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 serves as an annually updated source for direct evaluation of the data and processing methods employed. For each data source, 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. It is anticipated that some of the information contained in this document will be incrementally replaced by IPHC website content (https://www.iphc.int/data/iphc-secretariat-data), to be updated routinely in order to provide more interactive and timely access to the information produced here only once per calendar year.

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 latter includes some comment on avenues for additional data collection and/or analysis. The stock assessment is provided separately as document **IPHC-2019-AM095-10**. Mortality projections for 2019, including detailed results by IPHC Regulatory Area are now available through the IPHC's mortality projection tool (https://www.iphc.int/data/projection-tool).

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-2019-AM095-07**). In 2018, FISS expansions included Regulatory Areas 2B and 2C (**IPHC-2019-AM095-06**). This expansion represents the fifth in a six-year planned effort to sample all Pacific halibut habitat logistically possible within the 10-400 fathom (fm; 18-732 m) depth range. The time-series of modelled FISS data extends from 1993-2018.

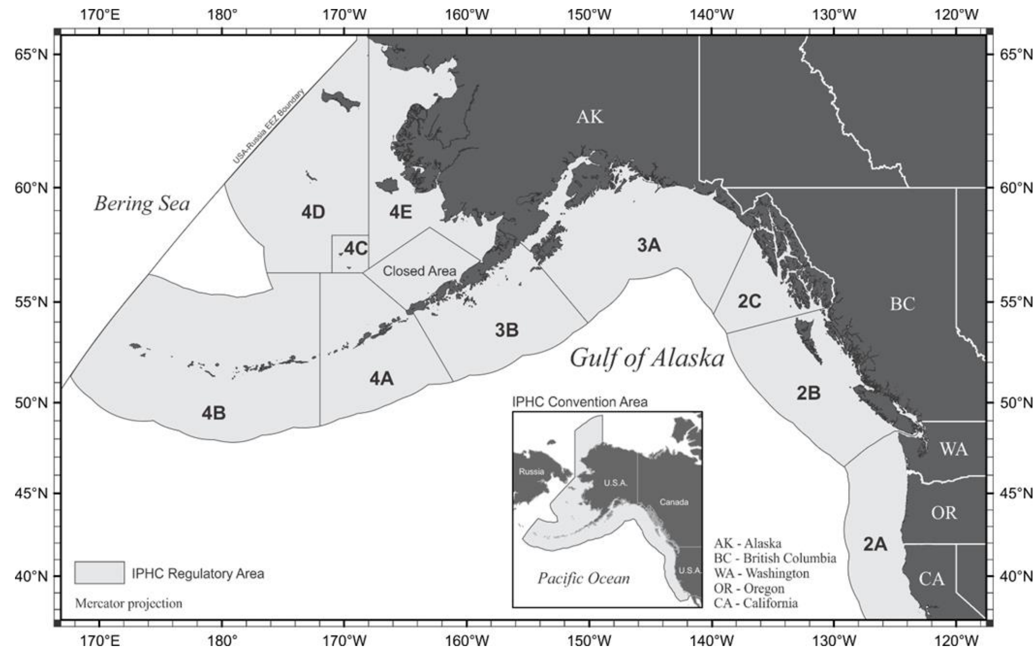


FIGURE 1. IPHC Regulatory Areas and the Pacific halibut geographical range within the territorial waters of Canada and the United States of America.

In addition to their use in supplementing the IPHC setline survey data in IPHC Regulatory Area 4CDE (**IPHC-2019-AM095-07**), 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 IPHC setline survey, 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-2019-AM095-07**). 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

[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

below). Modelled survey NPUE showed a second sequential decrease from 2017 to 2018 (-7% coastwide), with the most pronounced decrease in Biological Region 2 (-15%). Biological Region 4B increased by 6%; however, it remains near the lowest values of the modelled time-series (Figure 2). Individual IPHC Regulatory Areas ranged from a 6% increase (Area 4B), to a 27% decrease (Area 2C), with Areas 2C-4A all showing clear decreases (Figure 3).

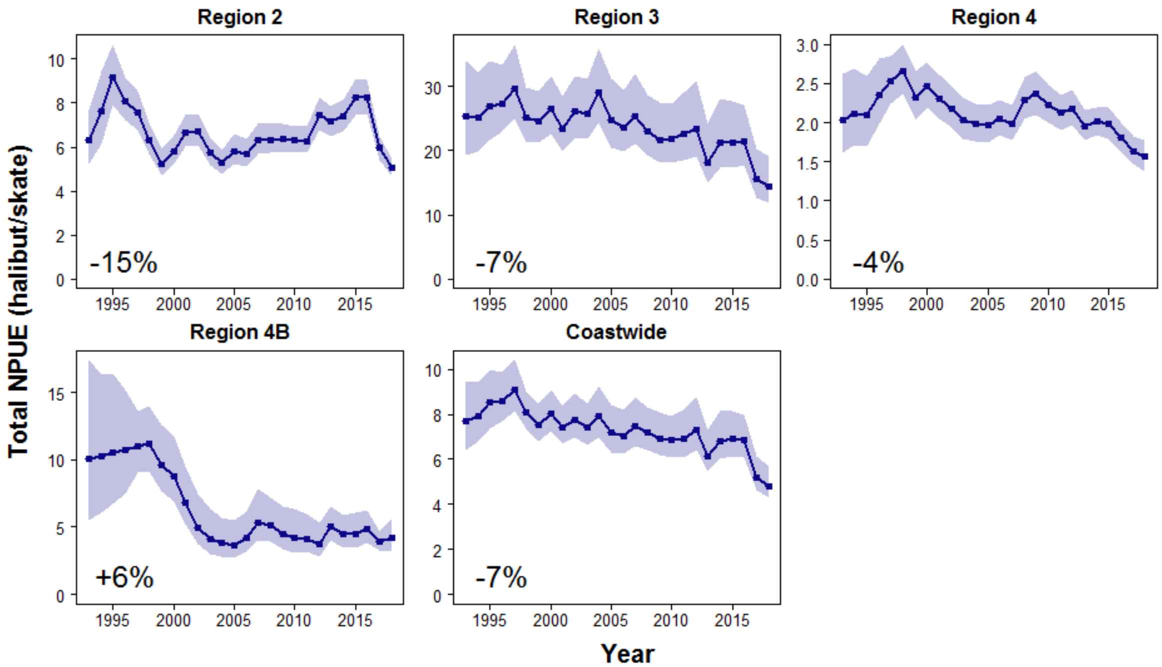


FIGURE 2. Trends in modeled survey NPUE by Biological Region, 1993-2018. Percentages indicate the change from 2017 to 2018. Shaded zones indicate 95% credible intervals.

Modelled survey WPUE (including all sizes of Pacific halibut captured by the FISS) decreased 6% from 2017 to 2018, the lowest value in the time series since 1993 (Figure 4). Biological Region 4B increased 11%, but Regions 2, 3 and 4 all decreased by 11, 5 and 4% respectively. IPHC Regulatory Area 2C showed the largest decrease, 21% from 2017-2018 (Figure 5). Trends in modelled legal-size, above the 32 inch (81.3 cm) minimum size limit (O32) WPUE (Figures 6 and 7) were similar to those for the modelled WPUE of all sizes of Pacific halibut captured by the FISS, but decreases were slightly less pronounced.

Time-series of modelled survey catch rates are provided in **Appendix A**.

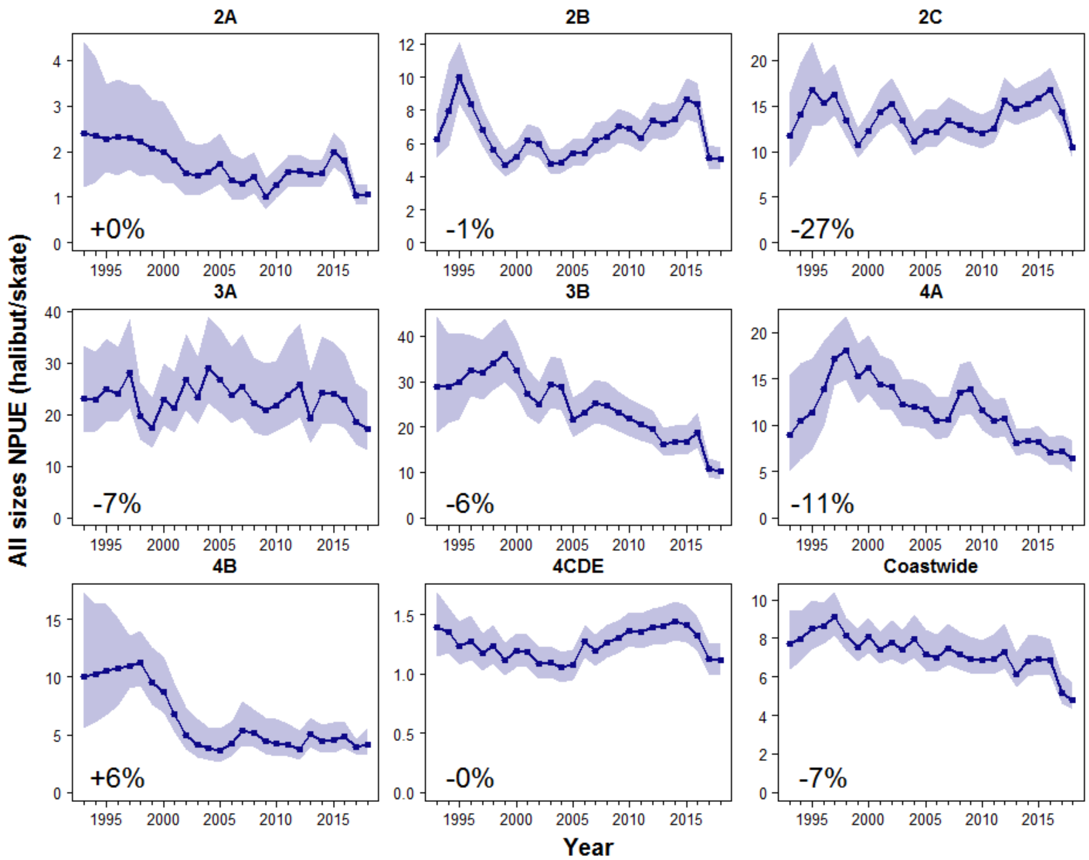


FIGURE 3. Trends in modelled survey NPUE by IPHC Regulatory Area, 1993-2018. Percentages indicate the change from 2017 to 2018. Shaded zones indicate 95% credible intervals.

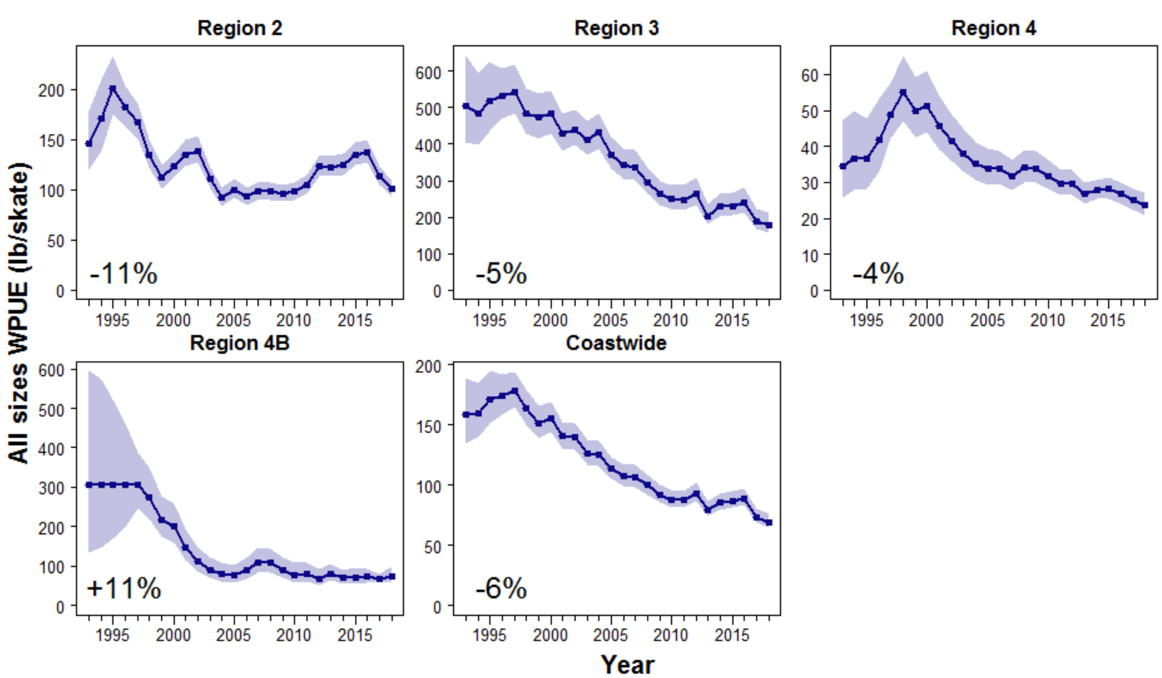


FIGURE 4. Trends in modelled survey WPUE by Biological Region, 1993-2018. Percentages indicate the change from 2017 to 2018. Shaded zones indicate 95% credible intervals.

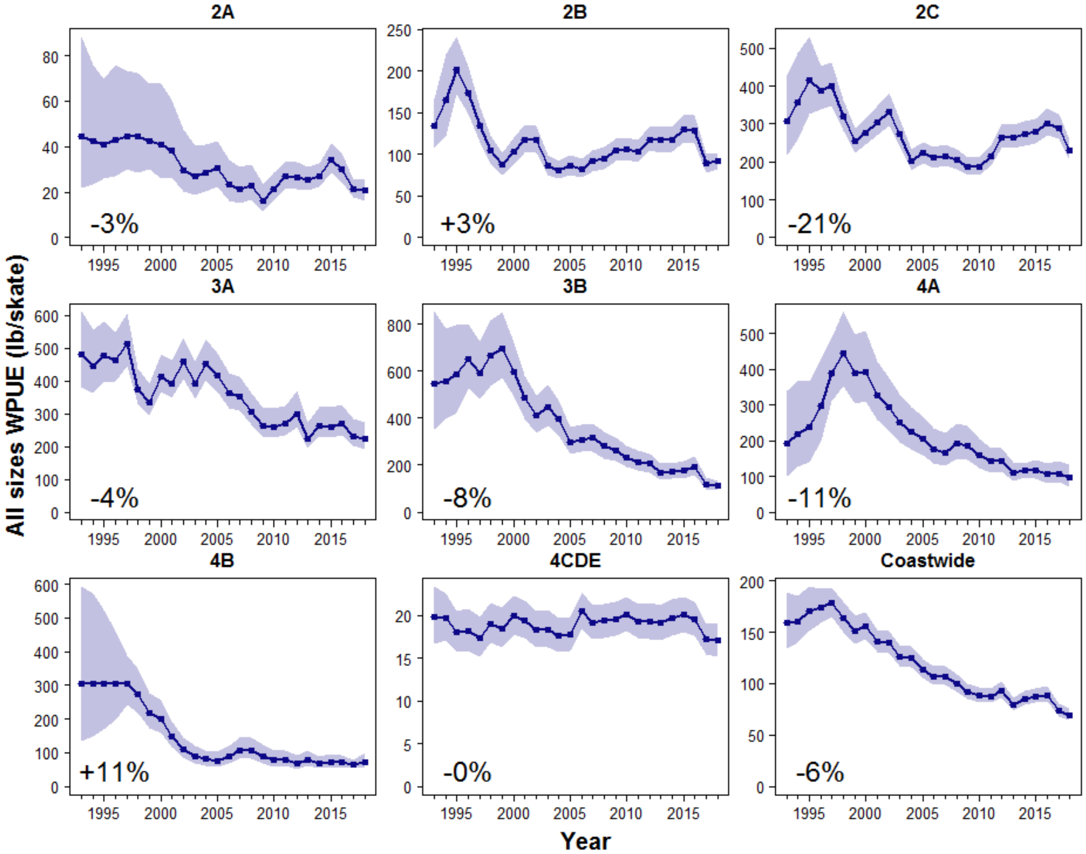


FIGURE 5. Trends in modelled survey legal (O32) WPUE by IPHC Regulatory Area, 1993-2018. Percentages indicate the change from 2017 to 2018. Shaded zones indicate 95% credible intervals.

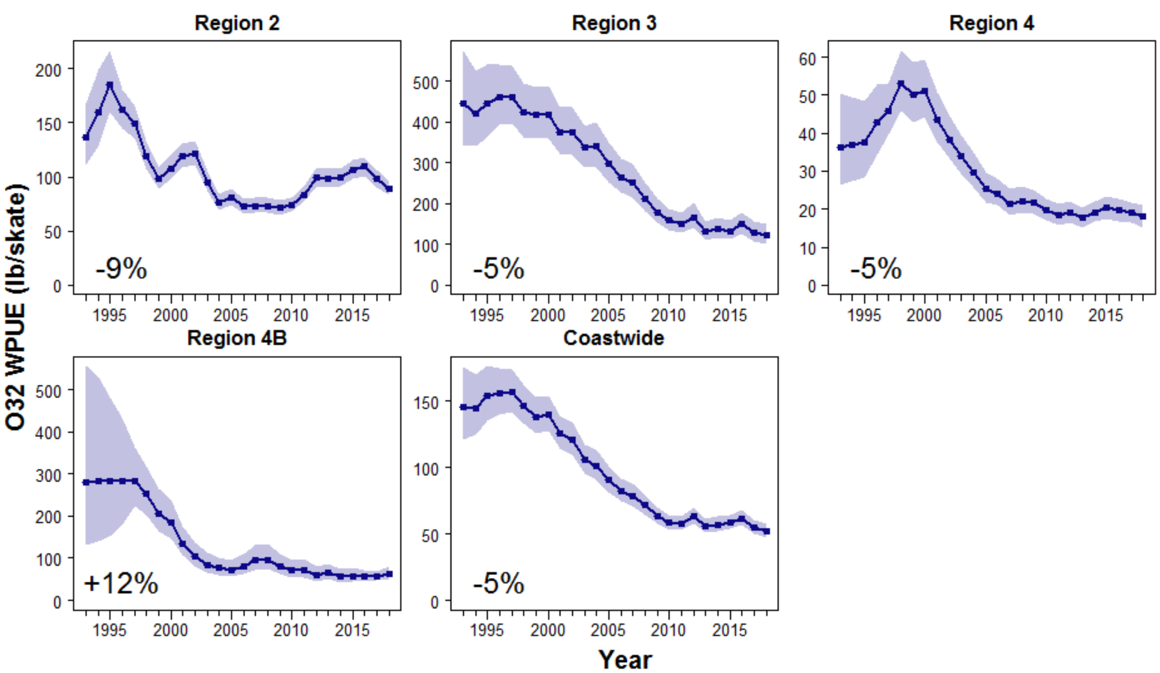


FIGURE 6. Trends in modelled survey legal (O32) WPUE by Biological Region, 1993-2018. Percentages indicate the change from 2017 to 2018. Shaded zones indicate 95% credible intervals.

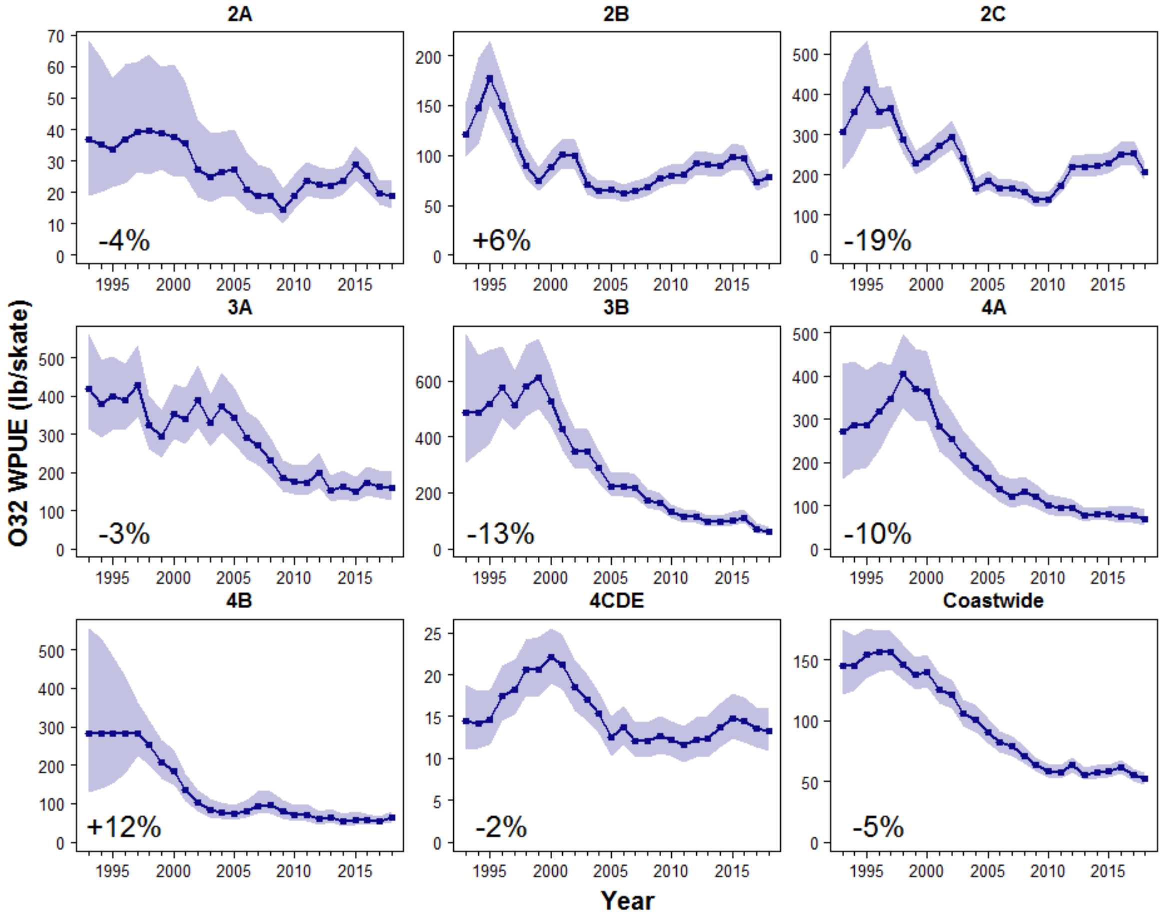


FIGURE 7. Trends in modelled survey legal (O32) WPUE by IPHC Regulatory Area, 1993-2018. Percentages indicate the change from 2017 to 2018. Shaded zones indicate 95% credible intervals.

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. Trends over the last five years indicate that population distribution has been relatively stable with 2018 estimates inside or close to the credible intervals for recent years (Figure 8). The FISS expansion in 2018 (**IPHC-2019-AM095-06**) scaled down the estimates for the entire time-series for Region 2 relative to those produced in 2017 and previously (**IPHC-2019-AM095-07**), and Region 2 was scaled down further from 2017-18 due to the sharp decrease in modelled survey WPUE in IPHC Regulatory Area 2C in 2018. Over a decadal time-period (FISS data prior to 1993 is insufficient to support modelling of WPUE or stock distribution) there has been an increasing proportion of the coastwide stock occurring in Biological Region 2 and a decreasing proportion occurring in Region 3. It is unknown to what degree either of these periods corresponds to historical distributions from the mid-1900s or to the average distribution likely to occur in the absence of fishing mortality. 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 reported in **Appendix A**.

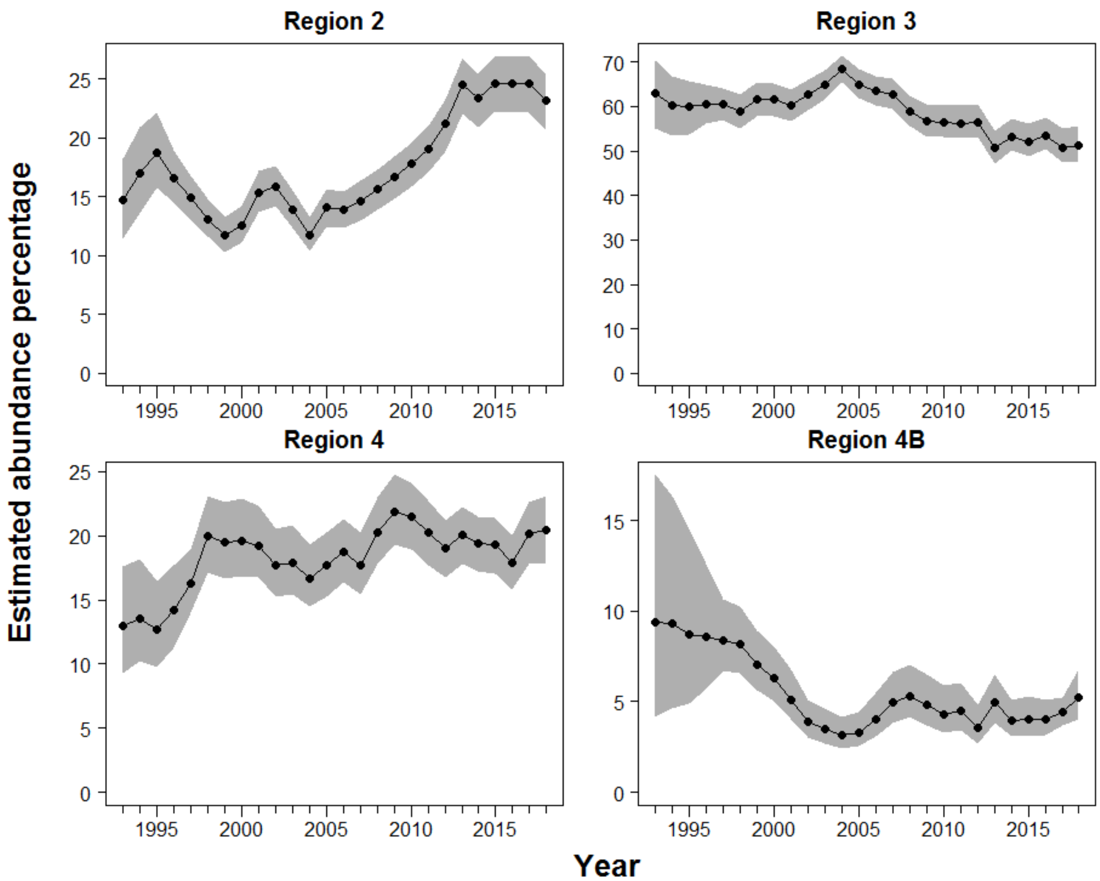


FIGURE 8. Estimated biological stock distribution (1993-2018) from modelled survey WPUE of all sizes of Pacific halibut captured by the FISS. Shaded zones indicate 95% credible intervals.

