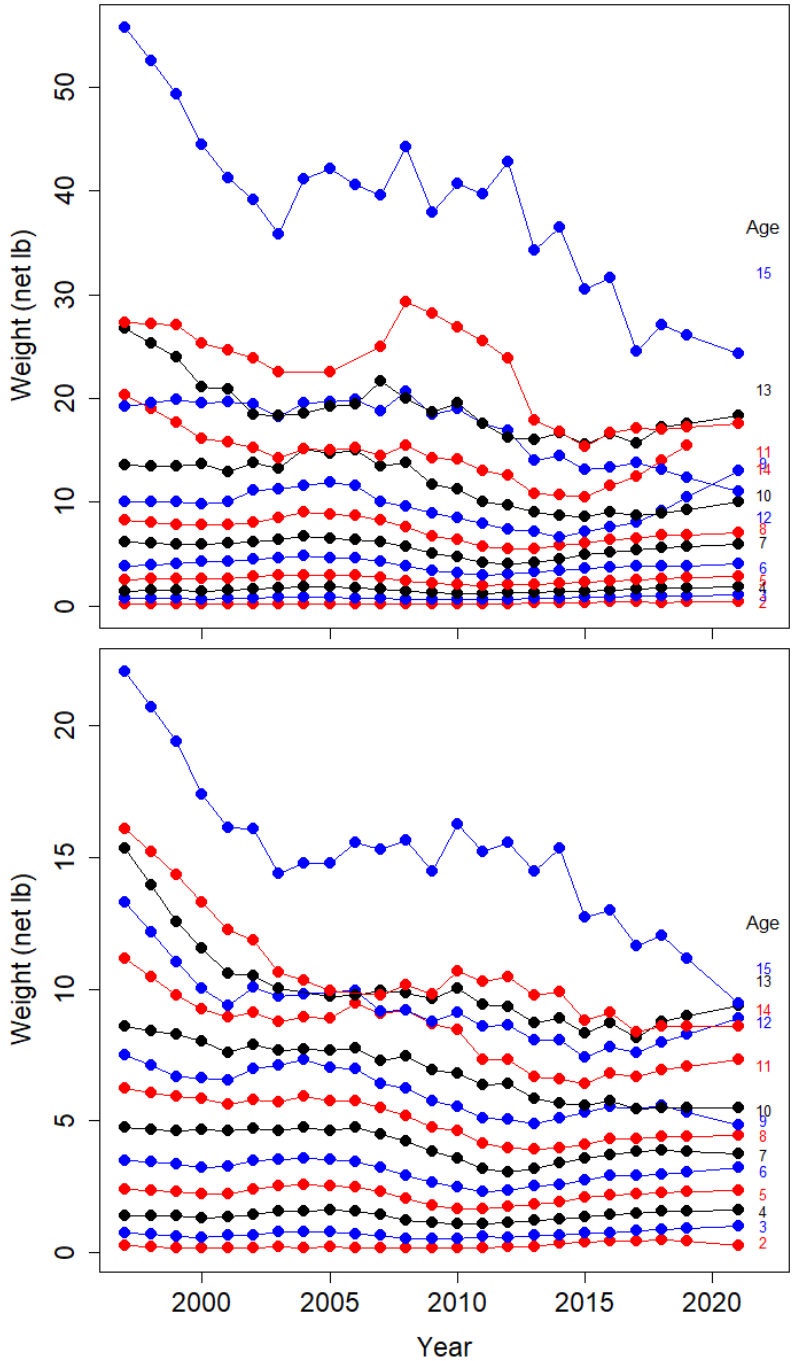

FIGURE 19. Smoothed trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the NMFS Bering Sea trawl survey. Ages 15 and greater have been aggregated. Note that no trawl survey was conducted in 2020 and weights were not yet available for 2022 at the time this document was produced.

The ages observed on the NMFS trawl surveys provide year-specific information with which to estimate age distributions from that trawl survey as well for other sources such as non-directed discards that report only length frequency information but encounter Pacific halibut of similar ages. However, there are no age data available from the NMFS trawl surveys before 1997, so a global (all years) age-length key (Figure 20) must be used to interpret lengths collected in earlier years and sometimes the terminal year when samples have not yet been aged (or were not collected, as in 2020-21). Using this key, and the observed age data for more recent 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. Along with several weaker cohorts, and an apparent anomaly in the 2004-2005 data, a strong 2005 cohort 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. The 2011 cohort is visible from 2014-2018; however, subsequent year-classes are difficult to discern, and additional observations may be needed to identify if there are also stronger cohorts in 2017 and 2018.

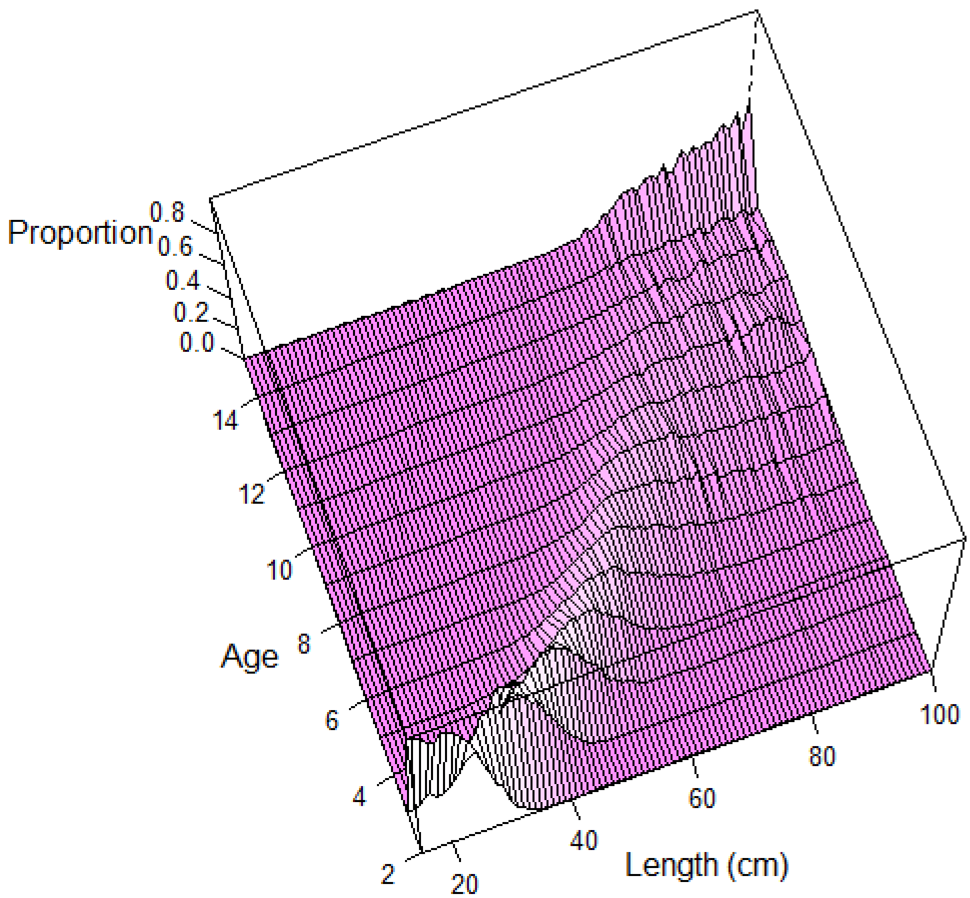

FIGURE 20. Global age-length key created from Pacific halibut captured by NMFS trawl surveys in Alaska. Proportions-at-age sum to 1.0 within each length.

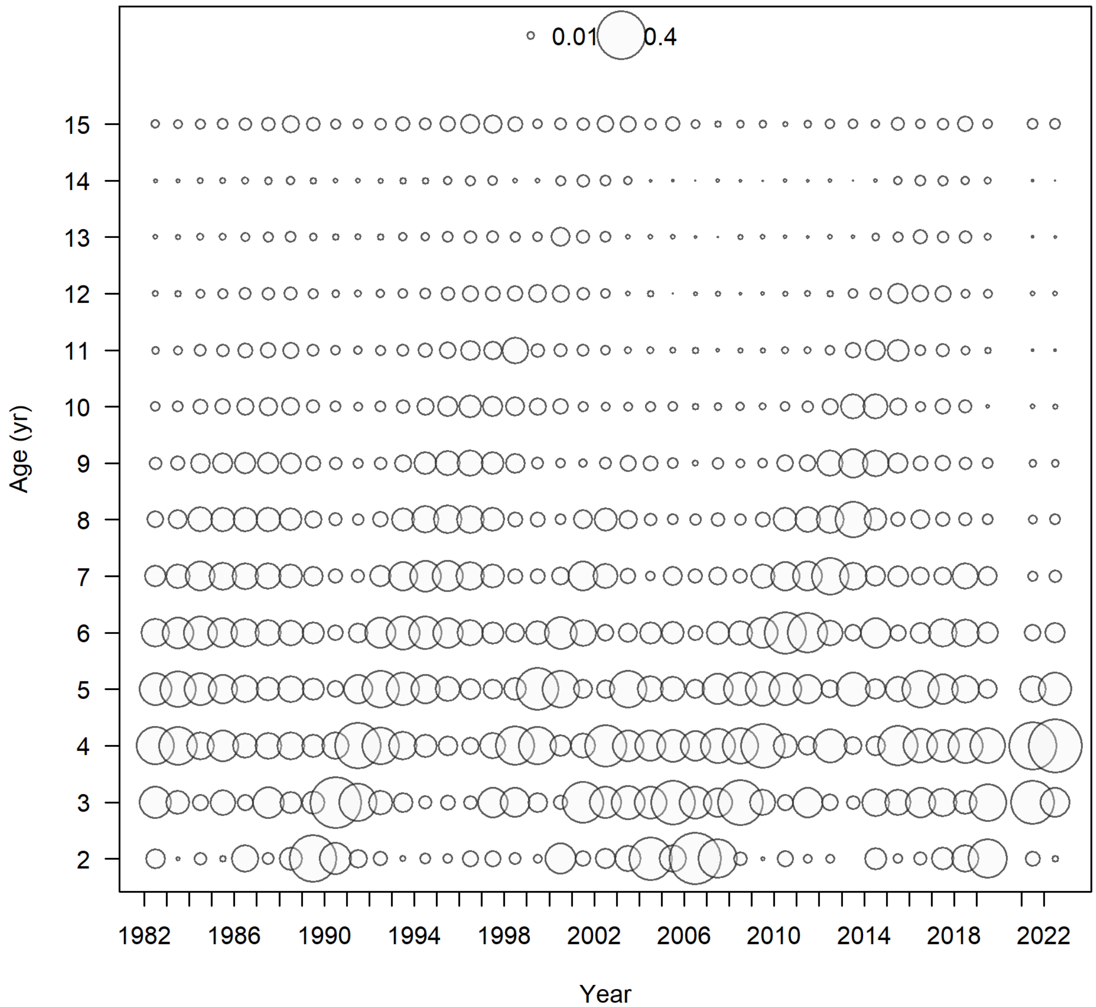

FIGURE 21. Proportions-at-age from the NMFS Bering Sea trawl survey. Ages 15 and greater have been aggregated; proportions sum to 1.0 within each year. Note that no survey took place in 2020.

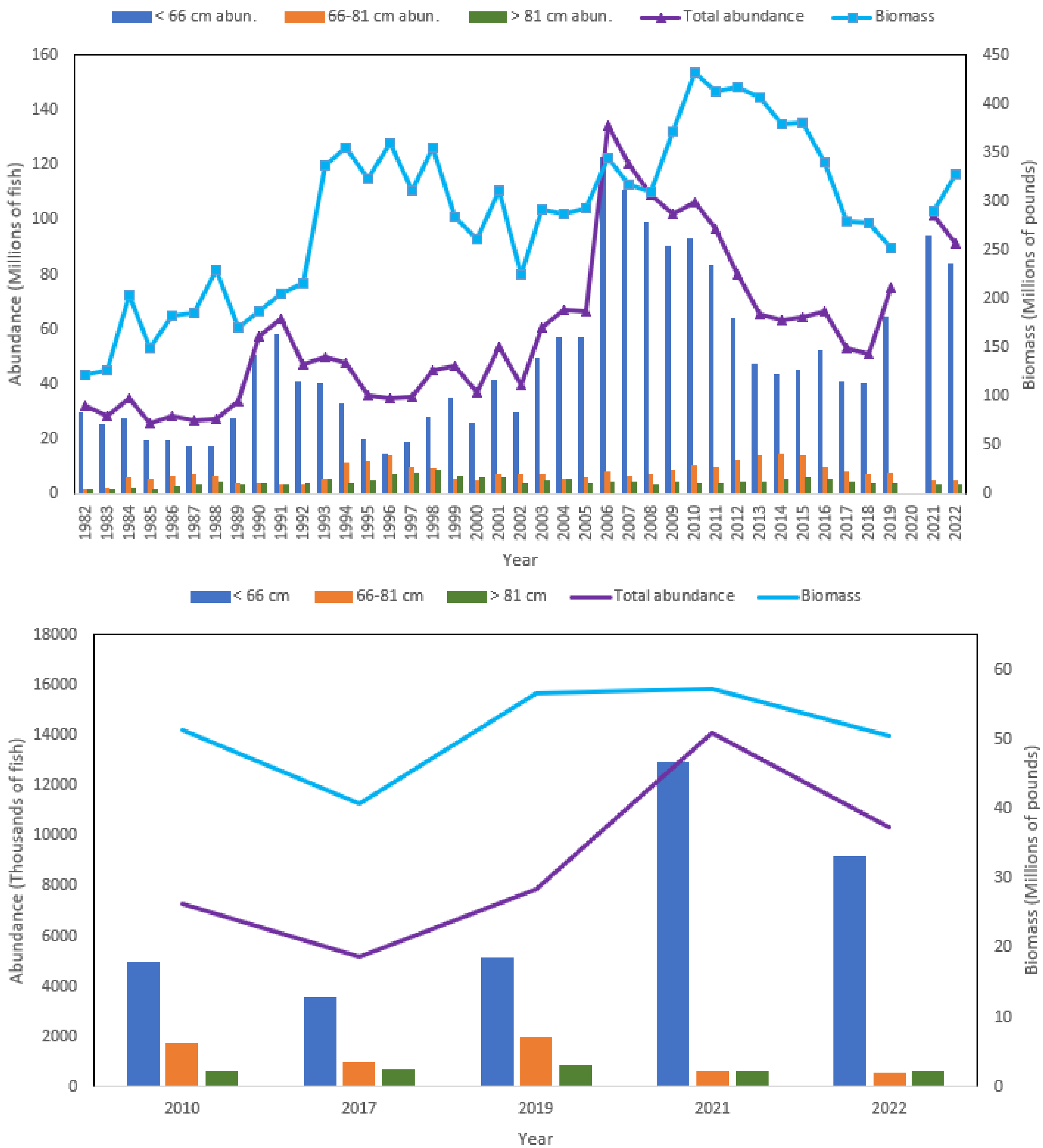

FIGURE 22. Design-based index of abundance (millions; purple line) and biomass (millions of pounds; blue line) of Pacific halibut from the NMFS Eastern Bering Sea trawl survey, 1982-2022 (upper panel) and northern Bering Sea (lower panel). Bars indicate abundance of size categories noted in the legend. Note that no survey took place in 2020.

FISHERY-DEPENDENT 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 via commercial fish tickets reported to the IPHC (IPHC-2022-AM098-06). 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 generally decreased to 2020 (the lowest in the last 40 years) in response to reduced mortality limits. The landings in 2021 and 2022 have again increased back to levels approaching those in 2017, due to higher adopted mortality limits. Prior to 1981, only aggregated landings for IPHC Regulatory Areas 4A-4CDE are available; landings from 1935-80 are not currently included in the IPHC's database. Although historical summaries, tables published in technical reports, and other IPHC documents are generally in agreement, the raw data are not able to be reprocessed directly, and therefore the landings estimates prior to 1981 are more uncertain than those after 1981. Historical landings prior to 1935 were reconstructed within current IPHC 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, and there are historical records of substantial tribal fisheries prior to that time. 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 more uncertain than the corresponding totals. Reconstructed landings estimates from 1888, 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).

