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Historical Coastwide IPHC Stock Assessments: 2006 to 2011 – *Compendium of documents*

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LIST OF DOCUMENTS FOR THE 2006 TO 2011 HISTORICAL COASTWIDE IPHC STOCK ASSESSMENTS

Assessment of the Pacific halibut stock at the end of 2011

Steven R. Hare

Abstract

Since 2006, the IPHC stock assessment model has been fitted to a coastwide dataset to estimate total exploitable biomass. Coastwide exploitable biomass at the beginning of 2012 is estimated to be 260 M lbs, down from the end of 2010 estimate of 317 M lbs. The model variant chosen for the assessment this year differs from the production version of the past few years. Termed “WobbleSQ” (as opposed to the earlier “Trendless”), its treatment of survey q is the only difference between the two models. The downward revision reflects weaker recruitment of the 1989-1997 cohorts, revised WPUE indices based on late-season data in 2010, and the ongoing retrospective behavior shown in the model. Female spawning biomass is estimated at 319 million pounds at the start of 2012, a decline of nearly 9% over the beginning of 2011 estimate of 350 million pounds. The female spawning biomass shows somewhat lesser retrospective behavior, possibly lending credence to our belief that the ongoing declines in size at age, which strongly affect selectivity-at-age, is one of the root causes of the retrospective behavior. Trawl estimates of abundance are similar to assessment estimates in most areas, and also provide evidence that while exploitable biomass and numbers continue to decline, the total biomass and number of halibut remains level, or slightly increasing. The coastwide exploitable biomass was apportioned among regulatory areas in accordance with survey estimates of relative abundance, modified by adjustments for hook competition and survey timing. Weighting of the survey indices follows a Kalman filter analysis, resulting in weights of 75:20:5 for the last three years.

Introduction

Each year the International Pacific Halibut Commission (IPHC) staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial and sport fisheries, other removals, and scientific surveys (Appendix A). A biologically determined level for total removals from each regulatory area is calculated by applying a fixed harvest rate to the estimate of exploitable biomass in that area. This level is called the “constant exploitation yield” or CEY for that area in the coming year. The corresponding level for catches in directed fisheries subject to allocation is called the fishery CEY. It comprises the commercial setline catch in all areas plus the sport catch in Area 2B, and the sport plus ceremonial and subsistence catches in Area 2A. It is calculated by subtracting from the total CEY an estimate of all unallocated removals - bycatch of halibut over 26 inches in length (hereafter, “O26”), wastage of O26 fish in the halibut fishery, fish taken for personal use, and sport catch except in Areas 2A and 2B. In 2010, a change was made in the method by which under 32 inch (U32) bycatch and commercial wastage was accounted for in determination of fishery CEY (Hare 2011a). Until 2010 all U32 bycatch and wastage mortality (BAWM) had been accounted for in the determination of the target harvest rate, which had been set at 0.20 for Area 2A, 2B, 2C and 3A and 0.15 in area 3B and 4. The new accounting methodology directly deducts BAWM between 26 and 32 inches (O26U32) from total CEY to determine fishery CEY. The new target harvest rates accompanying this change were set at 0.215 and 0.16125, replacing the old values of .20 and 0.15, respectively. Staff recommendations for catch limits in each area are based on the estimates of fishery CEY but may be higher or lower depending on a number of statistical, biological, and policy considerations. Similarly, the Commission's final quota decisions form the management targets for the coming year and are based on the staff's recommendations but may be higher or lower.

For many years, the staff assessed the stock in each regulatory area by fitting a model to the data from that area (Appendix B). This procedure relied on the assumption that the stock of fish of catchable size in each area was closed, meaning that net migration was negligible. A growing body of evidence from both the assessments (Clark and Hare 2007) and a mark-recapture experiment (Webster and Clark 2007, Webster 2010) showed that there is a continuing and predominantly eastward migration of catchable fish from the western area (Areas 3 and 4) to the eastern side (Area 2). The effect of this unaccounted for migration on the closed-area stock assessments was to produce underestimates of abundance in the western areas and overestimates in the eastern areas. To some extent that had almost certainly been the case for some time, meaning that exploitation rates were well above the target level in Area 2 and a disproportionate share of the catches had been taken from there.

In order to obtain an unbiased estimate of the total exploitable biomass (EBio), beginning with the 2006 assessment, the staff built a coastwide data set and fitted the standard assessment model to it. Exploitable biomass in each regulatory area was estimated by partitioning, or apportioning, the total EBio in proportion to an estimate of stock distribution derived from the IPHC setline survey catch rates (WPUE). Specifically, an index of abundance in each area was calculated by weighting survey WPUE by total bottom area between 0 and 400 fm (Hare et al. 2010). The logic of this apportionment is that survey WPUE can be regarded as a fishery-independent, consistent and relatively unbiased index of density, so multiplying it by bottom area gives a quantity proportional to total abundance. Beginning in 2009 two adjustments to the index for each area, one based on hook competition and the other on survey timing, were computed for use in biomass apportionment (Webster and Hare 2011). The staff's Catch Limit Recommendations are based on use of both adjustments. New in 2010 was a change to the weighting which has been used for the last several years of survey WPUE. Based on a statistical analysis of relative variability within a year compared to variability between years (Webster 2011), the new weighting places far more emphasis on the most recent year than was the case previously. The new "Kalman" weights are in the ratio of 75:20:5 for the past three years WPUE values (after adjusting for hook competition and survey timing). The estimated proportion in each area is then the adjusted and weighted index value for that area divided by the sum of the adjusted and weighted index values.

An alteration to the method by which individual regulatory area data are weighted to produce the coastwide dataset was implemented this year. Two types of data weighting are used, depending on the data type: "area-weighting" and "abundance-weighting" (Clark and Hare 2007). Area weighting uses the relative amount of bottom area to weight the individual datasets; WPUE time series are an example of data for which area-weighting is appropriate. Abundance weighting refers to the weighted-average of area specific data with weights computed as bottom area times survey NPUE. Age/sex compositions and mean length at age/sex are data for which abundance-weighting is appropriate. Until this year, all weighting used the 0-400 fm bottom areas and unadjusted survey NPUEs. This year, four different combinations of bottom area and survey adjustments were used, each matched to the apportionment choices used at the estimation of regulatory area EBio distribution stage (for determination of total CEY). The apportionment scenarios involved using either 0-400 fms or 20-275 fm definitions of bottom area, as well as using (or not using) the survey hook correction and survey timing adjustments. The differential weightings produce coastwide datasets that differ slightly and therefore produce slightly different model fits. The output of greatest concern – EBio – varied by a maximum of 1-2% among the different data weightings. The weighting, and that used in the Catch Limit Recommendations, is that adopted by the Commission in 2010 and uses the 0-400 fm bottom area definition and survey WPUE adjustment for hook competition and survey timing.

Changes to the assessment and apportionment in 2011

The following summarizes changes, additions, and updates to the 2011 assessment and apportionment procedures, compared to the previous halibut assessment (Hare 2011b)

- 2011 survey, commercial, bycatch, sport, personal use and wastage data added
- The Area 2B survey WPUE was modified slightly by removing, from the mid-1990s, stations on Dogfish Bank, which are outside the area where the current survey design is implemented (Webster and Hare 2012)
- Swept area estimates of Total (TBio) and Exploitable Biomass (EBio) from independent trawl surveys are updated for several regulatory areas.
- A definition of bottom area, reflecting the present survey design, of 20-275 fathoms was used as an alternative apportionment scheme
- Weighting of the regulatory area input datasets in constructing the coastwide dataset now reflects the combination of WPUE adjustments and choice of bottom area used for different apportionment schemes

Observations from the survey, commercial and other fisheries

The IPHC collects data from a variety of sources to characterize the fishery, status and population trends in all regulatory areas, and assist in fitting a population assessment model. Some of the more important datasets are summarized herein.

Halibut removals

Total removals from the halibut populations come from five categories: commercial catch (IPHC survey catch is included in this category), sport catch, bycatch (from a variety of fisheries targeting species other than halibut), personal use, and wastage from the commercial fishery. Bycatch and wastage are subdivided into O26 and U26 components as the U26 components are not used for purposes of determining fishery CEY (they are factored into the harvest rate). Detailed descriptions of each category are contained in the Fishery Removals section of the annual Report of Assessment and Research Activities (Gilroy et al. 2011). The 2011 regulatory area total removals are illustrated in Figure 1, coastwide total removals from 1935 to 2011 are illustrated in Figure 2, and regulatory area total removals for 1974-2011 are illustrated in Figure 3 (and listed in Appendix Tables A1-A8). On a coastwide basis, total removals are at their lowest level since 1984 and commercial removals at their lowest point since 1983. For temporal context, total removals are about 40% below the peak of the 1990s and about double the lowest value seen in the late 1970s. The pattern of changes between the mid-1980s removals and 2011 removals has been quite different among regulatory areas, however.

Definition of bottom area

The definition of halibut habitat is important to the process of apportioning coastwide biomass. It also plays a role in weighting various regulatory area datasets to construct the coastwide dataset used in fitting the stock assessment (Clark and Hare 2007). Until 2009, halibut habitat was defined as all bottom area between 0 and 300 fathoms. While the setline survey restricts stations to a range of 20-275 fm, the mean density estimates are applied to the larger habitat definition. A recent review of commercial landings revealed that commercial fishing for halibut is increasingly operating in waters deeper than 300 fm (Hare et al. 2010). Correspondingly, beginning in 2010, we expanded the definition of halibut habitat to 400 fm. In 2009, for the first time, the Area 4 island stations (termed Area "4I") were indexed separately from the Area 4D edge and the Area 4 continental shelf. However, as the station density differs between the Pribilof Island stations (termed "Area 4IC") and the St. Matthews island stations (termed "Area 4ID"), they are now indexed separately. It is conceivable that applying density estimates from the narrower, surveyed range of 20-275 fm to the broader, defined habitat, range of 0-400 fm results in a bias that differs by area. Staff designed and operated an expanded survey in Area 2A this year to better understand the operational constraints involved with operating our standard survey in both shallower (10-20 fm) and deeper (20-275 fm) waters (Webster et al. 2012). The bottom area computations and totals are described in Hare et al. (2010) and the square nautical miles of habitat are listed in Table A9.

Treatment of Area 4CDE

Due to its large size and relatively low density of halibut, Area 4CDE does not have a grid of setline survey stations across its entire range. Since 2000, the IPHC setline survey has included 48 stations along the 4D Edge at depths between 75 and 275 fm. Since 2006, 29 stations have been surveyed annually around the Pribilof Islands and St. Matthew Island. Extensive use is also made of the data from the NMFS annual Eastern Bering Sea trawl survey. Finally, a unique grid survey, comprised of 82 stations including matching a subset of the NMFS trawl survey stations, was carried out in 2006 over the southern Eastern Bering Sea shelf (Soderlund et al. 2007). Finally, a unique grid survey, comprised of 82 stations was carried out in 2006 over the southern Eastern Bering Sea shelf (Soderlund et al. 2007).

To construct a comprehensive and representative dataset for Area 4CDE, five subareas are indexed and then weighted by bottom area to compute indices of interest, similar to those computed for the other regulatory areas. The 4D Edge, with 48 setline survey stations, covers 15,313 nmi^2. Beginning in 2009, the 4CDE island stations were used to index the bottom area around the islands, and are separated into two groups. The first are the stations around the Pribilof Islands, operationally (though not officially) referred to as Area 4IC, which comprise 2,094 nmi^2. The other stations, around St. Matthew Island are operationally referred to Area 4ID and comprise 1,925 nmi^2. The reason for separating the groups of islands is that the station density differs; Area 4IC islands are on an approximately 7 nmi^2 grid, while the Area 4ID stations are on a 10 nmi^2 grid. The Bering Sea flats comprise the remainder of the Area 4CDE and, as of 2009, extend northwards to 65.5°N - though constrained on the western boundary by the International dateline. This region is operationally (again, not officially) split into Area 4N, which represented 59,499 nmi^2 and Area 4S, which represents 141,103 nmi^2. The areas differ slightly from the 2009 values as a result of the new NMFS northern shelf survey (discussed below). The boundaries for the five Area 4CDE areas are illustrated in Figure 4. Density estimates for the five areas all rely on surveys - Areas 4D

Edge, 4IC and 4ID on the IPHC setline survey; Areas 4S and 4N on trawl surveys as discussed in the next section.

NMFS and ADFG trawl surveys

Bering Sea

Every year, the IPHC places a sampler aboard the National Marine Fisheries Service (NMFS) Eastern Bering Sea (EBS) groundfish/crab trawl survey. The sampler collects biological data on the halibut catches, taking lengths of almost all halibut caught and selecting a subsample for aging. The 2011 effort is described in Sadorus and Lauth (2012). The catch rate of halibut (all sizes) on the NMFS EBS trawl survey is illustrated in Figure 5. Due to the high cost, and very low catch rate, of setline surveying halibut in the EBS, the IPHC does not conduct the Standardized Stock Assessment (SSA) grid survey in that region. While the IPHC survey does operate along the Area 4D shelf edge, that region is not indicative of densities and trends across the broad shelf. For the purposes of apportionment, it is vital that a measure of density for the EBS shelf be derived each year, and the NMFS groundfish trawl survey is leveraged to allow just such an estimate. The traditional NMFS survey (i.e., as operated from 1982-present) generates swept area estimates of abundance for the southern part of the EBS shelf (equivalent to operational IPHC area 4S). In 2006, the IPHC added 100 extra stations to the SSA grid survey and placed these across the shelf in conjunction with a subset of the NMFS stations to get an estimate of shelf-wide density (Soderlund et al. 2007). In that year, mean density was estimated to be 18.1 pounds per standardized survey skate. It is important to note that the value of 18.1 represented a weighted average of a value of 16.8 lbs for the shelf and 76 lbs/skate for the 4I stations. Starting in 2009, we have used the value of 16.8 lbs/skate as the standard O32 halibut density for Area 4S in 2006. Beginning in 2010, Area 4S comprises the part of the shelf covered by the traditional NMFS EBS shelf survey (see Fig. 4) and thus includes the southern parts of IPHC regulatory areas 4D and 4E. This differs from the definition of Area 4S utilized in 2009. The reason for the change is that starting in 2010 the NMFS expanded the EBS trawl survey north to 65.5 °N and covering the entire remainder of the EBS shelf. Part of the expanded NMNFS survey region was previously included with Area 4S but is now included as part of Area 4N (discussed below).

The 2006 setline estimate of Area 4S density is tied to the NMFS trawl survey to provide an annually varying estimate based on the following approach. From the NMFS trawl survey we obtain swept-area estimates of abundance at length. We then apply the stock assessment estimated survey selectivity at length schedule to the full catch to provide an index of survey catch rate, comparable to the SSA survey fishing gear. Figure 6 illustrates how the length frequency distribution resulting from this treatment of trawl survey data compares to the actual length frequencies collected in the 2006 IPHC special EBS setline survey. In this manner we are able to obtain, for a small fraction of the cost it would take to survey the southern EBS with a setline survey, a highly reliable index of halibut abundance across the EBS flats. Figure 7 provides an illustration of the time trend in abundance estimated from the trawl survey. In 2008, the index was at its lowest point since the mid-1980s, but the subsequent two years showed an increase of more than 50% over the 2008 value, before declining 20% this year. Figure 8 provides an illustration of the size composition of the Area 4S EBio. The index of total halibut biomass, has been increasing steadily since 2002, and had reached its highest level in the history of the trawl survey in 2010, before dropping 4% in 2011. The length frequency data indicate very large numbers of U32 fish across the southern EBS shelf (Fig. 9).

In 2009, the EBS shelf area north of 61°N was added to the definition of halibut habitat in Area 4CDE. However, as this northern shelf undoubtedly has a different (i.e., much lower) halibut density than the southern shelf, a different means of estimating density needed to be established. Fortunately, there has been an approximately triennial trawl survey, conducted in a similar manner to the 4S survey with a similar net, in the greater Norton Sound area since 1976. The survey was conducted by NMFS until 1991 and since then by the Alaska Department of Fish and Game (ADFG). In all, there have been surveys conducted in 1976, 1979, 1982, 1985, 1988, 1991, 1996, 1999, 2002, 2006, and 2008). There has been no formal analysis of the halibut data from the survey; however, ADFG provided us with the raw catch rate (WPUE) data at all stations fished each year. The survey has been conducted each time in a core area (indicated by the Norton Sound outline in Figure 4) as well as opportunistic stations often well away from Norton Sound. In 2009, in order to create a consistent index for Area 4N across years, we selected just the stations within the core area and calculated a simple mean value and its standard error (Fig. 10a). This index has units of kg of halibut per km^2 area swept. As there are no sample data, we are unable to derive an O32 index similar to that derived from the NMFS trawl survey. To create a density index comparable to the other IPHC areas (i.e., O32 lbs/standard skate), we proceeded in the following manner.

1. Compute mean density (and standard error) for each Norton Sound ("Area 4N") survey year
2. Compute mean density in NMFS southern shelf trawl survey ("Area 4S") for the same years and in the same units.
3. Regress the square root transform of 4N density on the square root transform of the 4S density and use the regression parameters to estimate density in the unsurveyed years for 4N
4. Transform the estimates back to their original scale and retain the actual survey values in the years a survey was conducted in 4N (rather than use the predicted values)
5. Construct a standard IPHC density index (lbs/skate) by multiplying the 4S index by the ratio of the 4N trawl density index to the 4S trawl density index.
6. Compute average density for survey stations within the Norton Sound core area for the 2010 expanded NMFS trawl survey.
7. Scale the Norton Sound WPUE time series by the ratio of the full 2010 NMFS expanded survey density to the Norton Sound core area average density. In 2010, average density in the Norton Sound core area was 136.0 kg/km^2 while average density across the entire expanded survey area was 119.0 kg/km^2, resulting in a scalar of 0.875 applied to the Norton Sound WPUE index.

This procedure makes several assumptions, most stringently that density trends in 4N and 4S, as well as in the Norton Sound core area and 4N, vary synchronously. Consideration of the years with actual survey data shows this to be a reasonable assumption and the square root transform down weights the single very large 4N data point of 1996 to achieve a closer match. The end result (Fig. 10b) is a density estimate comparable to the other IPHC areas. In general, 4N density averages 1/3rd to 1/10th of 4S density. As 4S is more than twice as large as 4N, the relative amount of overall added biomass to 4S is relatively minor (Fig. 10c). More importantly, all halibut are accounted for in Area 4CDE up to 65.5°N.

Gulf of Alaska/Aleutian Islands

Additionally, this year, the NMFS also operated their biennial Gulf of Alaska survey (Sadorus and Paulsson 2012, Figs. 11a-c). The triennial Aleutian Islands survey was not conducted this year, however it is used in a comparison of NMFS trawl and IPHC assessment biomass estimates (discussed later). In the Gulf of Alaska, swept area estimates of total biomass and total numbers of halibut (Fig. 12) showed a decline from the high levels seen in the 2009 survey. The large confidence intervals preclude determination of a statically significant trend but appear to indicate relatively level total abundance over the 1993-2011 time period. Trends in Gulf of Alaska exploitable biomass and exploitable numbers are, however, much more evident (Fig. 13). Area 3B has declined steadily since the peak in 1999, while 3A has declined steadily since the peak there in 2003. Due to the difficulty of trawling in many parts of 2C, it is questionable how representative the trawl survey is of halibut abundance in that region.

Alaska trawl swept-area estimates of abundance

The swept-area estimates of abundance derived from the three NMFS trawl surveys (Bering Sea, Gulf of Alaska, Aleutian Islands) are a valuable independent indicator of long-term trends in halibut biomass. While the survey regions do not correspond precisely to IPHC regulatory areas nor are the trawl surveys each conducted in all years, nevertheless it is useful to illustrate the abundance trends. Figure 12 illustrates the trawl swept area estimates of total numbers and total biomass, assembled into IPHC regulatory areas. Details of the area compilations and illustration of EBio trends are contained later in the document, in the section comparing assessment and trawl abundance estimates.

IPHC setline survey

The current SSA survey has been conducted since 1996 in almost all areas and in all years. A triangular design was used in 1996 and 1997, with the current 10 nmi regular grid used from 1998 to the present. Areas and years not surveyed are: the Eastern Bering Sea shelf which was surveyed only in 2006; Area 2A which was not surveyed in 1996, 1998, and 2000, the Area 4D edge which was not surveyed in 1996, 1998 and 1999, and Area 4A and 4B which were not surveyed in 1996. Setline surveys were conducted in Areas 2B, 2C, and 3A on a semi-regular basis between 1977 and 1986 before being discontinued for a decade. The surveys prior to 1984 used “J” hooks while all surveys from 1984 onwards were based on use of “C” hooks. In its current configuration, stations are placed on a 10-nautical mile grid between depths of 20 and 275 fm, resulting in a total of approximately 1280 stations. The 2011 SSA survey is fully described in White et al. (2012). A key indicator of stock status in each regulatory area is the weight of O32 halibut caught per standardized skate, termed the survey WPUE (Fig. 13 and Appendix Tables A9a and A9b). Survey WPUE has declined by over 50% on a coastwide basis over the past 10 years. While the rate of decline has differed among areas, there has been a substantial decrease in WPUE in all areas, indicative of a consistent coastwide decline in exploitable biomass. As described earlier, Area 4CDE is assembled from five subareas. The derived WPUE indices from each of those areas are each weighted by its respective bottom area to construct the single Area 4CDE WPUE time series shown in Figure 14. Note that this particular representation uses the 0-400 fm bottom are definition to compute the weighted average values for Area 4CDE as well as the coastwide Total value. A different perspective on the trend over time of survey catch of halibut is provided in Figure 15; this figure shows the trend in total numbers caught on the setline survey (per unit effort, NPUE).

The survey catch of halibut is sampled to obtain biological information about the stock including sex and age distribution and is described in Forsberg (2012a). The 2011 age distributions for males, females, and sexes combined for all regulatory areas are plotted in Figure 16. The age structure of the population is of considerable interest for a variety of reasons. These distributions indicate the relative abundance of fish available to the fishery, relative contributions to the female spawning biomass, etc. In 2011 as in the last several years, there is a general tendency for an older age structure in the western areas, relative to the eastern areas. In particular, the lack of fish older than 20 years is noted for Area 2. Areas 3B and 4A present somewhat anomalous age distributions in that they more closely resemble Area 2 than Area 3A or most Area 4 distributions. At least part of the explanation for the higher number of young fish may be that the settlement of juveniles from Gulf-wide spawning occurs primarily in these areas. In 2009, a reduced harvest rate was (of 0.15) was implemented in Area 3B in part based on the more truncated age distribution. Survey age-specific catch rates (Fig. 17) provide a means of gauging historic year class strength. Note that the age-specific catch rates are affected by the change in size at age thus the survey indexes numbers of fish selected to the gear and not necessarily total numbers of fish in the population compared across years. The very strong 1987 and 1988 classes are readily apparent in Figure 17. Optimistically, it appears that the 1999 and 2000 year classes are now entering the survey catch at the larger rates the assessment model has been predicting the last few years. The declining size at age is likely responsible for the delay in recruiting to the survey and it may still be a few years before these two year classes enter the commercial fishery in proportion to their overall numbers in the population.

Commercial fishery

The second major component of the annual IPHC data collection is sampling the commercial catch. The port sampling program is detailed in Erikson and MacTavish (2012) and age sampling in Forsberg (2012b). From commercial fishing logs, commercial CPUE is computed for each regulatory area (Fig. 18 and Appendix Table A10). As with the survey WPUE, there has been a consistent coastwide decline in commercial WPUE though not quite as pronounced. This is not unexpected however, as commercial fishers tend to move their effort to maintain their catch rate, whereas the survey maintains the same fishing locations every year. Approximately 1500 otoliths are collected and aged from each regulatory area (smaller samples in Areas 2A and 4B). Because commercially-caught halibut are gutted at sea, the sex of halibut is unknown when sampled at the port of landing. A statistical methodology has been developed, based on sex ratio at length in survey catches, to parse out male and female proportions at age (see Clark 2004). The estimated sex and age composition of the commercial catch, by regulatory area, is illustrated in Figure 20. It is important to note that the distribution of ages for the total (sexes combined) is not statistically estimated (the distribution represents the otolith readings); it is the sex-specific distributions that are statistically derived. As with the survey age samples, the fish in Area 2 are, on average, several years younger than fish caught in Areas 3 and 4. Here, as well, Area 3B (but not Area 4A) is anomalous in that the average age of fish is closer to the Area 2 average.

Part of the coastwide decline in exploitable biomass can be attributed to a decline in size at age. For a given number of halibut in the population, a smaller size at age results in a smaller cumulative biomass. Figure 20a shows how the average weights of halibut in survey and commercial catches have changed over the past 12 years. Average weight has declined by 25% in the survey catches and 33% in the commercial catches. While the decline could be due to a decline in average age of the fish in the catches (since younger fish are smaller), Figure 21b shows this has not been the case, as average ages in both the survey and commercial catch have not declined at nearly the same rate. Trends, by regulatory area, in average age and average weight are illustrated in Figure 21.

Lost yield from U32 bycatch

In 2009, a methodology was developed to estimate yield loss from bycatch in the non-directed fisheries (Hare 2010). Bycatch, which is unsexed but for which length samples are available, was partitioned into age and sex components and a life history simulation model then produced estimates of how much yield was lost to the directed commercial fishery, in units of pound of lost yield per pound of U32 bycatch. The yield loss ratio in general is around one pound per pound but varies by regulatory area, depending both on the size of the bycatch when taken as well as the size at age of halibut when taken in the commercial fishery. Figure 22 updates the lost yield computations from Hare (2010). Neither these, nor the previous calculations in Hare (2010) factored migration into the estimates, which has the effect of "spreading" the lost yield downstream from the area of capture. Work on evaluating the effect of migration on downstream distribution of lost yield is reported in Valero and Hare (2010 and 2011).

Description of the assessment model

The current halibut assessment model has remained essentially unchanged since 2003. It has been thoroughly described in an IPHC Scientific Report (Clark and Hare 2006) and was subjected to a peer review by two external scientists from the Center for Independent Experts (IPHC 2008). Since the Commission's acceptance of a coastwide stock assessment model, much of the focus of the staff and the industry is now on how the coastwide estimate of exploitable biomass is apportioned among regulatory areas. For both these reasons, the assessment model for 2011 is identical to that used for the last several assessments. In the interest of brevity, little discussion is presented here of the model itself. Interested readers are referred to Clark and Hare (2006, 2007, and 2008) for full details.

The IPHC assessment model is age- and sex-structured. Commercial and survey selectivities are both estimated as piecewise linear functions of observed mean length at age/sex in survey catches. (There is a 32-inch minimum size limit in the commercial fishery.) Commercial catchability is typically allowed to vary from year to year with a penalty of 0.03 on log differences. Some variation in survey catchability between years has been allowed in production fits since 2006. The model is fitted to commercial and survey catch at age/sex and CPUE.

Until 2006, estimates of halibut abundance were made using closed-area models for all areas except Areas 2A and 4CDE. Area 2A leveraged the Area 2B assessment and relative survey WPUE, while Area 4CDE relied upon the NMFS EBS trawl estimates of swept area abundance. The closed-area models are not considered reliable due to violation of the closed-population assumption. Due both to time constraints, as well as lack of confidence, we no longer fit or produce biomass estimates from the closed area models. The coastwide model has considerable more flexibility than the closed-area models, including sex-specific catchability, selectivity, and natural mortality parameters; it is fitted to CPUE (WPUE and NPUE) at age/sex (rather than just total CPUE), uses weaker selectivity smoothing, and neutral data weighting. Finally, and perhaps most importantly, the coastwide data set is far less noisy than the closed area datasets and fits to the data provide more confidence in the results than was the case for closed-area model results.

Alternative model fits

As has been done the past few years, several variants of the basic assessment model were fitted. Differences among most of the models concerned how survey and commercial catchability (generally termed "q") were parameterized. An additional model was fitted that excluded commercial CPUE, and is considered similar to many of the NMFS groundfish assessment models. The models are summarized as such:

(Trendless, also referred to as Base 2010) Survey q is allowed to vary annually, subject to a penalty on the amount of variation, but has an additional requirement that a regression of estimated survey catchability on year have zero slope. This was the selected production model since between 2007 and 2010.

(Vanilla, Alt. 1) Survey q constant: catchability is a single fixed (though estimated) value in all years.

(WobbleSQ, Alt. 2) Survey q drift: survey catchability estimated for each year, but (new this year) was allowed to drift freely. This resulted in a better fit, and lower EBio estimate (by 10 million pounds) than placing a penalty on the amount of "wobble", as was done the last few years.

(NMFS, Alt. 3) Survey q trendless drift (i.e., Base2010 model) but Commercial CPUE is disregarded.

(CAGEAN, Alt. 4) This is similar to the old IPHC CAGEAN model. Only commercial data are fitted and commercial q is allowed to drift.

Table 1 shows features of the Base2010 model fits as well as the alternatives. The differing trends in survey and commercial q are illustrated in Figure 23. The best fit, indicated by a ΔAIC score of zero is Alternative 2 (WobbleSQ) model. The next best fit is provided by the production model used the past four years, the survey q trendless drift (Base2010) model. The three other model fits are significantly worse. The range of exploitable biomass estimates produced by the five models is relatively narrow: 260 to 289 M lbs, a considerably lower range than produced by the 2010 assessment model variants which produced a range of 266 to 330 M lbs. In a departure from last year, the WobbleSQ model was allowed to have an unconstrained survey q. In previous years, the amount of drift in survey q was controlled by a penalty on year-to-year relative changes. Because the WobbleSQ model has consistently differed from the Trendless model in the time trajectory of survey q, I opted to allow the extra freedom in the parameter. The resulting model fit was superior to one with the usual constraint on survey q (lower AIC of 10) and produced an estimate of EBio of 260 M lbs, compared to a value of 270 M lbs for the constrained version of WobbleSQ.

In previous years, we have selected the Trendless model as the basis for apportionment, despite the fact that WobbleSQ was generally the better fitting model (as measured by AIC). In the 2011 assessment, Trendless was only two AIC points higher than WobbleSQ so it was retained since a difference of two is not large enough to eliminate a model from contention. Further, the argument that has long been made is that a great deal of effort goes into standardizing the survey and we have no ancillary indications of long-term changes in the catchability of the survey. However, the superior fit of the unconstrained WobbleSQ model, and its more conservative estimate of EBio, tips the scale in favor of using WobbleSQ as the production model for the 2012 Catch Limit Recommendations. In the interest of completeness and comparability, all biomass and yield calculations are done for both the WobbleSQ and Trendless models.

As part of the work to identify the cause of the retrospective behavior of the halibut assessment model (discussed below), a large number of variants of both models were fitted. A total of 16 different variants, each involving the change of a single model parameter or data weighting, were fitted and the resulting estimates of EBio and SBio tabulated. The point of the exercise, besides attempting to identify the cause of the retrospective behavior, was to illustrate the sensitivity of the model to different parameterizations and illustrate the amount of uncertainty that is due to model structure. The 16 variants are listed, and briefly described, in Table 2. The range of EBios for the 16 variants was considerably broader than the range of EBios for the five main candidate models.

Effect of the 2011 data on abundance estimates

Coastwide survey WPUE declined by 5% and commercial WPUE increased by 1% from 2010 to 2011 (Figs. 12 and 16; Appendix A tables A9 and A10). It must be noted, however, that the 2010 commercial WPUE value was revised downward from a value of 232 pounds/skate to a value of 210 pounds/skate as a result of including late arriving data not available at the time the dataset was locked for the 2010 assessment. This single change caused the Base2010 estimate of EBio of 317 M lbs to be revised downwards to a value of 292 M lbs. The 2011 assessment further reduces the estimate of EBio at the beginning of 2011 to 245 M lbs. The EBio estimate from the Trendless (Base2010) at the beginning of 2012 is then estimated to be 288 M lbs, for a total downward revision of 9% between the (original) 2011 beginning of year estimate and the 2012 beginning of year estimate. As noted earlier, the staff's recommended model this year is the WobbleSQ model and the sequence of revised EBios for this model is as follows: The original beginning of year EBio (from the 2010 assessment) was 295 M lbs, which was revised downwards to 267 M lbs with the 2010 dataset update. The 2011 assessment further revises that value downwards to 223 M lbs which compares to an estimated value of 260 M lbs for the beginning of 2012. Table 3 contains a summary of these changes. Note the estimated biomasses for beginning of year 2012 assume no size at age change between 2011 and 2012, an assumption which may well not hold true given the ongoing decline in size at age.

Evaluation of the assessment

Quality of fits

The WobbleSQ model fits survey NPUE at sex/age (Fig. 24), commercial catch at age (Fig. 25) and commercial NPUE at sex/age (Fig. 26) very well. There is no apparent pattern to the residuals from the fits, although the model initially underestimates slightly the early strength of the 1987 year class. The model fits the increasing number of fish aged 25 and older, particularly males, which are appearing in both the survey and commercial catches. The very low growth rate for male halibut means that many are not recruiting to the fishery until they are older than 25. This "plus" group is poised to increase even more in the new few years as the remains of the very large 1987 and 1988 year classes reach 25 years of age. The series of total survey and commercial NPUE and WPUE are also predicted closely (Fig. 27, middle panel).

Coastwide estimates of recruitment, exploitable biomass and spawning biomass

Exploitable biomass (EBio) at the beginning of 2012 is estimated to be 260 million pounds and female spawning biomass (SBio) is estimated to be 319 million pounds. Estimated EBio is down by about 18% from the beginning of year 2011, while SBio is about 9% lower than the

2011 beginning of year value estimated in the 2010 assessment. Note that the beginning of year 2011 values and the beginning of year 2012 values derive from different variants of model, which accounts for some of the inter-year decline (the inter-year decline for the same model as used for the 2010 assessment was 9%). EBio and SBio are both estimated to have declined continuously between 1998 and 2007 (Fig. 27, top right panel). EBio continued to decline until 2009, the model estimates that both are now on the increase, with SBio bottoming out in 2007 and EBio bottoming out in 2009. This differs slightly from the 2010 assessment in terms of when the turnarounds in decline for both EBio and SBio began. This point is discussed more fully in the Retrospective performance section. Recruitment (measured as age-eight fish in the year of assessment) has varied between 7 and 33 million halibut since the 1988 year class, with a mean of 17.9 million. The 1989 to 1997 year classes, presently 14 to 22 years old and the main target of the commercial fishery for the past several years, are all estimated to have been below average, with several of the year classes substantially below average (Fig. 27, top left panel). The sharply declining biomass over the past decade has resulted from these small year classes, in combination with reduced growth rates, replacing earlier year classes that were much larger, especially the 1987 and 1988 year classes. The projected increase in 2012 biomasses can be attributed, in large part, to the incoming 1998 through 2003 year classes that are estimated to be well above average, particularly the 1999 and 2000 year classes. The extent to which these year classes will contribute to EBio over the next few years depends on the growth rate which, as has been frequently noted, continues to decline.

The annual stock assessment produces an estimate of the total number of male and female halibut, ages 6 and older, in the ocean (Fig. 28, top panel). The time series of abundance shown in Figure 28 illustrates the strength of the celebrated 1987, and to a lesser extent 1988, year classes. As was the case year, the current assessment indicates that three large year classes – 1998, 1999, and 2000 – have entered the exploitable biomass and should be the largest contributors to the EBio and catch over the next few years. Presently, all three year classes are estimated to be larger – in terms of numbers – than the 1987 and 1988 year classes but we caution that their strength is not well determined and note that retrospective downward revisions of initial estimates are common to this class of models. However, it is important to note that size at age is much smaller now than it was 20 years ago. This has two important ramifications – first it means that the three strong year classes are only just beginning to reach the exploitable size range and, therefore, their true numbers in the population are still quite uncertain. Second, it also means that for a given number of halibut, their collective biomass will be far smaller than the 1987 and 1988 year classes (Fig. 28, bottom panel). Currently, a large fraction of males never reach the minimum size limit and thus never enter the exploitable biomass. It remains to be seen just how these year classes will develop into the exploitable component of the stock.

The estimated age composition of the coastwide spawning biomass shows a broad range of ages including 4% females age 20 and older (Fig. 29). While the age distribution is certainly truncated due to the size-selective effects of fishing, it is encouraging that production of eggs is not confined to a narrow range of ages and should ensure that adequate reproductive potential remains in the ocean for the foreseeable future. On an area-by-area basis, there are some departures from this pattern, particularly in Areas 2 and 3B which show a lower percentage of older females (See the Area summaries section).

Estimates of uncertainty

There are a number of ways of estimating the uncertainty associated with a given model fit and biomass estimate. They are all unsatisfactory in that they are conditioned on the correctness of the model when in fact it is the choice of one model rather than another that is the major source of uncertainty in assessments. This is well illustrated by the difference in area-specific biomass estimates between the coastwide and closed-area fits of the IPHC model as reported in past years. One standard method of illustrating uncertainty around an estimate, for a given model, is the likelihood profile. The bottom panels in Figure 27 show the likelihood profiles for both the exploitable biomass as well as the female spawning biomass for the WobbleSQ model. The 95% confidence interval (C.I.) for EBio is 187 to 342 million pounds, while the 95% C.I. for the female spawning biomass is 228 to 423 million pounds. Confidence intervals for the recruitment estimates were also computed and are plotted with the recruitment estimates (Fig. 27, top panel). For comparison purposes, the 95% C.I. for the alternative model fits described above are plotted in Fig. 30. The means of both EBio and SBio for all the alternative model fits lie within the 95% C.I. of the WobbleSQ (production) model estimates.

In addition to the standard variants, this year an additional 16 variants were fitted as part of an ongoing attempt to diagnose the cause of the production model's retrospective behavior (discussed below). The 16 variants involved changing a single parameter, or data or penalty, but keeping all other aspects of the model the same. The resultant EBio and SBio estimates are plotted as numbered circles on Figure 30. The same set of 16 variants was also run using the Trendless (Base2010) model as the base model (Fig. 31). While the exercise yielded no insight to the cause of the retrospective behavior, it does help to further illustrate the level of uncertainty that is associated with a biomass estimate from a stock assessment model. In particular, natural mortality can wield a large influence on biomass estimates and, in the case of both the WobbleSQ and Trendless models, yields a substantially lower estimate of EBio.

Retrospective performance

Each year's model fit estimates the abundance and other parameters for all years in the data series. One hopes that the present assessment will closely match the biomass trajectory estimated by the previous year's assessment. To the extent that it does not, the assessment is said to have poor retrospective performance.

Halibut assessments have exhibited retrospective behavior going back to the 1980s and the original catch-at-age mode, CAGEAN. The current assessment model, developed in 2003, has shown various levels of retrospective behavior since its development (Clark and Hare 2006). For the last several years, the assessment has revised downward the previous several years' exploitable biomass estimates (Fig. 32a), meaning that biomass was overestimated then and may be overestimated now if the cause of the retrospective problem lies somewhere within the model. There is some precedent for that; the assessment models in use in the mid-1990s and the early 2000s showed strong retrospective patterns that turned out to be the result of misspecified selectivity (age- rather than length-based). There is also the possibility that the retrospective pattern is caused in some way by the external estimation of the sex composition of the commercial catch, or by the internal prediction of surface age compositions prior to 2002 through the application of an age misclassification matrix (Clark and Hare 2006). Note that the retrospective behavior of the female spawning biomass is smaller than that for the EBio (Fig. 32b), indicating that the source of the behavior may be more closely linked to estimated numbers of males, whose selectivity at age has declined along with size-at-age.

Problems of this sort with the assessment machinery would manifest themselves as systematic revisions of the estimated relative strength of the year-classes present in the stock. That was true of the retrospective patterns caused by the misspecification of selectivity in the past: incoming year-classes would at first be estimated as weak because catch rates were low, but the real reason was low selectivity rather than low abundance. When they were later caught in large numbers, the estimates of relative year-class strength increased. The retrospective estimates of year class strength are plotted in Figure 32c. There is evidence of a systematic revision of estimates of year class strength as the 1994 through 2000 year class have all trended downward for the last five assessments. The pattern appears to change starting with the 2001 year class but these are more uncertain than the earlier year classes due to fewer years of observation and estimation.

In 2007, a check was made using a blind projection of the assessment from 2004 to 2007. Year-class strengths and other parameters from the 2004 assessment, along with just the catches from 2005-2007 which are needed to estimate fishing mortality, were used to project the 2007 age structure and then compared to the 2007 observed age structure. That projection demonstrated that the retrospective behavior appears to be caused solely by the data and not by the assessment model (Clark and Hare 2008). The magnitude of the retrospective pattern from earlier assessments has varied over the last few years. In 2009, the downward adjustment of earlier EBio assessments appeared to have relaxed, however the three subsequent assessments have seen a resumption and even an increase in the retrospective behavior.

Causes of retrospective behavior are notoriously difficult to diagnose (Legault 2009). In the case of halibut, it appears to result from lower NPUE catch rates than expected, given the estimated mortality rate. This could be due, for example, to a trend in natural (or undocumented fishing) mortality, or a trend in catchability. The catchability explanation seems less likely, however, given that a model which allows catchability to have a trend produces assessment estimates that differ little from models with tightly constrained catchability. In fact, all the usual variants of the production model that is fitted each year show a very similar retrospective pattern. We consider it most likely that the retrospective behavior continues to derive in part from the still declining growth rates. Each year, a new set of size at age data is collected and used to smooth earlier estimates of size at age. The addition of smaller sizes at age results in a reduction of the earlier estimated weights at age thus lowering EBio for the same number of fish. More important however is that as growth slows, fewer fish of the same age are selected to the gear and their lack of appearance in expected numbers forces the model to revise recruitment estimates to match the observed survey and commercial catch rates. The difference in retrospective behavior for the EBio vs. the SBio lends some credence to the growth rate change as the prime factor in the retrospective behavior. To summarize, there is ongoing retrospective behavior in the halibut assessment. The magnitude of the behavior showed no signs of slowing this year and the trend of successively lowering all earlier EBio estimates has continued. In response, the staff has continually recommended lower catch limits. A detailed summary of the past and present magnitude of the retrospective behavior, and its effect on realized harvest rate and harvest policy is contained in Valero (2012b).

Given that retrospective behavior in halibut assessment models has a long history with no resolution, or diagnosis, of the source it is unclear whether this issue can be resolved. Work in the next year will focus intently on attempting to resolve the source and it is anticipated that collaborative work with other assessment scientists will be conducted. Whether the present model and/or data issues are identified, there remains the possibility that an entirely new model should be developed. Another possibility to consider is basing catch limit recommendations on indicators other than the assessment estimate of biomass. Work along these lines is currently in development (Valero 2012a), in the form of a Management Strategy Evaluation

Harvest policy and status relative to reference points

The IPHC has developed, refined, and utilized a constant harvest rate policy since the 1980's. The policy was fully described in Clark and Hare (2006) and further modified as described in Hare and Clark (2008), and Hare (2011b). Stated succinctly, the policy was initially designed to harvest 20% of the coastwide exploitable biomass when the spawning biomass is estimated to be above 30% of the unfished level. The harvest rate is linearly decreased towards a rate of zero as the spawning biomass approaches 20% of the unfished level. This combination of harvest rate and precautionary levels of biomass protection have, in simulation studies, provided a large fraction of maximum available yield while minimizing risk to the spawning biomass. Following the CIE review of the assessment and harvest policy (Francis 2008, Medley 2008), the simulations on which the harvest policy was based were modified to incorporate "assessment error" (Hare and Clark 2008). This was implemented by adding autocorrelated error in estimation of the SBio, and having the harvest rates set according to the "perceived" state, as opposed to the "true" state, of the SBio. This form of robustification of the harvest policy is designed to protect the stock in the common situation where assessments tend to consistently too high or too low for a sequence of years, which corresponds to the current situation regarding the halibut assessment. For precautionary purposes, several areas (Area 3B and westwards) have had their target harvest rate reduced to 15%.

Since the early 2000s, and similar to many fisheries management agencies, the harvest policy has incorporated a measure designed to avoid rapid increases or decreases in catch limits, which can arise from a variety of factors including true changes in stock level as well as perceived changes resulting from changes in the assessment model. The adjustment, termed "Slow Up Fast Down (SUFastD)" is based on a target harvest rate of 20% but the realized rate differs due to the adjustment. The SUFD approach is somewhat different from similar phased-change policies of other agencies in that it is asymmetric around the target value, i.e., the catch limit responds more strongly to estimated decreases in biomass than to estimated increases. This occurs for two reasons: first, the assessment generally has a better information base for estimating decreasing biomass compared with increasing biomass; and second, such an asymmetric policy follows the Precautionary Approach.

Beginning with the 2011 Catch Limit Recommendations, the staff modified the SUFastD quota adjustment to a SUFullD adjustment. The basis for the adjustment is described in Hare 2011a and is summarized, briefly, as follows. The initial simulations that gave support to the SUFastD did not capture the current conditions faced by the stock over the past several years. Since implementation of the SUFastD adjustment, EBio has been in a constant downward trajectory. As removals have been in excess of 20% of EBio and each subsequent EBio estimate was lower than the previous year's estimate, the target harvest rate could never be met as only 50% of the intended reduction in removals were taken. Additionally, size-at-age of halibut has continued to decline and this always affects performance of the adjustment. Staff Catch Limit Recommendations (CLR) this year, as they were in 2010, are based on a SUFullD adjustment, i.e., one third of potential increases are taken and 100% of decreases are taken.

The unfished female spawning biomass ($B_{unfished}$) is computed by multiplying spawning biomass per recruit (SBR, from an unproductive regime) and average coastwide age-six recruitment (from an unproductive regime). The recruitment scaling uses the ratio of high to low recruitments based on long term recruitment estimates from Areas 2B, 2C and 3A and applied to the current coastwide average recruitment (Clark and Hare 2006) which we believe to represent a productive regime. The SBR value, computed from Area 2B/2C/3A size at age data from the 1960s and 1970s is 118.5 lbs per age-six recruit. Average coastwide recruitment for the 1990-2002 year classes (computed at age-six) is 20.39 million, and the estimate of unproductive regime average recruitment is 6.48 million recruits. This gives a $B_{unfished}$ of 768 million pounds, a B_{20} of 154 million, a B_{30} of 230 million pounds, and the 2012 female spawning biomass value of 319 million pounds establishes $B_{current}$ as 42% of $B_{unfished}$ (Fig. 34, top panel), down slightly from the 2011 beginning of year estimate of $B_{current}$ of 43%. The revised trajectory of SBio suggests that the female spawning biomass did drop below the B_{30} level between 2006 and 2009, which, had it been so estimated at the time, would have triggered a reduction in the harvest rate. On an annually estimated basis, however, the initially estimated stock size has not been that low; it is only retrospectively that the revised estimate of spawning biomass is estimated to have gone below to the reference point threshold. One problem with this method of establishing reference points is that the threshold and limit are dynamic, changing each year as the estimate of average recruitment changes.

In addition to monitoring the status of the female spawning biomass relative to reference points, success at achieving the harvest rate is also documented (Fig. 34, lower panel). The target harvest rate over the past decade for halibut has generally been 0.20. Exceptions include a briefly increased rate to 0.225 and 0.25 between 2004 and 2006, and a lowered rate of 0.15 in Areas 3B and 4. In 2011, the target harvest rates were set at 0.215 (Areas and 3A) and 0.161 (Areas 3B and 4); however, it is important to note that these were not actual target harvest rate increases. These new rates reflected a change in the method by which O26U32 bycatch and wastage are accounted for in determining fishery CEY (Hare 2011a). On a coastwide basis, however, recent realized harvest rates have hovered around 0.25 (Fig. 35). A sizable portion of this above-target harvest rate comes from the retrospective revision of exploitable biomass estimates. Thus, while the intended rate has been around 0.20, with staff recommended catch limits based on such a rate, a retrospective downwards revision of early exploitable biomass estimates, when combined with unchanged estimates of total removals generates higher realized harvest rates (Valero 2012b).

Estimates of realized harvest rate among individual regulatory areas require use of an apportionment method to calculate the underlying exploitable biomass. The apportionment method used by the staff uses survey timing and hook competition adjustments to the (0-400 fm) bottom area-weighted survey WPUE, which are then time-averaged using Kalman weights (discussed below) for apportionment purposes. The adjusted and Kalman-weighted WPUE time series is used in most of our data comparisons, e.g., WPUE trends over time, comparisons with trawl estimates of abundance, etc. The adjusted and Kalman-weighted survey WPUEs are used to apportion biomass to estimate recent realized harvest rates (described below). Realized harvest rates (Fig. 35) tend to increase from west (below or at the target harvest rate during the last decade) to east (up to three times above target for a number of years during the last decade in Areas 2B and 2C) though the eastern area realized harvest rates have declined sharply towards the target harvest rate during the last few years, in part due to lower catch limits. Also, until last year, another portion of the above-target performance resulted from the SUFD adjustment which prevented catch limits dropping fully to the target level indicated by contemporary estimates of exploitable biomass, in those areas where declines in catch limits were proposed.

A detailed summary of the past and present magnitude of the retrospective behavior, and its effect on realized harvest rate is contained in Valero (2012b). Under the assumption that the retrospective revision of current biomass estimates will match that of the past five years, a methodology to revise applied harvest rates to current biomass estimates was developed. In essence, if the contemporary biomass estimates are eventually revised downwards 40%, the applied harvest rates would be revised downwards by the same magnitudel, to values of 0.131 (from 0.215) and 0.098 (from 0.16125). Yield tables using both sets of harvest rates have been prepared and are presented in the Yield section below. However, more analysis of the effect of both existing measures and alternative adjustments is required and will be undertaken in 2012.

Comparison of assessment and trawl survey estimates of EBio

The National Marine Fisheries Service (NMFS) and Canadian Department of Fisheries and Oceans conduct bottom trawl surveys annually to triennially across most of the continental shelf of the U.S. west coast, British Columbia and Alaska. One method of possibly validating the coastwide assessment (and biomass partitioning) is to compare estimates produced by the two independent methods. We were able to obtain swept area estimates of abundance at length from trawl surveys that covered IPHC regulatory areas 2C westward to Area 4CDE. For Area 2B halibut are not sampled in the trawl survey and, in 2A too few halibut are caught to produce reliable estimates of abundance thus no comparisons are made for those two areas.

The NMFS conducts an annual survey on the Eastern Bering Sea shelf, a triennial survey in the Aleutian Islands and a biennial survey in the Gulf of Alaska. The NMFS trawl surveys do not precisely match IPHC regulatory areas. However, common areas can be generally defined:

Area 2C: NMFS GOA survey area Southeast matches IPHC Area 2C. Note that there is much rough/untrawlable ground in this region.

Area 3A: NMGS GOA regions Yakutat + Kodiak

Area 3B: NMFS GOA regions Chirikof + the eastern 70% of Shumagin

Area 4A: NMFS GOA Shumagin (western 30%) + AI region 799 + AI region 5699 (eastern 30%) + EBS region 50.

Area 4B: NMFS AI regions - 299 - 5699 (eastern 30%)

Area 4CDE: EBS regions - region 50.

Estimates of commercially exploitable biomass (i.e., the usual EBio) can be derived by applying the commercial selectivity curve to the swept area estimates of numbers at length and then applying the IPHC length weight relationship. For this comparison, the IPHC assessment estimates of EBio are partitioned among areas using the adjusted bottom-weighted survey WPUE index. The results are illustrated in Figure 36.

The agreement between the trawl and assessment estimates of abundance is surprisingly good for most of the areas. Areas 4A, 4B, and 4CDE are within a few percent of each other over the past few surveys. In Area 3A and 3B, the trends are generally captured though the trawl estimates of abundance tend to be lower by about a third. Area 2C, as anticipated provides the worst match. It is important to keep in mind the independence of the two estimates. The only commonality between them is use of a selectivity curve to derive EBio, and use of the NMFS survey to generate a density estimate for the shelf region. The assessment estimates incorporate assumptions and estimates of factors such as catchability, natural mortality, survey apportionment, etc. The trawl estimates make an assumption about the effective area swept by the survey trawl and assumes a capture probability value of 1.0 for all sizes encountered. This latter assumption may be one reason the Area 3A and 3B trawl estimates are lower if larger halibut are able to escape the trawl and thus be under-represented in the swept area estimates.

Finally, the trawl data may provide some evidence as regards the preponderance of smaller halibut, though the wide confidence intervals indicate that individual year estimates, and likely trends, are uncertain. The large number of small halibut in the Bering Sea was earlier discussed and illustrated in Figure 9. In Figures 37 (Area 3A) and 38 (Area 3B), we show the swept area estimates of numbers by 10 cm length class in the central Gulf. The 2009 NMFS trawl survey showed an unprecedented number of halibut in the 50-70 cm range. The 2011 values have subsided from the 2009 peak but the broad confidence intervals (see Figure 12) do not suggest a significant change in total biomass. The point is that over the past 15 years, total biomass in the Gulf has shown little trend, however since the larger fraction of the biomass now comes from smaller halibut, it follows that the total number of halibut has increased, or at least remained level. As (or, perhaps, if) those millions of smaller halibut grow, we should see a steady increase in EBio predicted by the coastwide assessment.

Apportioning the coastwide biomass among regulatory areas

The staff believes that survey WPUE-based apportionment is the most objective and consistent method of estimating the biomass distribution among areas and therefore the best distribution of total CEY to achieve the IPHC's goal of proportional harvest among areas (see Webster et al. 2011 for a discussion of alternatives). The validity of the survey WPUE apportioning requires that survey catchability – the relationship between density and WPUE – be roughly equal among areas. Over the past few years, several checks for area differences in catchability were made (Clark 2008a, Clark 2008b, Clark 2008c, Webster 2009) but results were inconclusive in determining differences. This year, the two same factors used in 2010 for adjusting survey WPUE were considered. Methodologies and analyses of both factors - in isolation and in combination - are contained in Webster and Hare (2011), and results updated for this year are illustrated in Figure 39. A brief summary of the rationale behind the two factors is presented below but details, are not repeated here - see Webster and Hare 2011. Following (potential) adjustment of the annual survey WPUE values, the IPHC has usually averaged the last few years' of values to smooth out annual variation in the survey. Starting last year, a weighting scheme based on a Kalman filter approach was adopted by staff as a superior and statistically-sound methodology (Webster 2011). This approach derives directly from discussions at the Commission's 2010 Annual Meeting and a request of staff by the Commission.

The apportionment of biomass results in a level of EBio for each regulatory area. Staff Catch Limit Recommendations are based on the fishery Constant Exploitation Yield (CEY) in each area. The fishery CEY is calculated by subtracting "other removals" from the total CEY, which itself is calculated by multiplying the area-specific target harvest rate and the area-specific EBio. Until last year, other removals had been comprised of O32 bycatch, O32 wastage, sport catch (except in Areas 2A and 2B where it is part of the fishery CEY), and personal use/subsistence (except in Area 2A, where it is part of the fishery CEY). As of 2011, bycatch and wastage mortality (BAWM) under 32 inches in length but over 26 inches (O26U32) are included in the fishery CEY calculations. U26 BAWM is, at present, still accounted for in determination of the target harvest rate. The effect of directly accounting for O26U32 BAWM was to increase the target harvest rate to .215 in Areas 2 and 3A and to 0.161 in Areas 3B and 4. The analysis upon which the change in O26U32 BAWM was based is given in Hare (2011a).

Adjustment factors

Hook competition

Catchability of halibut is affected by the presence of other bait takers, a process known as hook competition. If the average number of baits available to halibut varies substantially among regions, this might be a reason to adjust survey WPUE. To compute this adjustment, the return of baits by regulatory area is summed from survey data.

Timing of setline survey

The survey is designed to measure EBio at approximately the midpoint of the year in each regulatory area. Necessarily, the timing varies due to survey logistics. The timing of removals (commercial, sport and subsistence fishing, bycatch, wastage) also varies, even more substantially, among areas. It can be reasoned that an area where more of the annual removals are taken prior to our survey would “see” a smaller EBio than an otherwise identical situation where the other removals had not yet occurred. To compute this adjustment, we estimate the midpoint of the survey as well as fraction of removals prior to that time.

Bottom-area weighting factor

The IPHC setline survey operates on a 10 nautical mile grid in all IPHC regulatory areas, except for the broad shelf in Area 4CDE. Halibut are distributed, however, in both shallower and deeper waters. The choice of which bottom area definition to use is relatively subjective; both are biased. The broader definition (0-400 fm) assumes halibut density in 0-20 and 275-400 fm is the same as in the surveyed depths of 20-275 fms, an assumption that is almost certainly incorrect, at least for some areas. The narrower definition (20-275 fm) gives no credit for biomass distribution for areas that have larger areas in the shallower and deeper regions, areas in which commercial fishing is documented to occur. Staff recommendation is to use the broader area definition, applied equally to all areas, largely because fishing is known to occur in these depths in at least most of these areas. Initial work on potentially expanding the survey, at least periodically, to shallower and deeper regions is discussed in Webster et al. (2012). The relative amount of bottom area for the two definitions is listed below.

	2A	2B	2C	3A	3B	4A	4B	4CDE
0-400 fm	3.6%	7.5%	3.7%	12.4%	7.5%	5.0%	5.0%	55.5%
20-275 fm	3.7%	8.1%	4.1%	14.3%	8.7%	5.8%	4.0%	51.3%

Time-averaging methods of adjusting survey WPUE

A detailed statistical analysis was conducted last year to determine whether the default three year equal weighting method that had been used by the IPHC to weight recent survey WPUEs was optimal. The results (Webster 2011) show that, in fact, the most recent year’s survey should be disproportionally weighted compared to earlier years. This result derives from the relative variances within an area in a given year compared to interannual variance. Areas with a large number of stations, such as Area 3A and 2C should, in a statistical sense, give almost no weight to any but the most recent year's WPUE value. However, several areas with greater coefficients of variation, should still give some weight to the previous couple of years. Rather than utilize a different set of weights for each area, when the weights can vary somewhat depending on the period of years considered, we selected the weighting scheme (from Area 2A) which was most inclusive of previous years' data. That scheme results in weights of 75:20:5 (recent year first).

Raw, adjusted and time-averaged survey WPUE

For the purposes of weighting individual area regulatory datasets and apportioning EBio, the adjustments and weights described above are applied to the raw survey WPUE. The result of applying these corrections is illustrated in Figure 40. This particular figure reflects use of both adjustments and the 0-400 fm bottom area definition.

Methods of apportioning biomass and computing fishery CEY

Compared to the last several years, the options for apportioning biomass among regulatory areas this year is limited: there are just four options. The four options are as follows:

1. 0-400 fm bottom area weighting; no WPUE adjustments
2. 0-400 fm bottom area weighting; survey WPUE adjustments for hook competition and survey timing
3. 20-275 fm bottom area weighting; no survey WPUE adjustments
4. 20-275 fm bottom area weighting; survey WPUE adjustments for hook competition and survey timing

The regulatory area apportionments for these four options are listed in Table 4. As in 2010, the staff recommends Option 2, which has been the basis for Catch Limit Recommendations for the past three years.