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 a given regulatory area and year, the raw frequency of ages is an appropriate 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-13 Pacific halibut, corresponding to the 2005 cohort, were the most abundant in the 2018 data, although age distributions and sex ratios varied considerably among IPHC Regulatory Areas. Observations of the 2011 and 2012 cohorts (age-6 and age-7 in 2018), were pronounced relative to the historically low contribution of these ages to the FISS catch, increasing the stock assessment estimates (**IPHC-2019-AM095-09**). IPHC Regulatory Area 4CDE has produced a consistently high proportion of female catch in recent surveys (Figure 10)

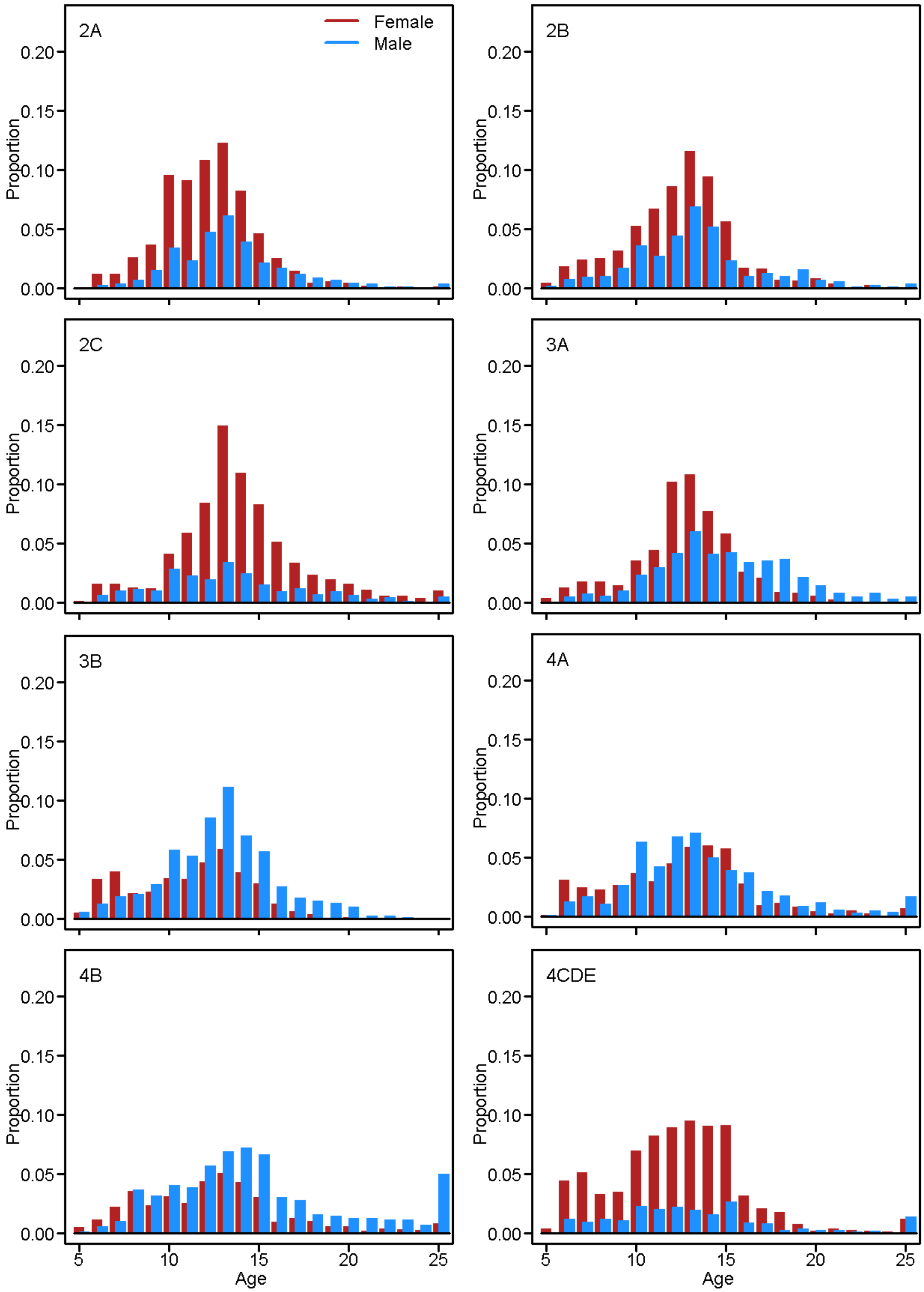


FIGURE 9. Age distributions from the 2018 FISS by IPHC Regulatory Area. Red bars indicate the proportion of females (by number) in the FISS catch, and the blue bars indicate proportions for male Pacific halibut.

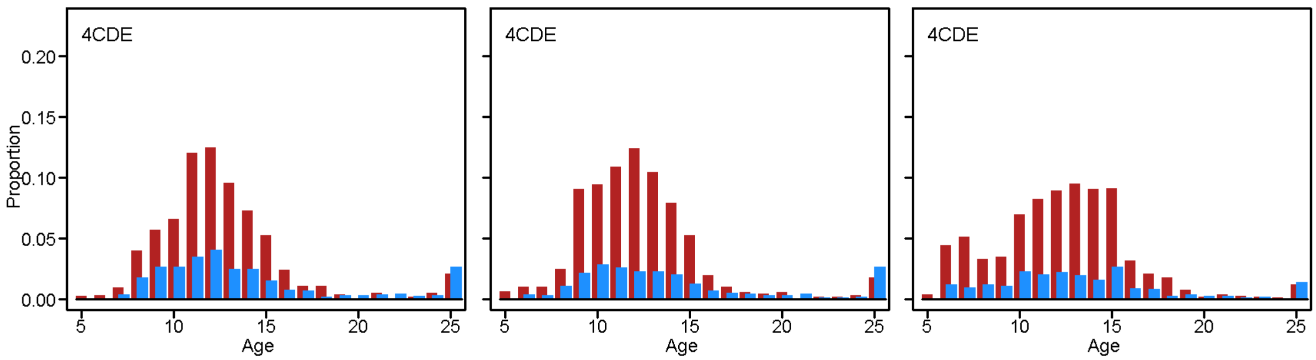


FIGURE 10. Age distributions from the 2016-18 FISS (left to right) for IPHC Regulatory Area 4CDE. Red bars indicate the proportion of females (by number) in the FISS catch, and the blue bars indicate proportions for male Pacific halibut.

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 11). 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 an increasing importance the 2005 year-class, observed to be age-13 in 2018.

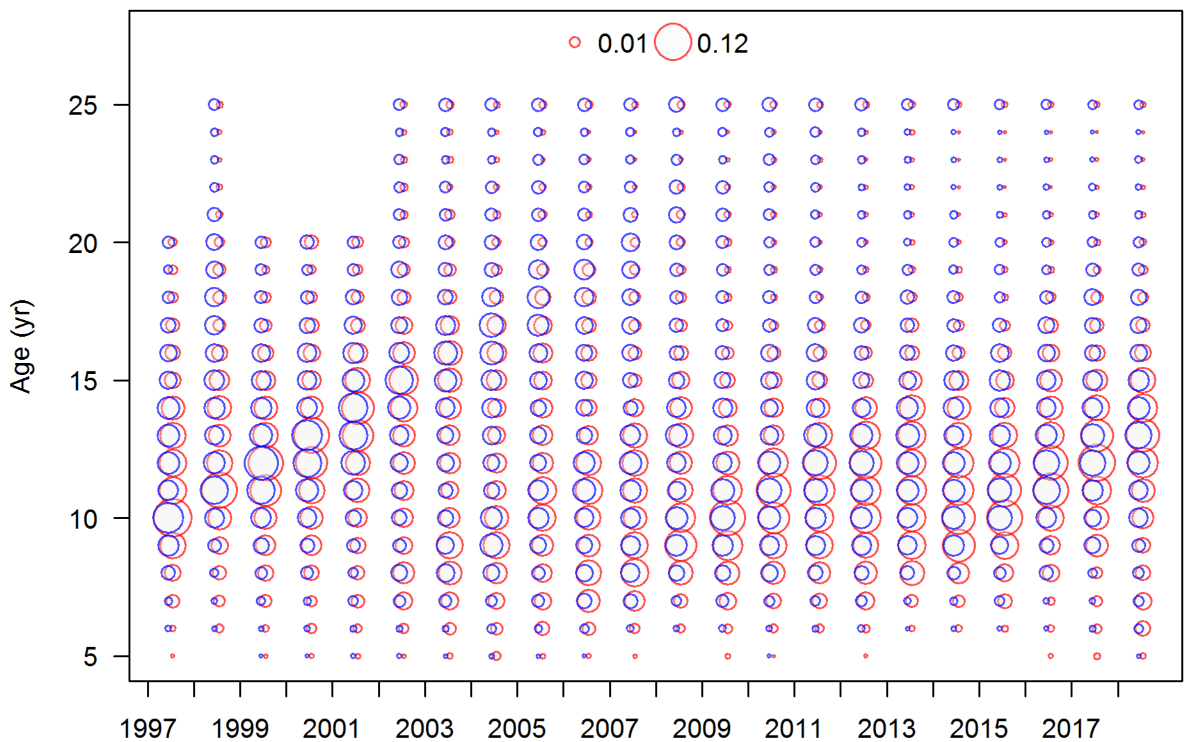


FIGURE 11. Recent coastwide proportions-at-age for females (red circles) and males (blue circles) from the FISS. Proportions sum to 1.0 across both sexes within each year.

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 12-13). 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 13).

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 Martell 2016). 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 14-15). 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.

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.

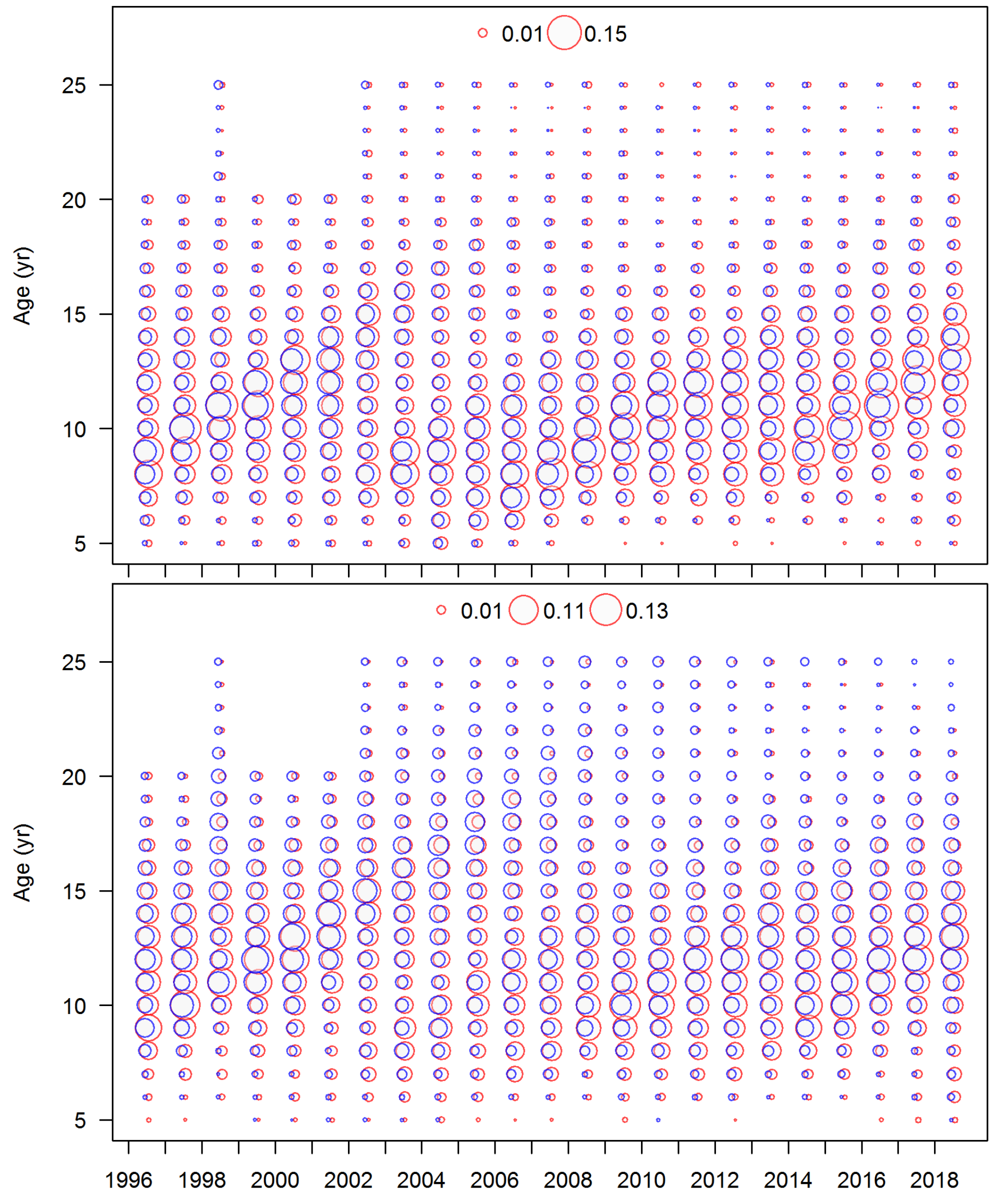


FIGURE 12. Recent proportions-at-age for female (red circles) and male (blue circles) Pacific halibut captured by the FISS from Biological Region 2 (upper panel) and Region 3 (lower panel). Proportions sum to 1.0 across both sexes within each year.

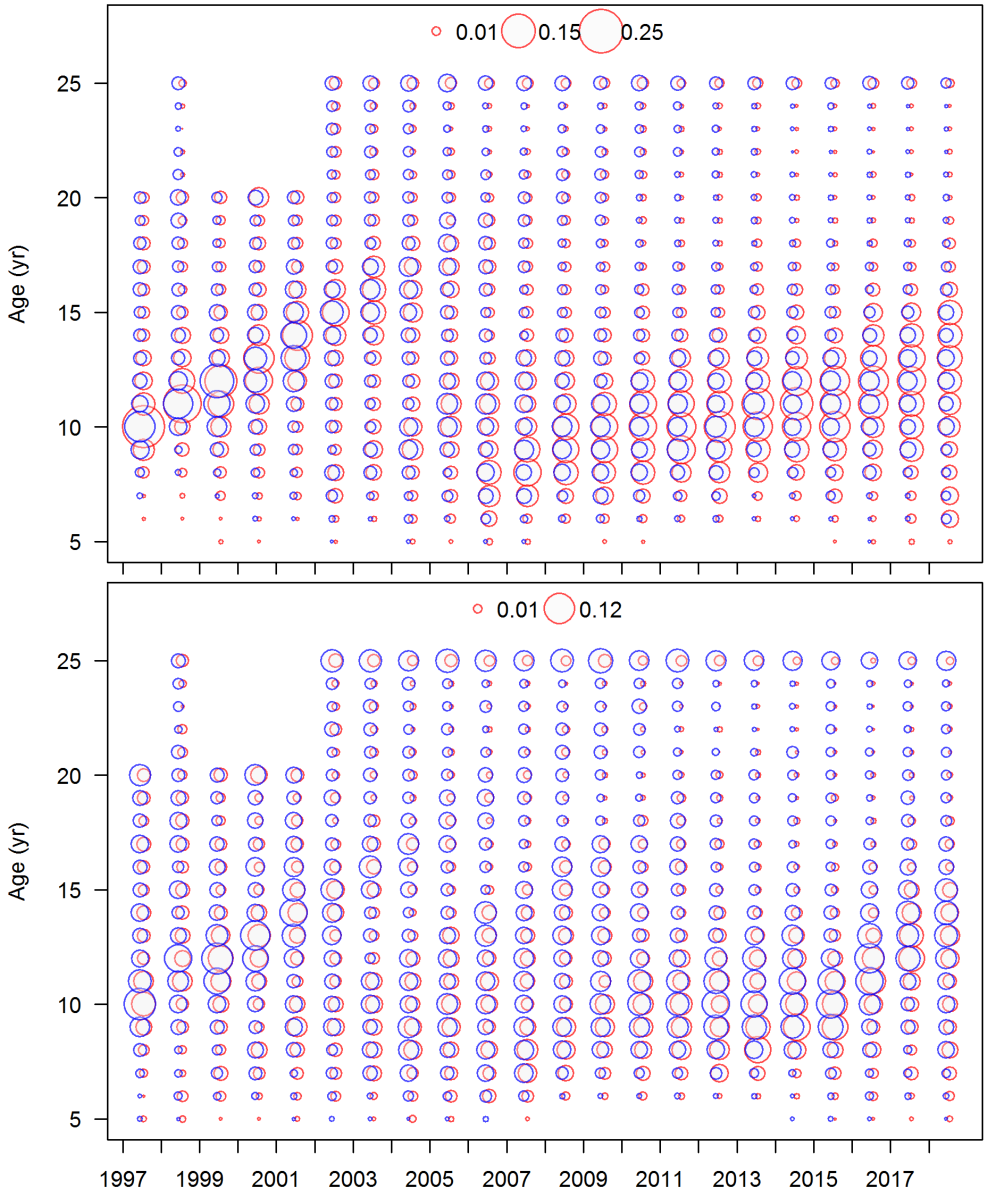


FIGURE 13. Recent proportions-at-age for female (red circles) and male (blue circles) Pacific halibut captured by the FISS from Biological Region 4 (upper panel) and Region 4B (lower panel). Proportions sum to 1.0 across both sexes within each year.

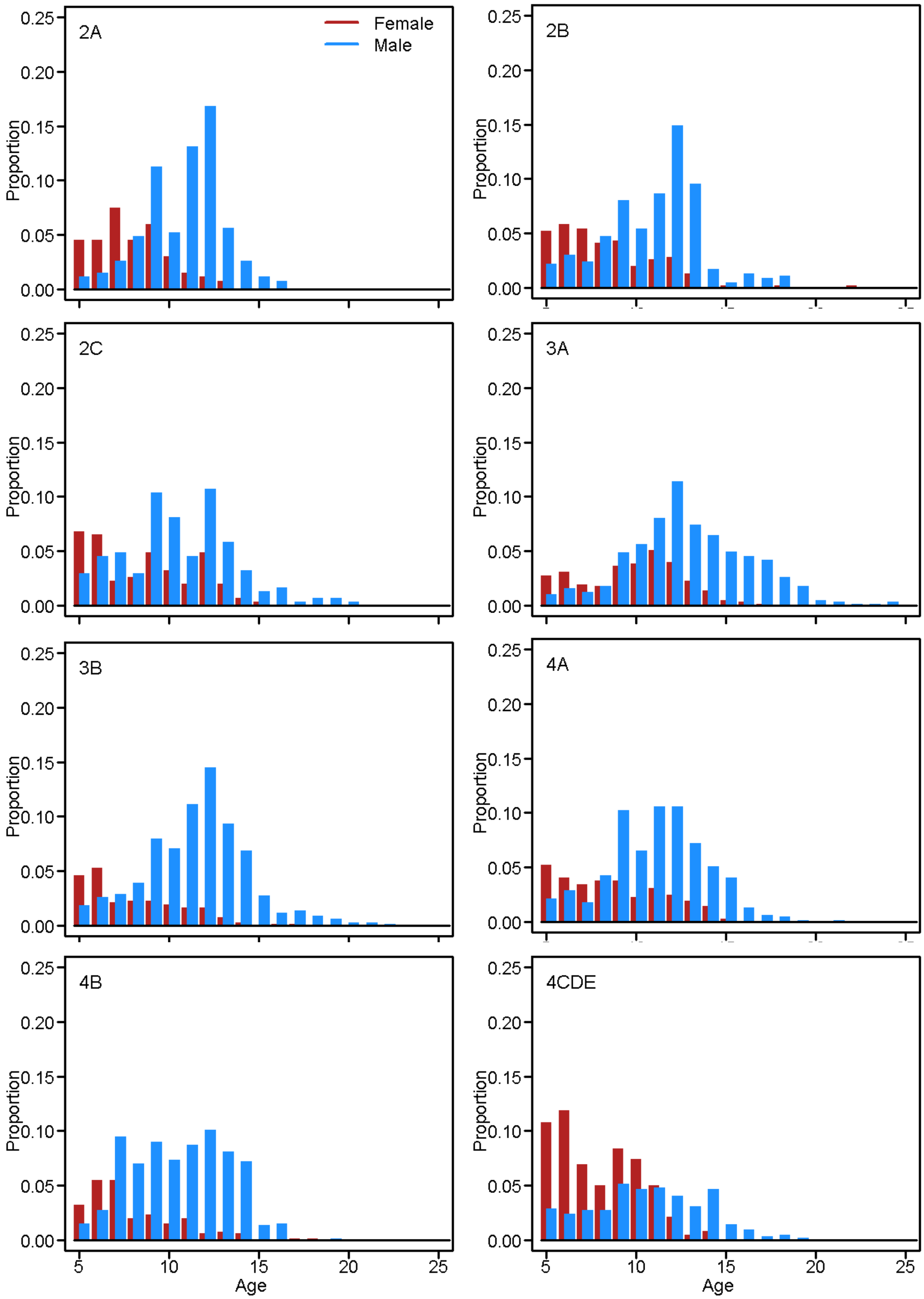


FIGURE 14. Sub-legal (U32) age distributions from the 2018 FISS by IPHC Regulatory Area.

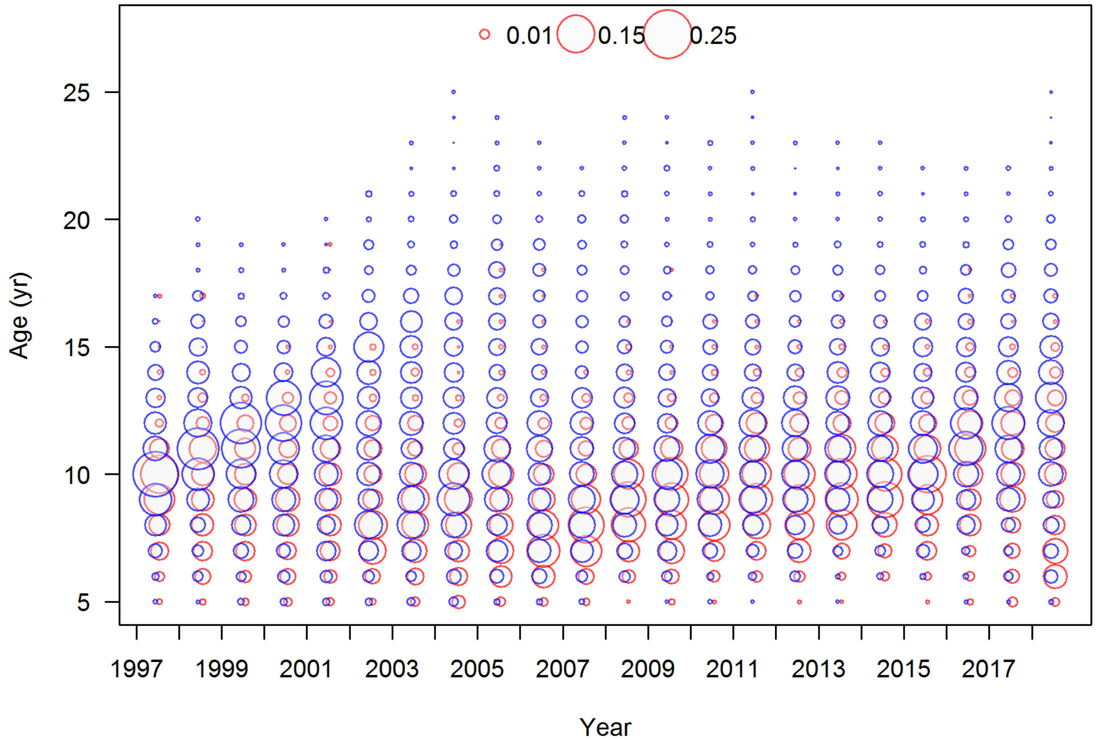


FIGURE 15. Recent coastwide proportions-at-age for sublegal (U32) female (red circles) and male (blue circles) Pacific halibut captured by the FISS. Proportions sum to 1.0 across both sexes within each year.

Because the 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 16); 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 some ages increasing, and others decreasing (Figure 17). 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, and that they differ by Biological Region. Current size-at-age (represented by an 'average' age-12 female Pacific halibut) is estimated to be at or near historical lows for all Biological Regions and coastwide with a considerable drop in in Biological Region 4B over the last decade (Figure 18).

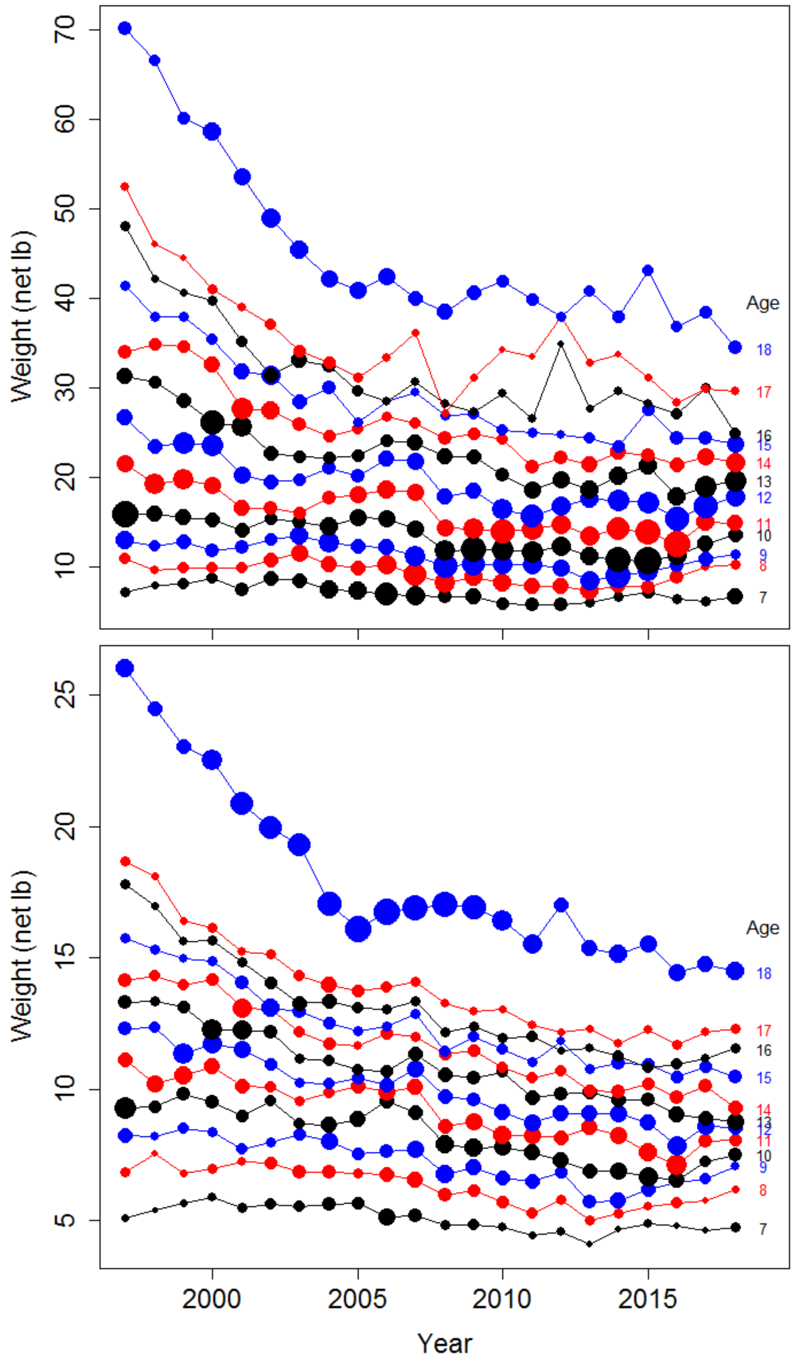


FIGURE 16. Weighted coastwide trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the FISS. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and older, and ages 7 and younger have been aggregated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

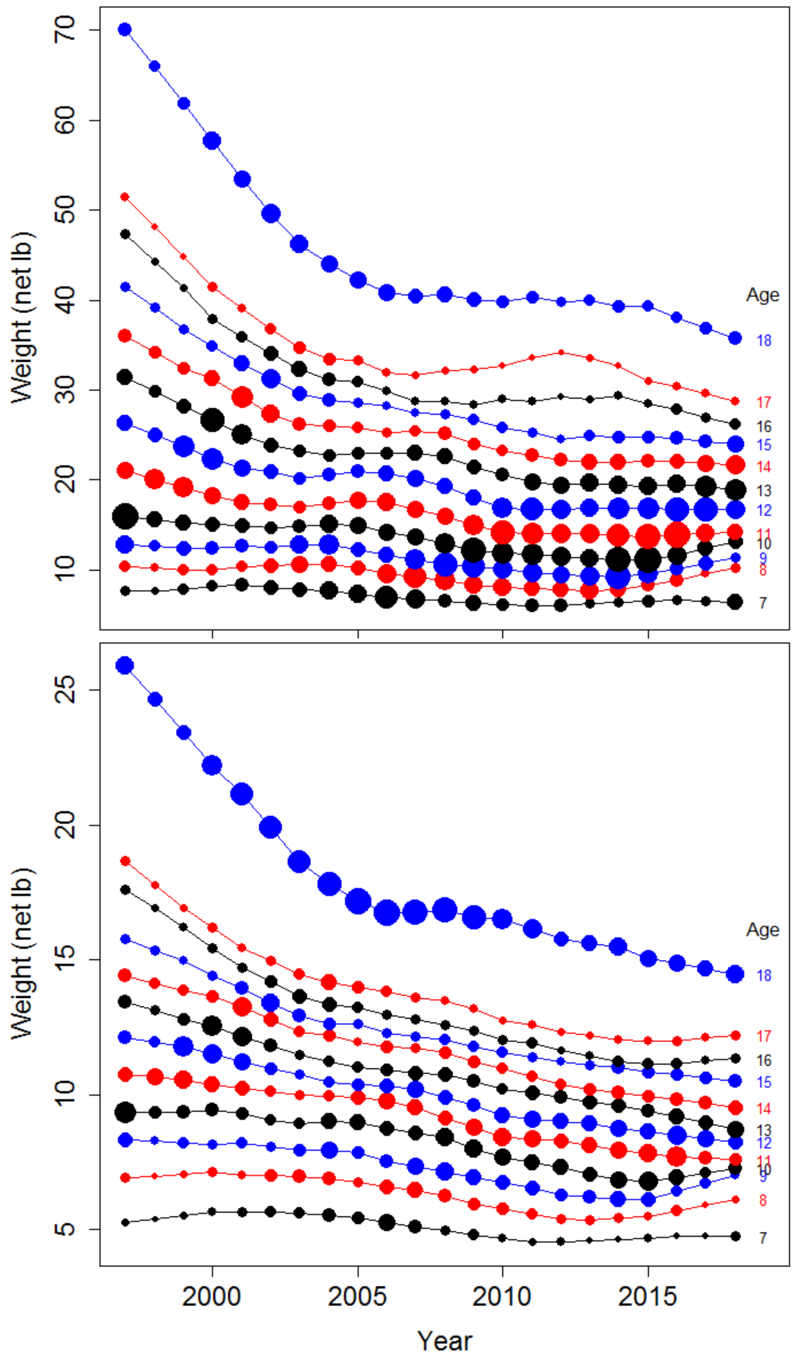


FIGURE 17. Weighted and smoothed recent coastwide trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the FISS. The size (area) of the points is proportional to the number of fish contributing to each observation; ages 18 and older, and ages 7 and younger have been aggregated for clarity.