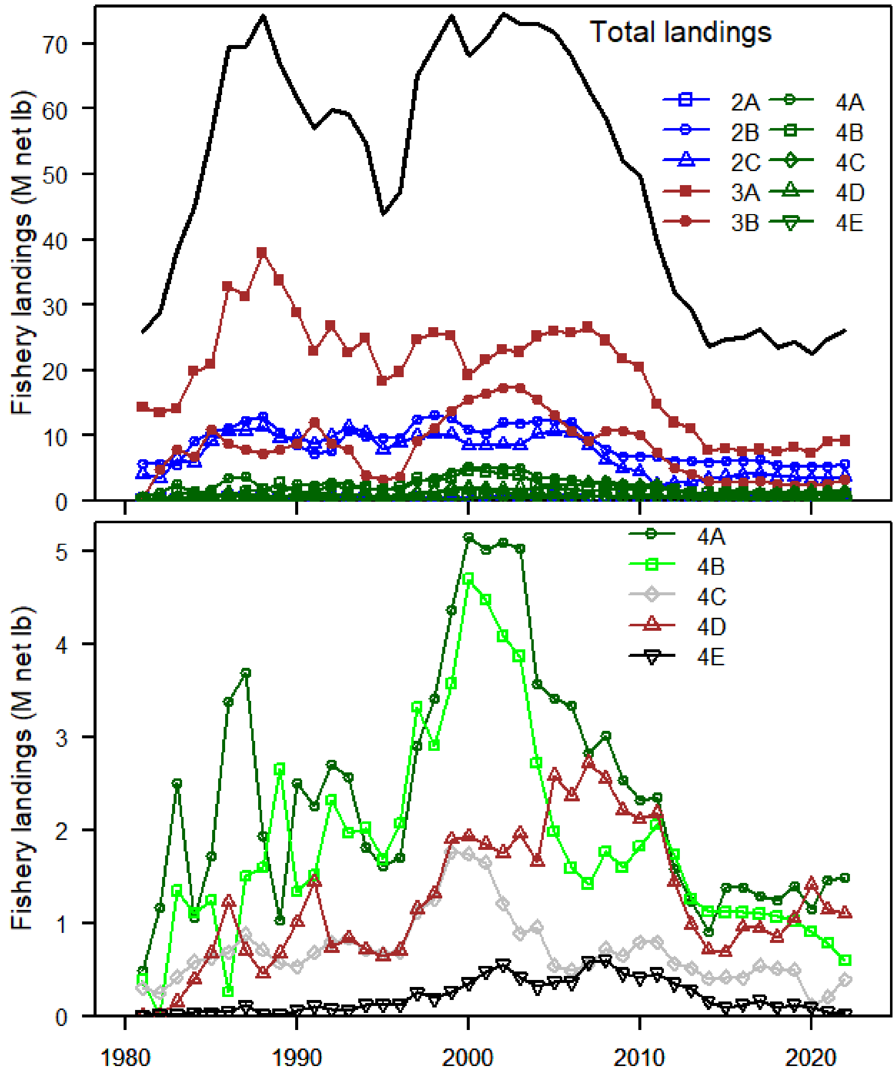

FIGURE 23. Recent landings of Pacific halibut by the directed commercial fishery by IPHC Regulatory Area (upper panel), and among Areas 4A to 4E for better resolution of the trends (lower panel).

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 (ADFG), Fisheries and Oceans Canada (DFO), 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. 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 around half of the total recreational mortality (Figure 25), with Areas 2C, 2B, and 2A each contributing somewhat less (in declining order). It is 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 were relatively stable from

2010-19. Recreational mortality was down sharply in 2020, particularly in 2A, 2B and 2C as many fisheries were impacted by restrictions on travel and other closures. These three fisheries rebounded sharply in 2021 due to relaxed domestic regulations and increased travel. Coastwide recreational mortality in 2022 was again close to the levels observed since 2010.

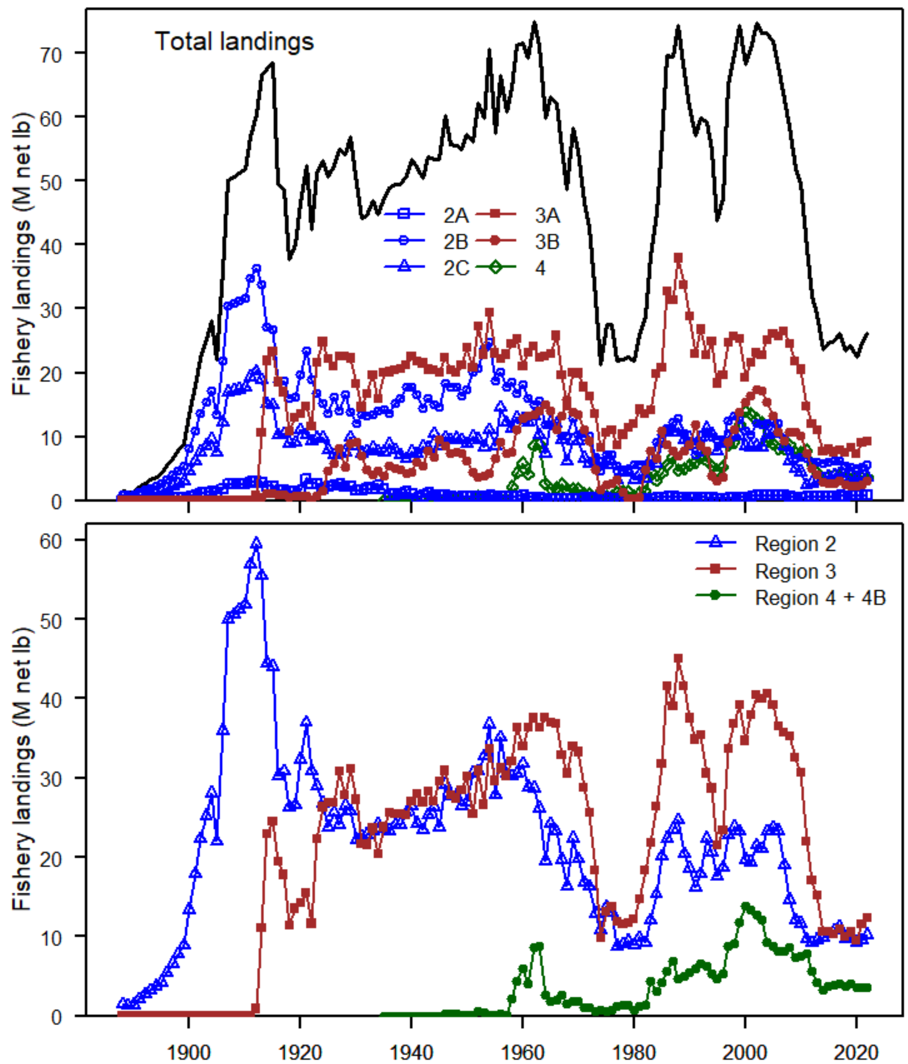

FIGURE 24. Historical landings of Pacific halibut by the directed commercial fishery by IPHC Regulatory Area (upper panel) and Biological Region (lower panel; Regions 4 and 4B are combined due to historical data aggregation).

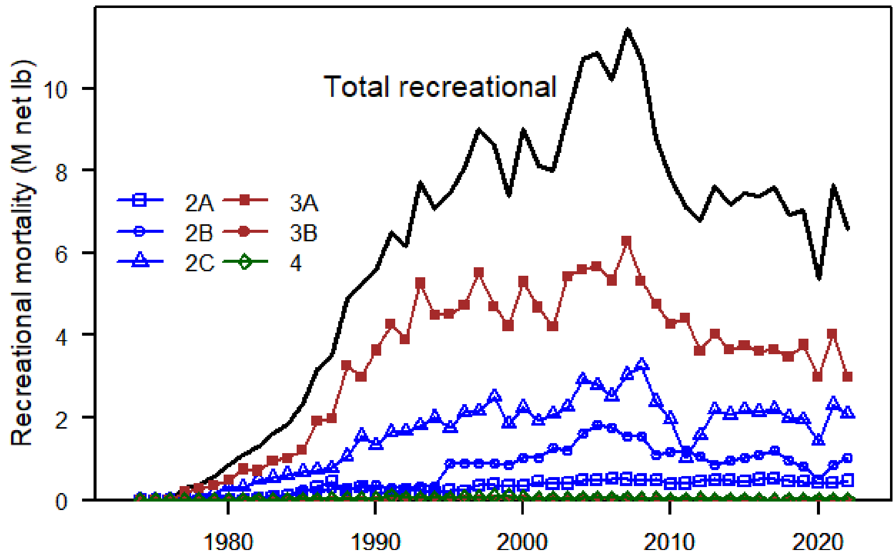

FIGURE 25. Recreational mortality of Pacific halibut by IPHC Regulatory Area.

Subsistence mortality

Subsistence harvest estimates are provided to the IPHC by the DFO and NMFS. Estimates are not generated annually in many cases, and therefore some values are applied through intervening years until the next estimate is made available, especially 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).

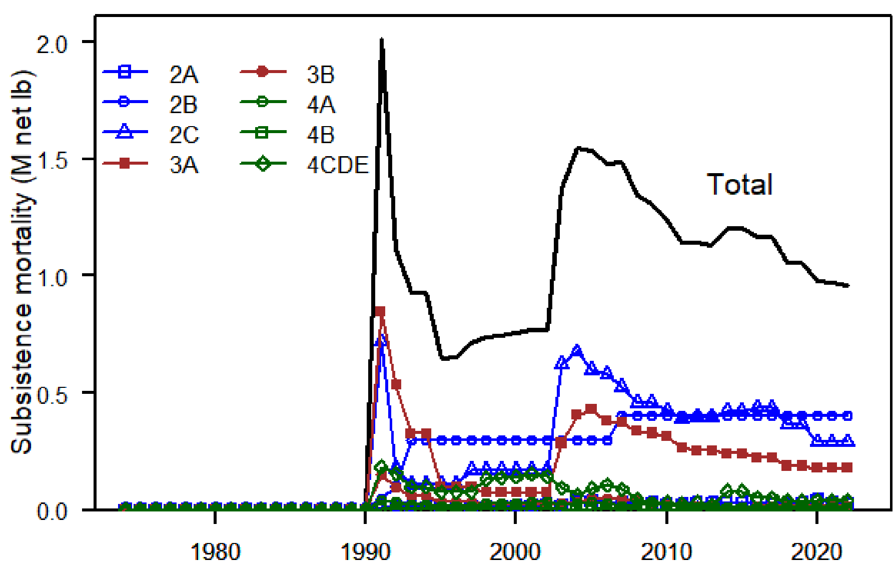

FIGURE 26. Reported subsistence mortality by IPHC Regulatory Area.

Directed commercial fishery discard mortality

Directed (targeted) commercial fishery 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. Briefly, mortality due to lost gear is assumed to occur at the same overall rate per unit of gear as observed catch rates, and lost gear estimates from commercial logbooks are scaled to represent the entire fishery in each year. Regulatory discards are based on the logbook-reported discards of legal (O32) Pacific halibut; these occur due to damaged fish, or on the last trip of the season when catch may exceed remaining quota on a particular vessel. Sublegal discards (associated with both the landed catch and lost gear) are estimated based on FISS sublegal encounter rates scaled to the entire fishery catch for IPHC Regulatory Areas 2A, 2C-4CDE. For IPHC Regulatory Area 2B, logbook reported sublegal discard rates (in numbers of fish) are scaled to represent the entire fishery catch, and the average sublegal fish weight from the FISS is used to convert these estimates into mortality in weight.

Based on these methods, discard mortality in the commercial fishery is estimated to have been highest in the late 1980s and to have subsequently declined, particularly in Area 3A in 1995 when the derby fishery was converted to a quota system (Figure 27). Increases from 1995 to 2010 correspond to the decline in size-at-age and more fish at older ages remaining below the minimum size limit. Declining discard mortality from 2010 to 2020 appears to be driven primarily by decreased mortality limits reducing the total quantity of gear fished each year. Increases in 2021 and 2022 are attributable to the shifts toward younger fish (i.e., from the 2005 to 2012 year-class) of which many are still below the current minimum size limit. The estimates of discard mortality cannot be delineated among IPHC Regulatory Areas 4A-4CDE prior to 1981, but the magnitude of that mortality is estimated to be very small (Figure 27, lower panel).

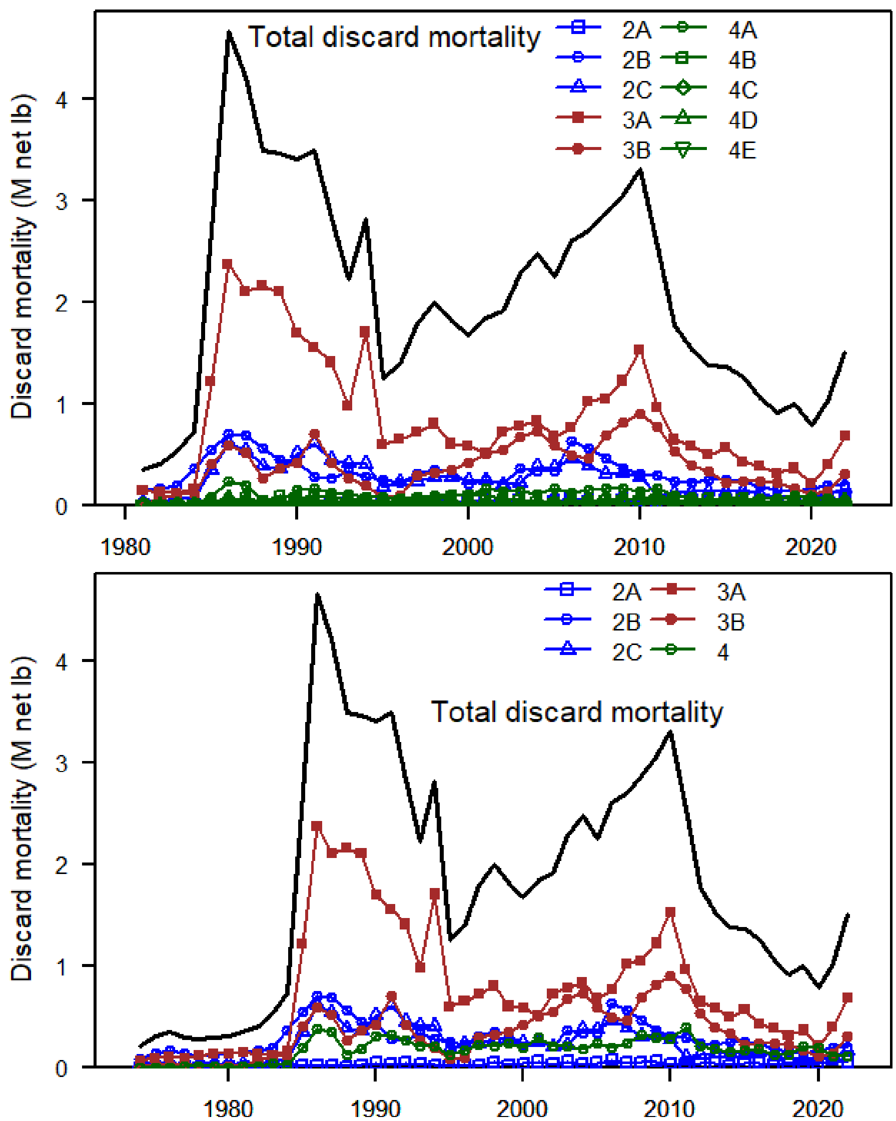

FIGURE 27. Discard mortality in the commercial fishery by IPHC Regulatory Area, 1981+ (upper panel), and 1974+, with Areas 4A-4CDE combined (lower panel).

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

Pacific halibut mortality from non-directed commercial fisheries, fisheries where the retention of Pacific halibut is prohibited, 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 IPHC Regulatory Areas 4A, 4B, and 4CDE only from 1990 to the present, during which time it declined from a peak of over 20 million lbs (~9,070 t) to an estimate 3.5 million pounds (~1,600 t) in 2021 (Figure 28, upper panel). Much of the decrease from 2019 to 2021 occurred in IPHC Regulatory Areas 3A and 4CDE. The estimate for 2022 increased 17% from 2021, but remains lower than any previous year in the time series; most of this increase was estimated to have occurred in IPHC Regulatory Area 4CDE. 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 (Figure 28, lower panel). It is likely that there was far 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. The effects of non-directed discards in the context of all sources of mortality for Pacific halibut have been extensively investigated, including recent analyses of the trade-offs between non-directed discards and the directed commercial fishery (Stewart et al. 2021).