The staff recommendation is the highlighted line in all the tables referencing apportionment. After determination of the fishery CEY, Staff catch limit recommendations (CLRs) are based on one other consideration – the "Slow Up Full Down" adjustment, which was adopted last year by staff as a means of limiting rapid increases in catch limits, while also acting in a precautionary sense to fully accept decreases in in catch limits.

Area-apportioned biomass, total and fishery constant exploitation yields

Area apportionment of EBio has four possibilities, corresponding to the apportionment percentages listed in Table 4. As noted earlier, the choice of apportionment option has a small effect on the estimated coast EBio, thus adding an extra bit of variability in the estimated amount of EBio in each regulatory area. Tables 5 and 6 list the estimated EBios in each area; Table 5 has the EBios for the preferred WobbleSQ model while Table 6 contains the values for the Trendless (Base 2010) model.

Following apportioning of biomass, total CEY is computed by multiplying each regulatory area EBio by the target harvest rate for that area: 0.215 for Areas 2 and 3A, 0.16125 for Areas 3B and 4. The next step is then to deduct "Other Removals" in order to compute fishery CEY, and the final step is to apply a SUFullD adjustment to any catch limits slated in increase the following year. Tables for all quantities were prepared for the preferred WobbleSQ model (Table 7) and for the Trendless/Base2010 model (Table 8), and also included a summary of the change from the 2011 catch limits.

As discussed in the Retrospective and Harvest Policy sections, an alternative set of applied harvest rates was developed (Valero 2012b) as one means of pre-emptively accounting for the ongoing retrospective behavior of both models. Those alternative harvest rates – 0.134 for Areas 2 and 3A and 0.098 for Areas 3B and 4 – give rise to a second set of tables of total CEY, fishery CEY, SUFullD and change from 2011 catch limits. The tables for the WobbleSQ model are in Table 9; the tables for Trendless/Base2010 are in Table 10. Finally, a comparison between the 2011 and 2012 EBios and fishery CEYs is given in Table 11.

Area summaries

The coastwide assessment indicates that the exploitable biomass of halibut has declined approximately 60% over the past decade. This declining trend is seen in almost all of the area-specific survey and commercial WPUE indices, though with turnarounds apparently beginning in several areas. But the breadth and reasons behind the trends vary by area. The following is a region by region discussion of the trends and grouping of diagnostic plots to assess the past and present removals, stock trends, and prospects for each area. For each of the areas, six plots are illustrated. These include the following:

1. Total removals – illustrated by category (commercial catch, sport, etc.)
2. Abundance indices – these include the raw and adjusted/weighted survey WPUE indices and the Coastwide assessment with adjusted/weighted survey partitioning.
3. 2011 age structure of the survey catch.
4. Surplus production. Stated simply, surplus production is the amount of total catch that, when taken exactly, keeps the exploitable biomass at the same level from one year to the next. If the biomass increases, then total catch (termed “removals”) was less than surplus production. If the biomass declines, then removals were greater than surplus production. Removals exceeding surplus production can lead to long-term declines in biomass; stock building results from taking less than surplus production.
5. WPUE and effort – Long-term trends in commercial fishing effort and WPUE.
6. 2011 age structure of the commercial catch.

Taken in total, these indicators convey a comprehensive picture for each area and serve as a helpful reference when discussing each regulatory area.

Area 2

Areas 2A, 2B and 2C indices are illustrated in Figures 41, 42, and 43, respectively. Between 1997 and 2006, total removals were stable in all three areas, averaging 1.6 million pounds in Area 2A, 13.5 million pounds in Area 2B, and 12.4 million pounds in Area 2C. Removals declined sharply between 2007 and 2011, in response to the change from closed-area to coastwide assessment and the resultant revised view of relative halibut abundance in Area 2. Bycatch of U32 fish in Area 2, and subsequent lost yield to constant Exploitation Yield (CEY), is estimated to be rather low, however yield lost to “upstream” bycatch of U32 halibut is estimated to be much greater than yield lost to “local” U32 bycatch (Valero and Hare 2011). Deductions to total CEY for O26 bycatch in Area 2A still represent a sizable portion of total removals, whereas O26 bycatch in

Areas 2B and 2C is relatively low. Surplus production estimates suggest that removals exceeded surplus production in Area 2 for most of the past decade, though in Area 2B surplus production has exceeded removals for the past four years. Commercial effort steadily increased in Area 2A for almost a decade but dropped sharply in 2009 and again in 2010, but showed a rebound in 2011. In Areas 2B and 2C commercial effort has steadily declined for the past five to six years.

The main indices of abundance all suggest a steady decline in biomass from the mid-1990s to the mid/late 2000s change to the coastwide assessment. Area 2A saw in 2009 a drop to the lowest survey WPUE on record, which had followed a drop of 50% from 2008, to an average survey catch of 8 pounds of O32 halibut per standard skate. In 2010, survey WPUE doubled, but it was still the third lowest value on record, however it increased again in 2011 to the highest unadjusted value since 2004. It should be noted that Area 2A is generally the area most affected by survey WPUE adjustments and the adjusted 2011 value actually declined slightly from the adjusted 2010 value. The 15-year trend in Area 2B survey WPUE is more complex than in the rest of Area 2. The 2008-2010 period saw an average of around 88 lbs/skate which is similar to values seen between 1998 and 2004, and is 50% higher than the series low values in 2006 and 2007. In 2011, however, survey WPUE receded 10% from the 2010 value. However, between 1995 and 1997, Area 2B survey WPUE averaged almost 150 lbs skate, a high level that was re-examined this year (Webster and Hare 2012) and found to be authentic. Area 2C, which declined from an average survey WPUE of around 250 lbs/skate in the late 1990s, seems to have stabilized following years of steep quota cuts and, for the first time, had the highest survey WPUE of any IPHC regulatory area (136 lbs/skate). Commercial WPUE tells basically the same story as survey WPUE for Areas 2A and 2C. Area 2B commercial WPUE was the highest on record and has increased for four straight years.

Survey partitioning of the coastwide biomass suggests that the beginning of year 2012 EBio is up in Areas 2A and 2C, and down in 2B from 2011 values. What is still a strong concern to staff is the generally much younger age structure of fish caught in Area 2. Mean age is around 11 years of age, with little difference between males and females. In particular, the catch of females is concentrated on ages where maturity at age is low thus removing females from the population before many have the opportunity to contribute to the spawning biomass.

All the indices are consistent with a picture of a steadily declining exploitable biomass up to at least 2007. The reasons for the decline are likely twofold. The first is the passing through of the two very large year classes of 1987 and 1988. Every assessment over the past decade has shown that those two year classes were very strong in comparison to the surrounding year classes. Now that those two year classes are 20 years old, their contribution to the exploitable biomass and catches has sharply declined and the drop in biomass was to be expected as they are replaced by year classes of lesser magnitude. Secondly, realized harvest rates were substantially higher than the target rate of 20%, and for a few years were in excess of 50% (of EBio, not total biomass). Harvest rates have been brought down sharply from peak levels in Area 2B (almost 80% in the years before the change to the coastwide assessment) but less so in Areas 2A and 2C.

Removals have been generally larger than surplus production and that stalled rebuilding of regional stocks. The reduced removals now appear to have arrested decline of the regional biomass and, across all of Area 2 it appears a rebuilding to higher levels hay have begun. While all areas appear stabilized, they remain at relatively low levels that limit available yield. There are multiple signs that two or three large year classes are set to enter the exploitable biomass, though this is dependent both on reducing harvest rates that are above target as well as on the growth rate.

On that score, it is encouraging that removals have been brought down over the past few years. Realized harvest rates remain slightly above target in all of Area 2 but are closer to target than at any time in the past decade.

Area 3

Areas 3A and 3B indices are illustrated in Figures 44 and 45, respectively. While these two areas occupy the current central area of distribution of the halibut stock, they have substantially different exploitation and biomass histories over the past 10-20 years.

Area 3A removals, both the total as well as the individual components (commercial, sport, bycatch) had from the mid-1980s to the mid-2000s., but have been steadily decreased the past four years. Commercial effort has also seen relatively little variation in the past 15-20 years. During the past decade when WPUE indices were falling sharply coastwide, Area 3A generally showed the most stability. However, Area 3A survey WPUE has declined for five consecutive years, before showing a slight increase in 2011 of 3% from the low value of 117 lbs/skate in 2010. This value is about 40% of the level seen in the late 1990s. Commercial WPUE is also at its lowest point since the change from "J" to "C" hooks in 1984 and is at about 66% of its late 1990s level. Paralleling the declines in survey and commercial WPUE, EBio has declined steadily in 3A since 2005.

Area 3B saw a large increase in removals beginning in 1996 which peaked in 2002; removals have dropped sharply since. Commercial fishing effort more than tripled in the seven years after 1996 and then declined modestly over the past four years, before increasing again beginning in 2008 and continuing through 2010 and then dropping slightly in 2011. We estimate that removals greatly exceeded surplus production between 1998 and at least 2007. Commercial and survey WPUE are at 25% and 19%, respectively, of their average level between 1997 and 1999. Area 3A has a much broader spectrum of ages in the population than is seen in Area 2. Average age for females in survey catches is 13 and for males is 16 years of age. Area 3B, however, is more similar to Area 2 in age distribution than to Area 3A.

For a long time, Area 3A had the appearance of being the most stable of the IPHC regulatory areas. The area has been fully exploited for many decades and there is a wealth of data detailing its population dynamics. The area also sits at the current center of halibut distribution and it appears that emigration is roughly equal to immigration. Like Area 2, Area 3A benefited from the very large year classes of 1987 and 1988 and the slow decline in exploitable biomass is the result of those year classes dying off. The biomass remains the largest of any of the regulatory areas; however the sharp declines of the past several years are a sign that exploitation rates have been too high, though we are not yet considering Area 3A as an "area of particular concern". Should this trend not reverse soon, we may reconsider applying that designation. Until the biomass decline has ended, recommended catch limits will trend downwards in Area 3A.

The situation in Area 3B is one that has concerned us for several years. Area 3B was relatively lightly fished until the mid-1990s. With the introduction of a regular survey, quotas were incrementally increased from 4 million pounds to a high of 17 million pounds. Predictably, catch rates declined steadily. Our view of Area 3B was that the area had an accumulated "surplus" biomass that could be (and was) taken but the level of catches was not sustainable. Removals were brought down to around 10 million pounds however the WPUE indices continue to drop sharply. The level of commercial effort expended to take the CEY is near an all-time high and has been increasing. The age distribution of the population is not broad and reflects one of an area fished at a much higher rate than is sustainable, or where both recruitment and emigration are also high. Like Area 4, Area 3B is a net (though smaller) exporter of halibut as emigration is larger than immigration. It is paramount that the ongoing decline in Area 3B be arrested - until that is accomplished, the true level of productivity in Area 3B cannot be estimated. Lowering the harvest rate in Area 3B (to 0.15 from 0.20 in 2010) was a precautionary move and one that has seen success in Area 4.

Area 4

Areas 4A, 4B, and 4CDE indices are illustrated in Figures 46, 47, and 48, respectively. The three areas have roughly similar commercial exploitation histories over the past decade and show generally similar trends. In all three areas, commercial catches increased from around 1.5 million pounds to around 4-5 million pounds between 1996 and 2001. All three areas have since declined to 2-3 million pounds though the trajectories differ. The target harvest rate is currently 0.15 in all of Area 4, with the change from 0.20 beginning in 2004 in 4B, 2006 in 4CDE and 2008 in 4A. Commercial effort mirrored the rise in removals from 1996-2001, however the drop in effort was not nearly as sharp as the drop in catches, and the drop in commercial WPUE is evident in the time series. Survey WPUE declined around 70% between the mid1990s and mid-2000s. All three areas have shown increases in recent years, with the turnarounds occurring immediately after the cut in the harvest rate in each area. All three areas, however, showed a decline in 2011, though Area 4B's decline was slight (1%). The recent leveling of WPUE, which reflect a slowing of the decline in EBio as estimated by the coastwide assessment, is evidence that the western portion of the stock, which is a net exporter of halibut, is best served by a lower harvest rate than that in the eastern areas. As the stock builds up, removals will also increase. There is evidence in both the assessment and the trawl surveys that large numbers of halibut, in the 50-80 cm size range, are found in Area 4 and should add substantially to the exploitable biomass over the next several years.

There are a couple of other observations that should be made about Area 4. The biggest concern, as regards productivity and sustainability of halibut, is the level of bycatch mortality. Most of the O32 bycatch in Area 4 most likely affects future yield within Area 4 itself. Over the past decade, O32 bycatch has averaged 3-4 million pounds resulting in an annual yield loss comparable to that level. On the other hand, U32 bycatch - which has also been on the order of 3-4 million pounds annually - results in a greater yield loss due to its smaller size and large numbers of killed halibut. Some potentially large fraction of yield loss, however is to areas "downstream" of Area 4 given migration of fish beyond at which they become vulnerable to fishing (Valero and Hare 2011). For most of the 2000s, removals exceeded surplus production in all three subareas of Area 4. It would appear that situation has reversed though it is probably too early to make a definitive declaration. Encouragingly, the age distributions in Area 4 are the broadest of any of the IPHC regulatory areas. Thus, Area 4 not only contributes to the spawning biomass in a ratio exceeding its removals, it is also a reservoir of older females which can be a valuable commodity for a fish population.

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Table 1. Alternative coastwide model fits. The AIC value is in relative units compared to the model with the lowest AIC score.

Model	Number of parameters	Δ AIC	Exploitable Biomass (Mlb)	Spawning Biomass (Mlb)
Trendless (Base2010)	187	+20	288	352
Vanilla (Alt. 1)	173	+334	262	315
WobbleSQ (Alt. 2)	187	0	260	319
NMFS (Alt. 3)	171	+129	289	358
CAGEAN (Alt. 4)	145	+127	266	306

Table 2. Sixteen variants of the assessment model, fitted to illustrate the effect of structural uncertainty on estimates of EBio.

Variant	Description
1	Freely estimate M for both sexes
2	Fix M at 0.15 for both sexes
3	Fit to Bycatch LFs – note Hessian not positive definite for this fit
4	Commercial q drift tolerance set at 0.01
5	Commercial q drift tolerance set at 0.05
6	Commercial q drift tolerance set at 50 (i.e., unconstrained)
7	Survey q drift tolerance set at 0.01
8	Survey q drift tolerance set at 0.1
9	Turn off robust estimation
10	Turn off variance scaling
11	Sex-specific CPUE lambda set to 0
12	Total CPUE lambda set to 0
13	Unisex parameters
14	Domed survey selectivity
15	Bycatch total not predicted
16	Bycatch level doubled in input data

Table 3. Effect of the 2010 and 2011 data on coastwide abundance estimates.

Model	2011 ebio 2010 assessment Data as of 11/10	2011 ebio 2010 assessment Data as of 11/11	2011 ebio 2011 assessment Data as of 11/11	2012 ebio 2011 assessment Data as of 11/11
Trendless (Base 2010)	318	292	245	288
WobbleSQ (Alt. 2)	295	267	223	260

Table 4. Shares of exploitable biomass by area according to various apportionment methods.

Weighting	Adjustment	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	1.9%	13.4%	10.5%	32.9%	13.7%	6.9%	7.6%	13.2%	100.0%
0-400	Timing/Hook	2.4%	13.4%	10.5%	35.4%	15.8%	5.7%	5.5%	11.3%	100.0%
20-275	None	1.7%	13.2%	10.5%	34.5%	14.5%	7.2%	5.6%	12.8%	100.0%
20-275	Timing/Hook	2.2%	13.1%	10.5%	36.8%	16.7%	6.0%	4.0%	10.7%	100.0%

Table 5. Exploitable biomass by area according to various apportionment methods for the preferred WobbleSQ model.

Weighting	Adjustment	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	4.907	35.052	27.411	86.218	35.831	18.001	19.936	34.644	262.000
0-400	Timing/Hook	6.148	34.904	27.279	91.997	41.167	14.856	14.251	29.397	260.000
20-275	None	4.443	33.586	26.729	87.858	36.969	18.349	14.319	32.746	255.000
20-275	Timing/Hook	5.617	33.393	26.561	93.550	42.445	15.134	10.193	27.108	254.000

Table 6. Exploitable biomass by area according to various apportionment methods for the Base2010 (Trendless) model.

Weighting	Adjustment	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	5.319	37.995	29.713	93.458	38.840	19.513	21.610	37.553	284.000
0-400	Timing/Hook	6.810	38.663	30.216	101.905	45.601	16.456	15.786	32.563	288.000
20-275	None	4.931	37.274	29.664	97.505	41.029	20.363	15.891	36.342	283.000
20-275	Timing/Hook	6.280	37.337	29.698	104.599	47.458	16.921	11.397	30.310	284.000

Table 7. Estimates of 2012 Total CEY, Other Removals, Fishery CEY, SUFullD Catch Limits and the percentage change from the 2011 Catch Limits, for the Wobble SQ model using harvest rates of 0.215 (Areas2 and 3A) and 0.16125 (Areas 3B and 4).

2012 Total CEY										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	1.055	7.536	5.893	18.537	5.778	2.903	3.215	5.586	50.503
0-400	Timing/Hook	1.322	7.504	5.865	19.779	6.638	2.395	2.298	4.740	50.543
20-275	None	0.955	7.221	5.747	18.889	5.961	2.959	2.309	5.280	49.322
20-275	Timing/Hook	1.208	7.179	5.711	20.113	6.844	2.440	1.644	4.371	49.510

2012 Other Removals										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.174	0.871	2.653	7.492	1.568	0.828	0.429	2.275	16.290
0-400	Timing/Hook	0.174	0.871	2.653	7.861	1.568	0.828	0.429	2.275	16.659
20-275	None	0.174	0.871	2.510	7.492	1.568	0.828	0.429	2.275	16.147
20-275	Timing/Hook	0.174	0.871	2.510	7.861	1.568	0.828	0.429	2.275	16.516

2012 Fishery CEY										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.881	6.665	3.240	11.045	4.210	2.075	2.786	3.311	34.213
0-400	Timing/Hook	1.148	6.633	3.212	11.918	5.070	1.567	1.869	2.465	33.884
20-275	None	0.781	6.350	3.237	11.397	4.393	2.131	1.880	3.005	33.175
20-275	Timing/Hook	1.034	6.308	3.201	12.252	5.276	1.612	1.215	2.096	32.994

2012 SUFullD										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.881	6.665	2.633	11.045	4.210	2.075	2.382	3.311	33.202
0-400	Timing/Hook	0.989	6.633	2.624	11.918	5.070	1.567	1.869	2.465	33.137
20-275	None	0.781	6.350	2.632	11.397	4.393	2.131	1.880	3.005	32.570
20-275	Timing/Hook	0.951	6.308	2.620	12.252	5.276	1.612	1.215	2.096	32.331

Change from 2011 Catch Limits										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	-3.2%	-12.9%	13.0%	-23.1%	-43.9%	-13.9%	9.3%	-11.0%	-19.2%
0-400	Timing/Hook	8.7%	-13.3%	12.6%	-17.0%	-32.5%	-35.0%	-14.3%	-33.7%	-19.3%
20-275	None	-14.1%	-17.0%	13.0%	-20.6%	-41.5%	-11.6%	-13.8%	-19.2%	-20.7%
20-275	Timing/Hook	4.5%	-17.5%	12.5%	-14.7%	-29.7%	-33.1%	-44.3%	-43.6%	-21.3%

Table 8. Estimates of 2012 Total CEY, Other Removals, Fishery CEY, SUFullD Catch Limits and the percentage change from the 2011 Catch Limits, for the Base2010 (Trendless) model using harvest rates of 0.215 (Areas2 and 3A) and 0.16125 (Areas 3B and 4).

2012 Total CEY										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	1.144	8.169	6.388	20.093	6.263	3.146	3.485	6.055	54.744
0-400	Timing/Hook	1.464	8.313	6.497	21.910	7.353	2.653	2.546	5.251	55.986
20-275	None	1.060	8.014	6.378	20.964	6.616	3.284	2.562	5.860	54.738
20-275	Timing/Hook	1.350	8.027	6.385	22.489	7.653	2.729	1.838	4.888	55.358
2012 Other Removals										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.174	0.871	2.653	7.861	1.568	0.828	0.429	2.275	16.659
0-400	Timing/Hook	0.174	0.871	2.653	8.408	1.568	0.828	0.429	2.275	17.206
20-275	None	0.174	0.871	2.653	7.861	1.568	0.828	0.429	2.275	16.659
20-275	Timing/Hook	0.174	0.871	2.653	8.408	1.568	0.828	0.429	2.275	17.206
2012 Fishery CEY										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.970	7.298	3.735	12.232	4.695	2.318	3.056	3.780	38.085
0-400	Timing/Hook	1.290	7.442	3.844	13.502	5.785	1.825	2.117	2.976	38.780
20-275	None	0.886	7.143	3.725	13.103	5.048	2.456	2.133	3.585	38.079
20-275	Timing/Hook	1.176	7.156	3.732	14.081	6.085	1.901	1.409	2.613	38.152
2012 SUFullD										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.930	7.298	2.798	12.232	4.695	2.318	2.472	3.740	36.484
0-400	Timing/Hook	1.037	7.442	2.835	13.502	5.785	1.825	2.117	2.976	37.517
20-275	None	0.886	7.143	2.795	13.103	5.048	2.425	2.133	3.585	37.118
20-275	Timing/Hook	0.999	7.156	2.797	14.081	6.085	1.901	1.409	2.613	37.040
Change from 2011 Catch Limits										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	2.2%	-4.6%	20.1%	-14.8%	-37.5%	-3.8%	13.4%	0.5%	-11.2%
0-400	Timing/Hook	13.9%	-2.7%	21.7%	-6.0%	-23.0%	-24.3%	-2.9%	-20.0%	-8.7%
20-275	None	-2.6%	-6.6%	20.0%	-8.8%	-32.8%	0.6%	-2.1%	-3.6%	-9.6%
20-275	Timing/Hook	9.8%	-6.5%	20.1%	-1.9%	-19.0%	-21.1%	-35.4%	-29.8%	-9.8%

Table 9. Estimates of 2012 Total CEY, Other Removals, Fishery CEY, SUFullD Catch Limits and the percentage change from the 2011 Catch Limits, for the Wobble SQ model using harvest rates of 0.131 (Areas2 and 3A) and 0.098 (Areas 3B and 4).

2012 Total CEY										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.697	4.977	3.892	12.243	3.806	1.912	2.118	3.680	33.326
0-400	Timing/Hook	0.892	5.065	3.958	13.350	4.469	1.613	1.547	3.191	34.085
20-275	None	0.646	4.883	3.886	12.773	4.021	1.996	1.557	3.562	33.323
20-275	Timing/Hook	0.823	4.891	3.890	13.703	4.651	1.658	1.117	2.970	33.703
2012 Other Removals										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.174	0.871	2.510	6.766	1.568	0.828	0.429	2.275	15.421
0-400	Timing/Hook	0.174	0.871	2.510	6.766	1.568	0.828	0.429	2.275	15.421
20-275	None	0.174	0.871	2.510	6.766	1.568	0.828	0.429	2.275	15.421
20-275	Timing/Hook	0.174	0.871	2.510	6.766	1.568	0.828	0.429	2.275	15.421
2012 Fishery CEY										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.523	4.106	1.382	5.477	2.238	1.084	1.689	1.405	17.905
0-400	Timing/Hook	0.718	4.194	1.448	6.584	2.901	0.785	1.118	0.916	18.664
20-275	None	0.472	4.012	1.376	6.007	2.453	1.168	1.128	1.287	17.902
20-275	Timing/Hook	0.649	4.020	1.380	6.937	3.083	0.830	0.688	0.695	18.282
2012 SUFullD										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.523	4.106	1.382	5.477	2.238	1.084	1.689	1.405	17.905
0-400	Timing/Hook	0.718	4.194	1.448	6.584	2.901	0.785	1.118	0.916	18.664
20-275	None	0.472	4.012	1.376	6.007	2.453	1.168	1.128	1.287	17.902
20-275	Timing/Hook	0.649	4.020	1.380	6.937	3.083	0.830	0.688	0.695	18.282
Change from 2011 Catch Limits										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	-42.6%	-46.3%	-40.7%	-61.9%	-70.2%	-55.0%	-22.5%	-62.2%	-56.4%
0-400	Timing/Hook	-21.1%	-45.2%	-37.8%	-54.2%	-61.4%	-67.4%	-48.7%	-75.4%	-54.6%
20-275	None	-48.1%	-47.6%	-40.9%	-58.2%	-67.3%	-51.6%	-48.2%	-65.4%	-56.4%
20-275	Timing/Hook	-28.7%	-47.4%	-40.8%	-51.7%	-58.9%	-65.5%	-68.4%	-81.3%	-55.5%

Table 10. Estimates of 2012 Total CEY, Other Removals, Fishery CEY, SUFullD Catch Limits and the percentage change from the 2011 Catch Limits, for the Wobble SQ model using alternative harvest rates of 0.131 (Areas2 and 3A) and 0.098 (Areas 3B and 4).

2012 Total CEY										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.643	4.592	3.591	11.295	3.511	1.764	1.954	3.395	30.744
0-400	Timing/Hook	0.805	4.572	3.574	12.052	4.034	1.456	1.397	2.881	30.771
20-275	None	0.582	4.400	3.502	11.509	3.623	1.798	1.403	3.209	30.026
20-275	Timing/Hook	0.736	4.374	3.479	12.255	4.160	1.483	0.999	2.657	30.143
2012 Other Removals										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.174	0.871	2.510	6.766	1.568	0.828	0.429	2.275	15.421
0-400	Timing/Hook	0.174	0.871	2.510	6.766	1.568	0.828	0.429	2.275	15.421
20-275	None	0.174	0.871	2.510	6.766	1.568	0.828	0.429	2.275	15.421
20-275	Timing/Hook	0.174	0.871	2.510	6.766	1.568	0.828	0.429	2.275	15.421
2012 Fishery CEY										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.469	3.721	1.081	4.529	1.943	0.936	1.525	1.120	15.323
0-400	Timing/Hook	0.631	3.701	1.064	5.286	2.466	0.628	0.968	0.606	15.350
20-275	None	0.408	3.529	0.992	4.743	2.055	0.970	0.974	0.934	14.605
20-275	Timing/Hook	0.562	3.503	0.969	5.489	2.592	0.655	0.570	0.382	14.722
2012 SUFullD										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	0.469	3.721	1.081	4.529	1.943	0.936	1.525	1.120	15.323
0-400	Timing/Hook	0.631	3.701	1.064	5.286	2.466	0.628	0.968	0.606	15.350
20-275	None	0.408	3.529	0.992	4.743	2.055	0.970	0.974	0.934	14.605
20-275	Timing/Hook	0.562	3.503	0.969	5.489	2.592	0.655	0.570	0.382	14.722
Change from 2011 Catch Limits										
Weighting	**Adjustment**	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
0-400	None	-48.5%	-51.4%	-53.6%	-68.5%	-74.1%	-61.2%	-30.1%	-69.9%	-62.7%
0-400	Timing/Hook	-30.6%	-51.6%	-54.4%	-63.2%	-67.2%	-73.9%	-55.6%	-83.7%	-62.6%
20-275	None	-55.2%	-53.9%	-57.4%	-67.0%	-72.6%	-59.7%	-55.3%	-74.9%	-64.4%
20-275	Timing/Hook	-38.3%	-54.2%	-58.4%	-61.8%	-65.5%	-72.8%	-73.9%	-89.7%	-64.2%

Table 11. Estimates of 2012 exploitable biomass and CEY from the 2011 assessment.

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2012 exploitable biomass	6.148	34.904	27.279	91.997	41.167	14.856	14.251	29.397	260.000
Proportion of total	0.024	0.134	0.105	0.354	0.158	0.057	0.055	0.113	1.000
Harvest rate	0.215	0.215	0.215	0.16125	0.16125	0.16125	0.16125	0.16125	<0.215
Total CEY	1.322	7.504	5.865	19.779	6.638	2.395	2.298	4.740	50.543
Other removals [2, 3]	0.174	0.871	2.653	7.861	1.568	0.828	0.429	2.275	16.659
2012 fishery CEY [2]	**1.148**	**6.633**	**3.212**	**11.918**	**5.070**	**1.567**	**1.869**	**2.465**	**33.884**

Notes:

[1] "Coastwide assessment" refers to the coastwide model fit with survey apportionment of the total biomass estimate among regulatory areas, and corrected for estimated rates of hook competition and survey timing.

[2] "Other removals" comprise O32 and U32/O26 wastage, O32 and U32/O26 bycatch, personal use, and in most areas sport catch. In Areas 2A and 2B sport catch is included in fishery CEY rather than in other removals.

[3] Assumes GHL of 0.931 M lbs. in Area 2C and 3.103 M lbs. in Area 3A.

Table 12. Estimates of 2011 exploitable biomass and CEY from the 2010 assessment (2010 RARA, p. 115).

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2011 exploitable biomass	2.997	38.250	23.874	109.841	48.066	23.583	26.992	43.397	317.000
Proportion of total	0.021	0.129	0.079	0.345	0.181	0.067	0.051	0.127	1.000
Harvest rate	0.215	0.215	0.215	0.16125	0.16125	0.16125	0.16125	0.16125	<0.215
Total CEY	1.426	8.792	5.386	23.520	9.242	3.426	2.603	6.502	60.897
Other removals [2]	0.476	0.848	3.057	9.162	1.734	0.858	0.394	2.515	19.044
2011 fishery CEY [2]	**0.950**	**7.944**	**2.329**	**14.358**	**7.509**	**2.568**	**2.208**	**3.987**	**41.853**
2010 catch limit	**0.910**	**7.650**	**2.330**	**14.360**	**7.510**	**2.410**	**2.180**	**3.720**	**41.070**

Notes:

[1] "Coastwide assessment" refers to the coastwide model fit with survey apportionment of the total biomass estimate among regulatory areas.

[2] "Other removals" comprise O32 and U32/O26 wastage, O32 and U32/O26 bycatch, personal use, and in most areas sport catch. In Areas 2A and 2B sport catch is included in fishery CEY rather than in other removals.

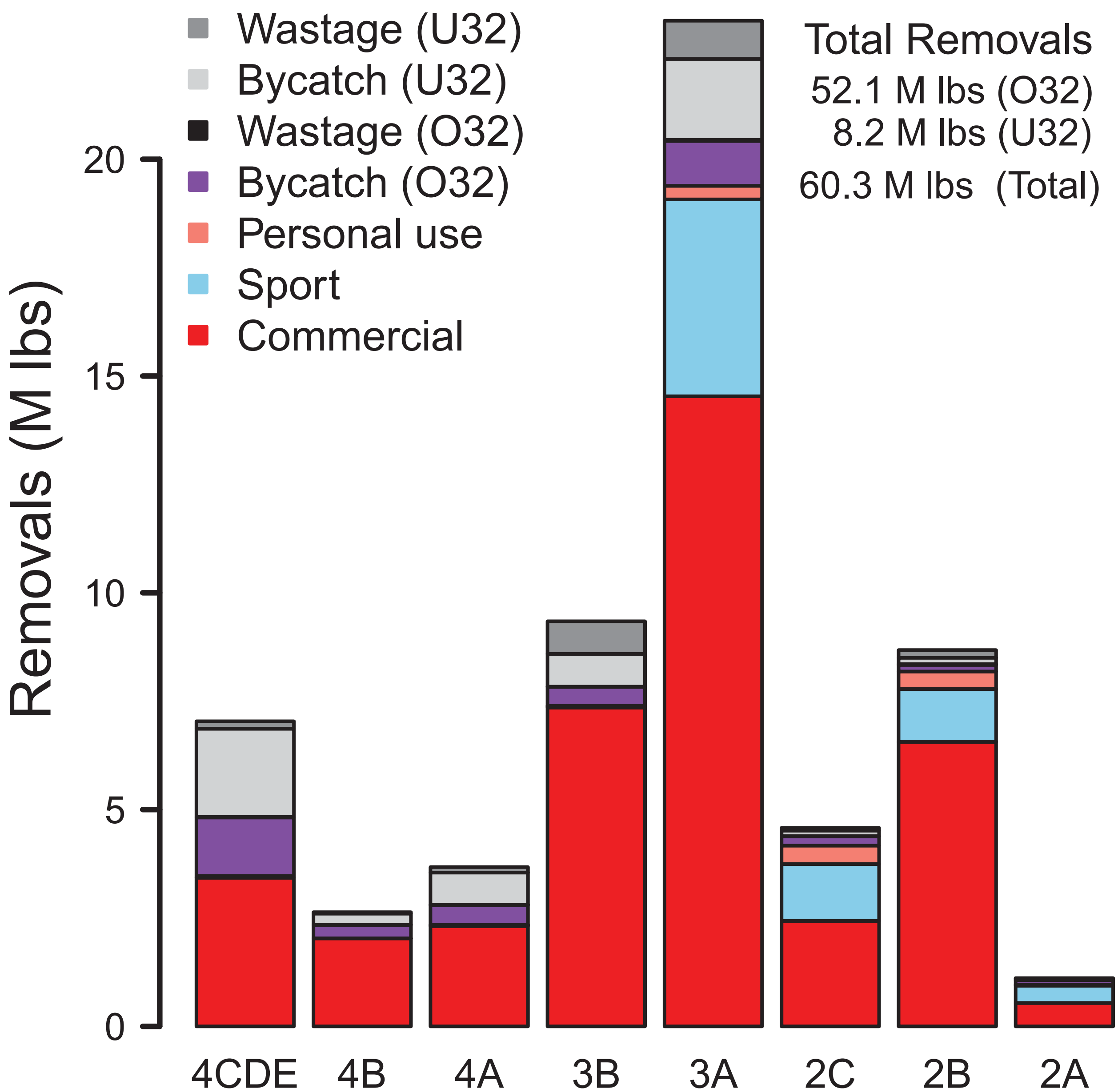


Figure 1. Total removals by type and regulatory area for 2011.

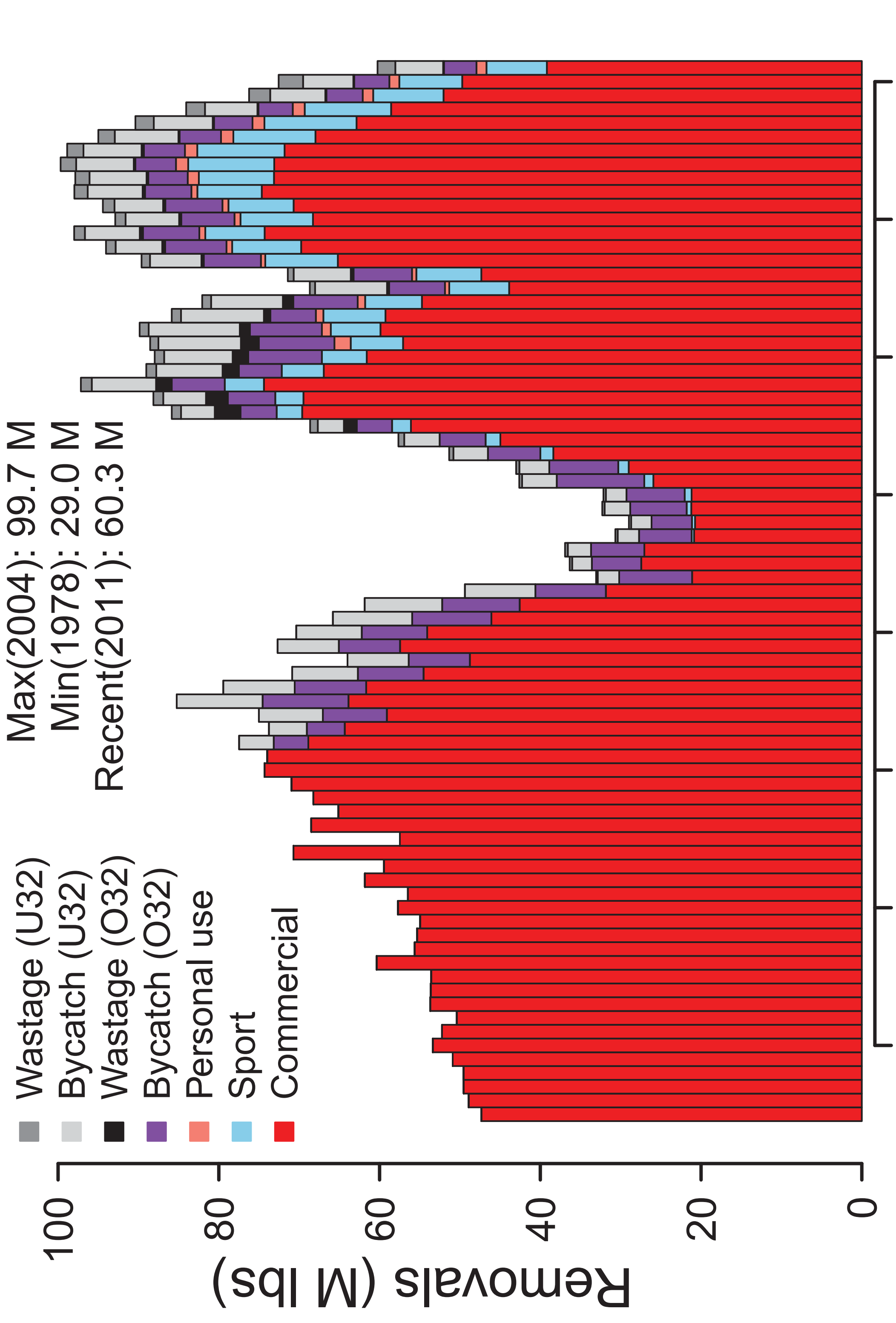


Figure 2. Total removals coastwide for the period 1935-2011. Year and amount of minimum, maximum, and most recent removals are also listed.

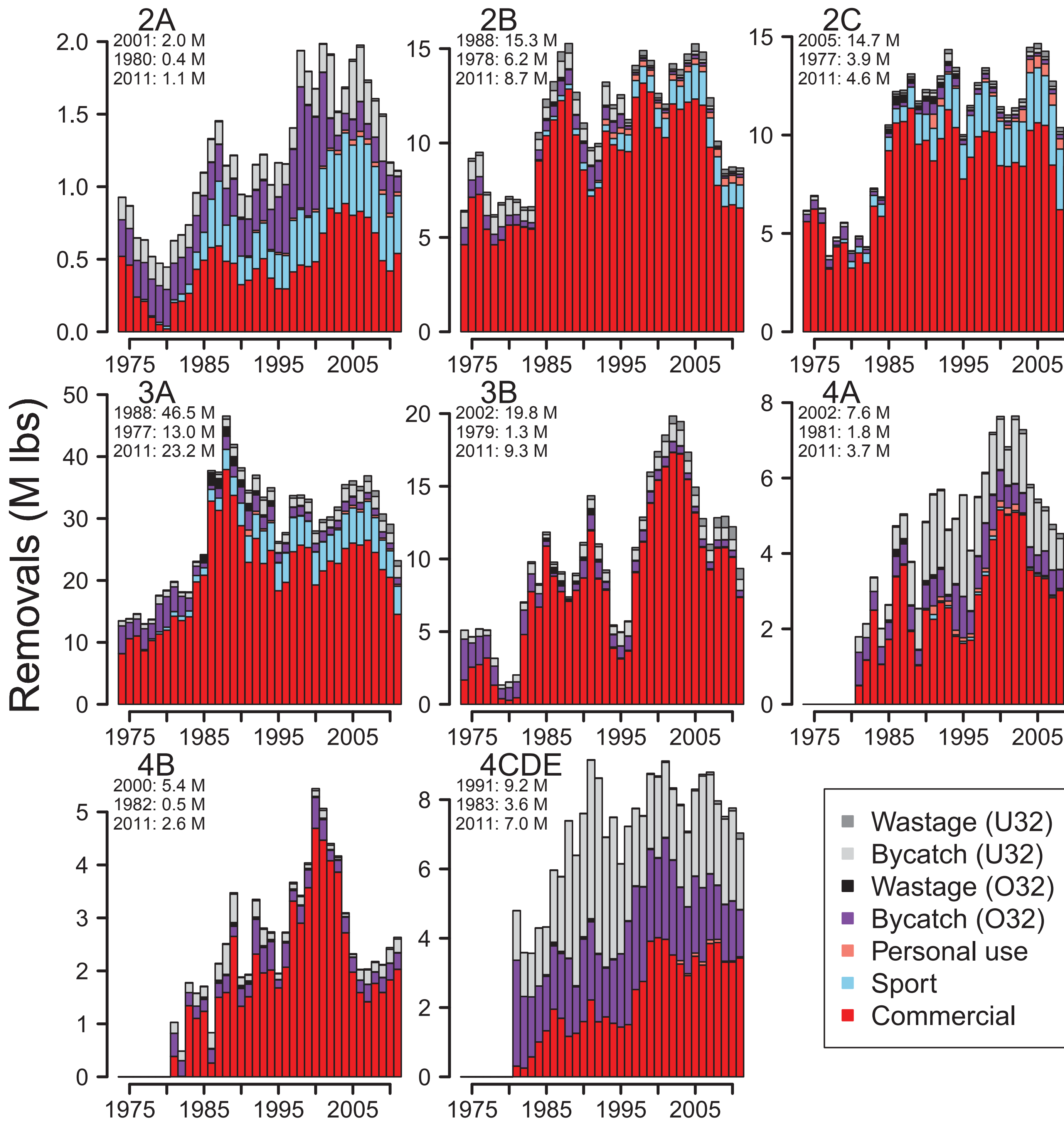


Figure 3. Total removals of halibut, by Regulatory Area, 1974-2011. Year and amount of minimum, maximum, and most recent removals are listed in the upper left corner for each regulatory area.

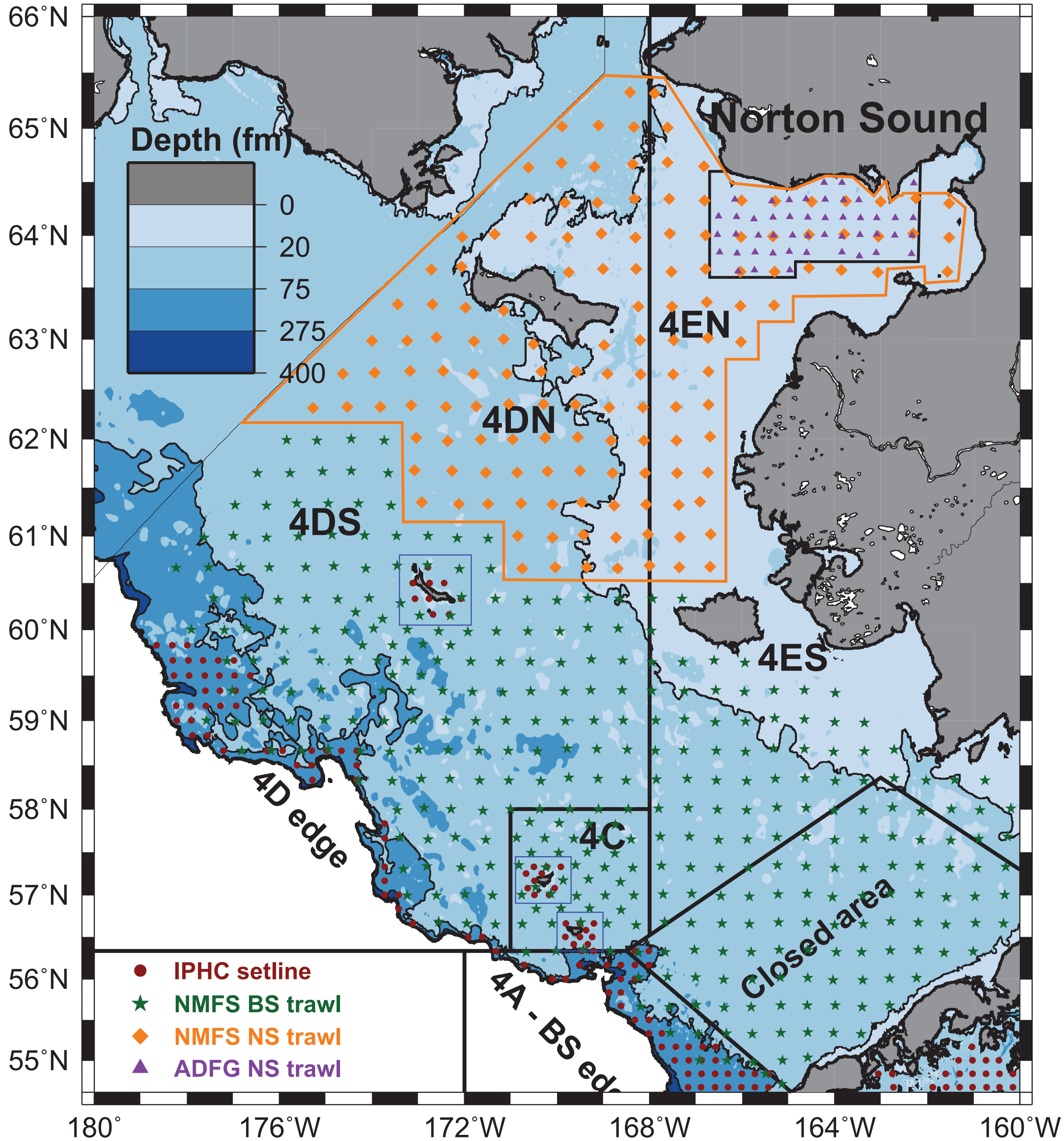


Figure 4. Summary of information sources and subareas utilized to construct a dataset for Area 4CDE. See text for details.

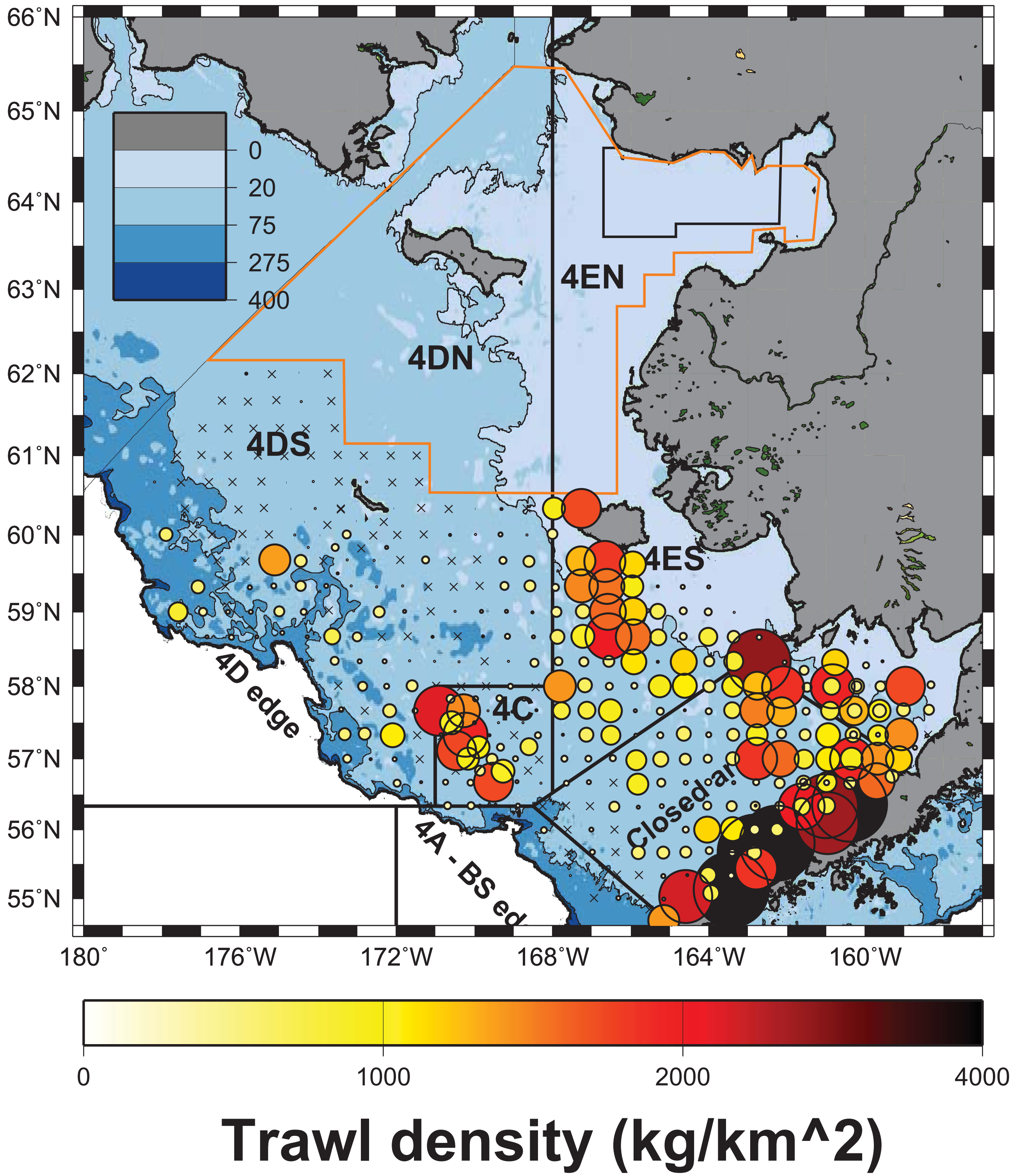


Figure 5. Catch rates of halibut (all sizes) at survey stations in the 2011 NMFS expanded Eastern Bering Sea trawl survey. The size of the circles is proportional to catch rate (kg/km^2) and conveys the same information as the coloring of the circles. Stations with zero catch are indicated by an "x".

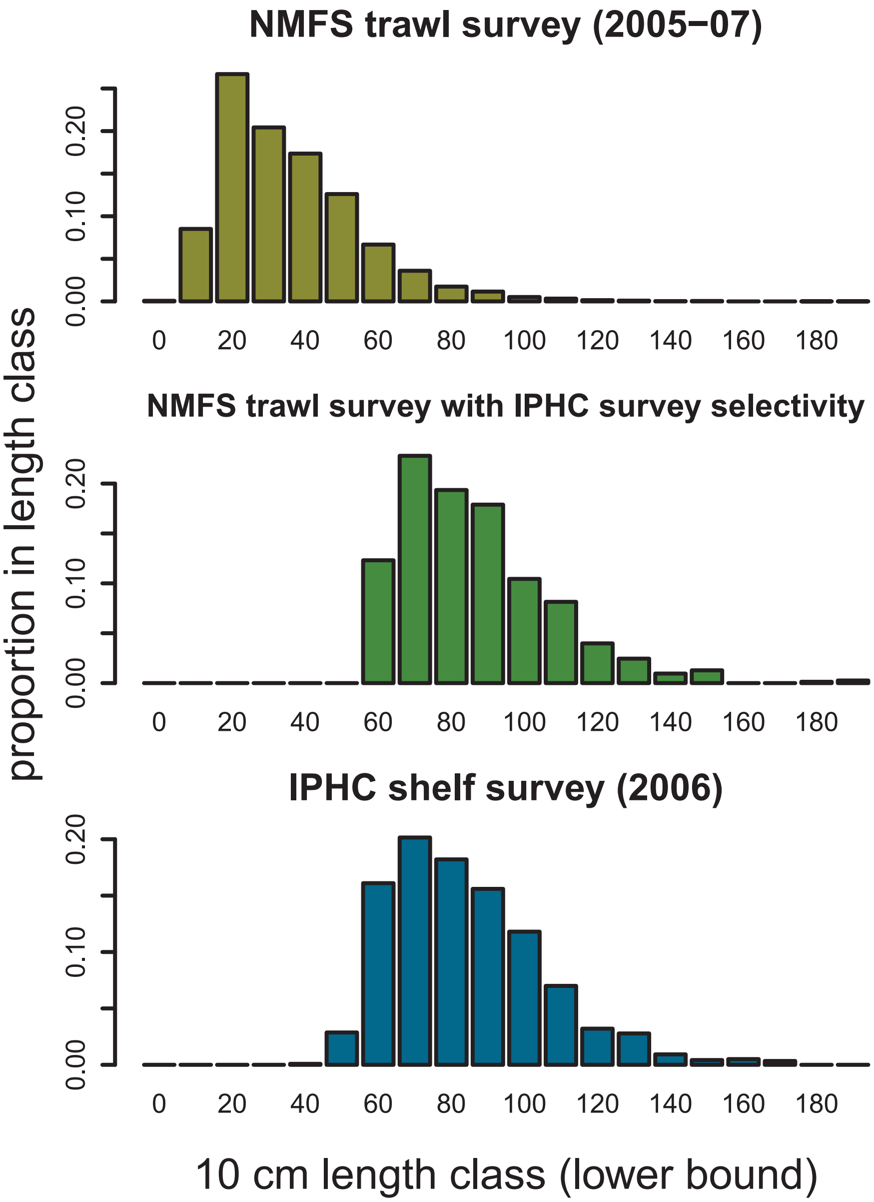


Figure 6. Comparison of NMFS trawl survey and IPHC length frequency compositions. The top panel shows the length frequency composition for all halibut caught by the NMFS trawl gear for years 2005-7. The middle panel shows the frequency distribution of lengths after the IPHC setline selectivity curve is applied to raw counts. The bottom panel illustrates the length composition of halibut in the 2006 IPHC shelf survey.

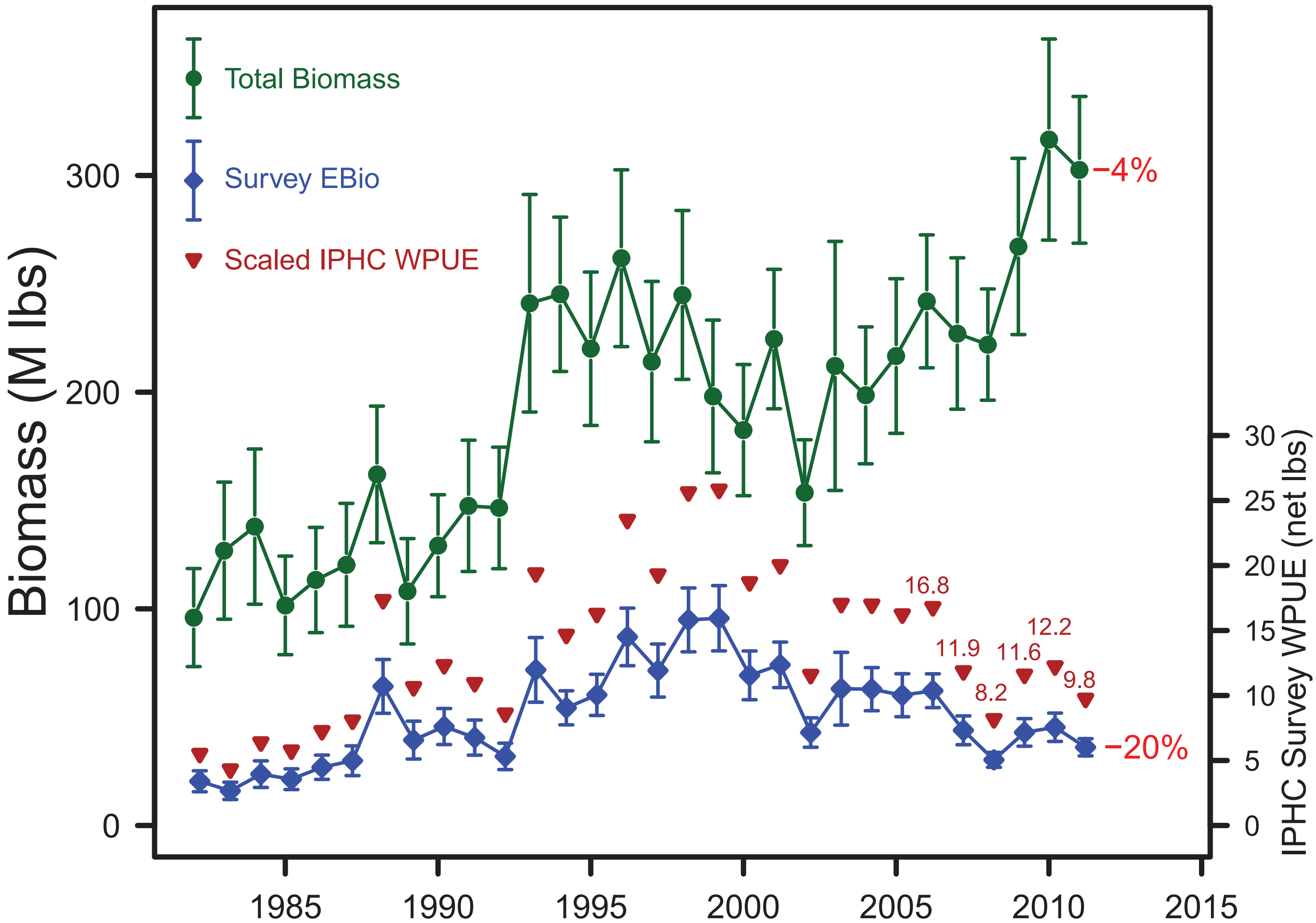


Figure 7. Swept-area estimates of halibut abundance from the NMFS EBS trawl survey. The red dots and error bars represent mean and 95% confidence interval for the total abundance; the blue diamonds are error bars represent mean and 95% confidence interval for abundance with survey selectivity applied to the total biomass (termed survey EBio). The inverted purple triangles represent the estimated density of O32 halibut (per standardized skate of gear) across the shelf; this index is scaled to the survey EBio trend (see text for full details). The percentages show the change in the index values from 2010 to 2011.