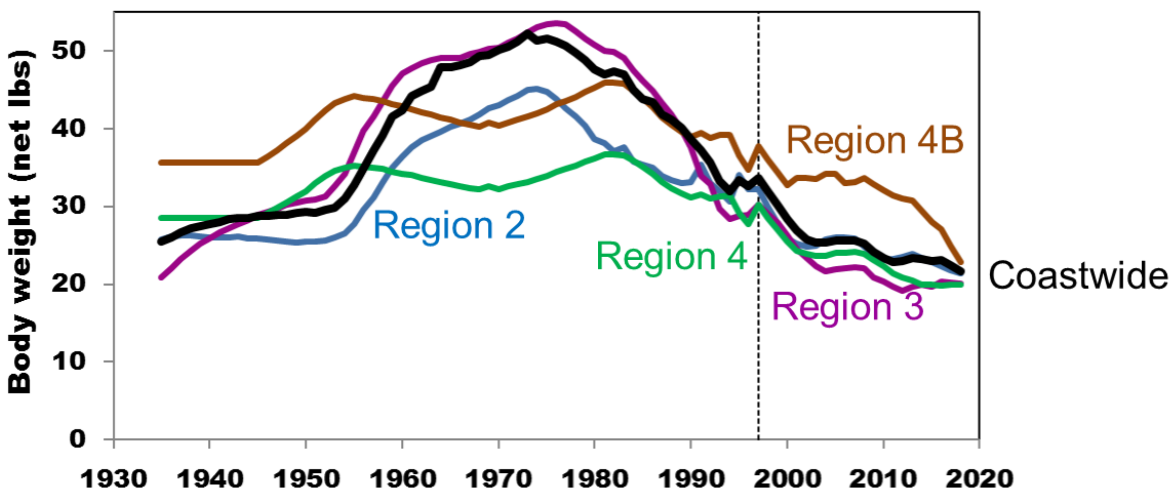


FIGURE 18. Estimated female average weight-at-age 12 trends from FISS and fishery data since 1935.

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 17). 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. Research to collect direct measurements of individual weight during FISS operations for comparison with those from the length-weight relationship are ongoing.

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 19). 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 20). 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.

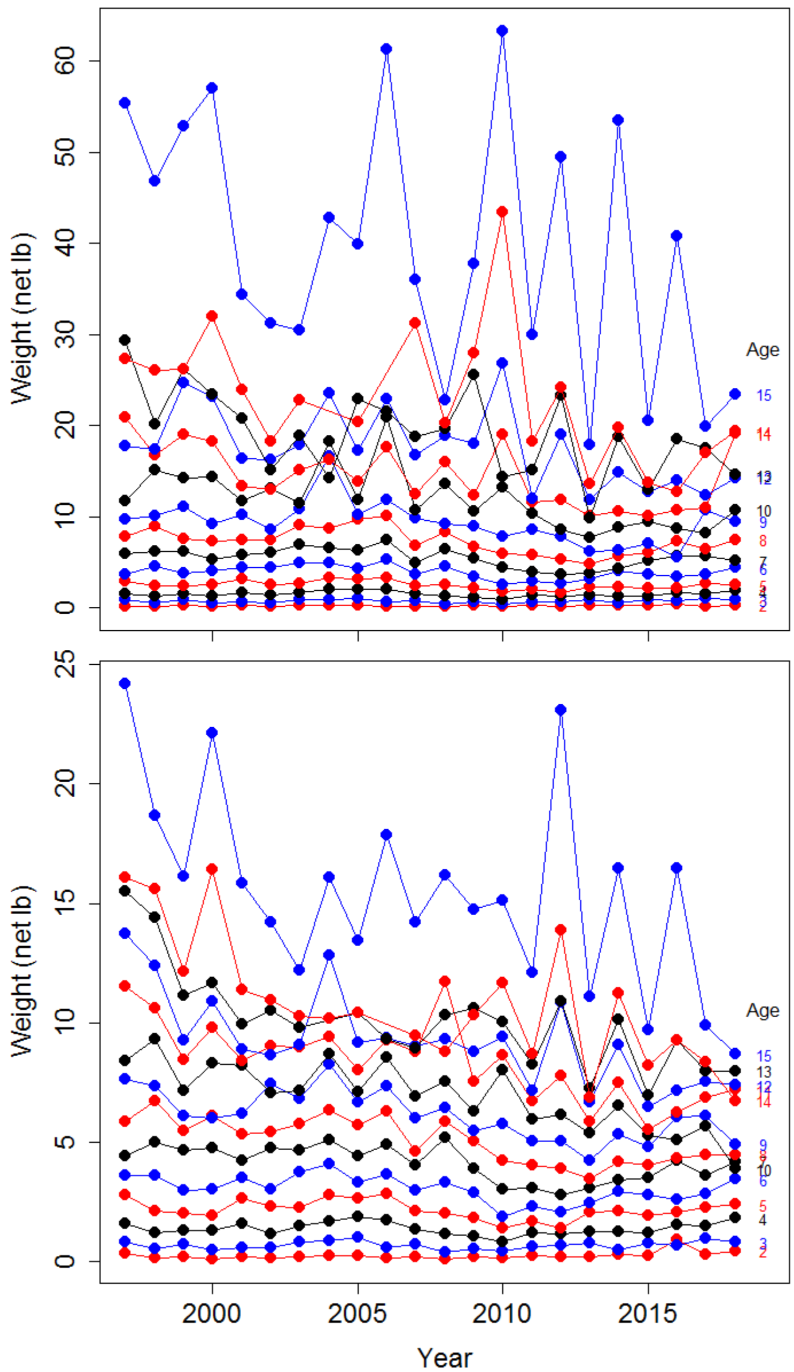


FIGURE 19. Raw trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the NMFS Bering Sea trawl survey. Ages 15 and greater have been aggregated.

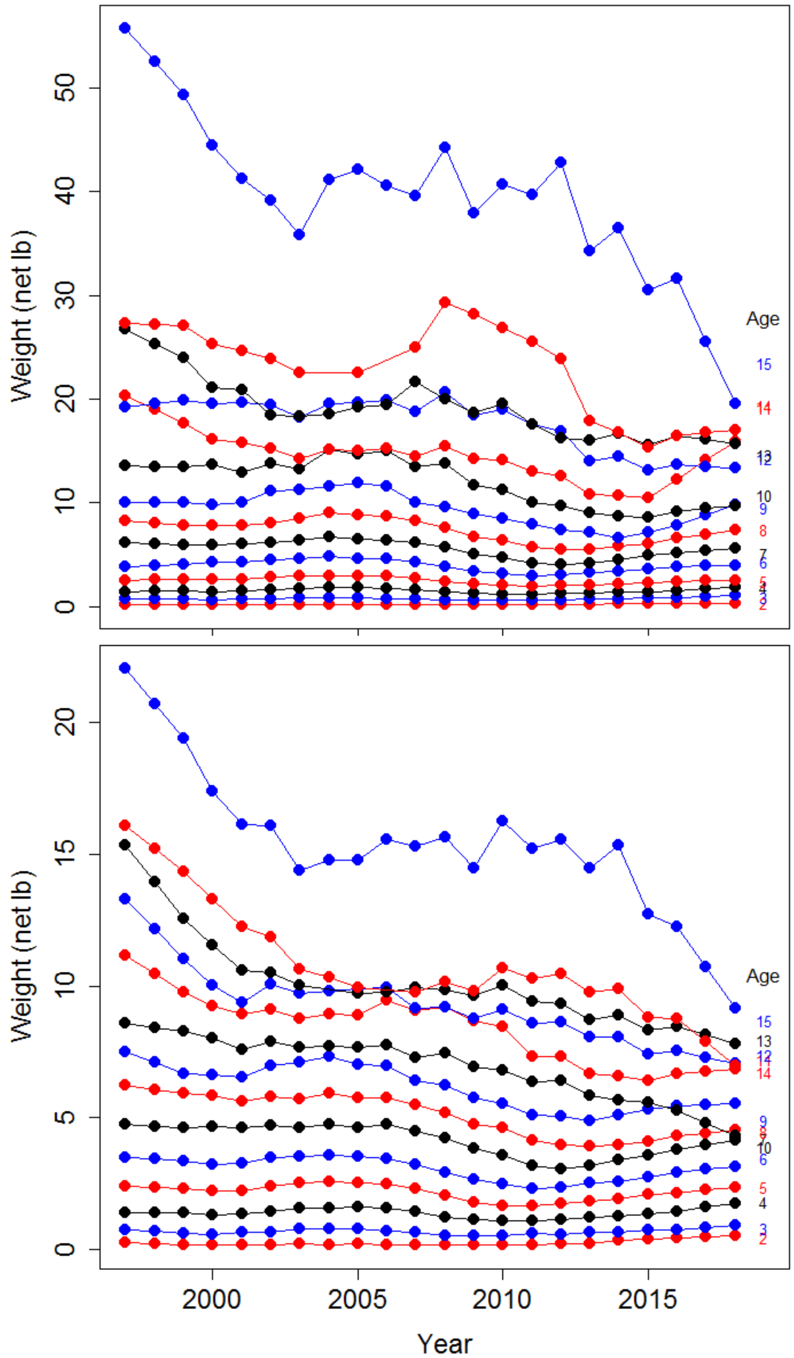


FIGURE 20. Smoothed trends in weight-at-age for female (upper panel), and male (lower panel) Pacific halibut captured by the NMFS Bering Sea trawl survey. Ages 15 and greater have been aggregated.

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 21) must be used to interpret lengths collected in earlier years and 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 22). 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 23), 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. The indications of the 2011 and 2012 cohorts from the FISS ages and other sources may be consistent with these trawl ages; however, the absolute magnitude of the year-classes remains unknown.

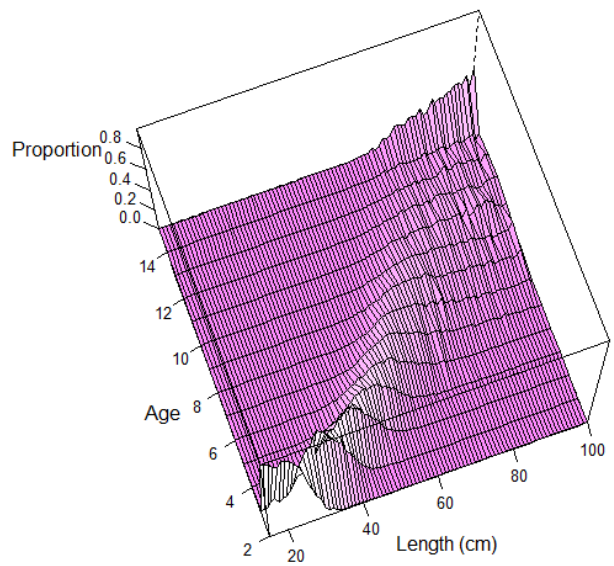


FIGURE 21. Global age-length key created from Pacific halibut captured by NMFS trawl surveys in Alaska. Proportions-at-age sum to 1.0 within each length.

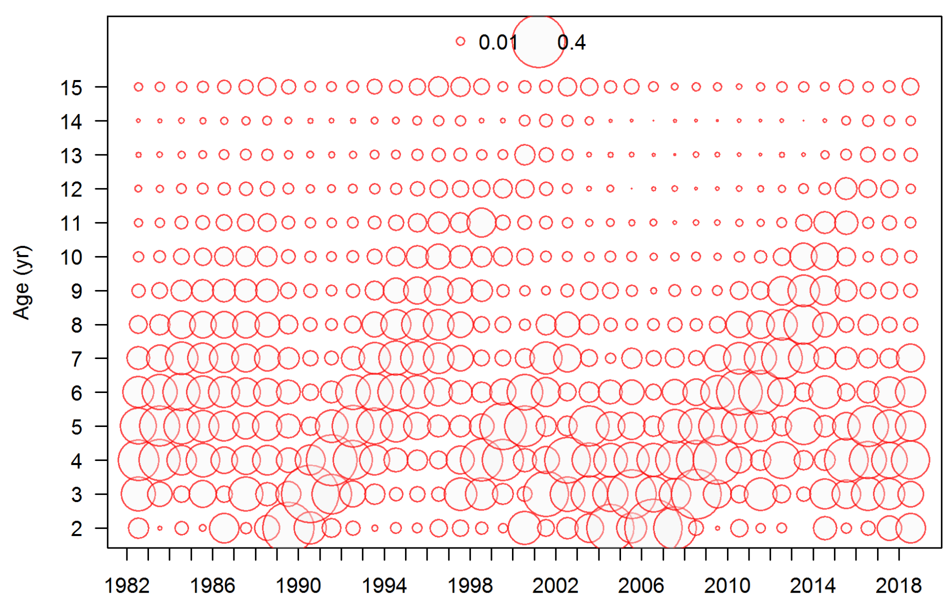


FIGURE 22. Proportions-at-age from the NMFS Bering Sea trawl survey. Ages 15 and greater have been aggregated; proportions sum to 1.0 within each year.

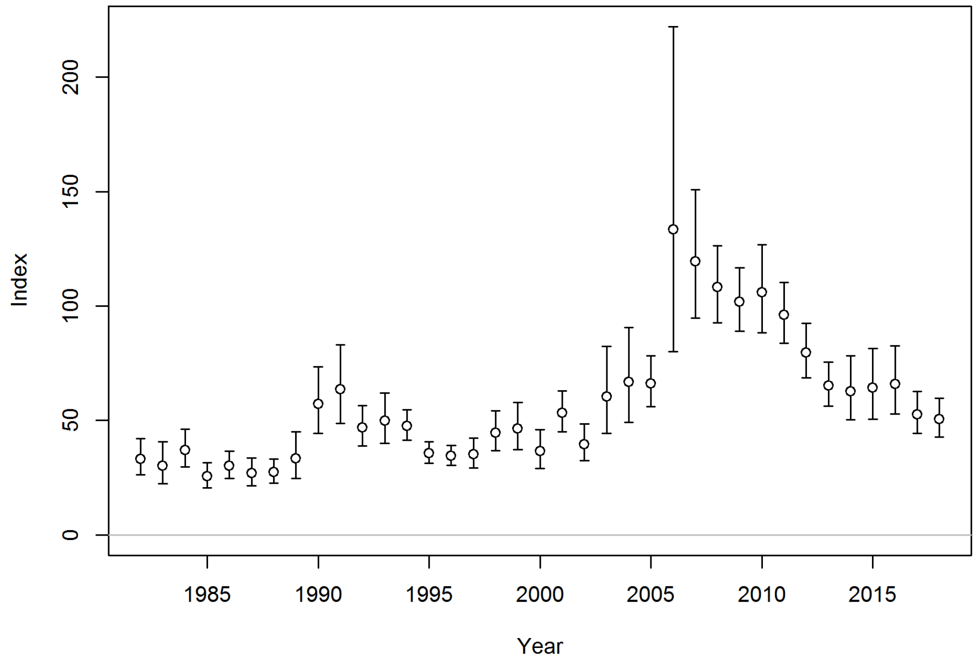


FIGURE 23. Index of abundance (millions) of Pacific halibut from the NMFS Bering Sea trawl survey, 1982-2018.

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, commercial fishery discards (a combination of mainly sub-legal and some legal-sized fish), recreational, subsistence, and bycatch mortality of Pacific halibut in fisheries targeting other species (Figure 24).

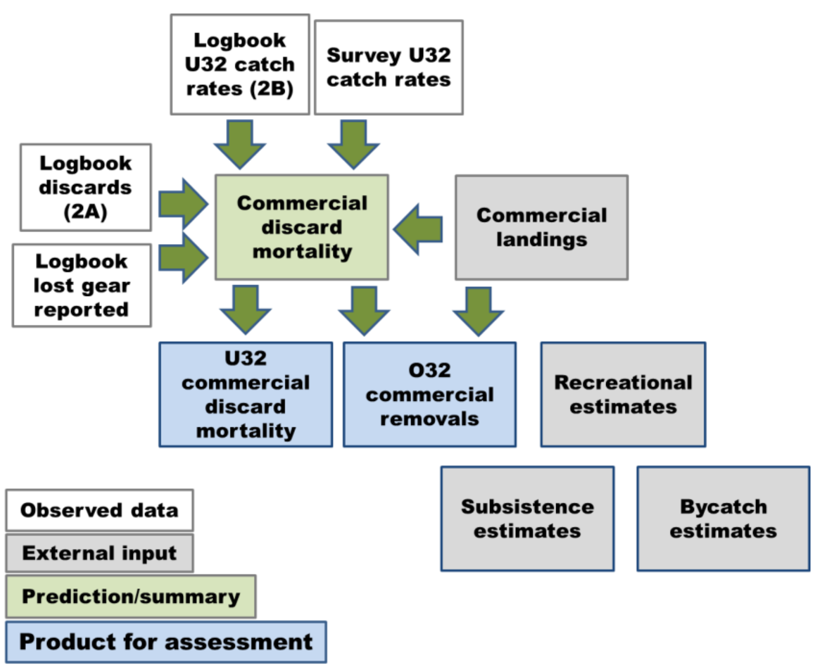


FIGURE 24. Relationships among estimates Pacific halibut mortality by source.

Landings of Pacific halibut from the directed fishery are documented through the use of commercial fish tickets, reported to the IPHC (**IPHC-2019-AM095-05**). From 1981 to the present, these landings are fully delineated by IPHC Regulatory Area (including all of Areas 4A-4CDE; Figure 25). Notably, coastwide fishery landings increased from 2014-17, the first increases since 2003, the decreased in 2018 in response to reduced mortality limits. 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. 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 (Appendix B, Figure 26).

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 27). Catch sharing plans tie the 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).

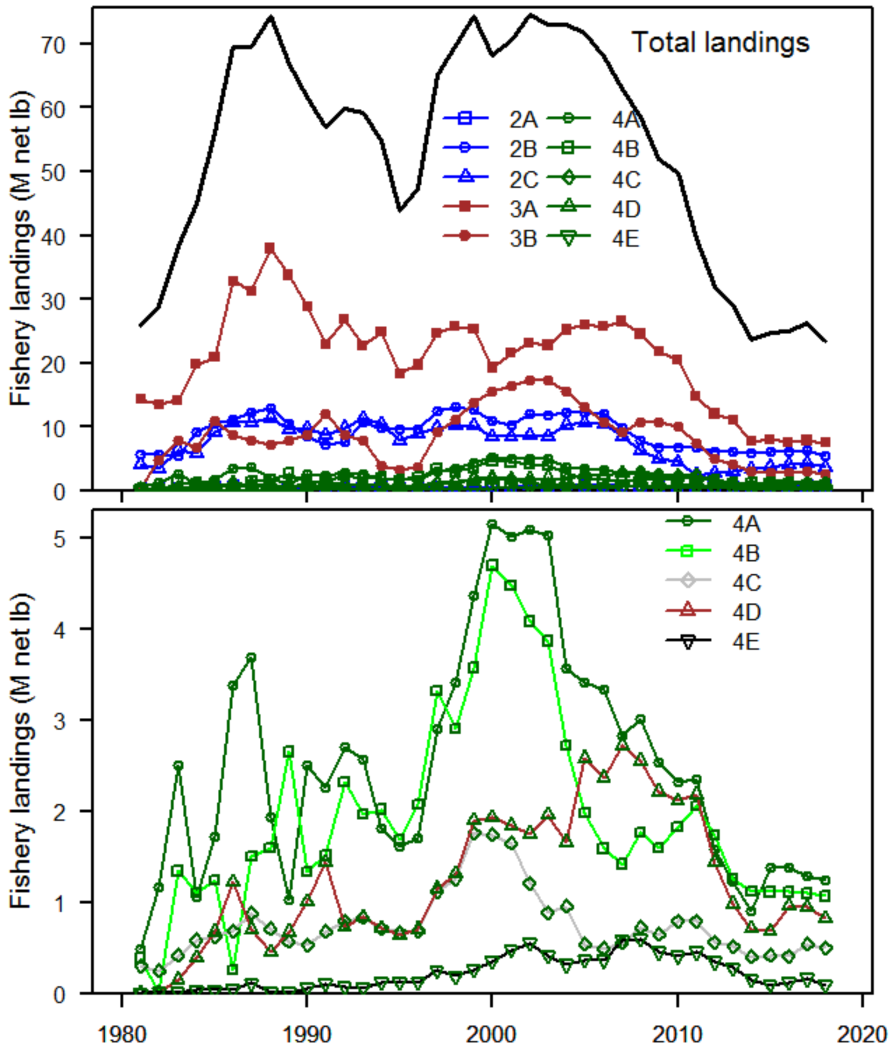
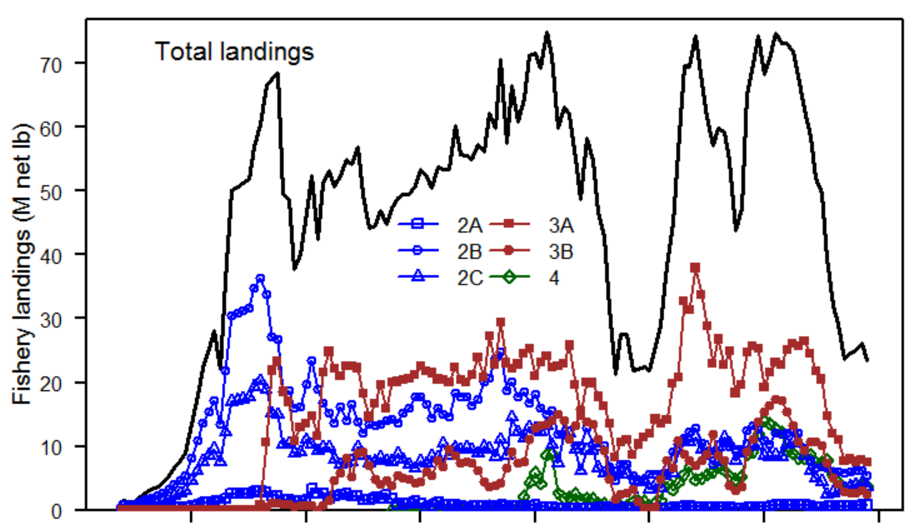


FIGURE 25. Recent landings of Pacific halibut by the directed commercial fishery by IPHC Regulatory Area (upper panel), and among Areas 4A to 4E for better resolution of the trends (lower panel).



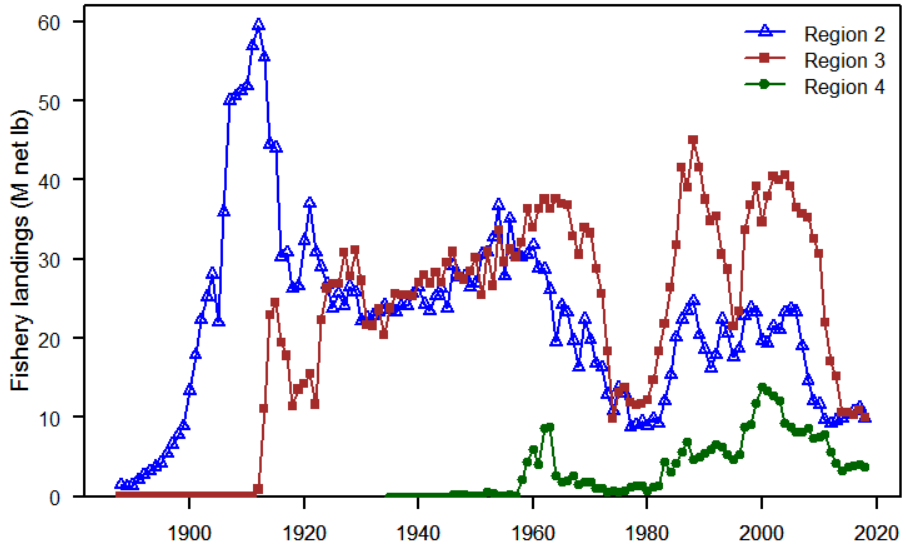


FIGURE 26. Historical landings of Pacific halibut by the directed commercial fishery by IPHC Regulatory Area (upper panel) and Biological Region (lower panel).

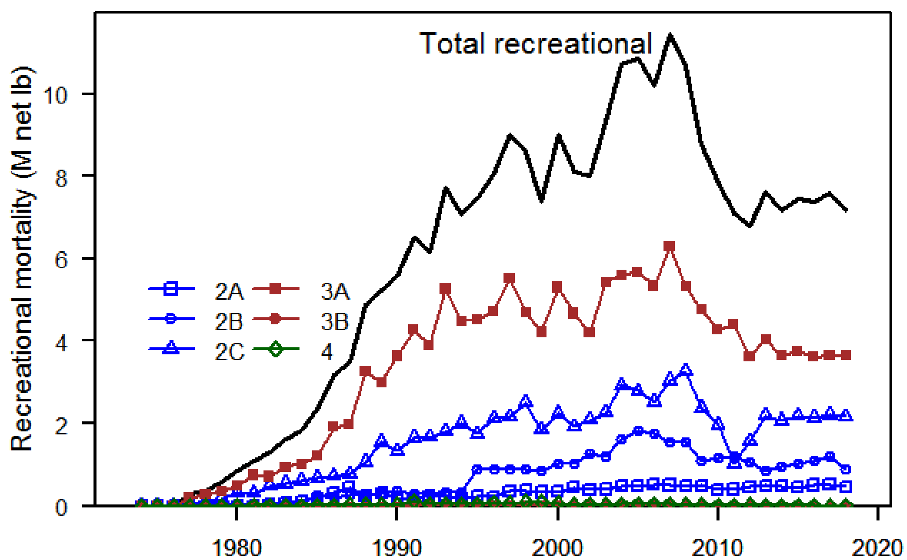


FIGURE 27. Recreational mortality of Pacific halibut by IPHC Regulatory Area.

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 28).