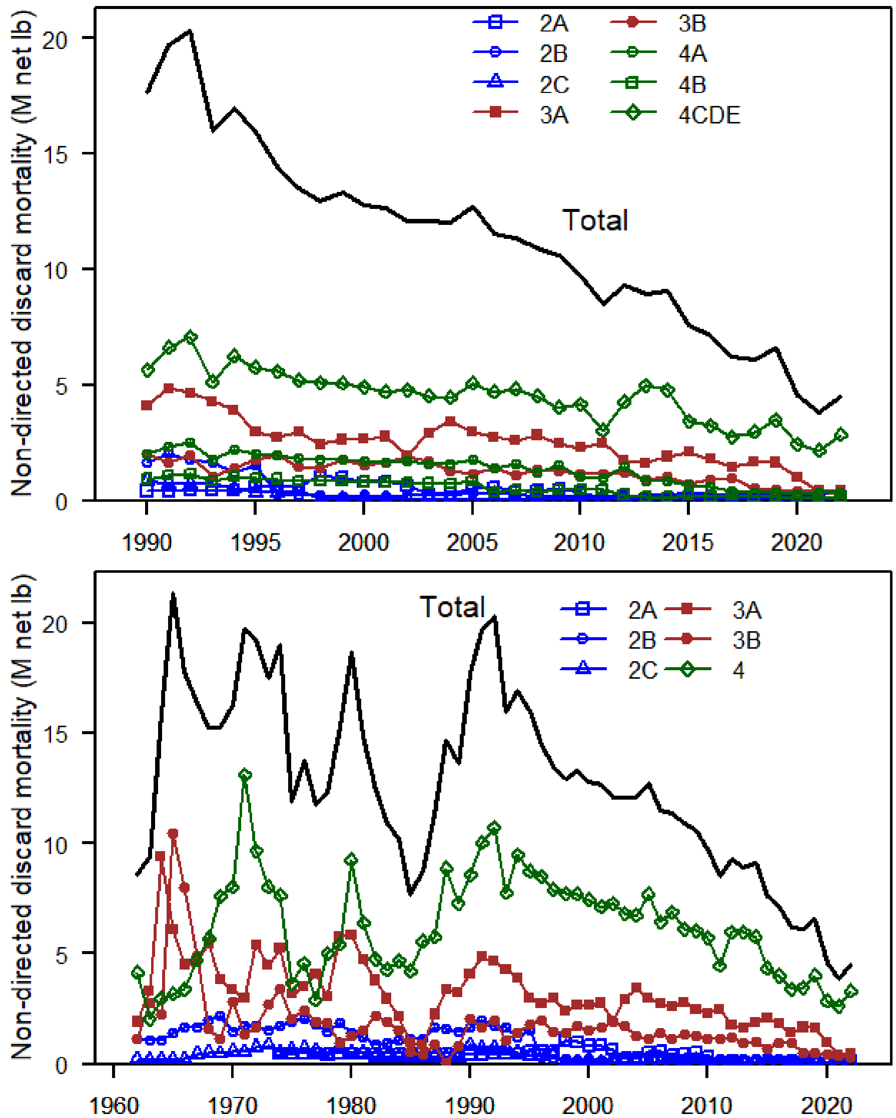

FIGURE 28. Pacific halibut discard mortality estimates from non-directed fisheries by IPHC Regulatory Area, 1990+ (upper panel), and 1962+, with Areas 4A-4CDE combined (lower panel).

Summary of Pacific halibut mortality from all sources

Mortality estimates from all sources show that the directed commercial fishery represents the majority of the historical fishing mortality (Figure 29). Mortality from all sources increased by 4% to an estimated 39.7 million pounds (~18,000 t) in 2022 as a function of increased mortality limits set by the IPHC although several sectors did not reach their full regulatory limits. Over the historical record of 1888-2022 mortality has totaled 7.3 billion pounds (~3.3 million t), ranging annually from 34 to 100 million pounds (16,000-45,000 t) with a 100-year annual average of 63 million pounds (~29,000 t). Time series tables of annual estimates by source are 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 IPHC Regulatory Area 3A has been the largest single source throughout the last five decades, but that Areas 3A and 3B represent a smaller fraction of the total in recent years than in previous decades (Figures 30-31). When mortality by source is compared among IPHC Regulatory areas, there are differing patterns in both the magnitude and distribution, with recreational mortality proportionally more important in IPHC Regulatory Areas 2A-3A, and non-directed discard mortality more important in IPHC Regulatory Areas 3B-4CDE.

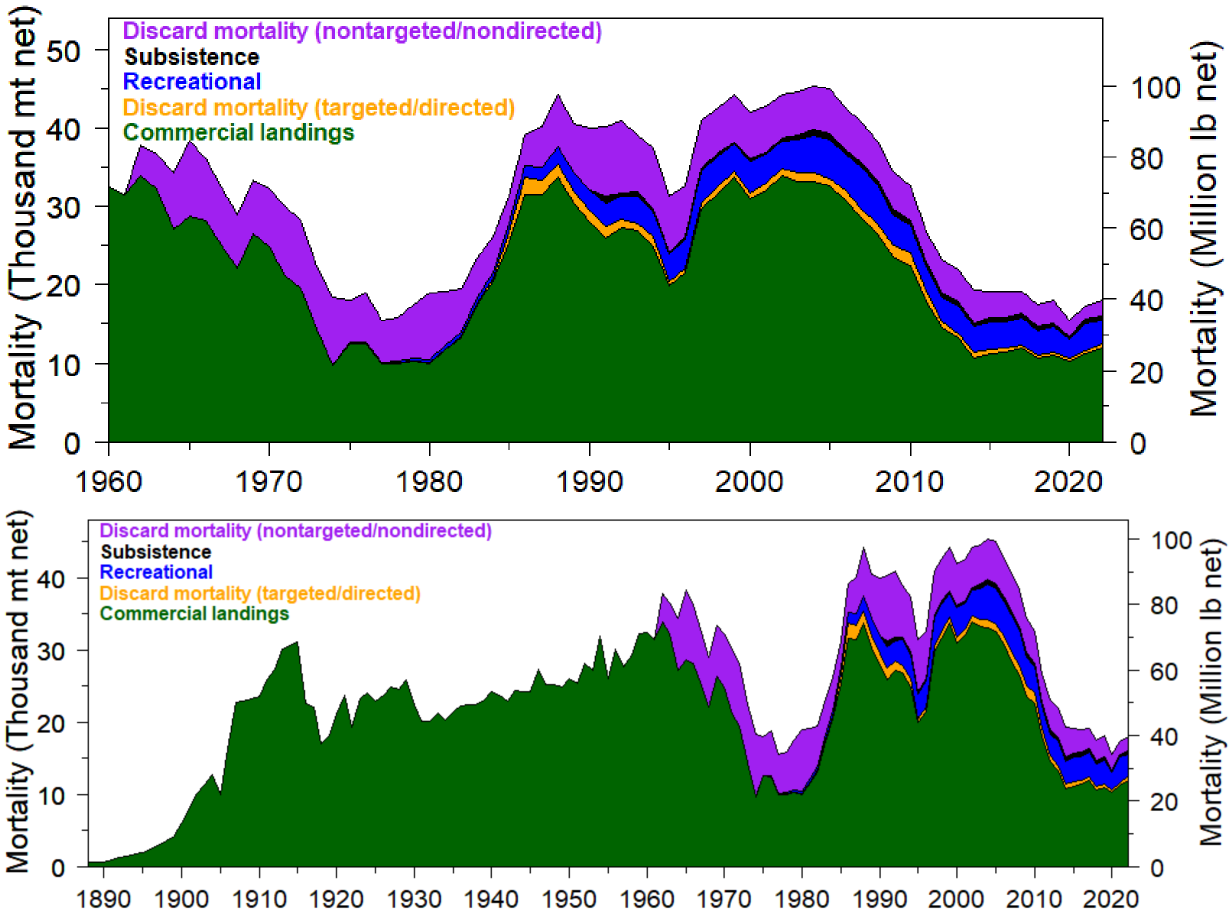

FIGURE 29. Summary of estimated historical mortality from all sources since 1960 (upper panel) and 1888 (lower panel).

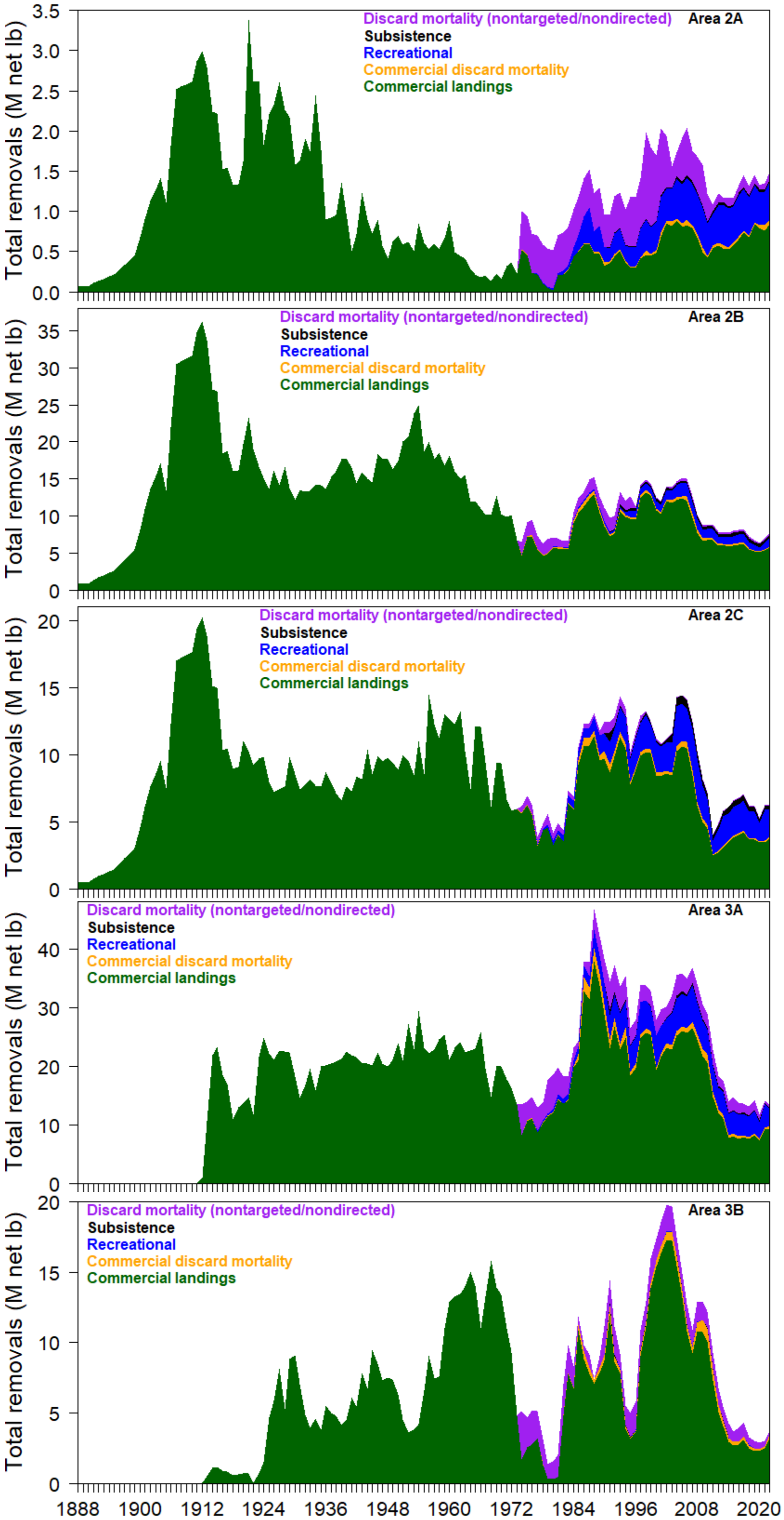

FIGURE 30. Estimated Pacific halibut mortality by source in IPHC Regulatory Areas 2A-3B since 1888. Note that the y-axes differ in scale.

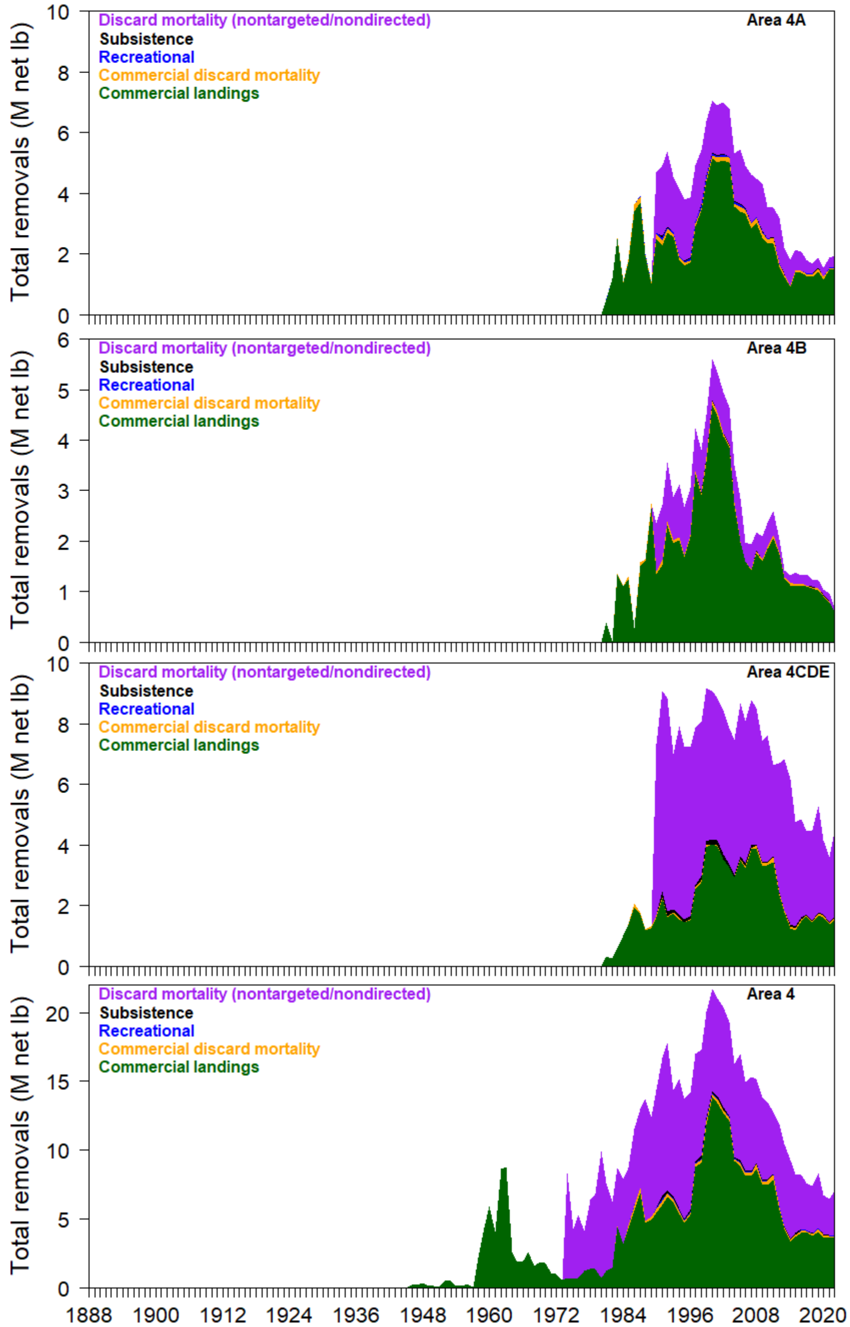

FIGURE 31. Estimated Pacific halibut mortality by source in IPHC Regulatory Areas 4A, 4B, 4CDE, and for Areas 4A-4CDE combined (lower panel) since 1888. Note that the y-axes differ in scale.

Commercial Pacific halibut fishery WPUE

Commercial fishery logbook data are collected by IPHC field staff located in major ports, and also reported directly to the IPHC by fishermen (IPHC-2022-AM098-07). 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).

Aggregate commercial 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 32) 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 was reevaluated (Monnahan and Stewart 2018) and the results of that investigation suggest a similar relationship than that estimated historically. 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, 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 could include all logbook records in all IPHC Regulatory Areas regardless of gear type if a model-based estimator were used. However, discussions with the IPHC's Scientific Review Board have not resulted 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 33). The weighted values are then summed to generate a coastwide 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.

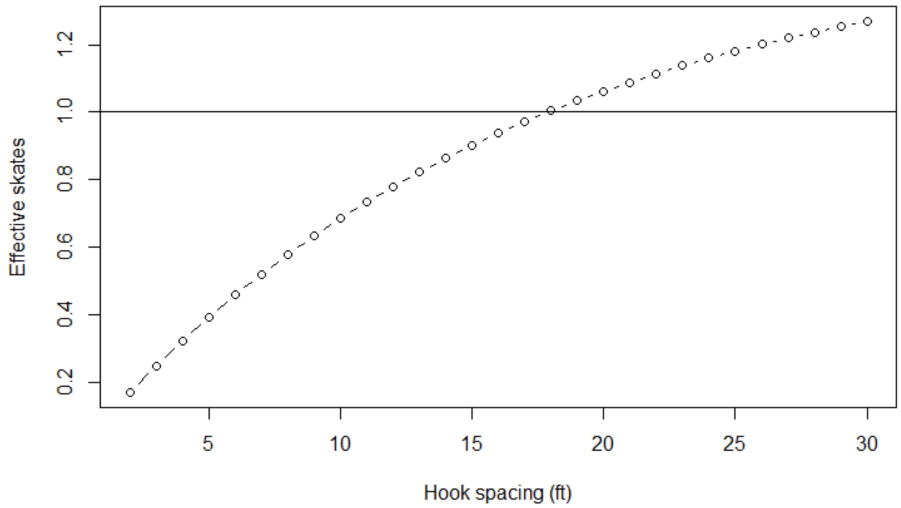

FIGURE 32. Relationship between hook spacing and the number of effective skates for setline survey and commercial fishery WPUE calculations (From: Hamley and Skud 1978).