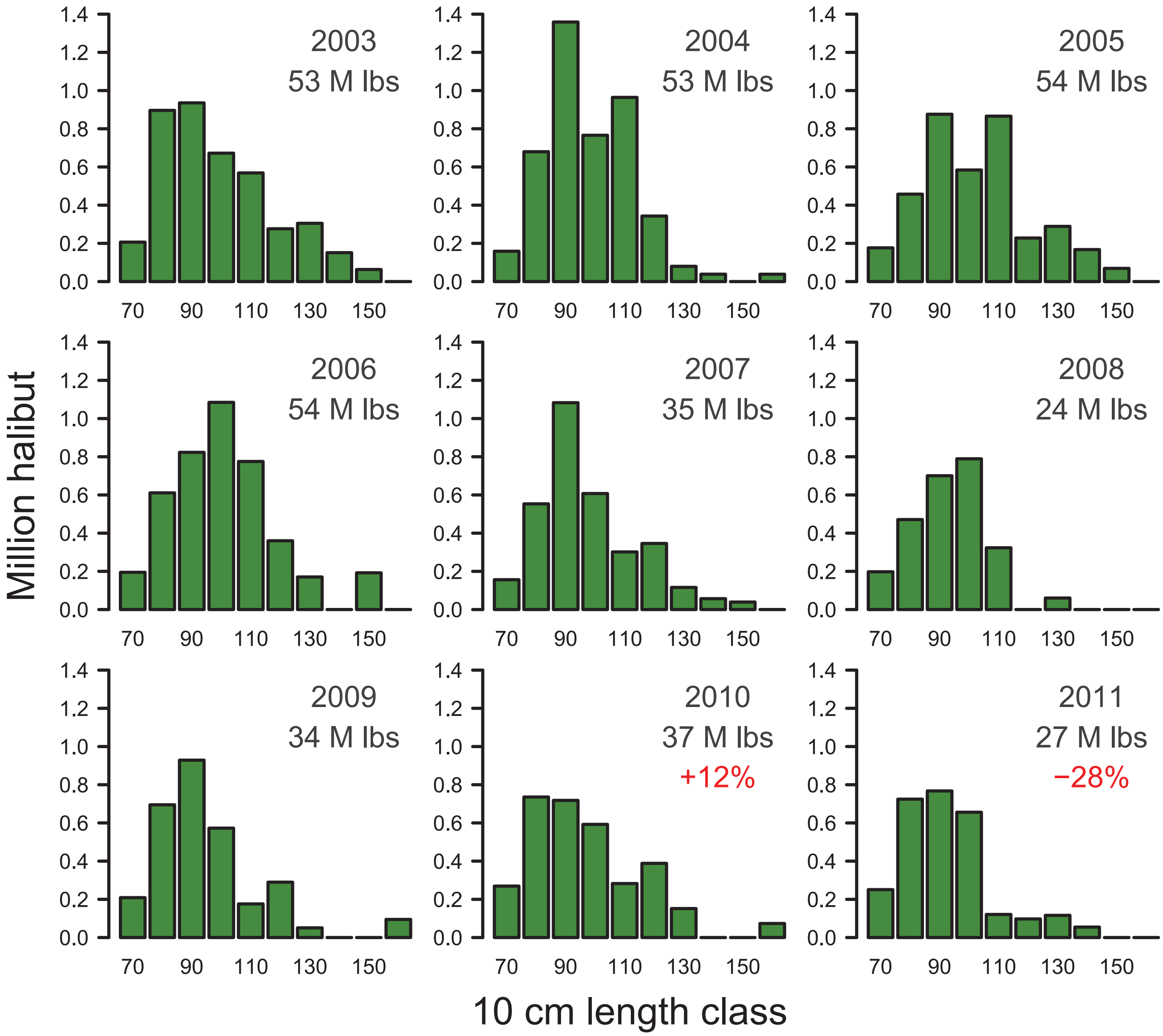


Figure 8. Swept area estimates of halibut EBio, by 10-cm length interval, in the NMFS EBS trawl survey for the years 2002 to 2010. Increases in estimated EBio over the previous year are indicated in the 2010 and 2011 plots. Exploitable numbers of halibut are illustrated by the darker bars. The percentages show the change in the index values from 2009 to 2010.

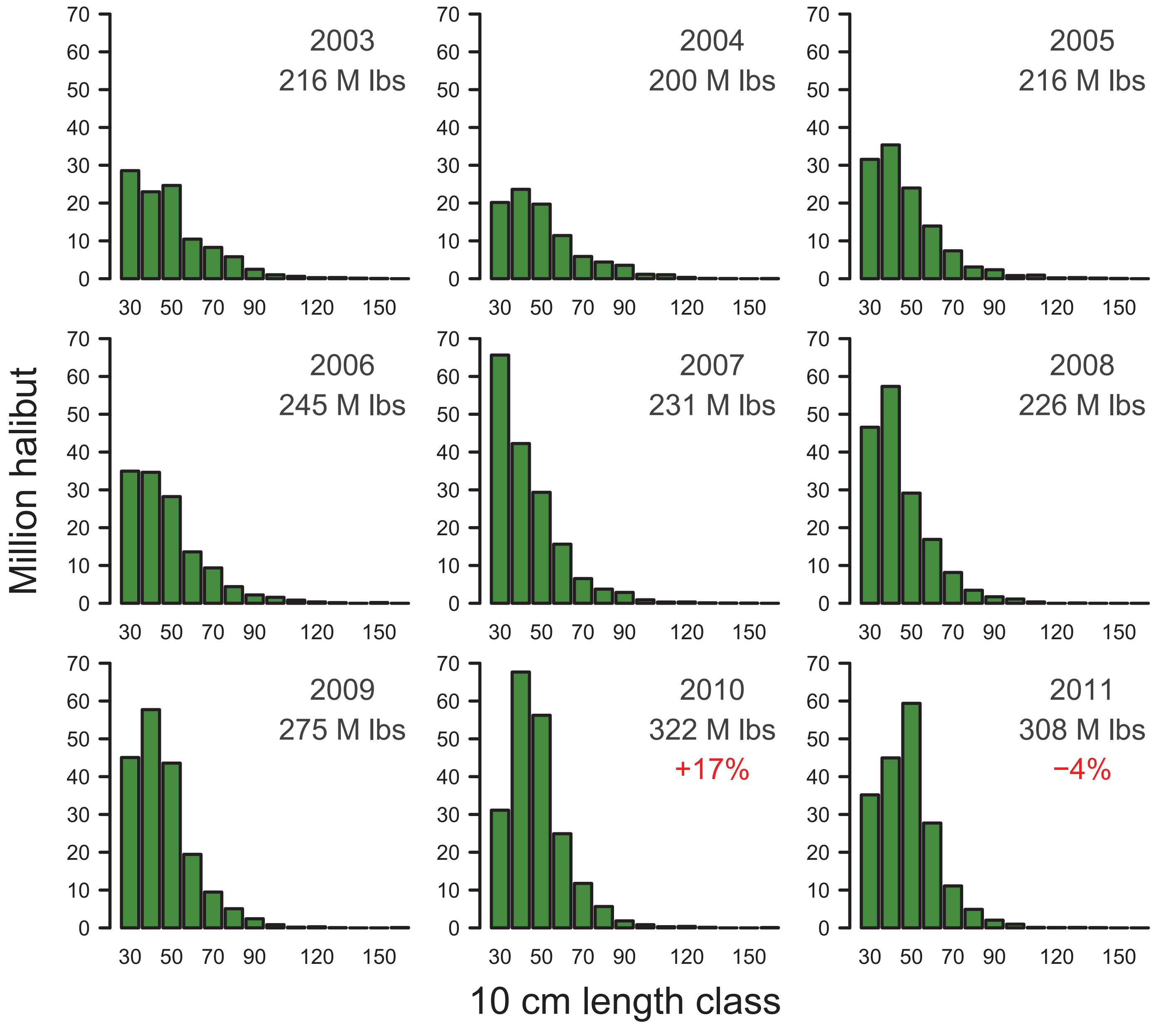


Figure 9. Swept area estimates of halibut TBio, by 10-cm length interval, in the NMFS EBS trawl survey for the years 2002 to 2011. Changes in estimated EBio over the previous year are indicated in the 2010 and 2011 plots.

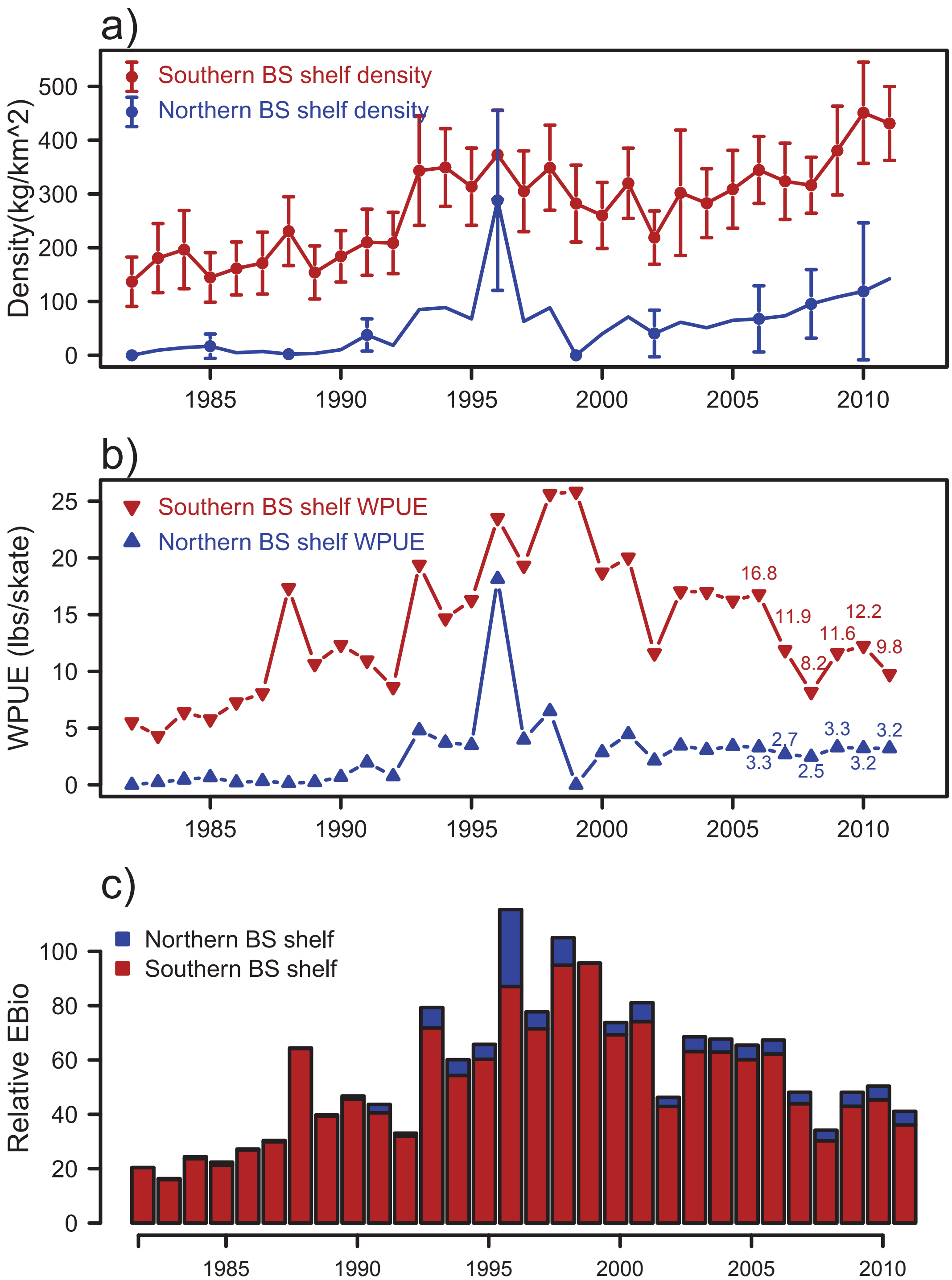


Figure 10. Time series used to construct an estimate of halibut biomass in the northern shelf region of Area 4CDE, termed Area 4N. See text for details.

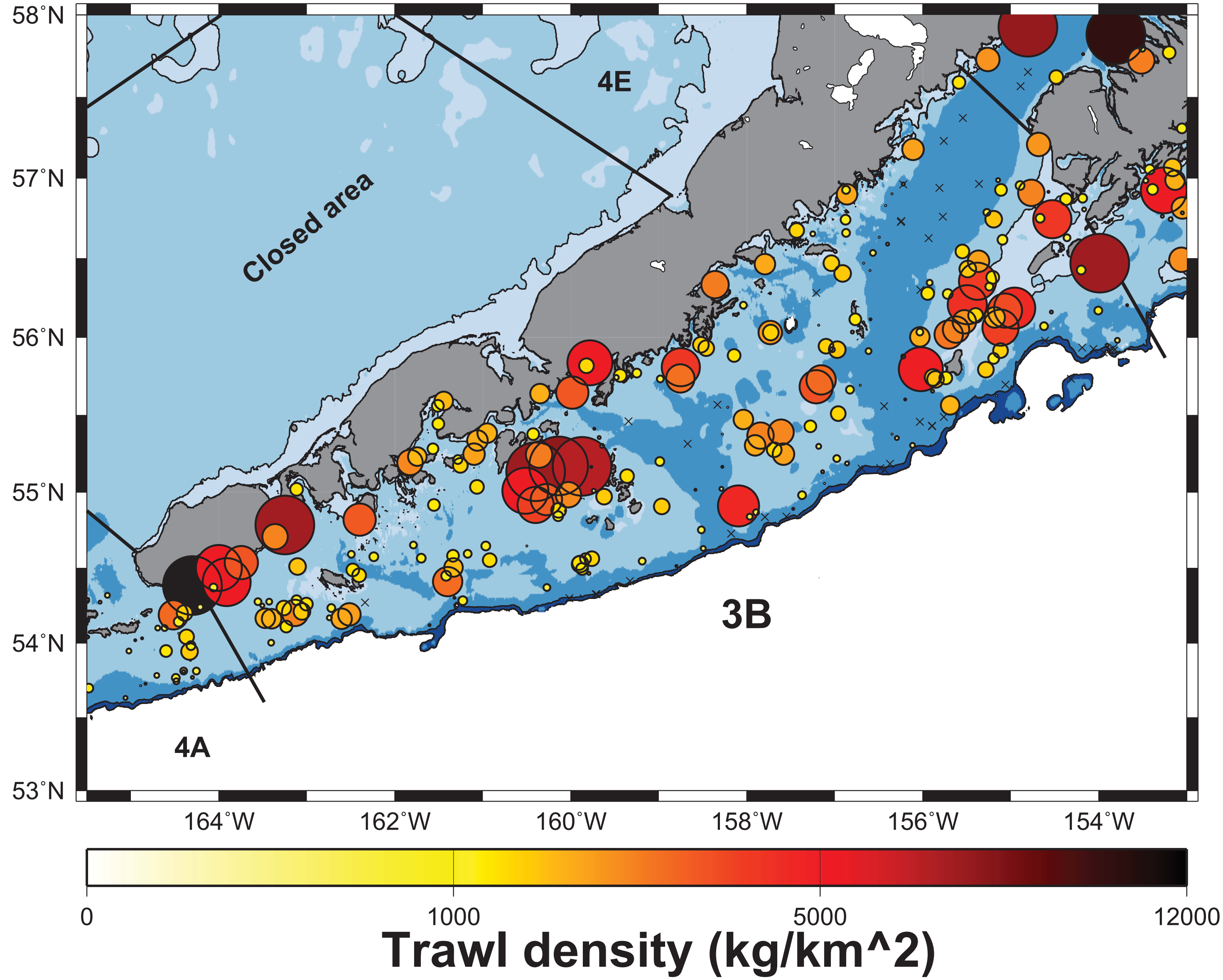


Figure 11a. Catch rates of halibut (all sizes) at survey stations in the 2011 NMFS biennial Gulf of Alaska trawl survey in the vicinity IPHC Area 3B. The size of the circles is proportional to catch rate (kg/km^2) and conveys the same information as the coloring of the circles. Stations with zero catch are indicated by an "x".

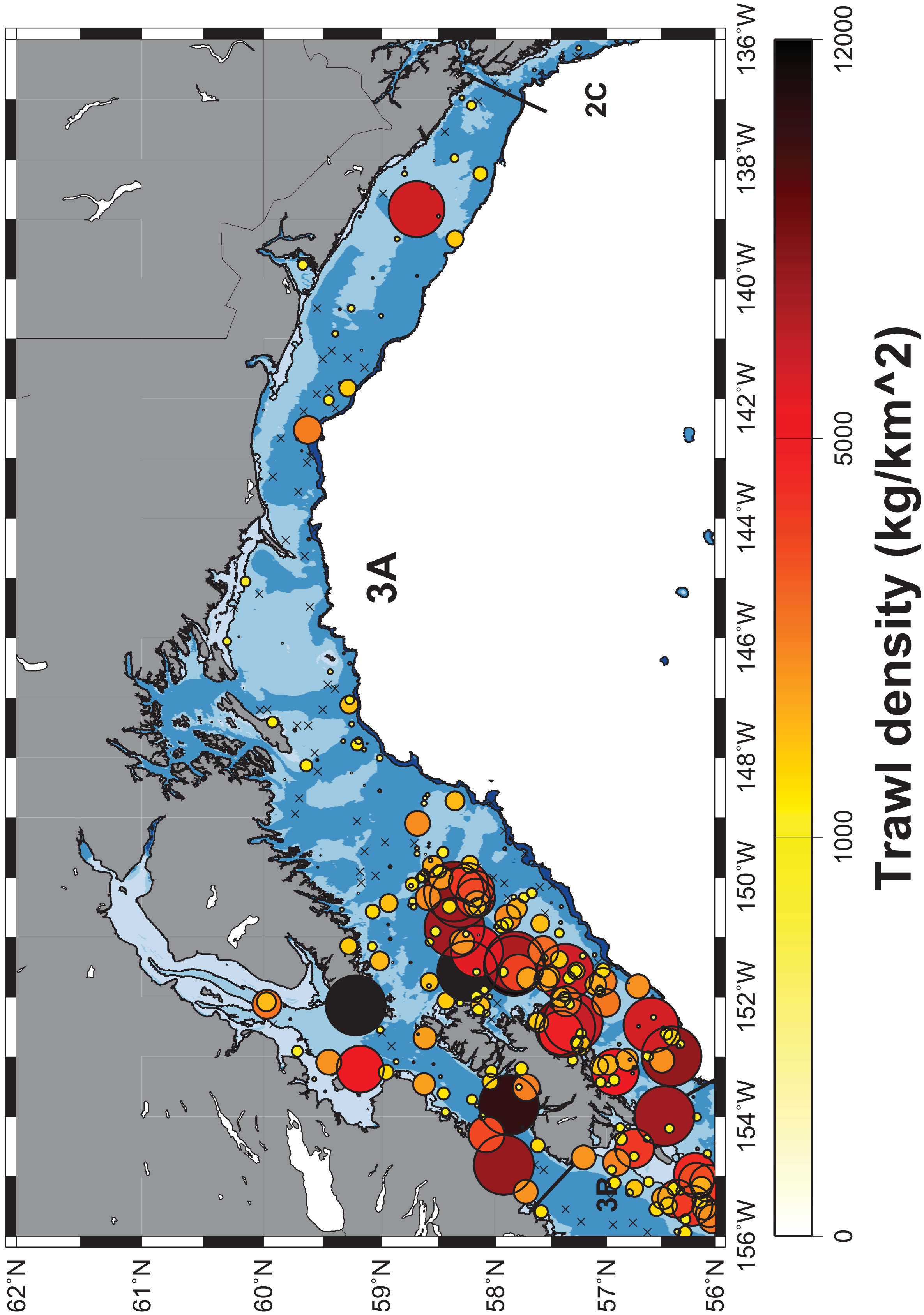


Figure 11b. Same as Figure 11a, but for IPHC Area 3A.

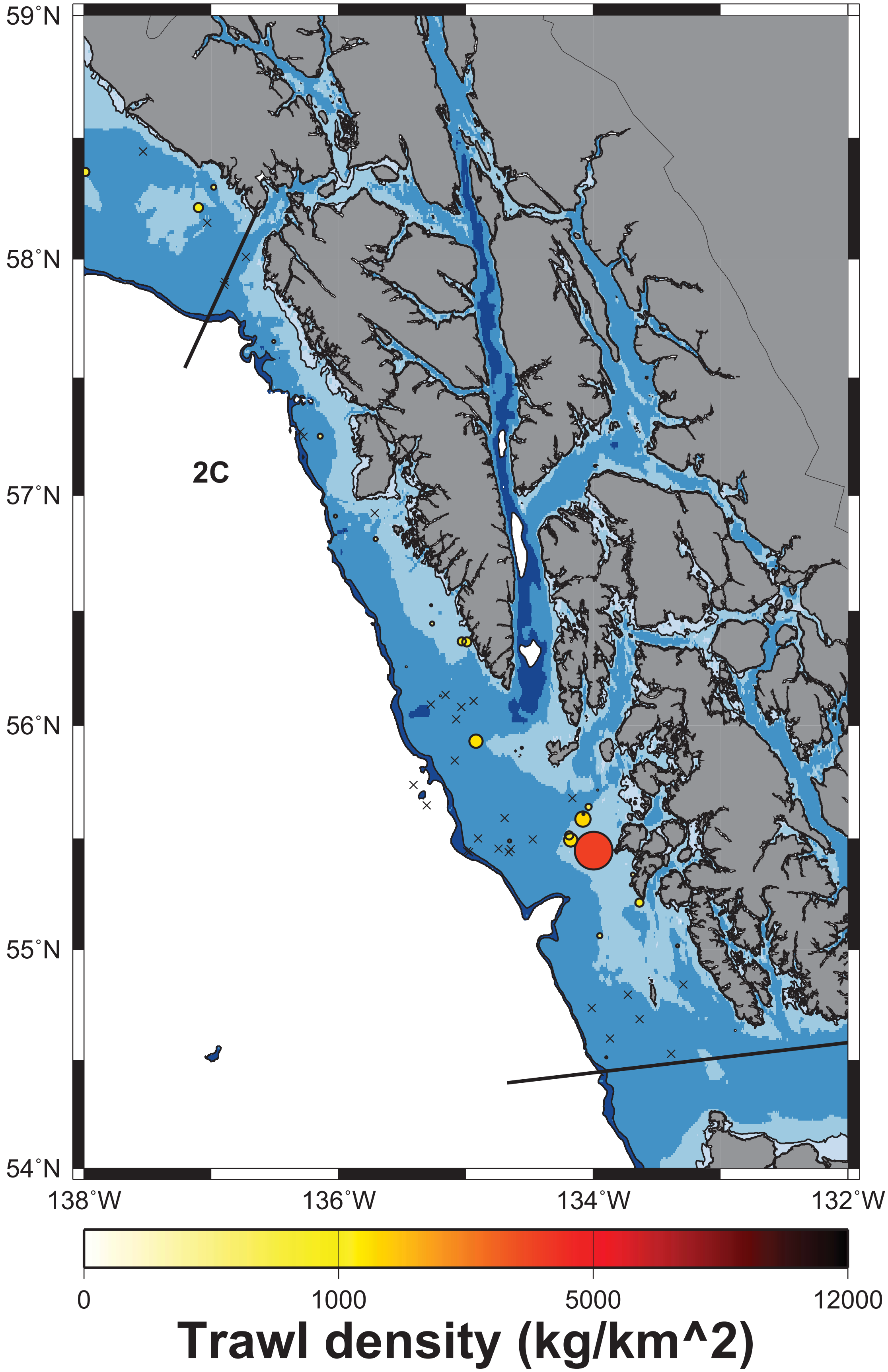


Figure 11c. Same as Figure 11a, but for IPHC Area 2C.

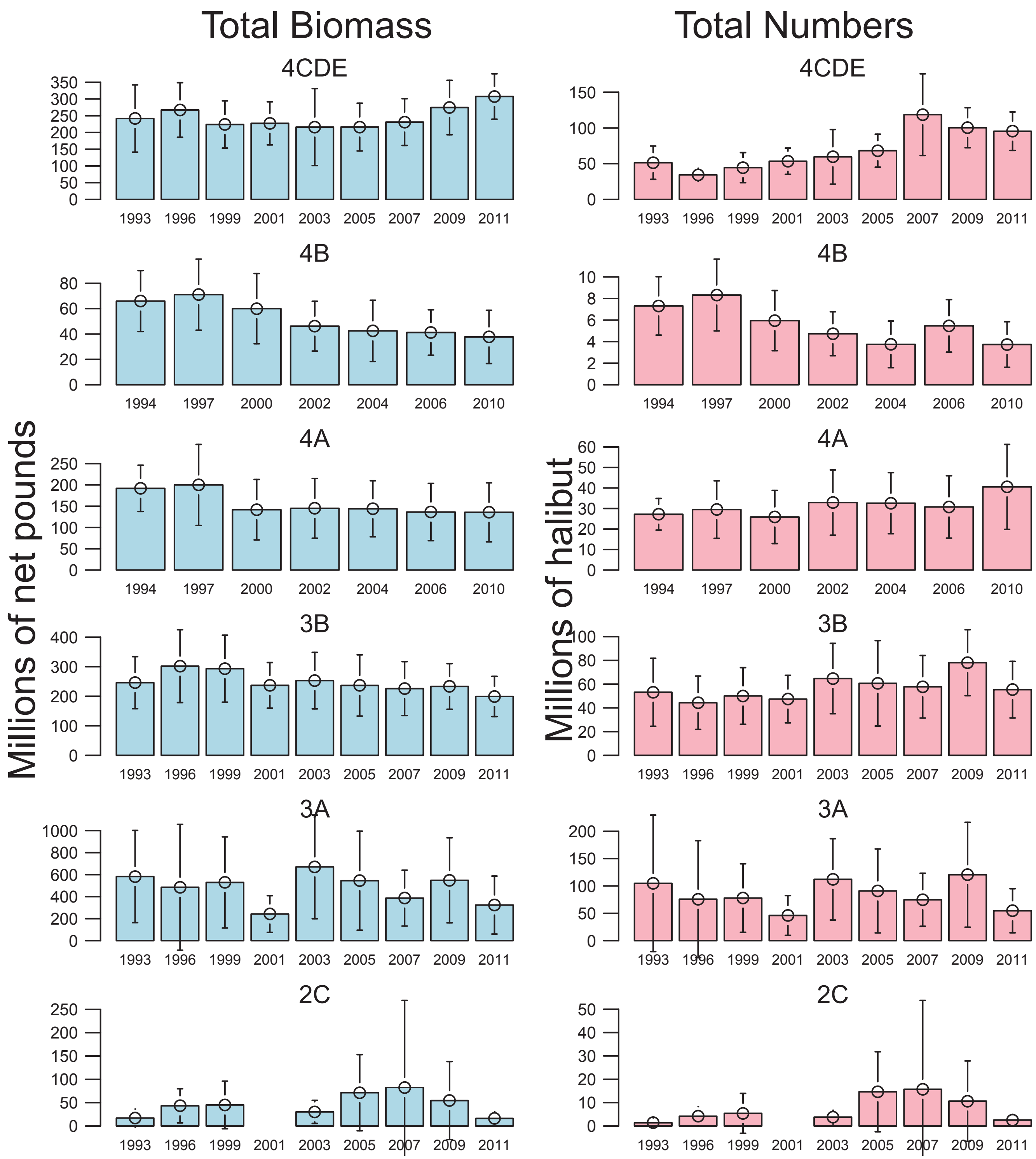


Figure 12. Swept area estimates of total biomass and total numbers of halibut in IPHC Areas 4CDE to 2C.

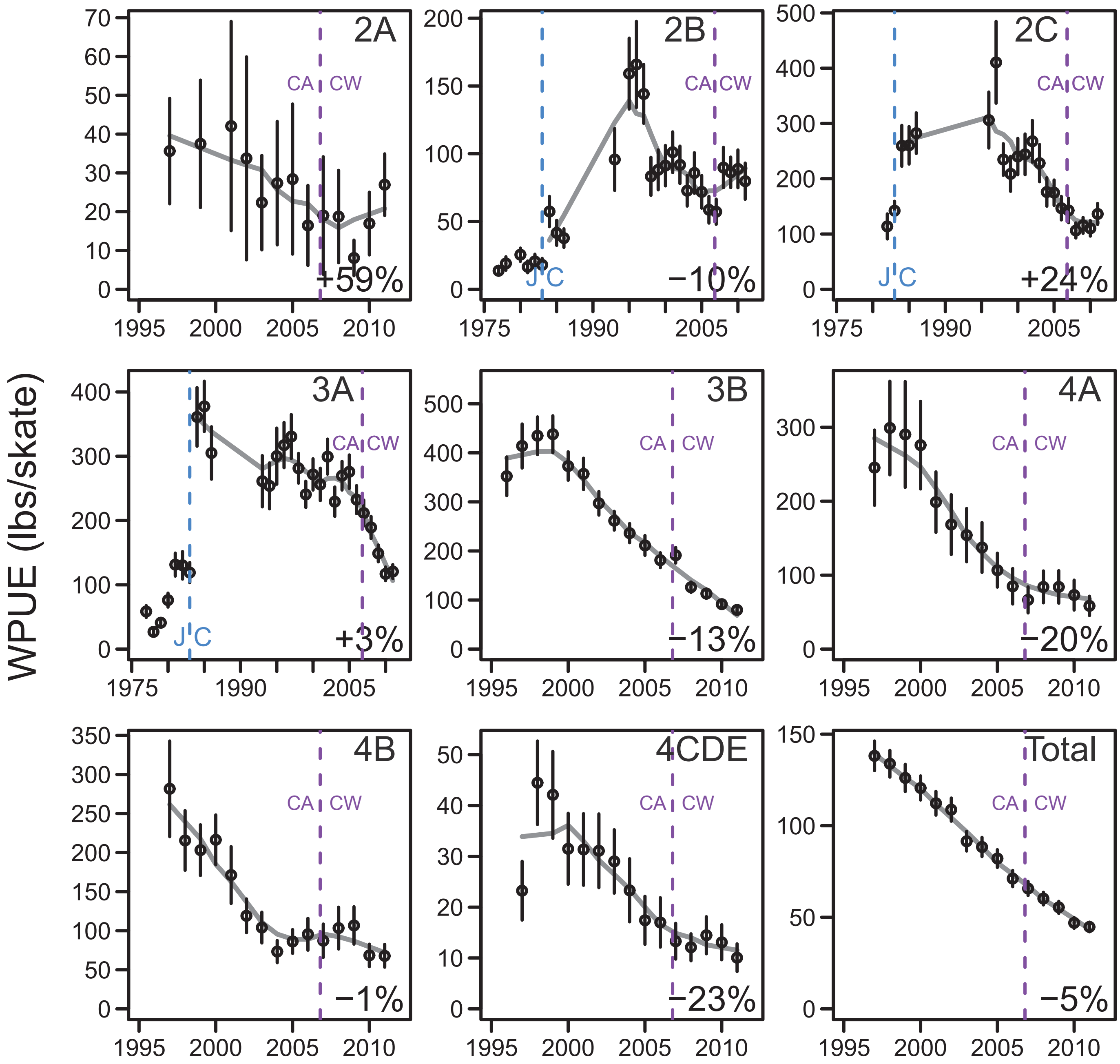


Figure 13. Survey WPUE (weight of O32 halibut per standardized skate of gear) by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The thick line is a smoother to illustrate trend; it is not an assessment model fitted to the WPUE data. The total is computed by area-weighting the individual area WPUE time series. Note that the timeline for Areas 2B, 2C, and 3A differ from the other areas and extends back to 1975. The data points prior to 1984 are from the "J" hook era. The dashed vertical line indicates the change from closed area (CA) to coastwide (CW) assessment. The percentages show the change in the index values from 2010 to 2011.

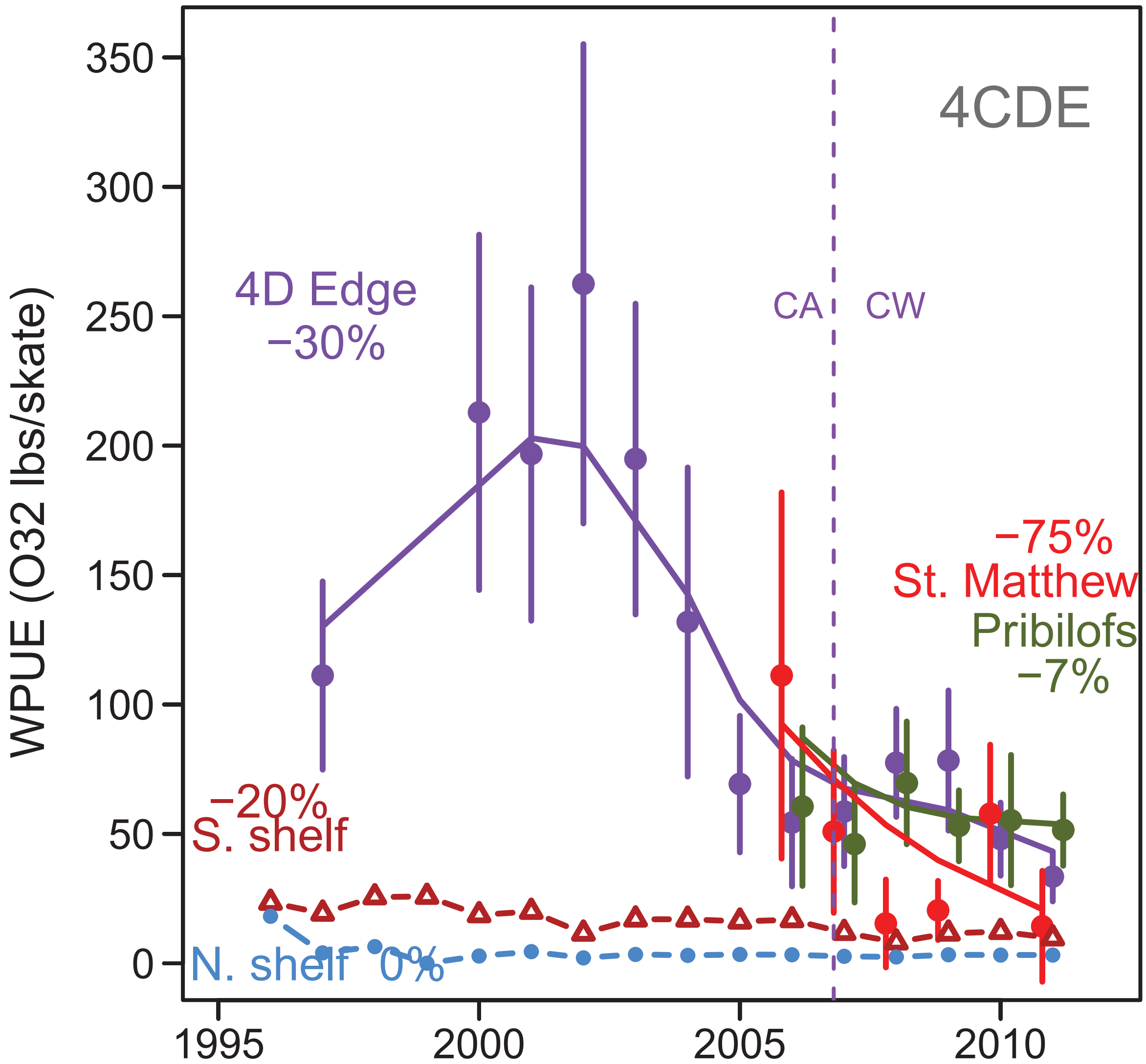


Figure 14. The five subarea components used to construct the WPUE survey index for Area 4CDE. The dashed vertical line indicates the change from closed area (CA) to coastwide (CW) assessment. The percentages show the change in the index values from 2010 to 2011.

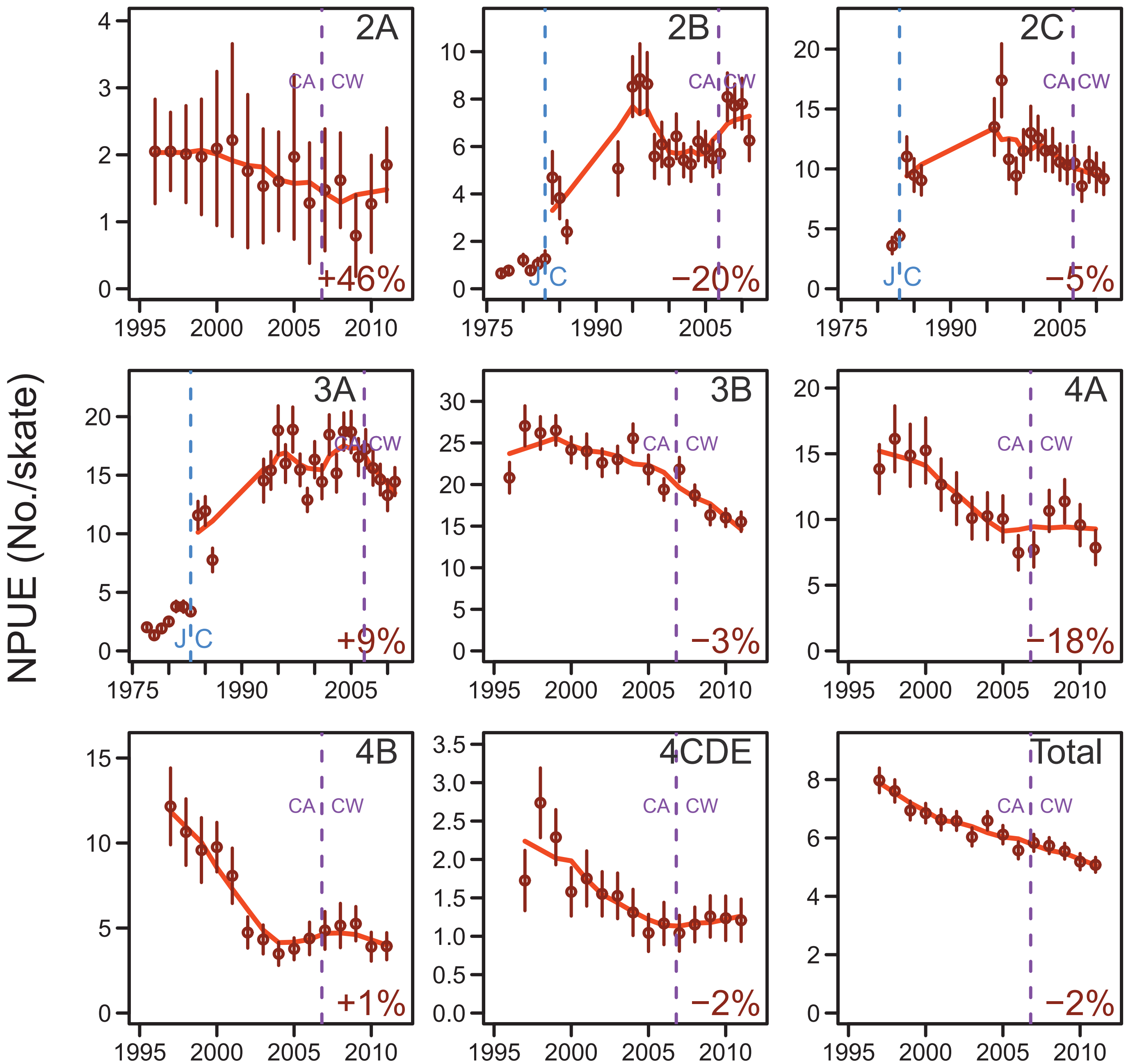


Figure 15. Survey NPUE (total number of halibut (all sizes) per standardized skate of gear) by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The thick line is a smoother to illustrate trend; it is not an assessment model fitted to the NPUE data. The total is computed by area-weighting the individual area NPUE time series. Note that the timeline for Areas 2B, 2C, and 3A differ from the other areas and extends back to 1975. The data points prior to 1984 are from the "J" hook era. The percentages show the change in the index values from 2010 to 2011.

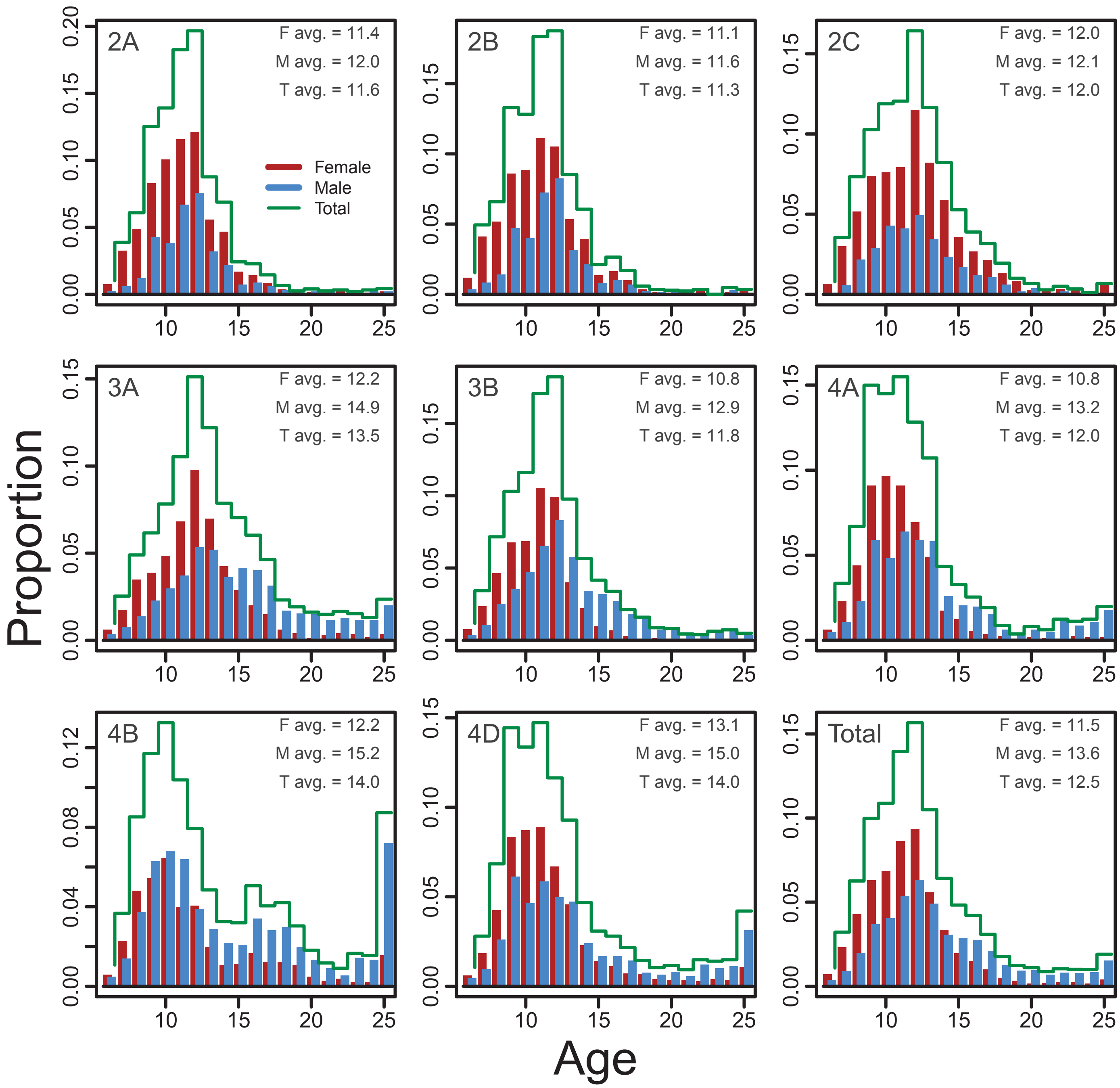


Figure 16. Regulatory area sex and age compositions from halibut taken in the 2011 IPHC stock assessment survey. Proportions are shown for females (red bars), males (blue bars) and sexes combined (green line). Average age is also shown, with "T" indicating Total (sexes combined).

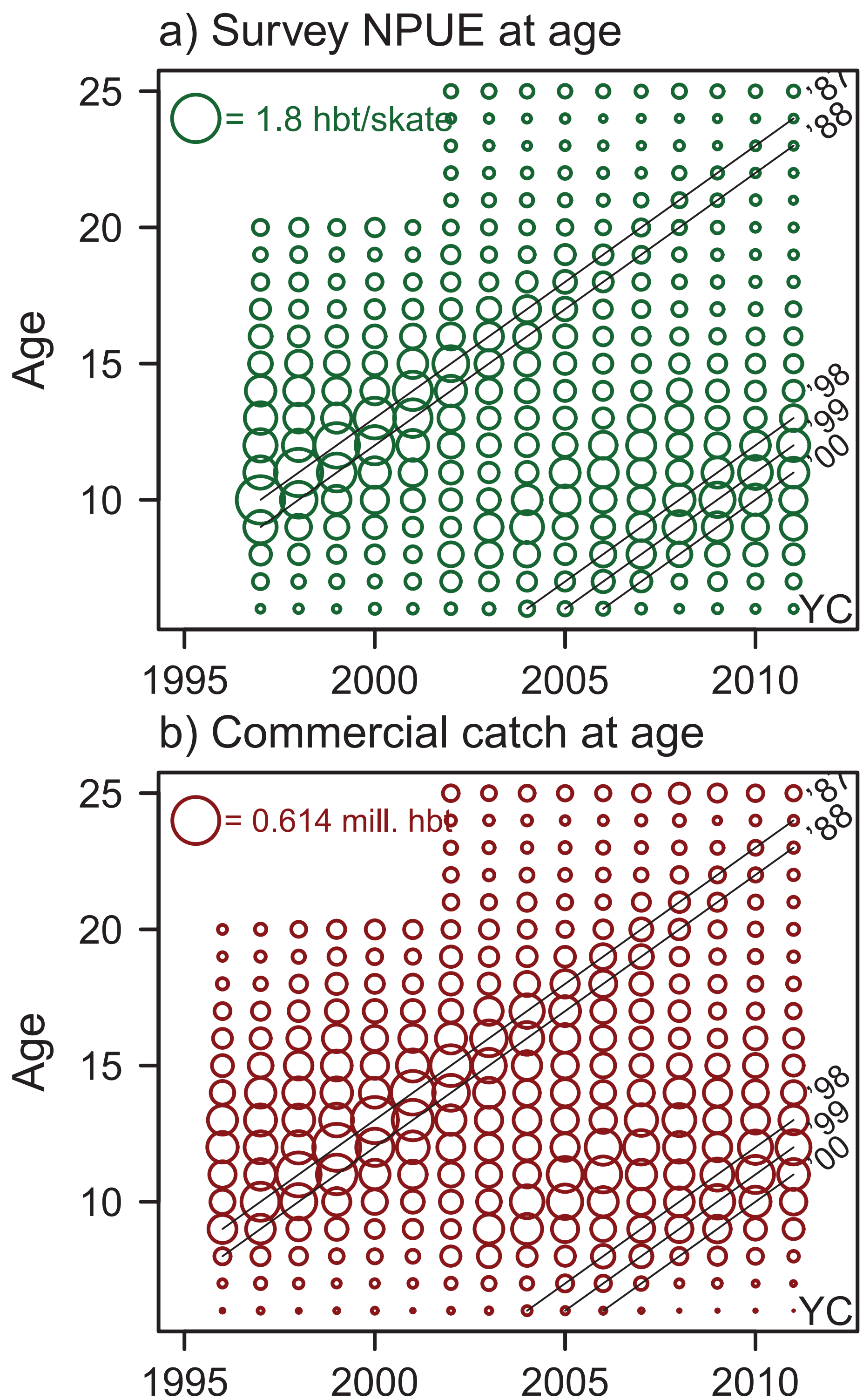


Figure 17. Bubble plots showing age-specific survey catch rate of halibut (both sexes combined, panel a), and catch at age (both sexes combined) in the commercial fishery (panel b).

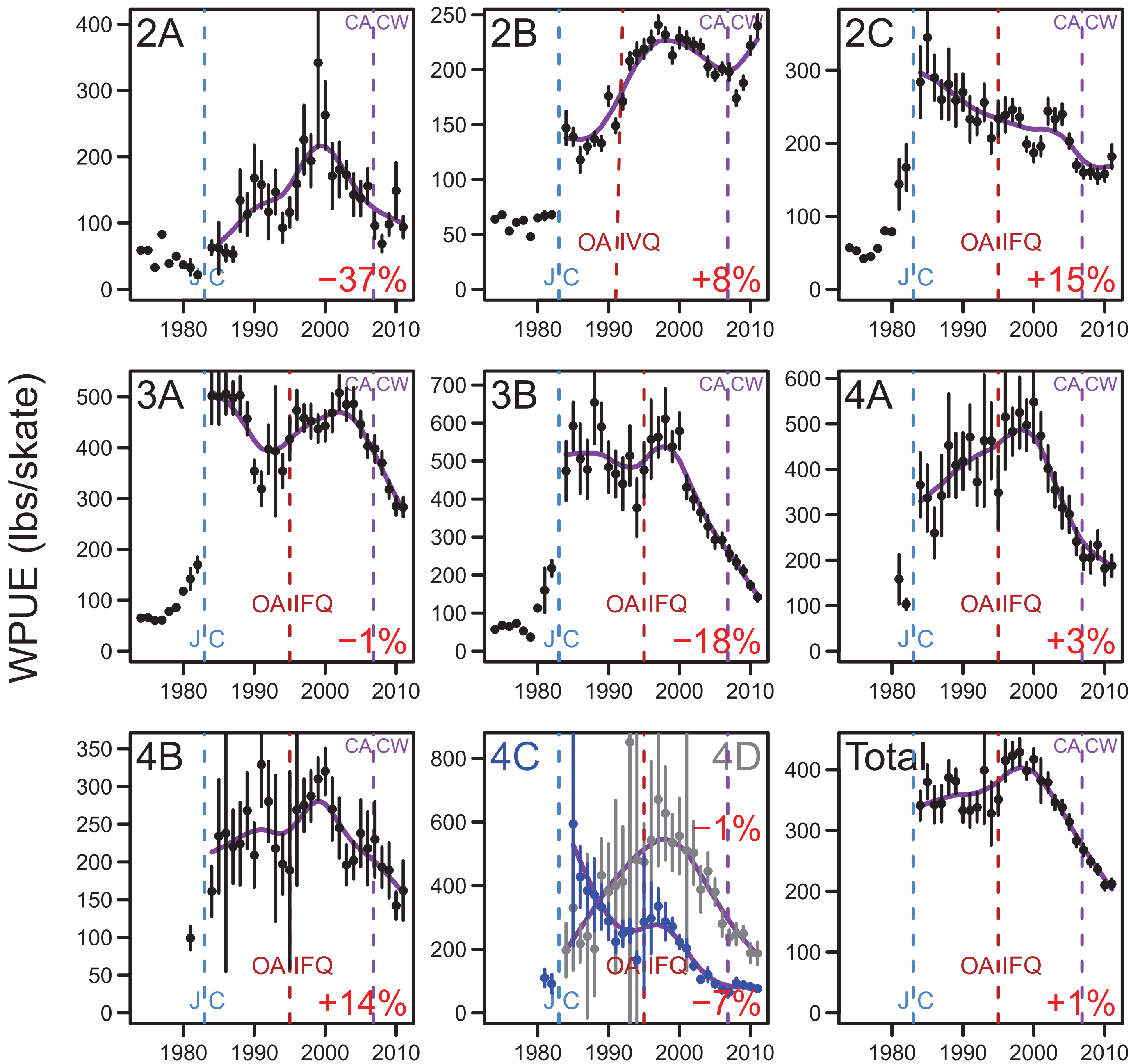


Figure 18. Commercial WPUE by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray/green line is a smoother to illustrate trend; it is not an assessment model fit to the CPUE data. The total is computed by area-weighting the individual area WPUE time series. The dashed vertical lines indicate transitions between J and C hook, between open access (OA) and Individual Vessel Quotas in Area 2B, and between open access and Individual Fishing Quotas in Areas 2C, 3, and 4. The percentages show the change in the index values from 2010 to 2011.

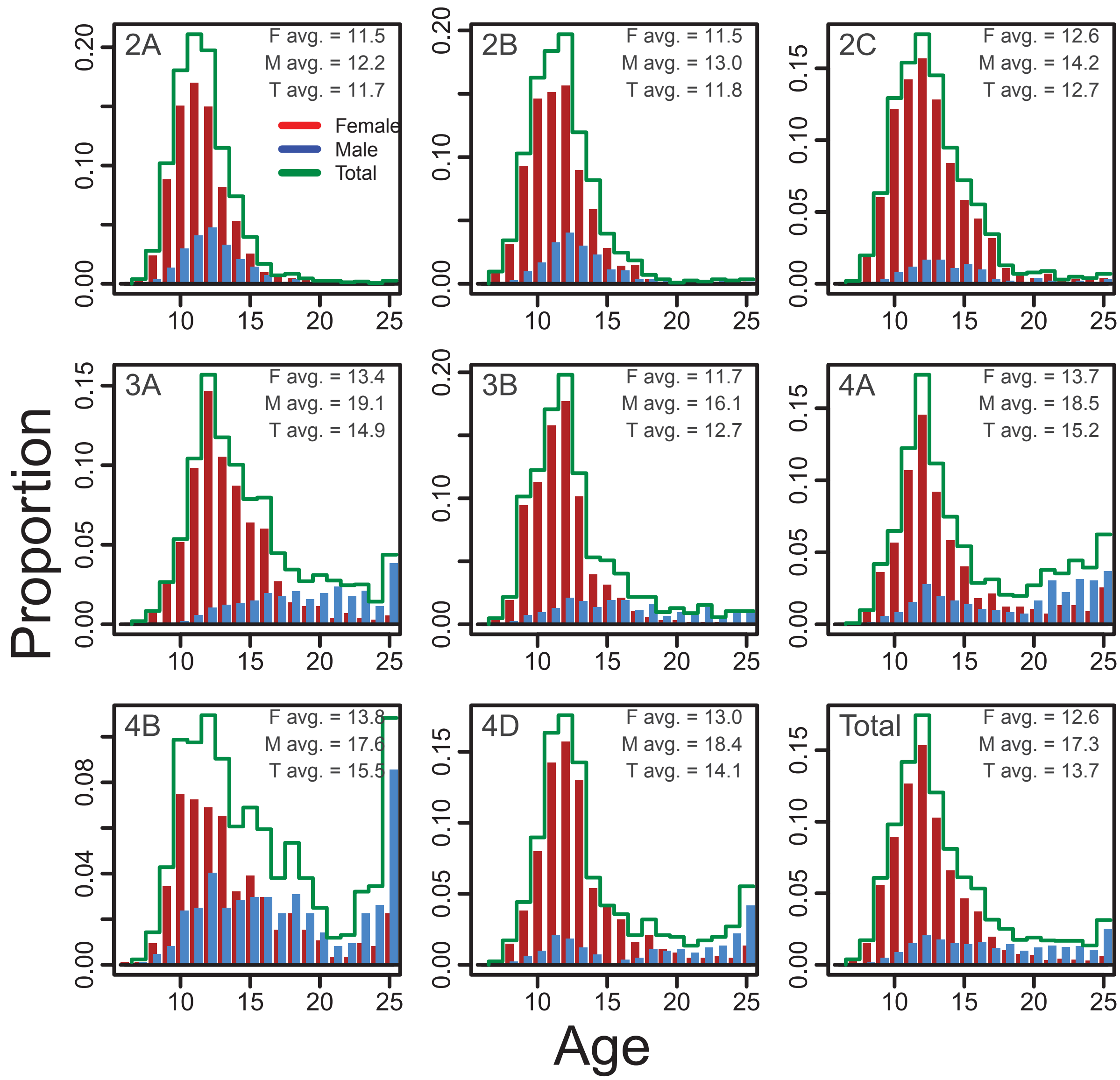


Figure 19. Regulatory area sex and age compositions from halibut sampled from commercial landings. Proportions are shown for females (red bars), males (blue bars) and sexes combined (green line). Average age is also shown, with "T" indicating Total (sexes combined).

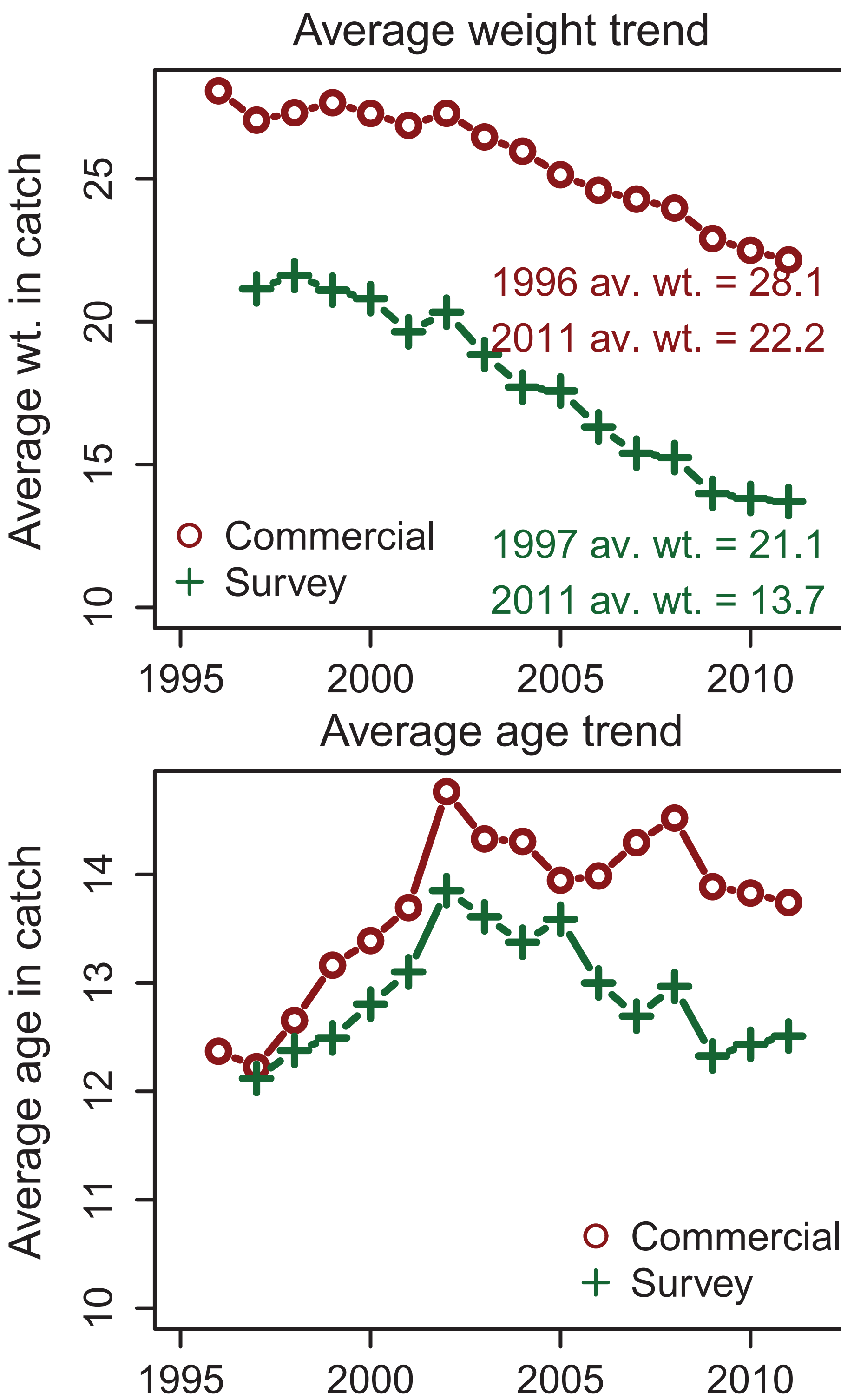


Figure 20. Average weight (panel a) and average weight (panel b) trends for the coastwide halibut stock for 1996 to 2011.