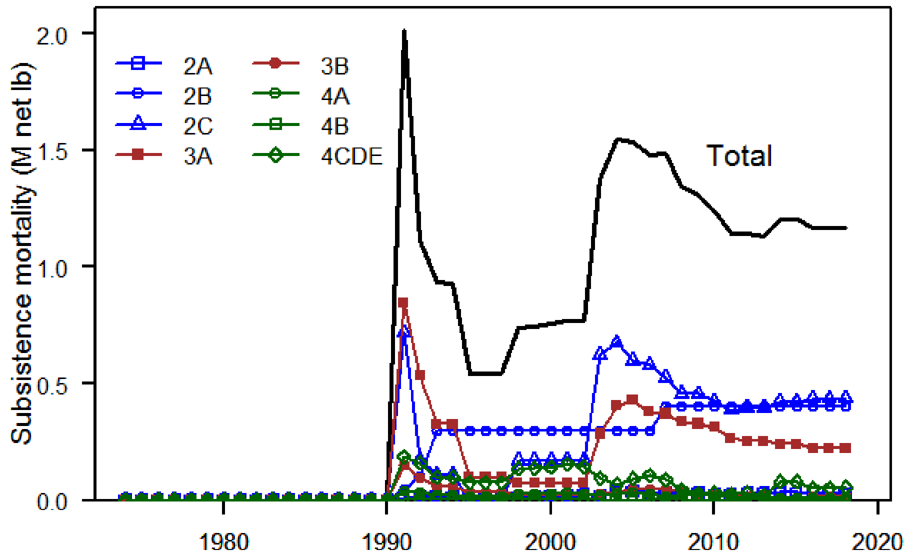


FIGURE 28. Reported subsistence mortality by IPHC Regulatory Area.

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-2019-AM095-05**). 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 29, 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 29, lower panel).

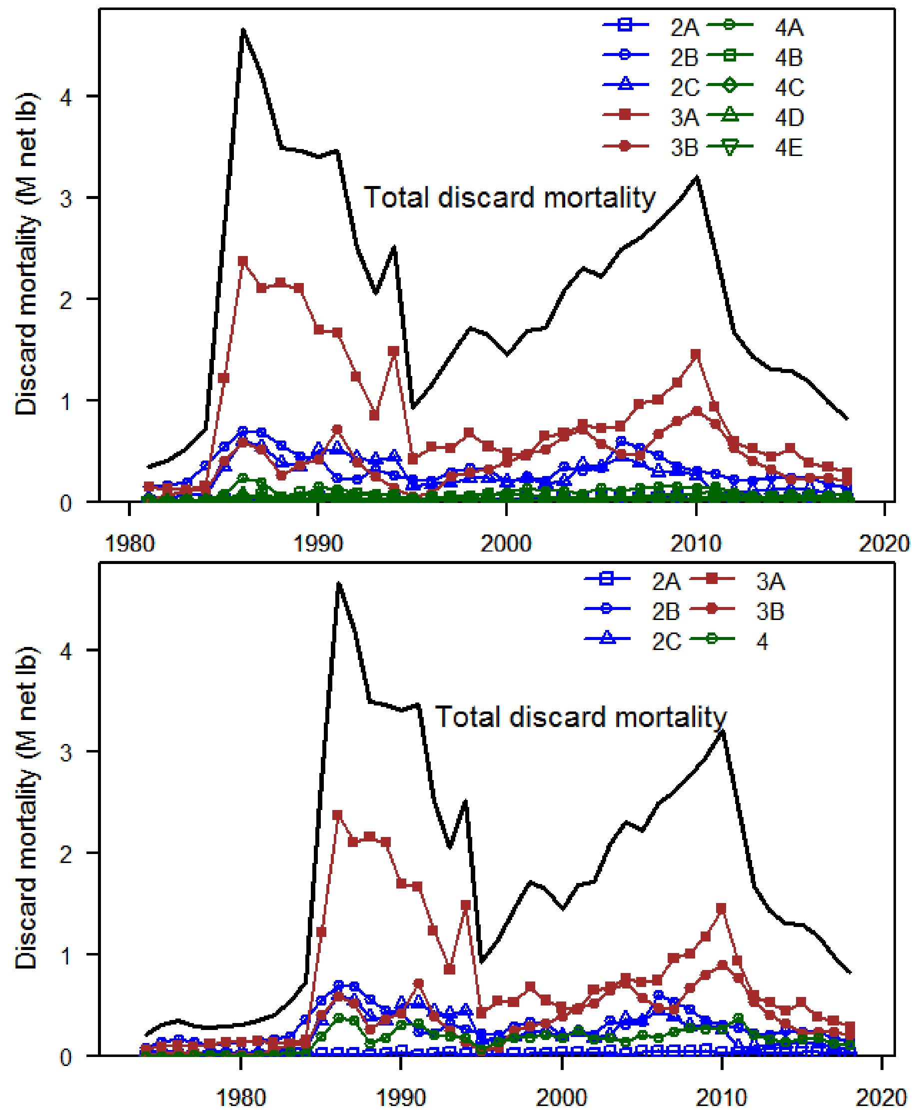


FIGURE 29. Discard mortality in the commercial fishery by IPHC Regulatory Area, 1981+ (upper panel), and 1974+, with Areas 4A-4CDE combined (lower panel).

Bycatch in non-Pacific halibut-target fisheries

The estimated mortality from fisheries where the retention of Pacific halibut is prohibited is termed ‘bycatch’. Mortality by individual IPHC Regulatory Area from these non-halibut-target fisheries is reported to the IPHC by the NMFS and DFO on an annual basis. These estimates vary greatly in quality and precision depending upon year, fishery, type of estimation method, and many other factors. Bycatch 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 6.1 million lbs (~2,750 t) in 2018 (Figure 30, upper panel). This total in 2018 represents the smallest estimate since the beginning of foreign industrial fishing in Alaska in the early 1960s. Bycatch in IPHC Regulatory Areas 4CDE and 3A (the two largest sources coastwide) increased from 2017 to 2018, but were largely offset by a decrease in IPHC Regulatory Area 3B. Prior to 1991, available bycatch 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 bycatch prior to the development of the foreign fishery in U.S. waters in the early 1960s; however, bycatch estimates are only available from 1962 to the present.

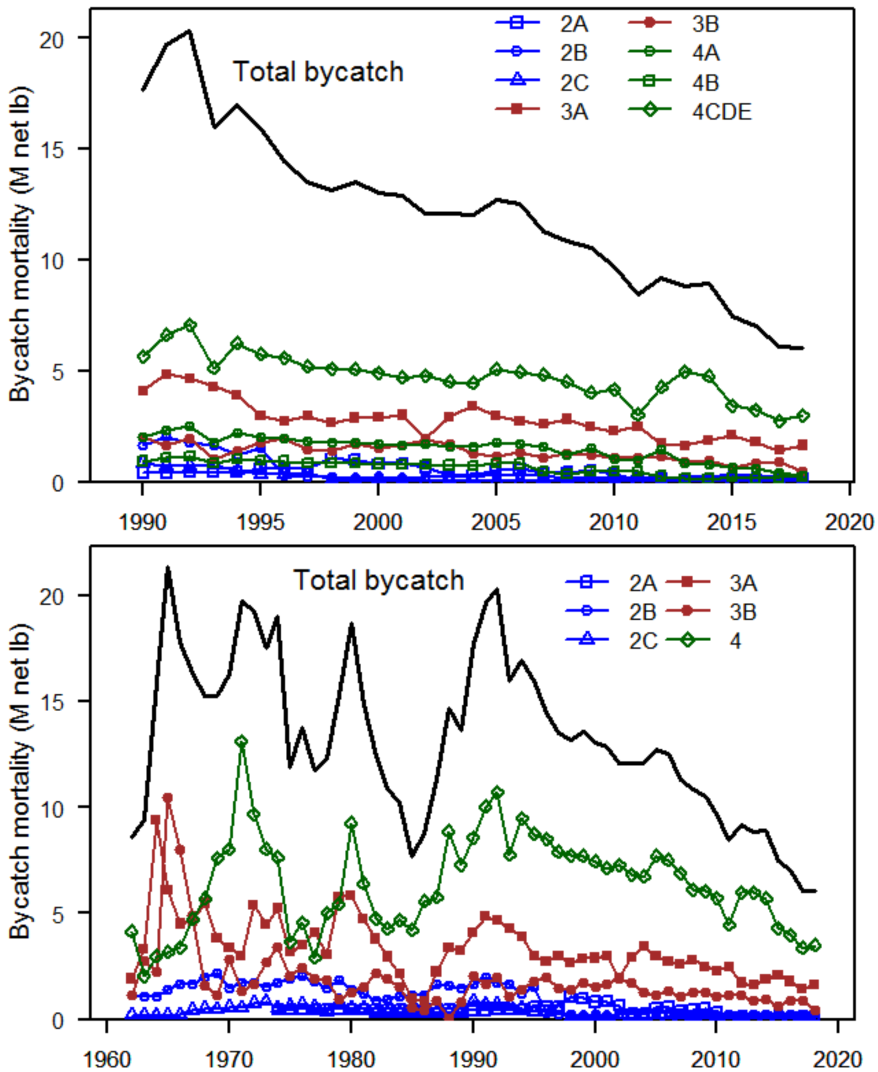


FIGURE 30. Pacific halibut bycatch estimates by IPHC Regulatory Area, 1990+ (upper panel), and 1962+, with Areas 4A-4CDE combined (lower panel).

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 (Figures 31-32). Mortality from all sources in 2018 was estimated to be 38.8 million pounds (~17,570 t), down 8% from 42.0 million pounds in 2017 (~19,050 t). Over the period 1919-2018 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; Appendix B, Figure 33). 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 (Appendix B, Figure 34). When mortality by source is compared among IPHC Regulatory areas, there are differing patterns in both the magnitude and distribution (Figures 35-37).

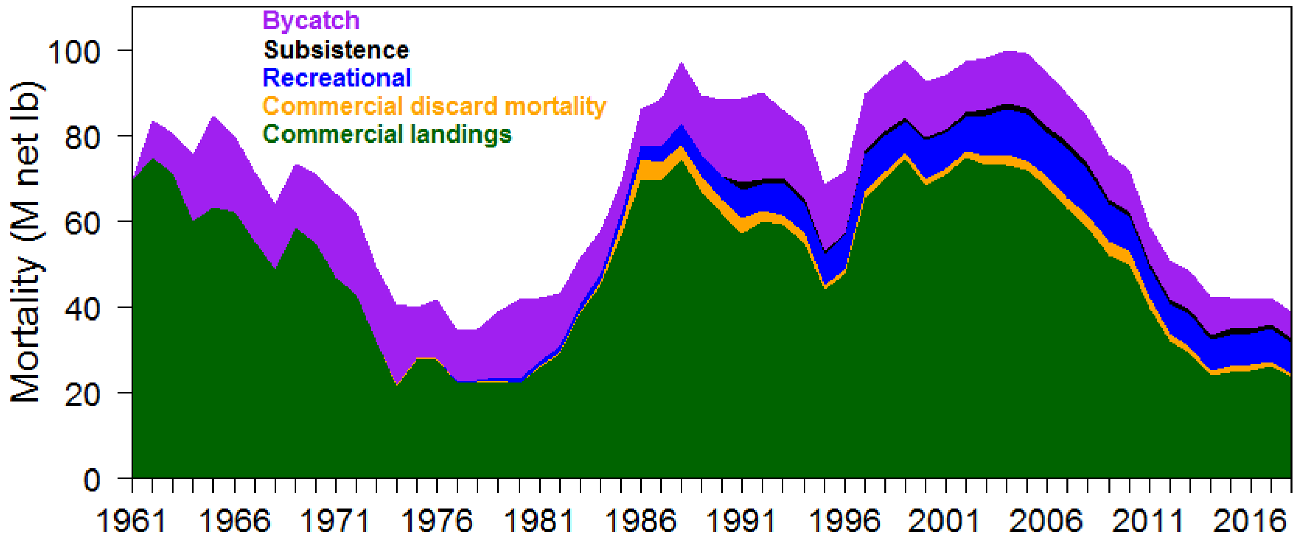


FIGURE 31. Pacific halibut mortality estimates from all sources since 1961.

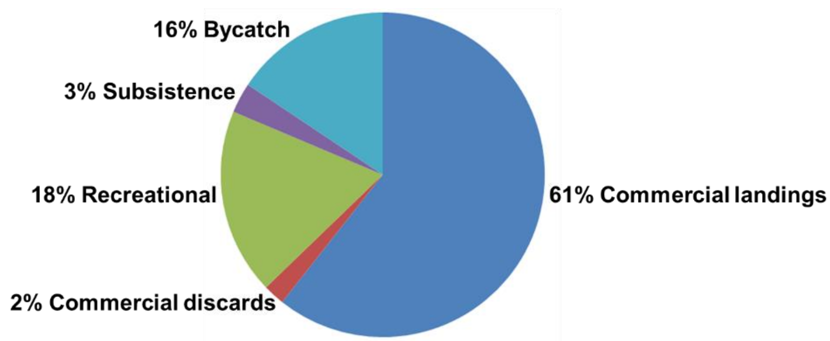


FIGURE 32. Distribution of Pacific halibut mortality by source in 2018.

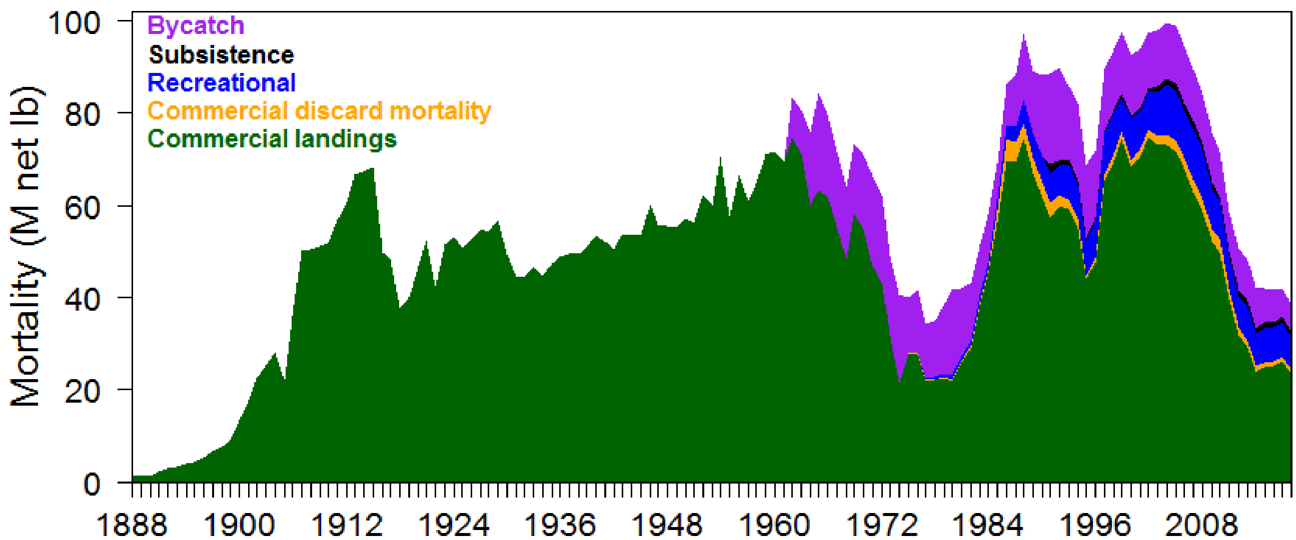


FIGURE 33. Summary of estimated historical mortality by source (colors), 1888-2018.

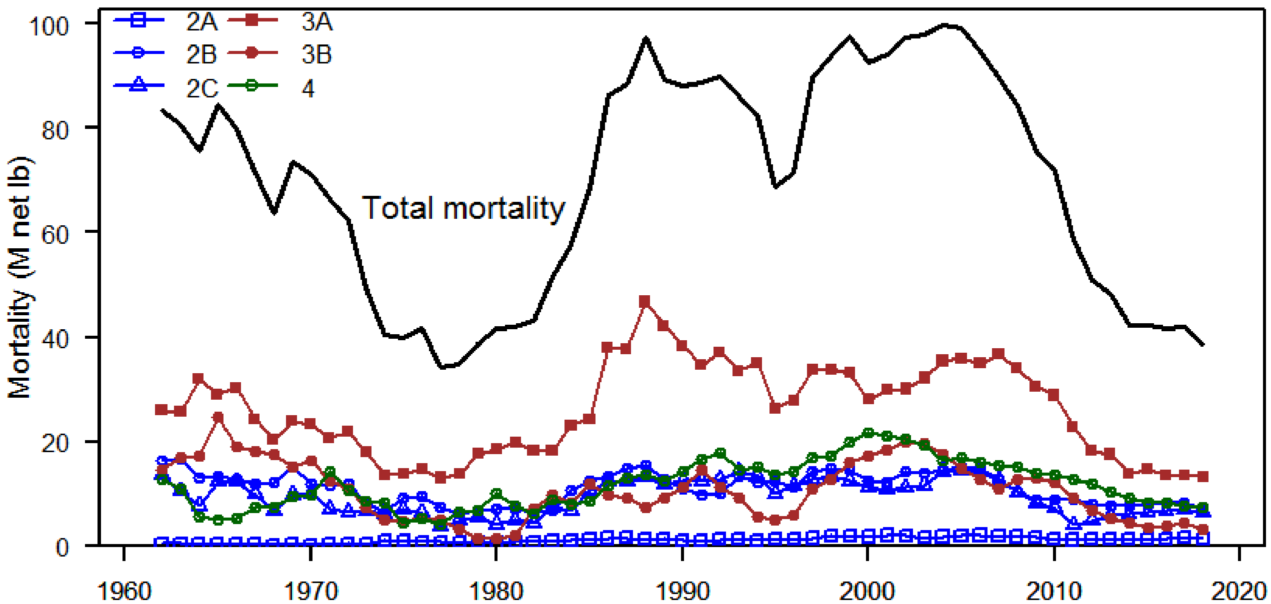


FIGURE 34. Pacific halibut mortality from all sources by IPHC Regulatory Area (Areas 4A-4CDE combined) since 1962.

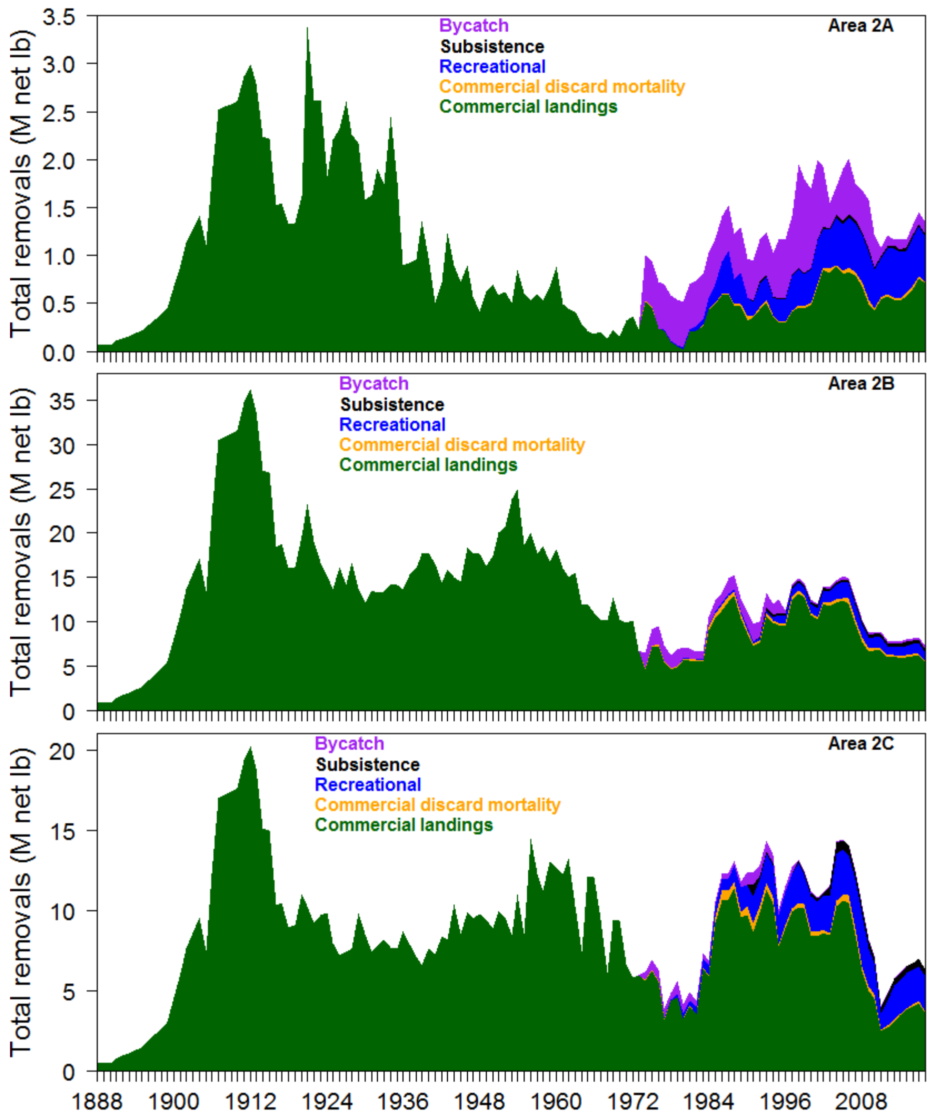


FIGURE 35. Estimated Pacific halibut mortality by source in IPHC Regulatory Areas 2A, 2B, and 2C since 1888. Note that the y-axes differ in scale.

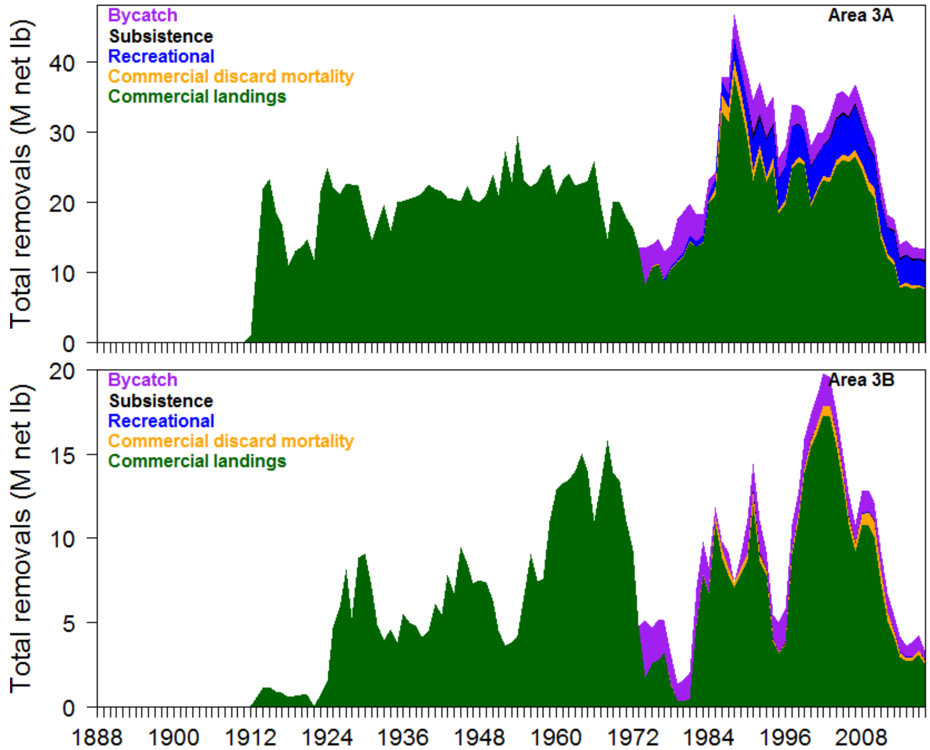


FIGURE 36. Estimated Pacific halibut mortality by source in IPHC Regulatory Areas 3A, and 3B since 1888. Note that the y-axes differ in scale.

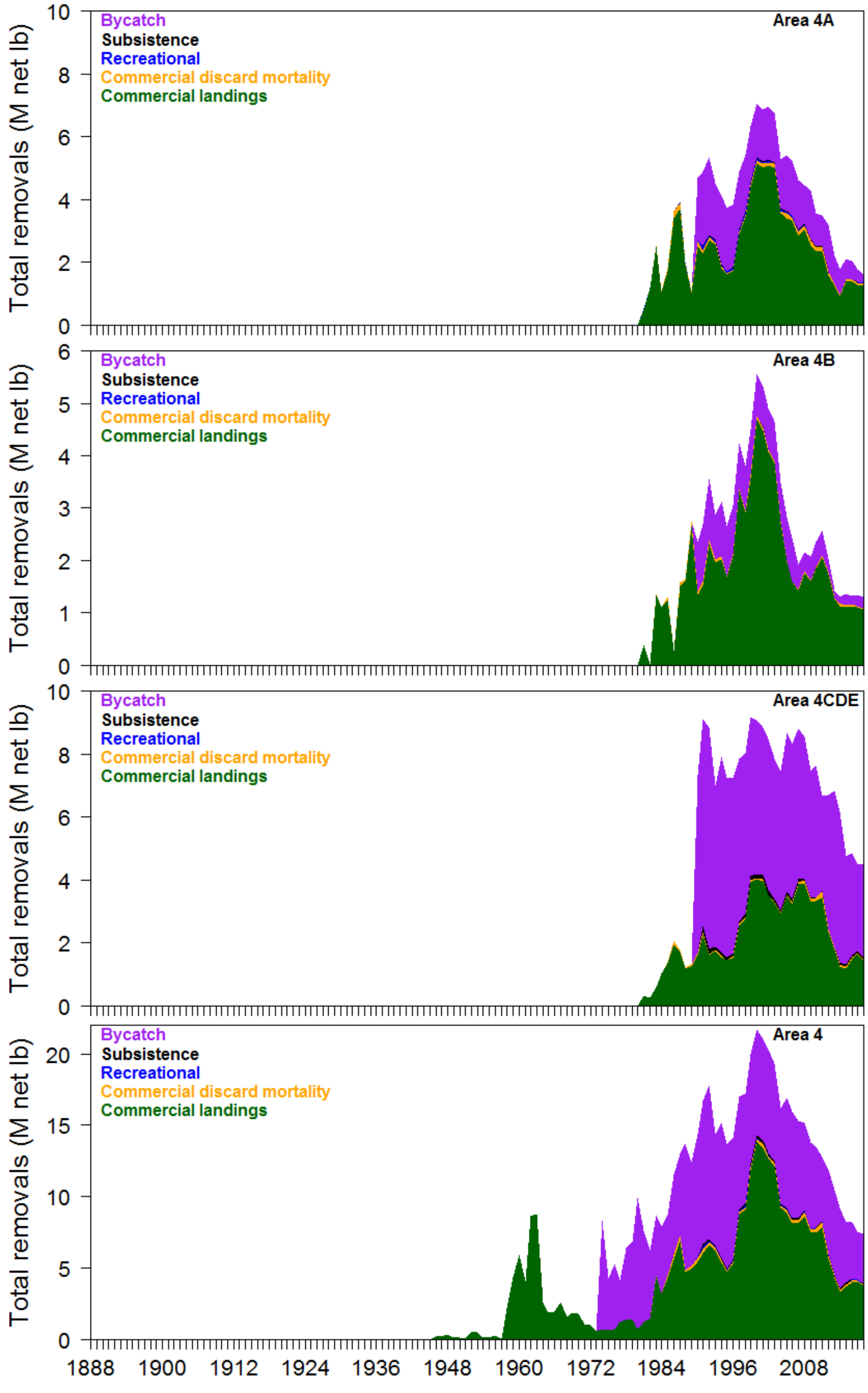


FIGURE 37. Estimated Pacific halibut mortality by source in IPHC Regulatory Areas 4A, 4B, 4CDE, and for Areas 4A-4CDE combined since 1888. Note that the y-axes differ in scale.

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 (Figure 38), with the most important missing component being the lack of sex-specific biological observations due to the dressing of Pacific halibut at sea. This information will be available for the 2017 and future fisheries via port sampling of genetic material (**IPHC-2019-AM095-05** and **IPHC-2019-AM095-14**), and it is anticipated that it will be included in the 2019 stock assessment.