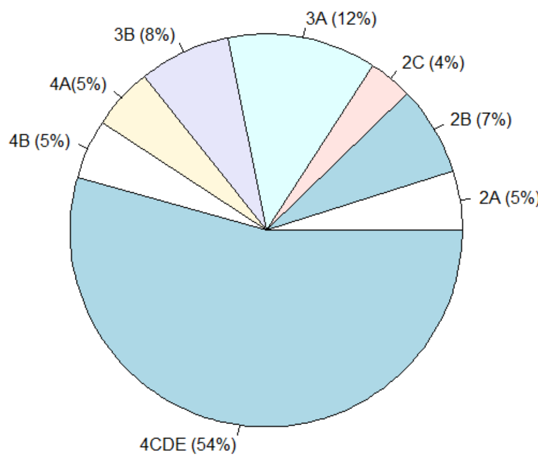

FIGURE 33. Relative spatial extent of each regulatory area.

All available logbook information was finalized on 1 November 2022 in order to provide adequate time for analysis and modeling. As is the case in all years, commercial fishery WPUE for 2022 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 for the stock assessment each year. Differences in the final data set reflect 1) the inclusion of logbooks that were not collected directly in the ports during the year of fishing (and were subsequently mailed in to the IPHC, or collected 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 a summary of the effect of each annual revision starting in 2012. 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.

Uncorrected commercial fishery WPUE in 2020 decreased by 15% from 2021 at the coastwide level (Figure 34). Applying the bias correction resulted in a projected 18% decrease from 2021 to 2022. Separate tribal and non-tribal commercial fishery trends are reported for IPHC Regulatory Area 2A and time-series by gear type (snap and fixed-hook) for most other IPHC Regulatory Areas (Figure 35). A notable difference in scale reflects the historically lower catch-per-effort estimated for snap compared to fixed-hook longline gear. This difference may reflect individual fishing practices among fishermen, spatial patterns, and other differences among the gears. It is also consistent with recent gear-calibration experiments conducted as part of the FISS (IPHC-2022-AM098-07). Regardless, the general trend of the time series for the two gear types within most IPHC Regulatory Areas is similar; however the annual trends differ considerably within individual IPHC Regulatory Areas.

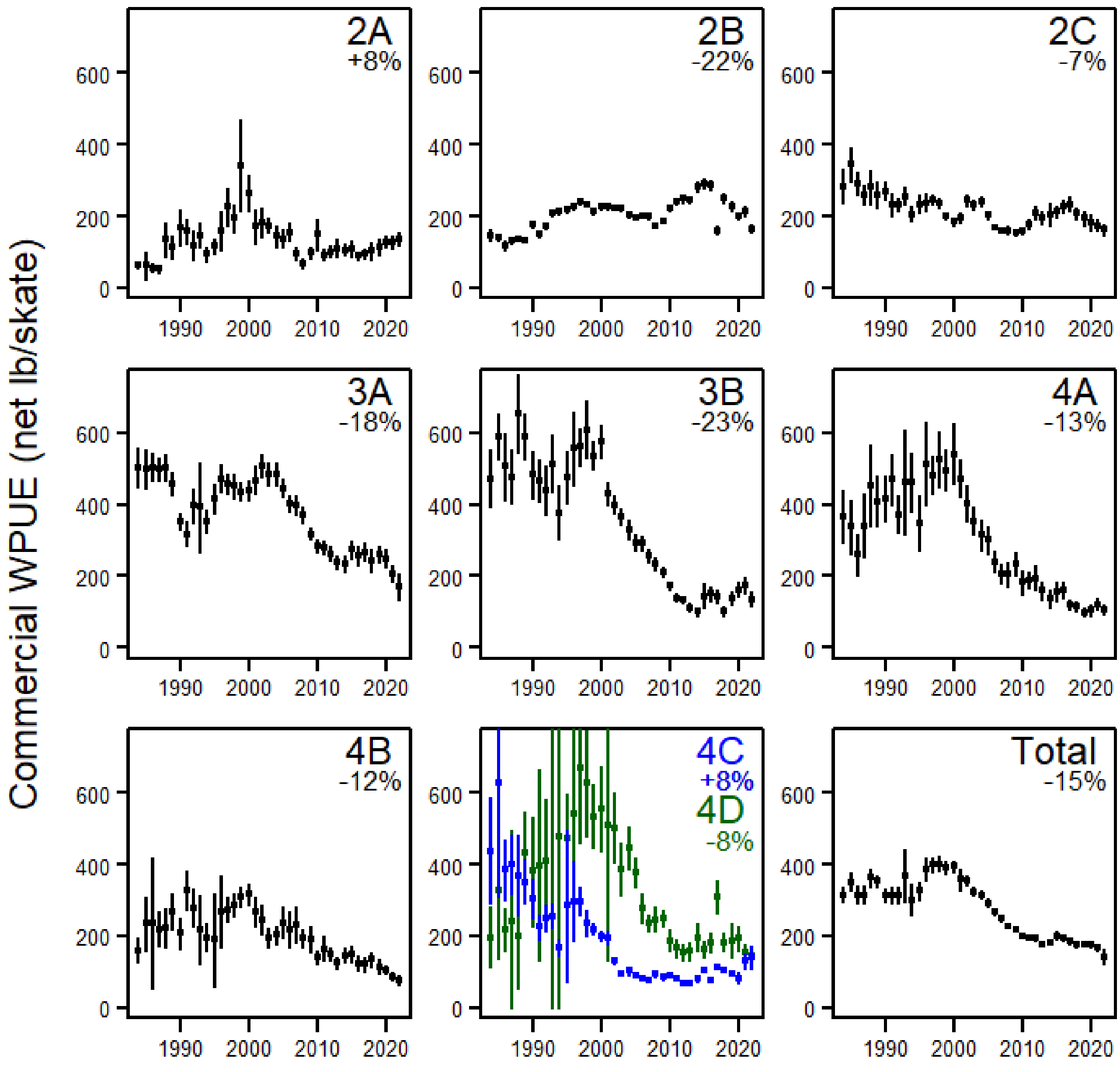

FIGURE 34. Trends in commercial fishery WPUE by IPHC Regulatory Area, 1984-2022. Percentages reported below the IPHC Regulatory Area label indicate the uncorrected change from 2020 to 2022 (see text above). The bias corrected "Total" percentage is 18% based on incomplete logbooks for 2022. Vertical lines indicate approximate 95% confidence intervals.

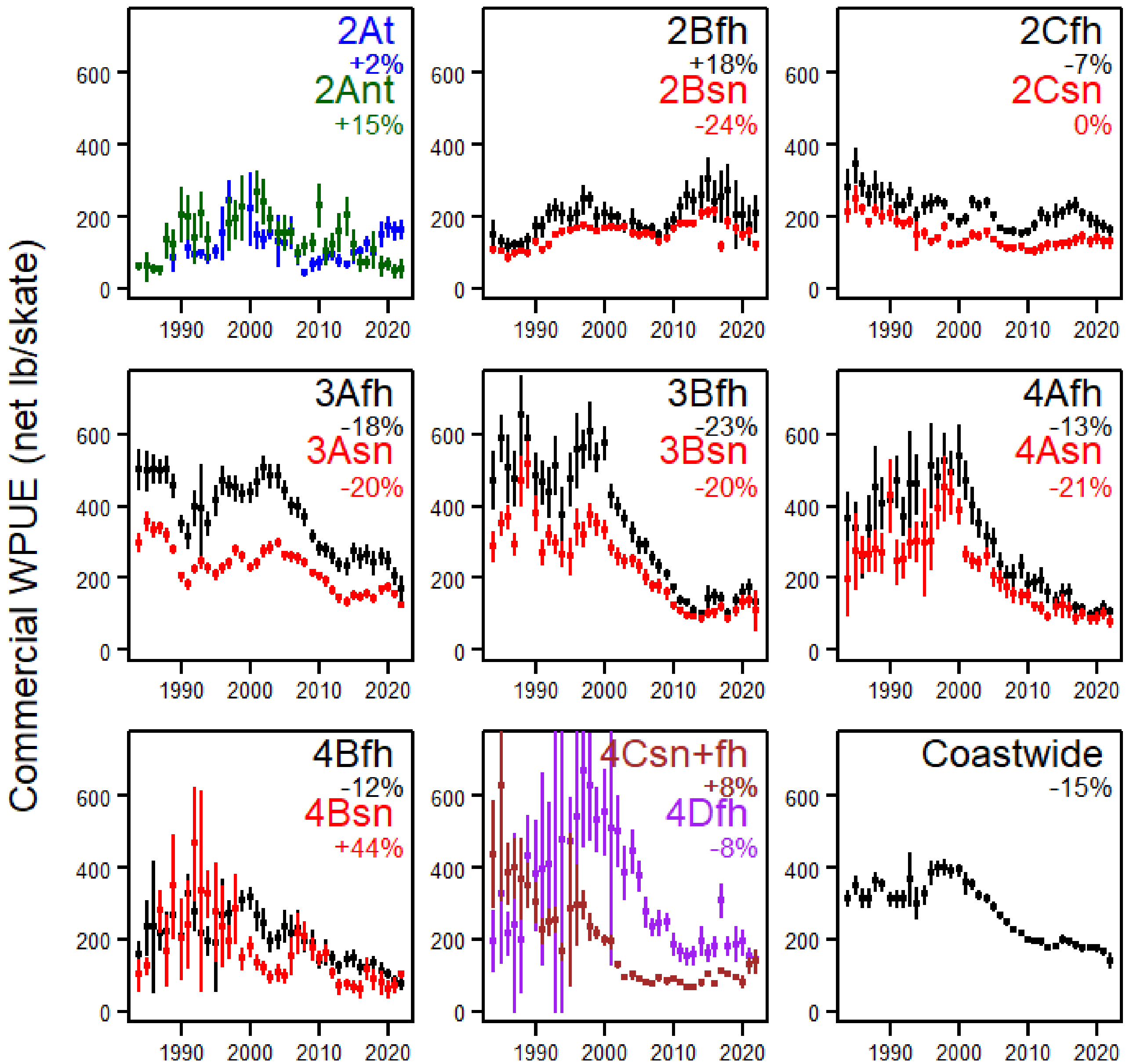

FIGURE 35. Trends in commercial fishery WPUE by IPHC Regulatory Area and gear, sector or area, 1984-2022. Percentages reported below the IPHC Regulatory Area label indicate the uncorrected change from 2020 to 2022 (see text above). In IPHC Regulatory Area 2A “t” denotes tribal and “nt” denotes non-tribal fisheries. In IPHC Regulatory Areas 2B-4B “fh” denotes fixed-hook gear and “sn” denotes snap gear. Vertical lines indicate approximate 95% confidence intervals.

Commercial fishery effort data for years prior to 1981 do not currently exist in the IPHC’s database. Therefore, summaries dating back to 1907 are the only records available and do not allow for reanalysis of the raw data. Prior to 1935, there are a number of differing time series available from technical and other IPHC reports. For this document, and all recent assessments, 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. Historical data and metadata recovery from the IPHC archives may make reanalysis possible in the future.

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 36), 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 36). Additional uncertainty throughout the historical series is reflected by increased coefficients of variation (fixed at 0.1) for all years prior to 1984.

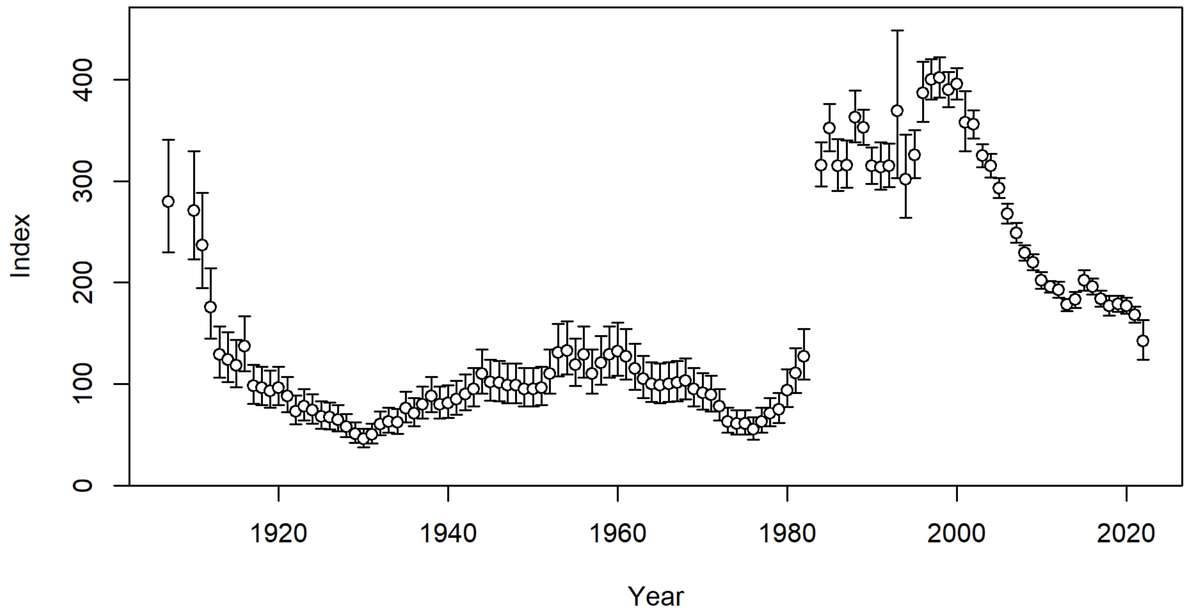

FIGURE 36. Coastwide commercial WPUE from historical records of effort and catch, as well as more recent direct logbook processing. The large change between 1982 and 1984 coincides with the adoption of circle hooks.

Commercial fishery age distributions

Recent commercial fishery age distributions are generated based on age-reading of otoliths collected by IPHC staff stationed in major ports. Otoliths are collected in proportion to the landings (in all ports that are annually staffed by the IPHC), and therefore the raw ages can be simply aggregated within each IPHC Regulatory Area and year to estimate the age composition of the landings. Beginning in 2017, a fin clip was collected from each sampled Pacific halibut, and subsequently analyzed via a genetic assay to determine the sex. For 2022, sex-specific age information was available for 2017-2021, with collection and analysis of subsequent samples ongoing. These data provide direct information on the sex ratio of the landings, a critically important improvement to the IPHC's annual fishery monitoring program.

The aggregate sex ratios in the commercial landings indicate that the fishery has comprised mainly female Pacific halibut in recent years, ranging from 51% in Biological Region 4B in 2019 and 2022 to 92% in Region 4 in 2017 (Table 1). With five years of data now available, it is possible to discern some consistent patterns, such as the strong negative relationship between average age in the landings and the percent female (Figure 37). This is consistent with dimorphic growth for Pacific halibut leading to a larger fraction of younger fish above the minimum size limit being females. Coastwide sex ratios have dropped from 82% female to 74% during 2017-21, consistent with the aging of the 2005 cohort. Relative patterns among Biological Regions have remained consistent over this period. From the sex-specific age composition estimates, it is clear that most fish in the landings less than about 15 years old are female (Figure 38).

Table 1. Percent of the directed commercial fishery landings comprised of female Pacific halibut by Biological Region.

Year	Coastwide	Biological Region 2	Biological Region 3	Biological Region 4	Biological Region 4B
2017	82%	82%	82%	92%	65%
2018	80%	82%	78%	91%	65%
2019	78%	80%	76%	89%	51%
2020	80%	79%	81%	84%	54%
2021	74%	73%	74%	88%	51%

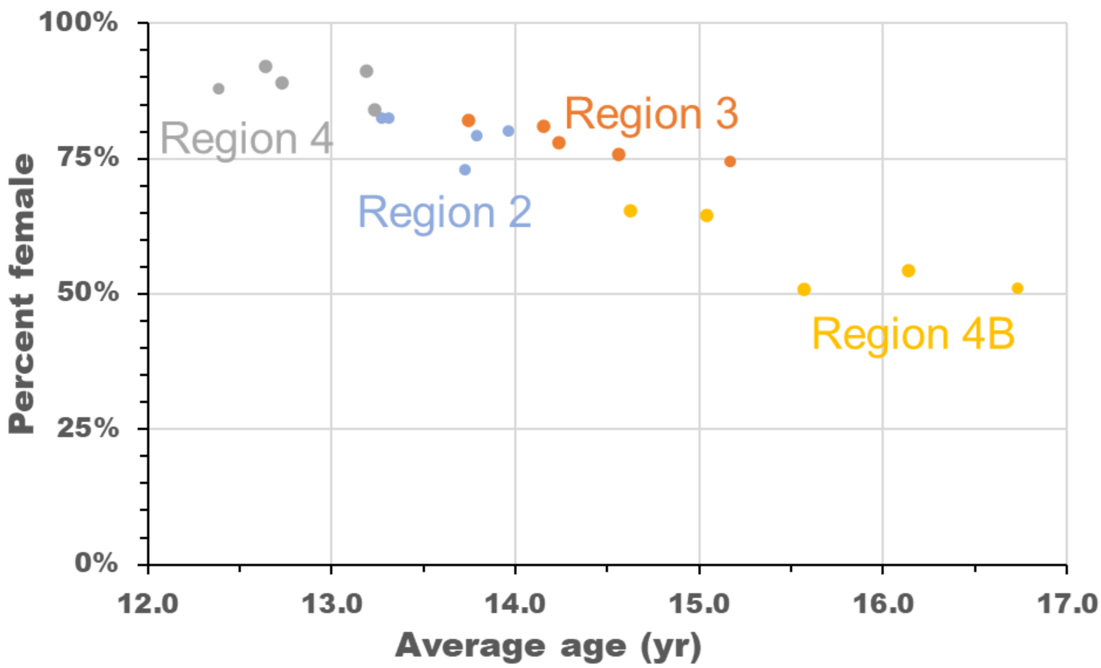

FIGURE 37. Relationship between percent female and average age in the directed commercial Pacific halibut fishery by Biological Region. Each point represents one year (2017-2021).