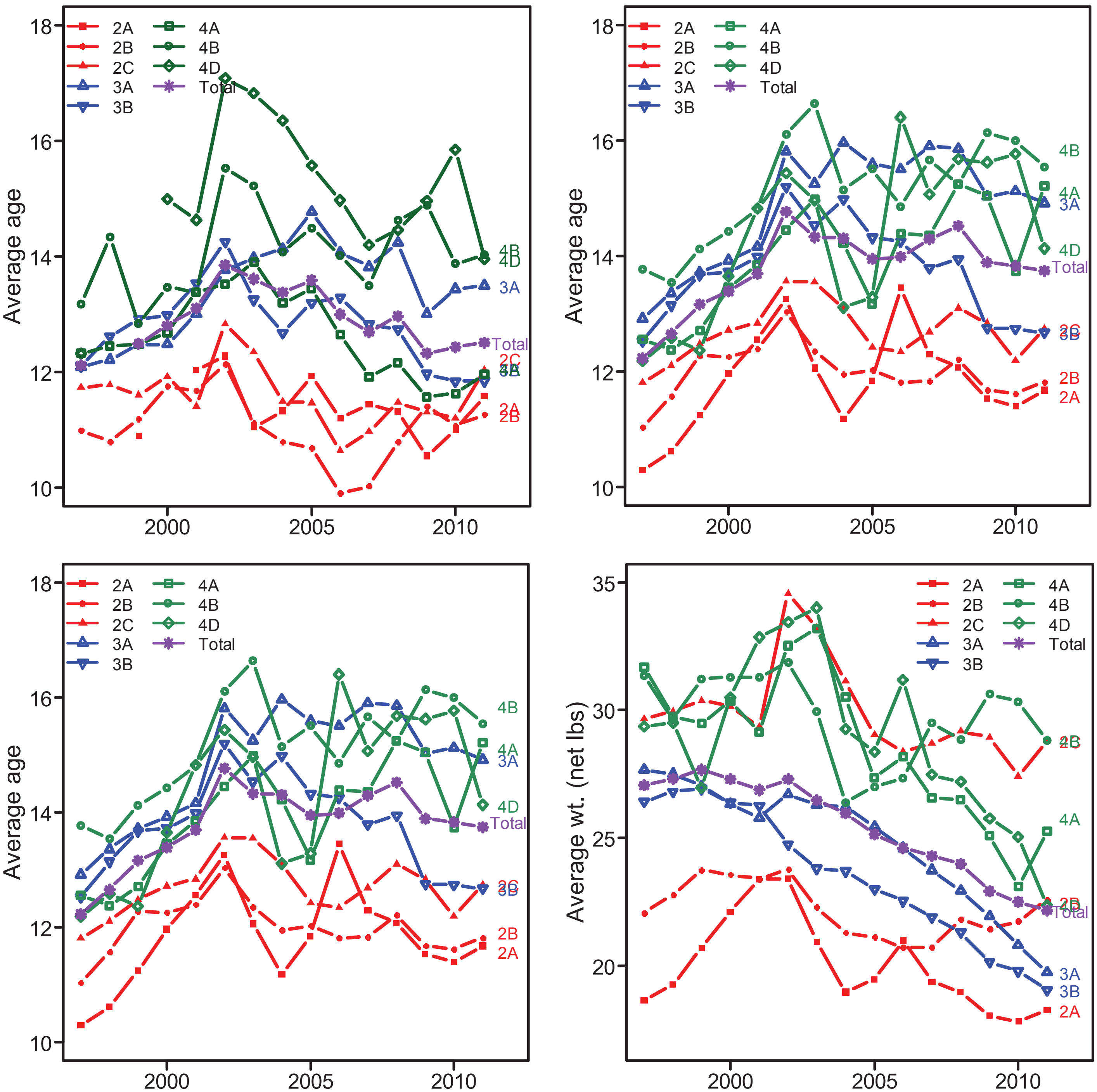


Figure 21. Trends in average age (top panels) and average weight (bottom panels) in survey catches (left panels) and commercial catches (right panels).

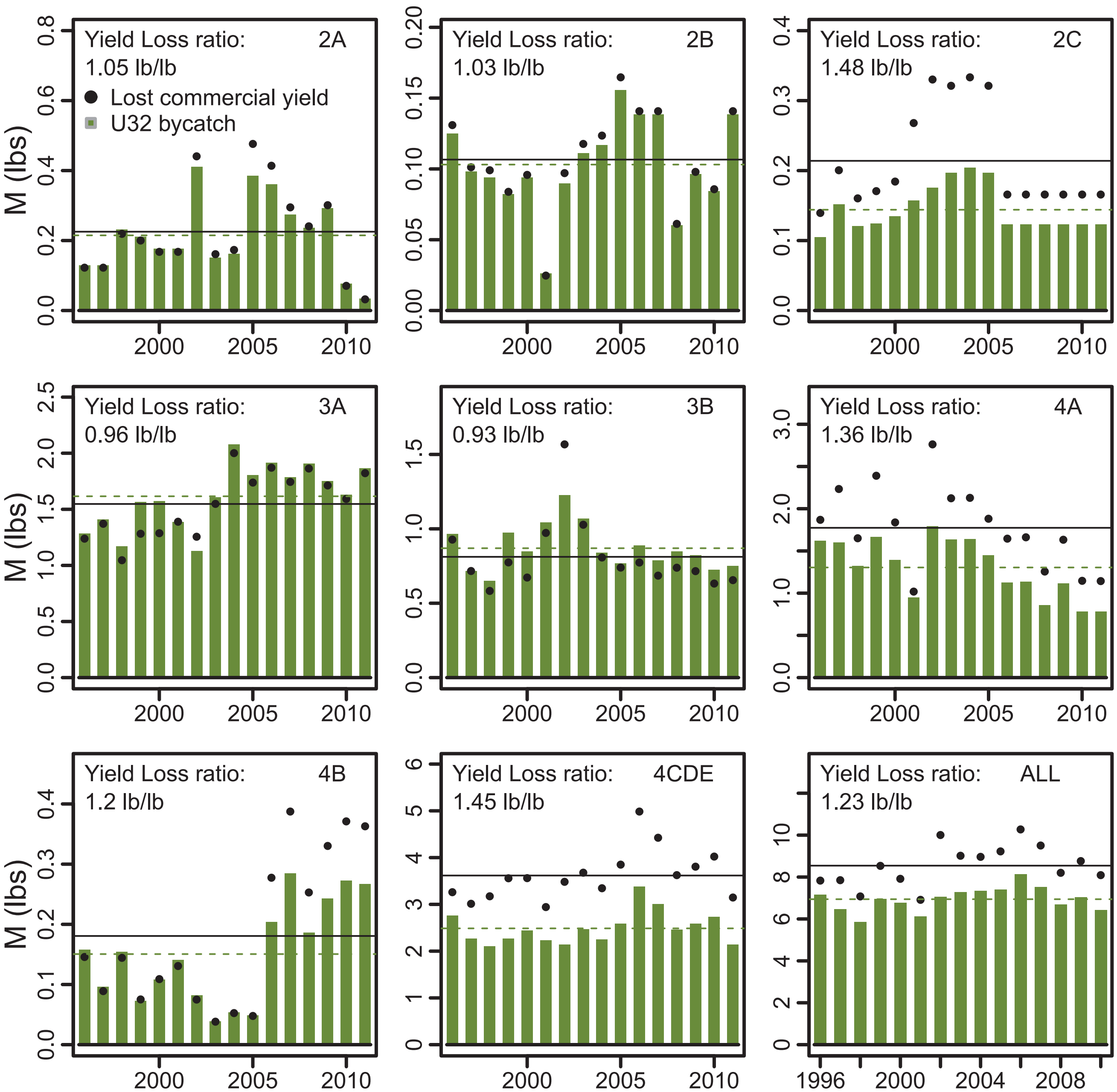


Figure 22. Illustration of impact of under-32 inch bycatch on future yield by regulatory area, without accounting for migration. The bars show estimated annual bycatch mortality, dots show estimated lost yield. Lost yield is estimated using growth models developed individually for each regulatory area. The dashed horizontal line is the average U32 bycatch over the 1996-2011 period; the solid horizontal line is the average yield loss over the same time frame.

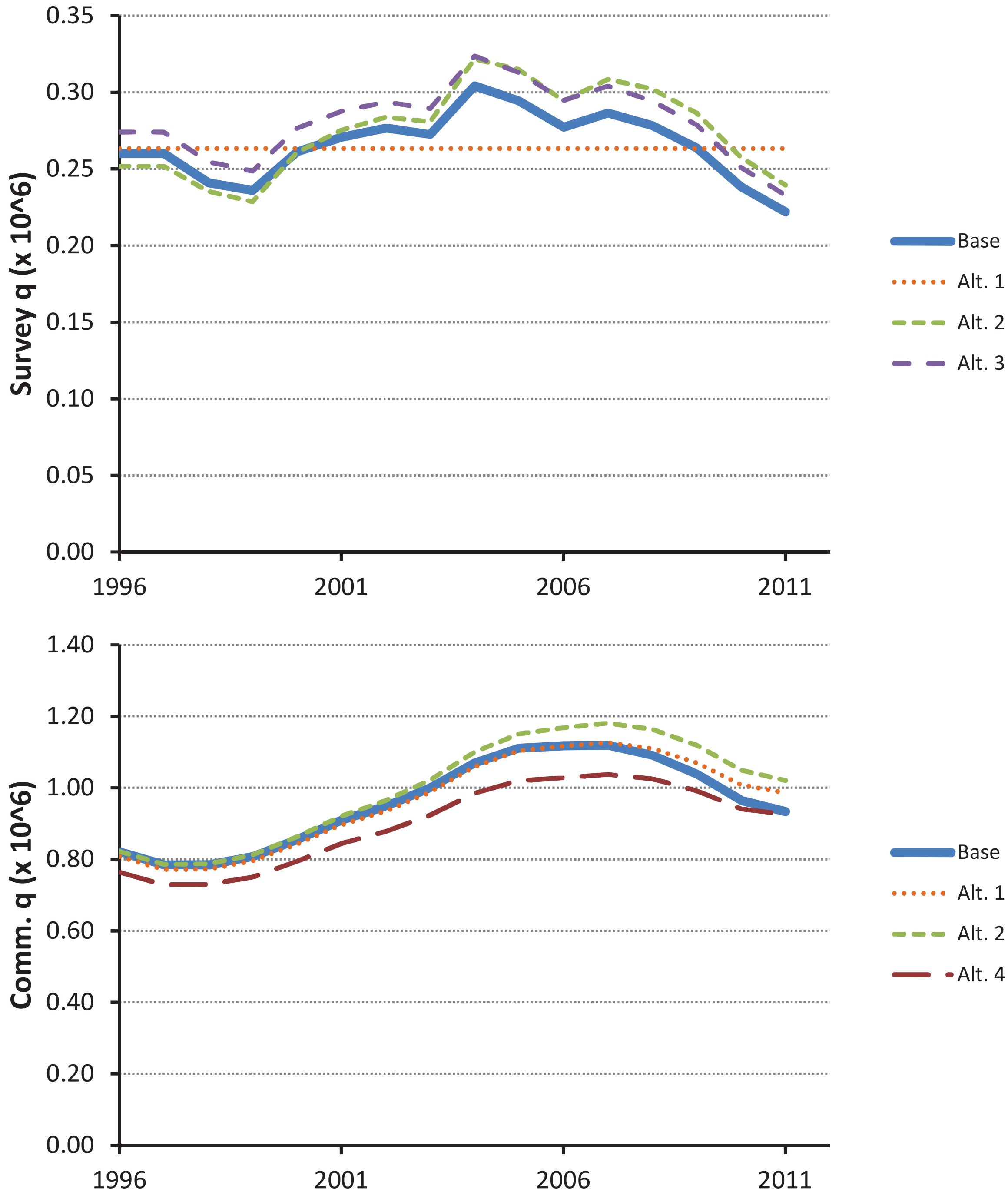


Figure 23. Illustration of time trends in survey and commercial "q" (catchability) among the Base and four Alternative assessment models. See text for details.

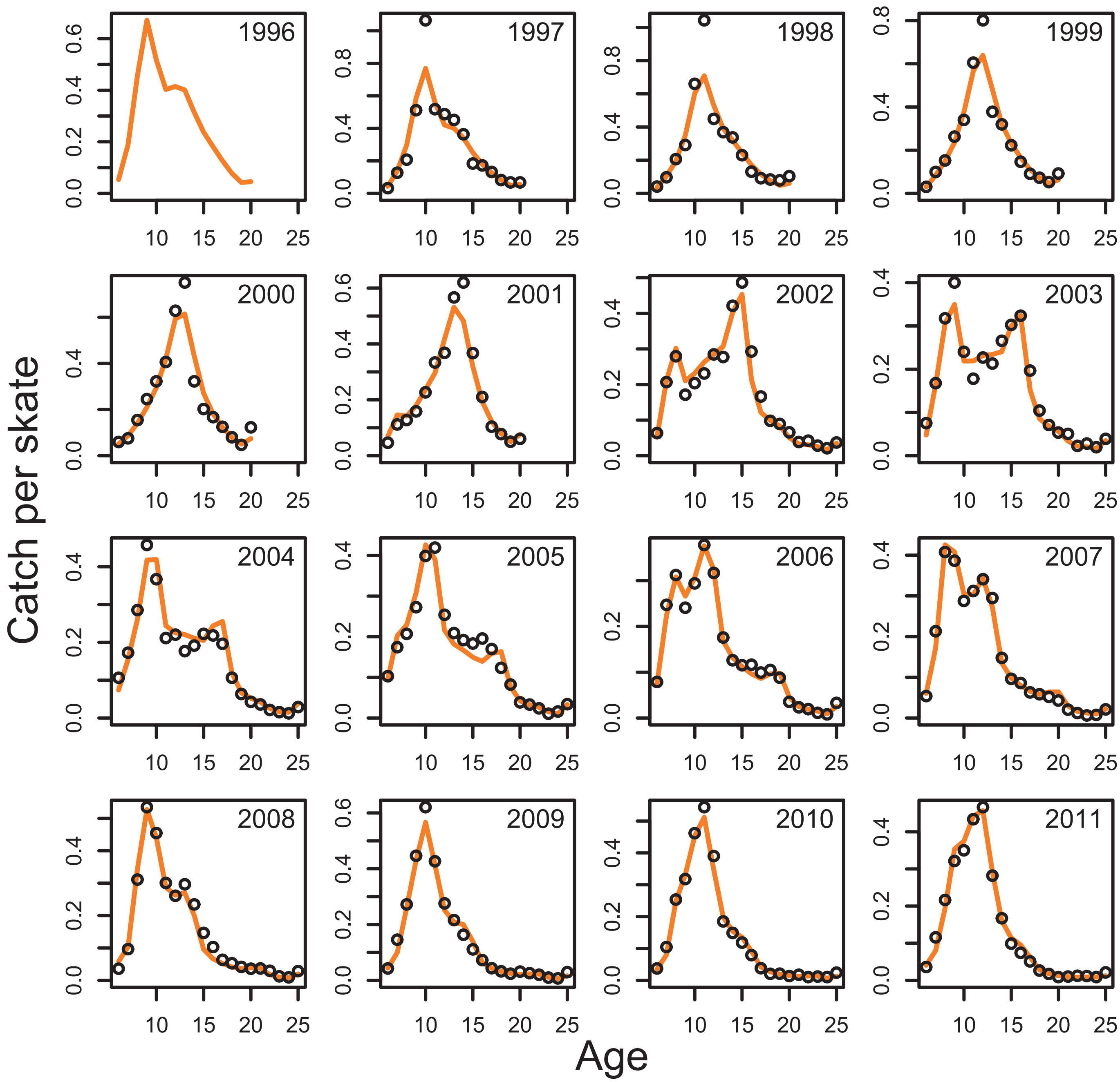


Figure 24a. Observed (points) and predicted (lines) survey NPUE at age of females in the 2011 coastwide model fit.

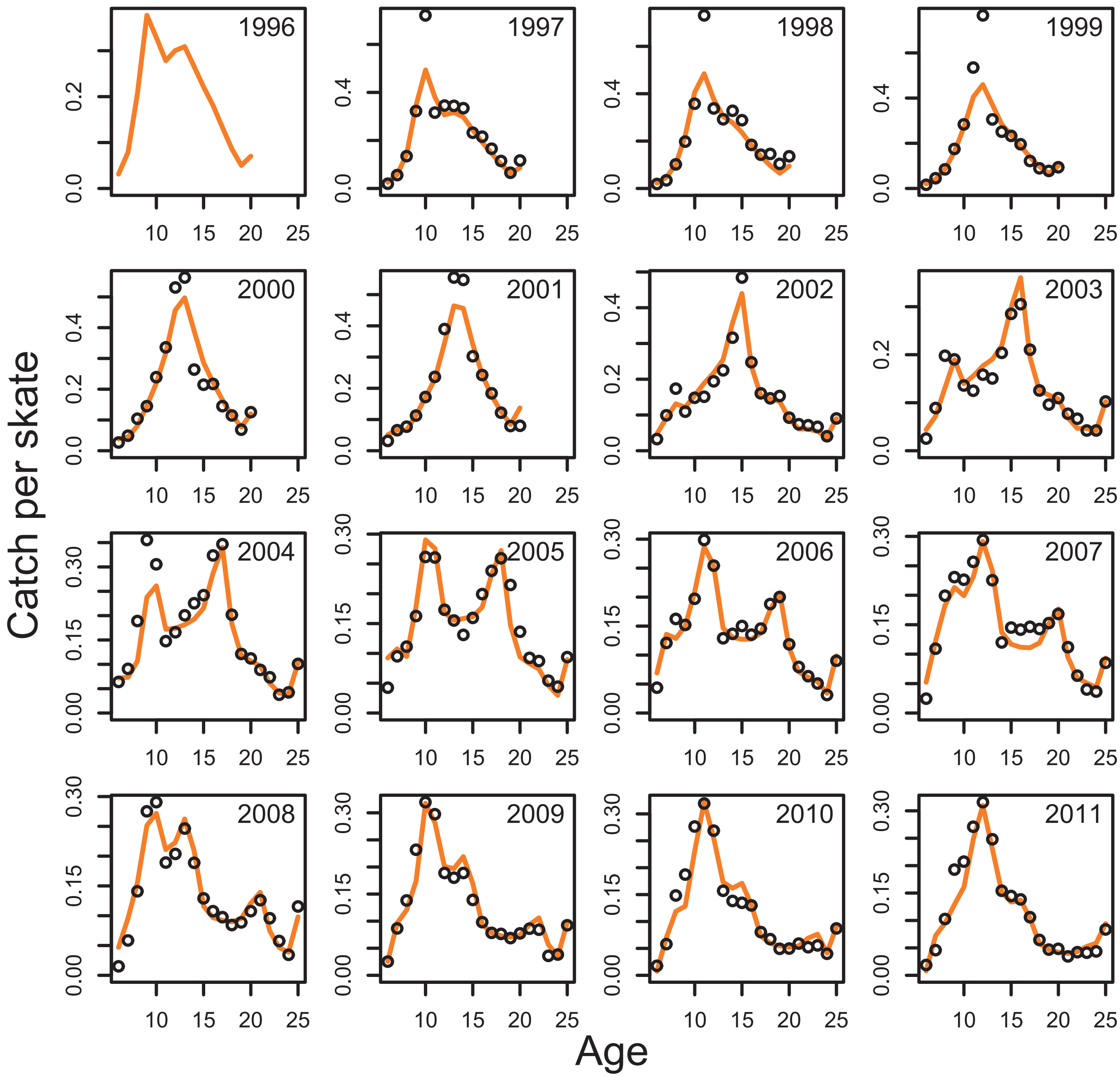


Figure 24b. Observed (points) and predicted (lines) survey NPUE at age of males in the 2011 coastwide model fit.

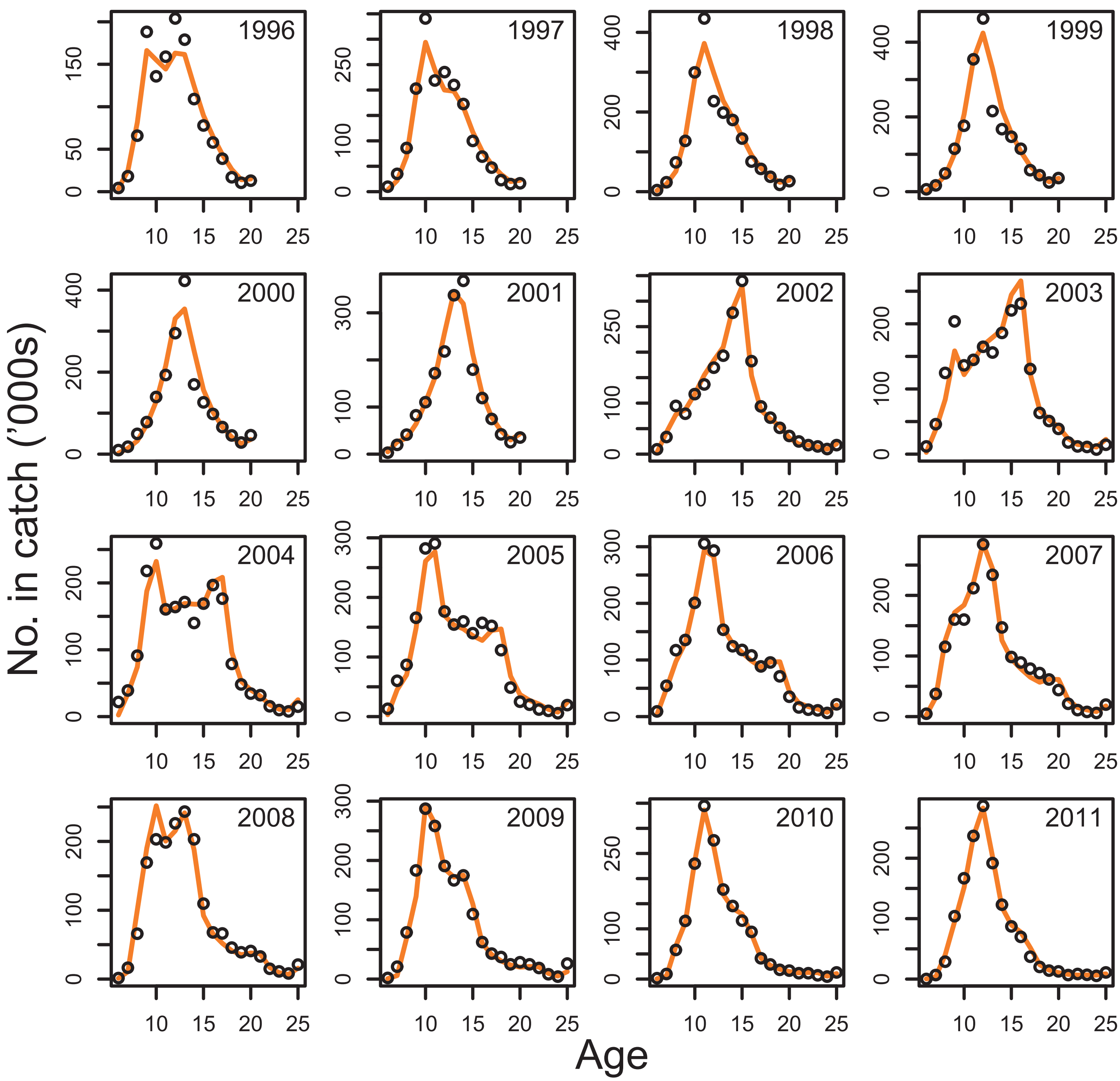


Figure 25a. Observed (points) and predicted (lines) commercial catch at age of females in the 2011 coastwide model fit.

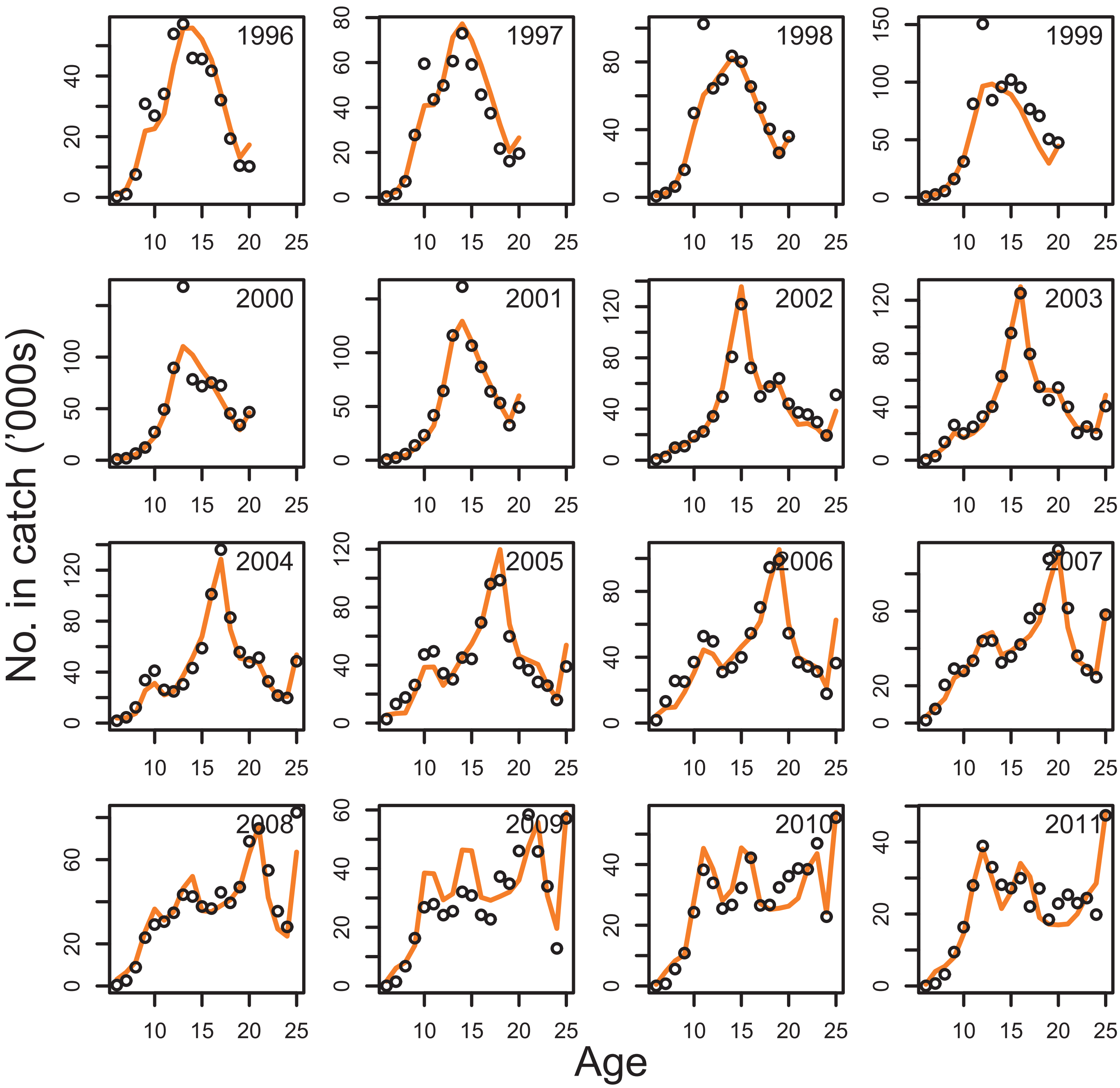


Figure 25b. Observed (points) and predicted (lines) commercial catch at age of males in the 2011 coastwide model fit.

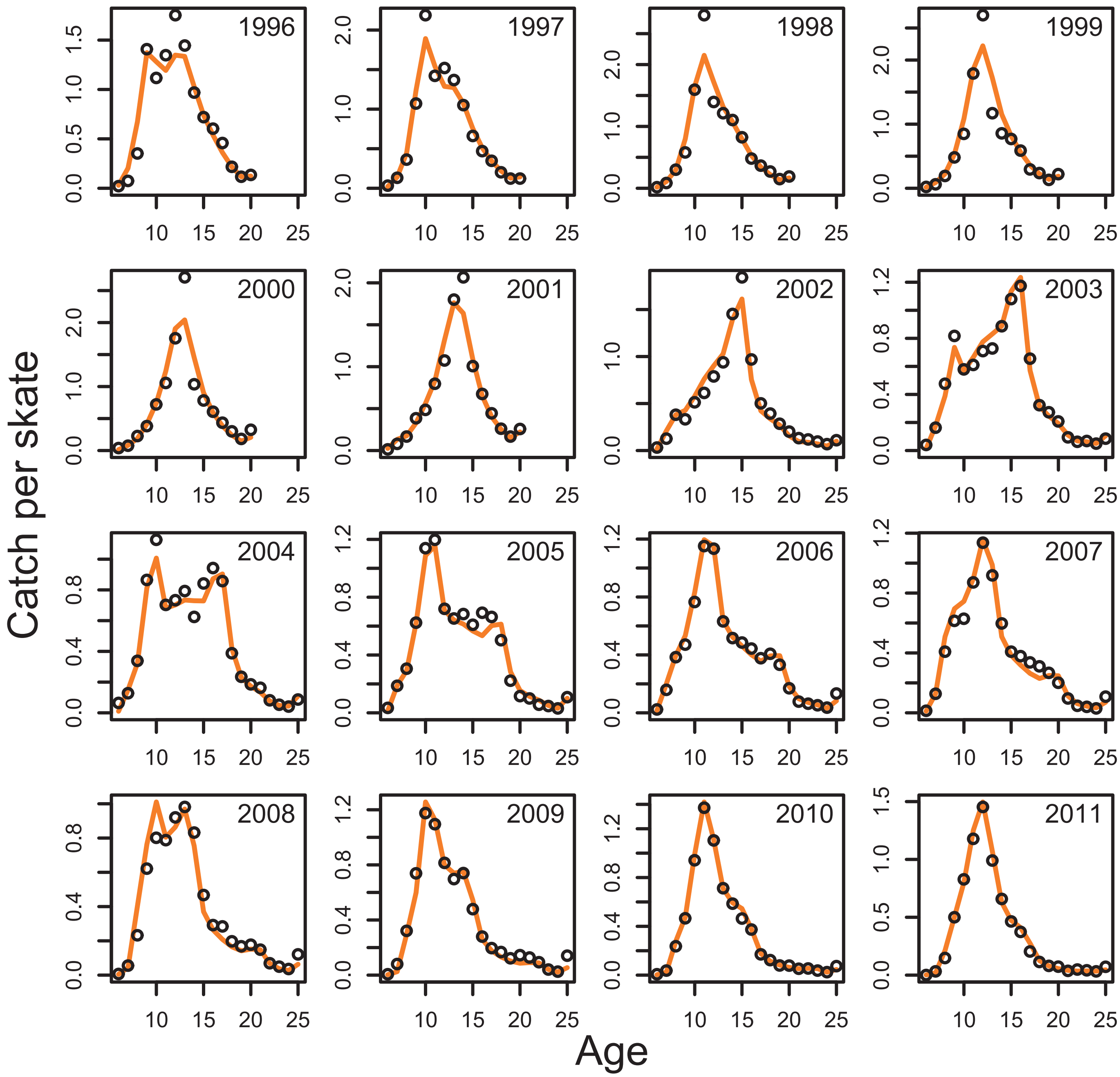


Figure 26a. Observed (points) and predicted (lines) commercial NPUE at age of females in the 2011 coastwide model fit.

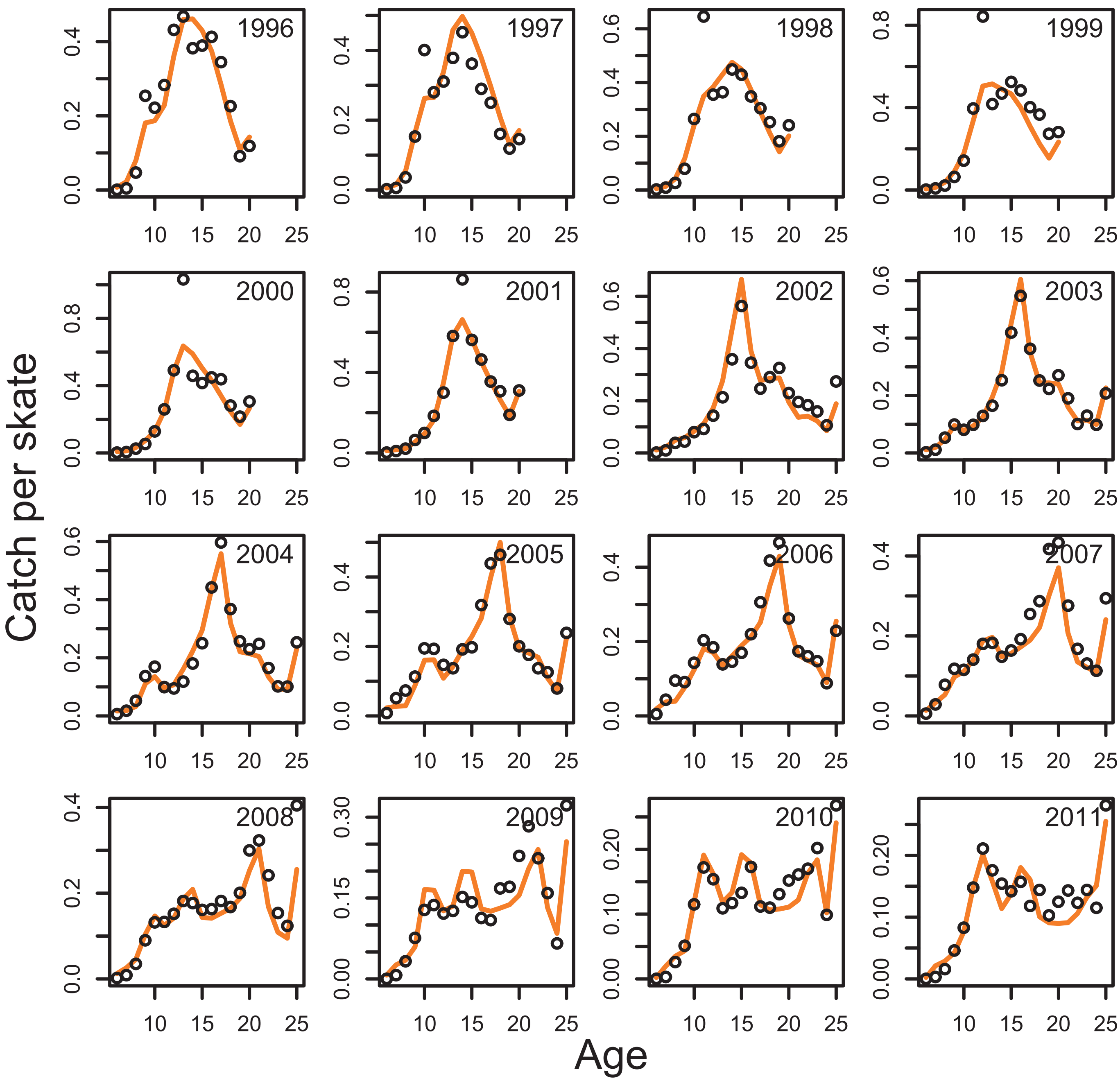


Figure 26b. Observed (points) and predicted (lines) commercial NPUE at age of males in the 2011 coastwide model fit.

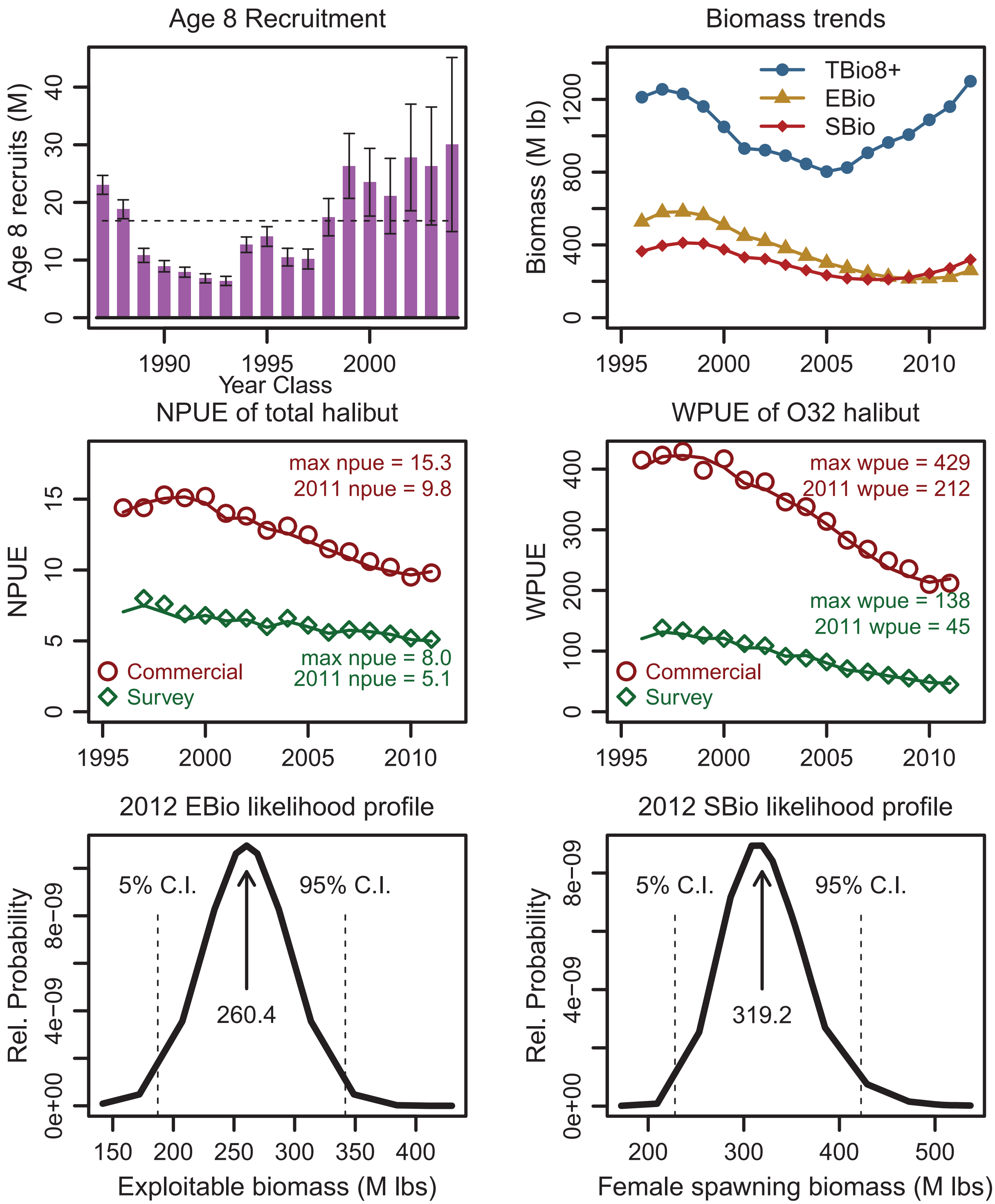
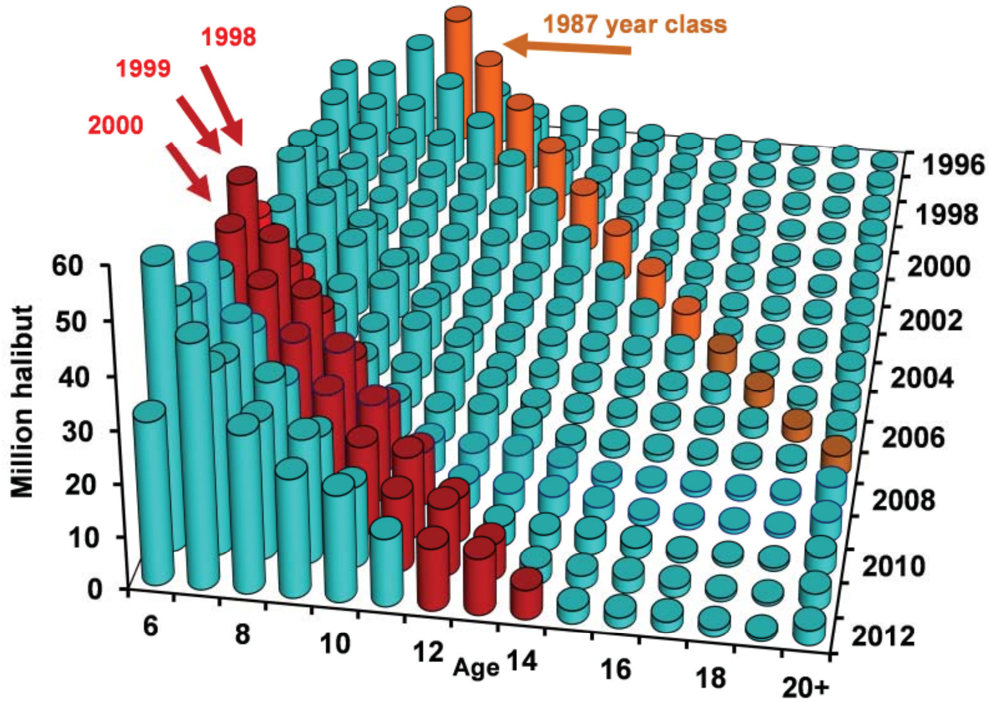


Figure 27. Features of the 2011 halibut coastwide assessment (WobbleSQ variant).

a) Total numbers in the population



b) Exploitable biomass in the population

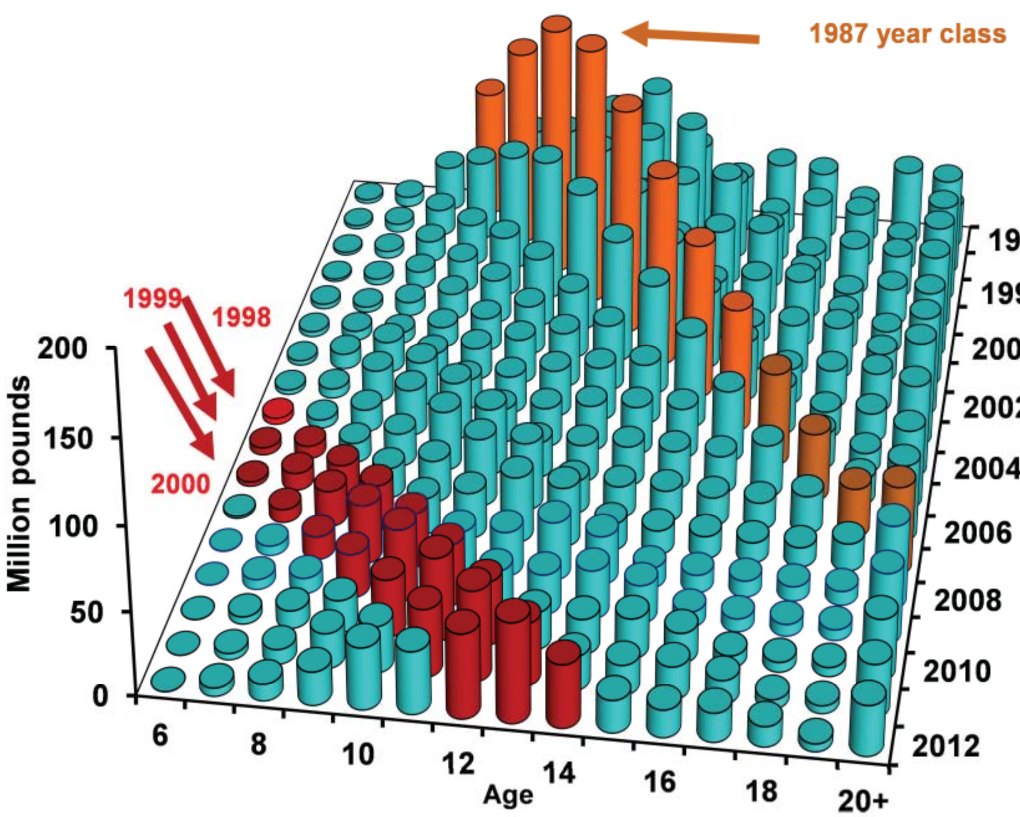


Figure 28. Coastwide population estimates in total numbers of halibut (panel a) and as EBio (panel b). Several large year classes are highlighted.

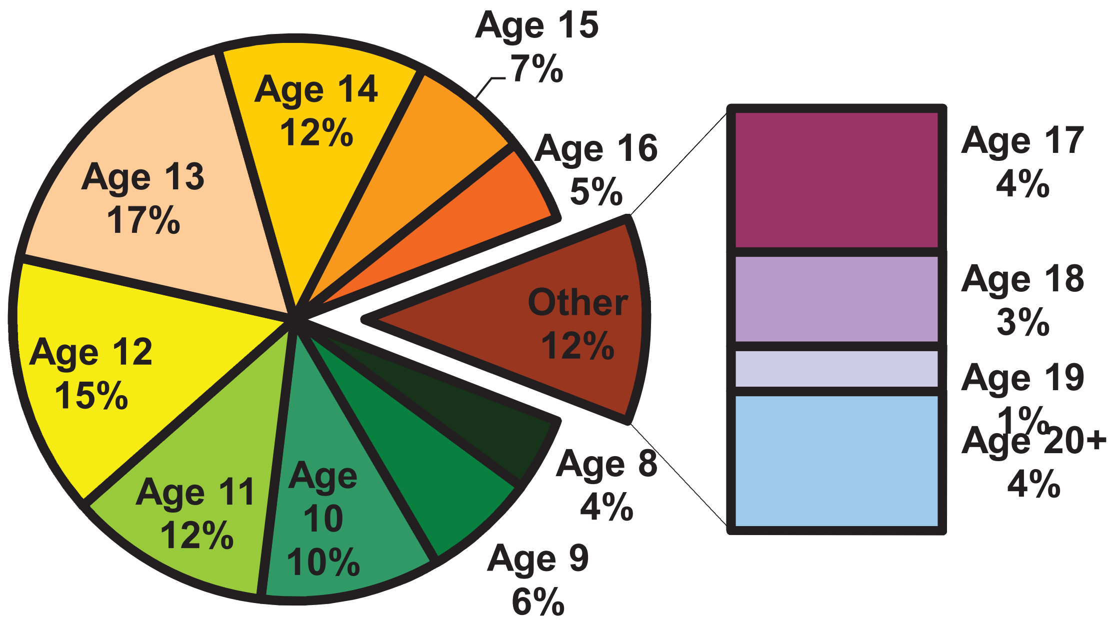


Figure 29. Estimated current age composition of the 2011 halibut female spawning biomass.

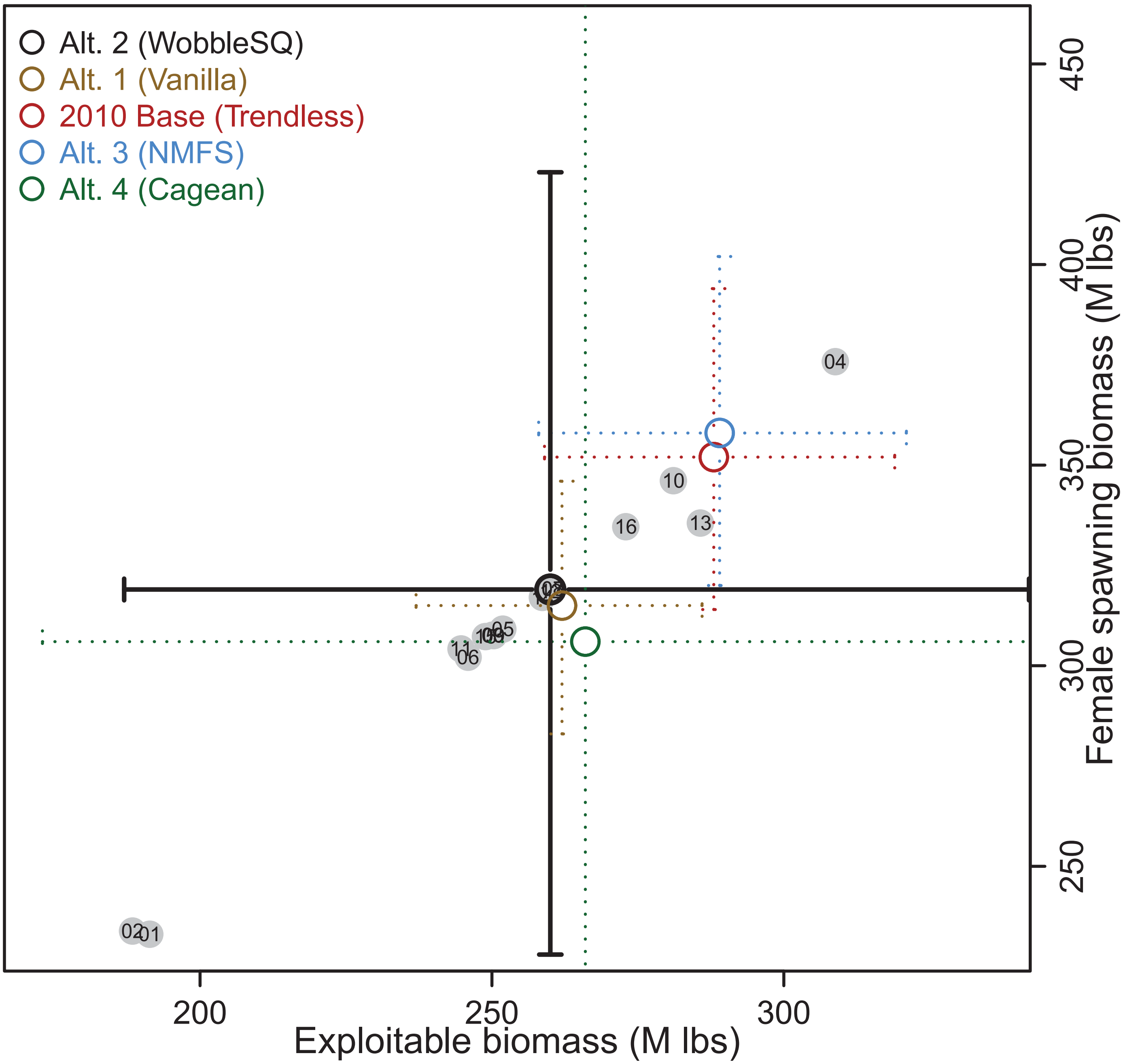


Figure 30. Illustration of maximum likelihood estimates (circles) for EBio and SBio for various model fits. The 95% percent asymptotic confidence intervals for the likelihood profiles are shown by the end caps of the horizontal and vertical bars extending from the circles. In this plot, the 16 alternative model fits are with the WobbleSQ model as the focus. See text for details.

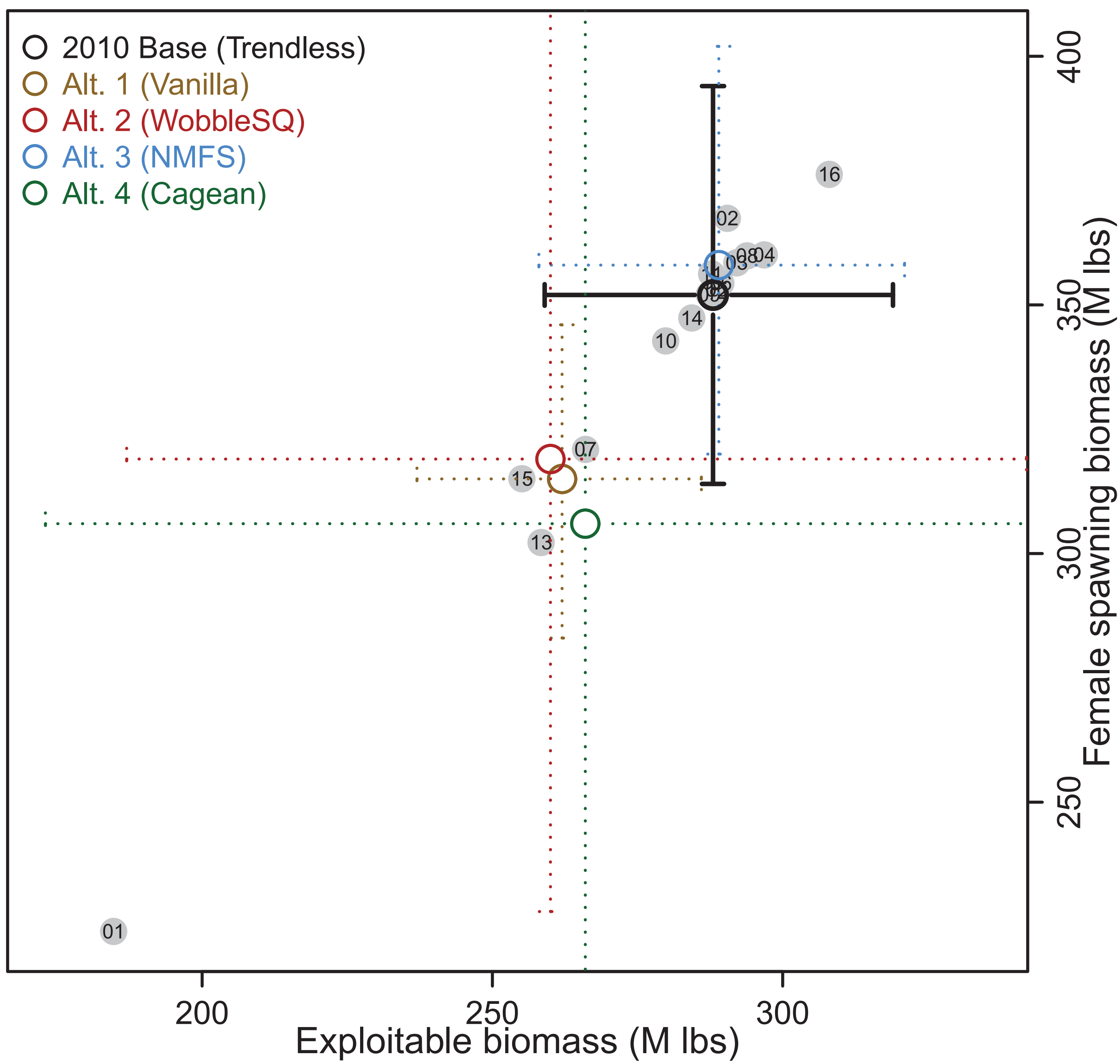


Figure 31. Same as Figure 31, but with Trendless model as the focus. See text for details.

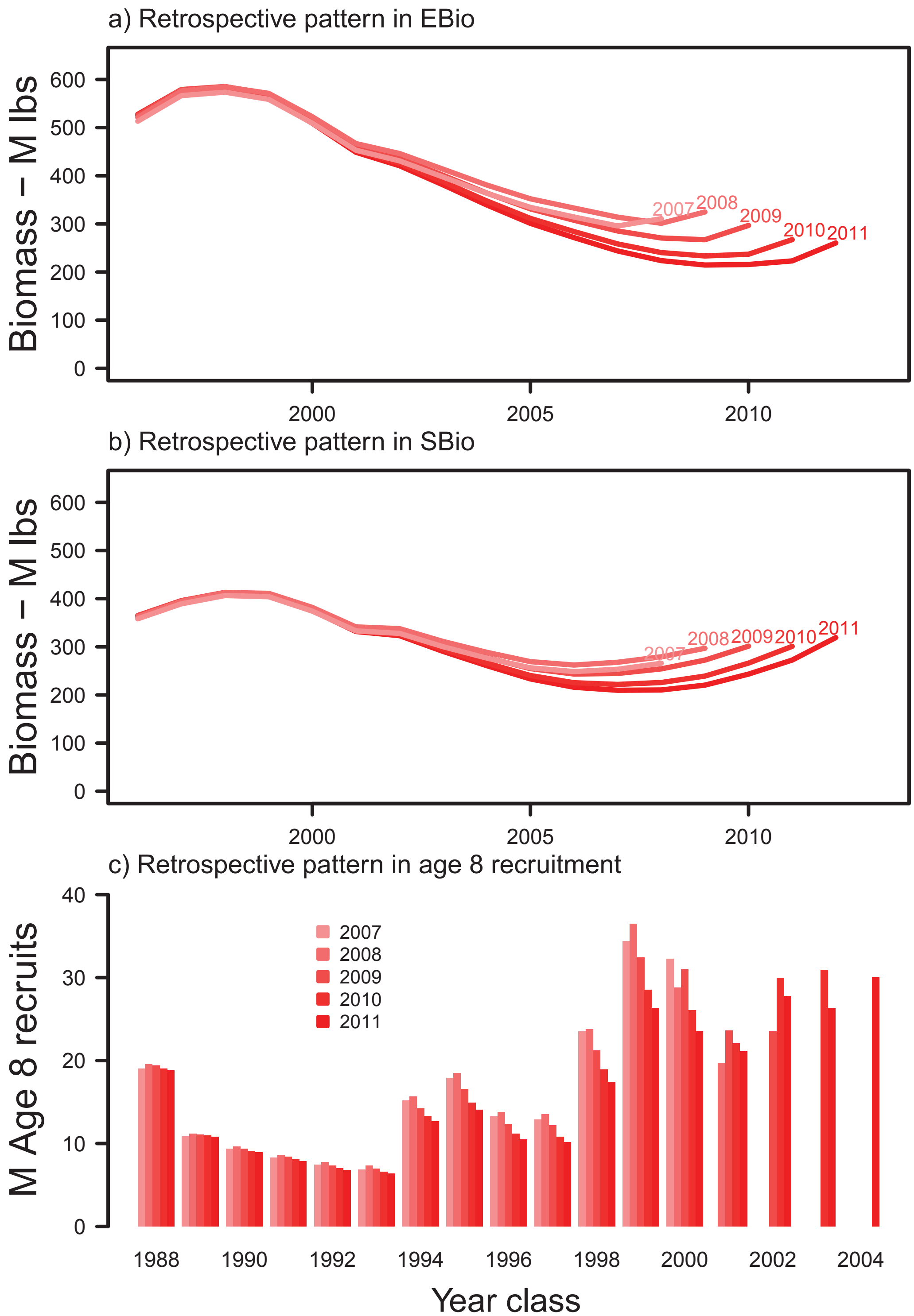


Figure 32. Retrospective behavior of the WobbleSQ 2011 halibut assessment model. The top panel illustrates the effect on estimates of EBio by sequentially removing years of data. The middle panel illustrates the effect on estimation of female spawning biomass and the bottom panel illustrates the effect on age eight recruitment. Note that the most recent year class (2004) is only estimated in the 2011 assessment, the 2003 year class in the 2010 and 2011 assessments, and so on. The x-axis is year for the biomass plots and year class for the recruitment plot.