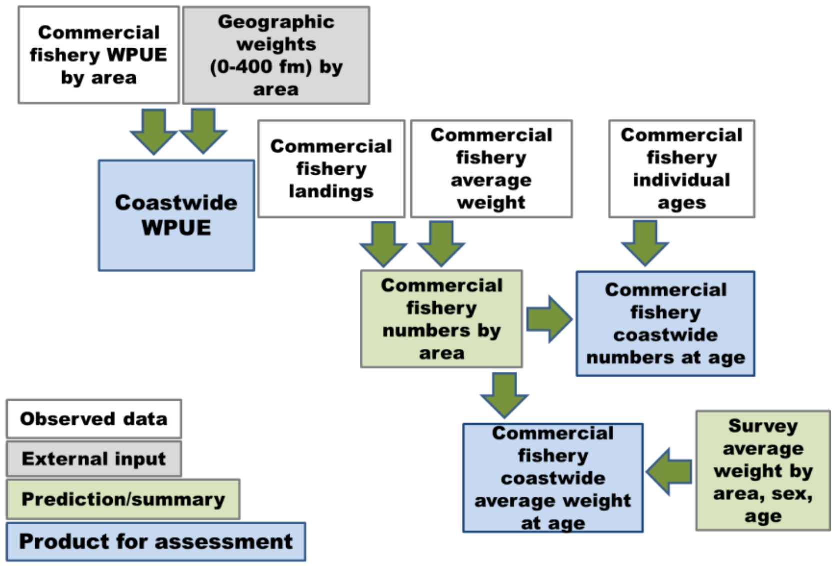


FIGURE 38. Relationships among fishery-dependent catch-rate and biological data sources.

Commercial Pacific halibut fishery WPUE

Commercial fishery logbook data is collected by port samplers, and reported directly to the IPHC by fishermen (**IPHC-2019-AM095-05**). 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 39) 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 and 2B, 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 may 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 40). 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.

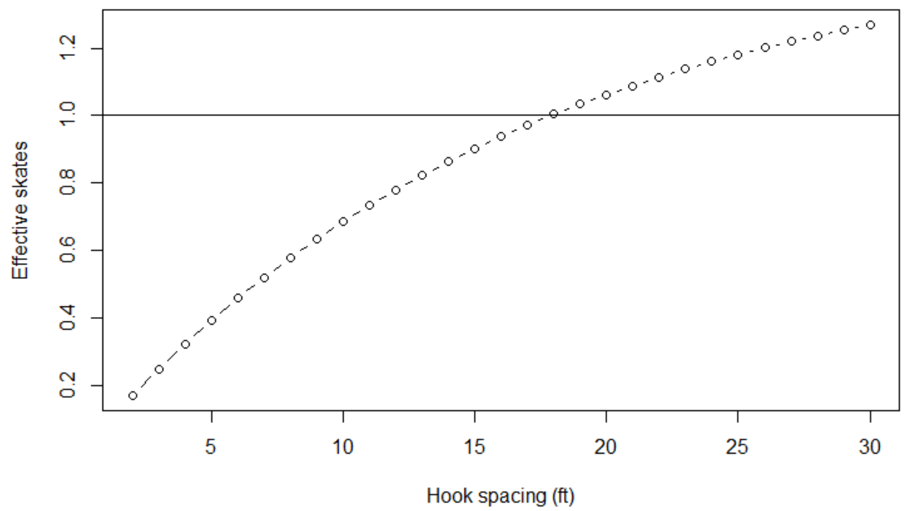


FIGURE 39. Relationship between hook spacing and the number of effective skates for setline survey and commercial fishery WPUE calculations (From: Hamley and Skud 1978).

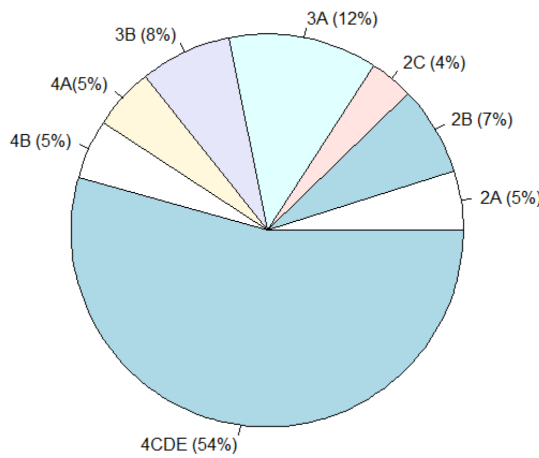


FIGURE 40. Relative spatial extent of each regulatory area.

All available information was finalized on 9 November 2018 in order to provide adequate time for analysis and modeling. As has been the case in all years, commercial fishery WPUE for 2018 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 until early November; the stock assessment data are processed immediately after). 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 six years (2012-2017) of post-assessment revisions resulting from additional logbooks available after the assessment deadline in early November. 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 41).

Uncorrected commercial fishery WPUE in 2018 decreased 11% from 2017 at the coastwide level. Applying the bias correction resulted in a larger estimated decrease of 13% for the coastwide commercial fishery WPUE with negative trends for all IPHC Regulatory Areas except 4B, ranging from -36% in 4D to -1% in Regulatory Area 4C.

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 42). 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.

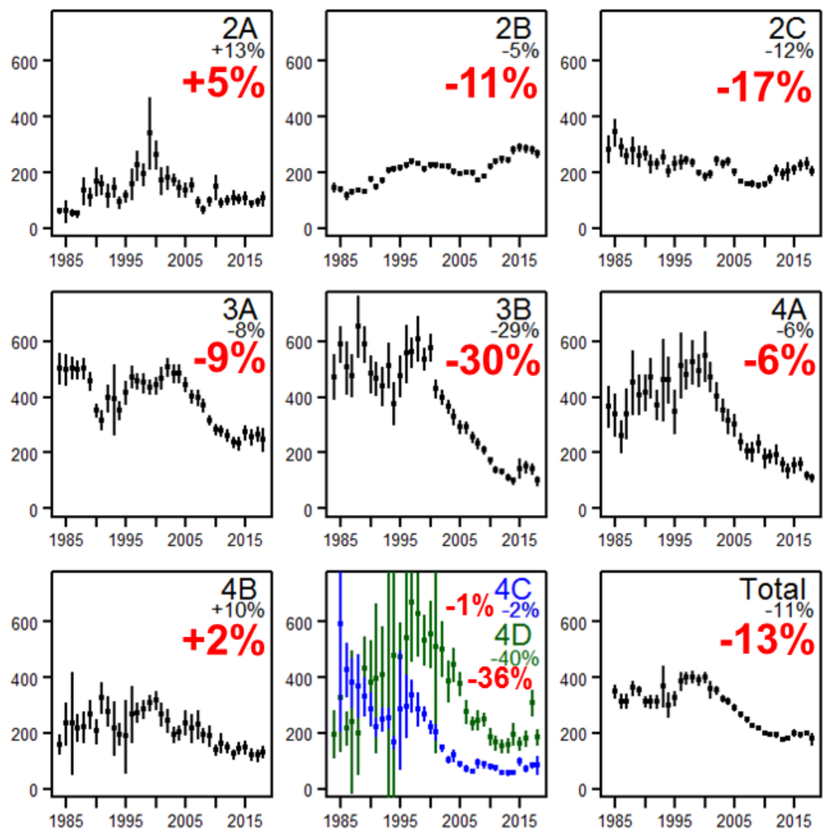


FIGURE 41. Trends in commercial fishery WPUE by IPHC Regulatory Area, 1984-2018. Percentages reported below the Regulatory Area label indicate the uncorrected change from 2017 to 2018 (see text above). Larger font percentages in each panel reflect the bias corrected percentage change anticipated when the remainder of the available logbook information is included. Vertical lines indicate approximate 95% confidence intervals.

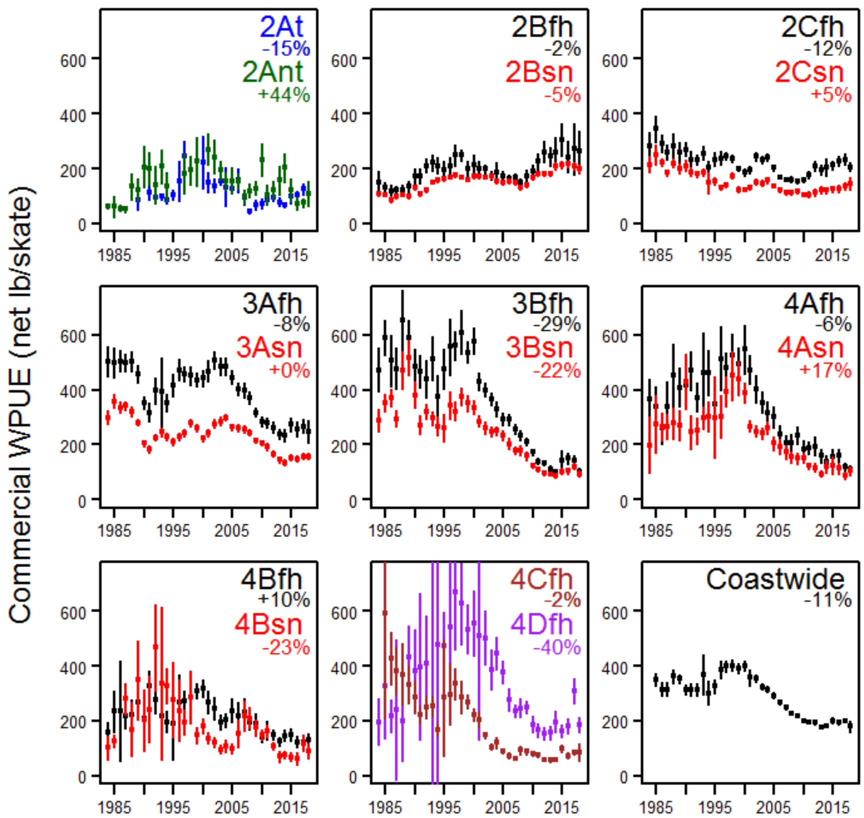


FIGURE 42. Trends in commercial fishery WPUE by Regulatory Area and gear, sector or area, 1984-2018. Percentages reported below the Regulatory Area label indicate the uncorrected change from 2017 to 2018 (see text above). In IPHC Regulatory Area 2A "t" denotes tribal and "nt" denotes non-tribal fisheries. 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 (Appendix C; Figure 43), 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 26). Despite these caveats, it is clear that catch rates were quite low around the time of the formation of the IPHC (in fact, this was the motivation for the original convention), and again in the late 1970s (Appendix C; Figure 43). Additional uncertainty throughout the historical series is reflected by increased coefficients of variation (fixed at 0.1) for all years prior to 1984.

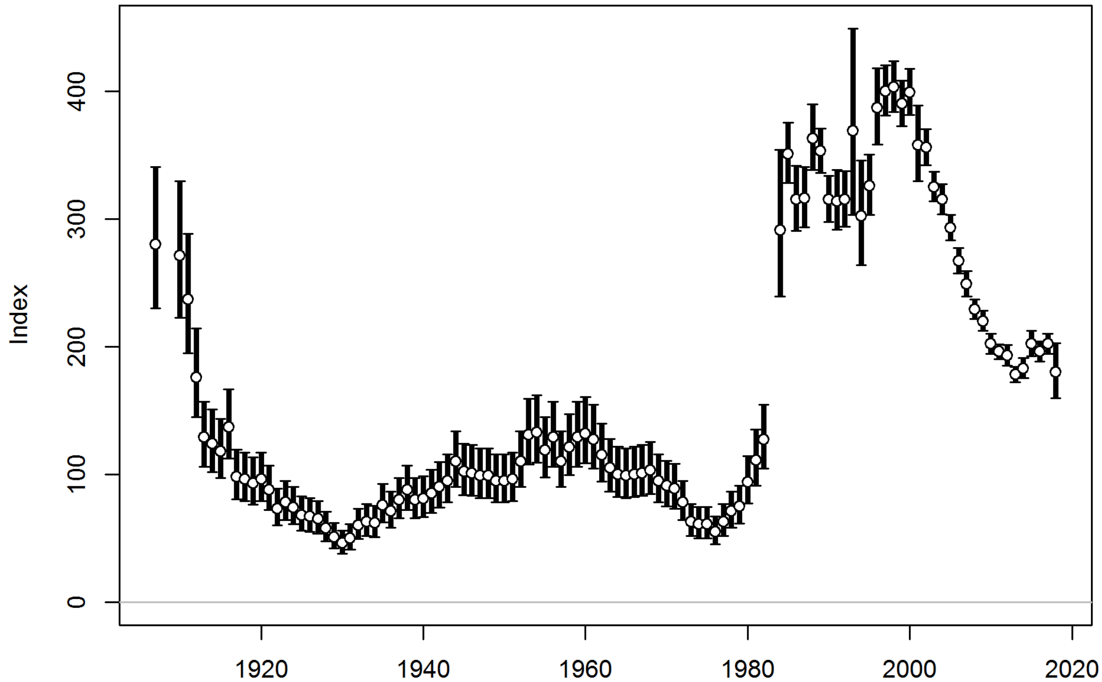


FIGURE 43. Coastwide commercial WPUE from historical records of effort and catch, as well as more recent direct logbook processing. The large change between 1982 and 1984 coincides with the adoption of circle hooks.

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. 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 routinely 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 44), followed by catches comprised primarily of 9 to 18 year-old Pacific halibut (that age range has comprised 86% of the landed catch since 1996). Age distributions in 2018 show a 2005 cohort, and weak recruitments from 2006 onward, noting that few fish are sampled in the commercial catch below ages 8-9 such that the most recent recruitments would not likely be detected.

FIGURE 44. Estimates of recent commercial fishery numbers-at-age. Circles represent proportions that sum to 1.0 within each year.

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 45). 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 46-48).

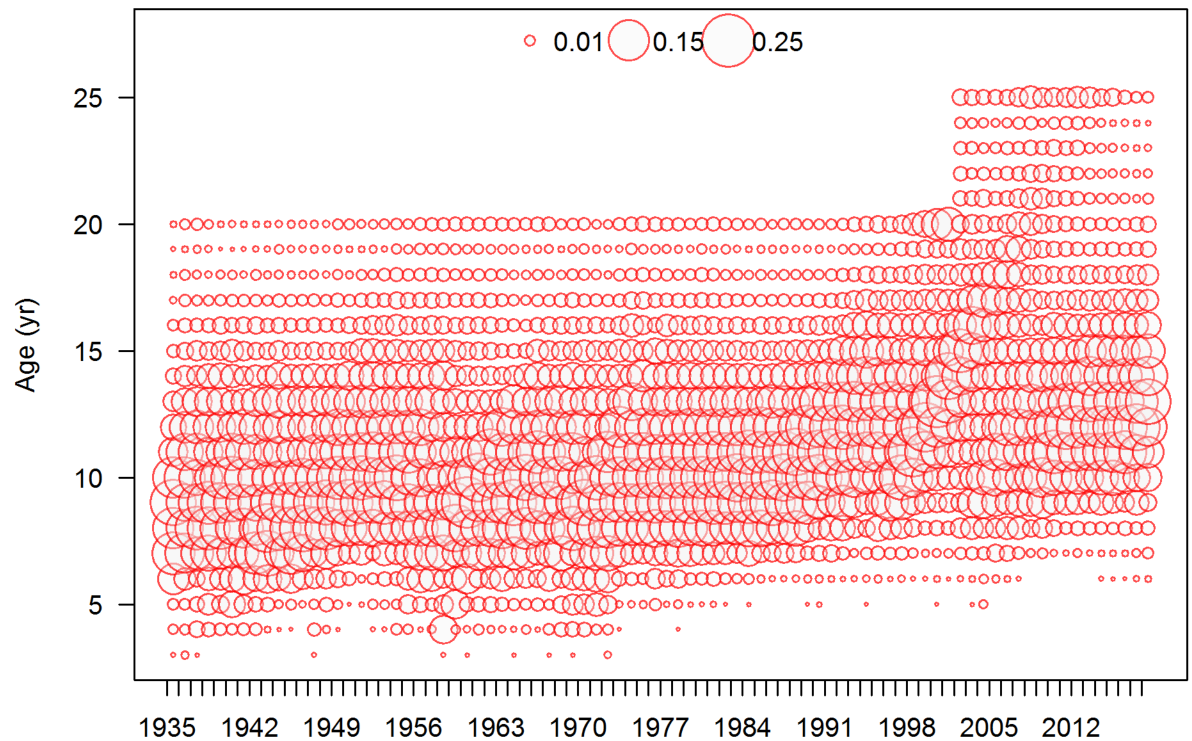


FIGURE 45. Coastwide commercial fishery proportions-at-age from the retained catch (male and female Pacific halibut combined). Note that the current 32 inch (82.3 cm) minimum size limit was implemented in 1973. Circles represent proportions that sum to 1.0 within each year.

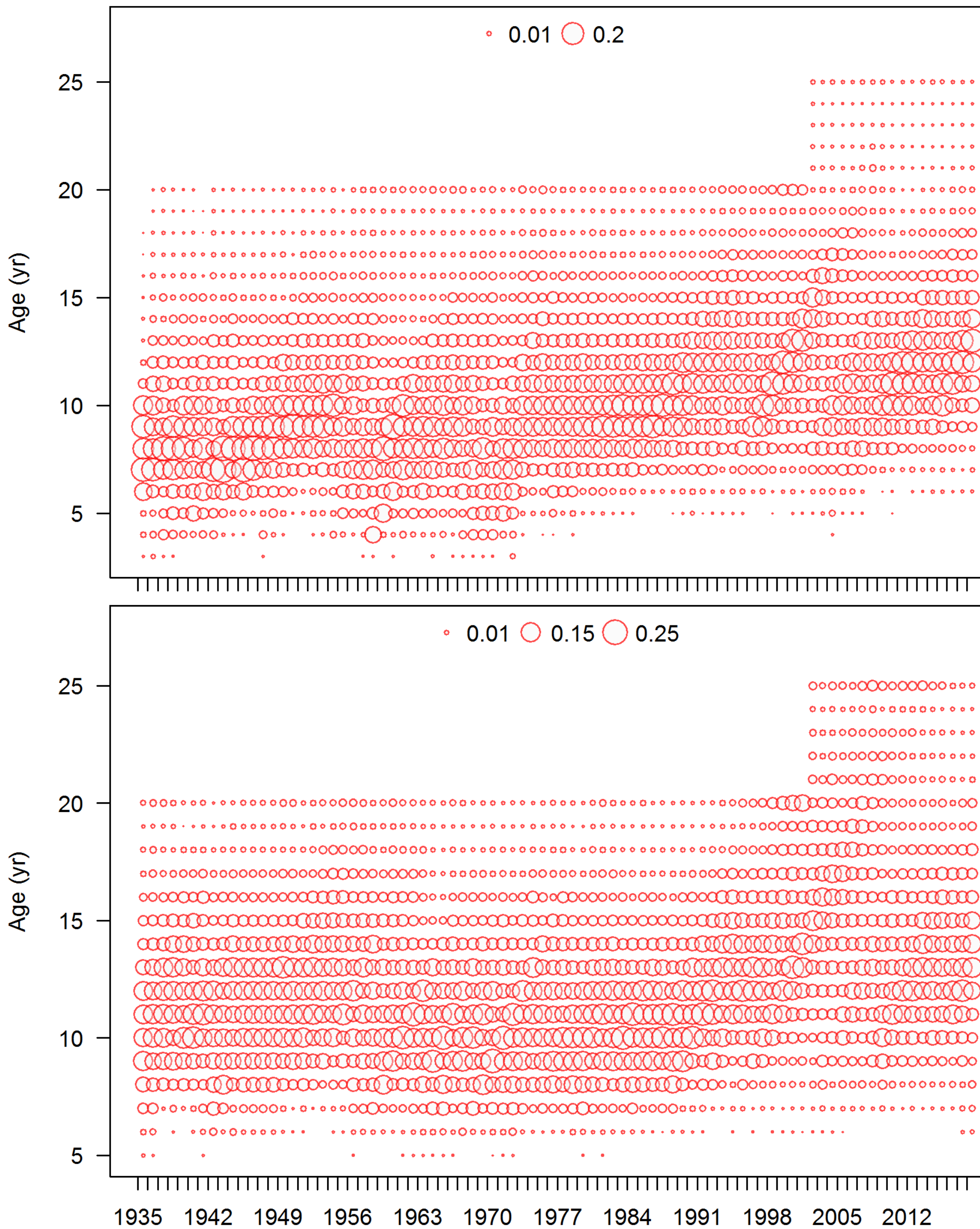


FIGURE 46. Commercial fishery proportions-at-age in the retained catch (male and female Pacific halibut combined) for Biological Region 2 (top panel), and Region 3 (bottom panel). Circles represent proportions that sum to 1.0 within each year.

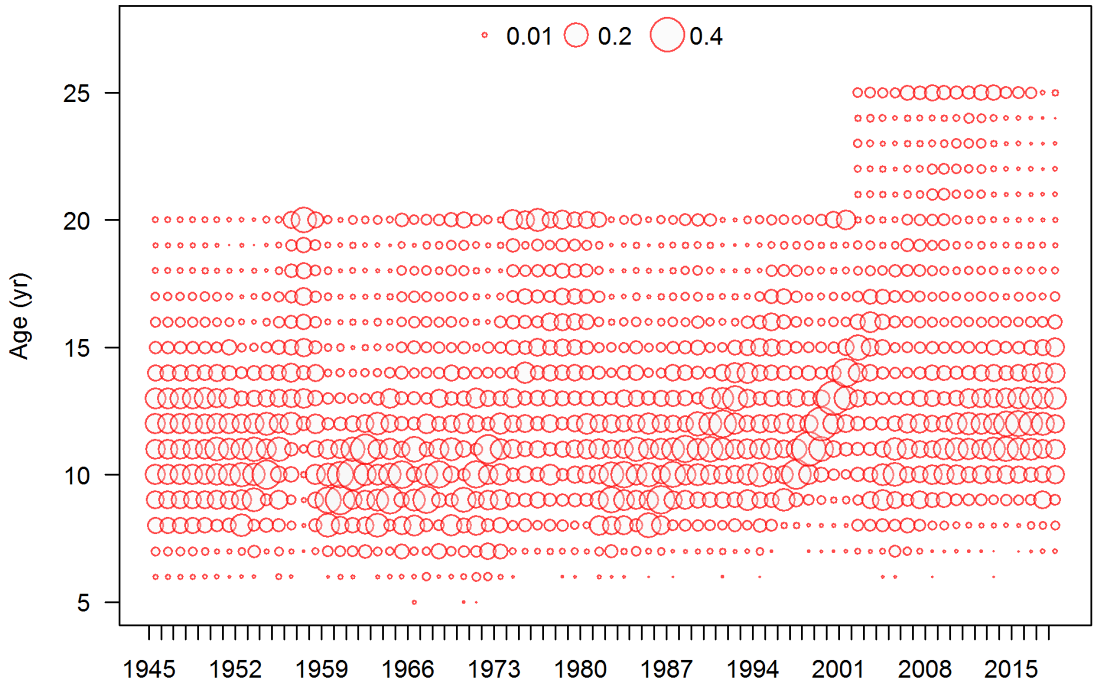


FIGURE 47. Commercial fishery proportions-at-age in the retained catch (male and female Pacific halibut combined) for Biological Region 4. Circles represent proportions that sum to 1.0 within each year.

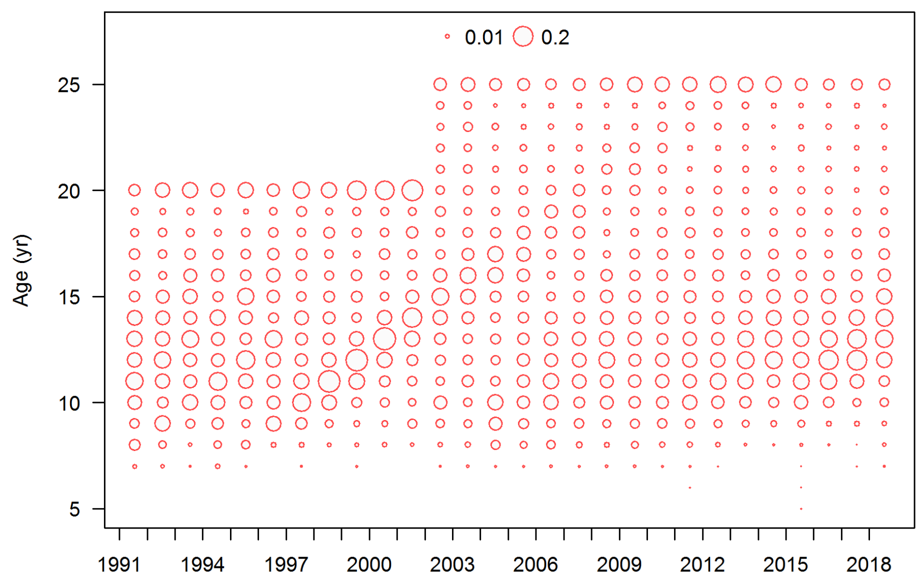


FIGURE 48. Commercial fishery proportions-at-age in the retained catch (male and female Pacific halibut combined) for Biological Region 4B. Circles represent proportions that sum to 1.0 within each year.

Commercial fishery weight-at-age

Lengths, weights, and otoliths are collected from the landed catch by port samplers each year. At present, no sex-specific information is available from port samples; however, genetic sex-assignments will be available for the 2019 stock assessment starting with the 2017 commercial samples (**IPHC-2019-AM095-14**). 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 in most IPHC Regulatory Areas, with a notable decrease in Area 2A in 2017 and 2018 (Figure 49). 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.

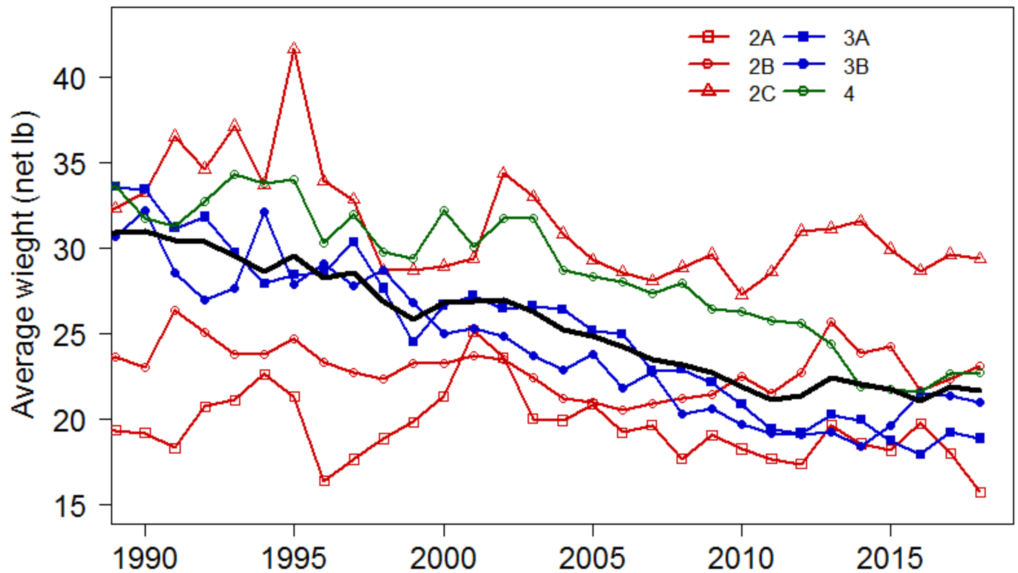


FIGURE 49. Recent average Pacific halibut weight by IPHC Regulatory Area in the directed fishery landings; thick black line indicates the coastwide average.

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 50). Also clearly visible is the effect of the implementation of the 32 inch (82.3 cm) minimum size limit in 1973.