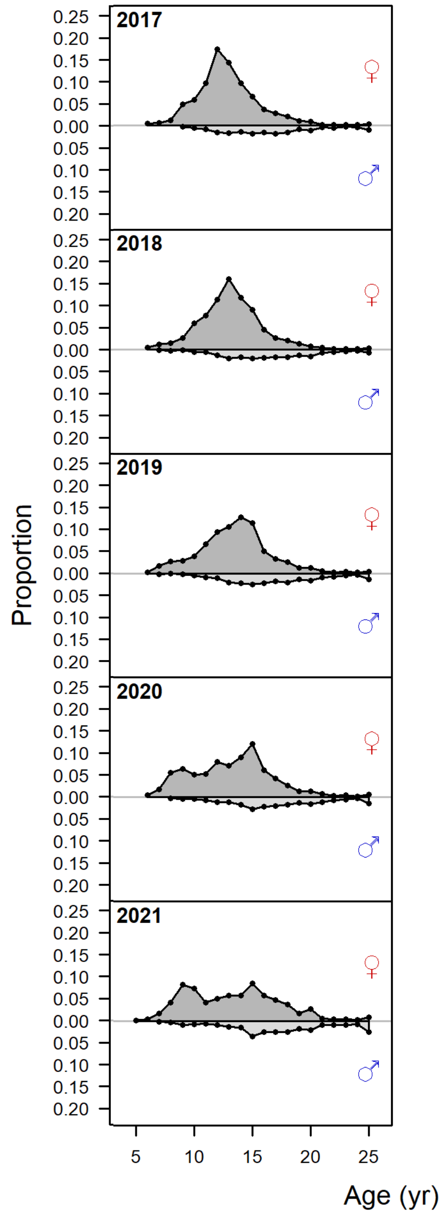

FIGURE 38. Estimates of the sex-specific age composition of the coastwide commercial fishery landings from 2017 to 2021.

IPHC field staff in major ports 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 fish 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 observed the FISS survey ages, but without as many younger fish. A very strong 1987 cohort is apparent moving through the stock from 1996 to the late 2000s, followed by catches comprised primarily of 9 to 18 year-old Pacific halibut (Figure 39). Age distributions in 2022 show that the fishery transitioned from older fish to the 2012 year-class (age 10 in 2022) representing the highest proportion for any single-age.

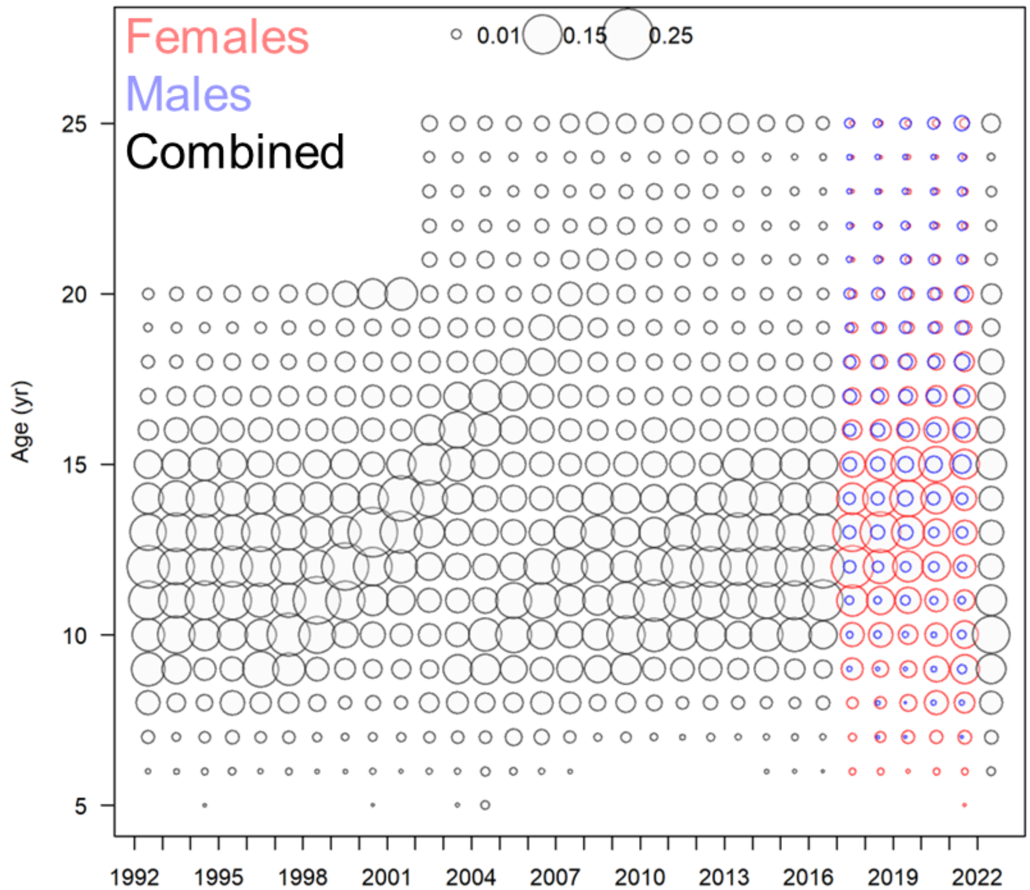

FIGURE 39. Estimates of recent commercial fishery proportions-at-age. Circles sum to 1.0 within each year (column). For 2017-2021, males are delineated by blue circles and females by red circles at each age.

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 all recent stock assessments, a file produced in association with Clark et al. (2000) provided the basis proportions at age by IPHC Regulatory Area from 1935 to 1990. Raw data in IPHC databases remains incomplete for recreating this information directly. Weighting of historical IPHC Regulatory Area-specific proportions followed the method applied to the more recent data: first obtaining an average individual weight by taking the product of the proportions-at-age and 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. The estimated numbers of fish in the landings by IPHC Regulatory Area were used to weight the proportions-at-age for aggregation to Biological Regions 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 40). 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 (Figures 41-42). 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.

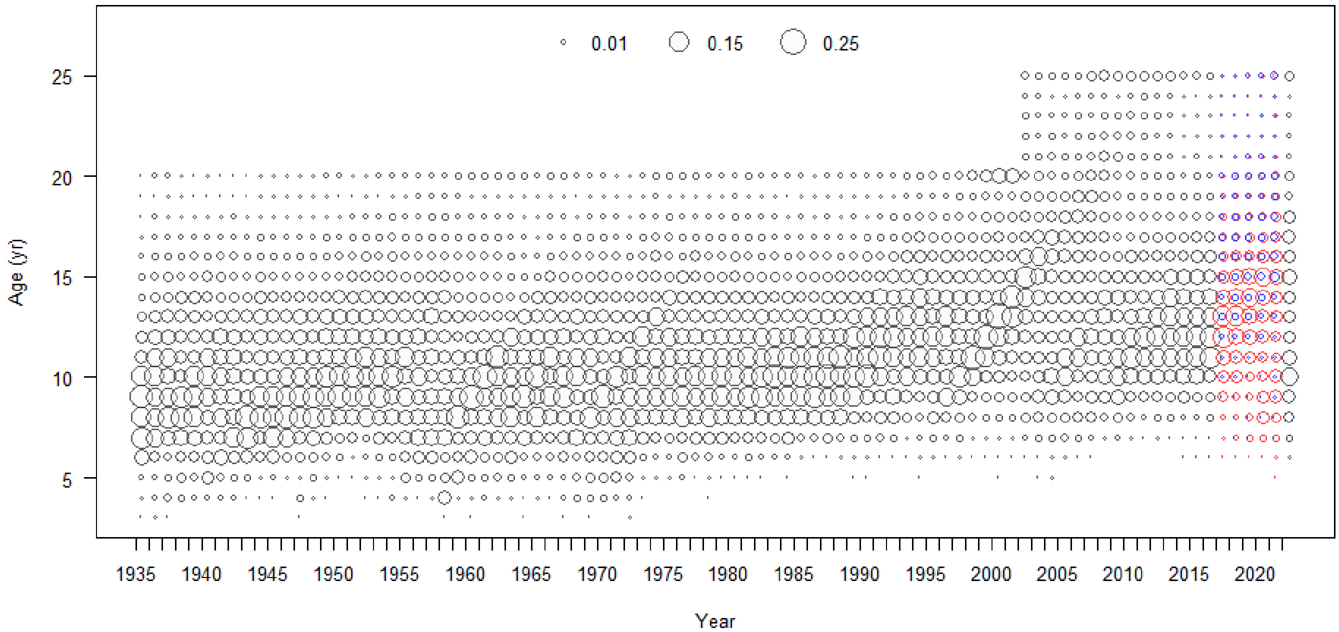

FIGURE 40. Historical coastwide commercial fishery proportions-at-age from the retained catch. Note that the current 32 inch (82.3 cm) minimum size limit was implemented in 1973. Circles sum to 1.0 within each year (column). For 2017-2021, males are delineated by blue circles and females by red circles at each age.

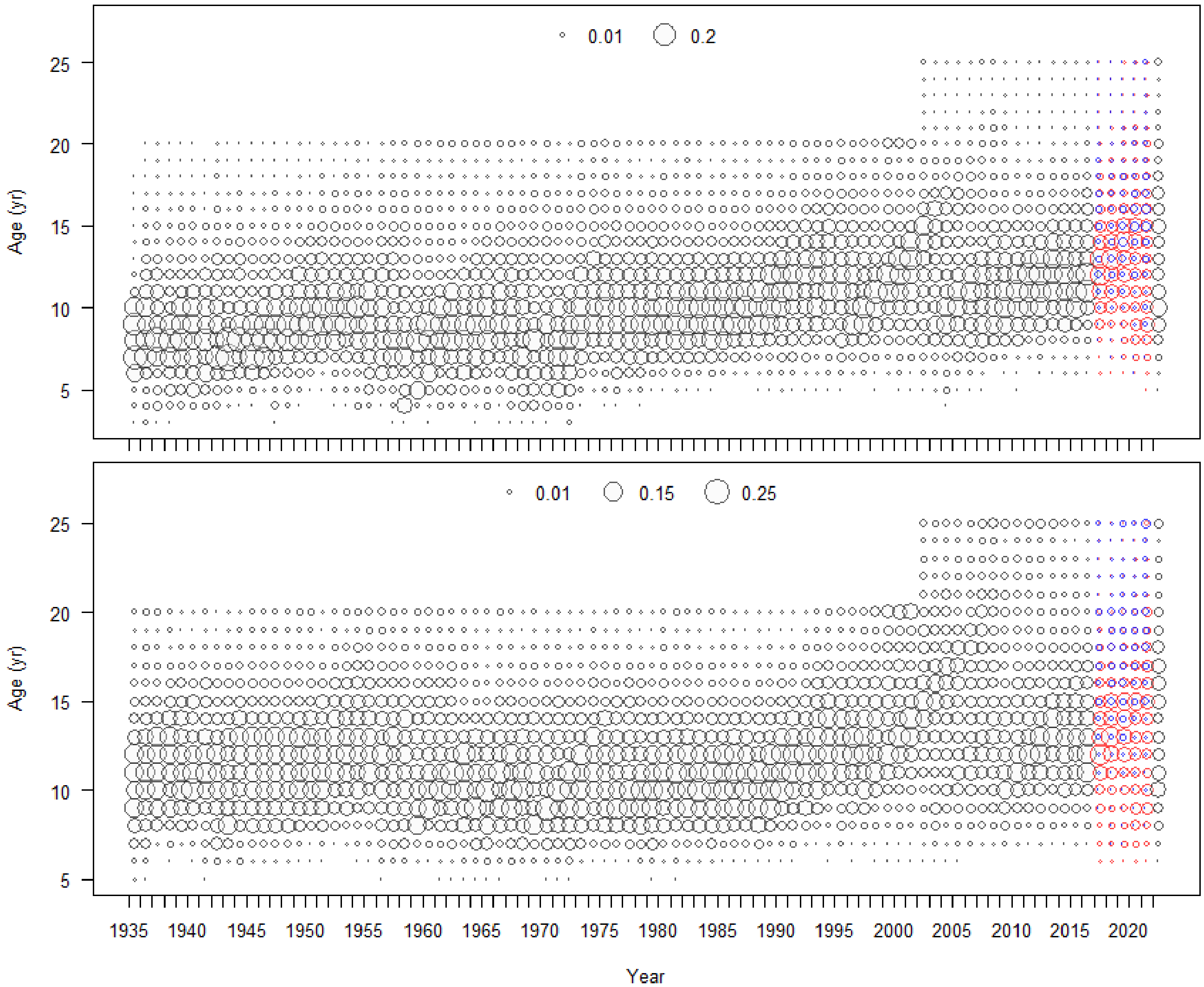

FIGURE 41. Commercial fishery proportions-at-age in the retained catch (male and female Pacific halibut combined) for Biological Region 2 (top panel), and Region 3 (bottom panel). Circles sum to 1.0 within each year (column). For 2017-2021, males are delineated by blue circles and females by red circles at each age.

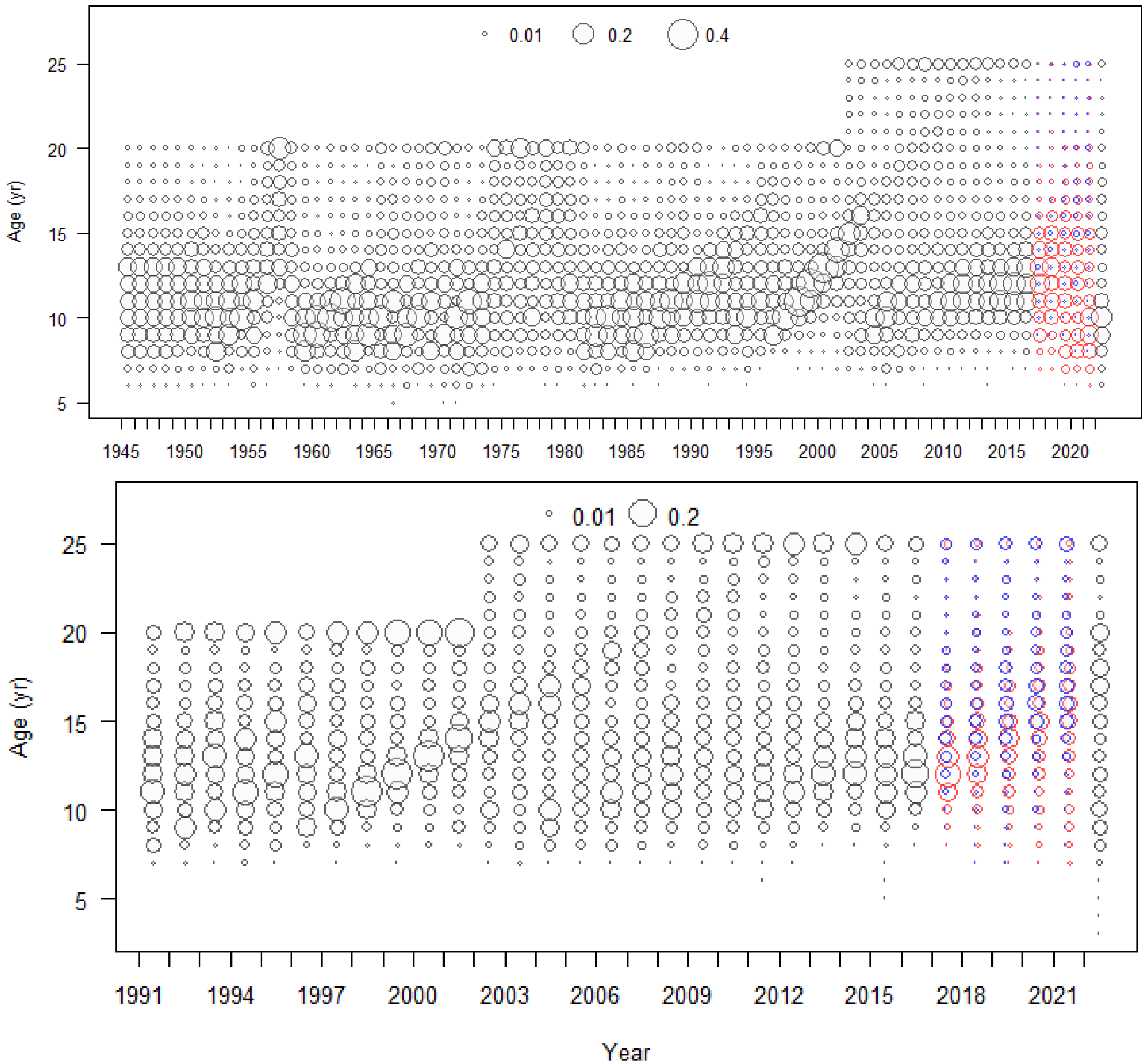

FIGURE 42. Commercial fishery proportions-at-age in the retained catch (male and female Pacific halibut combined) for Biological Region 4 (upper panel) and 4B (lower panel). Circles sum to 1.0 within each year (column). For 2017-2021, males are delineated by blue circles and females by red circles at each age. Note that the range of years is much shorter for Biological Region 4B.