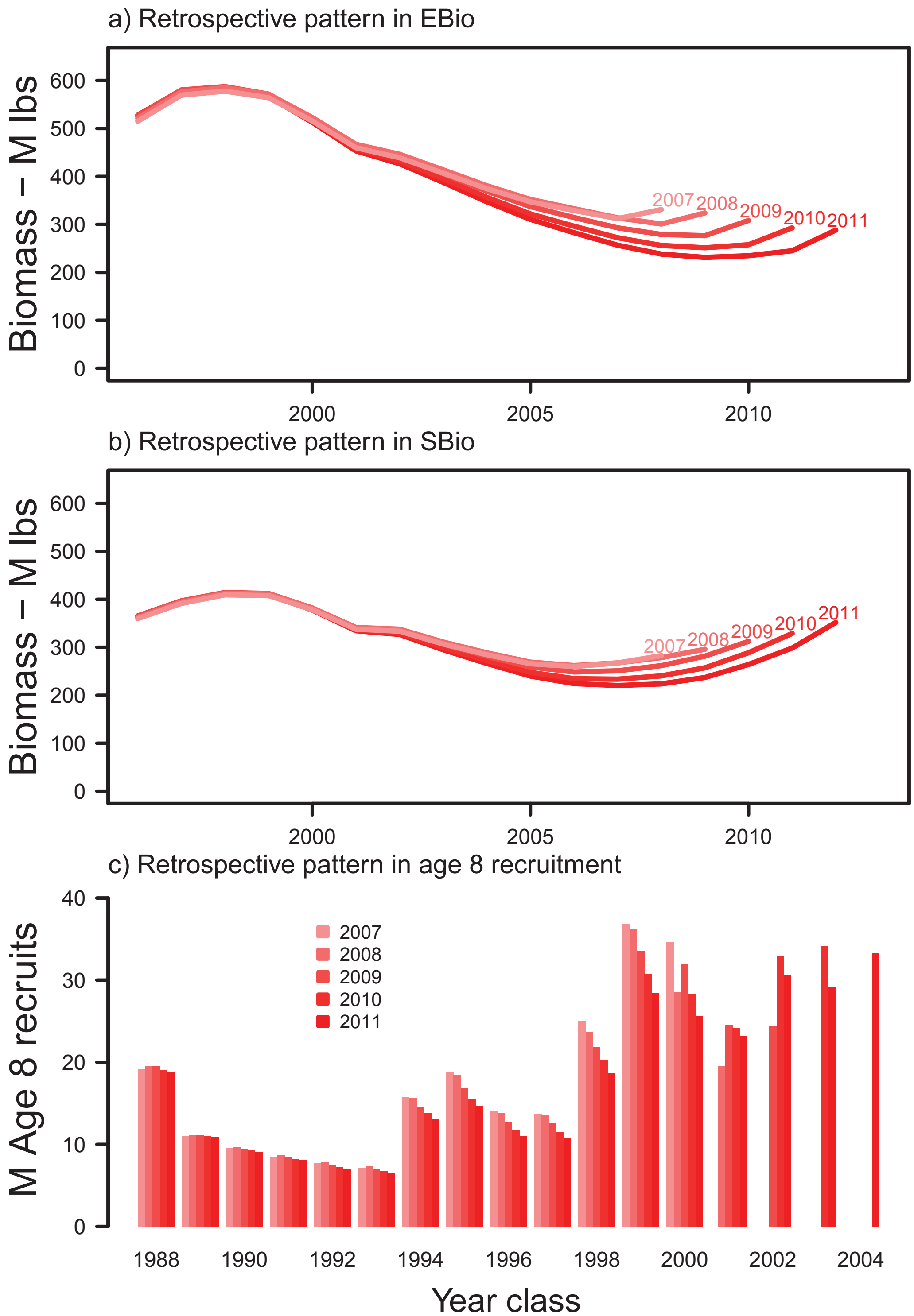


Figure 33. Same as Figure 32, but retrospective behavior of the Base2010 (Trendless) halibut assessment model.

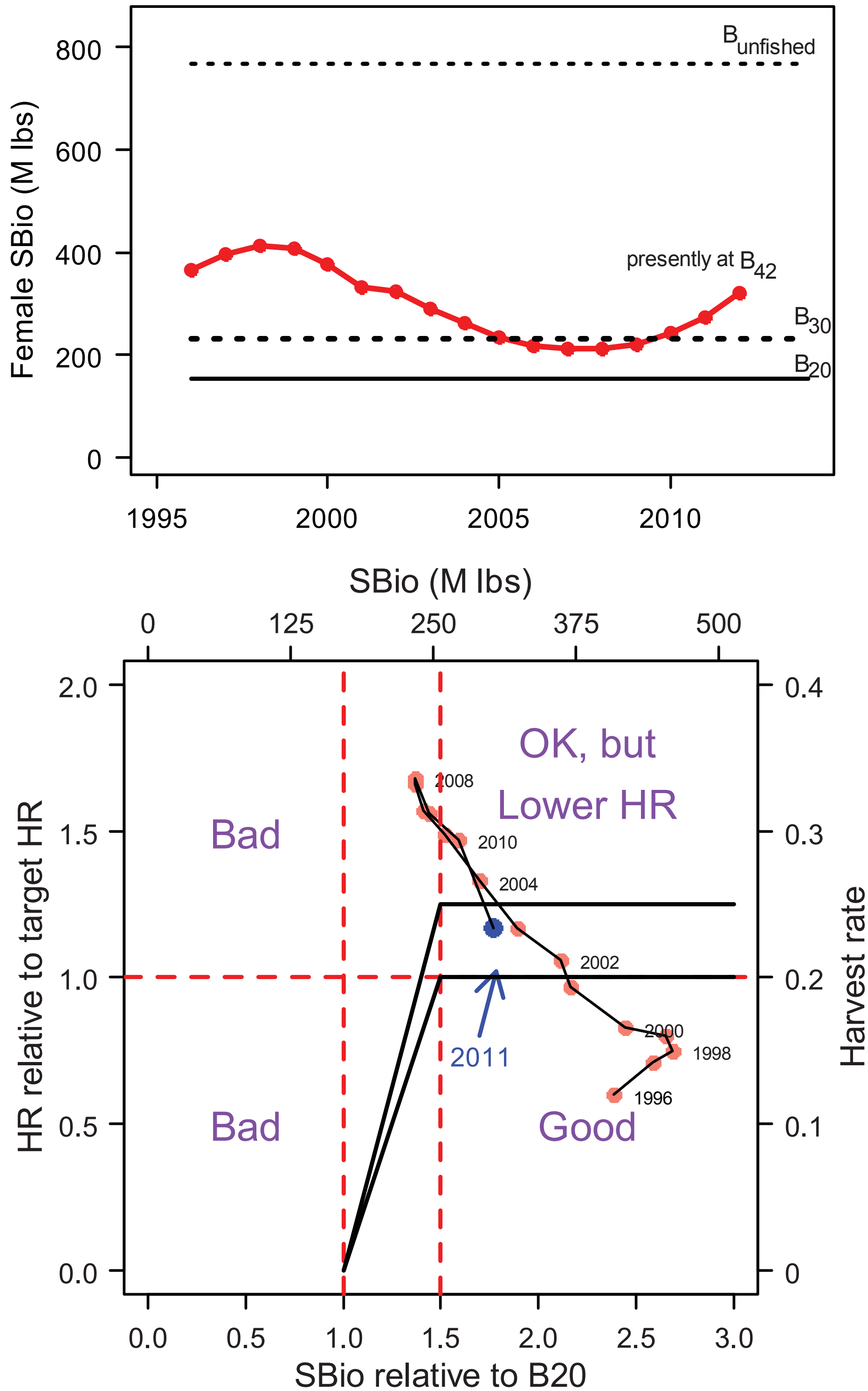


Figure 34. Trend and status of halibut management relative to reference points. Upper panel shows trajectory of female spawning biomass (SBio) relative to B_{20} and B_{30}, which are 20% and 30%, respectively of $SBio_{unfished}$ The lower panel plots the same data , relative to B20 along the x-axis and and the vertical axis illustrates realized harvest rate relative to a target harvest rate of 0.20 (value of 1.0) and the previous target harvest rate of 0.25 (value of 1.25).

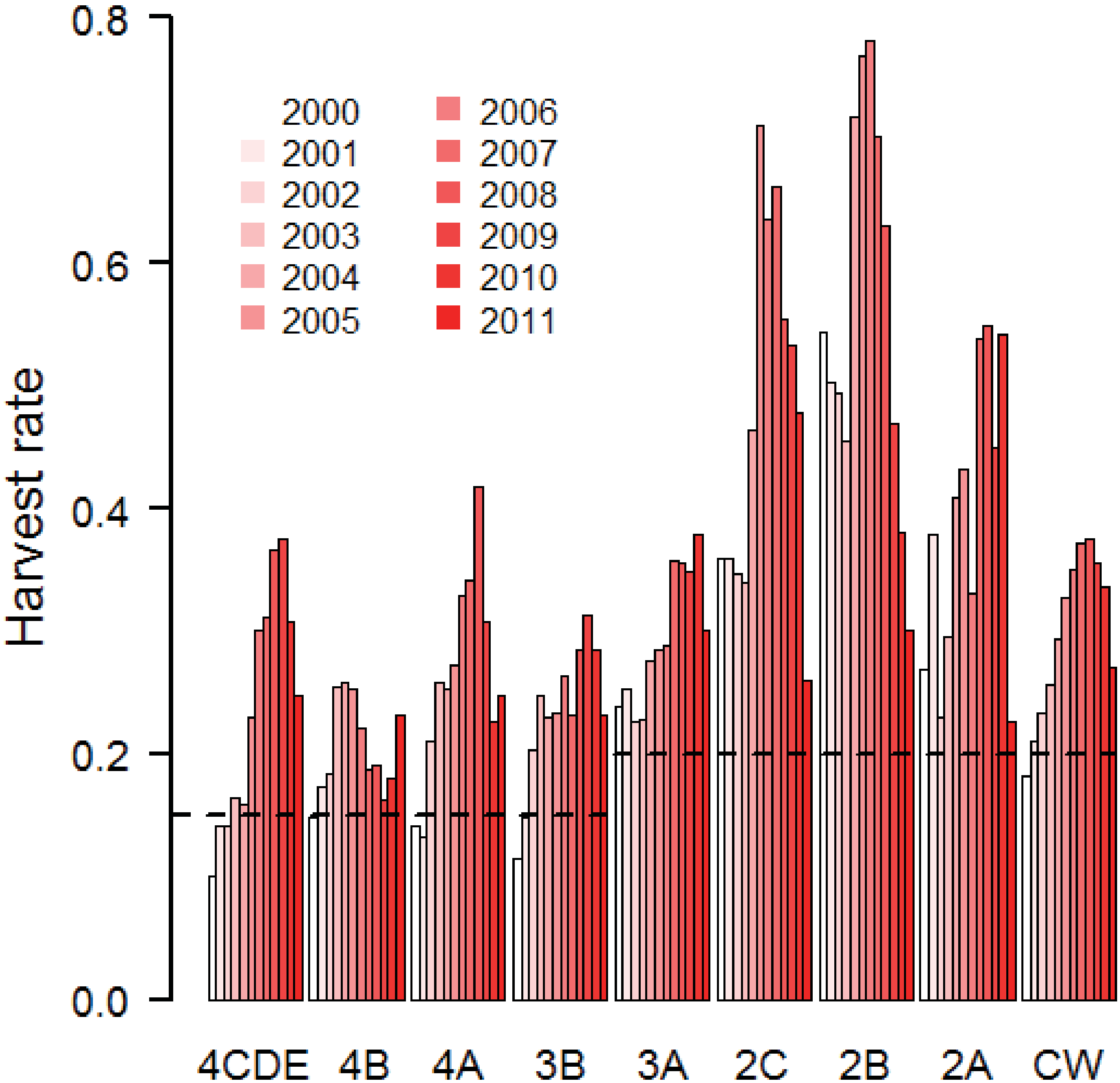


Figure 35. Summary of estimated realized harvest rates from the coastwide assessment, using adjusted and weighted survey WPUE to partition biomass among areas.

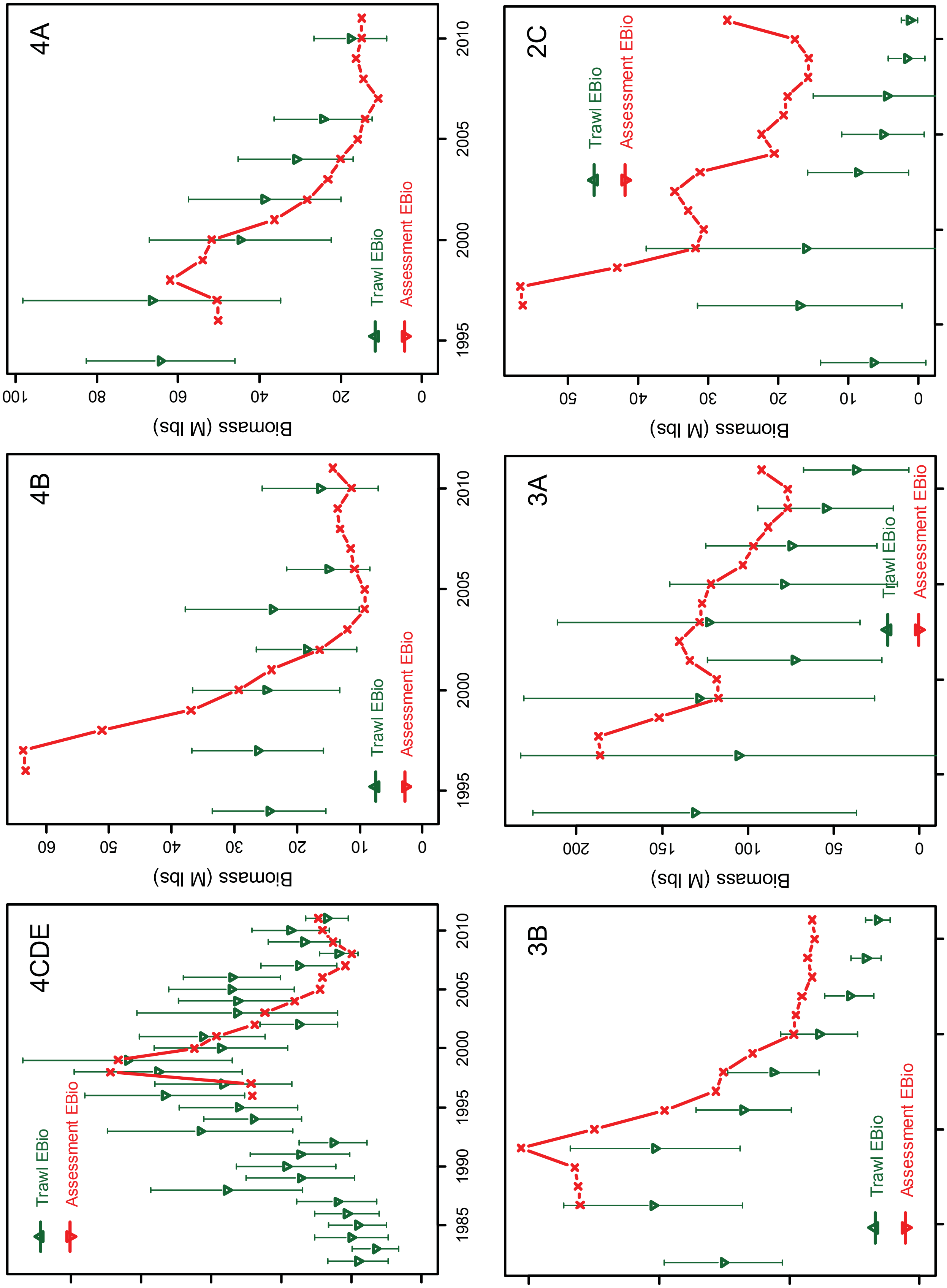


Figure 36. Comparison of IPHC assessment estimates (using adjusted survey WPUE) and NMFS swept area estimates of EBio.

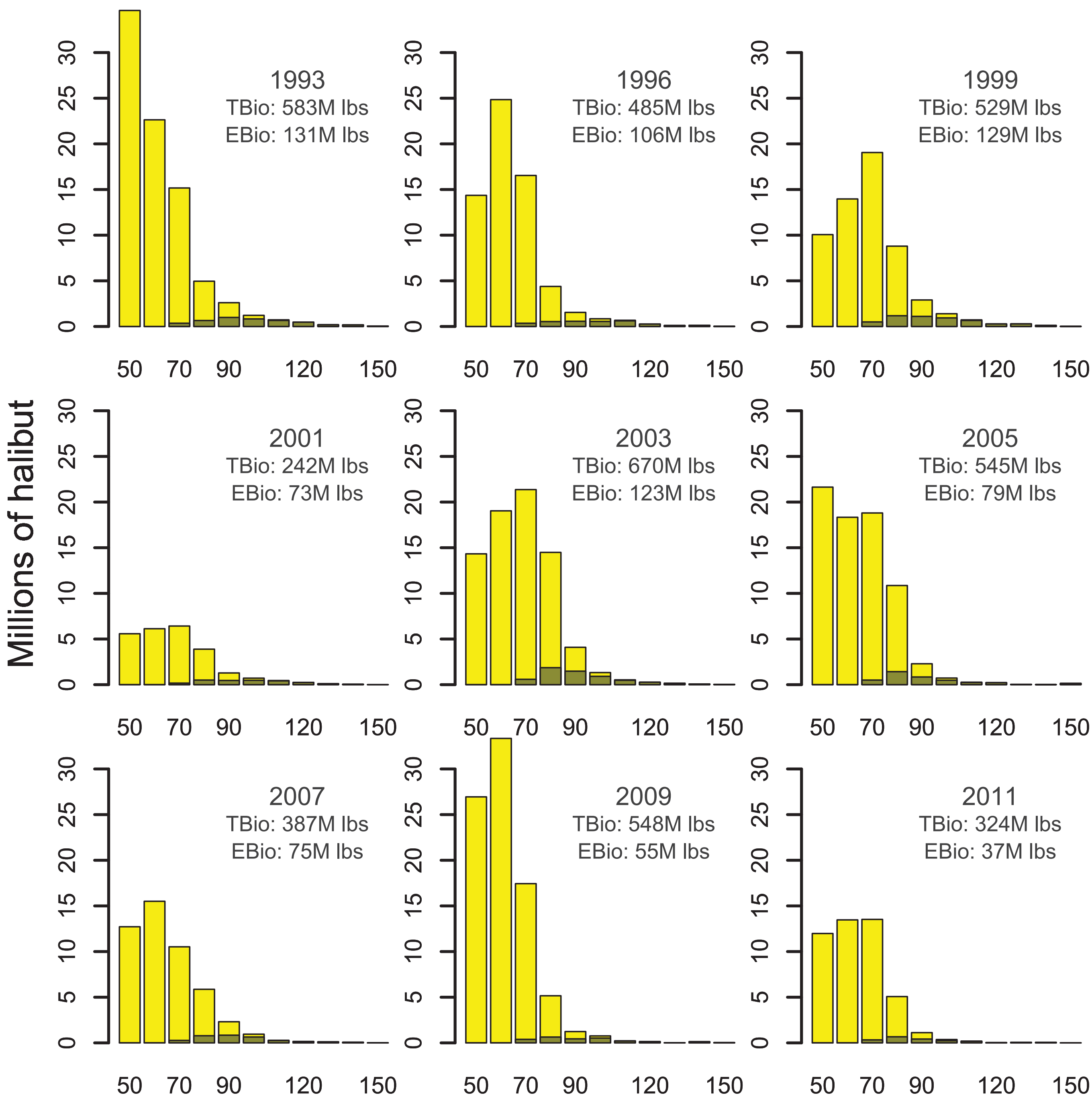


Figure 37. Swept area estimates of halibut in IPHC regulatory Area 3A, by 10-cm length interval, in the NMFS EBS trawl survey for the years 1993 to 2011. Values for total (TBio) and Exploitable (EBio) biomass estimated by the survey are also listed. Exploitable numbers of halibut are illustrated by the darker bars.

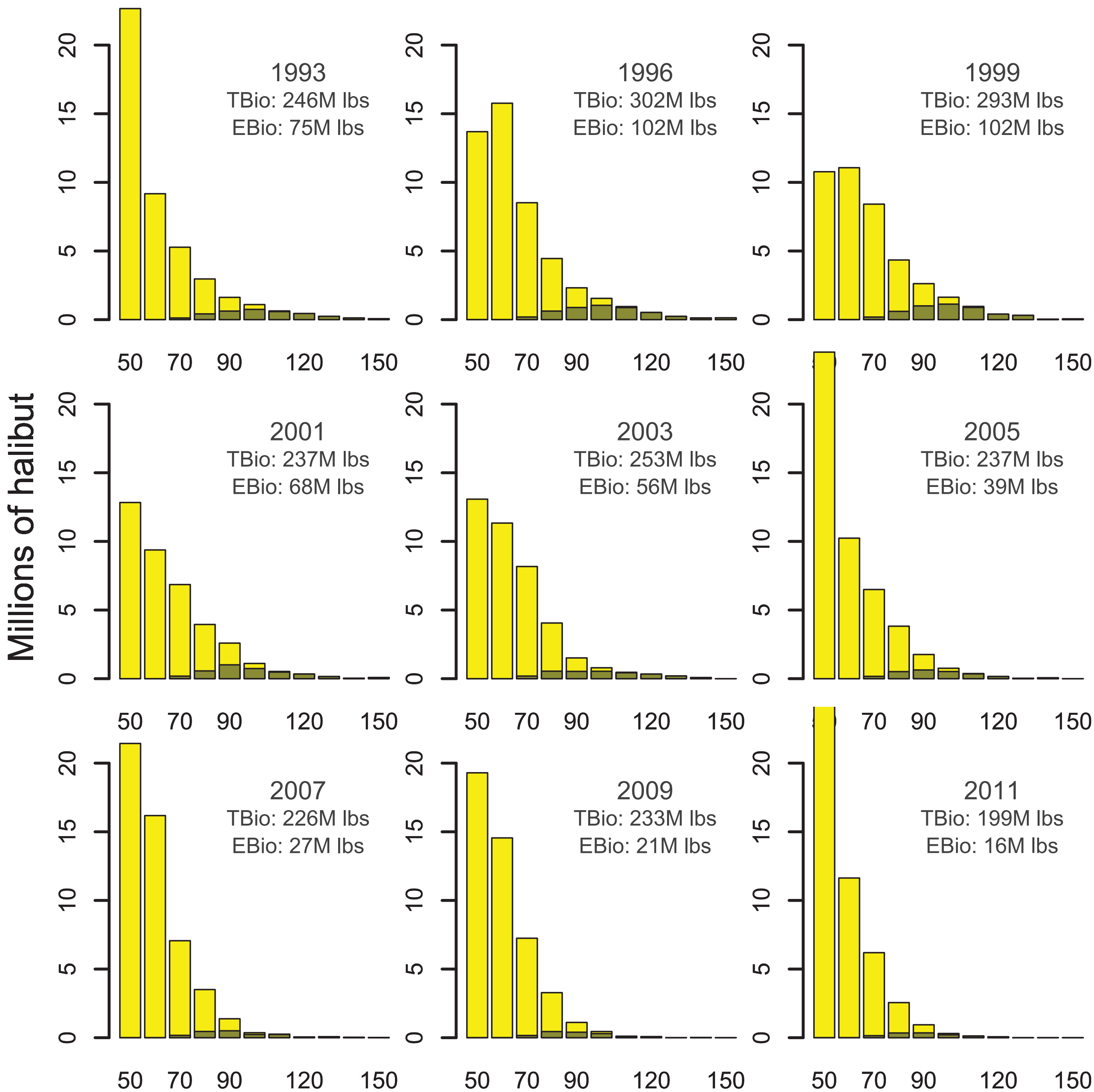


Figure 38. Same as Figure 34, but for IPHC regulatory area 3B.

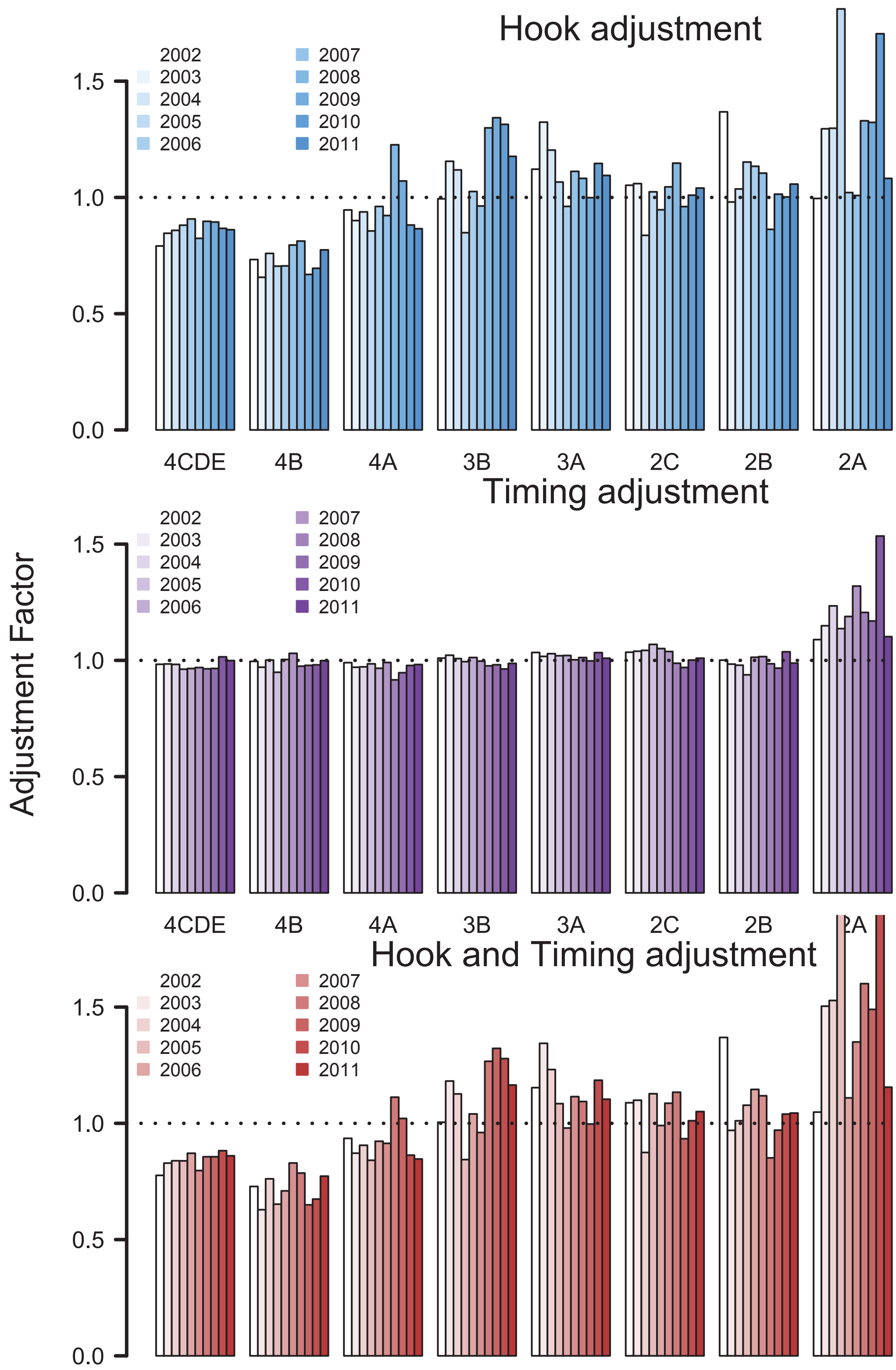


Figure 39. Illustration of the adjustments to survey WPUE for hook competition (top panel), survey timing (middle panel) and the two factors in combination (bottom panel).

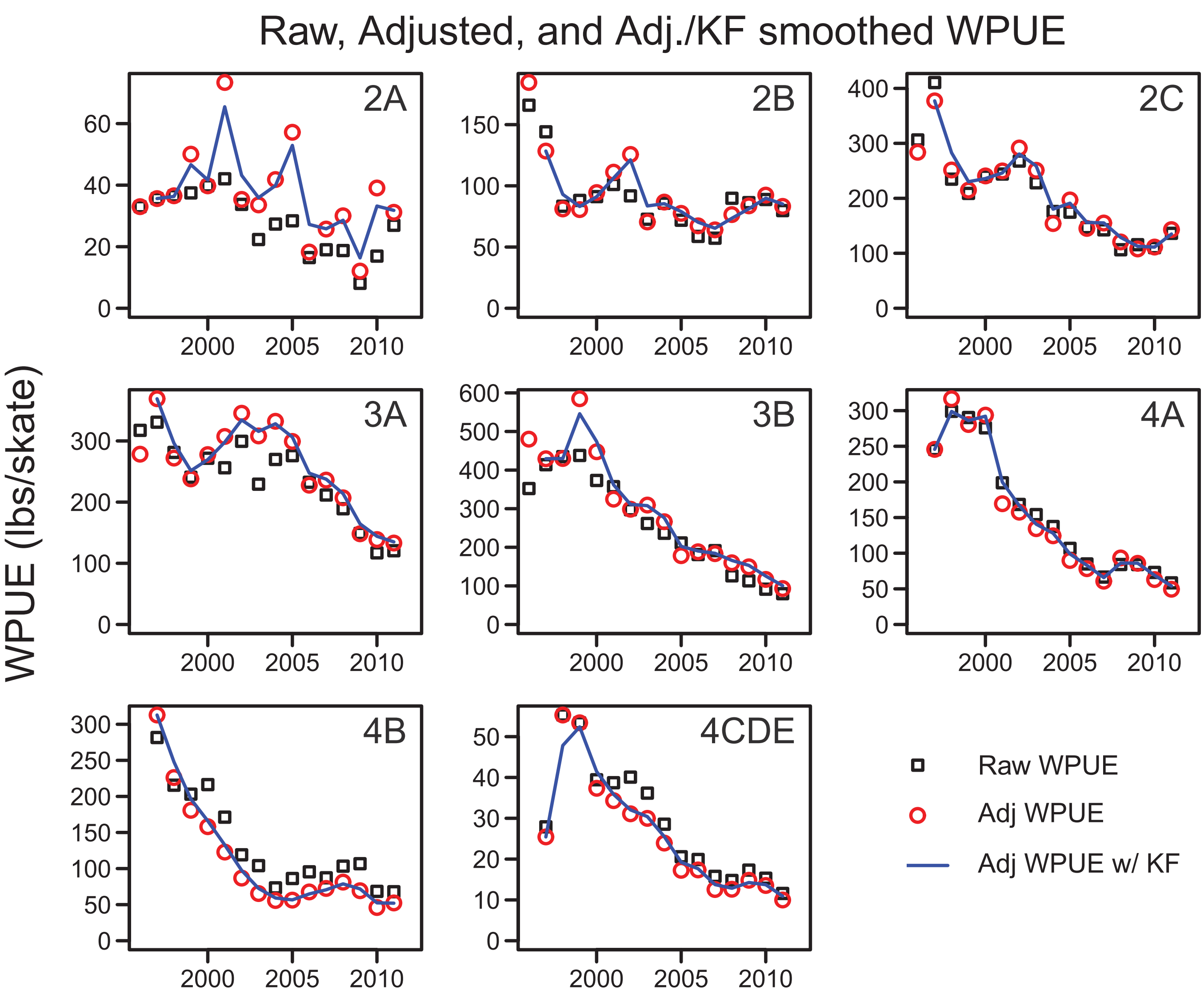


Figure 40. Illustration of the effect of adjusting survey WPUE for the effects of hook competition and survey timing and using Kalman-weights to time-average the adjusted values. This particular illustration used the 0-400 fm bottom area definition.

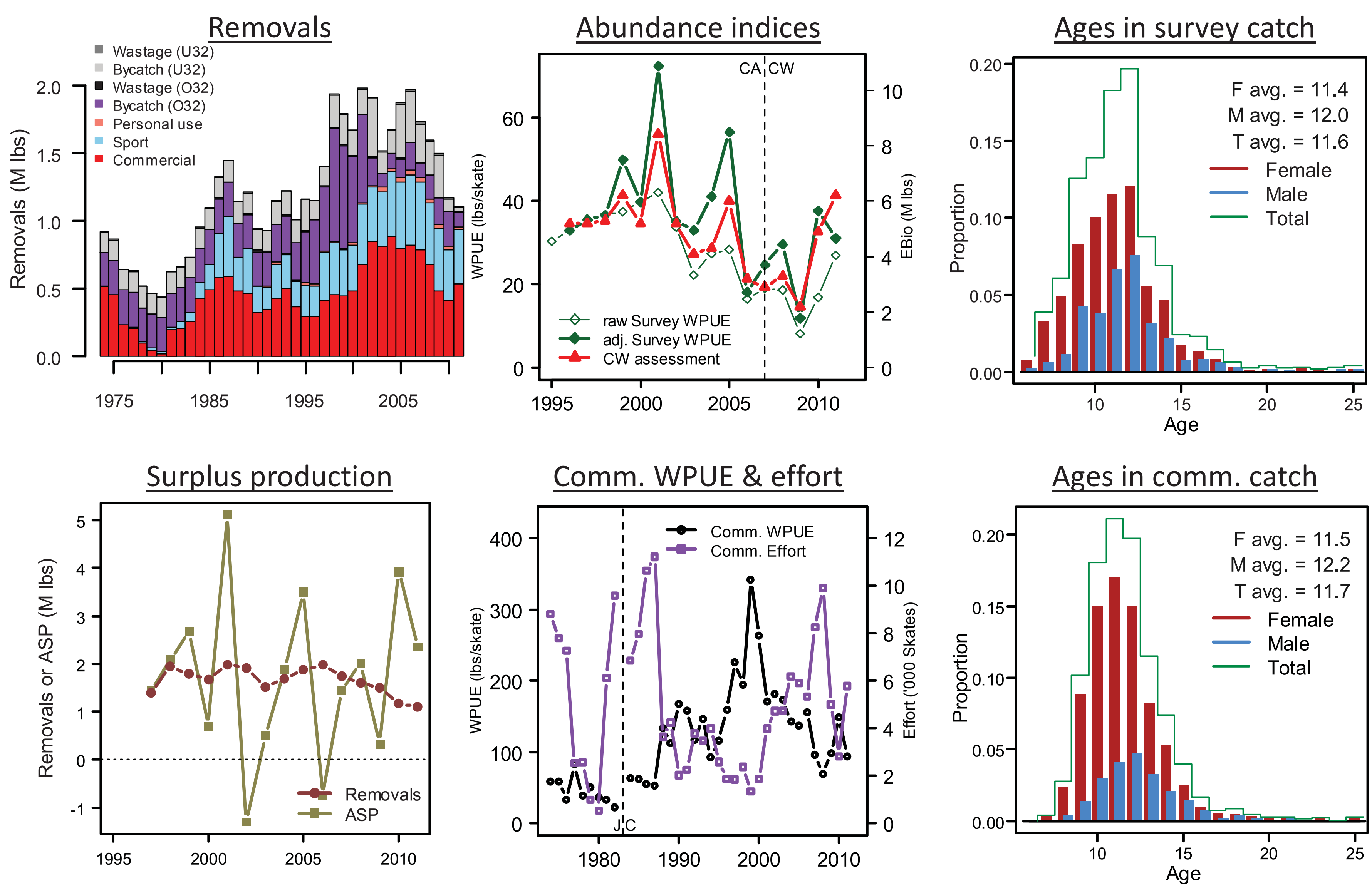


Figure 41. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 2A.

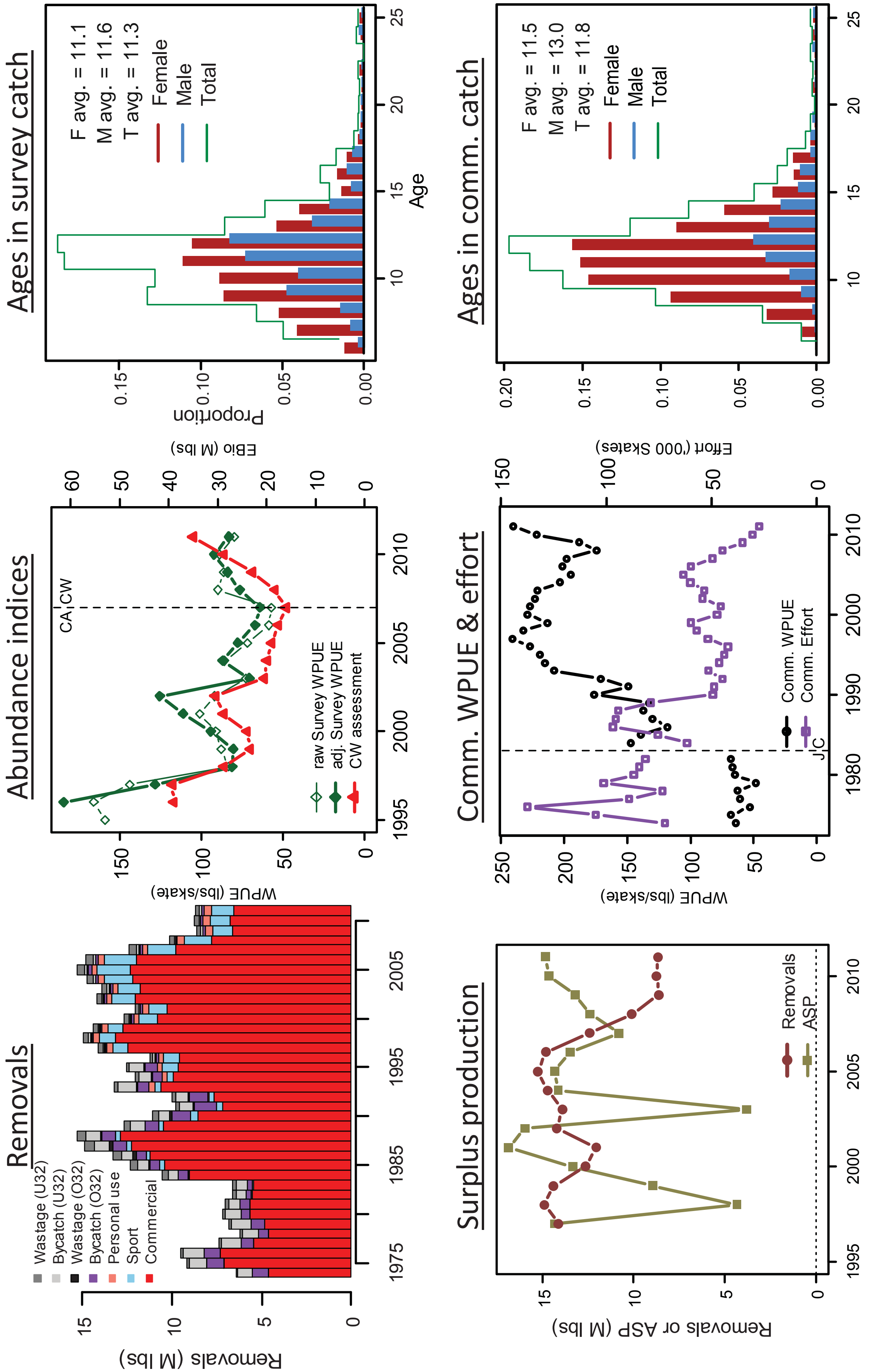


Figure 42. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 2B.

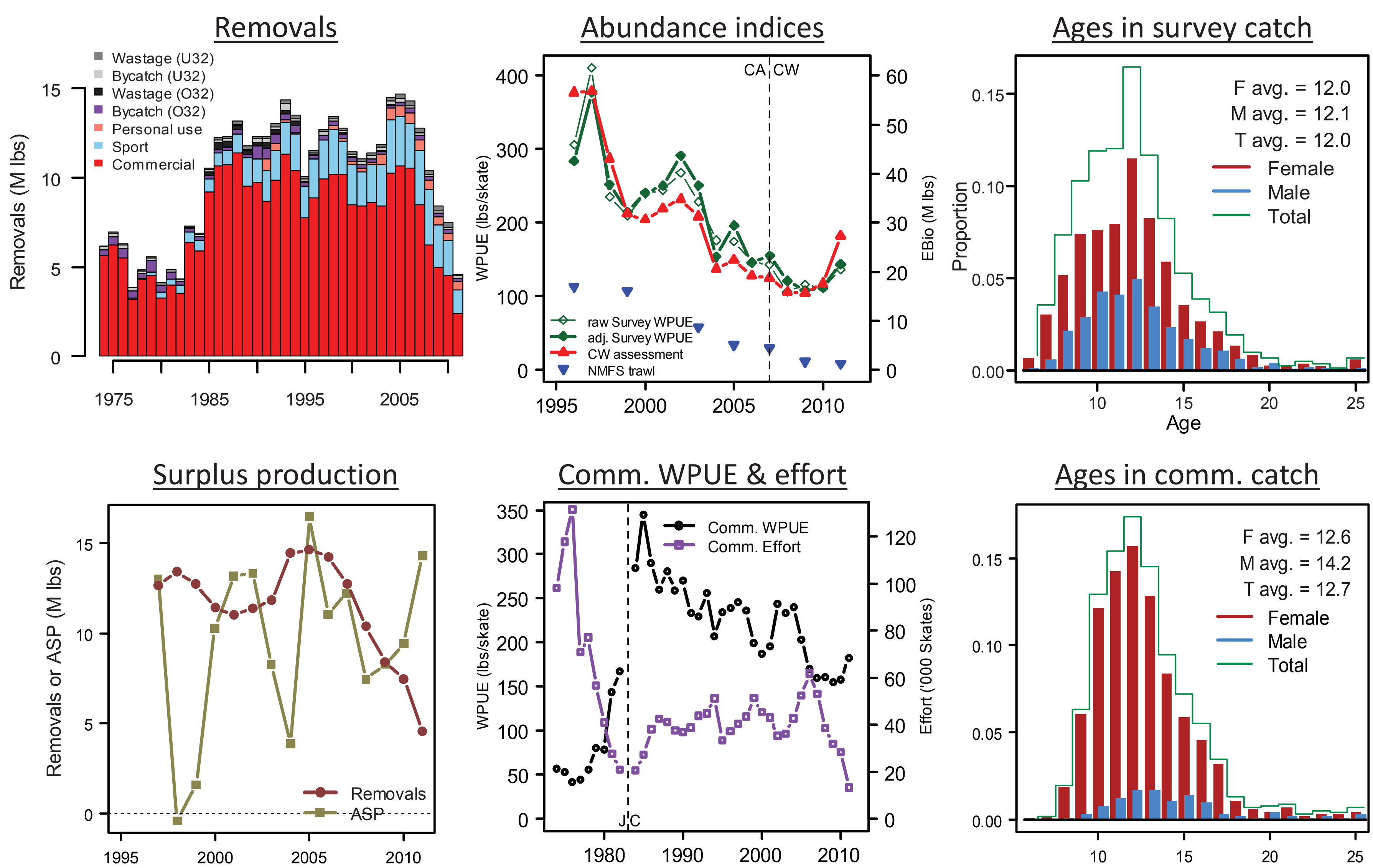


Figure 43. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 2C.

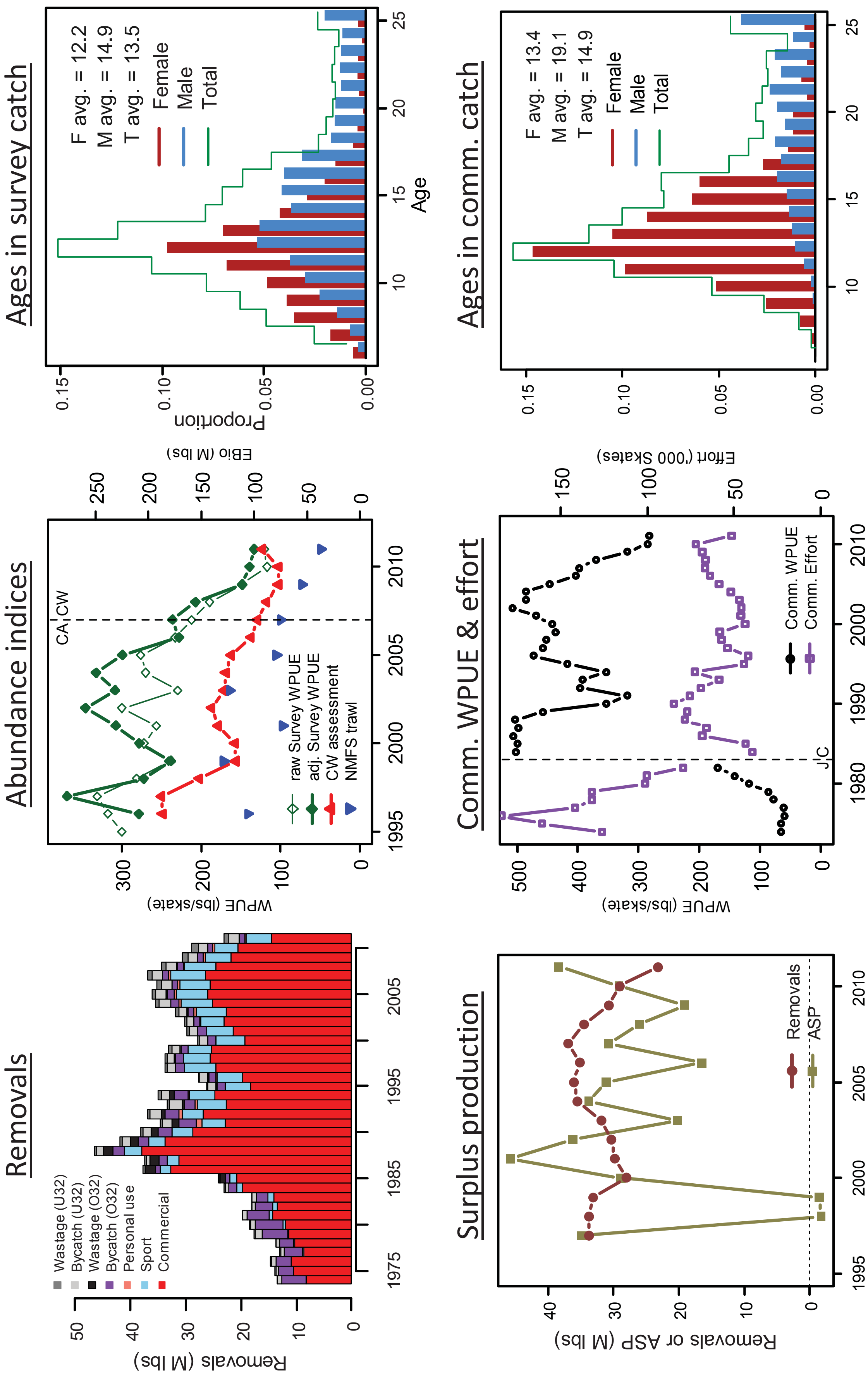


Figure 44. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 3A.

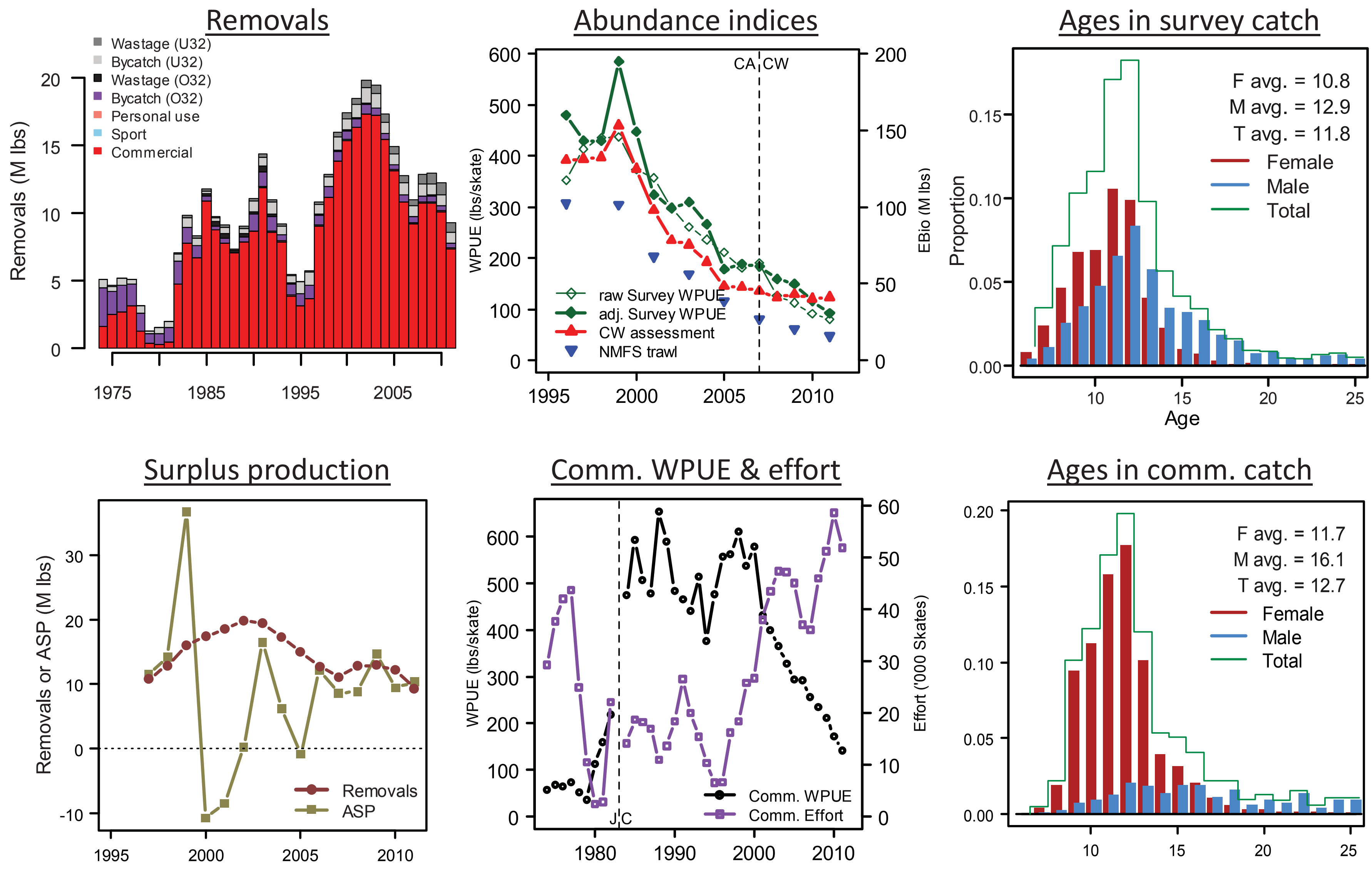


Figure 45. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 3B.

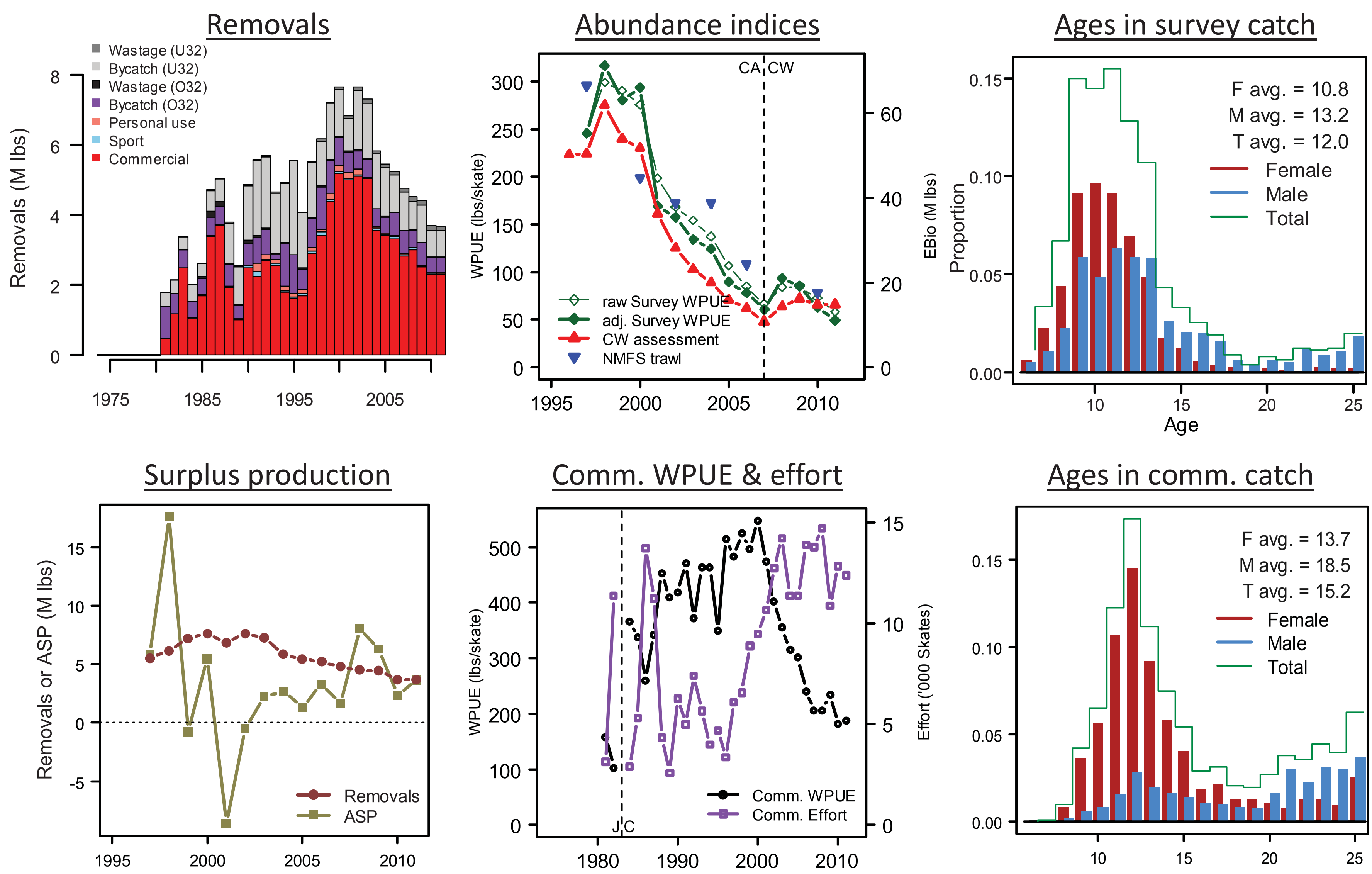


Figure 46. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 4A.

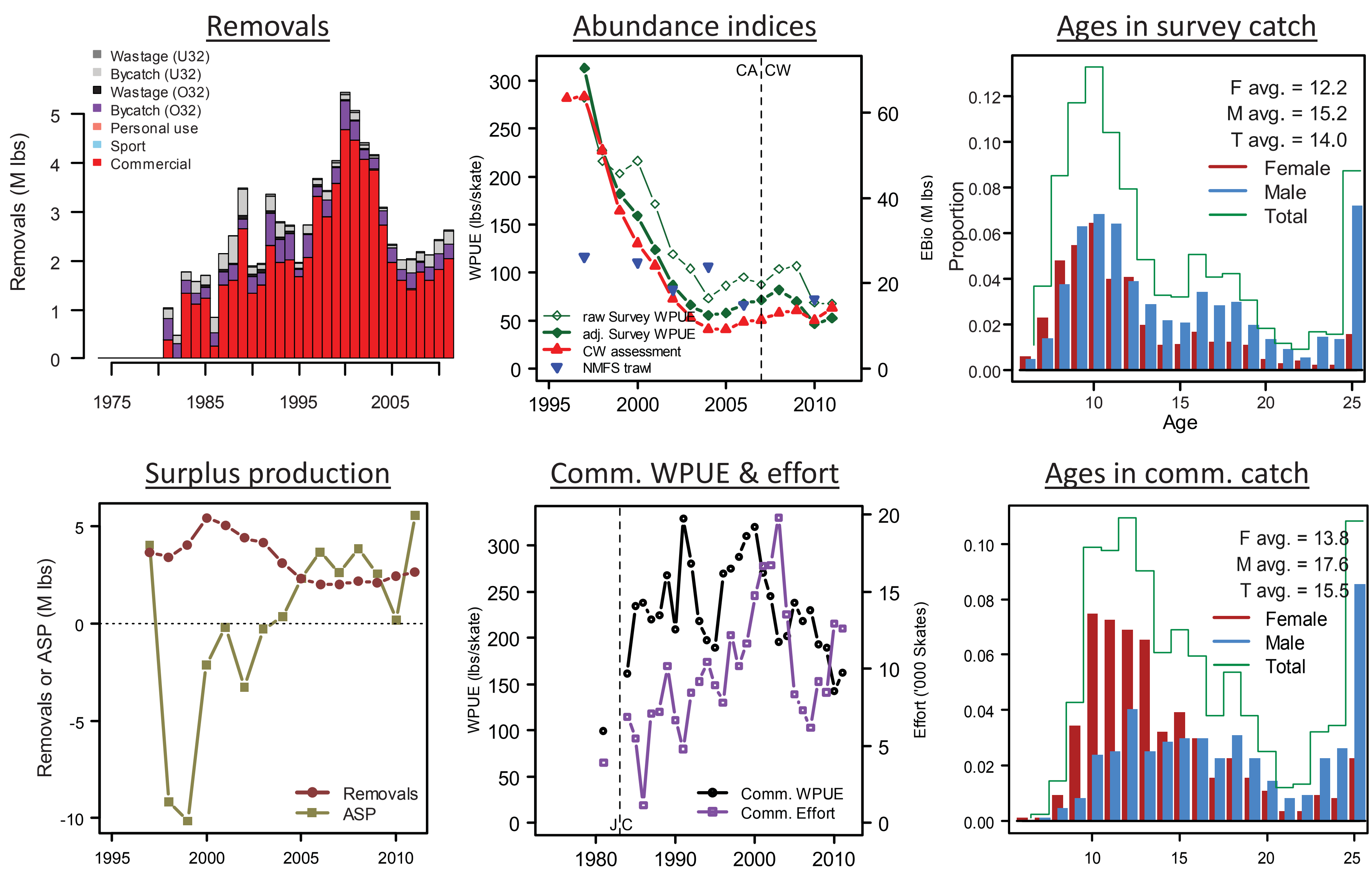


Figure 47. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 4B.