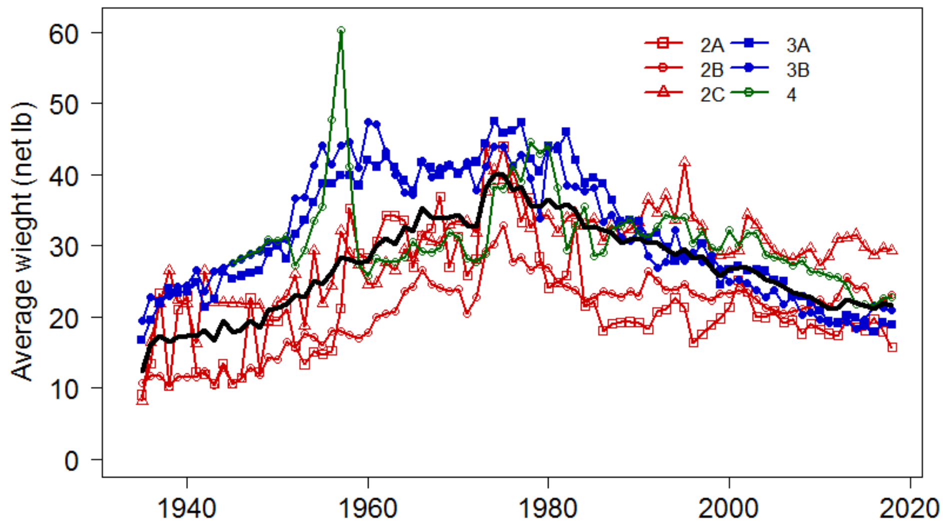


FIGURE 50. Historical trends in average individual Pacific halibut weight in the commercial fishery landings; thick black line indicates the coastwide average. The current 32 inch (81.3 cm) minimum size limit went into effect in 1974.

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 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 relative to 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 51). 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 52).

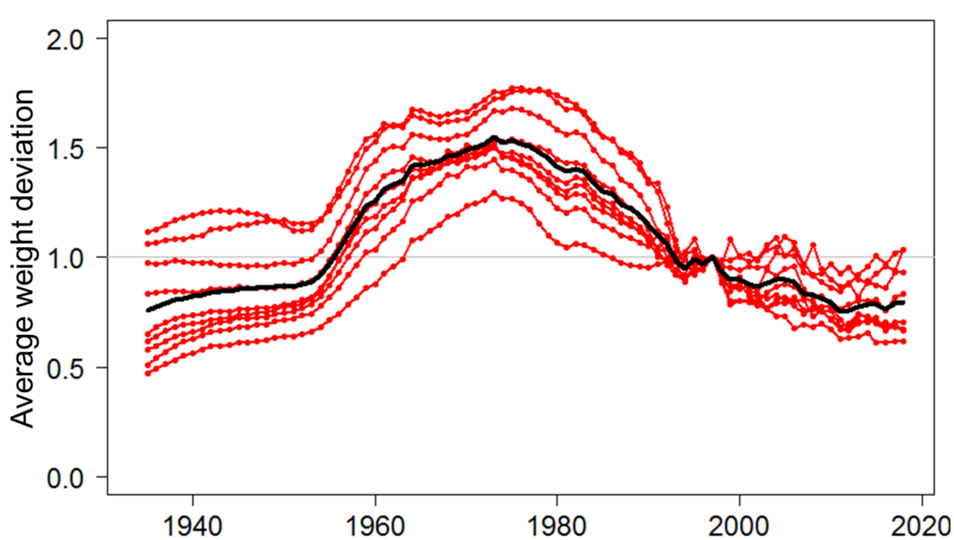


FIGURE 51. Trends in coastwide average individual Pacific halibut weight as deviations from 1997 in the commercial fishery landings for Pacific halibut aged 8-16 years old (red lines). The black line represents the average trend among the nine ages included.

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 muted historical pattern (Figure 53). 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. 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.

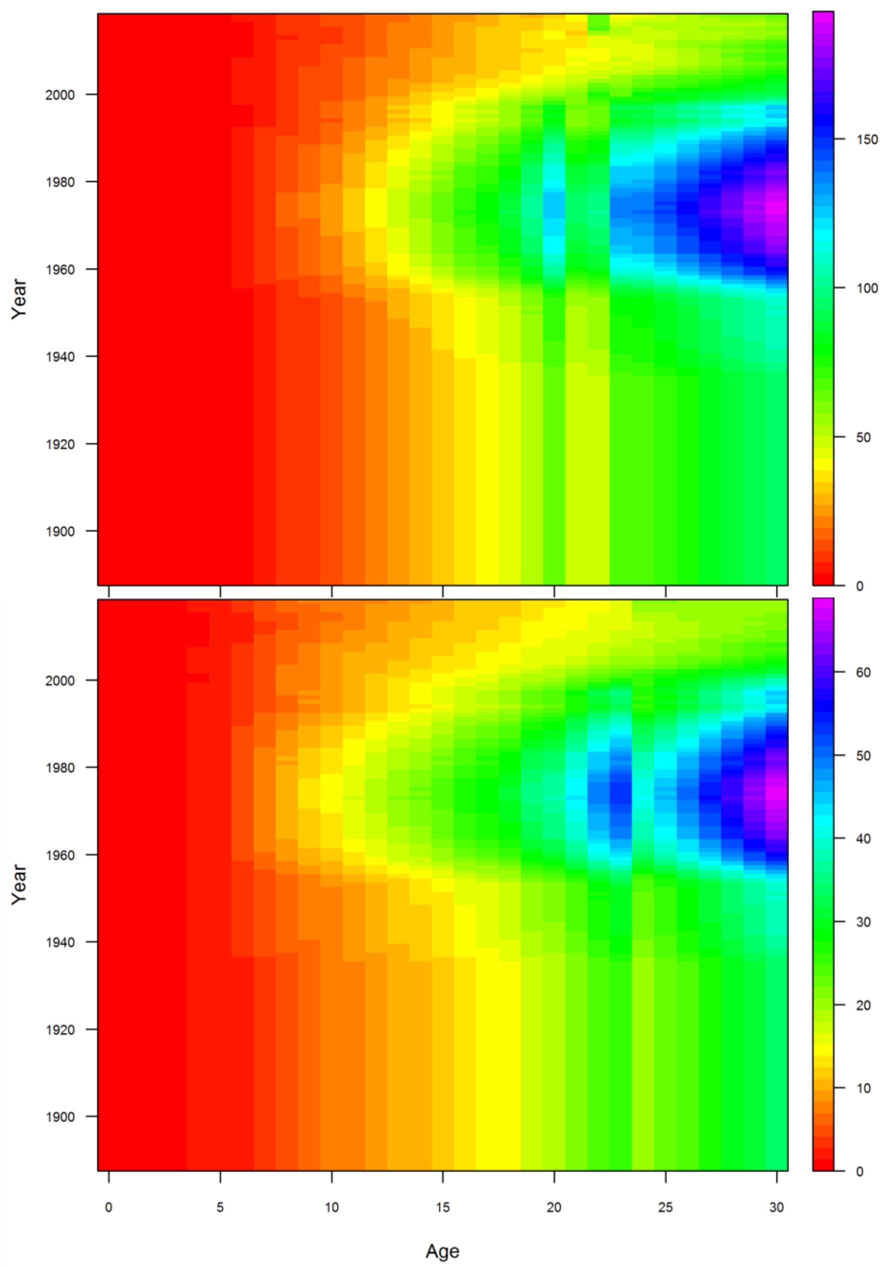


FIGURE 52. Time series of coastwide weight-at-age (net lb) for female (upper panel), and male (lower panel) Pacific halibut from all IPHC Regulatory Areas (note that the scale differs between panels).

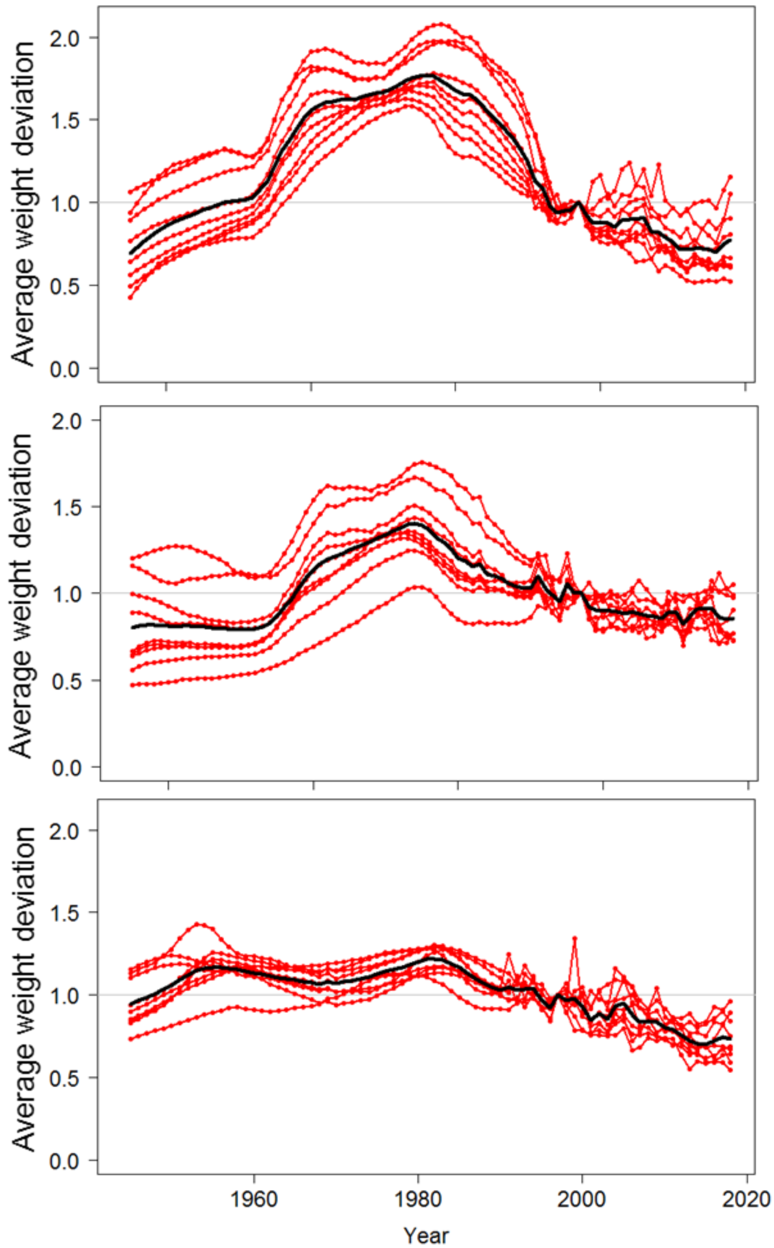


FIGURE 53. Trends in average individual Pacific halibut weight as deviations from 1997 in the commercial fishery landings for Pacific halibut aged 8-16 years old (red lines) from Biological Region 2 (upper panel), Region 3 (middle panel), and Region 4 (lower panel). The black lines represent the average 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 54) compared to the coastwide FISS over a similar time-period (Figure 11). The recreational data also contained a few Pacific halibut at ages 2-3, 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 distribution is the increased abundance of Pacific halibut at age-6, consistent with the FISS data suggesting a slightly larger year class in that year relative to other recent years; however the age-7 Pacific halibut are not nearly as pronounced in the recreational ages. 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.

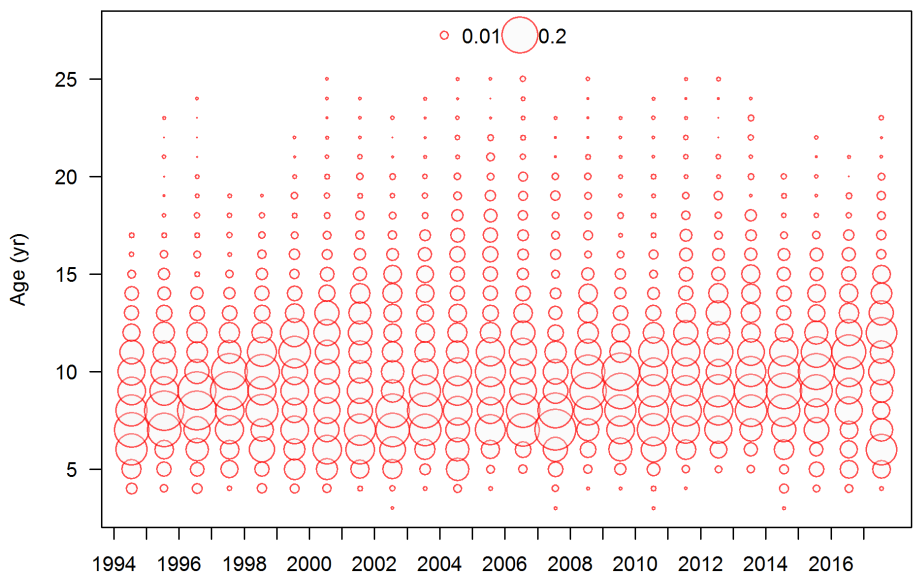


FIGURE 54. Proportions-at-age from the recreational fishery in IPHC Regulatory Area 3A (male and female Pacific halibut combined). Circles represent proportions that sum to 1.0 within each year.

Age distributions from Pacific halibut bycatch

The length-distribution of Pacific halibut caught as bycatch in fisheries targeting other species 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 of the estimated bycatch are used in the annual interim management procedure calculations where mortality tables specifically to delineate O26 and U26 bycatch 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 1998-2017, and the global key used for prior years and 2018. Coastwide aggregate bycatch lengths were summarized into predicted ages via these annual age-length keys. Estimated bycatch 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 55). 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 bycatch. Some evidence of increased recruitment corresponding to the 2011 and 2012 year-classes is also present in this data set.

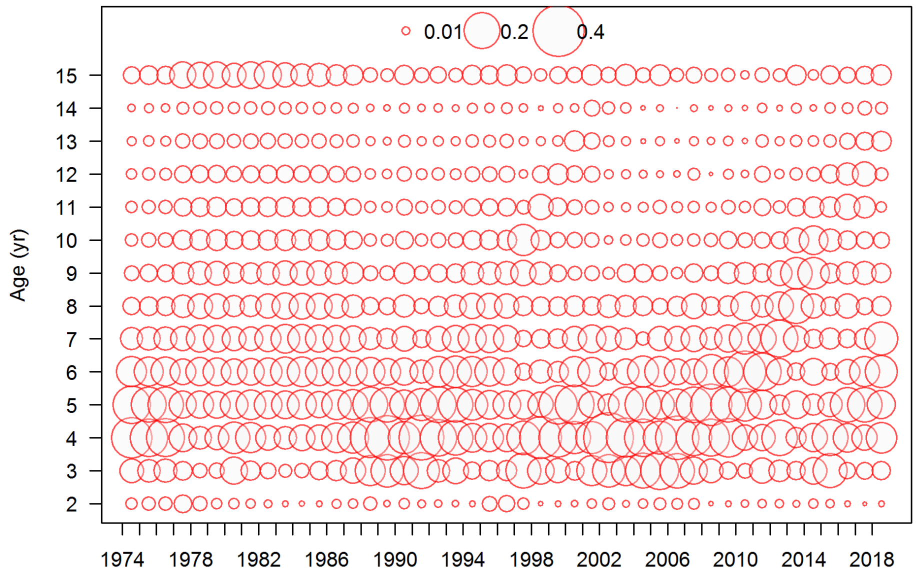


FIGURE 55. Coastwide proportions-at-age from the aggregate bycatch fisheries (male and female Pacific halibut combined). Circles represent proportions that sum to 1.0 within each year.

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 56). 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 (**IPHC-2019-AM095-05**). 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.

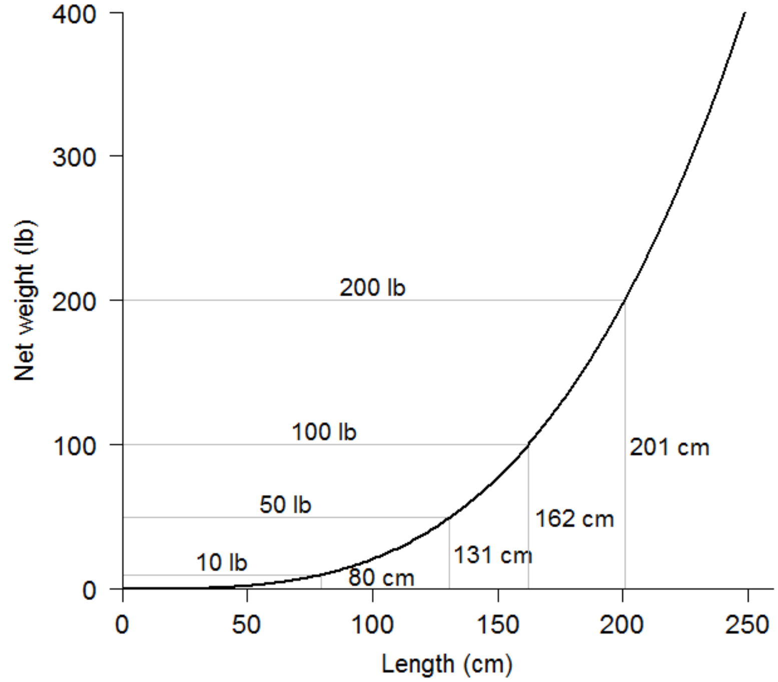


FIGURE 56. The conversion relationship for length in centimeters to net weight in pounds.

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 57). A research program to evaluate the current maturity schedule has been ongoing since 2017 (**IPHC-2019-AM095-14**).

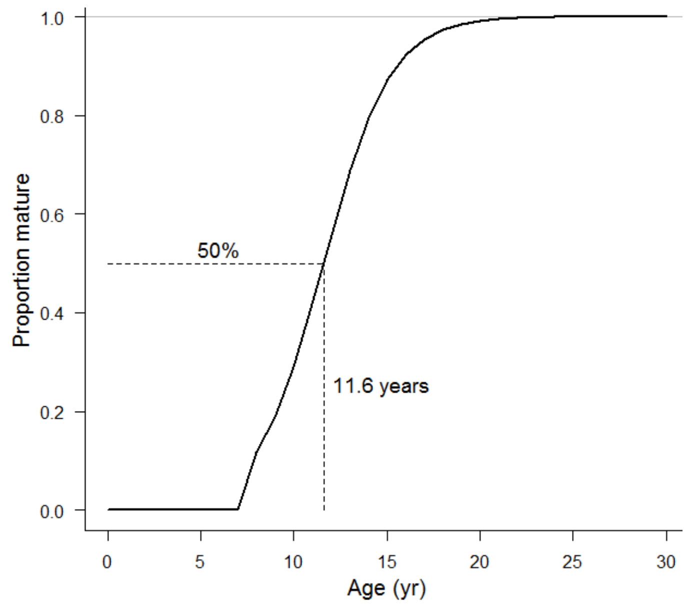


FIGURE 57. The maturity ogive used in recent Pacific halibut assessments. Note that this is a logistic curve, trimmed to be equal to zero below age-8.

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, b, 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. Current understanding of adult movement rates for most areas is reasonably well understood, based on extensive historical and more recent PIT tagging studies (Valero and Webster 2012). However, most historical summaries of these data have been conducted by specific IPHC Regulatory Area, and detailed analysis of these data was originally based on the length of the tagged Pacific halibut (Webster et al. 2013). Webster (2015a; and extended analysis) provided these rates as a function of age and by Biological Region. For Pacific halibut less than age-5, most of the available data come from historical studies that used trawl gear (rather than longline gear) to capture fish for tagging (Valero and Webster 2012). Hilborn et al. (1995) used data from studies conducted in the 1980s to estimate movement parameters for juveniles among specific regulatory areas within Biological Regions 2 and 3. These data suggest relatively high rates of 'downstream' movement to the east and south. Similar results are unavailable for Regions 4 or 4B, although raw recovery rates from juvenile Pacific halibut tagged in the Bering Sea and Aleutians suggest appreciable movement to all other IPHC Regulatory Areas over 5-10 years of life (Webster 2015b). The lack of data from Region 4 is particularly problematic, given that this is the area where the greatest abundance of 2-4 year old Pacific halibut are observed, and therefore assumptions about movement rates will be most important.

In 2015, this varied information was assembled into a single framework representing the IPHC's best available information regarding movement-at-age among Biological Regions. Key assumptions in constructing this hypothesis included:

- ages 0-1 do not move (most of the young Pacific halibut reported in Hilborn et al. (1995) were aged 2-4),
- movement generally increases from ages 2-4,
- age 2 Pacific halibut cannot move from Region 4 to Region 2 in a single year, and
- relative movement rates of Pacific halibut age 2-4 to/from Region 4 are similar to those observed for 2-4 year-old Pacific halibut compared to older Pacific halibut in Region 3.

Based on these assumptions, appreciable emigration is estimated to occur from Region 4, decreasing with age. Pacific halibut age-2 to age-4 move from Region 3 to Region 2 and from Region 4B to Regions 3 and 2, and some movement of older Pacific halibut is estimated to occur from Region 2 back to Region 3 (Figure 58).

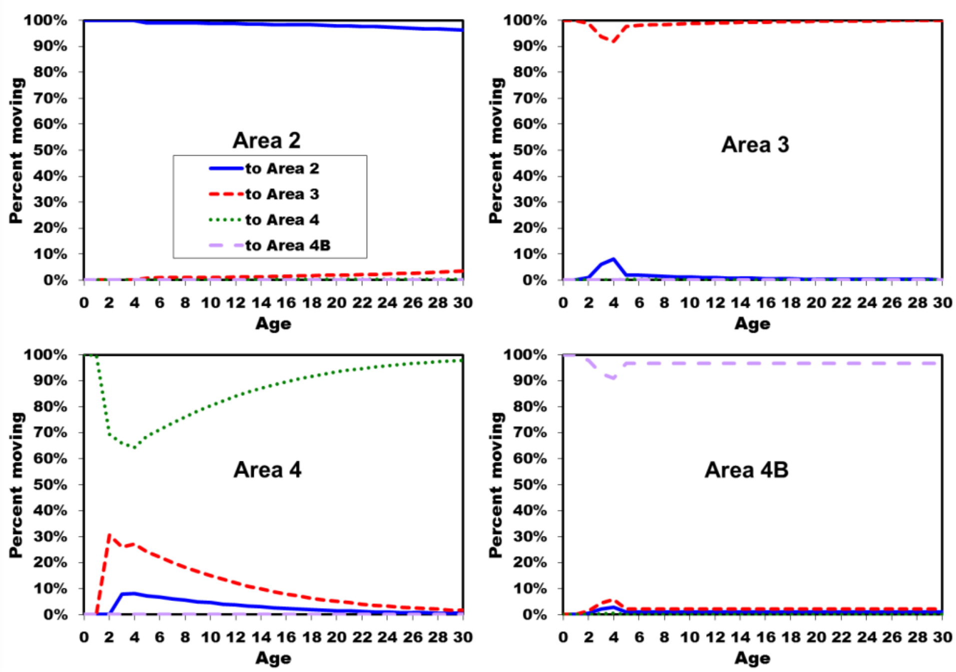


FIGURE 58. Estimated aggregate annual movement rates by age among Biological Regions based on currently available data.

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. A description of ongoing PDO research as well as access to the time-series of estimates can be found at: http://jisao.washington.edu/pdo/. For Pacific halibut, the positive 'phase' of the PDO (years up to and including 1947 and 1977-2006) and subsequent recruitment of juveniles into the commercial fishery appears to be correlated (Clark and Hare 2002, Clark et al. 1999). Recent reinvestigation of this analysis revealed that the correlation still appears strong using all available data (Stewart and Martell 2016). It is therefore worthwhile to monitor the recent trends in the PDO time series for qualitative purposes, as this represents some of the only information available related to juvenile Pacific halibut abundance prior to their entry into the survey and fishery around age-8-10. Inspection of the most recent PDO values indicates that deviations from 2006-2013 were negative, representing the longest period of negative annual values observed since the late 1970s. Positive values were observed over 2014-18 (Figure 59); 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 estimated in each year's stock assessment (**IPHC-2019-AM095-09**).

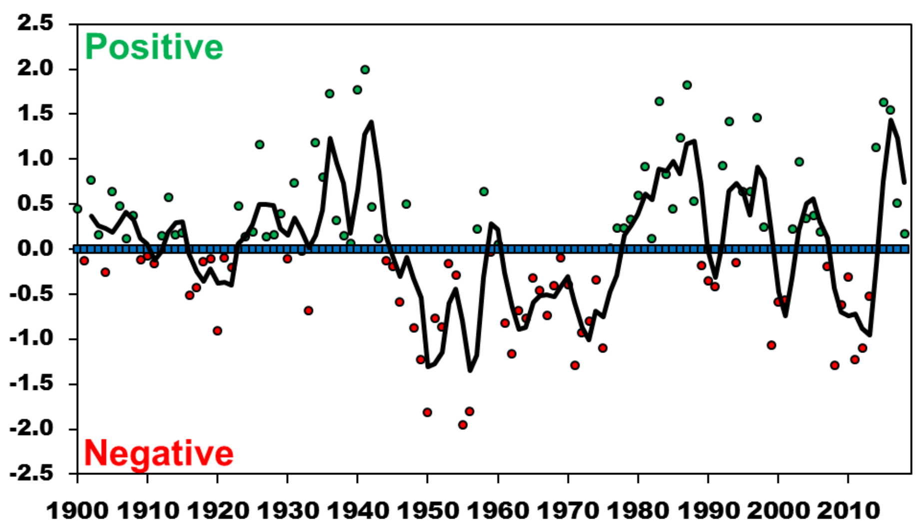


FIGURE 59. Time series of annual average PDO conditions (deviations from the long-term mean). Monthly means were obtained from (http://jisao.washington.edu/pdo/).

Broadly, across the Gulf of Alaska, anomalous conditions during 2014-2016 and again in 2018 have led to several relevant ecosystem observations. Warmer than normal water temperatures (even over deeper shelf depths) appear to be correlated with seabird and marine mammal mortality events (Zador and Yasumiishi 2017) and other conditions that suggest historical patterns of productivity related to the PDO may not be relevant to the most recent few years. Of particular concern was the apparently large mortality event observed in the Pacific cod (*Gadus macrocephalus*) stock in the Gulf of Alaska, and associated declines in biomass (Barbeaux et al. 2017). However, this same time period also appears to have produced a very large 2014 year class for the sablefish (*Anoplopoma fimbria*) stock (Hanselman et al. 2017). The effects of these ecosystem conditions on Pacific halibut in the Gulf of Alaska may take several years to become apparent, as the primary sources of comprehensive data used for stock assessment contain few Pacific halibut less than 5-7 years of age.

Empirical harvest rates

Given that the interim management procedure has not been consistently applied in recent years, and a revised harvest strategy policy is under development via the MSE process, an option for evaluating relative harvest rates based solely on data (rather than stock assessment output) is presented here. Consider that we are interested in an empirical measure of exploitation (*U*) in each year (*y*) and Biological Region (*r*). A desirable metric is proportional to the O26 catch (*C*) and some measure of the biomass (*B*):

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

The measure 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, 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 constant 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-2019-AM095-07**). Given this approximation, and 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 biological regions; however, all Regions experienced peak harvest rates between 2003 and 2009 (Figure 60). The harvest rates in all Regions were generally lower than most historical values over the period 2012 -2014, but increased in all Regions 2 and 3 during 2017-18.

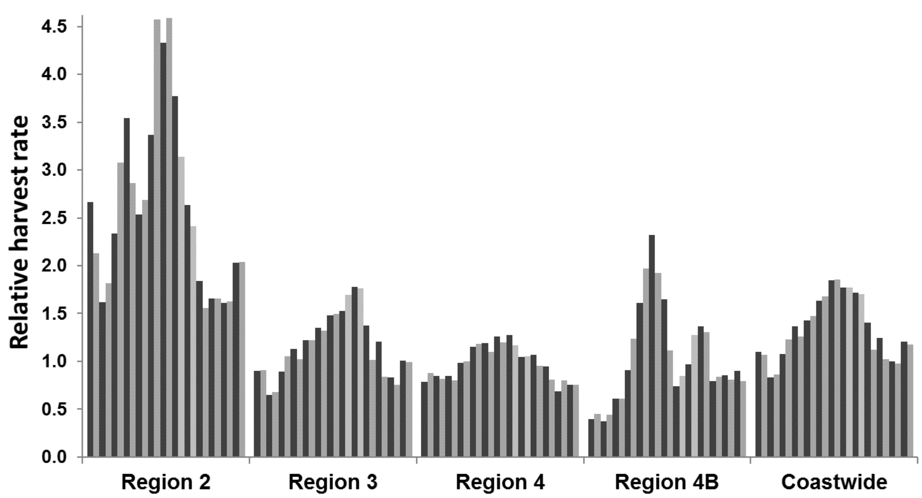


FIGURE 60. Empirical harvest rates from 1993-2018. All rates are relative to the coastwide average over the period 2014-2016, which is arbitrarily set equal to 1.0.