Commercial fishery weight-at-age

The recent coastwide average weight of a landed Pacific halibut has been relatively stable since 2010 (Figure 43). IPHC Regulatory Area 2C and more recently 2B have produced the largest fish on average during this period. These observations accurately reflect the fishery landings but include the combined effects of weight-at-age, age and sex structure, as well as selectivity and fishery behavior when considered relative to the underlying Pacific halibut population.

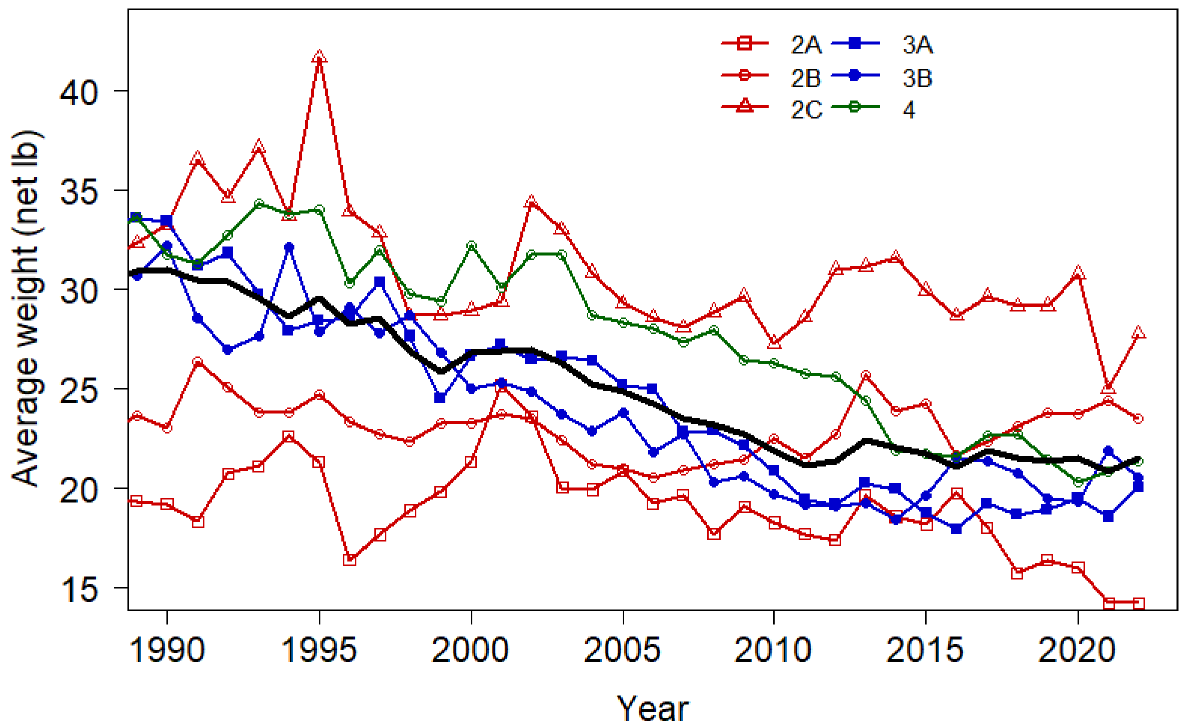

FIGURE 43. Recent average Pacific halibut weight by IPHC Regulatory Area in the directed commercial fishery landings; thick black line indicates the coastwide average.

Recreating historical observations of average Pacific halibut weight is 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 and therefore the weight (Southward 1962). Subsequent investigation of the relationship between otolith measurements and individual length (Clark 1992a) 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 44). Also clearly visible is the effect of the implementation of the 32 inch (82.3 cm) minimum size limit in 1973.

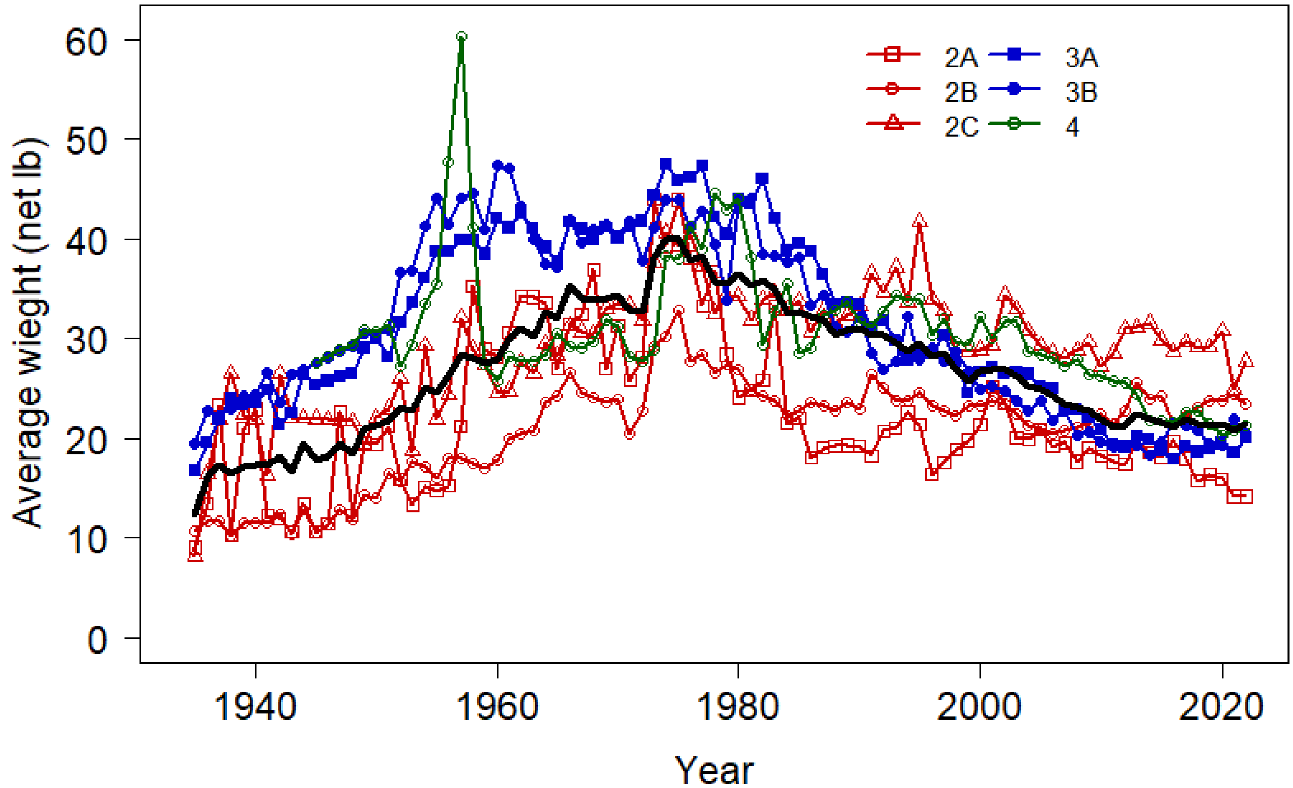

FIGURE 44. Historical trends in average individual Pacific halibut weight in the commercial fishery landings; thick black line indicates the coastwide average. The current 32 inch (81.3 cm) minimum size limit was implemented in 1973.

Following the same method applied to the age-composition data (weighting the historical weight-at-age for each IPHC Regulatory Area by the number of fish in the landings for that Area), weight-at-age by Biological Region and coastwide was 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 in average weight 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 FISS data (1997). Only legal-sized fish from the FISS catch are included in these weights-at-age in order to make them comparable to fishery landings. These age-specific deviations show very similar temporal patterns, despite expected differences on an absolute scale (Figure 45). 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 the mid-2000s, followed by increasing trends for younger ages over the last decade (Figure 17).

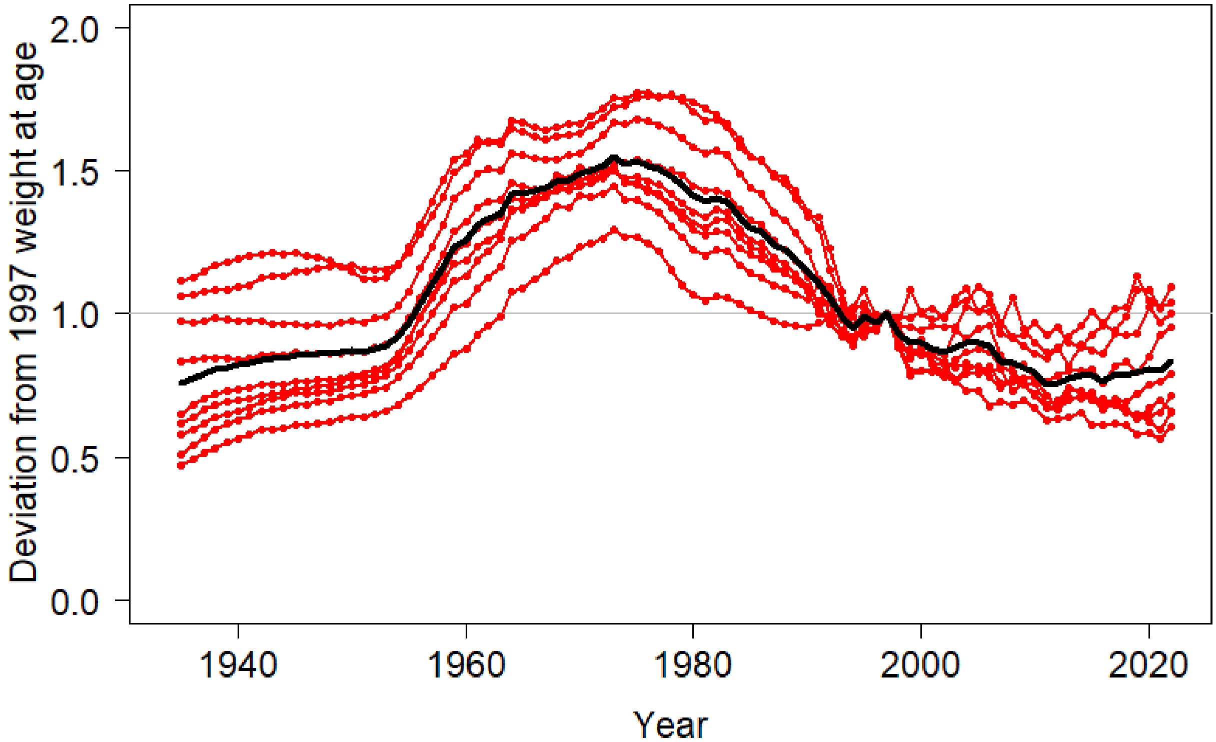

FIGURE 45. Trends in coastwide average individual Pacific halibut weight as deviations from 1997 in the commercial fishery landings for Pacific halibut aged 8-16 years old (red lines). The black line represents the average trend among the nine ages included.

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 less pronounced historical pattern (Figure 46). 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 younger ages and continued declines for older ages. No historical data pre-dating 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 for assessment purposes.

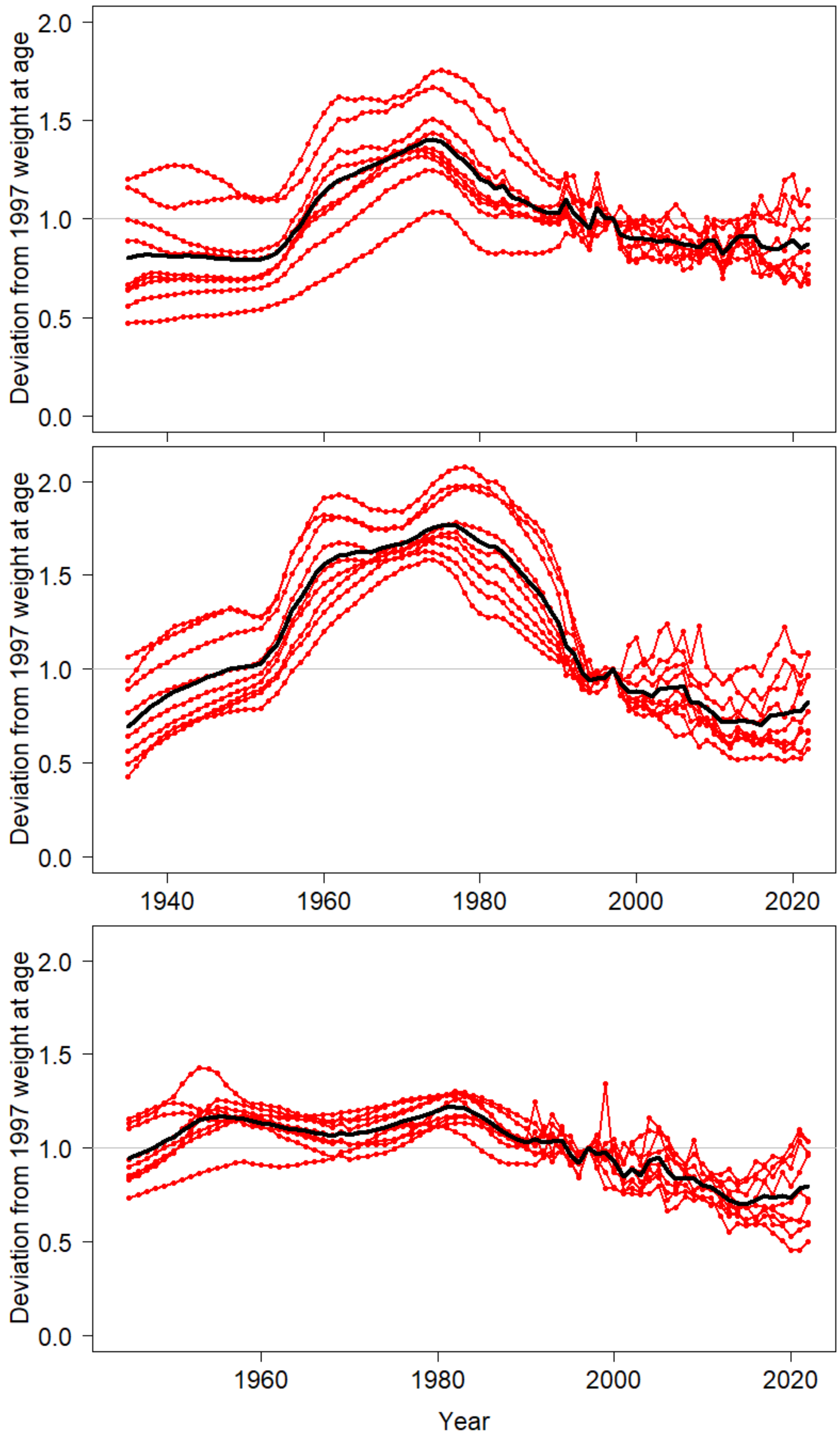

FIGURE 46. Trends in average individual Pacific halibut weight from 1935 as deviations from 1997 in the commercial fishery landings for Pacific halibut aged 8-16 years old (red lines) from Biological Region 2 (upper panel), Region 3 (middle panel), and Region 4 (lower panel including a shorter time-series beginning in 1945). 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 ADFG, and the ages read by IPHC Secretariat staff. These age samples are weighted by port-specific harvest and summarized for use in the stock assessment. (B. King, ADFG, pers. comm.). Due to the delays in exchange and processing, the most current year of data is usually one year behind other data sources (2021 for this stock assessment). These data showed a generally larger proportion at ages younger than age 5, and smaller proportion greater than age 15 (Figure 47) compared to the IPHC Regulatory Area 3A FISS ages over a similar time period (Figure 9). The recreational data also contained a few Pacific halibut below age 4, which is younger than any observed in the FISS. Because some of the smallest size-at-age occurs in IPHC Regulatory Area 3A, this observation suggests selectivity for smaller Pacific halibut in the recreational fishery than in the FISS. These data clearly show the 2012 cohort, the most abundant at each age during 2018-2021. Although these data are not geographically comprehensive, recreational mortality 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 IPHC 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.