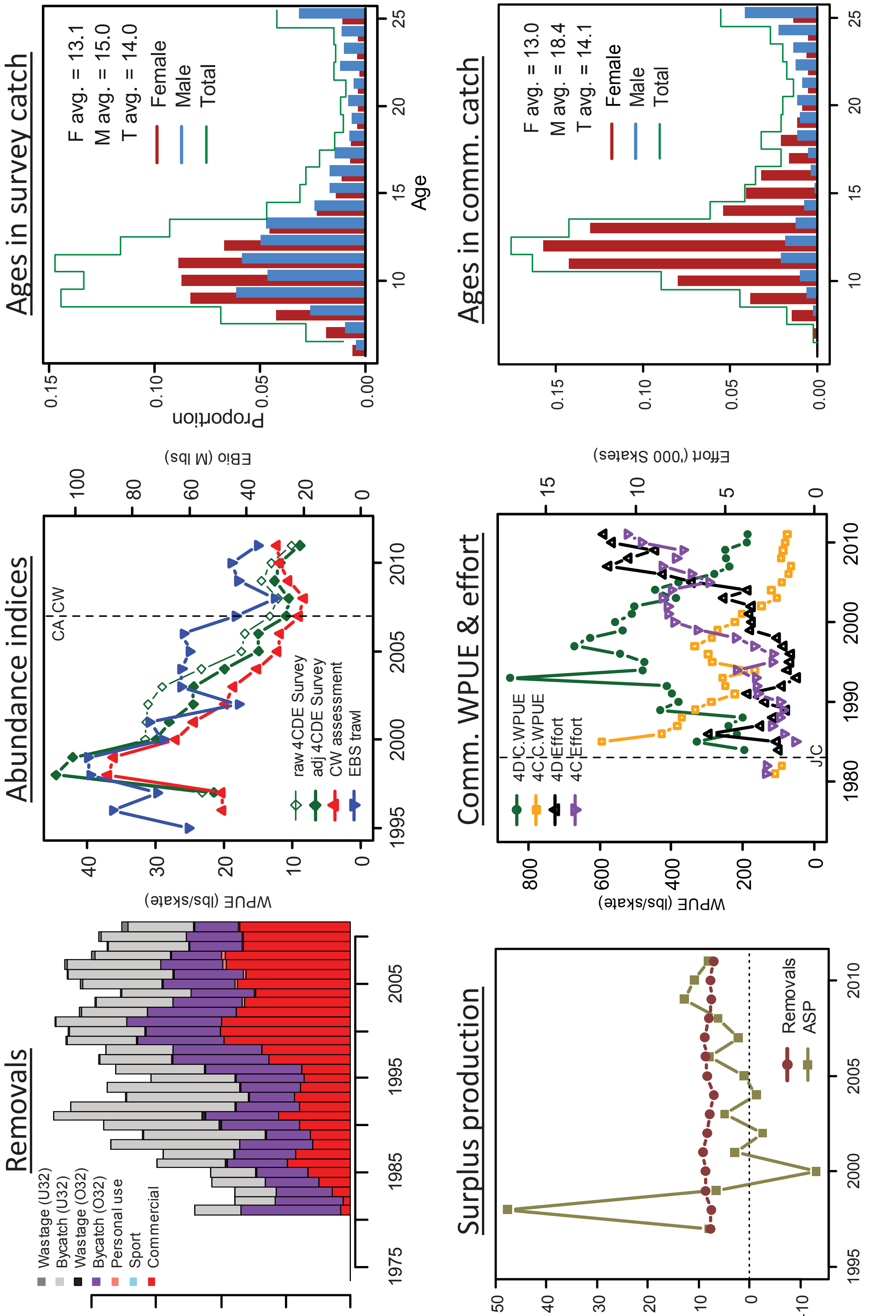


Figure 48. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 4CDE.

Appendix A. Selected fishery and survey data summaries.

Table A1. Total removals (million pounds, net weight). Removals include commercial catch, IPHC survey catches, sport catch, personal use catch, bycatch and wastage. All sizes (including U32 bycatch and wastage) are included in this table.

	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1974	0.928	6.430	6.174	13.499	5.103	8.331	----	----	----	40.465
1975	0.870	9.181	6.927	13.849	4.654	4.282	----	----	----	39.763
1976	0.648	9.508	6.282	14.643	5.198	5.285	----	----	----	41.564
1977	0.634	7.390	3.868	13.023	5.116	4.138	----	----	----	34.169
1978	0.519	6.198	4.815	13.752	3.174	6.377	----	----	----	34.835
1979	0.473	6.840	5.564	17.616	1.329	6.793	----	----	----	38.615
1980	0.446	7.164	4.121	18.442	1.529	9.948	----	----	----	41.650
1981	0.629	7.010	4.868	19.846	2.020	7.618	----	----	----	41.991
1982	0.669	6.601	4.325	18.161	7.042	6.212	----	----	----	43.010
1983	0.738	6.625	7.302	18.150	9.804	8.723	----	----	----	51.342
1984	0.960	10.553	6.855	23.095	8.300	7.894	----	----	----	57.657
1985	1.100	12.323	10.514	24.174	11.845	8.685	----	----	----	68.641
1986	1.332	13.249	12.212	37.741	9.782	11.540	----	----	----	85.856
1987	1.455	14.830	12.279	37.490	9.112	12.978	----	----	----	88.144
1988	1.148	15.272	13.110	46.548	7.387	13.699	----	----	----	97.164
1989	1.218	12.686	11.730	41.967	9.009	12.417	----	----	----	89.027
1990	0.948	11.061	12.309	38.184	11.132	----	4.851	1.886	7.607	87.978
1991	0.936	9.758	12.284	34.549	14.350	----	5.582	1.936	9.153	88.548
1992	1.154	9.975	13.006	37.007	11.032	----	5.702	3.351	8.628	89.855
1993	1.224	13.228	14.347	33.446	9.236	----	4.646	2.809	6.923	85.859
1994	1.014	12.023	13.435	34.973	5.457	----	4.933	2.737	7.498	82.070
1995	1.166	12.557	10.017	26.289	4.987	----	5.556	1.957	6.152	68.681
1996	1.158	11.245	11.503	27.728	5.734	----	4.085	2.732	7.233	71.418
1997	1.406	14.109	12.661	33.713	10.785	----	5.512	3.673	7.754	89.613
1998	1.939	14.900	13.416	33.786	12.878	----	6.152	3.427	7.541	94.039
1999	1.796	14.373	12.735	33.111	15.976	----	7.211	4.039	8.759	98.000
2000	1.677	12.630	11.441	27.996	17.386	----	7.634	5.442	8.686	92.892
2001	1.987	12.062	11.019	29.822	18.522	----	6.830	5.067	9.117	94.426
2002	1.915	14.200	11.383	30.256	19.832	----	7.645	4.405	8.340	97.976
2003	1.521	13.892	11.829	31.849	19.452	----	7.283	4.170	7.865	97.861
2004	1.687	14.715	14.457	35.470	17.343	----	5.830	3.097	7.089	99.688
2005	1.878	15.253	14.653	36.079	14.940	----	5.441	2.324	8.304	98.872
2006	1.976	14.818	14.261	35.173	12.773	----	5.234	2.029	8.732	94.996
2007	1.735	12.395	12.740	36.898	11.009	----	4.770	2.036	8.796	90.379
2008	1.607	10.095	10.382	34.471	12.837	----	4.527	2.178	7.966	84.063
2009	1.501	8.604	8.412	30.731	12.929	----	4.422	2.121	7.515	76.235
2010	1.170	8.731	7.476	29.071	12.215	----	3.695	2.440	7.760	72.558
2011	1.113	8.679	4.580	23.195	9.343	----	3.674	2.634	7.037	60.255

Table A2. Commercial catch (million pounds, net weight). Figures include IPHC research catches.

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.520	4.620	5.600	8.190	1.670	0.710	----	----	----	----	----	21.310
1975	0.460	7.130	6.240	10.600	2.560	0.630	----	----	----	----	----	27.620
1976	0.240	7.280	5.530	11.040	2.730	0.720	----	----	----	----	----	27.540
1977	0.210	5.430	3.190	8.640	3.190	1.220	----	----	----	----	----	21.880
1978	0.100	4.610	4.320	10.300	1.320	1.350	----	----	----	----	----	22.000
1979	0.050	4.860	4.530	11.340	0.390	1.370	----	----	----	----	----	22.540
1980	0.020	5.650	3.240	11.970	0.280	0.710	----	----	----	----	----	21.870
1981	0.202	5.658	4.007	14.228	0.451	----	0.494	0.386	0.298	0.008	0.004	25.736
1982	0.211	5.538	3.501	13.524	4.800	----	1.169	0.010	0.243	0.004	0.007	29.007
1983	0.265	5.438	6.381	14.132	7.755	----	2.495	1.343	0.415	0.148	0.014	38.386
1984	0.431	9.054	5.867	19.767	6.688	----	1.053	1.104	0.580	0.392	0.035	44.971
1985	0.493	10.389	9.206	20.840	10.889	----	1.717	1.237	0.620	0.674	0.036	56.101
1986	0.581	11.225	10.611	32.802	8.819	----	3.381	0.261	0.686	1.223	0.043	69.632
1987	0.592	12.246	10.685	31.308	7.758	----	3.692	1.501	0.878	0.703	0.111	69.474
1988	0.486	12.858	11.364	37.906	7.082	----	1.931	1.592	0.707	0.453	0.009	74.388
1989	0.472	10.431	9.532	33.735	7.843	----	1.025	2.651	0.571	0.674	0.013	66.947
1990	0.325	8.574	9.728	28.847	8.694	----	2.503	1.333	0.529	1.005	0.060	61.598
1991	0.355	7.191	8.687	22.926	11.934	----	2.255	1.513	0.678	1.437	0.105	57.081
1992	0.435	7.626	9.819	26.782	8.622	----	2.699	2.317	0.793	0.727	0.071	59.891
1993	0.504	10.627	11.290	22.738	7.855	----	2.561	1.962	0.831	0.836	0.064	59.268
1994	0.370	9.911	10.379	24.844	3.860	----	1.803	2.017	0.715	0.711	0.121	54.731
1995	0.297	9.623	7.766	18.336	3.125	----	1.617	1.680	0.668	0.643	0.127	43.882
1996	0.296	9.546	8.871	19.693	3.663	----	1.700	2.069	0.680	0.706	0.120	47.344
1997	0.413	12.423	9.916	24.637	9.062	----	2.908	3.318	1.117	1.152	0.250	65.196
1998	0.460	13.172	10.196	25.698	11.161	----	3.417	2.901	1.256	1.308	0.188	69.757
1999	0.450	12.705	10.143	25.316	13.835	----	4.369	3.571	1.760	1.893	0.263	74.305
2000	0.483	10.811	8.445	19.273	15.413	----	5.155	4.692	1.736	1.931	0.351	68.290
2001	0.680	10.288	8.403	21.539	16.336	----	5.015	4.468	1.647	1.844	0.479	70.699
2002	0.851	12.073	8.602	23.131	17.313	----	5.091	4.080	1.210	1.753	0.555	74.659
2003	0.819	11.789	8.412	22.754	17.223	----	5.024	3.863	0.886	1.956	0.415	73.141
2004	0.884	12.162	10.234	25.167	15.460	----	3.561	2.719	0.954	1.655	0.314	73.110
2005	0.803	12.331	10.625	26.033	13.171	----	3.404	1.975	0.534	2.578	0.370	71.824
2006	0.830	12.005	10.492	25.714	10.791	----	3.332	1.590	0.493	2.368	0.366	67.981
2007	0.789	9.772	8.473	26.493	9.249	----	2.828	1.416	0.551	2.720	0.578	62.869
2008	0.682	7.755	6.206	24.521	10.748	----	3.015	1.763	0.724	2.552	0.600	58.566
2009	0.490	6.637	4.955	21.755	10.779	----	2.528	1.593	0.644	2.210	0.455	52.046
2010	0.419	6.729	4.486	20.503	10.114	----	2.325	1.829	0.789	2.116	0.410	49.720
2011	0.540	6.560	2.431	14.533	7.351	----	2.313	2.030	0.792	2.179	0.458	39.187

Table A3. Sport catch (million pounds, net weight).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1974	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1975	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1976	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1977	0.013	0.008	0.072	0.196	0.000	0.000	0.000	0.000	0.289
1978	0.010	0.004	0.082	0.282	0.000	0.000	0.000	0.000	0.378
1979	0.015	0.009	0.174	0.365	0.000	0.000	0.000	0.000	0.563
1980	0.019	0.006	0.332	0.488	0.000	0.000	0.000	0.000	0.845
1981	0.019	0.012	0.318	0.751	0.000	0.012	0.000	0.000	1.112
1982	0.050	0.033	0.489	0.716	0.000	0.011	0.000	0.000	1.299
1983	0.063	0.052	0.553	0.945	0.000	0.003	0.000	0.000	1.616
1984	0.118	0.062	0.621	1.026	0.000	0.013	0.000	0.000	1.840
1985	0.193	0.262	0.682	1.210	0.000	0.008	0.000	0.000	2.355
1986	0.333	0.186	0.730	1.908	0.000	0.020	0.000	0.000	3.177
1987	0.446	0.264	0.780	1.989	0.000	0.030	0.000	0.000	3.509
1988	0.249	0.252	1.076	3.264	0.000	0.036	0.000	0.000	4.877
1989	0.327	0.318	1.559	3.005	0.000	0.024	0.000	0.000	5.233
1990	0.197	0.381	1.330	3.638	0.000	0.040	0.000	0.000	5.586
1991	0.158	0.292	1.654	4.264	0.014	0.127	0.000	0.000	6.509
1992	0.250	0.290	1.668	3.899	0.029	0.043	0.000	0.000	6.179
1993	0.246	0.328	1.811	5.265	0.018	0.057	0.000	0.000	7.725
1994	0.186	0.328	2.001	4.487	0.021	0.042	0.000	0.000	7.065
1995	0.236	0.887	1.759	4.488	0.022	0.055	0.000	0.000	7.447
1996	0.229	0.887	2.129	4.740	0.021	0.077	0.000	0.000	8.083
1997	0.355	0.887	2.172	5.514	0.028	0.069	0.000	0.000	9.025
1998	0.383	0.887	2.501	4.702	0.017	0.096	0.000	0.000	8.586
1999	0.338	0.859	1.843	4.228	0.017	0.094	0.000	0.000	7.379
2000	0.344	1.021	2.258	5.305	0.015	0.073	0.000	0.000	9.016
2001	0.446	1.015	1.925	4.675	0.016	0.029	0.000	0.000	8.106
2002	0.399	1.260	2.090	4.202	0.013	0.048	0.000	0.000	8.012
2003	0.404	1.218	2.258	5.427	0.009	0.031	0.000	0.000	9.347
2004	0.487	1.613	2.937	5.606	0.007	0.053	0.000	0.000	10.703
2005	0.484	1.841	2.798	5.672	0.014	0.050	0.000	0.000	10.859
2006	0.516	1.773	2.526	5.337	0.014	0.046	0.000	0.000	10.212
2007	0.504	1.556	3.049	6.283	0.025	0.044	0.000	0.000	11.461
2008	0.457	1.520	3.083	5.629	0.018	0.043	0.000	0.000	10.750
2009	0.458	1.098	2.383	4.758	0.030	0.024	0.000	0.000	8.751
2010	0.373	1.156	1.971	4.285	0.024	0.016	0.000	0.000	7.825
2011	0.398	1.220	1.313	4.541	0.025	0.018	0.000	0.000	7.515

Table A4. Personal use (million pounds, net weight).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1974	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1975	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1976	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1977	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1978	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1979	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1980	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1981	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1982	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1983	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1984	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1985	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1986	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1987	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1989	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1990	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.010	0.050	0.720	0.960	0.060	0.230	0.000	0.000	2.030
1992	0.014	0.100	0.370	0.490	0.030	0.110	0.000	0.000	1.114
1993	0.016	0.300	0.110	0.330	0.060	0.120	0.000	0.000	0.936
1994	0.011	0.300	0.110	0.330	0.060	0.120	0.000	0.000	0.931
1995	0.014	0.300	0.000	0.097	0.037	0.094	0.000	0.000	0.542
1996	0.015	0.300	0.000	0.097	0.037	0.094	0.000	0.000	0.543
1997	0.015	0.300	0.000	0.097	0.037	0.094	0.000	0.000	0.543
1998	0.011	0.300	0.170	0.097	0.037	0.094	0.000	0.000	0.709
1999	0.011	0.300	0.170	0.074	0.020	0.166	0.000	0.000	0.741
2000	0.018	0.300	0.170	0.074	0.020	0.166	0.000	0.000	0.748
2001	0.016	0.300	0.170	0.074	0.020	0.166	0.000	0.000	0.746
2002	0.016	0.300	0.170	0.074	0.020	0.166	0.000	0.000	0.746
2003	0.027	0.300	0.628	0.280	0.028	0.021	0.003	0.096	1.383
2004	0.019	0.300	0.677	0.404	0.034	0.029	0.001	0.056	1.520
2005	0.036	0.300	0.598	0.429	0.046	0.036	0.001	0.091	1.537
2006	0.036	0.300	0.598	0.429	0.046	0.036	0.001	0.091	1.537
2007	0.036	0.300	0.580	0.380	0.050	0.027	0.003	0.107	1.483
2008	0.030	0.405	0.525	0.372	0.048	0.015	0.002	0.092	1.489
2009	0.029	0.405	0.458	0.334	0.032	0.017	0.001	0.030	1.306
2010	0.025	0.405	0.425	0.313	0.023	0.015	0.001	0.032	1.239
2011	0.025	0.405	0.425	0.313	0.023	0.015	0.001	0.038	1.245

Table A5. O32 Bycatch (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1974	0.252	0.899	0.371	4.478	2.816	1.901	----	----	----	10.717
1975	0.252	0.909	0.451	2.612	1.661	1.106	----	----	----	6.991
1976	0.252	0.940	0.503	2.740	1.945	1.180	----	----	----	7.560
1977	0.254	0.720	0.407	3.366	1.546	1.976	----	----	----	8.269
1978	0.253	0.553	0.213	2.443	1.307	3.404	----	----	----	8.173
1979	0.253	0.696	0.638	4.491	0.689	3.451	----	----	----	10.218
1980	0.253	0.516	0.418	4.928	0.870	5.740	----	----	----	12.725
1981	0.252	0.533	0.403	3.990	1.095	4.366	----	----	----	10.639
1982	0.252	0.299	0.199	3.197	1.684	2.952	----	----	----	8.583
1983	0.253	0.292	0.200	2.083	1.219	2.473	----	----	----	6.520
1984	0.252	0.515	0.211	1.512	0.922	2.307	----	----	----	5.719
1985	0.252	0.546	0.201	0.796	0.341	2.245	----	----	----	4.381
1986	0.253	0.557	0.203	0.674	0.198	2.612	----	----	----	4.497
1987	0.253	0.791	0.203	1.587	0.392	2.668	----	----	----	5.894
1988	0.253	0.772	0.203	2.124	0.042	3.202	----	----	----	6.596
1989	0.253	0.719	0.203	1.801	0.438	1.914	----	----	----	5.328
1990	0.253	1.030	0.675	2.640	1.216	----	0.627	0.335	2.380	9.156
1991	0.253	1.223	0.545	3.129	1.036	----	0.731	0.236	2.254	9.407
1992	0.276	1.016	0.574	2.646	1.114	----	0.728	0.656	1.943	8.953
1993	0.276	0.651	0.333	1.911	0.465	----	0.129	0.479	1.407	5.651
1994	0.276	0.572	0.396	2.355	0.848	----	1.200	0.536	1.831	8.014
1995	0.381	0.706	0.219	1.464	0.828	----	1.089	0.149	2.110	6.946
1996	0.474	0.166	0.233	1.404	0.962	----	0.590	0.458	2.979	7.266
1997	0.474	0.109	0.240	1.545	0.728	----	0.845	0.198	2.973	7.112
1998	0.834	0.117	0.238	1.471	0.730	----	1.189	0.327	2.725	7.631
1999	0.761	0.108	0.231	1.283	0.742	----	0.911	0.336	2.644	7.016
2000	0.634	0.128	0.254	1.286	0.645	----	0.806	0.580	2.290	6.623
2001	0.645	0.149	0.184	1.620	0.633	----	0.572	0.387	2.917	7.107
2002	0.204	0.153	0.166	1.074	0.712	----	0.533	0.196	2.733	5.771
2003	0.102	0.133	0.144	1.179	0.499	----	0.519	0.220	2.112	4.908
2004	0.115	0.140	0.149	1.523	0.393	----	0.520	0.294	1.920	5.054
2005	0.139	0.191	0.144	1.322	0.359	----	0.460	0.279	2.212	5.106
2006	0.204	0.151	0.214	1.062	0.508	----	0.649	0.232	2.137	5.157
2007	0.103	0.154	0.215	0.989	0.451	----	0.656	0.325	1.897	4.790
2008	0.172	0.067	0.216	1.058	0.485	----	0.496	0.211	1.553	4.258
2009	0.198	0.109	0.216	0.972	0.469	----	0.645	0.277	1.631	4.517
2010	0.261	0.093	0.215	0.904	0.416	----	0.452	0.311	1.723	4.375
2011	0.106	0.152	0.214	1.035	0.430	----	0.451	0.306	1.350	4.044

Table A6. O32 Commercial wastage (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.000	0.000	0.000	0.000	0.000	0.000	----	----	----	----	----	0.000
1975	0.000	0.000	0.000	0.000	0.000	0.000	----	----	----	----	----	0.000
1976	0.000	0.000	0.000	0.000	0.000	0.000	----	----	----	----	----	0.000
1977	0.000	0.000	0.000	0.000	0.000	0.000	----	----	----	----	----	0.000
1978	0.000	0.000	0.000	0.000	0.000	0.000	----	----	----	----	----	0.000
1979	0.000	0.000	0.000	0.000	0.000	0.000	----	----	----	----	----	0.000
1980	0.000	0.000	0.000	0.000	0.000	0.000	----	----	----	----	----	0.000
1981	0.000	0.000	0.000	0.000	0.000	----	0.061	0.044	0.022	0.024	0.001	0.000
1982	0.000	0.000	0.000	0.000	0.000	----	0.183	0.014	0.037	0.066	0.002	0.000
1983	0.000	0.000	0.000	0.000	0.000	----	0.138	0.056	0.033	0.026	0.004	0.000
1984	0.000	0.000	0.000	0.000	0.000	----	0.028	0.023	0.010	0.007	0.000	0.000
1985	0.002	0.102	0.216	0.929	0.200	----	0.027	0.070	0.015	0.018	0.000	1.601
1986	0.004	0.203	0.433	1.857	0.401	----	0.110	0.058	0.023	0.044	0.003	3.200
1987	0.003	0.173	0.368	1.580	0.341	----	0.092	0.062	0.028	0.059	0.004	2.722
1988	0.001	0.049	0.206	1.506	0.122	----	0.051	0.044	0.015	0.014	0.001	1.952
1989	0.007	0.046	0.193	1.458	0.194	----	0.046	0.035	0.015	0.015	0.001	2.028
1990	0.015	0.117	0.243	1.110	0.216	----	0.036	0.040	0.014	0.014	0.002	1.939
1991	0.002	0.072	0.347	1.143	0.418	----	0.008	0.009	0.003	0.003	0.001	2.227
1992	0.007	0.053	0.245	0.643	0.181	----	0.024	0.029	0.010	0.010	0.002	1.254
1993	0.009	0.096	0.192	0.341	0.063	----	0.026	0.030	0.010	0.010	0.002	0.813
1994	0.001	0.069	0.228	0.845	0.039	----	0.020	0.017	0.007	0.008	0.001	1.288
1995	0.003	0.039	0.054	0.128	0.009	----	0.034	0.028	0.014	0.015	0.002	0.257
1996	0.001	0.029	0.044	0.177	0.022	----	0.026	0.023	0.009	0.010	0.002	0.348
1997	0.006	0.037	0.040	0.074	0.054	----	0.033	0.029	0.011	0.012	0.003	0.289
1998	0.001	0.053	0.041	0.154	0.056	----	0.020	0.016	0.005	0.007	0.002	0.358
1999	0.007	0.040	0.067	0.117	0.071	----	0.020	0.016	0.004	0.008	0.002	0.395
2000	0.007	0.028	0.038	0.059	0.058	----	0.015	0.012	0.004	0.007	0.001	0.260
2001	0.003	0.046	0.037	0.065	0.032	----	0.012	0.007	0.002	0.009	0.001	0.271
2002	0.005	0.036	0.026	0.139	0.034	----	0.007	0.004	0.001	0.005	0.001	0.290
2003	0.002	0.035	0.025	0.068	0.035	----	0.008	0.004	0.002	0.008	0.002	0.215
2004	0.000	0.036	0.031	0.076	0.015	----	0.011	0.007	0.003	0.010	0.002	0.197
2005	0.005	0.037	0.032	0.156	0.026	----	0.012	0.007	0.003	0.010	0.002	0.287
2006	0.002	0.036	0.021	0.051	0.011	----	0.008	0.007	0.003	0.008	0.001	0.139
2007	0.003	0.029	0.029	0.053	0.018	----	0.010	0.009	0.003	0.010	0.002	0.156
2008	0.001	0.022	0.012	0.061	0.004	----	0.061	0.044	0.022	0.024	0.001	0.133
2009	0.001	0.020	0.010	0.044	0.021	----	0.183	0.014	0.037	0.066	0.002	0.130
2010	0.001	0.027	0.009	0.021	0.020	----	0.138	0.056	0.033	0.026	0.004	0.105
2011	0.004	0.020	0.005	0.029	0.007	----	0.028	0.023	0.010	0.007	0.000	0.099

Table A7-1. U32 Bycatch (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1974	0.154	0.830	0.161	0.770	0.604	5.718	----	----	----	8.236
1975	0.154	0.999	0.188	0.546	0.412	2.544	----	----	----	4.843
1976	0.154	1.124	0.205	0.756	0.498	3.383	----	----	----	6.120
1977	0.155	1.097	0.173	0.728	0.348	0.938	----	----	----	3.439
1978	0.155	0.918	0.164	0.612	0.533	1.619	----	----	----	4.001
1979	0.154	1.156	0.183	1.290	0.246	1.968	----	----	----	4.997
1980	0.154	0.856	0.102	0.924	0.376	3.496	----	----	----	5.908
1981	0.154	0.655	0.104	0.730	0.468	2.042	----	----	----	4.153
1982	0.154	0.568	0.103	0.600	0.491	1.804	----	----	----	3.720
1983	0.154	0.651	0.104	0.873	0.716	1.796	----	----	----	4.294
1984	0.154	0.559	0.091	0.628	0.586	2.385	----	----	----	4.402
1985	0.154	0.593	0.100	0.205	0.236	1.962	----	----	----	3.249
1986	0.154	0.604	0.101	0.162	0.212	2.964	----	----	----	4.197
1987	0.154	0.858	0.101	0.653	0.481	3.071	----	----	----	5.317
1988	0.154	0.837	0.101	1.241	0.008	5.655	----	----	----	7.996
1989	0.155	0.779	0.101	1.465	0.380	5.368	----	----	----	8.248
1990	0.155	0.649	0.181	1.473	0.829	----	1.540	0.147	3.552	8.525
1991	0.155	0.770	0.189	1.714	0.635	----	2.118	0.109	4.574	10.262
1992	0.168	0.728	0.161	2.022	0.866	----	2.035	0.308	5.050	11.339
1993	0.168	1.010	0.409	2.381	0.596	----	1.698	0.310	3.740	10.313
1994	0.168	0.647	0.127	1.553	0.538	----	1.706	0.120	4.076	8.934
1995	0.233	0.816	0.122	1.494	0.917	----	2.678	0.106	2.589	8.956
1996	0.141	0.133	0.111	1.294	0.970	----	1.584	0.159	2.717	7.109
1997	0.141	0.105	0.157	1.420	0.715	----	1.541	0.098	2.224	6.402
1998	0.248	0.096	0.123	1.191	0.659	----	1.297	0.157	2.029	5.800
1999	0.226	0.085	0.127	1.602	0.995	----	1.582	0.073	2.139	6.830
2000	0.188	0.102	0.141	1.606	0.865	----	1.336	0.106	2.324	6.667
2001	0.192	0.028	0.157	1.390	1.042	----	0.935	0.145	2.164	6.052
2002	0.431	0.092	0.174	1.120	1.212	----	1.695	0.081	2.035	6.784
2003	0.158	0.115	0.197	1.611	1.065	----	1.564	0.039	2.348	7.275
2004	0.171	0.121	0.204	2.082	0.837	----	1.567	0.053	2.135	7.300
2005	0.398	0.165	0.196	1.808	0.766	----	1.386	0.050	2.460	7.043
2006	0.374	0.143	0.127	1.913	0.892	----	1.063	0.193	3.219	7.793
2007	0.284	0.146	0.127	1.782	0.793	----	1.075	0.270	2.857	7.325
2008	0.250	0.064	0.128	1.906	0.853	----	0.814	0.176	2.339	6.455
2009	0.310	0.104	0.128	1.750	0.825	----	1.057	0.231	2.456	6.861
2010	0.084	0.088	0.128	1.628	0.731	----	0.741	0.260	2.596	6.343
2011	0.034	0.145	0.127	1.863	0.755	----	0.740	0.255	2.033	6.343

Table A7-2. Break down of U32 Bycatch (million pounds, net weight) into U26 and U32/O26 components.

U26	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1996	0.006	0.024	0.030	0.578	0.437	0.752	0.035	1.155	3.015
1997	0.006	0.017	0.042	0.621	0.343	0.878	0.023	0.893	2.823
1998	0.011	0.019	0.032	0.425	0.244	0.592	0.045	1.032	2.400
1999	0.010	0.013	0.039	0.526	0.300	1.053	0.030	1.456	3.427
2000	0.008	0.016	0.044	0.528	0.261	0.814	0.038	1.504	3.213
2001	0.008	0.003	0.080	0.709	0.531	0.413	0.038	1.146	2.929
2002	0.096	0.020	0.097	0.629	0.656	1.169	0.017	1.251	3.936
2003	0.035	0.025	0.100	0.815	0.532	1.004	0.011	1.560	4.081
2004	0.038	0.026	0.103	1.053	0.418	1.006	0.014	1.418	4.077
2005	0.120	0.036	0.099	0.914	0.382	0.890	0.014	1.634	4.090
2006	0.126	0.022	0.039	1.045	0.417	0.735	0.125	2.081	4.590
2007	0.074	0.023	0.039	0.973	0.370	0.743	0.175	1.847	4.245
2008	0.031	0.010	0.039	1.041	0.398	0.563	0.114	1.512	3.708
2009	0.041	0.016	0.039	0.956	0.385	0.731	0.149	1.588	3.905
2010	0.004	0.014	0.039	0.889	0.342	0.512	0.168	1.678	3.646
2011	0.003	0.023	0.039	1.017	0.353	0.511	0.165	1.314	3.425

O26/U32	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1996	0.135	0.109	0.081	0.717	0.533	0.833	0.125	1.562	4.094
1997	0.135	0.088	0.115	0.798	0.372	0.663	0.075	1.332	3.578
1998	0.237	0.077	0.091	0.765	0.415	0.705	0.112	0.997	3.400
1999	0.216	0.072	0.088	1.076	0.695	0.529	0.043	0.684	3.403
2000	0.180	0.086	0.097	1.079	0.604	0.522	0.068	0.820	3.455
2001	0.184	0.025	0.077	0.680	0.511	0.522	0.106	1.019	3.123
2002	0.335	0.072	0.076	0.491	0.557	0.525	0.064	0.784	2.903
2003	0.123	0.090	0.097	0.796	0.533	0.559	0.029	0.788	3.016
2004	0.134	0.095	0.101	1.029	0.419	0.560	0.038	0.717	3.093
2005	0.278	0.129	0.097	0.893	0.383	0.496	0.036	0.826	3.139
2006	0.247	0.121	0.088	0.868	0.475	0.328	0.068	1.138	3.334
2007	0.210	0.123	0.088	0.809	0.422	0.332	0.095	1.010	3.090
2008	0.219	0.054	0.089	0.865	0.454	0.251	0.062	0.827	2.821
2009	0.269	0.087	0.089	0.794	0.439	0.326	0.081	0.868	2.955
2010	0.080	0.074	0.089	0.739	0.389	0.229	0.092	0.918	2.609
2011	0.031	0.122	0.088	0.846	0.402	0.228	0.090	0.719	2.526

Table A8. U32 Commercial wastage (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.002	0.081	0.042	0.061	0.013	0.002	----	----	----	----	----	0.201
1975	0.004	0.143	0.048	0.091	0.021	0.002	----	----	----	----	----	0.309
1976	0.002	0.164	0.044	0.107	0.025	0.002	----	----	----	----	----	0.344
1977	0.002	0.135	0.026	0.093	0.032	0.004	----	----	----	----	----	0.292
1978	0.001	0.113	0.036	0.115	0.014	0.004	----	----	----	----	----	0.283
1979	0.001	0.119	0.039	0.130	0.004	0.004	----	----	----	----	----	0.297
1980	0.000	0.136	0.029	0.132	0.003	0.002	----	----	----	----	----	0.302
1981	0.002	0.152	0.036	0.147	0.006	----	0.004	0.002	0.002	0.000	0.000	0.351
1982	0.002	0.163	0.033	0.124	0.067	----	0.010	0.000	0.002	0.000	0.000	0.401
1983	0.003	0.192	0.064	0.117	0.114	----	0.023	0.009	0.004	0.000	0.000	0.526
1984	0.005	0.363	0.065	0.162	0.104	----	0.010	0.008	0.006	0.001	0.000	0.724
1985	0.006	0.431	0.109	0.194	0.179	----	0.017	0.010	0.006	0.001	0.000	0.953
1986	0.007	0.474	0.134	0.338	0.152	----	0.036	0.002	0.007	0.003	0.000	1.153
1987	0.007	0.498	0.142	0.373	0.140	----	0.041	0.013	0.010	0.002	0.001	1.227
1988	0.005	0.504	0.160	0.507	0.133	----	0.022	0.015	0.008	0.001	0.000	1.355
1989	0.004	0.393	0.142	0.503	0.154	----	0.012	0.026	0.007	0.002	0.000	1.243
1990	0.003	0.310	0.152	0.476	0.177	----	0.031	0.013	0.007	0.003	0.001	1.173
1991	0.003	0.160	0.142	0.413	0.253	----	0.029	0.016	0.009	0.004	0.001	1.030
1992	0.004	0.162	0.169	0.525	0.190	----	0.036	0.026	0.011	0.002	0.001	1.126
1993	0.005	0.216	0.202	0.480	0.179	----	0.035	0.023	0.011	0.002	0.001	1.154
1994	0.002	0.196	0.194	0.559	0.091	----	0.026	0.024	0.010	0.002	0.002	1.106
1995	0.002	0.186	0.097	0.282	0.049	----	0.015	0.013	0.006	0.001	0.001	0.652
1996	0.002	0.184	0.115	0.323	0.059	----	0.016	0.017	0.007	0.001	0.001	0.725
1997	0.002	0.248	0.136	0.426	0.161	----	0.029	0.029	0.011	0.002	0.003	1.047
1998	0.002	0.275	0.147	0.473	0.218	----	0.039	0.025	0.014	0.003	0.002	1.198
1999	0.003	0.276	0.154	0.491	0.296	----	0.055	0.031	0.022	0.004	0.003	1.335
2000	0.003	0.240	0.135	0.393	0.370	----	0.072	0.041	0.024	0.004	0.005	1.287
2001	0.005	0.236	0.143	0.459	0.443	----	0.080	0.038	0.026	0.006	0.008	1.444
2002	0.009	0.286	0.155	0.516	0.528	----	0.092	0.032	0.022	0.008	0.010	1.658
2003	0.009	0.302	0.165	0.530	0.593	----	0.104	0.029	0.018	0.011	0.009	1.770
2004	0.011	0.343	0.225	0.612	0.597	----	0.085	0.018	0.023	0.012	0.008	1.934
2005	0.013	0.388	0.260	0.659	0.558	----	0.093	0.012	0.015	0.022	0.010	2.030
2006	0.014	0.410	0.283	0.667	0.511	----	0.101	0.009	0.015	0.025	0.011	2.046
2007	0.016	0.438	0.267	0.918	0.423	----	0.132	0.018	0.032	0.032	0.010	2.286
2008	0.015	0.262	0.212	0.924	0.681	----	0.133	0.019	0.017	0.060	0.014	2.337
2009	0.015	0.231	0.262	1.118	0.773	----	0.139	0.012	0.014	0.050	0.010	2.624
2010	0.007	0.233	0.242	1.417	0.887	----	0.138	0.032	0.020	0.052	0.010	3.038
2011	0.006	0.177	0.065	0.881	0.752	----	0.127	0.033	0.040	0.109	0.023	2.213

Table A8-2. Break down of U32 Wastage (million pounds, net weight) into U26 and U32/O26 components.

U26	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1996	0.000	0.004	0.007	0.009	0.003	0.001	0.001	0.000	0.025
1997	0.000	0.006	0.004	0.011	0.006	0.001	0.001	0.001	0.029
1998	0.000	0.003	0.004	0.009	0.007	0.001	0.001	0.001	0.026
1999	0.000	0.004	0.004	0.013	0.011	0.002	0.002	0.001	0.037
2000	0.000	0.003	0.006	0.009	0.014	0.003	0.003	0.001	0.039
2001	0.000	0.003	0.006	0.014	0.016	0.005	0.002	0.003	0.048
2002	0.000	0.006	0.005	0.016	0.025	0.010	0.001	0.002	0.065
2003	0.000	0.008	0.004	0.016	0.032	0.008	0.002	0.001	0.071
2004	0.000	0.017	0.010	0.017	0.038	0.010	0.001	0.001	0.095
2005	0.000	0.016	0.015	0.025	0.038	0.008	0.001	0.004	0.107
2006	0.000	0.017	0.022	0.033	0.043	0.014	0.001	0.005	0.136
2007	0.000	0.017	0.012	0.039	0.042	0.018	0.002	0.005	0.134
2008	0.000	0.007	0.011	0.033	0.074	0.020	0.001	0.005	0.151
2009	0.000	0.005	0.012	0.046	0.067	0.019	0.001	0.006	0.155
2010	0.000	0.004	0.009	0.048	0.080	0.020	0.002	0.006	0.169
2011	0.000	0.004	0.004	0.041	0.074	0.018	0.004	0.017	0.161

O26/U32	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1996	0.002	0.180	0.108	0.314	0.056	0.015	0.016	0.009	0.700
1997	0.002	0.242	0.132	0.415	0.155	0.028	0.028	0.015	1.018
1998	0.002	0.272	0.143	0.464	0.211	0.038	0.024	0.018	1.172
1999	0.003	0.272	0.150	0.478	0.285	0.053	0.029	0.028	1.298
2000	0.003	0.237	0.129	0.384	0.356	0.069	0.038	0.032	1.248
2001	0.005	0.233	0.137	0.445	0.427	0.075	0.036	0.037	1.396
2002	0.009	0.280	0.150	0.500	0.503	0.082	0.031	0.038	1.593
2003	0.009	0.294	0.161	0.514	0.561	0.096	0.027	0.037	1.699
2004	0.011	0.326	0.215	0.595	0.559	0.075	0.017	0.042	1.839
2005	0.013	0.372	0.245	0.634	0.520	0.085	0.011	0.043	1.923
2006	0.014	0.393	0.261	0.634	0.468	0.087	0.008	0.046	1.910
2007	0.016	0.421	0.255	0.879	0.381	0.114	0.016	0.069	2.152
2008	0.015	0.255	0.201	0.891	0.607	0.113	0.018	0.086	2.186
2009	0.015	0.226	0.250	1.072	0.706	0.120	0.011	0.068	2.469
2010	0.007	0.229	0.233	1.369	0.807	0.118	0.030	0.076	2.869
2011	0.006	0.173	0.061	0.840	0.678	0.109	0.029	0.155	2.052

Table A9a. IPHC setline survey WPUE of O32 fish in weight (net pounds per skate).

Figures refer to entire areas. For cases where only part of an area was fished (e.g., northern 2B, western 3A), the WPUE shown is an adjusted value. J-hook values are raw J-hook catch rates. Area 4CDE is constructed from five subareas: Area 4D Edge, Area 4IC (Pribilofs), 4ID (St. Matthew); Area 4S (southern Bering Sea shelf), and 4N (northern Bering Sea shelf. The 4N and 4S time series are constructed using trawl survey data (see text for full details). The bottom area (0-400fm) in thousands of nmi^2 is also listed for each area.

Bottom	2A	2B	2C	3A	3B	4A	4B	4D	4IC	4ID	4S	4N	4CDE	Total
0-400	14.132	29.601	14.580	49.178	29.584	19.888	19.711	15.313	2.094	1.925	141.103	59.499	219.934	396.608
20-275	10.725	23.770	11.915	41.998	25.581	16.989	11.865	14.318	1.951	1.693	109.163	23.323	150.448	293.291
	J-Hook WPUE:													
1974	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1976	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1977	---	13	---	58	---	---	---	---	---	---	---	---	---	---
1978	---	19	---	27	---	---	---	---	---	---	---	---	---	---
1979	---	---	---	41	---	---	---	---	---	---	---	---	---	---
1980	---	25	---	76	---	---	---	---	---	---	---	---	---	---
1981	---	16	---	131	---	---	---	---	---	---	---	---	---	---
1982	---	21	114	130	---	---	---	---	---	---	6	0	---	---
1983	---	18	142	119	---	---	---	---	---	---	4	0	---	---
	C-Hook WPUE:													
1984	---	57	260	361	---	---	---	---	---	---	6	1	---	---
1985	---	42	261	378	---	---	---	---	---	---	6	1	---	---
1986	---	38	283	305	---	---	---	---	---	---	7	0	---	---
1987	---	---	---	---	---	---	---	---	---	---	8	0	---	---
1988	---	---	---	---	---	---	---	---	---	---	17	0	---	---
1989	---	---	---	---	---	---	---	---	---	---	11	0	---	---
1990	---	---	---	---	---	---	---	---	---	---	12	1	---	---
1991	---	---	---	---	---	---	---	---	---	---	11	2	---	---
1992	---	---	---	---	---	---	---	---	---	---	9	1	---	---
1993	---	96	---	261	---	---	---	---	---	---	19	5	---	---
1994	---	---	---	254	---	---	---	---	---	---	15	4	---	---
1995	29	159	---	300	---	---	---	---	---	---	16	4	---	---
1996	32	166	306	317	352	---	---	---	---	---	24	18	---	---
1997	35	144	411	331	414	245	282	111	111	111	19	4	23	138
1998	36	83	232	281	435	299	216	299	299	299	26	7	45	134
1999	37	88	205	241	438	290	203	290	290	290	26	0	42	126
2000	39	91	233	272	373	276	216	213	213	213	19	3	32	121
2001	41	101	237	256	357	199	171	197	197	197	20	5	31	112
2002	33	92	261	299	297	168	119	263	263	263	12	2	31	109
2003	22	73	223	229	262	154	104	195	195	195	17	4	29	92
2004	27	86	173	270	236	137	73	132	132	132	17	3	23	88
2005	28	72	171	276	211	107	86	69	69	69	16	3	18	82
2006	16	59	144	233	181	85	96	54	82	65	17	3	17	71
2007	19	57	140	212	191	67	87	59	41	60	12	3	13	66
2008	19	90	108	189	126	84	103	78	31	94	8	3	13	60
2009	8	86	115	149	113	84	107	78	34	59	12	3	15	55
2010	17	89	110	117	91	73	68	48	59	51	12	3	13	47
2011	27	80	136	121	80	58	68	33	51	14	10	3	10	45

Table A9b. Standard errors of IPHC setline survey WPUE of O32 fish in weight (net pounds per skate).

Same as Table A9, but showing the standard errors of WPUE for each regulatory area.

Bottom	2A	2B	2C	3A	3B	4A	4B	4D	4IC	4ID	4S	4N	4CDE	Total
0-400	14.132	29.601	14.580	49.178	29.584	19.888	19.711	15.313	2.094	1.925	141.103	59.499	219.934	396.608
20-275	10.725	23.770	11.915	41.998	25.581	16.989	11.865	14.318	1.951	1.693	109.163	23.323	150.448	293.291
	J-Hook WPUE:													
1974	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1976	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1977	---	1.7	---	4.6	---	---	---	---	---	---	---	---	---	---
1978	---	2.5	---	2.3	---	---	---	---	---	---	---	---	---	---
1979	---	---	---	3.2	---	---	---	---	---	---	---	---	---	---
1980	---	2.4	---	5.4	---	---	---	---	---	---	---	---	---	---
1981	---	2.2	---	8.9	---	---	---	---	---	---	---	---	---	---
1982	---	2.6	11.3	10.7	---	---	---	---	---	---	1.1	0	---	---
1983	---	2.4	8.5	7.9	---	---	---	---	---	---	0.9	0	---	---
	C-Hook WPUE:													
1984	---	5.6	18.5	22.8	---	---	---	---	---	---	1.3	0.1	---	---
1985	---	4.6	17.0	19.6	---	---	---	---	---	---	1.2	0.1	---	---
1986	---	3.4	18.4	20.4	---	---	---	---	---	---	1.5	0.0	---	---
1987	---	---	---	---	---	---	---	---	---	---	1.7	0.1	---	---
1988	---	---	---	---	---	---	---	---	---	---	3.6	0.0	---	---
1989	---	---	---	---	---	---	---	---	---	---	2.2	0.0	---	---
1990	---	---	---	---	---	---	---	---	---	---	2.6	0.1	---	---
1991	---	---	---	---	---	---	---	---	---	---	2.3	0.4	---	---
1992	---	---	---	---	---	---	---	---	---	---	1.8	0.2	---	---
1993	---	11.4	---	19.9	---	---	---	---	---	---	4.0	1.0	---	---
1994	---	---	---	17.9	---	---	---	---	---	---	3.0	0.8	---	---
1995	9.5	13.1	---	21.8	---	---	---	---	---	---	3.4	0.7	---	---
1996	8.2	15.9	25.3	17.6	19.7	---	---	---	---	---	4.9	3.8	---	---
1997	6.8	10.9	37.0	17.1	22.4	25.4	30.6	18.2	18.2	18.2	4.0	0.8	4.0	2.9
1998	7.5	7.0	14.3	11.5	19.2	31.7	19.1	31.7	31.7	31.7	5.3	1.4	3.6	4.1
1999	8.2	7.4	15.8	10.2	18.8	35.8	16.2	35.8	35.8	35.8	5.4	0.0	3.7	4.3
2000	10.8	7.4	16.5	12.2	14.5	29.6	15.9	34.3	34.3	34.3	3.9	0.6	3.3	3.5
2001	13.5	7.5	18.4	12.6	16.0	20.5	18.2	32.2	32.2	32.2	4.2	0.9	3.3	3.5
2002	13.1	6.9	18.9	13.6	12.1	20.2	10.8	46.3	46.3	46.3	2.4	0.4	3.2	3.6
2003	6.1	5.7	16.8	11.4	9.6	18.0	9.9	30.0	30.0	30.0	3.5	0.7	2.7	3.1
2004	8.0	7.5	12.8	11.2	9.8	16.9	7.1	29.8	29.8	29.8	3.5	0.6	2.6	3.1
2005	9.7	6.0	11.5	13.0	10.1	11.5	7.6	13.2	13.2	13.2	3.4	0.7	2.4	2.4
2006	5.2	4.9	10.6	10.9	7.6	12.0	10.2	12.3	15.3	35.4	3.5	0.7	2.2	2.4
2007	7.6	4.6	11.1	10.1	7.9	8.8	10.7	10.5	11.3	15.7	2.5	0.6	1.9	1.8
2008	6.0	7.4	6.8	8.6	5.3	10.8	13.4	10.4	11.9	8.5	1.7	0.5	1.7	1.3
2009	2.3	5.6	7.2	6.5	4.9	11.0	11.9	13.5	6.8	5.7	2.4	0.7	1.6	1.8
2010	4.0	7.0	7.0	5.3	3.9	10.1	7.2	7.1	12.6	13.4	2.5	0.7	1.5	1.7
2011	4.0	6.7	9.5	5.4	4.0	6.5	7.3	4.8	6.9	10.7	2.0	0.7	1.3	1.4

Table A10. Commercial WPUE (net pounds per skate).

Values before 1984 are raw J-hook catch rates, with no hook correction. 1983 is excluded because it consists of a mixture of J- and C-hook data. No value is shown for area/years after 1980 with fewer than 500 skates of reported catch/effort data. Total column recomputed in 2007 with new bottom area numbers.

	2A	2B	2C	3A	3B	4A	4B	4C	4D	4E	Total
J-hook CPUE:											
1974	59	64	57	65	57	---	---	---	---	---	---
1975	59	68	53	66	68	---	---	---	---	---	---
1976	33	53	42	60	65	---	---	---	---	---	---
1977	83	61	45	61	73	---	---	---	---	---	---
1978	39	63	56	78	53	---	---	---	---	---	---
1979	50	48	80	86	37	---	---	---	---	---	---
1980	37	65	79	118	113	---	---	---	---	---	---
1981	33	67	145	142	160	158	99	110	---	---	---
1982	22	68	167	170	217	103	---	91	---	---	---
1983	---	---	---	---	---	---	---	---	---	---	---
C-hook CPUE:											
1984	63	148	314	524	475	366	161	NA	197	---	350
1985	62	147	370	537	602	333	234	594	330	---	395
1986	60	120	302	522	515	265	238	427	239	---	351
1987	57	131	260	504	476	341	220	384	241	---	345
1988	134	137	281	503	655	453	224	371	201	---	387
1989	124	134	258	455	590	409	268	331	384	---	376
1990	168	175	269	353	484	434	209	288	381	---	334
1991	158	148	233	319	466	471	329	223	398	---	333
1992	115	171	230	397	440	372	278	249	412	---	338
1993	147	208	256	393	514	463	218	257	851	---	399
1994	93	215	207	353	377	463	198	167	480	---	328
1995	116	219	234	416	476	349	189	286	475	---	351
1996	159	226	238	473	556	515	269	297	543	---	415
1997	226	241	246	458	562	483	275	335	671	---	423
1998	194	232	236	451	611	525	287	287	627	---	429
1999	342	213	199	437	538	497	310	271	535	---	398
2000	263	229	186	443	577	547	318	223	556	---	416
2001	169	226	196	469	431	474	270	203	511	---	382
2002	181	222	244	507	399	402	245	148	503	---	379
2003	173	221	233	487	364	355	196	105	389	---	346
2004	143	203	240	485	328	315	202	120	444	---	338
2005	137	195	203	446	293	301	238	91	379	---	314
2006	155	201	170	403	292	241	218	72	280	---	283
2007	96	198	160	398	257	206	230	65	237	---	268
2008	69	174	161	370	234	206	193	94	247	---	249
2009	98	199	155	318	211	234	189	88	249	---	236
2010	149	222	158	285	173	182	142	82	188	---	210
2011	94	240	182	283	142	188	162	76	187	---	212

Appendix B. Evolution of IPHC assessment methods, 1982-2007

From 1982 through 1994, the halibut stock assessment relied on CAGEAN, a simple age-structured model fitted to commercial catch-at-age and catch-per-effort data (Quinn et al. 1985). The constant age-specific commercial selectivities used in the model were fundamental model parameters, estimated directly.

Beginning in the late 1980s, halibut growth rates in Alaska declined dramatically. As a result, age-specific selectivity decreased. CAGEAN did not allow for that, and by the mid-1990s was seriously underestimating abundance. In effect, it interpreted lower catches as an indication of lower abundance, whereas the real cause was lower selectivity. Incoming year classes were initially estimated to be small, but in subsequent years' assessments those estimates would increase when unexpectedly large numbers of fish from those year classes appeared in the catches. The year-to-year changes in the stock trajectory shown by the assessment therefore developed a strong retrospective pattern. Each year's fit showed a steep decline toward the end, but each year the whole trajectory shifted upward.

The staff sought to remedy that problem by making selectivity a function of length in a successor model developed in 1995. It accounted not only for the age structure of the population, but also for the size distribution of each age group and the variations in growth schedule that had been observed. The fundamental selectivity parameters in this model were the two parameters of a function (the left limb of a normal density) by which the selectivity of an individual fish was determined from its length. The age-specific selectivity of an entire age group was calculated by integrating length-specific selectivity over the estimated length distribution of the age group, and that age-specific selectivity was used to calculate predicted catches. The new model was fitted to both commercial data and IPHC setline survey data, with separate length-specific selectivity functions. Commercial catchability and selectivity were allowed to drift slowly over time, while survey catchability and selectivity were held constant (Sullivan et al. 1999).

When this model was fitted to data from Area 2B and Area 3A, quite different length-specific selectivities were estimated, which suggested that fishery selectivity was not wholly determined by the properties of the gear and the size of the fish but also depended on fish behavior (e.g., migration). These behavioral elements are likely to be more related to age than size. The age of sexual maturity, for example, remained virtually the same in Alaska despite the tremendous decrease in growth, so the size at maturity is now much smaller than it was. While size must affect selectivity, it was thought that age was also influential.

To allow for that, the model was fitted in two ways. The original form was called the "length-specific" fit, because a single set of estimates of the two parameters of the length-based survey selectivity function was used in all years. In a second form, called the "age-specific" fit, the parameters were allowed to drift over time (like the commercial selectivity parameters), but they were required (by a heavy penalty) to vary in such a way that the integrated age-specific selectivities calculated in each year remained constant over time.

The usual diagnostics gave little reason to prefer one fit over the other. Goodness of fit was similar: good for both in 2B, not so good for either in 3A. The retrospective behavior of both fits was dramatically better than that of CAGEAN and quite satisfactory in all cases, although the length-specific fit was more consistent from year to year in 3A and the age-specific fit was more consistent in 2B (Clark and Parma 1999). The two fits produced very similar estimates of abundance in Areas 2B and 2C, but in 3A the length-specific estimates were substantially higher,

so out of caution the staff catch limit recommendations were based on the age-specific fit through 1999.

The assessment model was simplified and recoded as a purely age-structured model in 2000 to eliminate some problems associated with the modeling of growth and the distribution of length at age. It retained the option of modeling survey selectivity as a function of mean length at age (observed not predicted), but the production fits continued to be based on constant age-specific survey selectivity, estimated directly as a vector of age-specific values rather than as a parametric function of age.

The fit of this model to Area 3A data in 2002 showed a dramatic retrospective pattern, similar to the pattern of successive CAGEAN fits in the mid-1990s. Treating setline survey selectivity as length-specific rather than age-specific largely eliminated the pattern. Accumulated data showing very similar trends in catch at length in IHPC setline surveys and NMFS trawl surveys provided further evidence that setline selectivity is, after all, determined mainly by size rather than by age (Clark and Hare 2003).

Another anomaly of the 3A model fit in 2002 was the unexpectedly large number of old fish (age 20+) in the last few years' catches. This was found to be the result of an increase in the proportion of otoliths read by the break-and-burn rather than surface method. Surface readings tend to understate the age of older fish, and IPHC age readers had been gradually doing more and more break-and-burn readings as the number of older fish in the catches increased. The poor model fit at these ages indicated a need to deal explicitly with the bias and variance of both kinds of age readings.

An entirely new model was written for the 2003 assessment (Clark and Hare 2004). Both commercial and survey selectivity were parameterized as piecewise linear functions of mean length at age in survey catches, and were required to reach an asymptote of one at or before a length of 130 cm. Because females are larger than males, all of the population accounting and predictions were done separately for each sex. (The age/sex/size composition of the commercial landings was estimated external to the assessment for this purpose.) The observed age compositions (surface or break-and-burn) were predicted by applying estimated misclassification matrices to the age distributions. Even in its most parsimonious form—with just one survey and one commercial selectivity schedule for both sexes in all years—this model achieved very good fits to the sex-specific observations and good retrospective performance. It also produced somewhat higher estimates of average recruitment and recruitment variability. With this simple model it was feasible do standalone analytical assessments of abundance in Areas 3B, 4A, and 4B for the first time, using data from 1996-2003.

Only two minor changes were made for the 2004 assessment, and neither had a significant effect on the estimates of abundance. First, both the 2004 PIT tag recoveries (Clark and Chen 2005) and a reanalysis of earlier wire tag data (Clark 2005) indicated that commercial selectivity is not always asymptotic; it appeared to be more dome-shaped in Area 2B and more ramp-shaped in Area 3A. Fitting the assessment model with free-form selectivity schedules showed much the same thing for commercial selectivity, namely an assortment of shapes beyond 120 cm. Nevertheless a schedule that reaches an asymptote of one at 120 cm is a good approximation to and compromise among the free estimates, and using an asymptotic commercial schedule is desirable for computing exploitable biomass and reporting harvest rates, so that it what was used in the assessment. All of the freely estimated survey selectivities either level out or increase after 120 cm. Freely estimated survey selectivities present no practical difficulties, so they were estimated that way in the assessment, and most of the estimates were ramp-shaped.

Apart from a few minor and inconsequential corrections and alterations, the 2005 analytical assessment was the same as the 2004 assessment. The only important change in procedure was the use of the NMFS trawl survey to estimate biomass in Area 4CDE where an analytical assessment was not done.

In 2006, growing concerns about migration of O32 fish from western to eastern areas led the staff to doubt the validity of the closed-area assessments that had been done for many years (Clark and Hare 2007a). The staff has estimated since 2006 coastwide abundance by fitting the model to a coastwide dataset, and estimated biomass in each area in accordance with survey estimates of relative abundance (Clark and Hare 2007b). U32 discard mortality in the halibut fishery was added to the removals beginning with the 2007 assessment; it had the effect of decreasing the present biomass estimate by less than 1%. In 2010, bycatch and wastage mortality between 26 and 32 inches was included in “other removals” when determining fishery CEY. Previously, the accounting for these removals was factored into the target harvest rate determination.

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Assessment of the Pacific halibut stock at the end of 2010

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Abstract

Since 2006, the IPHC stock assessment model has been fitted to a coastwide dataset to estimate total exploitable biomass. Coastwide exploitable biomass at the beginning of 2011 is estimated to be 318 million pounds. The assessment revises last year's estimate of 334 million pounds at the start of 2010 downwards to 275 million pounds, and projects an increase of 16% over that value to arrive at the 2011 value of 318 million pounds. The downward revision is part of a still present, but relatively modest, retrospective behavior shown in the model. Female spawning biomass is estimated at 350 million pounds at the start of 2011. This is an increase of nearly 6% over the beginning of 2010 estimate of 331 million pounds. The female spawning biomass shows little evidence of retrospective behavior, lending credence to our belief that ongoing declines in size at age, which strongly affect selectivity-at-age, are the root cause of the retrospective behavior. Projections based on the currently estimated age compositions suggest that both exploitable and spawning biomass will increase over the next several years as several strong year classes recruit to the fishable and spawning components of the population. Projected increases are tempered both by potential ongoing decreases in size-at-age, as well as realized harvest rates which continue to be above target in several regulatory areas. Trawl estimates of abundance are similar to assessment estimates in most areas, and also provide evidence of very large numbers of small halibut. The coastwide exploitable biomass was apportioned among regulatory areas in accordance with survey estimates of relative abundance, modified by adjustments for hook competition and survey timing. Weighting of the survey indices follows a Kalman filter analysis, resulting in weights of 75:20:5 for the last three years. Options have also been provided to allow for direct deduction of bycatch and wastage mortality under 32 inches in calculation of fishery constant exploitation yield.