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 remarkably coherent and potentially highly informative for stock assessment, harvest policy, and MSE analyses.

Summary of improvements for 2018

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 2018 these included:

- The results of the FISS expansion in Biological Region 2 (**IPHC-2019-AM095-07** and **IPHC-2019-AM095-07**)
- Standard updating of preliminary values from 2017 (mortality, commercial logbooks and commercial age distributions) and all available current-year information at the beginning of November 2018.

Data sources for potential future analyses and relevant research projects

Research priorities for technical development of the stock assessment are reported in that document. The IPHC's research program (**IPHC-2019-AM095-14**) is actively addressing the most important gaps in current biological understanding of Pacific halibut. This section represents a list of potential projects relating specifically to existing and new data sources that could benefit the Pacific halibut stock assessment and related analyses in the future. It is not a prioritized list, nor is it fully comprehensive; there are other datasets not listed here but available for analysis that may be added in the future.

- The work of Monnahan and Stewart (2015) modelling commercial fishery catch rates has been extended to include spatial effects, and will be reevaluated in the future for comparison with the WPUE calculations currently used in the stock assessment models. A revised hook spacing relationship (Monnahan and Stewart 2017) will be investigated for inclusion into IPHC database processing algorithms.
- Reevaluation of the historical length-weight relationship to determine whether recent changes in length-at-age are also accompanied by changes in weight-at-length and how this may change estimates of removals over time is ongoing.
- A historical investigation on the factors influencing observed size-at-age, and ageing of additional samples from key periods and areas to support this analysis is ongoing at the IPHC.
- There is the potential that trawl surveys, particularly the Bering Sea trawl survey, could provide information on recruitment strengths for Pacific halibut several years prior to currently available sources of data.

- There is a vast quantity of archived historical data that is currently inaccessible until organized, electronically entered, and formatted into the IPHC's database with appropriate meta-data. Information on historical fishery landings, effort, and age samples would provide a much clearer (and more reproducible) perception of the historical period.
- Additional efforts could be made to reconstruct estimates of subsistence harvest prior to 1991.
- NMFS observer data from the directed Pacific halibut fleet in Alaska could be evaluated for use in updating DMRs and the age-distributions for discard mortality. This may be more feasible if observer coverage is increased and if smaller vessels (< 40 feet LOA, 12.2 m) are observed in the future.
- Historical bycatch length frequencies and mortality estimates need to be reanalyzed accounting for sampling rates in target fisheries and evaluating data quality over the historical period. This work is ongoing at the IPHC.

RECOMMENDATION/S

That the Commission **NOTE** paper IPHC-2019-AM095-08 which provides 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.

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APPENDICES

<u>Appendix A</u>: Time series' of modelled FISS trend and biological distribution information.

<u>Appendix B</u>: Time series' of mortality estimates.

<u>Appendix C</u>: Time series of fishery catch-rates.

APPENDIX A

Time series' of modelled FISS trend and biological distribution information

TABLE A1. Time-series of modelled FISS NPUE by IPHC Regulatory Area (numbers/skate). Years prior to 1984 are based on surveys conducted with "J" hooks, years prior to 1993 on mean catch-rate, and years 1993+ on the space-time model.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE	Coastwide
1977	NA	0.60	NA	2.00	NA	NA	NA	NA	NA
1978	NA	0.80	NA	1.30	NA	NA	NA	NA	NA
1979	NA	NA	NA	1.90	NA	NA	NA	NA	NA
1980	NA	1.20	NA	2.50	NA	NA	NA	NA	NA
1981	NA	0.80	NA	3.80	NA	NA	NA	NA	NA
1982	NA	1.00	3.60	3.80	NA	NA	NA	NA	NA
1983	NA	1.30	4.40	3.40	NA	NA	NA	NA	NA
1984	NA	4.70	11.00	11.60	NA	NA	NA	NA	NA
1985	NA	3.80	9.50	11.90	NA	NA	NA	NA	NA
1986	NA	2.40	9.00	7.80	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA
1990	NA	NA	NA	NA	NA	NA	NA	NA	NA
1991	NA	NA	NA	NA	NA	NA	NA	NA	NA
1992	NA	NA	NA	NA	NA	NA	NA	NA	NA
1993	2.40	6.28	11.72	23.09	28.92	8.96	10.03	1.39	7.72
1994	2.34	7.98	14.06	22.84	28.78	10.41	10.24	1.35	7.94
1995	2.27	9.99	16.76	24.92	29.85	11.38	10.53	1.24	8.52
1996	2.32	8.40	15.30	24.11	32.51	13.95	10.72	1.28	8.62
1997	2.30	6.82	16.22	28.22	31.97	17.15	11.00	1.17	9.11
1998	2.22	5.62	13.43	19.60	34.07	18.11	11.21	1.24	8.11
1999	2.07	4.67	10.74	17.34	36.10	15.33	9.58	1.11	7.53
2000	1.99	5.17	12.29	22.82	32.43	16.19	8.74	1.20	8.06
2001	1.82	6.21	14.30	21.18	27.19	14.35	6.83	1.18	7.41
2002	1.52	5.97	15.26	26.81	24.92	14.08	4.97	1.08	7.77
2003	1.47	4.80	13.46	23.36	29.45	12.20	4.12	1.10	7.41
2004	1.56	4.85	11.17	29.01	28.93	11.99	3.84	1.05	7.94
2005	1.74	5.41	12.24	26.69	21.61	11.70	3.67	1.07	7.18
2006	1.37	5.42	12.18	23.89	23.10	10.51	4.24	1.27	7.00
2007	1.29	6.21	13.48	25.38	25.12	10.61	5.34	1.19	7.46
2008	1.44	6.36	12.96	22.11	24.63	13.48	5.12	1.26	7.19
2009	1.01	7.00	12.42	20.83	23.03	13.84	4.44	1.30	6.93
2010	1.26	6.88	12.02	21.76	21.78	11.64	4.21	1.36	6.85
2011	1.54	6.36	12.56	23.79	20.57	10.43	4.15	1.35	6.93
2012	1.57	7.36	15.63	25.81	19.54	10.69	3.74	1.39	7.30
2013	1.49	7.19	14.76	19.24	16.27	8.01	5.01	1.40	6.13
2014	1.53	7.42	15.26	24.13	16.78	8.27	4.44	1.44	6.81
2015	2.00	8.67	15.83	23.92	16.70	8.15	4.50	1.42	6.90
2016	1.80	8.40	16.78	22.87	18.85	6.99	4.87	1.33	6.85
2017	1.05	5.11	14.35	18.47	10.72	7.18	3.92	1.13	5.18
2018	1.05	5.08	10.43	17.20	10.12	6.37	4.17	1.12	4.81

TABLE A2. Recent time-series of modelled FISS WPUE (all sizes) by IPHC Regulatory Area (net lb/skate).

Year	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1993	44.3	134.0	308.2	480.0	547.5	192.7	305.6	19.9	158.8
1994	42.3	164.9	357.5	443.9	553.6	218.3	305.4	19.7	160.0
1995	40.8	202.5	414.9	476.2	585.6	236.9	304.7	18.0	171.1
1996	43.1	173.2	388.8	461.6	649.2	296.5	305.4	18.2	174.3
1997	44.7	133.6	400.3	513.2	592.4	390.3	305.0	17.4	178.1
1998	44.4	105.0	318.9	374.7	665.3	444.6	272.7	19.0	163.6
1999	42.6	87.6	254.8	335.3	695.0	389.4	218.0	18.5	151.6
2000	41.0	102.8	275.2	413.9	595.1	391.9	200.0	19.9	155.5
2001	38.3	116.8	304.4	393.1	484.4	327.8	147.1	19.5	140.5
2002	29.8	116.8	333.0	459.6	410.6	293.3	110.7	18.3	139.5
2003	27.0	85.9	274.9	392.4	447.8	251.7	89.4	18.4	126.5
2004	28.3	81.2	202.5	454.0	396.8	225.2	80.8	17.6	125.1
2005	30.5	86.5	222.5	416.3	299.2	205.8	76.3	17.8	113.3
2006	23.2	82.6	210.2	363.8	307.7	176.7	87.8	20.6	107.0
2007	21.4	91.7	215.0	351.0	314.8	166.3	107.5	19.2	106.4
2008	22.8	95.5	204.8	306.4	280.6	192.5	108.4	19.4	99.8
2009	16.3	105.3	186.9	261.9	264.3	187.1	89.9	19.6	91.8
2010	21.2	106.4	186.9	260.9	234.2	159.6	77.6	20.1	88.0
2011	26.8	102.7	213.9	269.0	214.4	142.2	80.1	19.3	87.3
2012	26.4	118.1	265.0	299.5	204.8	141.6	67.2	19.3	92.6
2013	25.5	117.0	264.9	224.8	168.4	110.6	80.2	19.1	79.6
2014	27.1	117.9	272.6	264.0	172.3	115.3	69.0	19.7	85.1
2015	34.3	130.4	279.9	260.9	176.5	116.6	71.2	20.0	86.9
2016	30.3	128.5	301.5	269.5	193.7	105.6	72.6	19.5	89.0
2017	21.2	88.8	290.4	231.0	119.5	108.4	66.0	17.2	73.4
2018	20.6	91.8	228.6	222.1	110.1	96.7	73.6	17.1	69.3

TABLE A3. Recent time-series of modelled FISS O32 WPUE by IPHC Regulatory Area (net lb/skate).

Year	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1993	37.0	120.7	307.1	418.7	485.0	271.4	280.6	14.5	145.0
1994	35.3	147.0	357.2	381.0	487.5	284.8	282.2	14.1	144.8
1995	33.7	176.9	411.4	398.2	519.5	286.0	283.4	14.5	153.7
1996	36.7	149.3	357.0	388.8	574.6	318.4	283.7	17.5	156.1
1997	39.1	116.6	366.2	428.8	515.5	345.7	283.5	18.3	156.3
1998	39.5	90.1	286.4	324.4	582.1	404.1	252.5	20.6	146.5
1999	39.0	74.1	227.8	294.3	614.1	368.6	206.3	20.6	137.8
2000	37.6	87.9	244.7	352.7	526.3	364.6	184.3	22.1	139.4
2001	35.6	100.3	271.3	342.0	428.3	283.4	135.4	21.2	125.6
2002	27.3	99.1	294.4	389.3	346.9	253.1	103.2	18.5	121.0
2003	25.0	70.9	240.1	329.6	349.0	215.4	84.1	17.1	106.1
2004	26.4	64.7	167.7	373.7	287.4	186.0	77.0	15.3	101.1
2005	27.3	65.8	184.1	342.9	222.6	164.1	72.6	12.5	90.3
2006	21.0	61.4	166.8	290.0	224.2	136.9	80.8	13.8	82.4
2007	18.7	64.4	165.1	272.6	218.0	121.7	94.4	12.0	78.8
2008	18.9	68.3	157.1	233.0	174.8	130.7	97.0	12.1	71.3
2009	14.4	76.6	137.3	187.2	164.0	120.1	80.5	12.7	63.5
2010	19.1	79.9	138.3	175.3	132.0	100.8	70.3	12.3	58.5
2011	23.7	80.9	171.8	173.9	114.6	93.9	71.3	11.6	57.8
2012	22.6	92.6	219.0	199.7	113.6	93.2	59.4	12.3	63.2
2013	21.9	90.7	219.8	151.7	96.6	75.7	64.3	12.3	55.2
2014	23.5	89.1	222.7	162.7	94.5	79.9	55.7	13.6	57.0
2015	28.9	98.3	228.8	150.8	103.0	79.6	57.9	14.8	58.1
2016	25.4	96.7	250.5	172.2	111.4	75.4	56.9	14.5	61.4
2017	19.7	73.9	254.1	163.0	71.4	76.9	55.8	13.6	54.9
2018	18.8	78.3	206.7	158.6	62.1	69.5	62.8	13.3	52.1

TABLE A4. Modelled FISS stock distribution estimates (all sizes) by Biological Region.

Year	Region 2 (2A, 2B, 2C)	Region 3 (3A, 3B)	Region 4 (4A, 4CDE)	Region 4B
1993	14.7%	63.0%	13.0%	9.4%
1994	17.0%	60.1%	13.6%	9.3%
1995	18.7%	59.9%	12.7%	8.7%
1996	16.6%	60.6%	14.2%	8.6%
1997	14.9%	60.4%	16.3%	8.4%
1998	13.1%	58.7%	20.0%	8.2%
1999	11.7%	61.7%	19.5%	7.1%
2000	12.6%	61.5%	19.6%	6.3%
2001	15.3%	60.3%	19.3%	5.1%
2002	15.8%	62.6%	17.7%	3.9%
2003	13.9%	64.7%	17.9%	3.5%
2004	11.7%	68.4%	16.7%	3.2%
2005	14.1%	65.0%	17.7%	3.3%
2006	13.9%	63.4%	18.8%	4.0%
2007	14.6%	62.7%	17.7%	4.9%
2008	15.6%	58.8%	20.3%	5.3%
2009	16.7%	56.6%	21.9%	4.8%
2010	17.8%	56.4%	21.5%	4.3%
2011	19.0%	56.3%	20.2%	4.5%
2012	21.1%	56.3%	19.0%	3.6%
2013	24.4%	50.6%	20.0%	4.9%
2014	23.4%	53.3%	19.4%	4.0%
2015	24.6%	52.1%	19.3%	4.0%
2016	24.6%	53.5%	17.9%	4.0%
2017	24.6%	50.8%	20.2%	4.4%
2018	23.1%	51.2%	20.4%	5.2%

TABLE A5. Modelled FISS stock distribution estimates (all sizes) by IPHC Regulatory Area.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE
1993	1.4%	6.3%	7.0%	37.1%	25.9%	6.1%	9.4%	6.9%
1994	1.3%	7.7%	8.0%	34.1%	26.0%	6.9%	9.3%	6.7%
1995	1.2%	8.8%	8.7%	34.1%	25.8%	7.0%	8.7%	5.7%
1996	1.2%	7.4%	8.0%	32.5%	28.1%	8.5%	8.6%	5.7%
1997	1.2%	5.6%	8.1%	35.3%	25.1%	11.0%	8.4%	5.3%
1998	1.3%	4.8%	7.0%	28.1%	30.7%	13.6%	8.2%	6.3%
1999	1.4%	4.3%	6.0%	27.1%	34.6%	12.9%	7.1%	6.6%
2000	1.3%	4.9%	6.4%	32.6%	28.9%	12.7%	6.3%	7.0%
2001	1.3%	6.2%	7.8%	34.3%	26.0%	11.7%	5.1%	7.6%
2002	1.0%	6.2%	8.6%	40.4%	22.2%	10.6%	3.9%	7.1%
2003	1.0%	5.0%	7.8%	38.0%	26.7%	10.0%	3.5%	7.9%
2004	1.1%	4.8%	5.8%	44.5%	23.9%	9.0%	3.2%	7.7%
2005	1.3%	5.7%	7.1%	45.0%	19.9%	9.1%	3.3%	8.5%
2006	1.1%	5.7%	7.1%	41.7%	21.7%	8.3%	4.0%	10.5%
2007	1.0%	6.4%	7.3%	40.4%	22.3%	7.9%	4.9%	9.8%
2008	1.1%	7.1%	7.4%	37.6%	21.2%	9.7%	5.3%	10.6%
2009	0.9%	8.5%	7.3%	34.9%	21.7%	10.2%	4.8%	11.6%
2010	1.2%	9.0%	7.6%	36.3%	20.1%	9.1%	4.3%	12.4%
2011	1.5%	8.7%	8.8%	37.7%	18.5%	8.2%	4.5%	12.0%
2012	1.4%	9.5%	10.3%	39.6%	16.7%	7.7%	3.6%	11.3%
2013	1.6%	10.9%	12.0%	34.6%	16.0%	7.0%	4.9%	13.1%
2014	1.6%	10.3%	11.5%	38.0%	15.3%	6.8%	4.0%	12.6%
2015	1.9%	11.1%	11.6%	36.7%	15.3%	6.7%	4.0%	12.5%
2016	1.7%	10.7%	12.2%	37.1%	16.4%	6.0%	4.0%	12.0%
2017	1.4%	9.0%	14.2%	38.5%	12.3%	7.4%	4.4%	12.7%
2018	1.5%	9.8%	11.8%	39.2%	12.0%	7.0%	5.2%	13.4%

TABLE A6. Modelled FISS O32 stock distribution estimates by IPHC Regulatory Area.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE
1993	1.3%	6.2%	7.6%	35.4%	25.1%	9.4%	9.4%	5.5%
1994	1.2%	7.6%	8.9%	32.3%	25.4%	9.9%	9.5%	5.3%
1995	1.1%	8.6%	9.6%	31.7%	25.5%	9.4%	9.0%	5.2%
1996	1.1%	7.1%	8.2%	30.5%	27.8%	10.2%	8.9%	6.1%
1997	1.2%	5.5%	8.4%	33.6%	24.9%	11.1%	8.9%	6.4%
1998	1.3%	4.6%	7.0%	27.1%	30.0%	13.9%	8.5%	7.7%
1999	1.4%	4.0%	5.9%	26.2%	33.6%	13.4%	7.3%	8.1%
2000	1.3%	4.7%	6.3%	31.0%	28.5%	13.1%	6.5%	8.6%
2001	1.4%	5.9%	7.8%	33.3%	25.7%	11.3%	5.3%	9.2%
2002	1.1%	6.1%	8.7%	39.4%	21.6%	10.5%	4.2%	8.4%
2003	1.2%	5.0%	8.1%	38.0%	24.8%	10.2%	3.9%	8.8%
2004	1.3%	4.8%	6.0%	45.2%	21.5%	9.3%	3.7%	8.3%
2005	1.5%	5.4%	7.3%	46.5%	18.6%	9.1%	3.9%	7.6%
2006	1.2%	5.5%	7.3%	43.1%	20.6%	8.4%	4.8%	9.1%
2007	1.2%	6.1%	7.5%	42.3%	20.9%	7.8%	5.9%	8.3%
2008	1.3%	7.1%	7.9%	40.0%	18.5%	9.2%	6.7%	9.2%
2009	1.1%	9.0%	7.8%	36.0%	19.5%	9.5%	6.2%	10.9%
2010	1.6%	10.2%	8.5%	36.7%	17.1%	8.7%	5.9%	11.4%
2011	2.0%	10.4%	10.7%	36.8%	15.0%	8.2%	6.0%	10.9%
2012	1.7%	10.9%	12.5%	38.7%	13.6%	7.4%	4.6%	10.6%
2013	1.9%	12.2%	14.3%	33.6%	13.2%	6.9%	5.7%	12.2%
2014	2.0%	11.6%	14.0%	34.9%	12.5%	7.1%	4.8%	13.0%
2015	2.4%	12.6%	14.2%	31.8%	13.4%	6.9%	4.9%	13.9%
2016	2.0%	11.7%	14.7%	34.3%	13.7%	6.2%	4.5%	12.9%
2017	1.7%	10.0%	16.6%	36.3%	9.8%	7.0%	5.0%	13.5%
2018	1.8%	11.2%	14.3%	37.2%	9.0%	6.7%	5.9%	13.9%

APPENDIX B

Time series' of mortality estimates

TABLE B1. Time-series of fishery landings by IPHC Regulatory Area (million lb, net wt.).

Year	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1888	0.07	0.89	0.50	0.00	0.00	0.00	NA	NA	NA	1.47
1889	0.07	0.79	0.44	0.00	0.00	0.00	NA	NA	NA	1.29
1890	0.07	0.84	0.47	0.00	0.00	0.00	NA	NA	NA	1.37
1891	0.11	1.30	0.73	0.00	0.00	0.00	NA	NA	NA	2.13
1892	0.14	1.69	0.94	0.00	0.00	0.00	NA	NA	NA	2.77
1893	0.16	1.96	1.09	0.00	0.00	0.00	NA	NA	NA	3.22
1894	0.19	2.29	1.28	0.00	0.00	0.00	NA	NA	NA	3.76
1895	0.21	2.59	1.45	0.00	0.00	0.00	NA	NA	NA	4.25
1896	0.27	3.31	1.84	0.00	0.00	0.00	NA	NA	NA	5.42
1897	0.33	4.02	2.24	0.00	0.00	0.00	NA	NA	NA	6.59
1898	0.39	4.73	2.64	0.00	0.00	0.00	NA	NA	NA	7.77
1899	0.45	5.45	3.04	0.00	0.00	0.00	NA	NA	NA	8.94
1900	0.68	8.17	4.56	0.00	0.00	0.00	NA	NA	NA	13.41
1901	0.90	10.90	6.08	0.00	0.00	0.00	NA	NA	NA	17.87
1902	1.13	13.62	7.60	0.00	0.00	0.00	NA	NA	NA	22.34
1903	1.27	15.37	8.57	0.00	0.00	0.00	NA	NA	NA	25.21
1904	1.41	17.12	9.55	0.00	0.00	0.00	NA	NA	NA	28.08
1905	1.11	13.41	7.48	0.00	0.00	0.00	NA	NA	NA	22.00
1906	1.81	21.95	12.24	0.00	0.00	0.00	NA	NA	NA	36.00
1907	2.52	30.48	17.00	0.00	0.00	0.00	NA	NA	NA	50.00
1908	2.55	30.86	17.21	0.00	0.00	0.00	NA	NA	NA	50.62
1909	2.58	31.23	17.42	0.00	0.00	0.00	NA	NA	NA	51.23
1910	2.61	31.61	17.63	0.00	0.00	0.00	NA	NA	NA	51.85
1911	2.87	34.71	19.36	0.00	0.00	0.00	NA	NA	NA	56.93
1912	3.00	36.29	20.24	0.86	0.04	0.00	NA	NA	NA	60.43
1913	2.79	33.80	18.85	10.58	0.52	0.00	NA	NA	NA	66.54
1914	2.24	27.11	15.12	21.87	1.08	0.00	NA	NA	NA	67.43
1915	2.22	26.84	14.97	23.31	1.15	0.00	NA	NA	NA	68.48
1916	1.53	18.46	10.30	18.56	0.92	0.00	NA	NA	NA	49.76
1917	1.55	18.78	10.47	16.96	0.84	0.00	NA	NA	NA	48.60
1918	1.32	16.02	8.93	10.88	0.54	0.00	NA	NA	NA	37.69
1919	1.34	16.22	9.05	12.90	0.64	0.00	NA	NA	NA	40.14
1920	1.62	19.73	11.01	13.59	0.67	0.00	NA	NA	NA	46.62
1921	3.39	23.37	10.22	14.75	0.73	0.00	NA	NA	NA	52.46
1922	2.61	19.02	9.22	11.63	0.02	0.00	NA	NA	NA	42.49
1923	2.62	16.71	9.72	21.60	0.67	0.00	NA	NA	NA	51.32
1924	1.82	15.14	9.86	24.82	1.50	0.00	NA	NA	NA	53.14
1925	2.20	13.65	7.99	22.16	4.66	0.00	NA	NA	NA	50.66
1926	2.32	16.12	7.17	21.01	5.85	0.00	NA	NA	NA	52.47
1927	2.62	14.09	7.42	22.62	8.20	0.00	NA	NA	NA	54.95
1928	2.27	16.63	7.58	22.54	5.25	0.00	NA	NA	NA	54.26
1929	2.18	13.77	9.85	22.27	8.86	0.00	NA	NA	NA	56.92
1930	1.58	12.12	8.53	18.19	9.09	0.00	NA	NA	NA	49.51
1931	1.63	13.53	7.39	14.61	7.06	0.00	NA	NA	NA	44.22
1932	1.90	13.25	7.74	16.71	4.89	0.00	NA	NA	NA	44.49
1933	1.75	13.37	8.15	19.67	3.97	0.00	NA	NA	NA	46.91
1934	2.45	14.12	7.68	15.88	4.58	0.00	NA	NA	NA	44.72
1935	1.77	14.21	7.58	19.96	3.82	0.00	NA	NA	NA	47.34
1936	0.90	13.67	8.75	20.09	5.52	0.00	NA	NA	NA	48.92
1937	0.92	15.29	7.87	20.47	5.00	0.00	NA	NA	NA	49.54
1938	0.95	16.00	7.15	20.66	4.79	0.00	NA	NA	NA	49.55
1939	1.36	17.67	6.56	21.16	4.15	0.00	NA	NA	NA	50.90
1940	0.98	17.81	7.62	22.50	4.48	0.00	NA	NA	NA	53.38

TABLE B1. Continued.

Year	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1941	0.51	16.53	7.25	21.84	6.10	0.00	NA	NA	NA	52.23
1942	0.72	14.37	8.35	21.50	5.46	0.00	NA	NA	NA	50.39
1943	1.24	15.97	8.15	20.51	7.83	0.00	NA	NA	NA	53.70
1944	0.90	15.07	10.38	20.36	6.73	0.00	NA	NA	NA	53.44
1945	0.73	14.58	8.49	20.07	9.52	0.01	NA	NA	NA	53.40
1946	0.90	18.37	9.90	22.40	8.50	0.20	NA	NA	NA	60.27
1947	0.57	17.67	9.50	20.44	7.33	0.19	NA	NA	NA	55.70
1948	0.41	17.67	9.75	19.93	7.50	0.30	NA	NA	NA	55.56
1949	0.62	16.34	9.45	21.12	7.38	0.12	NA	NA	NA	55.03
1950	0.70	17.46	8.84	23.86	6.30	0.08	NA	NA	NA	57.23
1951	0.59	20.04	9.97	20.86	4.54	0.05	NA	NA	NA	56.05
1952	0.62	20.63	9.56	27.27	3.62	0.56	NA	NA	NA	62.26
1953	0.50	23.80	8.41	22.84	3.81	0.48	NA	NA	NA	59.84
1954	0.85	24.90	11.04	29.46	4.21	0.13	NA	NA	NA	70.58
1955	0.61	18.65	8.54	23.06	6.57	0.09	NA	NA	NA	57.52
1956	0.53	20.06	14.51	22.11	9.12	0.26	NA	NA	NA	66.59
1957	0.60	17.69	12.25	22.85	7.43	0.04	NA	NA	NA	60.85
1958	0.52	18.49	11.20	24.52	7.60	2.18	NA	NA	NA	64.51
1959	0.67	16.83	13.03	25.36	11.00	4.31	NA	NA	NA	71.20
1960	0.89	18.16	12.72	21.05	12.90	5.90	NA	NA	NA	71.61
1961	0.50	16.08	12.29	23.07	13.28	4.07	NA	NA	NA	69.27
1962	0.45	15.03	13.24	24.04	13.48	8.62	NA	NA	NA	74.86
1963	0.41	15.52	10.24	22.31	13.98	8.77	NA	NA	NA	71.24
1964	0.28	11.86	7.43	22.56	15.04	2.62	NA	NA	NA	59.78
1965	0.21	11.97	12.07	22.98	14.07	1.88	NA	NA	NA	63.18
1966	0.18	11.04	12.04	25.77	11.05	1.94	NA	NA	NA	62.02
1967	0.20	10.11	9.41	19.66	13.26	2.58	NA	NA	NA	55.22
1968	0.14	10.15	6.11	14.77	15.83	1.60	NA	NA	NA	48.59
1969	0.23	12.82	9.33	20.08	13.92	1.90	NA	NA	NA	58.27
1970	0.16	10.26	9.37	19.91	13.37	1.78	NA	NA	NA	54.84
1971	0.32	9.85	6.61	17.76	11.04	1.08	NA	NA	NA	46.65
1972	0.37	10.13	5.78	16.30	9.28	1.02	NA	NA	NA	42.88
1973	0.23	6.73	5.98	13.50	4.79	0.52	NA	NA	NA	31.74
1974	0.52	4.62	5.60	8.19	1.67	0.71	NA	NA	NA	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	NA	NA	NA	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	NA	NA	NA	27.54
1977	0.21	5.43	3.19	8.64	3.19	1.22	NA	NA	NA	21.88
1978	0.10	4.61	4.32	10.30	1.32	1.35	NA	NA	NA	22.00
1979	0.05	4.86	4.53	11.34	0.39	1.37	NA	NA	NA	22.54
1980	0.02	5.65	3.24	11.97	0.28	0.71	NA	NA	NA	21.87
1981	0.20	5.66	4.01	14.23	0.45	NA	0.49	0.39	0.31	25.74
1982	0.21	5.54	3.50	13.52	4.80	NA	1.17	0.01	0.25	29.01
1983	0.27	5.44	6.38	14.13	7.76	NA	2.50	1.34	0.58	38.39
1984	0.43	9.05	5.87	19.77	6.69	NA	1.05	1.10	1.01	44.97
1985	0.49	10.39	9.21	20.84	10.89	NA	1.72	1.24	1.33	56.10
1986	0.58	11.23	10.61	32.80	8.82	NA	3.38	0.26	1.95	69.63
1987	0.59	12.25	10.69	31.31	7.76	NA	3.69	1.50	1.69	69.47
1988	0.49	12.86	11.36	37.91	7.08	NA	1.93	1.59	1.17	74.39
1989	0.47	10.43	9.53	33.74	7.84	NA	1.03	2.65	1.26	66.95
1990	0.33	8.57	9.73	28.85	8.69	NA	2.50	1.33	1.59	61.60
1991	0.36	7.19	8.69	22.93	11.93	NA	2.26	1.51	2.22	57.08
1992	0.44	7.63	9.82	26.78	8.62	NA	2.70	2.32	1.59	59.89
1993	0.50	10.63	11.29	22.74	7.86	NA	2.56	1.96	1.73	59.27

TABLE B1. Continued.