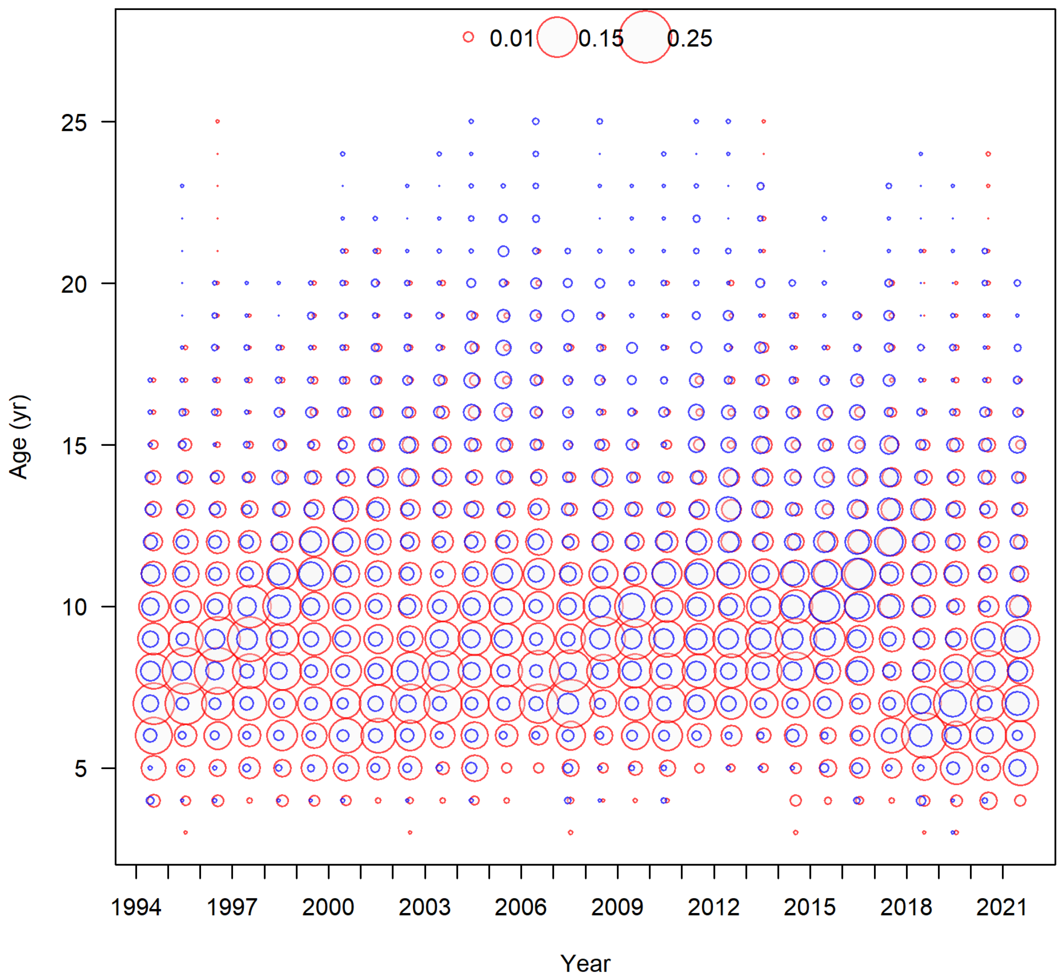

FIGURE 47. Proportions-at-age for male (blue circles) and female Pacific halibut (red circles) from the recreational fishery in IPHC Regulatory Area 3A. Circles sum to 1.0 within each year (column).

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 NMFS and DFO. Historically, the raw length frequencies are summarized by target fishery within gear type (i.e., trawl, hook-and-line, and pot), then aggregated (weighting by the catch) in order to better represent the differing contributions and sampling rates for each fishery in each IPHC Regulatory Area and coastwide. Weighted length-frequencies are used 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 trawl survey data, and the global key used for early years (prior to 1998) and terminal years where trawl survey ages are not yet available (or not collected as in the case of 2020). 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 48). Consistent with the NMFS Bering Sea trawl survey data, both the 1987 cohort and the strong 2004-05 year-classes are clearly visible in this data set. Increased proportions corresponding to the 2011-12 year-classes are also present. The use of an age-length key may blur the specific years in which larger cohorts occur. Data from the terminal year (2022) are not shown, as the length frequency information from these fisheries lags one year in reporting.

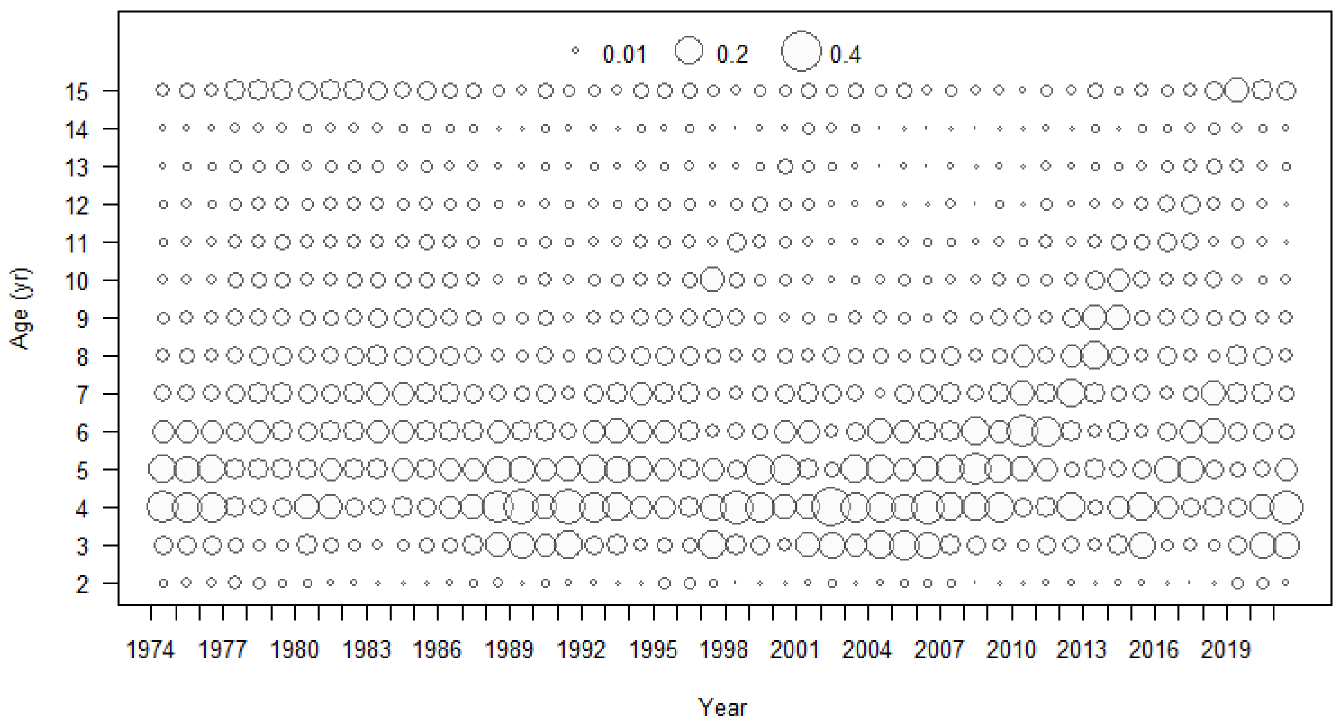

FIGURE 48. Coastwide proportions-at-age from the aggregate non-directed commercial fisheries (male and female Pacific halibut combined). Circles sum to 1.0 within each year (column).

AUXILIARY SOURCES OF INFORMATION

Several additional sources of information are evaluated directly or are 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 in published and archived IPHC documents.

Weight-length relationship

The weight-length relationship for Pacific halibut was developed in 1926, re-evaluated in 1991 (Clark), and has been historically applied as standard practice in the calculation of many quantities used for assessment and management purposes. 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 49). In 2013, the IPHC staff initiated a program to begin sampling individual weights during port sampling, this was expanded in 2015 to include some data collection on FISS vessels and during routine port sampling in all ports. From 2016, all fish sampled from the commercial landings have been individually weighed. From 2019, individual Pacific halibut weights have been collected during all FISS sampling. These direct observations have reduced the use of the weight-length relationship in most IPHC analyses.

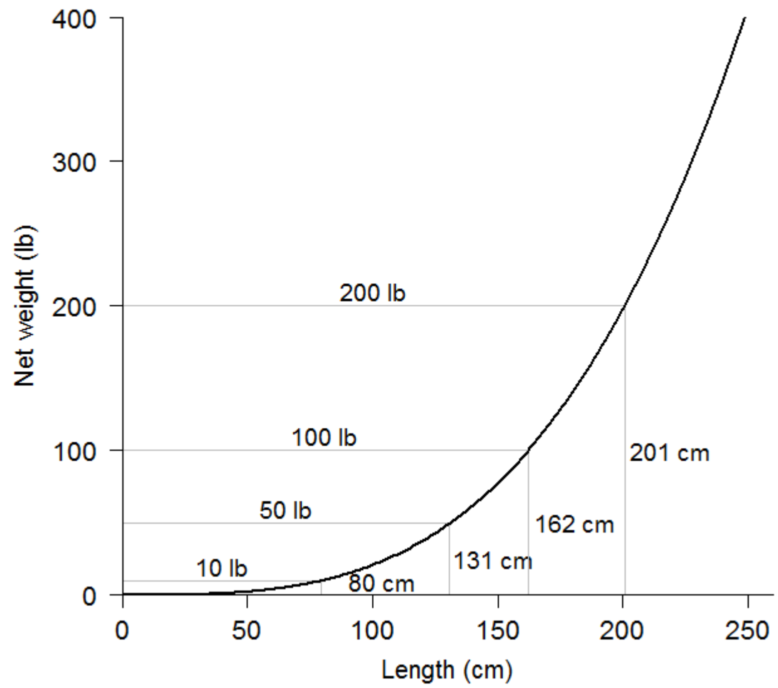

FIGURE 49. The historical conversion relationship for length in centimeters to net weight in pounds.

An update to the historical length-weight relationship was completed in 2021 (IPHC-2022-AM098-INF07). That analysis provides more accurate weight-length relationships by IPHC Regulatory Area applicable for the years 2017-present and should be used on recent data in place of the historical relationship.

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 50). A research program to evaluate the current maturity schedule has been ongoing since 2017, and included collection of a large number of samples in 2022 for histological analysis (IPHC-2022-AM098-11).

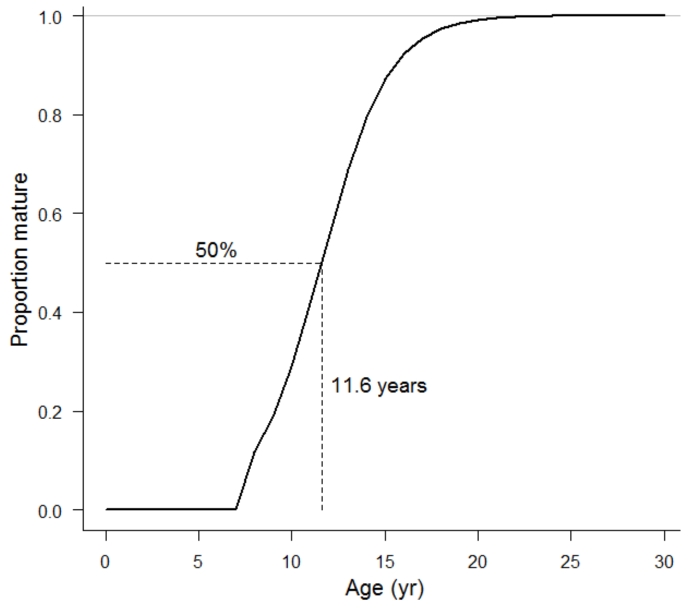

FIGURE 50. The maturity ogive used in recent Pacific halibut assessments. Note that this is a logistic curve, trimmed to be equal to zero below age-8.

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; Figure 51). Analysis of surface ages from each decade back to the 1920s also corroborated those results (Forsberg and Stewart 2015).

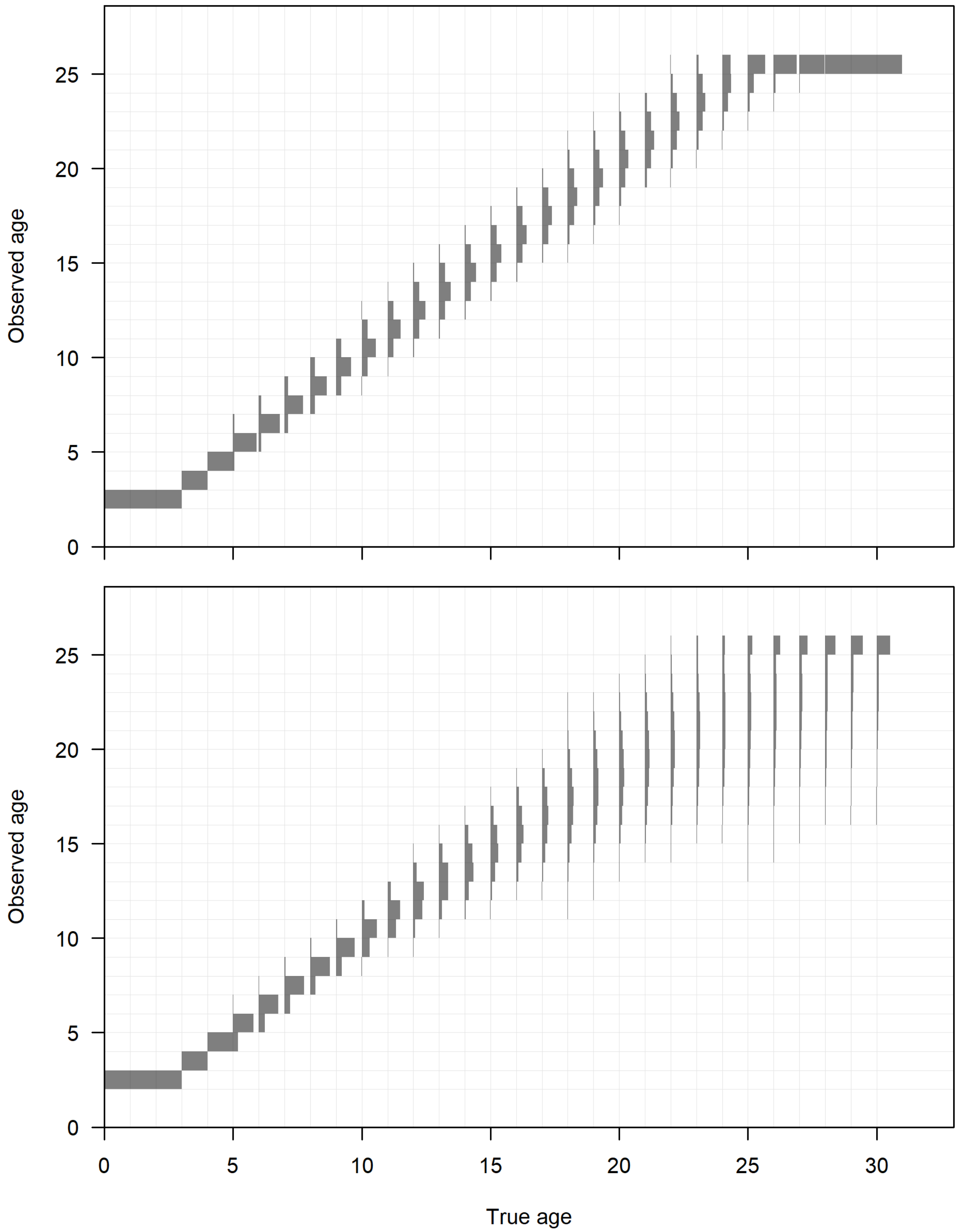

FIGURE 51. Ageing bias and imprecision relationships for break-and-bake ageing (upper panel) and surface ageing (lower panel) used in recent stock assessments.

Movement rates among Biological Regions

Historically aggregated movement rates from the IPHC's PIT-tagging program (Webster et al. 2013) and other studies suggest complex links across the entire geographic range within convention waters and variable movement rates over time. A recent review of historical tagging studies has provided a comprehensive summary of what is known regarding juvenile through adult movement, spawning and juvenile rearing areas (Carpi et al. 2021). Further investigation of plausible movement rates and their role in historical and future population dynamics and fishery management has proceeded as part of the IPHC's MSE process.

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. For Pacific halibut, the positive 'phase' of the PDO (years up to and including 1947, 1977-2006, and 2014-19) and concurrent average recruitment appears to be correlated (Clark and Hare 2002; Clark et al. 1999). The most recent PDO observations comprise the only information available related to Pacific halibut abundance prior to each cohort's first 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 (Figure 52). Positive values were observed over 2014-19, and there have been negative values for 2020-22. Historically, it usually takes a few years before it can be determined whether a change represents a new phase or just annual variability. Recent 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 (Litzow et al. 2020). The correlation between the PDO and average recruitment strength is re-estimated in each year's stock assessment (IPHC-2022-SA-01).