Introduction

Each year the International Pacific Halibut Commission (IPHC) staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial and sport fisheries, other removals, and scientific surveys (Appendix A). A biologically determined level for total removals from each regulatory area is calculated by applying a fixed harvest rate to the estimate of exploitable biomass in that area. This level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding level for catches in directed fisheries subject to allocation is called the fishery CEY. It comprises the commercial setline catch in all areas plus the sport catch in Area 2B, and the sport plus ceremonial and subsistence catches in Area 2A. It is calculated by subtracting from the total CEY an estimate of all unallocated removals - bycatch of halibut over 32 inches in length (hereafter, "O32"), wastage of O32 fish in the halibut fishery, fish taken for personal use, and sport catch except in Areas 2A and 2B. This year, in response to directions to staff from IPHC Commissioners, alternative methodologies of accounting for U32 bycatch and wastage mortality (BAWM) were developed (Hare 2011). Until this year, U32 BAWM was accounted for in the determination of the target harvest rate. In brief, the new methodologies allow for direct accounting in determination of fishery CEY. Staff recommendations for catch limits in each area are based on the estimates of fishery CEY but may be higher or lower depending on a number of statistical, biological, and policy considerations. Similarly, the Commission's final quota decisions form the management targets for the coming year and are based on the staff's recommendations but may be higher or lower.

For many years, the staff assessed the stock in each regulatory area by fitting a model to the data from that area (Appendix B). This procedure relied on the assumption that the stock of fish of catchable size in each area was closed, meaning that net migration was negligible. A growing body of evidence from both the assessments (Clark and Hare 2007) and a mark-recapture experiment (Webster and Clark 2007, Webster 2010) showed that there is a continuing and predominantly eastward migration of catchable fish from the western area (Areas 3 and 4) to the eastern side (Area 2). The effect of this unaccounted for migration on the closed-area stock assessments was to produce underestimates of abundance in the western areas and overestimates in the eastern areas. To some extent this has almost certainly been the case for some time, meaning that exploitation rates were well above the target level in Area 2 and a disproportionate share of the catches have been taken from there.

In order to obtain an unbiased estimate of the total exploitable biomass (EBio), beginning with the 2006 assessment, the staff built a coastwide data set and fitted the standard assessment model to it. Exploitable biomass in each regulatory area was estimated by partitioning, or apportioning, the total EBio in proportion to an estimate of stock distribution derived from the IPHC setline survey catch rates (WPUE). Specifically, an index of abundance in each area was calculated by multiplying weighted survey WPUE by total bottom area between 0 and 400 fm (Hare et al. 2010). The logic of this apportionment is that survey WPUE can be regarded as an index of density, so multiplying it by bottom area gives a quantity proportional to total abundance. This year two adjustments to the index for each area, one based on hook competition and the other on survey timing, were computed for use in biomass apportionment. The staff's Catch Limit Recommendations are based on use of both adjustments. New this year is a change to the weighting which has been used for the last several years of survey WPUE. Based on a statistical analysis of relative variability within a year compared to between years (Webster 2011), the new weighting places far more emphasis on the most recent year than was the case previously. The new "Kalman" weights are in the ratio of 75:20:5 for the past three years WPUE values (after adjusting for hook competition and survey timing). The estimated proportion in each area is then the adjusted and weighted index value for that area divided by the sum of the adjusted and weighted index values.

Changes to the assessment and apportionment in 2010

The following summarizes changes, additions, and updates to the 2010 assessment and apportionment procedures, compared to the previous halibut assessment (Hare 2010)

- 2010 survey and commercial data added
- The setline survey stations around the Pribilof Islands ("Area 4IC") and St. Matthew island ("Area 4ID") are indexed separately due to their differing station density
- A new expanded NMFS northern Bering Sea trawl survey is used to compute exploitable biomass density. This new survey is used to adjust earlier estimates of density computed from the (much smaller) ADFG Norton Sound trawl survey.
- Swept area estimates of Exploitable Biomass (EBio) from independent trawl surveys are updated for several regulatory areas.

- Two adjustment factors are computed for the survey index - hook competition and timing of setline survey.
- The (possibly adjusted) survey indices are averaged over the past three years using both an equally-weighted (1:1:1) and a new Kalman weights (75:20:5) scheme to apportion 2011 beginning of year biomass
- In addition to O32 (Over 32”) and U32 (Under 32”), we now also refer to U26 (Under 26”) and U32/O26 (Under 32” and Over 26”) sized halibut.
- Alternatives to account for U32/O26 and U26 bycatch and wastage mortality in determination of fishery CEY are presented.
- The three factors (adjustments, time averaging, U32 BAWM accounting) result in 12 possible exploitable biomass apportionment schemes.

Observations from the survey, commercial and other fisheries

The IPHC collects data from a variety of sources to characterize the fishery, status and population trends in all regulatory areas, and assist in fitting a population assessment model. Some of the more important datasets are summarized herein.

Halibut removals

Total removals from the halibut populations come from seven categories: commercial catch (IPHC survey catch is included in this category), sport catch, O32 bycatch (from a variety of fisheries targeting species other than halibut), personal use, O32 wastage from the commercial fishery, sublegal-sized bycatch from non-target fisheries, and sublegal-sized wastage from the commercial fishery. Note that this year, additional breakdowns of U32 bycatch and U32 wastage, into U26 and U32/O26 components, are provided to allow for alternative fishery CEY computations. Detailed descriptions of each category are contained in the Fishery Removals section of the annual Report of Assessment and Research Activities (Gilroy et al. 2011). The 2010 regulatory area total removals are illustrated in Figure 1, coastwide total removals from 1935 to 2010 are illustrated in Figure 2, and regulatory area total removals for 1974-2010 are illustrated in Figure 3 (and listed in Appendix Tables A1-A8). On a coastwide basis, total removals are at their lowest level since 1996 and third lowest total over the past 23 years. The pattern of changes between 1996 removals and 2010 removals has been quite different among regulatory areas, however.

Definition of bottom area

The definition of halibut habitat is important to the process of apportioning coastwide biomass. It also plays a role in weighting various regulatory area datasets to construct the coastwide dataset used in fitting the stock assessment (Clark and Hare 2007). Until 2009, halibut habitat was defined as all bottom area between 0 and 300 fathoms. While the setline survey restricts stations to a range of 20-275 fm, the mean density estimates are applied to the larger habitat definition. A recent review of commercial landings revealed that commercial fishing for halibut is increasingly operating in waters deeper than 300 fm (Hare et al. 2010). Correspondingly, beginning in 2010, we expanded the definition of halibut habitat to 400 fm. In 2009, for the first time, the Area 4 island stations (termed Area “4I”) were indexed separately from the Area 4D edge and the Area 4 continental shelf. However, as the station density differs between the Pribilof Island stations (termed “Area 4IC”) and the St. Matthews island stations (termed “Area 4ID”), they are now indexed separately. It is conceivable that applying density estimates from the narrower, surveyed range of 20-275 fm to the broader, defined habitat, range of 0-400 fm results in a bias that differs by area. Staff has begun development of a potentially expanded survey into deeper and shallower waters than the current survey to examine this issue (Hare et al. 2011, Webster and Hare 2010a, Webster and Hare 2011a). The bottom area computations and totals are described in Hare et al. (2010) and the square nautical miles of habitat are listed in Table A9.

Treatment of Area 4CDE

Due to its large size and relatively low density of halibut, Area 4CDE does not have a grid of setline survey stations across its entire range. Since 2000, the IPHC setline survey has included 48 stations along the 4D Edge at depths between 75 and 275 fm. Since 2006, 29 stations have been surveyed annually around the Pribilof Islands and St. Matthew Island. Finally, a unique grid survey, comprised of 82 stations was carried out in 2006 over the southern Eastern Bering Sea shelf (Soderlund et al. 2007). Extensive use is also made of the data from the NMFS annual Eastern Bering Sea trawl survey.

To construct a comprehensive and representative dataset for Area 4CDE, five subareas are indexed and then weighted by bottom area to compute indices of interest, similar to those computed for the other regulatory areas. The 4D Edge, with 48 setline survey stations, covers 15,313 nmi^2. Beginning in 2009, the 4CDE island stations were used to index the bottom area around the islands. This year, the island stations are separated into two groups. The first are the stations around the Pribilof Islands, operationally (though not officially) referred to as Area 4IC, which comprise 2,094 nmi^2. The other stations, around St. Matthew Island are operationally referred to Area 4ID and comprise 1,925 nmi^2. The reason for separating the groups of islands is that the station density differs; Area 4IC islands are on an approximately 7 nmi^2 grid, while the Area 4ID stations are on a 10 nmi^2 grid. The Bering Sea flats comprise the remainder of the Area 4CDE and, as of 2009, extend northwards to 65.5°N - though constrained on the western boundary by the International dateline. This region is operationally (again, not officially) split into Area 4N, which represented 59,499 nmi^2 and Area 4S, which represents 141,103 nmi^2. The areas differ slightly from the 2009 values as a result of the new NMFS northern shelf survey (discussed below). The boundaries for the five Area 4CDE areas are illustrated in Figure 4. Density estimates for the five areas all rely on surveys - Areas 4D Edge, 4IC and 4ID on the IPHC setline survey; Areas 4S and 4N on trawl surveys as discussed in the next section.

NMFS and ADFG Bering Sea trawl surveys

Every year, the IPHC places a sampler aboard the National Marine Fisheries Service (NMFS) Eastern Bering Sea (EBS) groundfish/crab trawl survey. The sampler collects biological data on the halibut catches, taking lengths of almost all halibut caught and selecting a subsample for aging. The 2010 effort is described in Sadorus and Lauth (2011). The catch rate of halibut (all sizes) on the NMFS EBS trawl survey is illustrated in Figure 5. Additionally, this year, the NMFS also operated their triennial Aleutian Islands survey (Fig. 6). While the Aleutian Islands survey is not used as part of the IPHC assessment, it is used to compare in a comparison of NMFS trawl and IPHC assessment biomass estimates (discussed later).

Due to the high cost, and very low catch rate, of setline surveying halibut in the EBS, the IPHC does not conduct the Standardized Stock Assessment (SSA) grid survey in that region. While the IPHC survey does operate along the Area 4D shelf edge, that region is not indicative of densities and trends across the broad shelf. For the purposes of apportionment, it is vital that a measure of density for the EBS shelf be derived each year, and the NMFS groundfish trawl survey is leveraged to allow just such an estimate. The traditional NMFS survey (i.e., as operated form 1982-2009) generates swept area estimates of abundance for the southern part of the EBS shelf (equivalent to operational IPHC area 4S). In 2006, the IPHC added 100 extra stations to the SSA grid survey and placed these across the shelf to get an estimate of shelf-wide density (Soderlund et al. 2007). In that year, mean density was estimated to be 18.1 pounds per standardized survey skate. It is important to note that the value of 18.1 represented a weighted average of a value of 16.8 lbs for the shelf and 76 lbs/skate for the 4I stations. Starting in 2009, we use the value of 16.8 lbs/skate as the standard O32 halibut density for Area 4S in 2006. Beginning in 2010, Area 4S comprises the part of the shelf covered by the traditional NMFS EBS shelf survey (see Fig. 4) and thus includes the southern parts of IPHC regulatory areas 4D and 4E. This differs from the definition of Area 4S utilized in 2009. The reason for the change is that starting in 2010, the NMFS expanded the EBS trawl survey north to 65.5 °N and covering the entire remainder of the EBS shelf. Part of the expanded NMNFS survey region was previously included with Area 4S but is now included as part of Area 4N (discussed below).

The 2006 setline estimate of Area 4S density is tied to the NMFS trawl survey to provide an annually varying estimate based on the following approach. From the NMFS trawl survey we obtain swept-area estimates of abundance at length. We then apply the stock assessment estimated survey selectivity at length schedule to the full catch to provide an index of survey catch rate, comparable to the SSA survey fishing gear. Figure 7 illustrates how the length frequency distribution resulting from this treatment of trawl survey data compares to the actual length frequencies collected in the 2006 IPHC special EBS setline survey. In this manner we are able to obtain, for a small fraction of the cost it would take to survey the southern EBS with a setline survey, a highly reliable index of halibut abundance across the EBS flats. Figure 8 provides an illustration of the time trend in abundance estimated from the trawl survey. In 2008, the index was at its lowest point since the mid-1980s, but the last two years have shown an increase of more than 50% over the 2008 value. Figure 9 provides an illustration of the size composition of the Area 4S EBio. The index of total halibut biomass, has been increasing steadily since 2002, and is at its highest level in the history of the trawl survey. The length frequency data indicate very large numbers of U32 fish across the southern EBS shelf (Fig. 10).

In 2009, the EBS shelf area north of 61°N was added to the definition of halibut habitat in Area 4CDE. However, as this northern shelf undoubtedly has a different (i.e., much lower) halibut density than the southern shelf, a different means of estimating density needed to be established. Fortunately, there has been an approximately triennial trawl survey, conducted in a similar manner to the 4S survey with a similar net, in the greater Norton Sound area since 1976. The survey was conducted by NMFS until 1991 and since then by the Alaska Department of Fish and Game (ADFG). In all, there have been surveys conducted in 1976, 1979, 1982, 1985, 1988, 1991, 1996, 1999, 2002, 2006, and 2008). There has been no formal analysis of the halibut data from the survey; however, ADFG provided us with the raw catch rate (WPUE) data at all stations fished each year. The survey has been conducted each time in a core area (indicated by the Norton Sound outline in Figure 4) as well as opportunistic stations often well away from Norton Sound. In 2009, in order to create a consistent index for Area 4N across years, we selected just the stations within the core area and calculated a simple mean value and its standard error (Fig. 11a). This index has units of kg of halibut per km^2 area swept. As there are no sample data, we are unable to derive an O32 index similar to that derived from the NMFS trawl survey. To create a density index comparable to the other IPHC areas (i.e., O32 lbs/standard skate), we proceeded in the following manner.

1. Compute mean density (and standard error) for each Norton Sound ("Area 4N") survey year
2. Compute mean density in NMFS southern shelf trawl survey ("Area 4S") for the same years and in the same units.
3. Regress the square root transform of 4N density on the square root transform of the 4S density and use the regression parameters to estimate density in the unsurveyed years for 4N
4. Transform the estimates back to their original scale and retain the actual survey values in the years a survey was conducted in 4N (rather than use the predicted values)
5. Construct a standard IPHC density index (lbs/skate) by multiplying the 4S index by the ratio of the 4N trawl density index to the 4S trawl density index.
6. Compute average density for survey stations within the Norton Sound core area for the 2010 expanded NMFS trawl survey.
7. Scale the Norton Sound WPUE time series by the ratio of the full 2010 NMFS expanded survey density to the Norton Sound core area average density. In 2010, average density in the Norton Sound core area was 136.0 kg/km^2 while average density across the entire expanded survey area was 119.0 kg/km^2, resulting in a scalar of 0.875 applied to the Norton Sound WPUE index.

This procedure makes several assumptions, most stringently that density trends in 4N and 4S, as well as in the Norton Sound core area and 4N, vary synchronously. Consideration of the years with actual survey data shows this to be a reasonable assumption and the square root transform down weights the single very large 4N data point of 1996 to achieve a closer match. The end result (Fig. 11b) is a density estimate comparable to the other IPHC areas. In general, 4N density averages 1/3rd to 1/10th of 4S density. As 4S is more than twice as large as 4N, the overall added biomass to 4S is relatively minor (Fig. 11c). More importantly, all halibut are accounted for in Area 4CDE up to 65.5°N.

IPHC setline survey

The current SSA survey has been conducted since 1996 in almost all areas and in all years. A triangular design was used in 1996 and 1997, with the current 10 nmi regular grid used from 1998 to the present. Areas and years not surveyed are: the Eastern Bering Sea shelf which was surveyed only in 2006; Area 2A which was not surveyed in 1996, 1998, and 2000, the Area 4D edge which was not surveyed in 1996, 1998 and 1999, and Area 4A and 4B which were not surveyed in 1996. Setline surveys were conducted in Areas 2B, 2C, and 3A on a semi-regular basis between 1977 and 1986 before being discontinued for a decade. The surveys prior to 1984 used "J" hooks while all surveys from 1984 onwards were based on use of "C" hooks. In its current configuration, stations are placed on a 10-nautical mile grid between depths of 20 and 275 fm, resulting in a total of approximately 1280 stations. The 2010 SSA survey is fully described in White et al. (2011). A key indicator of stock status in each regulatory area is the weight of O32 halibut caught per standardized skate, termed the survey WPUE (Fig. 12 and Appendix Table A9). Survey WPUE has declined by over 50% on a coastwide basis over the past 10 years. While the rate of decline has differed among areas, there has been a substantial decrease in WPUE in all areas, indicative of a consistent coastwide decline in exploitable biomass. As described earlier, Area 4CDE is assembled from five subareas. The derived WPUE indices from each of those areas are each weighted by its respective bottom area to construct the single Area 4CDE WPUE time series shown in Figure 12. The component time series are illustrated in Figure 13, which gives a unified perspective on the relative densities of halibut in the different sub-areas of Area 4CDE.

The survey catch of halibut is sampled to obtain biological information about the stock including sex and age distribution and is described in Forsberg (2011a). The 2010 age distributions for males, females, and sexes combined for all regulatory areas are plotted in Figure 14. The age structure of the population is of considerable interest for a variety of reasons. These distributions indicate the relative abundance of fish available to the fishery, relative contributions to the female spawning biomass, etc. In 2010 as in the last several years, there is a general tendency for an older age structure in the western areas, relative to the eastern areas. In particular, the lack of fish older than 20 years is noted for Area 2. Areas 3B and 4A present somewhat anomalous age distributions in that they more closely resemble Area 2 than Area 3A or most Area 4 distributions. The reasons for this are not completely understood although the estimated rate of fishing mortality is not excessive and there appears to be substantial recruitment into this area. At least part of the explanation for the higher number of young fish may be that the settlement of juveniles from Gulf-wide spawning occurs primarily in these areas. In 2009, a reduced harvest rate was (of 0.15) was implemented in Area 3B in part based on the more truncated age distribution. Survey age-specific catch rates (Fig. 15) provide a means of gauging historic year class strength. Note that the age-specific catch rates are affected by the change in growth rate thus the survey indexes numbers of fish selected to the gear and not necessarily total numbers of fish in the population compared across years. The very strong 1987 and 1988 classes are readily apparent in Figure 15. Optimistically, it appears that the 1999 and 2000 year classes are now entering the survey catch at the larger rates the assessment model has been predicting the last few years. The declining growth is likely responsible for the delay in recruiting to the survey and it may still be a few years before these two year classes enter the commercial fishery in proportion to their overall numbers in the population.

Commercial fishery

The second major component of the annual IPHC data collection is sampling the commercial catch. The port sampling program is detailed in Erikson and MacTavish (2011) and age sampling in Forsberg (2011b). From commercial fishing logs, commercial CPUE is computed for each regulatory area (Fig. 16 and Appendix Table A10). As with the survey WPUE, there has been a consistent coastwide decline in commercial WPUE though not quite as pronounced. This is not unexpected however, as commercial fishers tend to move their effort to maintain their catch rate, whereas the survey maintains the same fishing locations every year. Approximately 1500 otoliths are collected and aged from each regulatory area (smaller samples in Areas 2A and 4B). Because commercially-caught halibut are gutted at sea, the sex of halibut is unknown when sampled at the port of landing. A statistical methodology has been developed, based on sex ratio at length in survey catches, to parse out male and female proportions at age (see Clark 2004). The estimated sex and age composition of the commercial catch, by regulatory area, is illustrated in Figure 17. It is important to note that the distribution of ages for the total (sexes combined) is not statistically estimated (the distribution represents the otolith readings); it is the sex-specific distributions that are statistically derived. As with the survey age samples, the fish in Area 2 are, on average, several years younger than fish caught in Areas 3 and 4. Here, as well, Area 3B (but not Area 4A) is anomalous in that the average age of fish is closer to the Area 2 average.

Part of the coastwide decline in exploitable biomass can be attributed to a decline in size at age. For a given number of halibut in the population, a smaller size at age results in a smaller cumulative biomass. Figure 18a shows how the average weights of halibut in survey and commercial catches have changed over the past 12 years. Average weight has declined by 25% in the survey catches and 33% in the commercial catches. While the decline could be due to a decline in average age of the fish in the catches (since younger fish are smaller), Figure 18b shows this has not been the case, as average ages in both the survey and commercial catch have not declined at nearly the same rate. Trends, by regulatory area, in average age and average weight are illustrated in Figure 19.

Lost yield from U32 bycatch

In 2009, a methodology was developed to estimate yield loss from bycatch in the non-directed fisheries (Hare 2010). Bycatch, which is unsexed but for which length samples are available, was partitioned into age and sex components and a life history simulation model then allowed an estimate of how much yield was lost to the directed commercial fishery, in units of pound of lost yield per pound of U32 bycatch. The yield loss ratio in general is around one pound per pound but varies by regulatory area, depending both on the size of the bycatch when taken as well as the size at age of halibut when taken in the commercial fishery. Figure 20 updates the lost yield computations from Hare (2010b). Neither these, nor the previous calculations in Hare (2010) factored migration into the estimates, which has the effect of "spreading" the lost yield downstream from the area of capture. Work on evaluating the effect of migration on downstream distribution of lost yield is reported in Valero and Hare (2010 and 2011).

Description of the assessment model

The current halibut assessment model has remained essentially unchanged since 2003. It has been thoroughly described in an IPHC Scientific Report (Clark and Hare 2006) and was subjected to a peer review by two external scientists from the Center for Independent Experts (IPHC 2008). Since the Commission's acceptance of a coastwide stock assessment model, much of the focus of the staff and the industry is now on how the coastwide estimate of exploitable biomass is apportioned among regulatory areas. For both these reasons, the assessment model for 2010 is identical to that used for the 2008 and 2009 assessments. In the interest of brevity, little discussion is presented here of the model itself. Interested readers are referred to Clark and Hare (2006, 2007, and 2008) for full details.

Much of the assessment documentation that follows also differs little from the documentation of the 2009 assessment. The primary reason for this relates to an unfortunate occurrence in regard to the computer used in conducting the assessment. Almost immediately following the initial completion of the assessment, the hard drive on which the assessment resides suffered a catastrophic failure and, for reasons related to this year's coincident relocation of the IPHC's headquarters, had only a bi-weekly backup. The necessity of re-creating the assessment from "scratch" meant that much of the usual internal model testing and alternative fitting could not be conducted. The deadline for RARA submission also limited editing the amount of editing done on the assessment document. The primary output of the assessment – the estimate of coastwide EBio on which apportionment is based – differed by less than 0.20% between the initial and recreated assessments. Most, if not all, of this minor difference resulted from incremental additions to the datasets (primarily the commercial catch) between the assessments. The EBio value used in the apportionment process is that computed from the initial assessment as staff Catch Limit Recommendations were based on that value.

The IPHC assessment model is age- and sex-structured. Commercial and survey selectivities are both estimated as piecewise linear functions of observed mean length at age/sex in survey catches. (There is a 32-inch minimum size limit in the commercial fishery.) Commercial catchability is typically allowed to vary from year to year with a penalty of 0.03 on log differences. Some variation in survey catchability between years has been allowed in production fits since 2006. The model is fitted to commercial and survey catch at age/sex and CPUE.

Until 2006, estimates of halibut abundance were made using closed-area models for all areas except Areas 2A and 4CDE. Area 2A leveraged the Area 2B assessment and relative survey WPUE, while Area 4CDE relied upon the NMFS EBS trawl estimates of swept area abundance. The closed-area models are not considered reliable due to violation of the closed-population assumption. Due both to time constraints, as well as lack of confidence, we no longer fit or produce biomass estimates from the closed area models. The coastwide model has considerable more flexibility than the closed-area models, including sex-specific catchability, selectivity, and natural mortality parameters; it is fitted to CPUE (WPUE and NPUE) at age/sex (rather than just total CPUE), uses weaker selectivity smoothing, and neutral data weighting. Finally, and perhaps most importantly, the coastwide data set is far less noisy than the closed area datasets and fits to the data provide more confidence in the results than was the case for closed-area model results. The closed area model fits are not discussed further.

Alternative model fits

As has been done the past few years, several versions of the basic assessment model were fitted. Differences among all the models concerned how survey and commercial catchability (generally termed “q”) were parameterized. Two additional models were fitted that excluded commercial CPUE, and are considered similar to many of the NMFS groundfish assessment models. The models are summarized as such:

(Base) Survey q trendless drift: same as Survey q drift, but with the additional requirement that a regression of estimated survey catchability on year have zero slope. This means that survey catchability was allowed to vary but not to show any trend over time. This has been the selected production model since 2007.

(Alternative 1) Survey q constant: catchability is a single fixed (though estimated) value in all years.

(Alternative 2) Survey q drift: survey catchability estimated for each year, but with a penalty of 0.05 on log differences. This is similar to the treatment of commercial catchability.

(Alternative 3) Survey q trendless drift (i.e., Base model) but Commercial CPUE is not included in the likelihood.

(Alternative 4) Survey q drift (i.e., Alt. 2) but Commercial CPUE is not included in the likelihood.

(Alternative 5) Survey and commercial q both constant: this is similar to the old IPHC CAGEAN model.

Table 1 shows features of the Base model as well as the alternatives. The differing trends in survey and commercial q are illustrated in Figure 21. The best fit, indicated by a ΔAIC score of zero is Alternative 2 (survey q drift) model. Nearly as good a fit is provided by the production model used these past three years, the survey q trendless drift (Base) model. The four other model fits are significantly worse. The exploitable biomass estimate produced by five of the models is relatively narrow, though wider than last year: between 266 and 330 M lbs. Alternative 4, which allows survey q to drift freely and is not fitted to commercial CPUE data produces a low estimate of exploitable biomass (266 M lbs). This occurs because Alternative 4 estimates survey q to be much higher than the other models. As has been the case the past two years, we select the base model (i.e., survey q trendless drift) as the production model and the coastwide exploitable biomass estimate of 318 million pounds forms the basis for apportionment among regulatory areas. Note that the apportionment actually uses an EBio value of 317 M lbs; this was the initial EBio estimate when the assessment was first fitted (prior to the hard drive failure and assessment re-creations) as it formed the basis for staff Catch Limit Recommendations. Our preference for the Base model over Alternative 2, which is favored on the basis of the AIC criterion, has to do with the rigor of the IPHC survey. A great deal of effort goes into standardizing the survey and we have no ancillary indications of long-term changes in the catchability of the survey. We will continue to monitor and analyze potential catchability trends.

Effect of the 2010 data on abundance estimates

Coastwide survey WPUE declined by 15% and commercial WPUE declined by 6% from 2009 to 20010 (Figs. 12 and 16; Appendix A tables A9 and A10). As a result, the 2010 coastwide model fit is revised downwards, by about 18%, from the estimate of abundance at the beginning of 2010 made in the 2009 assessment (Table 2). On the other hand, the 2010 fit shows an increase in abundance, of about 16%, between the beginning of 2010 and the beginning of 2011. The net result is an estimated decrease of 5% between the 2010 beginning of year exploitable biomass and the 2011 beginning of year exploitable biomass. Note the estimated biomasses for beginning of year 2011 assume no size at age change between 2010 and 2011, an assumption which may well not hold true given the ongoing decline in size at age.

Evaluation of the assessment

Quality of fits

The model predicts survey NPUE at sex/age (Fig. 22) and commercial catch at age (Fig. 23) very well. There is no apparent pattern to the residuals from the fits, although the model initially underestimates slightly the early strength of the 1987 year class. The model is successfully predicting the increasing number of fish aged 25 and older, particularly males, which are appearing in both the survey and commercial catches. The very low growth rate for male halibut means that many are not recruiting to the fishery until they are older than 25. This "plus" group is poised to increase even more in the new few years as the remains of the very large 1987 and 1988 year classes reach 25 years of age. The series of total survey and commercial CPUE are also predicted closely (Fig. 24, middle panel).

Coastwide estimates of recruitment, exploitable biomass and spawning biomass

Exploitable biomass (EBio) at the beginning of 2011 is estimated to be 318 million pounds and female spawning biomass (SBio) is estimated to be 350 million pounds. Estimated EBio is down by about 5% from the beginning of year 2010, while SBio is a bit over 6% higher than the 2010 beginning of year value estimated in the 2009 assessment. EBio and SBio are both estimated to have declined continuously between 1998 and 2007 (Fig. 24, top right panel). EBio continued to decline until 2009, the model estimates that both are now on the increase, with SBio bottoming out in 2007 and EBio bottoming out in 2009. This differs slightly from the 2009 assessment in terms of when the turnarounds in decline for both EBio and SBio began. This point is discussed more fully in the Retrospective performance section. Recruitment (measured as age-eight fish in the year of assessment) has varied between 7 and 33 million halibut since the 1988 year class, with a mean of 17.9 million. The 1989 to 1997 year classes, presently 14 to 22 years old and the main target of the commercial fishery for the past several years, are all estimated to have been below average, several of the year classes substantially below average (Fig. 24, top left panel). The sharply declining biomass over the past decade has resulted from these small year classes, in combination with reduced growth rates, replacing earlier year classes that were much larger, especially the 1987 and 1988 year classes. The projected increase in 2011 biomasses can be attributed, in large part, to the incoming 1998 through 2003 year classes that are estimated to be well above average, particularly the 1999 and 2000 year classes. The extent to which these year classes will contribute to EBio over the next few years depends on the growth rate which, as has been frequently noted, continues to decline.

Estimates of uncertainty

There are a number of ways of estimating the uncertainty associated with a given model fit and biomass estimate. They are all unsatisfactory in that they are conditioned on the correctness of the model when in fact it is the choice of one model rather than another that is the major source of uncertainty in assessments. This is well illustrated by the difference in area-specific biomass estimates between the coastwide and closed-area fits of the IPHC model as reported in past years. One standard method of illustrating uncertainty around an estimate, for a given model, is the likelihood profile. The bottom panels in Figure 24 show the likelihood profiles for both the exploitable biomass as well as the female spawning biomass. The 95% confidence interval (C.I.) for EBio is 283 to 355 million pounds, while the 95% C.I. for the female spawning biomass is 309 to 394 million pounds. Confidence intervals for the recruitment estimates were also computed and are plotted with the recruitment estimates (Fig. 24, top panel). For comparison purposes, the 95% C.I. for the alternative model fits described above are plotted in Fig. 25. The means of both EBio and SBio for all the alternative model fits, with the exception of Alternative 4, lie within the 95% C.I. of the Base (production) model estimates. Alternative 4, due to its unconstrained survey q parameter and non-use of commercial CPUE has very wide C.I.s, indicating relatively high uncertainty in the biomass estimates.

Retrospective performance

Each year's model fit estimates the abundance and other parameters for all years in the data series. One hopes that the present assessment will closely match the biomass trajectory estimated by the previous year's assessment. To the extent that it does not, the assessment is said to have poor retrospective performance.

Our assessment shows modest retrospective behavior for the last few years. Each year the assessment has revised downward the previous year's exploitable biomass estimates (Fig. 26a), meaning that biomass was overestimated then and may be overestimated now if the cause of the retrospective problem lies somewhere within the model. There is some precedent for that; the assessment models in use in the mid 1990s and the early 2000s showed strong retrospective patterns that turned out to be the result of misspecified selectivity (age- rather than length-based). There is also the possibility that the retrospective pattern is caused in some way by the external estimation of the sex composition of the commercial catch, or by the internal prediction of surface age compositions prior to 2002 through the application of an age misclassification matrix (Clark and Hare 2006). Note that the retrospective behavior of the female spawning biomass is substantially smaller than that for the EBio (Fig. 26b), indicating that the source of the behavior may be more closely linked to estimated numbers of males, whose selectivity at age has declined along with the growth rate.

Problems of this sort with the assessment machinery would manifest themselves as systematic revisions of the estimated relative strength of the year-classes present in the stock. That was true of the retrospective patterns caused by the misspecification of selectivity in the past: incoming year-classes would at first be estimated as weak because catch rates were low, but the real reason was low selectivity rather than low abundance. When they were later caught in large numbers, the estimates of relative year-class strength increased. The retrospective estimates of year class strength are plotted in Figure 26c. There is some evidence of a systematic revision of estimates of year class strength as the 1994 through 1998 year class have all trended downward for the last five assessments. The pattern does not hold for the 2000 and more recent year class strength estimates.

In 2007, a check was made using a blind projection of the assessment from 2004 to 2007. Year-class strengths and other parameters from the 2004 assessment, along with just the catches from 2005-2007 which are needed to estimate fishing mortality, were used to project the 2007 age structure and then compared to the 2007 observed age structure. That projection demonstrated that the retrospective behavior appears to be caused solely by the data and not by the assessment model (Clark and Hare 2008). We also note that the magnitude of the retrospective pattern from earlier assessments has lessened considerably over the last few years. The difference between the 2010 assessment of the last few EBios and the earlier assessments of the same EBios differ generally by less than 15%, which is generally within the error range of a good stock assessment.

Causes of retrospective behavior are notoriously difficult to diagnose. In the case of halibut, it appears to result from lower NPUE catch rates than expected, given the estimated mortality rate. This could be due, for example, to a trend in natural (or undocumented fishing) mortality, or a trend in catchability. The catchability explanation seems less likely, however, given that a model which allows catchability to have a trend produces assessment estimates that differ little from models with tightly constrained catchability. We consider it most likely that the retrospective behavior continues to derive in part, if not in whole, from the still declining growth rates. Each year, a new set of size at age data is collected and used to smooth earlier estimates of size at age. The addition of smaller sizes at age results in a reduction of the earlier estimated weights at age thus lowering EBio for the same number of fish. More important however is that as growth slows, fewer fish of the same age are selected to the gear and their lack of appearance in expected numbers forces the model to revise recruitment estimates to match the observed survey and commercial catch rates. The difference in retrospective behavior for the EBio vs. the SBbio lends credence to the growth rate change as the prime factor in the retrospective behavior. To summarize, there is ongoing retrospective behavior in the halibut assessment. The magnitude of the behavior is modest and the trend of successively lowering all earlier EBio estimates has greatly tapered off. We do not feel the retrospective behavior weakens the assessment in any way, and analyses of the recognized patterns will continue.

Harvest policy, status relative to reference points and biomass projections

The IPHC has developed, refined, and utilized a constant harvest rate policy since the 1980's. The policy was fully described in Clark and Hare (2006) and further modified as described in Hare and Clark (2008). Stated succinctly, the policy is to harvest 20% of the coastwide exploitable biomass when the spawning biomass is estimated to be above 30% of the unfished level. The harvest rate is linearly decreased towards a rate of zero as the spawning biomass approaches 20% of the unfished level. This combination of harvest rate and precautionary levels of biomass protection have, in simulation studies, provided a large fraction of maximum available yield while minimizing risk to the spawning biomass. Since the early 2000s, and similar to many fisheries management agencies, the harvest policy has incorporated a measure designed to avoid rapid increases or decreases in catch limits, which can arise from a variety of factors including true changes in stock level as well as perceived changes resulting from changes in the assessment model. The adjustment, termed "Slow Up Fast Down (SUFD)" is based on a target harvest rate of 20% but the realized rate usually a bit different (Fig. 27). The SUFD approach is somewhat different from similar phased-change policies of other agencies in that it is asymmetric around the target value, i.e., the catch limit responds more strongly to estimated decreases in biomass than to estimated increases. This occurs for two reasons: first, the assessment generally has a better information base for estimating decreasing biomass compared with increasing biomass; and second, such an asymmetric policy follows the Precautionary Approach.

This year, staff has proposed that the SUFD quota adjustment be suspended or modified to a "Slow Up Full Down" adjustment. In brief, the simulations that gave support to SUFD did not capture the current conditions faced by the stock (Hare 2011). Since implementation of the SUFD adjustment, EBio has been in a constant downward trajectory. As removals have been in excess of 20% of EBio and each subsequent EBio estimate is lower than the previous year's estimate, the target harvest rate can never be met as only 50% of the intended reduction in removals is taken. Additionally, size-at-age of halibut has continued to decline and this always affects performance of the adjustment. Staff Catch Limit Recommendations (CLR) this year are based on a "Slow Up Full Down" adjustment, i.e., one third of potential increases are taken and 100% of decreases are taken, but catch numbers are also present for the standard "Slow Up Fast Down" adjustment as well as an approach that suspends SUFD (i.e., CLR = fishery CEY).

The unfished female spawning biomass ($B_{unfished}$) is computed by multiplying spawning biomass per recruit (SBR, from an unproductive regime) and average coastwide age-six recruitment (from an unproductive regime). The recruitment scaling uses the ratio of high to low recruitments based on long term recruitment estimates from Areas 2B, 2C and 3A and applied to the current coastwide average recruitment (Clark and Hare 2006) which we believe to represent a productive regime. The SBR value, computed from Area 2B/2C/3A size at age data from the 1960s and 1970s is 118.5 lbs per age-six recruit. Average coastwide recruitment for the 1990-2001 year classes (computed at age-six) is 21.5 million, and the estimate of unproductive regime average recruitment is 6.84 million recruits. This gives a $B_{unfished}$ of 811 million pounds, a B_{20} of 162 million, a B_{30} of 243 million pounds, and the 2011 female spawning biomass value of 350 million pounds establishes $B_{current}$ as 43% of $B_{unfished}$ (Fig. 28, top panel), up from the 2010 beginning of year estimate of $B_{current}$ of 38%. The revised trajectory of SBio suggests that the female spawning biomass did drop slightly below the B_{30} level which, had it been so estimated at the time, would have triggered a reduction in the harvest rate. On an annually estimated basis, however, the stock has not been that low; it is only retrospectively that we estimate the spawning biomass to have gone below to the reference point threshold. One problem with this method of establishing reference points is that the threshold and limit are dynamic, changing each year as the estimate of average recruitment changes. In this year's calculation the very strong 2001 year class was included among the year classes used to compute average recruitment. However, due to the downward revision of several year classes in this year's assessment, the estimate of $B_{unfished}$ actually declined from the 2009 estimate. Corresponding, B_{20} and B_{30} values also dropped slightly. The projected increase in the 2010 SBio results in the new determination that $B_{current}$ is around B_{43}. The estimated age composition of the coastwide spawning biomass shows a broad range of ages including 7% females age 20 and older (Fig. 28, bottom panel). While the age distribution is certainly truncated due to the size-selective effects of fishing, it is encouraging that production of eggs is not confined to a narrow range of ages and should ensure that adequate reproductive potential remains in the ocean for the foreseeable future. On an area-by-area basis, there are some departures from this pattern, particularly in Areas 2 and 3B which show a lower percentage of older females (See the Area summaries section).

In addition to monitoring the status of the female spawning biomass relative to reference points, success at achieving the harvest rate is also documented (Fig. 29). The harvest rate over the past decade for halibut has generally been 0.20. Exceptions include a briefly increased rate to 0.225 and 0.25 between 2004 and 2006, and a lower rate of 0.15 in Areas 4B and 4CDE. On a coastwide basis, however, recent realized harvest rates have hovered around 0.25. A sizable portion of this above-target harvest rate comes from the retrospective revision of exploitable biomass estimates. Thus, while the intended rate has been around 0.20, with catch limits based on such a rate, a retrospective revision of exploitable biomass, when combined with unchanged estimates of total removals generates higher realized harvest rates. Another portion of the above-target performance results from the SUFD adjustment which prevents catch limits dropping fully to the target level indicated by contemporary estimates of exploitable biomass. Estimates of realized harvest rate among individual regulatory areas require use of an apportionment method to calculate the underlying exploitable biomass. This year staff favors the use of survey timing and hook competition adjustments to the bottom area-weighted survey WPUE (discussed below) for apportionment purposes. This was also true in 2009. Thus, new this year, we use the adjusted (and Kalman weights adjusted, discussed below) WPUE time series in most of our data comparisons, e.g., WPUE trends over time, comparisons with trawl estimates of abundance, etc. The adjusted and Kalman-weighted survey WPUEs are therefore used to apportion biomass to estimates recent realized harvest rates (Fig. 30). Realized harvest rates tend to increase from west (below or at the target harvest rate during the last decade) to east (high above target during the last decade) though the eastern area harvest rates have declined sharply towards the target harvest rate during the last few years, in part due to lower catch limits.

The annual stock assessment produces an estimate of the total number of male and female halibut, ages 6 and older, in the ocean (Fig. 31, top panel). With this set of numbers and assuming that life history parameters, such as size at age and maturity at age, remain close to what they are today, we can make biomass and yield projections for several years into the future. Because the age range of halibut in the catch is generally in the 10-20 year old range (9 to 15 for females constituting most of the catch), estimates of recruitment – which are often imprecise – should not much influence the projections. The time series of abundance shown in Figure 31 illustrate the strength of the celebrated 1987, and to a lesser extent 1988, year classes. As was true last year, the current assessment suggests that three large year classes – 1998, 1999, and 2000 – are poised to enter the exploitable biomass over the next few years. Presently, both year classes look to be larger – in terms of numbers – than the 1987 and 1988 year classes. However, it is important to note that size at age is much smaller now than it was 20 years ago. This has two important ramifications – first it means that the three strong year classes are only just beginning to reach the exploitable size range and, therefore, their true numbers in the population are still quite uncertain. Secondly, it also means that for a given number of halibut, their collective biomass will be lower (Fig. 31, bottom panel). Currently, a large fraction of males never reach the minimum size limit and thus never enter the exploitable biomass. It remains to be seen just how these year classes will develop into the exploitable component of the stock. If we assume that size at age remains at the values seen this year, then the projections for both the exploitable biomass and spawning biomass are very optimistic (Fig. 32) and indicate that the declines we have seen over the past decade are on the verge of reversing. It important to note that total removals should still remain at around 20% of the exploitable biomass and not be kept high in anticipation of future increases. The dashed indicate how harvest rates in excess of 0.20 will limit future EBio increases. As happened in the mid 1990s, when the biomass rises, higher catch limits will follow.

Comparison of assessment and trawl survey estimates of EBio

The National Marine Fisheries Service (NMFS) and Canadian Department of Fisheries and Oceans conduct bottom trawl surveys annually to triennially across most of the continental shelf of the U.S. west coast, British Columbia and Alaska. One possible method of possibly validating the coastwide assessment (and biomass partitioning) is to compare estimates produced by the two independent methods. We were able to obtain swept area estimates of abundance at length from trawl surveys that covered IPHC regulatory areas 2C westward to Area 4CDE. For Area 2B halibut are not sampled in the trawl survey and, in 2A too few halibut are caught to produce reliable estimates of abundance thus no comparisons are made for those two areas.

The NMFS conducts an annual survey on the Eastern Bering Sea shelf, a triennial survey in the Aleutian Islands and a biennial survey in the Gulf of Alaska. The NMFS trawl surveys do not precisely match IPHC regulatory areas. However, common areas can be generally defined:

Area 2C: NMFS GOA survey area Southeast matches IPHC Area 2C. Note that there is much rough/untrawlable ground in this region.

Area 3A: NMGS GOA regions Yakutat + Kodiak

Area 3B: NMFS GOA regions Chirikof + the eastern 70% of Shumagin

Area 4A: NMFS GOA Shumagin (western 30%) + AI region 799 + AI region 5699 (eastern 30%) + EBS region 50.

Area 4B: NMFS AI regions - 299 - 5699 (eastern 30%)

Area 4CDE: EBS regions - region 50.

Estimates of commercially exploitable biomass (i.e., the usual EBio) can be derived by applying the commercial selectivity curve to the swept area estimates of numbers at length and then applying the IPHC length weight relationship. For this comparison, the IPHC assessment estimates of EBio are partitioned among areas using the adjusted bottom-weighted survey WPUE index. The results are illustrated in Figure 33.

The agreement between the trawl and assessment estimates of abundance is surprisingly good for most of the areas. Areas 4A, 4B, and 4CDE are within a few percent of each other over the past few surveys. In Area 3A and 3B, the trends are generally captured though the trawl estimates of abundance tend to be lower by about a third. Area 2C, as anticipated provides the worst match. It is important to keep in mind the independence of the two estimates. The only commonality between them is use of a selectivity curve to derive EBio. The assessment estimates incorporate assumptions and estimates of factors such as catchability, natural mortality, survey apportionment, etc. The trawl estimates make an assumption about the effective area swept by the survey trawl and assumes a capture probability value of 1.0 for all sizes encountered. This latter assumption may be one reason the Area 3A and 3B trawl estimates are lower if larger halibut are able to escape the trawl and thus be under-represented in the swept area estimates.

Finally, the trawl data provide confirming evidence as regards the preponderance of smaller halibut. The large number of small halibut in the Bering Sea was earlier discussed and illustrated in Figure 10. In Figure 34, we show the swept area estimates of numbers by 10 cm length class in Area 3A. There is an unprecedented number of halibut in the 50-70 cm range. Thus, while the trawl estimate of EBio is not that large, the estimate of Total Biomass is near the top of the range over the past 15 years. As those millions of smaller halibut grow, we should see the steady increase in EBio predicted by the coastwide assessment.

Apportioning the coastwide biomass among regulatory areas

The staff believes that survey WPUE-based apportionment is the most objective and consistent method of estimating the biomass distribution among areas and therefore the best distribution of total CEY to achieve the IPHC's goal of proportional harvest among areas (see Webster et al. 2011 for a discussion of alternatives). The validity of the survey WPUE apportioning requires that survey catchability – the relationship between density and WPUE – be roughly equal among areas. Over the past few years, several checks for area differences in catchability were made (Clark 2008a, Clark 2008b, Clark 2008c, Webster 2009b) but results were inconclusive in determining differences. This year, the two same factors used in 2010 for adjusting survey WPUE were considered. Methodologies and analyses of both factors - in isolation and in combination - are contained in Webster and Hare (2010b), with results updated for this year in Webster and Hare (2011b). A brief summary of the rationale behind the two factors is presented below but details, and the adjustments themselves, are not repeated here - see Webster and Hare 2010. Following (potential) adjustment of the annual survey WPUE values, the IPHC has usually averaged the last few years' of values to smooth out annual variation in the survey. This year, a weighting scheme based on a Kalman filter approach is being recommended by staff as a superior and statistically-sound methodology (Webster 2011). This approach derives directly from discussions at the Commission's 2010 Annual Meeting and a request of staff by the Commission.

The apportionment of biomass results in a level of EBio for each regulatory area. Staff Catch Limit Recommendations are based on the fishery Constant Exploitation Yield (CEY) in each area. The fishery CEY is calculated by subtracting "other removals" from the total CEY, which itself is calculated by multiplying the area-specific target harvest rate and the area-specific EBio. For the past several years, other removals have been comprised of O32 bycatch, O32 wastage, sport catch (except in Areas 2A and 2B where it is part of the fishery CEY), and personal use/subsistence (except in Area 2A, where it is part of the fishery CEY). Bycatch and wastage mortality (BAWM) under 32 inches in length was not explicitly included in the fishery CEY calculations, but was incorporated into determination of the target harvest rate. This year, two other alternatives for inclusion of U32 BAWM into Other Removals are presented. The analysis upon which these alternatives are based is given in Hare (2011).

Adjustment factors

Hook competition. Catchability of halibut is affected by the presence of other bait takers, a process known as hook competition. If the average number of baits available to halibut varies substantially among regions, this might be a reason to adjust survey WPUE. To compute this adjustment, the return of baits by regulatory area is summed from survey data.

Timing of setline survey. The survey is designed to measure EBio at approximately the midpoint of the year in each regulatory area. Necessarily, the timing varies due to survey logistics. The timing of removals (commercial, sport and subsistence fishing, bycatch, wastage) also varies, even more substantially, among areas. It can be reasoned that an area where more of the annual removals are taken prior to our survey would "see" a smaller EBio than an otherwise identical situation where the other removals had not yet occurred. To compute this adjustment, we estimate the midpoint of the survey as well as fraction of removals prior to that time.

Time-averaging methods of adjusting survey WPUE

Equal weighting (1:1:1). This has been the default method used by the IPHC for time weighting of various factors, including survey WPUE for apportionment purposes. Under this scheme, the three most recent WPUE values are averaged, with equal weight given to each year.

Reverse weighting using Kalman weights (75:20:5). A detailed statistical analysis was conducted this year to determine whether the default three year equal weighting method used by the IPHC to weight recent survey WPUEs was optimal. The results (Webster 2011) show that, in fact, the most recent year's survey should be disproportionally weighted compared to earlier years. This result derives from the relative variances within an area in a given year compared to interannual variance. Areas with a large number of stations, such as Area 3A and 2C should, in a statistical sense, give almost no weight to any but the most recent year's WPUE value. However, several areas with greater coefficients of variation, should still give some weight to the previous couple of years. Rather than utilize a different set of weights for each area, when the weights can vary somewhat depending on the period of years considered, we selected the weighting scheme (from Area 2A) which was most inclusive of previous years' data. That scheme results in weights of 75:20:5 (recent year first).

Accounting for U32 BAWM

No inclusion in Other Removals. This has been the default method used by the IPHC for the last several years. Mortality from BAWM less than 32 inches in length is accounted for in determination of the appropriate target harvest rate.

U32/O26 BAWM is included in Other Removals. At the 2010 IPHC Annual Meeting, the Commission requested that staff develop a methodology to consistently incorporate U32/O26 removals across all sectors giving rise to mortality on this size group. The SBR analysis presented in Hare (2011) used a target SBR of 32% of the unfished level (associated with a harvest rate of

0.20 in the current harvest framework) to determine what harvest rate would result from achieving the same target SBR when including U32/O26 mortality in Other Removals from CEY. In this scenario, the target harvest rate is increased from 20% to 21.5% in all of Area 2 and Area 3A, and from 15% to 16.125% in Area 3B, and all of Area 4. All BAWM between 26 and 32 inches in length is included as part of Other Removals. The deductions are taken from total CEY in the area where the mortality occurred.

All O32 BAWM in included in Other Removals. In this scenario, the target harvest rate is increased from 20% to 23% in all of Area 2 and Area 3A, and from 15% to 17.25% in Area 3B and all of Area 4. The U32/O26 BAWM is deducted in the area where the mortality occurred, the U26 BAWM mortality is deducted in proportion to the distribution of EBio.

Methods of apportioning biomass and computing fishery CEY

Last year, the staff presented 32 methods of apportioning biomass, allowing for different combinations of WPUE adjustments, WPUE time-averaging and consideration of historical catches. Staff recommended the method that used hook competition and survey timing adjustment of bottom weighted survey WPUE, equally weighted over the prior three years. This year, fewer alternatives are presented for consideration. The potential correction for station depth distribution as well as any consideration of historical catches has been dropped. Further, we do not consider the two remaining adjustments (hook competition and survey timing) in isolation. The potential combination of WPUE adjustments and time-weighting results in four possible EBio apportionment scenarios. However, for each apportionment scenario, there are three options for treatment of U32 BAWM in determining total CEY and fishery CEY. This results in a total 12 options for calculation of total and fishery CEY:

<u>No U32 BAWM inclusion in Other Removals</u>
1. No WPUE adjustments, equal time-weighting
2. Both WPUE adjustments, equal time-weighting
3. No WPUE adjustments, reverse time-weighting
4. Both WPUE adjustments, reverse time-weighting

<u>U32/O26 BAWM included in Other Removals</u>
5. No WPUE adjustments, equal time-weighting
6. Both WPUE adjustments, equal time-weighting
7. No WPUE adjustments, reverse time-weighting
8. Both WPUE adjustments, reverse time-weighting

<u>All U32 BAWM included in Other Removals</u>
9. No WPUE adjustments, equal time-weighting
10. Both WPUE adjustments, equal time-weighting
11. No WPUE adjustments, reverse time-weighting
12. Both WPUE adjustments, reverse time-weighting

As discussed in the 2011 Staff Regulatory Proposals document contained in the Annual Meeting "Bluebook", the staff recommends Option No. 8 from above list:

- Hook + survey timing adjustment
- Reverse-weighting for time averaging
- U32/O26 BAWM included in Other Removals

The staff recommendation (Option 8) is the highlighted line in all the tables referencing apportionment. After determination of the fishery CEY, Staff catch limit recommendations (CLRs) are based on one other consideration – the “Slow Up Fast Down” adjustment, which has been used for the past decade as a means of limiting rapid increases or decreases in catch limits. This year, options are presented for continued use of the SUFD, a modification termed “Slow Up Full Down”, and non-use of a SUFD adjustment, in which case the Staff CLR is simply the fishery CEY. As these SUFD options are not part of the assessment or apportionment, they are not detailed here but are presented and discussed in the 2011 Staff Regulatory Proposals document contained in the Annual Meeting “Bluebook”.

Area-apportioned biomass, total and fishery constant exploitation yields

Area apportionment of EBio, which is not affected by choice of U32 BAWM, has four possibilities. The shares that accrue to each area are given in Table 3 and the EBio values are given in Table 4. Note that the coastwide EBio value used in these tables is 317 M lbs, and not the 318 M lbs value documented in the assessment summary above, as the staff CLRs (which were determined in November) were based on that value.

There are 12 different options for computing total and fishery CEY. Options 1-4 have a target harvest rate of 20% for Areas 2 and 3A, a target harvest rate of 15% for Area 3B and Area 4, and do not directly deduct any U32 BAWM. The Other Removals used to compute fishery CEY for these four options are given in Table 5a. Options 5-8 have a target harvest rate of 21.5% for Areas 2 and 3A, a target harvest rate of 16.125% for Area 3B and Area 4, and directly deduct U32/O26 BAWM. The Other Removals used to compute fishery CEY for these four options are given in Table 5b. Options 9-12 have a target harvest rate of 23% for Areas 2 and 3A, a target harvest rate of 17.25% for Area 3B and Area 4, and directly deduct all U32 BAWM. These options are complicated by how the U26 BAWM component is determined for each regulatory area. The U26 BAWM is distributed in proportion to the distribution of EBio, however the distribution of EBio depends on the choice of WPUE adjustments and time-weighting that are used. As there are four combinations of WPUE and time-averaging, there are four different distributions of U26 BAWM. The Other Removals used to compute fishery CEY for these four options are given in Table 5c.

Total CEY for each of the 12 options is given in Table 6 and fishery CEY for each of the 12 options is given in Table 7. The staff recommendation (Option 8) of hook competition and survey timing, reverse (Kalman weights) time-weighting, and direct deduction for U32/O26 BAWM is highlighted in the tables and is used in the summary listed in Table 8. Finally, a comparison between the 2010 and 2011 EBios and fishery CEYs is given in Table 9.

Area summaries

The coastwide assessment indicates that the exploitable biomass of halibut has declined approximately 50% over the past decade. This declining trend is seen in almost all of the area-specific survey and commercial WPUE indices, though with turnarounds apparently beginning in several areas. But the breadth and reasons behind the trends vary by area. The following is a region by region discussion of the trends and grouping of diagnostic plots to assess the past and present removals, stock trends, and prospects for each area. For each of the areas, six plots are illustrated. These include the following:

1. Total removals – illustrated by category (commercial catch, sport, etc.)
2. Abundance indices – these include the raw and adjusted/weighted survey WPUE indices and the Coastwide assessment with adjusted/weighted survey partitioning.
3. 2010 age structure of the survey catch.
4. Surplus production. Stated simply, surplus production is the amount of total catch that, when taken exactly, keeps the exploitable biomass at the same level from one year to the next. If the biomass increases, then total catch (termed "removals") was less than surplus production. If the biomass declines, then removals were greater than surplus production. Removals exceeding surplus production can lead to long-term declines in biomass; stock building results from taking less than surplus production.
5. WPUE and effort – Long-term trends in commercial fishing effort and WPUE.
6. 2010 age structure of the commercial catch.

Taken in total, these indicators convey a comprehensive picture for each area and serve as a helpful reference when discussing each regulatory area.

Area 2

Areas 2A, 2B and 2C indices are illustrated in Figures 35, 36, and 37, respectively. Between 1997 and 2006, total removals were stable in all three areas, averaging 1.6 million pounds in Area 2A, 13.5 million pounds in Area 2B, and 12.4 million pounds in Area 2C. Removals declined sharply between 2007 and 2010, in response to the change from closed-area to coastwide assessment and the resultant revised view of relative halibut abundance in Area 2. Bycatch of U32 fish in Area 2, and subsequent lost yield to constant Exploitation Yield (CEY), is estimated to be rather low, however yield lost to "upstream" bycatch of U32 halibut is estimated to be much greater than yield lost to "local" U32 bycatch (Valero and Hare 2011). Deductions to total CEY for O32 bycatch in Area 2A still represent a sizable portion of total removals, whereas O32 bycatch in Areas 2B and 2C is relatively low. Surplus production estimates suggest that removals exceeded surplus production in Area 2 for most of the past decade, though in Area 2B surplus production has exceeded removals for the past three years. Commercial effort steadily increased in Area 2A for almost a decade but dropped sharply in 2009 and again in 2010. In Areas 2B and 2C commercial effort has steadily declined for the past four to five years.

The main indices of abundance all suggest a steady decline in biomass from the mid 1990s to the late 2000s. Area 2A saw in 2009 a drop to the lowest survey WPUE on record, which had followed a drop of 50% from 2008, to an average survey catch of 8 pounds of O32 halibut per standard skate. In 2010, survey WPUE doubled, however was still the third lowest value on record. Over the past five years, Area 2A survey WPUE has averaged 16 lbs/skate, which is less than half the average for the period 1995-2000. The 15-year trend in Area 2B survey WPUE is more complex than in the rest of Area 2. The past three years have seen an average of around 88 lbs/skate which is similar to values seen between 1998 and 2004, and is 50% higher than the series low values in 2006 and 2007. However, between 1995 and 1997, Area 2B survey WPUE averaged almost 150 lbs skate. Area 2C, which declined from an average survey WPUE of around 250 lbs/skate in the late 1990s has apparently leveled off at around 100 lbs/skate over the past three years. Thus, while it does appear that Area 2C declines have been arrested, the stabilized level is the lowest on record and at least 60% lower than the highest level. Commercial WPUE tells basically the same story as survey WPUE for Areas 2A and 2C. Area 2B commercial WPUE was the second highest on record and has increased for three straight years. Survey partitioning of the coastwide biomass suggests that the beginning of year 2011 EBio is up sharply in Areas 2A and 2B, and level in 2C from 2010 values. What is still a strong concern to staff is the generally much younger age structure of fish caught in Area 2. Mean age is around 11 years of age, with little difference between males and females. In particular, the catch of females is concentrated on ages where maturity at age is low thus removing females from the population before many have the opportunity to contribute to the spawning biomass.