Year	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1994	0.37	9.91	10.38	24.84	3.86	NA	1.80	2.02	1.55	54.73
1995	0.30	9.62	7.77	18.34	3.13	NA	1.62	1.68	1.44	43.88
1996	0.30	9.55	8.87	19.69	3.66	NA	1.70	2.07	1.51	47.34
1997	0.41	12.42	9.92	24.64	9.06	NA	2.91	3.32	2.52	65.20
1998	0.46	13.17	10.20	25.70	11.16	NA	3.42	2.90	2.75	69.76
1999	0.45	12.71	10.14	25.32	13.84	NA	4.37	3.57	3.92	74.31
2000	0.48	10.81	8.45	19.27	15.41	NA	5.16	4.69	4.02	68.29
2001	0.68	10.29	8.40	21.54	16.34	NA	5.02	4.47	3.97	70.70
2002	0.85	12.07	8.60	23.13	17.31	NA	5.09	4.08	3.52	74.66
2003	0.82	11.79	8.41	22.75	17.22	NA	5.02	3.86	3.26	73.14
2004	0.88	12.16	10.23	25.17	15.46	NA	3.56	2.72	2.92	73.11
2005	0.80	12.33	10.63	26.03	13.17	NA	3.40	1.98	3.48	71.82
2006	0.83	12.01	10.49	25.71	10.79	NA	3.33	1.59	3.23	67.98
2007	0.79	9.77	8.47	26.49	9.25	NA	2.83	1.42	3.85	62.87
2008	0.68	7.76	6.21	24.52	10.75	NA	3.02	1.76	3.88	58.57
2009	0.49	6.64	4.96	21.76	10.78	NA	2.53	1.59	3.31	52.05
2010	0.42	6.73	4.49	20.50	10.11	NA	2.33	1.83	3.32	49.72
2011	0.54	6.69	2.45	14.67	7.32	NA	2.35	2.05	3.43	39.51
2012	0.57	5.98	2.69	12.03	5.05	NA	1.58	1.74	2.34	31.99
2013	0.54	6.04	3.03	11.08	4.09	NA	1.23	1.25	1.77	29.04
2014	0.53	5.88	3.42	7.66	2.92	NA	0.91	1.12	1.26	23.70
2015	0.57	5.99	3.77	7.97	2.70	NA	1.37	1.11	1.19	24.67
2016	0.65	6.14	4.00	7.57	2.72	NA	1.38	1.11	1.48	25.05
2017	0.76	6.24	4.22	7.82	3.10	NA	1.29	1.10	1.65	26.17
2018	0.71	5.47	3.61	7.49	2.50	NA	1.25	1.07	1.41	23.50

TABLE B2. Time-series of removals from all sources by IPHC Regulatory Area (million lb, net wt.).

Year	2A	2B	2C	3A	3B	4	Total
1888	0.07	0.89	0.50	0.00	0.00	0.00	1.47
1889	0.07	0.79	0.44	0.00	0.00	0.00	1.29
1890	0.07	0.84	0.47	0.00	0.00	0.00	1.37
1891	0.11	1.30	0.73	0.00	0.00	0.00	2.13
1892	0.14	1.69	0.94	0.00	0.00	0.00	2.77
1893	0.16	1.96	1.09	0.00	0.00	0.00	3.22
1894	0.19	2.29	1.28	0.00	0.00	0.00	3.76
1895	0.21	2.59	1.45	0.00	0.00	0.00	4.25
1896	0.27	3.31	1.84	0.00	0.00	0.00	5.42
1897	0.33	4.02	2.24	0.00	0.00	0.00	6.59
1898	0.39	4.73	2.64	0.00	0.00	0.00	7.77
1899	0.45	5.45	3.04	0.00	0.00	0.00	8.94
1900	0.68	8.17	4.56	0.00	0.00	0.00	13.41
1901	0.90	10.90	6.08	0.00	0.00	0.00	17.87
1902	1.13	13.62	7.60	0.00	0.00	0.00	22.34
1903	1.27	15.37	8.57	0.00	0.00	0.00	25.21
1904	1.41	17.12	9.55	0.00	0.00	0.00	28.08
1905	1.11	13.41	7.48	0.00	0.00	0.00	22.00
1906	1.81	21.95	12.24	0.00	0.00	0.00	36.00
1907	2.52	30.48	17.00	0.00	0.00	0.00	50.00
1908	2.55	30.86	17.21	0.00	0.00	0.00	50.62
1909	2.58	31.23	17.42	0.00	0.00	0.00	51.23
1910	2.61	31.61	17.63	0.00	0.00	0.00	51.85
1911	2.87	34.71	19.36	0.00	0.00	0.00	56.93
1912	3.00	36.29	20.24	0.86	0.04	0.00	60.43
1913	2.79	33.80	18.85	10.58	0.52	0.00	66.54
1914	2.24	27.11	15.12	21.87	1.08	0.00	67.43
1915	2.22	26.84	14.97	23.31	1.15	0.00	68.48
1916	1.53	18.46	10.30	18.56	0.92	0.00	49.76
1917	1.55	18.78	10.47	16.96	0.84	0.00	48.60
1918	1.32	16.02	8.93	10.88	0.54	0.00	37.69
1919	1.34	16.22	9.05	12.90	0.64	0.00	40.14
1920	1.62	19.73	11.01	13.59	0.67	0.00	46.62
1921	3.39	23.37	10.22	14.75	0.73	0.00	52.46
1922	2.61	19.02	9.22	11.63	0.02	0.00	42.50
1923	2.62	16.71	9.72	21.60	0.67	0.00	51.32
1924	1.82	15.14	9.86	24.82	1.50	0.00	53.14
1925	2.20	13.65	7.99	22.16	4.66	0.00	50.66
1926	2.32	16.12	7.17	21.01	5.85	0.00	52.47
1927	2.62	14.09	7.42	22.62	8.20	0.00	54.95
1928	2.27	16.63	7.58	22.54	5.25	0.00	54.26
1929	2.18	13.77	9.85	22.27	8.86	0.00	56.93
1930	1.58	12.12	8.53	18.19	9.09	0.00	49.51
1931	1.63	13.53	7.39	14.61	7.06	0.00	44.22
1932	1.90	13.25	7.74	16.71	4.89	0.00	44.49
1933	1.75	13.37	8.15	19.67	3.97	0.00	46.91
1934	2.45	14.12	7.68	15.88	4.58	0.00	44.72
1935	1.77	14.21	7.58	19.96	3.82	0.00	47.34
1936	0.90	13.67	8.75	20.09	5.52	0.00	48.92
1937	0.92	15.29	7.87	20.47	5.00	0.00	49.54
1938	0.95	16.00	7.15	20.66	4.79	0.00	49.55
1939	1.36	17.67	6.56	21.16	4.15	0.00	50.90
1940	0.98	17.81	7.62	22.50	4.48	0.00	53.38

TABLE B2. Continued.

Year	2A	2B	2C	3A	3B	4	Total
1941	0.51	16.53	7.25	21.84	6.10	0.00	52.23
1942	0.72	14.37	8.35	21.50	5.46	0.00	50.39
1943	1.24	15.97	8.15	20.51	7.83	0.00	53.70
1944	0.90	15.07	10.38	20.36	6.73	0.00	53.44
1945	0.73	14.58	8.49	20.07	9.52	0.01	53.40
1946	0.90	18.37	9.90	22.40	8.50	0.20	60.27
1947	0.57	17.67	9.50	20.44	7.33	0.19	55.70
1948	0.41	17.67	9.75	19.93	7.50	0.30	55.56
1949	0.62	16.34	9.45	21.12	7.38	0.12	55.03
1950	0.70	17.46	8.84	23.86	6.30	0.08	57.23
1951	0.59	20.04	9.97	20.86	4.54	0.05	56.05
1952	0.62	20.63	9.56	27.27	3.62	0.56	62.26
1953	0.50	23.80	8.41	22.84	3.81	0.48	59.84
1954	0.85	24.90	11.04	29.46	4.21	0.13	70.58
1955	0.61	18.65	8.54	23.06	6.57	0.09	57.52
1956	0.53	20.06	14.51	22.11	9.12	0.26	66.59
1957	0.60	17.69	12.25	22.85	7.43	0.04	60.85
1958	0.52	18.49	11.20	24.52	7.60	2.18	64.51
1959	0.67	16.83	13.03	25.36	11.00	4.31	71.20
1960	0.89	18.16	12.72	21.05	12.90	5.90	71.61
1961	0.50	16.08	12.29	23.07	13.28	4.07	69.27
1962	0.45	16.21	13.45	25.96	14.65	12.76	83.47
1963	0.41	16.60	10.45	25.62	16.77	10.81	80.66
1964	0.28	12.96	7.64	31.93	17.30	5.59	75.70
1965	0.21	13.40	12.27	29.08	24.51	5.06	84.54
1966	0.18	12.70	12.25	30.28	19.03	5.34	79.79
1967	0.20	11.76	9.85	24.29	18.16	7.30	71.56
1968	0.14	12.11	6.63	20.25	17.41	7.28	63.81
1969	0.23	15.00	9.79	23.89	15.09	9.50	73.50
1970	0.16	11.73	9.93	23.30	16.21	9.80	71.13
1971	0.32	11.59	7.15	20.74	12.40	14.18	66.37
1972	0.37	11.88	6.54	21.71	10.98	10.69	62.16
1973	0.23	8.24	6.82	17.95	7.49	8.55	49.27
1974	1.00	6.43	6.17	13.50	5.10	8.33	40.54
1975	0.94	9.18	6.93	13.85	4.65	4.28	39.84
1976	0.72	9.51	6.28	14.64	5.20	5.29	41.63
1977	0.70	7.39	3.87	13.02	5.12	4.14	34.24
1978	0.59	6.20	4.82	13.75	3.17	6.38	34.90
1979	0.54	6.84	5.56	17.62	1.33	6.79	38.68
1980	0.52	7.16	4.12	18.44	1.53	9.95	41.72
1981	0.70	7.01	4.87	19.85	2.02	7.62	42.06
1982	0.74	6.60	4.33	18.16	7.04	6.21	43.08
1983	0.81	6.63	7.30	18.15	9.80	8.72	51.41
1984	1.03	10.55	6.86	23.10	8.30	7.89	57.73
1985	1.17	12.33	10.53	24.26	11.86	8.70	68.86
1986	1.41	13.27	12.25	37.92	9.82	11.56	86.23
1987	1.53	14.85	12.31	37.64	9.14	13.00	88.47
1988	1.22	15.28	13.13	46.69	7.40	13.70	97.42
1989	1.30	12.69	11.75	42.11	9.03	12.43	89.29
1990	0.97	11.07	12.42	38.29	11.15	14.36	88.27
1991	0.94	9.76	12.31	34.55	14.48	16.69	88.74
1992	1.16	9.98	12.83	37.11	11.12	17.78	89.98
1993	1.24	13.24	14.36	33.48	9.24	14.39	85.95

TABLE B2. Continued.

Year	2A	2B	2C	3A	3B	4	Total
1994	1.02	12.03	13.46	35.04	5.46	15.18	82.19
1995	1.17	12.56	10.02	26.33	5.00	13.67	68.75
1996	1.16	11.24	11.52	27.81	5.76	14.09	71.59
1997	1.41	14.12	12.67	33.74	10.82	16.97	89.72
1998	1.95	14.90	13.18	33.81	12.88	17.23	93.96
1999	1.80	14.38	12.45	33.05	15.93	20.01	97.62
2000	1.69	12.55	11.19	28.02	17.34	21.74	92.53
2001	2.00	12.03	10.78	29.75	18.53	21.04	94.14
2002	1.93	14.08	11.10	30.00	19.79	20.35	97.25
2003	1.55	13.90	11.56	32.08	19.64	19.29	98.02
2004	1.72	14.64	14.29	35.37	17.49	16.23	99.72
2005	1.91	15.15	14.42	35.84	14.93	16.93	99.18
2006	2.02	14.96	14.09	34.90	12.68	16.00	94.65
2007	1.76	12.58	12.49	36.71	10.84	15.35	89.73
2008	1.68	10.29	10.29	34.00	12.80	15.15	84.21
2009	1.58	8.71	8.15	30.50	12.88	13.82	75.63
2010	1.22	8.77	7.20	28.85	12.16	13.52	71.72
2011	1.09	8.83	4.00	22.76	9.26	12.74	58.68
2012	1.22	7.85	4.81	18.23	6.75	11.93	50.79
2013	1.17	7.75	5.77	17.53	5.41	10.45	48.07
2014	1.16	7.75	6.05	13.88	4.24	9.23	42.31
2015	1.17	8.01	6.52	14.59	3.59	8.23	42.10
2016	1.32	8.13	6.73	13.57	3.84	8.19	41.79
2017	1.46	8.27	6.98	13.47	4.24	7.57	41.99
2018	1.36	7.20	6.31	13.30	3.18	7.40	38.74

TABLE B3. Time-series of mortality by source (million lb, net wt.).

Year	Commercial landings	Commercial discards	Recreational	Subsistence	Bycatch	Total
1888	1.47	0.00	0.00	0.00	0.00	1.47
1889	1.29	0.00	0.00	0.00	0.00	1.29
1890	1.37	0.00	0.00	0.00	0.00	1.37
1891	2.13	0.00	0.00	0.00	0.00	2.13
1892	2.77	0.00	0.00	0.00	0.00	2.77
1893	3.22	0.00	0.00	0.00	0.00	3.22
1894	3.76	0.00	0.00	0.00	0.00	3.76
1895	4.25	0.00	0.00	0.00	0.00	4.25
1896	5.42	0.00	0.00	0.00	0.00	5.42
1897	6.59	0.00	0.00	0.00	0.00	6.59
1898	7.77	0.00	0.00	0.00	0.00	7.77
1899	8.94	0.00	0.00	0.00	0.00	8.94
1900	13.41	0.00	0.00	0.00	0.00	13.41
1901	17.87	0.00	0.00	0.00	0.00	17.87
1902	22.34	0.00	0.00	0.00	0.00	22.34
1903	25.21	0.00	0.00	0.00	0.00	25.21
1904	28.08	0.00	0.00	0.00	0.00	28.08
1905	22.00	0.00	0.00	0.00	0.00	22.00
1906	36.00	0.00	0.00	0.00	0.00	36.00
1907	50.00	0.00	0.00	0.00	0.00	50.00
1908	50.62	0.00	0.00	0.00	0.00	50.62
1909	51.23	0.00	0.00	0.00	0.00	51.23
1910	51.85	0.00	0.00	0.00	0.00	51.85
1911	56.93	0.00	0.00	0.00	0.00	56.93
1912	60.43	0.00	0.00	0.00	0.00	60.43
1913	66.54	0.00	0.00	0.00	0.00	66.54
1914	67.43	0.00	0.00	0.00	0.00	67.43
1915	68.48	0.00	0.00	0.00	0.00	68.48
1916	49.76	0.00	0.00	0.00	0.00	49.76
1917	48.60	0.00	0.00	0.00	0.00	48.60
1918	37.69	0.00	0.00	0.00	0.00	37.69
1919	40.14	0.00	0.00	0.00	0.00	40.14
1920	46.62	0.00	0.00	0.00	0.00	46.62
1921	52.46	0.00	0.00	0.00	0.00	52.46
1922	42.49	0.00	0.00	0.00	0.00	42.49
1923	51.32	0.00	0.00	0.00	0.00	51.32
1924	53.14	0.00	0.00	0.00	0.00	53.14
1925	50.66	0.00	0.00	0.00	0.00	50.66
1926	52.47	0.00	0.00	0.00	0.00	52.47
1927	54.95	0.00	0.00	0.00	0.00	54.95
1928	54.26	0.00	0.00	0.00	0.00	54.26
1929	56.92	0.00	0.00	0.00	0.00	56.92
1930	49.51	0.00	0.00	0.00	0.00	49.51
1931	44.22	0.00	0.00	0.00	0.00	44.22
1932	44.49	0.00	0.00	0.00	0.00	44.49
1933	46.91	0.00	0.00	0.00	0.00	46.91
1934	44.72	0.00	0.00	0.00	0.00	44.72
1935	47.34	0.00	0.00	0.00	0.00	47.34
1936	48.92	0.00	0.00	0.00	0.00	48.92
1937	49.54	0.00	0.00	0.00	0.00	49.54
1938	49.55	0.00	0.00	0.00	0.00	49.55
1939	50.90	0.00	0.00	0.00	0.00	50.90

TABLE B3. Continued.

Year	Commercial landings	Commercial discards	Recreational	Subsistence	Bycatch	Total
1940	53.38	0.00	0.00	0.00	0.00	53.38
1941	52.23	0.00	0.00	0.00	0.00	52.23
1942	50.39	0.00	0.00	0.00	0.00	50.39
1943	53.70	0.00	0.00	0.00	0.00	53.70
1944	53.44	0.00	0.00	0.00	0.00	53.44
1945	53.40	0.00	0.00	0.00	0.00	53.40
1946	60.27	0.00	0.00	0.00	0.00	60.27
1947	55.70	0.00	0.00	0.00	0.00	55.70
1948	55.56	0.00	0.00	0.00	0.00	55.56
1949	55.03	0.00	0.00	0.00	0.00	55.03
1950	57.23	0.00	0.00	0.00	0.00	57.23
1951	56.05	0.00	0.00	0.00	0.00	56.05
1952	62.26	0.00	0.00	0.00	0.00	62.26
1953	59.84	0.00	0.00	0.00	0.00	59.84
1954	70.58	0.00	0.00	0.00	0.00	70.58
1955	57.52	0.00	0.00	0.00	0.00	57.52
1956	66.59	0.00	0.00	0.00	0.00	66.59
1957	60.85	0.00	0.00	0.00	0.00	60.85
1958	64.51	0.00	0.00	0.00	0.00	64.51
1959	71.20	0.00	0.00	0.00	0.00	71.20
1960	71.61	0.00	0.00	0.00	0.00	71.61
1961	69.27	0.00	0.00	0.00	0.00	69.27
1962	74.86	0.00	0.00	0.00	8.61	83.47
1963	71.24	0.00	0.00	0.00	9.42	80.66
1964	59.78	0.00	0.00	0.00	15.91	75.70
1965	63.18	0.00	0.00	0.00	21.36	84.54
1966	62.02	0.00	0.00	0.00	17.77	79.79
1967	55.22	0.00	0.00	0.00	16.34	71.56
1968	48.59	0.00	0.00	0.00	15.22	63.81
1969	58.27	0.00	0.00	0.00	15.23	73.50
1970	54.84	0.00	0.00	0.00	16.29	71.13
1971	46.65	0.00	0.00	0.00	19.72	66.37
1972	42.88	0.00	0.00	0.00	19.28	62.16
1973	31.74	0.00	0.00	0.00	17.53	49.27
1974	21.31	0.20	0.00	0.00	19.03	40.54
1975	27.62	0.31	0.00	0.00	11.91	39.84
1976	27.54	0.34	0.00	0.00	13.75	41.63
1977	21.88	0.29	0.29	0.00	11.78	34.24
1978	22.00	0.28	0.38	0.00	12.24	34.90
1979	22.54	0.30	0.56	0.00	15.28	38.68
1980	21.87	0.30	0.85	0.00	18.70	41.72
1981	25.74	0.35	1.11	0.00	14.86	42.06
1982	29.01	0.40	1.30	0.00	12.37	43.08
1983	38.39	0.53	1.62	0.00	10.88	51.41
1984	44.97	0.72	1.84	0.00	10.19	57.73
1985	56.10	2.70	2.36	0.00	7.70	68.86
1986	69.63	4.65	3.18	0.00	8.76	86.22
1987	69.47	4.20	3.51	0.00	11.28	88.46
1988	74.39	3.49	4.88	0.00	14.66	97.42
1989	66.95	3.46	5.23	0.00	13.65	89.29
1990	61.60	3.40	5.59	0.00	17.68	88.27
1991	57.08	3.47	6.51	2.01	19.67	88.74

TABLE B3. Continued.

Year	Commercial landings	Commercial discards	Recreational	Subsistence	Bycatch	Total
1992	59.89	2.50	6.18	1.11	20.29	89.98
1993	59.27	2.06	7.73	0.93	15.96	85.95
1994	54.73	2.51	7.07	0.93	16.95	82.19
1995	43.88	0.93	7.46	0.54	15.93	68.75
1996	47.34	1.15	8.08	0.54	14.46	71.59
1997	65.20	1.45	9.03	0.54	13.51	89.72
1998	69.76	1.72	8.59	0.74	13.16	93.96
1999	74.31	1.64	7.38	0.75	13.54	97.62
2000	68.29	1.45	9.01	0.76	13.02	92.53
2001	70.70	1.69	8.10	0.77	12.88	94.14
2002	74.66	1.72	8.01	0.77	12.09	97.25
2003	73.14	2.09	9.35	1.38	12.07	98.02
2004	73.11	2.31	10.71	1.55	12.05	99.73
2005	71.82	2.22	10.86	1.54	12.74	99.18
2006	67.98	2.49	10.20	1.48	12.50	94.65
2007	62.87	2.60	11.47	1.49	11.31	89.73
2008	58.57	2.76	10.68	1.34	10.86	84.21
2009	52.05	2.95	8.79	1.31	10.54	75.63
2010	49.72	3.21	7.85	1.24	9.70	71.72
2011	39.51	2.47	7.10	1.15	8.45	58.68
2012	31.99	1.67	6.78	1.15	9.20	50.78
2013	29.04	1.43	7.63	1.13	8.83	48.07
2014	23.70	1.30	7.18	1.20	8.93	42.31
2015	24.67	1.29	7.46	1.20	7.47	42.10
2016	25.05	1.18	7.38	1.17	7.02	41.79
2017	26.17	0.99	7.60	1.17	6.07	41.99
2018	23.50	0.83	7.19	1.17	6.06	38.74

Appendix C

Time series' of fishery catch-rates

TABLE C1. Time-series of commercial fishery WPUE by Regulatory Area (net lb/skate). Years prior to 1984 are based on fishing conducted with "J" hooks.

Year	2A	2B	2C	3A	3B	4A	4B	4C	4D	4E	Total
1907	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	280
1910	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	271
1911	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	237
1912	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	176
1913	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	129
1914	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	124
1915	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	118
1916	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	137
1917	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	98
1918	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	96
1919	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	93
1920	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	96
1921	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	88
1922	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	73
1923	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	78
1924	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	74
1925	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	68
1926	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	67
1927	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	65
1928	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	58
1929	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	51
1930	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	46
1931	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	50
1932	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	60
1933	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	63
1934	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	62
1935	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	76
1936	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	71
1937	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	80
1938	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	88
1939	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	80
1940	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	81
1941	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	85
1942	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	90
1943	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	95
1944	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	110
1945	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	102
1946	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	101
1947	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	99
1948	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	99
1949	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	95
1950	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	95
1951	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	96

TABLE C1. Continued.

Year	2A	2B	2C	3A	3B	4A	4B	4C	4D	4E	Total
1952	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	110
1953	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	131
1954	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	133
1955	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	119
1956	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	129
1957	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	110
1958	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	121
1959	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	129
1960	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	132
1961	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	127
1962	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	115
1963	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	105
1964	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100
1965	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	99
1966	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	100
1967	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	101
1968	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	103
1969	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	95
1970	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	91
1971	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	89
1972	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	78
1973	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	63
1974	59	64	57	65	57	NA	NA	NA	NA	NA	61
1975	59	68	53	66	68	NA	NA	NA	NA	NA	61
1976	33	53	42	60	65	NA	NA	NA	NA	NA	55
1977	83	61	45	61	73	NA	NA	NA	NA	NA	63
1978	39	63	56	78	53	NA	NA	NA	NA	NA	71
1979	50	48	80	86	37	NA	NA	NA	NA	NA	75
1980	37	65	79	118	113	NA	NA	NA	NA	NA	94
1981	33	67	144	142	160	158	99	110	NA	NA	111
1982	22	69	146	168	203	103	NA	91	NA	NA	127
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	63	147	284	502	474	366	161	NA	197	NA	291
1985	62	139	345	500	592	337	234	594	330	NA	351
1986	55	118	290	506	506	260	238	427	218	NA	315
1987	53	130	260	498	478	342	220	384	241	NA	316
1988	134	137	281	503	654	453	224	371	201	NA	363
1989	113	133	258	457	590	409	268	333	432	NA	353
1990	168	176	270	354	484	418	209	288	381	NA	315
1991	158	149	233	319	466	471	329	223	399	NA	314
1992	117	171	230	397	440	372	280	249	412	NA	315
1993	147	208	256	393	514	463	218	257	851	NA	369
1994	93	215	207	354	377	463	197	167	480	NA	302
1995	116	219	234	417	476	349	189	286	475	NA	326
1996	159	227	239	473	557	515	269	297	543	NA	387
1997	226	241	246	458	563	483	275	335	671	NA	400
1998	194	232	236	452	611	525	287	287	627	NA	403
1999	342	213	199	437	538	497	310	271	535	NA	390
2000	263	229	187	443	579	548	320	223	556	NA	399
2001	171	227	196	469	431	474	270	203	511	NA	358

TABLE C1. Continued.

Year	2A	2B	2C	3A	3B	4A	4B	4C	4D	4E	Total
2002	181	223	244	508	399	402	245	148	503	NA	356
2003	173	221	233	485	365	355	196	105	388	NA	325
2004	143	203	240	486	328	315	202	120	445	NA	315
2005	137	195	203	446	293	301	238	91	379	NA	293
2006	156	201	170	403	292	241	218	72	280	NA	267
2007	96	198	160	398	257	206	230	65	237	NA	249
2008	69	174	161	370	234	206	193	94	247	NA	229
2009	98	188	155	318	211	234	189	88	249	NA	220
2010	149	222	158	285	173	182	142	82	188	NA	202
2011	92	240	175	280	140	189	165	75	166	NA	196
2012	102	248	207	263	133	194	149	60	155	108	193
2013	110	246	195	238	112	160	127	56	157	NA	178
2014	106	282	204	234	100	136	146	60	196	NA	183
2015	109	291	212	274	144	156	149	98	164	NA	202
2016	88	288	226	257	150	162	123	73	180	NA	196
2017	95	282	234	268	141	119	120	87	308	NA	202
2018	107	268	206	247	101	111	133	86	185	NA	180