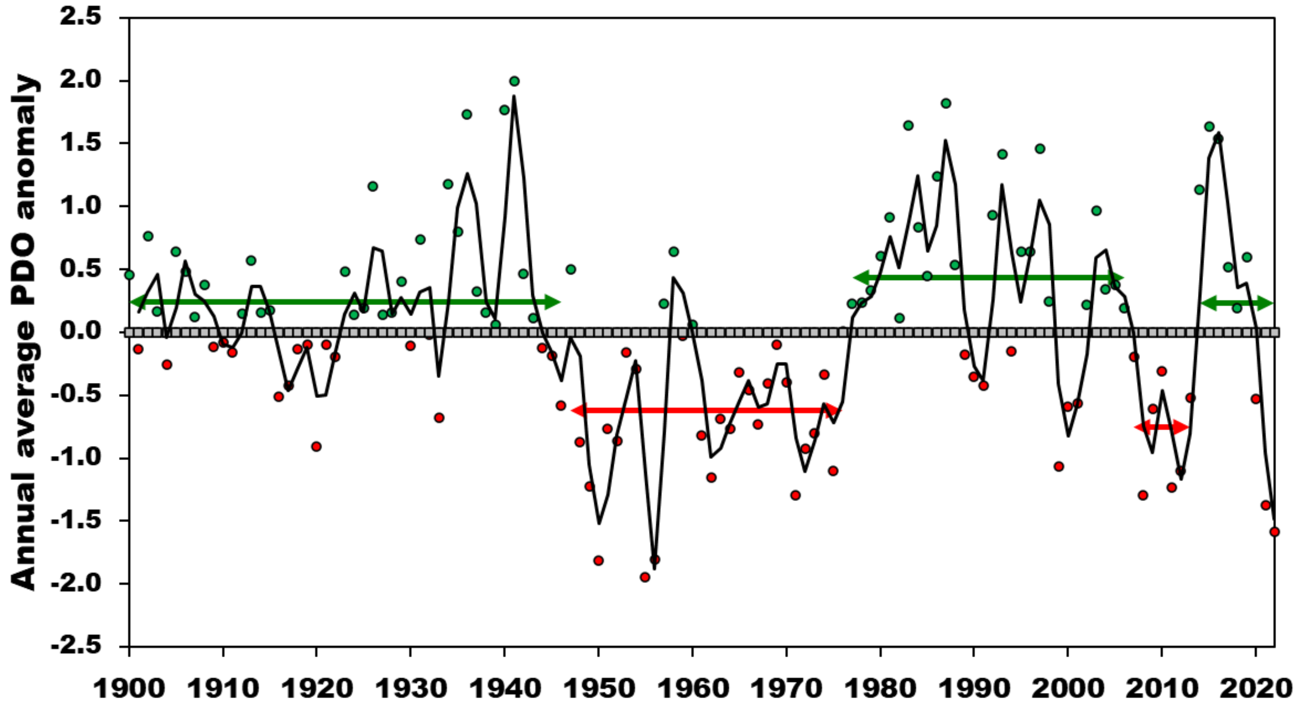

FIGURE 52. Time series of annual average PDO conditions (deviations from the long-term mean). Horizontal lines indicate average values over each historical phase.

Recent reports for the Eastern Bering Sea, Aleutian Islands, Gulf of Alaska, British Columbia, and the California current all detail rapidly changing ecosystems over the last decade with intermittent marine 'heat waves', reduced sea ice, and mortality events for species such as crabs, Pacific cod and seabirds becoming more common.. Negative PDO conditions have generally corresponded to a more productive ecosystem in the California Current, although some hypoxia events have occurred (Harvey et al. 2022). In British Columbia, salmon productivity has remained low; however, updated information since 2020 was unavailable (Boldt et al. 2021). The Gulf of Alaska continues to recover toward more normal conditions following the warmer years from 2014-16 and in 2019 (Ferriss and Zador 2022). The Bering Sea temperatures and ice cover was also much closer to the long term average in 2022 than in recent warmer years (Siddon 2022). The Aleutian Islands ecosystem continues to experience above average temperature conditions (Ortiz and Zador 2022). Links between these observations of the physical and biological ecosystem and the success of Pacific halibut remain unknown. However, the last decade appears to have produced very large 2014, 2016 and 2019 year classes for the sablefish (*Anoplopoma fimbria*) stock (Goethel et al. 2022). 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 recruitments from the 2014 and subsequent years are clearly identified in the FISS and 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-2023-AM099-09). 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 values of *U* were scaled relative to the coastwide aggregate in the terminal year, providing a relative metric of exploitation rates over time and among Biological Regions. Much higher *U* values are estimated for Biological Region 2 than in other Regions; however, all Regions experienced peak harvest rates between 2003 and 2009 (Figure 53). The harvest rates in all Biological Regions were generally lower than most historical values over the period 2012 -2016, but increased, especially in Region 2 and coastwide during 2017-22 with all but 4B reaching recent highs in 2022.

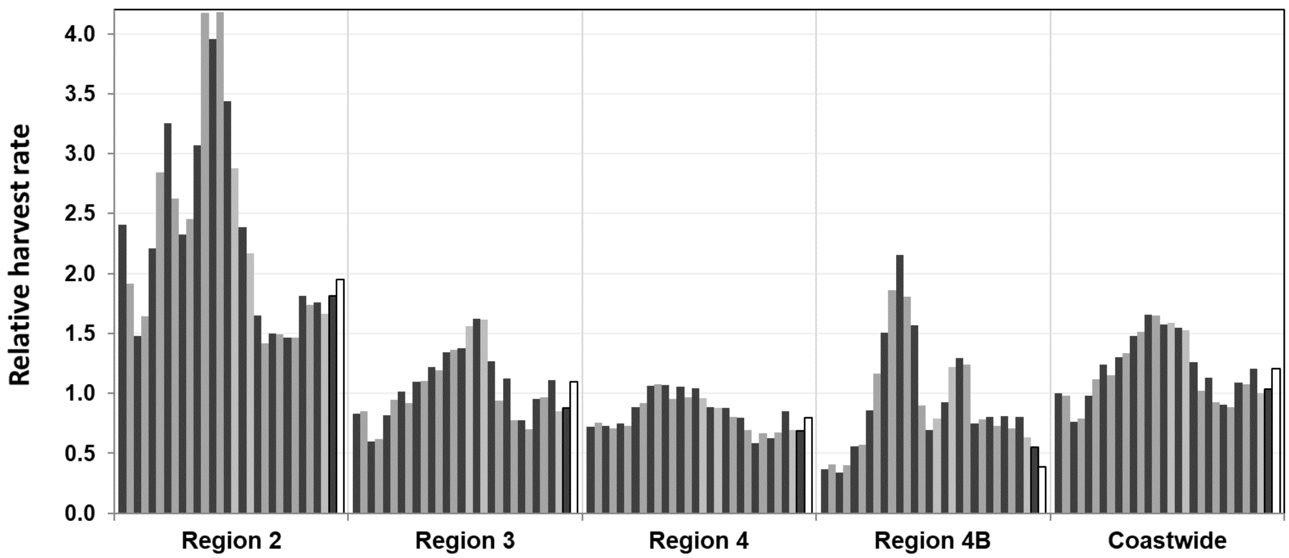

FIGURE 53. Empirical harvest rates from 1993-2022. All rates are relative to the coastwide aggregate in the terminal year (open bars), which is arbitrarily set equal to 1.0.

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 2022

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 2022 these included:

- Standard updating of preliminary values from 2021 including mortality estimates, commercial logbooks and commercial age distributions.
- Inclusion of all current-year data available as of 1 November 2022.
- Development of a bootstrapping routine to describe the actual sampling designs completed for collection of otoliths each year for use in data weighting within assessment models (IPHC-2022-SRB020-07).

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 and included in the 5-year research plan for 2022-26 (IPHC-2023-AM099-06).

REFERENCES

Bell, F.H., Dunlop, H.A., and Freeman, N.L. 1952. Pacific Coast halibut landings 1888-1950 and catch according to area of origin. International Pacific Halibut Commission Report No. 17. 47 p.

Boldt, J.L., Javorski, A., and Chandler, P.C. 2021. State of the physical, biological and selected fishery resources of Canadian marine ecosystems in 2020. Canadian Technical Report of Fisheries and Aquatic Sciences 3434. 240 p.

Carpi, P., Loher, T., Sadorus, L.L., Forsberg, J.E., Webster, R.A., Planas, J.V., Jasonowicz, A., Stewart, I.J., and Hicks, A.C. 2021. Ontogenetic and spawning migration of Pacific halibut: a review. Reviews in Fish Biology and Fisheries **31**: 879-908. doi:10.1007/s11160-021-09672-w.

Chapman, D.G., Myhre, R.J., and Southward, G.M. 1962. Utilization of Pacific halibut stocks: Maximum sustainable yield, 1960. International Pacific Halibut Commission Scientific Report No. 31. 35 p.

Clark, W.G. 1992a. Estimation of Halibut Body Size from Otolith Size. International Pacific Halibut Commission Scientific Report No. 75.

Clark, W.G. 1992b. Validation of the IPHC length-weight relationship for halibut. IPHC Report of Assessment and Research Activities 1991. p. 113-116.

Clark, W.G. 2002. Comparison of fixed-hook and snap-hook CPUE. IPHC Report of Assessment and Research Activities 2001. p. 191-196.

Clark, W.G. 2004a. Nonparametric estimates of age misclassification from paired readings. Canadian Journal of Fisheries and Aquatic Sciences **61**: 1881-1889.

Clark, W.G. 2004b. Statistical distribution of IPHC age readings. IPHC Report of Assessment and Research Activities 2003. p. 99-110.

Clark, W.G., and Hare, S.R. 2002. Effects of climate and stock size on recruitment and growth of Pacific halibut. North American Journal of Fisheries Management **22**: 852-862.

Clark, W.G., and Hare, S.R. 2006. Assessment and management of Pacific halibut: data, methods, and policy. International Pacific Halibut Commission Scientific Report No. 83, Seattle, Washington. 104 p.

Clark, W.G., Vienneau, B.A., Blood, C.L., and Forsberg, J.E. 2000. A review of IPHC catch sampling for age and size composition from 1935 through 1999, including estimates for the years 1963-1990. International Pacific Halibut Commission Technical Report No. 42.

Clark, W.G., Hare, S.R., Parma, A.M., Sullivan, P.J., and Trumble, R.J. 1999. Decadal changes in growth and recruitment of Pacific halibut (*Hippoglossus stenolepis*). Canadian Journal of Fisheries and Aquatic Sciences **56**: 242-252.

Ferriss, B.E., and Zador, S. 2022. Ecosystem Staus Report 2022: Gulf of Alaska. Stock Assessment and Fishery Evaluation Report. North Pacific Fishery Managment Council. Anchorage, Alaska. 227 p.

Forsberg, J.E., and Stewart, I.J. 2015. Re-ageing of archived otoliths from the 1920s to the 1990s. IPHC Report of Assessment and Research Activities 2014. p. 405-428.

Goethel, D.R., Rodgveller, C.J., Echave, K.B., Shotwell, S.K., Siwicke, K.A., Hanselman, D., Malecha, P.W., Cheng, M., Williams, M., Omori, K., and Lunsford, C.R. 2022. Assessment of the sablefish stock in Alaska. NPFMC Bering Sea, Aleutian Islands and Gulf of Alaska SAFE. 182 p.

Hamley, J.M., and Skud, B.E. 1978. Factors affecting longline catch and effort: II Hook-spacing. International Pacific Halibut Commission Scientific Report No. 62. p. 15-24.

Harvey, C., Garfield, T., Williams, G., and Tolimieri, N. 2022. 2021-2022 California Current ecosystem status report. CCIEA Team Report 1. 100p.

Jannot, J., Tran, H., Kong, T., and Sawyer van Vleck, K. 2023. Fisheries data overview (2022): preliminary statistics. IPHC-2023-AM099-07.

Leaman, B.M., Kaimmer, S.M., and Webster, R.A. 2012. Circle hook size and spacing effects on the catch of Pacific halibut. Bulletin of Marine Science **88**(3): 547-557.

Litzow, M.A., Hunsicker, M.E., Bond, N.A., Burke, B.J., Cunningham, C.J., Gosselin, J.L., Norton, E.L., Ward, E.J., and Zador, S.G. 2020. The changing physical and ecological meanings of North Pacific Ocean climate indices. Proceedings of the National Academy of Sciences of the United States of America **117**(14): 7665-7671. doi:10.1073/pnas.1921266117.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.R., and Francis, R.C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society **78**(6): 1069-1079.

Monnahan, C.C., and Stewart, I.J. 2015. Evaluation of commercial logbook records: 1991-2013. IPHC Report of Assessment and Research Activities 2014. p. 213-220.

Monnahan, C.C., and Stewart, I.J. 2018. The effect of hook spacing on longline catch rates: Implications for catch rate standardization. Fisheries Research **198**: 150-158. doi:10.1016/j.fishres.2017.10.004.

Ortiz, I., and Zador, S. 2022. Ecosystem status report 2022: Aleutian Islands. Stock Assessment and Fishery Evaluation Report. North Pacific Fishery Management Council. Anchorage, Alaska. 138 p.

Piner, K.R., and Wischnioski, S.G. 2004. Pacific halibut chronology of bomb radiocarbon in otoliths from 1944 to 1981 and a validation of ageing methods. Journal of Fish Biology **64**: 1060-1071.

Planas, J. 2023. Report on current and future biological and ecosystem science research activities. IPHC-2023-AM099-12.

Seitz, A.C., Farrugia, T.J., Norcross, B.L., Loher, T., and Nielsen, J.L. 2017. Basin-scale reproductive segregation of Pacific halibut (Hippoglossus stenolepis). Fisheries Management and Ecology **24**(4): 339-346. doi:10.1111/fme.12233.

Siddon, E. 2022. Ecosystem Status Report 2022: Eastern Bering Sea. Stock Assessment and Fishery Evaluation Report. North Pacific Fishery Management Council. Anchorage, Alaska. 226 p.

Skud, B.E. 1975. Revised estimates of halibut abundance and the Thompson-Burkenroad debate. International Pacific Halibut Commission Scientific Report No. 56. 36 p.

Southward, G.M. 1962. A Method of Calculating Body Lengths from Otolith Measurements for Pacific Halibut and its Application to Portlock-Albatross Grounds Data between 1935 and 1957. Journal of the Fisheries Research Board of Canada **19**(2): 339-362. doi:10.1139/f62-019.

Stewart, I., and Hicks, A. 2019. 2019 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: development. IPHC-2019-SRB014-07. 100 p.

Stewart, I., and Hicks, A. 2022. Development of the 2022 Pacific halibut (*Hippoglossus stenolepis*) stock assessment. IPHC-2022-SRB020-07. 128 p.

Stewart, I., and Hicks, A. 2023. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2022. IPHC-2023-SA-01. 37 p.

Stewart, I.J. 2014. Overview of data sources for the Pacific halibut stock assessment and related analyses. IPHC Report of Assessment and Research Activities 2013. p. 95-168.

Stewart, I.J., Hicks, A.C., and Carpi, P. 2021. Fully subscribed: Evaluating yield trade-offs among fishery sectors utilizing the Pacific halibut resource. Fisheries Research **234**. doi:10.1016/j.fishres.2020.105800.

Thompson, C.H., Dunlop, H.A., and Bell, F.H. 1931. Biological statistics of the Pacific halibut fishery (1) Changes in yield of a standardized unit of gear. International Pacific Halibut Commission Report No. 6. 119 p.

Ualesi, K. 2023. IPHC Fishery-independent-setline-survey (FISS) design and implementation in 2022. IPHC-2023-AM099-08.

Webster, R. 2023a. 2023-25 FISS design evaluation. IPHC-2023-AM099-10.

Webster, R. 2023b. Space-time modelling of survey data. IPHC-2023-AM099-09. 6 p.

Webster, R., and Stewart, I. 2022. Revision of the IPHC length-weight relationship. IPHC-2022-AM098-INF07. 29 p.

Webster, R.A., Clark, W.G., Leaman, B.M., and Forsberg, J.E. 2013. Pacific halibut on the move: a renewed understanding of adult migration from a coastwide tagging study. Canadian Journal of Fisheries and Aquatic Sciences **70**(4): 642-653. doi:10.1139/cjfas-2012-0371.

Webster, R.A., Soderlund, E., Dykstra, C.L., and Stewart, I.J. 2020. Monitoring change in a dynamic environment: spatio-temporal modelling of calibrated data from different types of fisheries surveys of Pacific halibut. Canadian Journal of Fisheries and Aquatic Sciences **77**: 1421-1432.

Wilson, D., Planas, J., Stewart, I., Hicks, A., Hutniczak, B., Webster, R., and Jannot, J. 2023. International Pacific Halibut Commission 5-year program of integrated research and monitoring (2022-26). IPHC-2023-AM099-06. 54 p.