All the indices are consistent with a picture of a steadily declining exploitable biomass up to at least 2007. The reasons for the decline are likely twofold. The first is the passing through of the two very large year classes of 1987 and 1988. Every assessment over the past decade has shown that those two year classes were very strong in comparison to the surrounding year classes. Now that those two year classes are 20 years old, their contribution to the exploitable biomass and catches has sharply declined and the drop in biomass was to be expected as they are replaced by year classes of lesser magnitude. Secondly, realized harvest rates were substantially higher than the target rate of 20%, and for a few years were in excess of 50% (of EBio, not total biomass). Harvest rates have been brought down sharply from peak levels in Area 2B but less so in Areas 2A and 2C.

Removals have been generally larger than surplus production and that stalled rebuilding of regional stocks. The reduced removals now appear to have arrested decline of the regional biomass and, at least in Area 2B, a rebuilding to higher levels has begun. Area 2A and 2C appear stabilized but at a low level that limits available yield. There are multiple signs that two or three large year classes are set to enter the exploitable biomass, though this is dependent both on reducing harvest rates that are above target as well as on the growth rate. On that score, it is encouraging that removals have been brought down over the past few years. Realized harvest rates remain above target in all of Area 2 but are closer to target than at any time in the past decade.

Area 3

Areas 3A and 3B indices are illustrated in Figures 38 and 39, respectively. While these two areas occupy the current central area of distribution of the halibut stock, they have substantially different exploitation and biomass histories over the past 10-20 years.

Area 3A removals, both the total as well as the individual components (commercial, sport, bycatch) have been relatively stable over the past 15 years. Commercial effort has also seen relatively little variation. During the past decade when WPUE indices were falling sharply coastwide, Area 3A generally showed the most stability. However, Area 3A survey WPUE has now shown five consecutive years of decline and the 2010 value of 117 lbs/skate is by far the lowest on record and is about 40% of the level seen in the late 1990s. Commercial WPUE is also at its lowest point since the change from “J” to “C” hooks in 1984 and is at about 66% of its late 1990s level. Paralleling the declines in survey and commercial WPUE, EBio has declined steadily in 3A since 2005.

Area 3B saw a large increase in removals beginning in 1996 which peaked in 2002; removals have dropped sharply since. Commercial fishing effort more than tripled in the seven years after 1996 and then declined modestly over the past four years, before increasing again beginning in

2008 and continuing through 2010. We estimate that removals greatly exceeded surplus production between 1998 and at least 2007. Commercial and survey WPUE are at 31% and 21%, respectively, of their average level between 1997 and 1999. Area 3A has a much broader spectrum of ages in the population than is seen in Area 2. Average age for females in survey catches is 13 and for males is 16 years of age. Area 3B, however, is more similar to Area 2 in age distribution than to Area 3A.

For a long time, Area 3A had the appearance of being the most stable of the IPHC regulatory areas. The area has been fully exploited for many decades and there is a wealth of data detailing its population dynamics. The area also sits at the current center of halibut distribution and it appears that emigration is roughly equal to immigration. Like Area 2, Area 3A benefited from the very large year classes of 1987 and 1988 and the slow decline in exploitable biomass is the result of those year classes dying off. The biomass remains by far the largest of any of the regulatory areas, however the sharp declines of the past several years are a sign that exploitation rates may be too high, though we are not yet considering Area 3A as an "area of particular concern". Should this trend not reverse soon, we may reconsider applying that designation. Until the biomass decline has ended, recommended catch limits will trend downwards in Area 3A.

The situation in Area 3B is one that has concerned us for several years. Area 3B was relatively lightly fished until the mid 1990s. With the introduction of a regular survey, quotas were incrementally increased from 4 million pounds to a high of 17 million pounds. Predictably, catch rates declined steadily. Our view of Area 3B was that the area had an accumulated "surplus" biomass that could be (and was) taken but the level of catches was not sustainable. Removals were brought down to around 10 million pounds however the WPUE indices continue to drop sharply. The level of commercial effort expended to take the CEY is at an all time high and increasing. The age distribution of the population is not broad and reflects one of an area fished at a much higher rate than is sustainable, or where both recruitment and emigration are also high. Like Area 4, Area 3B is a net (though smaller) exporter of halibut as emigration is larger than immigration. It is paramount that the ongoing decline in Area 3B be arrested - until that is accomplished, the true level of productivity in Area 3B cannot be estimated. Using a lower harvest rate in Area 3B is a precautionary move and one that has seen success in Area 4. We also note that while the recommended target harvest of 0.15 was accepted for Area 3B in 2010, application of the SUFD adjustment resulted in a realized harvest rate closer to 0.20.

Area 4

Areas 4A, 4B, and 4CDE indices are illustrated in Figures 40, 41, and 42, respectively. The three areas have roughly similar commercial exploitation histories over the past decade and show generally similar trends. In all three areas, commercial catches increased from around 1.5 million pounds to around 4-5 million pounds between 1996 and 2001. All three areas have since declined to 2-3 million pounds though the trajectories differ. The target harvest rate is currently 0.15 in all of Area 4, with the change from 0.20 beginning in 2004 in 4B, 2006 in 4CDE and 2008 in 4A. Commercial effort mirrored the rise in removals from 1996-2001, however the drop in effort was not nearly as sharp as the drop in catches, and the drop in commercial WPUE is evident in the time series. Survey WPUE declined around 70% between the mid1990s and mid 2000s. All three areas have shown increases in recent years, with the turnarounds occurring immediately after the cut in the harvest rate in each area. All three areas, however, showed a decline in 2010. The recent increases in WPUE, which reflect slow increases in EBio as estimated by the coastwide assessment, are evidence that the western portion of the stock, which is a net exporter of halibut, is best served by a lower harvest rate than that in the eastern areas. As the stock builds up, removals will also increase. There is evidence in both the assessment and the trawl surveys that extremely large numbers of halibut, in the 50-80 cm size range, are found in Area 4 and should continue to add substantially to the exploitable biomass over the next several years.

There are a couple of other observations that should be made about Area 4. The biggest concern, as regards productivity and sustainability of halibut, is the level of bycatch mortality. Most of the O32 bycatch in Area 4 most likely affects future yield within Area 4 itself. Over the past decade, O32 bycatch has averaged 3-4 million pounds resulting in an annual yield loss comparable to that level. On the other hand, U32 bycatch - which has also been on the order of 3-4 million pounds annually - results in a greater yield loss due to its smaller size and large numbers of killed halibut. Some potentially large fraction of yield loss, however is to areas "downstream" of Area 4 given migration of fish beyond at which they become vulnerable to fishing (Valero and Hare 2011). For most the 2000s, removals exceeded surplus production in all three subareas of Area 4. It would appear that situation has reversed though it is probably too early to make a definitive declaration. Encouragingly, the age distributions in Area 4 are the broadest of any of the IPHC regulatory areas. Thus, Area 4 not only contributes to the spawning biomass in a ratio exceeding its removals, it is also a reservoir of older females which can be a valuable commodity for a fish population.

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Table 1. Alternative coastwide model fits. The AIC value is in relative units compared to the model with the lowest AIC score.

Model	Number of parameters	Δ AIC	Exploitable Biomass (Mlb)
Base	180	+2	318
Alternative 1	167	+234	287
Alternative 2	180	0	295
Alternative 3	166	+84	318
Alternative 4	166	+82	266
Alternative 5	153	+599	330

Table 2. Effect of the 2010 data on coastwide abundance estimates.

Area	2010 ebio 2009 assessment Data as of 11/09	2010 ebio 2010 assessment Data as of 11/10	2011 ebio 2010 assessment Data as of 11/10
Coastwide assessment:	334	275	318

Table 3. Shares of exploitable biomass by area according to various apportionment methods.

WPUE adjustment	Time weighting	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
None	Equal	0.9%	12.1%	7.5%	34.7%	15.2%	7.4%	8.5%	13.7%	100.0%
Both	Equal	1.6%	11.1%	7.4%	36.3%	18.9%	7.2%	5.9%	11.6%	100.0%
None	Reverse	1.1%	13.3%	8.3%	32.0%	14.8%	7.7%	7.9%	15.0%	100.0%
Both	Reverse	2.1%	12.9%	7.9%	34.5%	18.1%	6.7%	5.1%	12.7%	100.0%

Table 4. Exploitable biomass by area according to various apportionment methods.

WPUE adjustment	Time weighting	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
None	Equal	2.997	38.250	23.874	109.841	48.066	23.583	26.992	43.397	317.000
Both	Equal	5.115	35.205	23.490	115.028	59.859	22.980	18.604	36.720	317.000
None	Reverse	3.447	42.246	26.235	101.310	46.780	24.447	24.887	47.649	317.000
Both	Reverse	6.632	40.893	25.051	109.395	57.318	21.248	16.141	40.323	317.000

Table 5a. Other removals in detail, used for options with no direct deduction for U32 BAWM

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Sport catch[1]	0.341	1.092	2.057	5.727	0.040	0.042	0.000	0.000	9.299
O32 bycatch	0.199	0.109	0.214	0.951	0.445	0.438	0.279	1.566	4.201
Personal use	0.030	0.405	0.458	0.329	0.026	0.034	0.001	0.027	1.310
O32 wastage	0.001	0.019	0.009	0.020	0.010	0.007	0.003	0.013	0.082
Total [2]	**0.200**	**0.533**	**2.738**	**7.027**	**0.521**	**0.521**	**0.283**	**1.606**	**13.429**

Table 5b. Other removals in detail, used for options with direct deduction for U32/O26 BAWM

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Total from Table 5a	0.200	0.533	2.738	7.027	0.521	0.521	0.283	1.606	13.429
U32/O26 BAWM	0.276	0.315	0.319	2.135	1.213	0.337	0.111	0.909	5.615
Total	**0.476**	**0.848**	**3.057**	**9.162**	**1.734**	**0.858**	**0.394**	**2.515**	**19.044**

Table 5c. Other removals in detail, used for options with direct deduction for all U32 BAWM

		2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Total from Table 5b		**0.476**	**0.848**	**3.057**	**9.162**	**1.734**	**0.858**	**0.394**	**2.515**	**19.044**
U26 BAWM										
None	Equal	0.036	0.454	0.284	1.304	0.571	0.280	0.321	0.515	3.765
Both	Equal	0.061	0.418	0.279	1.366	0.711	0.273	0.221	0.436	3.765
None	Reverse	0.041	0.502	0.312	1.203	0.556	0.290	0.296	0.566	3.765
Both	Reverse	0.079	0.486	0.297	1.299	0.681	0.252	0.192	0.479	3.765
Totals										
None	Equal	**0.512**	**1.302**	**3.341**	**10.467**	**2.304**	**1.138**	**0.715**	**3.031**	**22.809**
Both	Equal	**0.537**	**1.266**	**3.336**	**10.528**	**2.444**	**1.131**	**0.615**	**2.951**	**22.809**
None	Reverse	**0.517**	**1.350**	**3.369**	**10.365**	**2.289**	**1.148**	**0.690**	**3.081**	**22.809**
Both	Reverse	**0.555**	**1.334**	**3.355**	**10.461**	**2.414**	**1.110**	**0.586**	**2.994**	**22.809**

[1] The sport catch value listed here include the GHL values (i.e. not the projected sport catches) of 0.788 M lbs in Area 2C and 3.65 M lbs in Area 3A. The projected guided sector sport catches for 2011 are 1.279 M lbs (for a total of 2.548 M lbs) in Area 2C and 2.992 M lbs (for a total of 5.069 M lbs) in Area 3A.

[2] Totals do not include sport catch in Areas 2A and 2B, nor personal use in Area 2A, as these are counted as part of the fishery CEY.

Table 6. Total CEY (in M lbs) by area according to various apportionment options. Area-specific target harvest rates are listed above each regulatory area.

No U32 BAWM inclusion in Other Removals											
	WPUE	**Time**	0.20	0.20	0.20	0.20	0.15	0.15	0.15	0.15	**<0.20**
Option	**adjustment**	**weighting**	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4CDE**	**Total**
1	None	Equal	0.599	7.650	4.775	21.968	7.210	3.537	4.049	6.510	56.298
2	Both	Equal	1.023	7.041	4.698	23.006	8.979	3.447	2.791	5.508	56.492
3	None	Reverse	0.689	8.449	5.247	20.262	7.017	3.667	3.733	7.147	56.212
4	Both	Reverse	1.326	8.179	5.010	21.879	8.598	3.187	2.421	6.048	56.649
U32/O26 BAWM included in Other Removals											
	WPUE	**Time**	0.215	0.215	0.215	0.215	0.16125	0.16125	0.16125	0.16125	**<0.215**
Option	**adjustment**	**weighting**	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4CDE**	**Total**
5	None	Equal	0.644	8.224	5.133	23.616	7.751	3.803	4.352	6.998	60.520
6	Both	Equal	1.100	7.569	5.050	24.731	9.652	3.706	3.000	5.921	60.729
7	None	Reverse	0.741	9.083	5.641	21.782	7.543	3.942	4.013	7.683	60.428
8	Both	Reverse	1.426	8.792	5.386	23.520	9.242	3.426	2.603	6.502	60.897
All U32 BAWM included in Other Removals											
	WPUE	**Time**	0.23	0.23	0.23	0.23	0.1725	0.1725	0.1725	0.1725	**<0.23**
Option	**adjustment**	**weighting**	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4CDE**	**Total**
9	None	Equal	0.689	8.798	5.491	25.263	8.291	4.068	4.656	7.486	64.743
10	Both	Equal	1.176	8.097	5.403	26.456	10.326	3.964	3.209	6.334	64.966
11	None	Reverse	0.793	9.717	6.034	23.301	8.069	4.217	4.293	8.219	64.644
12	Both	Reverse	1.525	9.405	5.762	25.161	9.887	3.665	2.784	6.956	65.146

Table 7. Fishery CEY (in M lbs) by area according to various apportionment options. Area-specific harvest rates are listed above each regulatory area.

No U32 BAWM inclusion in Other Removals											
	WPUE	**Time**	0.20	0.20	0.20	0.20	0.15	0.15	0.15	0.15	**<0.20**
Option	**adjustment**	**weighting**	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4CDE**	**Total**
1	None	Equal	0.399	7.117	2.037	14.941	6.689	3.016	3.766	4.904	42.869
2	Both	Equal	0.823	6.508	1.960	15.979	8.458	2.926	2.508	3.902	43.063
3	None	Reverse	0.489	7.916	2.509	13.235	6.496	3.146	3.450	5.541	42.783
4	Both	Reverse	1.126	7.646	2.272	14.852	8.077	2.666	2.138	4.442	43.220
U32/O26 BAWM included in Other Removals											
	WPUE	**Time**	0.215	0.215	0.215	0.215	0.16125	0.16125	0.16125	0.16125	**<0.215**
Option	**adjustment**	**weighting**	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4CDE**	**Total**
5	None	Equal	0.168	7.376	2.076	14.454	6.017	2.945	3.958	4.483	41.476
6	Both	Equal	0.624	6.721	1.993	15.569	7.919	2.848	2.606	3.406	41.684
7	None	Reverse	0.265	8.235	2.583	12.620	5.810	3.084	3.619	5.168	41.383
8	Both	Reverse	0.950	7.944	2.329	14.358	7.509	2.568	2.208	3.987	41.853
All U32 BAWM included in Other Removals											
	WPUE	**Time**	0.23	0.23	0.23	0.23	0.1725	0.1725	0.1725	0.1725	**<0.23**
Option	**adjustment**	**weighting**	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4CDE**	**Total**
9	None	Equal	0.178	7.495	2.150	14.797	5.987	2.930	3.941	4.455	41.934
10	Both	Equal	0.640	6.831	2.066	15.928	7.881	2.833	2.594	3.383	42.157
11	None	Reverse	0.276	8.367	2.665	12.936	5.780	3.069	3.603	5.138	41.835
12	Both	Reverse	0.971	8.071	2.407	14.700	7.473	2.555	2.198	3.962	42.337

Table 8. Estimates of 2011 exploitable biomass and CEY from the 2010 assessment

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2011 exploitable biomass	2.997	38.250	23.874	109.841	48.066	23.583	26.992	43.397	317.000
Proportion of total	0.021	0.129	0.079	0.345	0.181	0.067	0.051	0.127	1.000
Harvest rate	0.215	0.215	0.215	0.16125	0.16125	0.16125	0.16125	0.16125	<0.215
Total CEY	1.426	8.792	5.386	23.520	9.242	3.426	2.603	6.502	60.897
Other removals [2, 3]	0.476	0.848	3.057	9.162	1.734	0.858	0.394	2.515	19.044
2011 fishery CEY [2]	**0.950**	**7.944**	**2.329**	**14.358**	**7.509**	**2.568**	**2.208**	**3.987**	**41.853**

Notes:

[1] "Coastwide assessment" refers to the coastwide model fit with survey apportionment of the total biomass estimate among regulatory areas, and corrected for estimated rates of hook competition.

[2] "Other removals" comprise O32 and U32/O26 wastage, O32 and U32/O26 bycatch, personal use, and in most areas sport catch. In Areas 2A and 2B sport catch is included in fishery CEY rather than in other removals.

[3] Assumes GHL of 0.788 M lbs. in Area 2C and 3.650 M lbs. in Area 3A.

Table 9. Estimates of 2010 exploitable biomass and CEY from the 2009 assessment (2009 RARA, p. 114).

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2010 exploitable biomass	4.1	30.4	25.1	131.0	65.7	21.7	19.9	36.2	334
Proportion of total	0.012	0.091	0.075	0.392	0.197	0.065	0.059	0.108	1.000
Harvest rate	0.20	0.20	0.20	0.20	0.15	0.15	0.15	0.15	<0.20
Total CEY	0.819	6.076	5.020	26.192	9.859	3.251	2.979	5.431	59.627
Other removals [2]	0.246	0.522	2.630	7.913	0.950	1.131	0.229	1.610	15.231
2009 fishery CEY [2]	**0.573**	**5.554**	**2.390**	**18.279**	**8.909**	**2.120**	**2.750**	**3.821**	**44.396**
2010 catch limit	**0.810**	**7.500**	**4.400**	**19.990**	**9.900**	**2.330**	**2.160**	**3.580**	**50.670**

Notes:

[1] "Coastwide assessment" refers to the coastwide model fit with survey apportionment of the total biomass estimate among regulatory areas. "Area assessments" are the closed-area model fits.

[2] "Other removals" comprise O32 wastage, O32 bycatch, personal use, and in most areas sport catch. In Areas 2A and 2B sport catch is included in fishery CEY rather than in other removals.

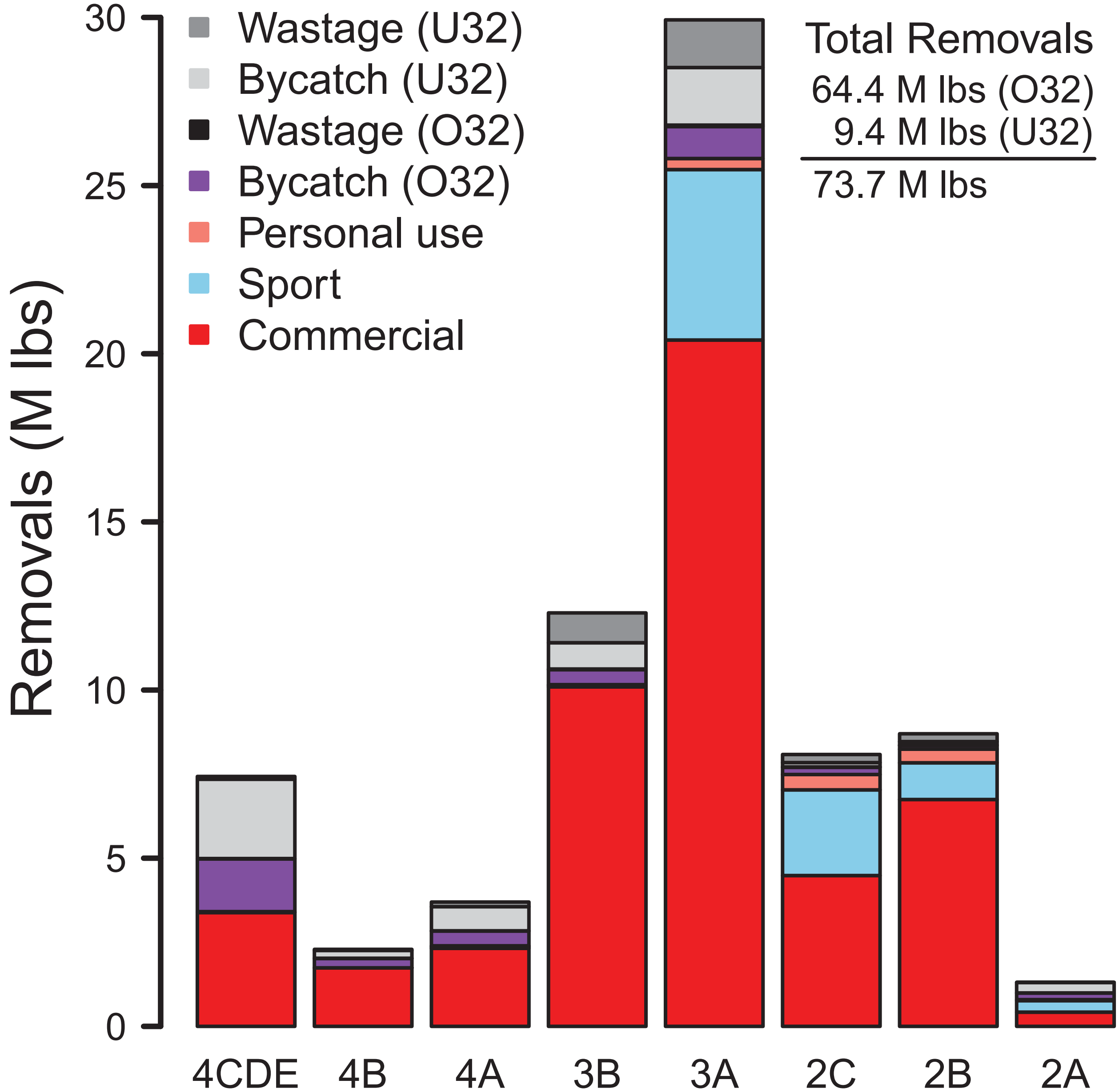


Figure 1. Total removals by type and regulatory area for 2010.

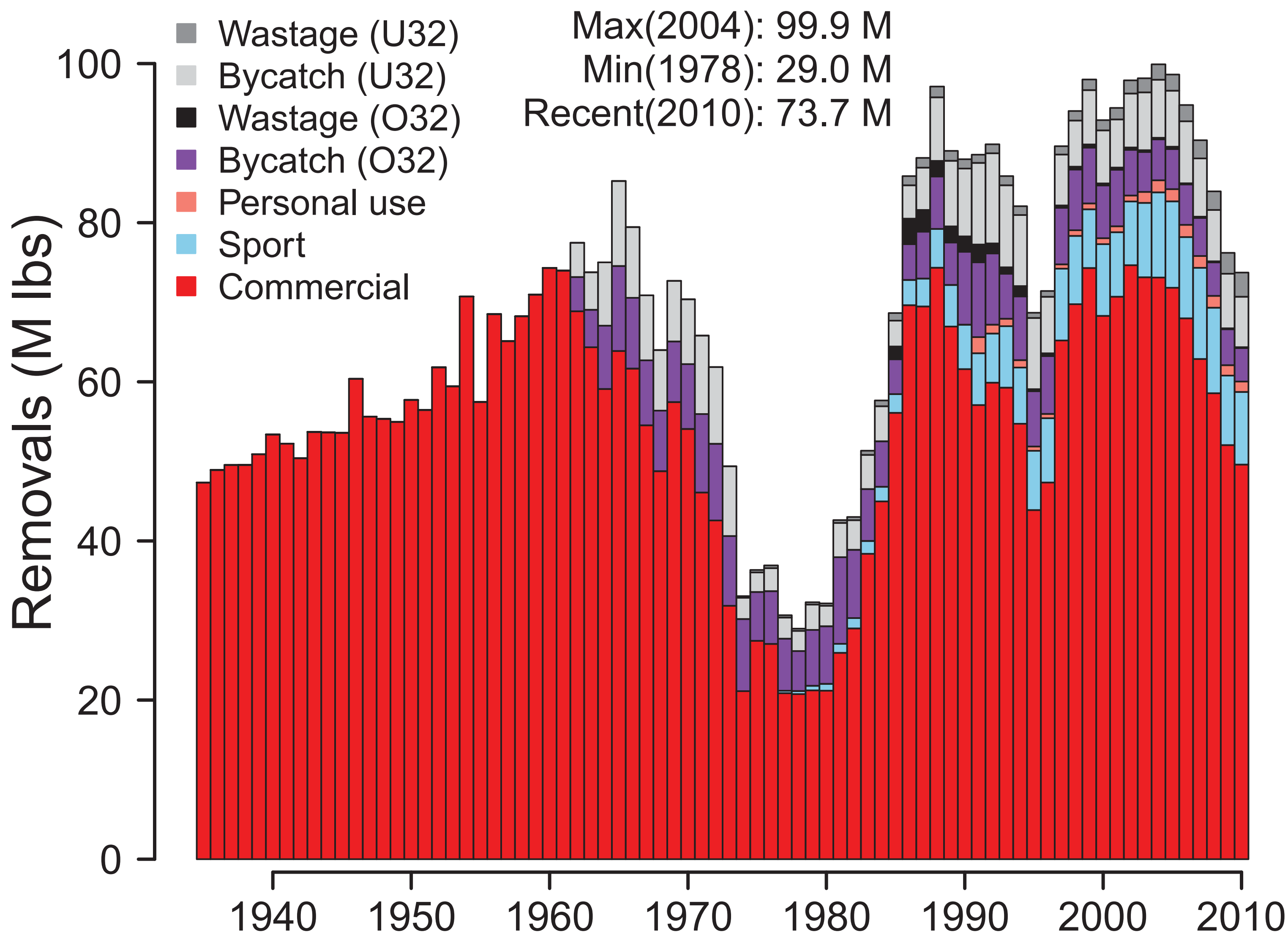


Figure 2. Total removals coastwide for the period 1935-2010. Year and amount of minimum, maximum, and most recent removals are also listed.

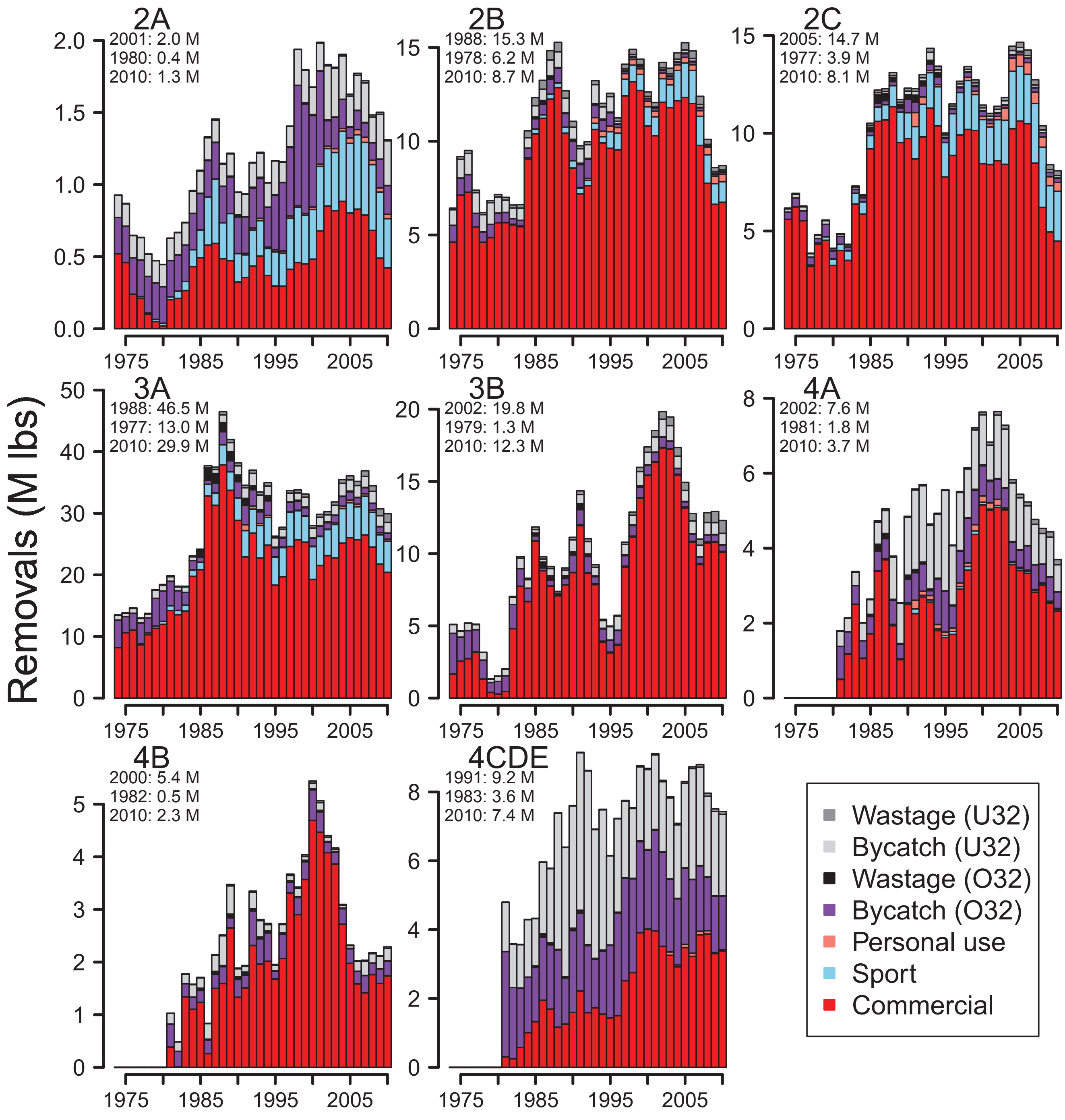


Figure 3. Total removals of halibut, by Regulatory Area, 1974-2010. The two U32 categories (bycatch and wastage, colored in gray) are not included in the total removals listed in Table A1). Year and amount of minimum, maximum, and most recent removals are listed in the upper left corner for each regulatory area.

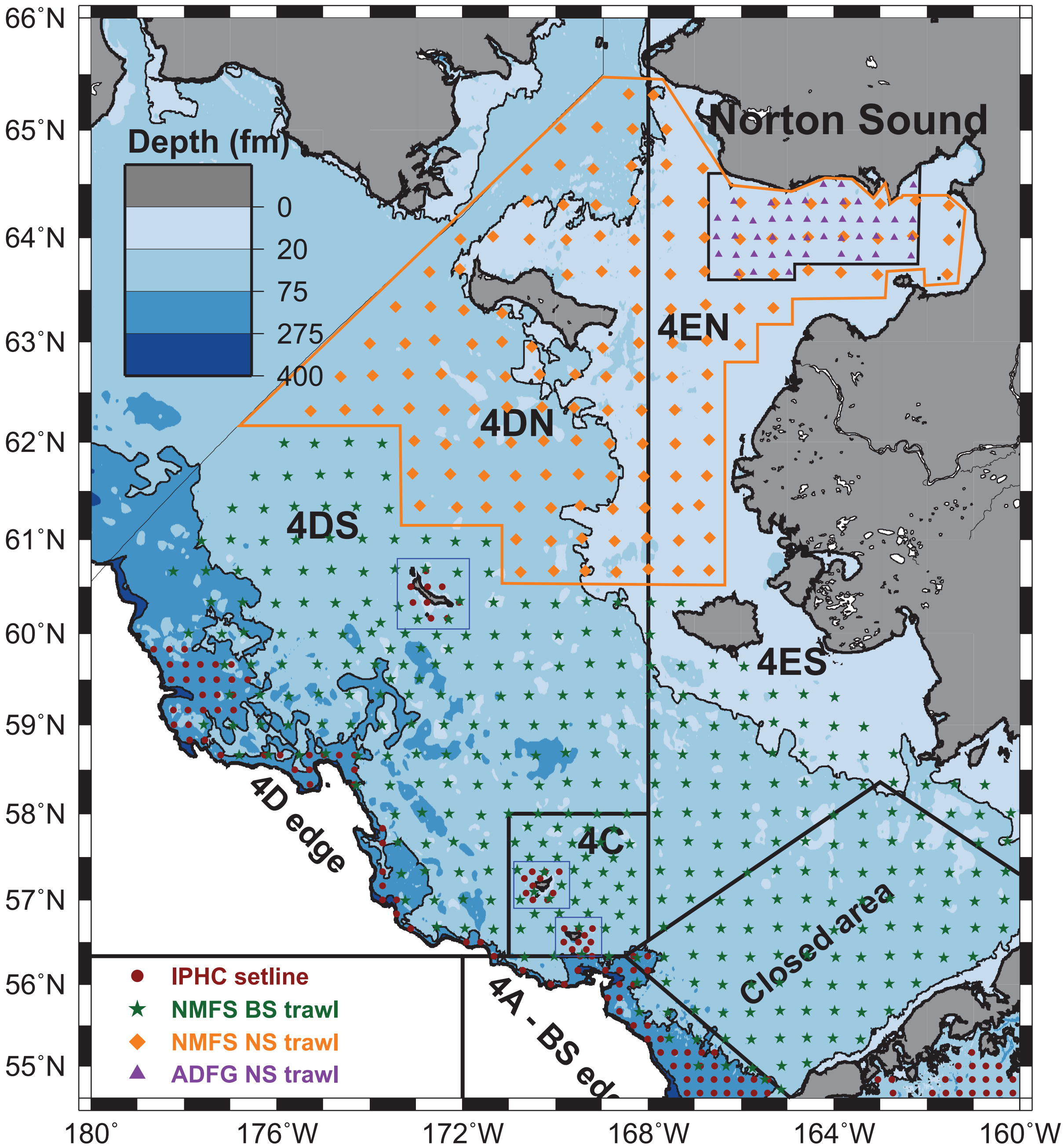


Figure 4. Summary of information sources and subareas utilized to construct a dataset for Area 4CDE. See text for details.

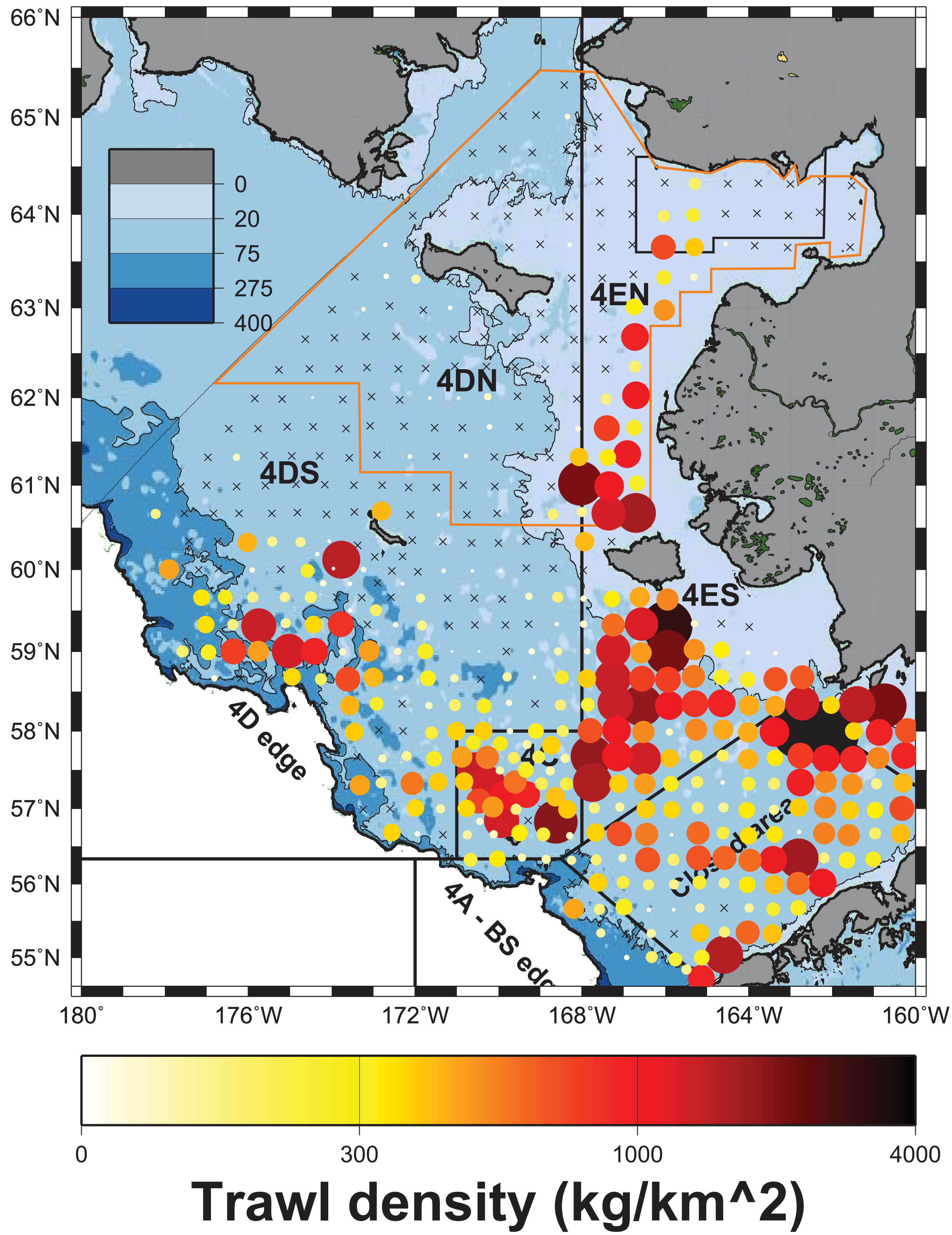


Figure 5. Catch rates of halibut (all sizes) at survey stations in the 2010 NMFS expanded Eastern Bering Sea trawl survey. The size of the circles is proportional to catch rate (kg/km^2) and conveys the same information as the coloring of the circles. Stations with zero catch are indicated by an "x".

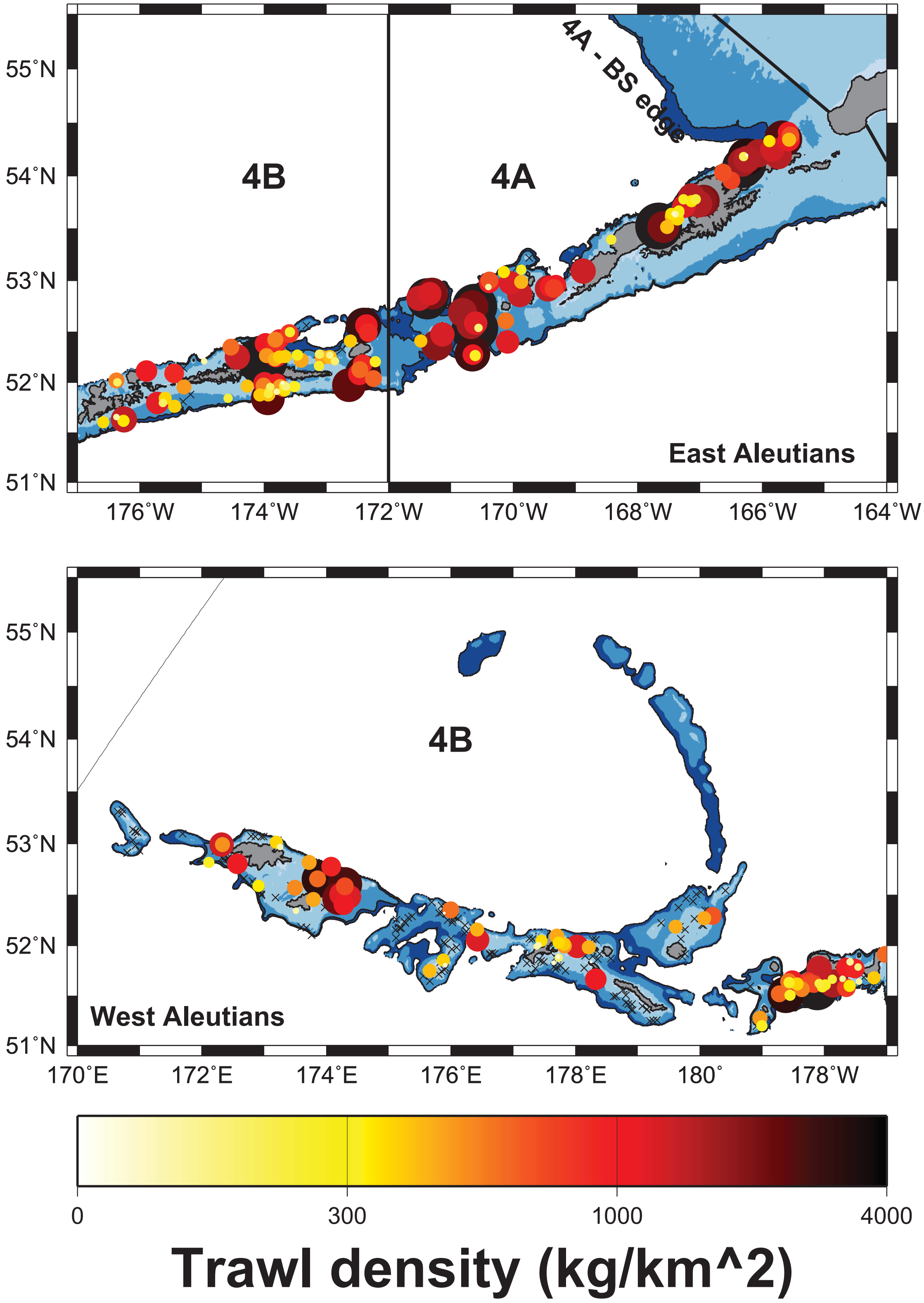


Figure 6. Catch rates of halibut (all sizes) at survey stations in the 2010 NMFS triennial Aleutian Islands trawl survey. The size of the circles is proportional to catch rate (kg/km²) and conveys the same information as the coloring of the circles. Stations with zero catch are indicated by an "x".

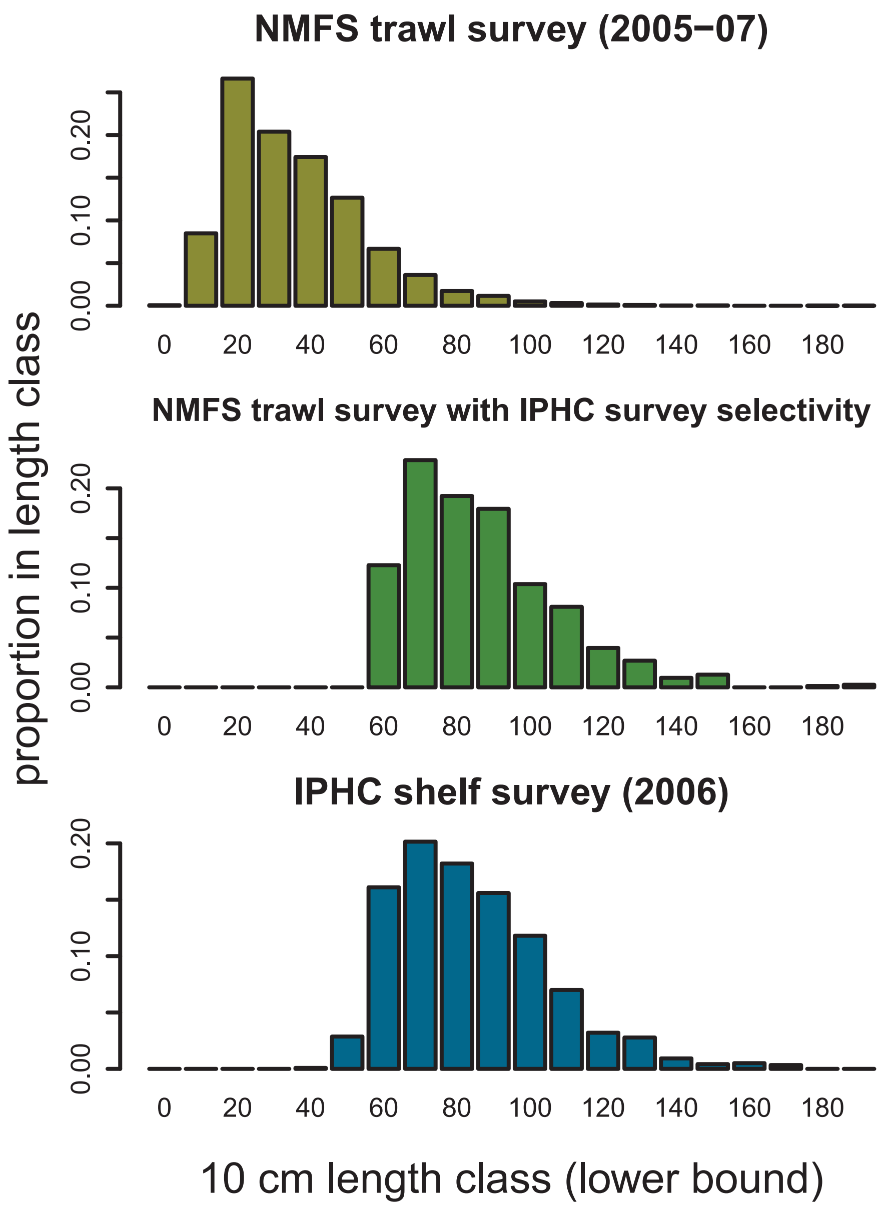


Figure 7. Comparison of NMFS trawl survey and IPHC length frequency compositions. The top panel shows the length frequency composition for all halibut caught by the NMFS trawl gear for years 2005-7. the middle panel shows the frequency distribution of lengths after the IPHC setline selectivity curve is applied to raw counts. The bottom panel illustrates the length composition of halibut in the 2006 IPHC shelf survey.

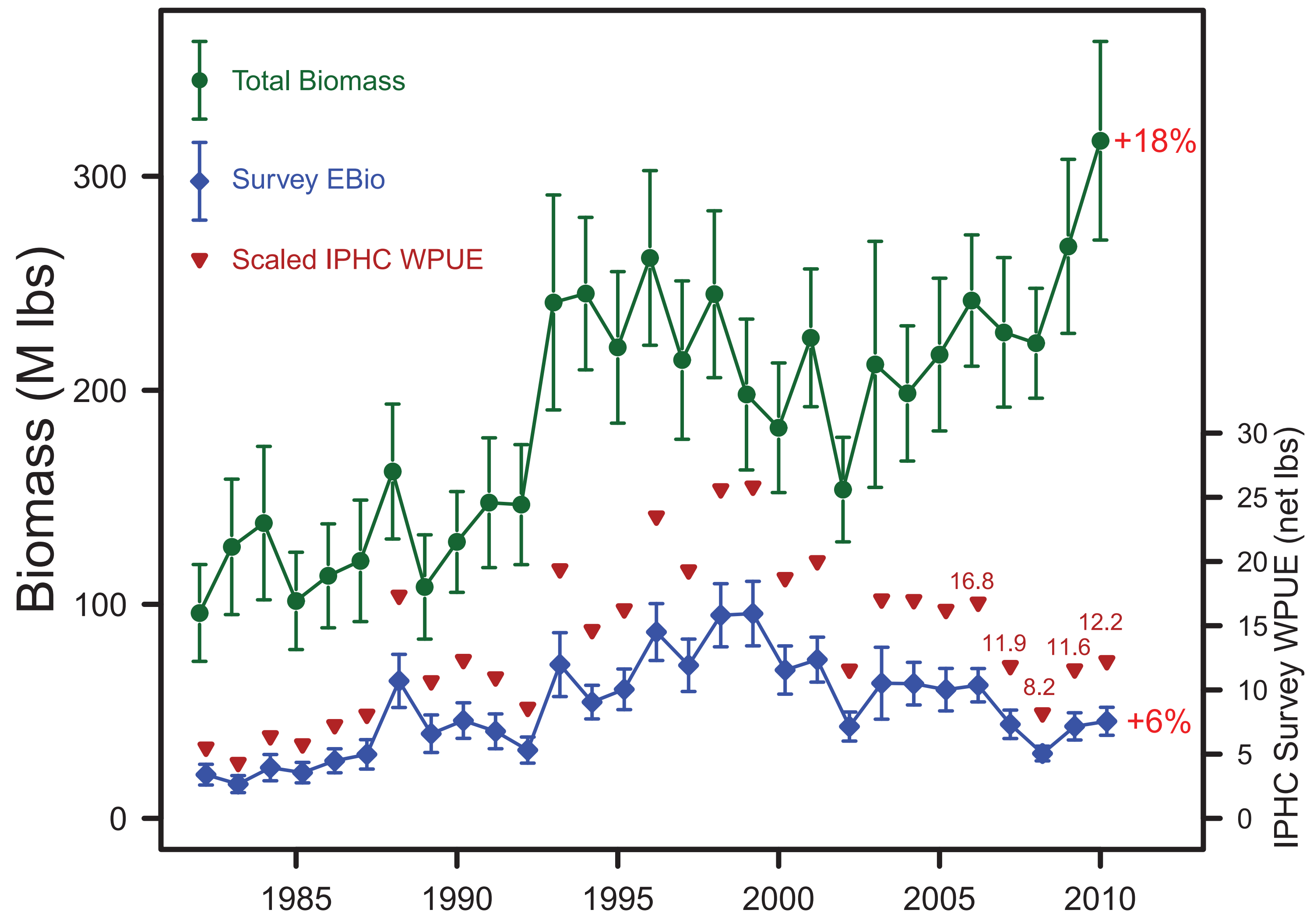


Figure 8. Swept-area estimates of halibut abundance from the NMFS EBS trawl survey. The red dots and error bars represent mean and 95% confidence interval for the total abundance; the blue diamonds are error bars represent mean and 95% confidence interval for abundance with survey selectivity applied to the total biomass (termed survey EBio). The inverted purple triangles represent the estimated density of O32 halibut (per standardized skate of gear) across the shelf; this index is scaled to the survey EBio trend (see text for full details). The percentages show the change in the index values from 2009 to 2010.

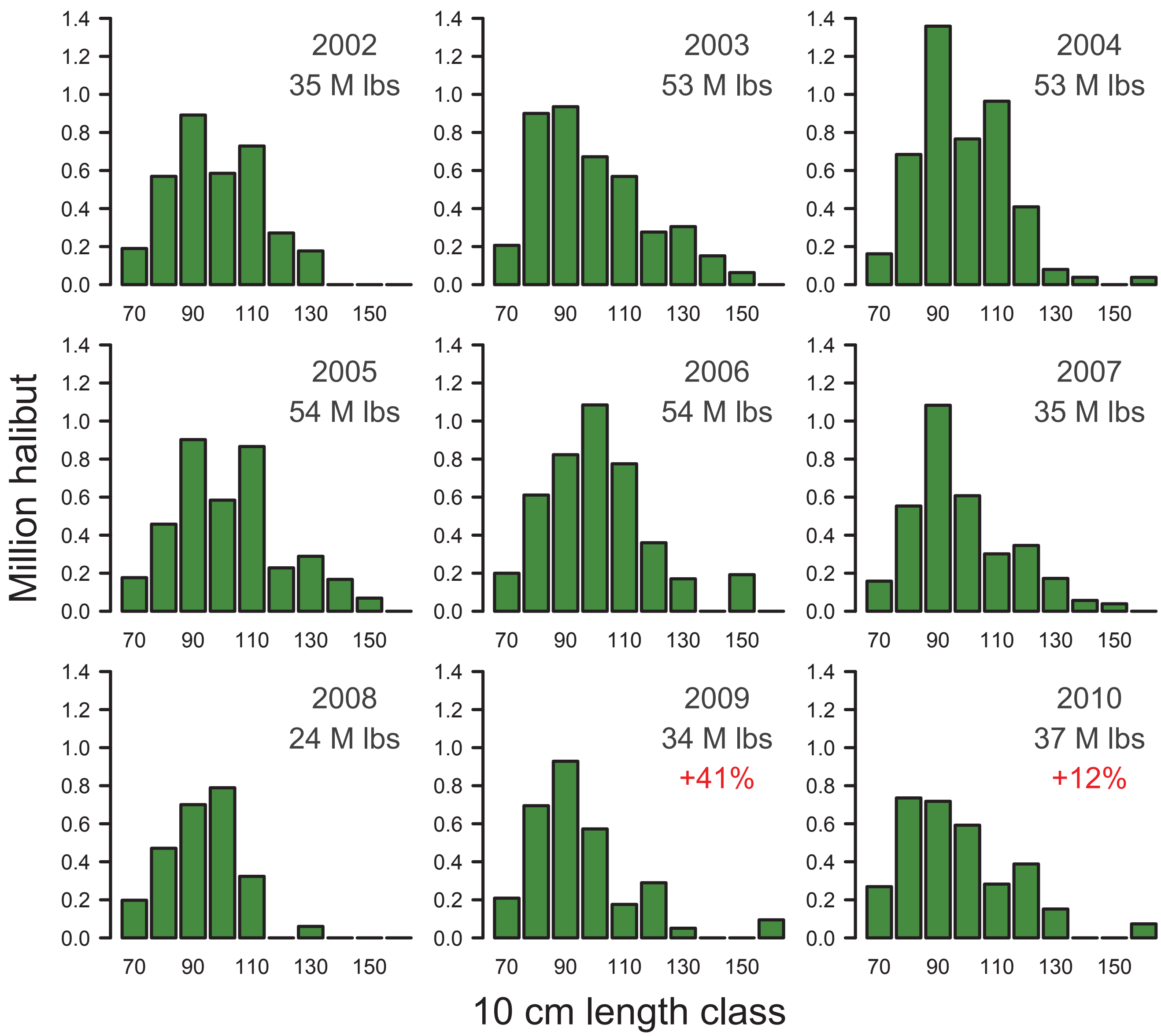


Figure 9. Swept area estimates of halibut EBio, by 10-cm length interval, in the NMFS EBS trawl survey for the years 2002 to 2010. Increases in estimated EBio over the previous year are indicated in the 2009 and 2001 plots. Exploitable numbers of halibut are illustrated by the darker bars. The percentages show the change in the index values from 2009 to 2010.

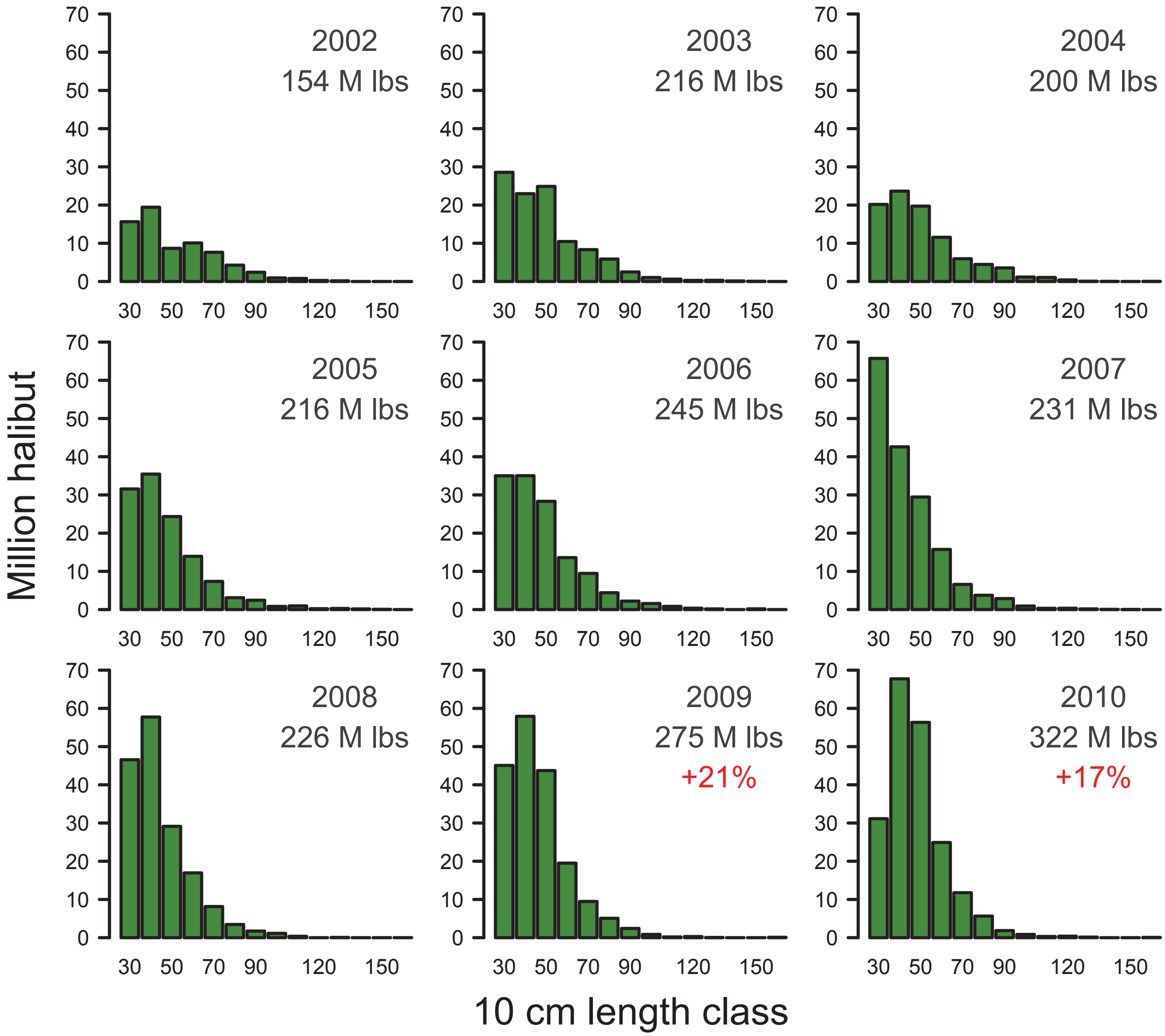


Figure 10. Swept area estimates of halibut TBio, by 10-cm length interval, in the NMFS EBS trawl survey for the years 2002 to 2010. Increases in estimated EBio over the previous year are indicated in the 2009 and 2001 plots. Exploitable numbers of halibut are illustrated by the darker bars. The percentages show the change in the index values from 2009 to 2010.

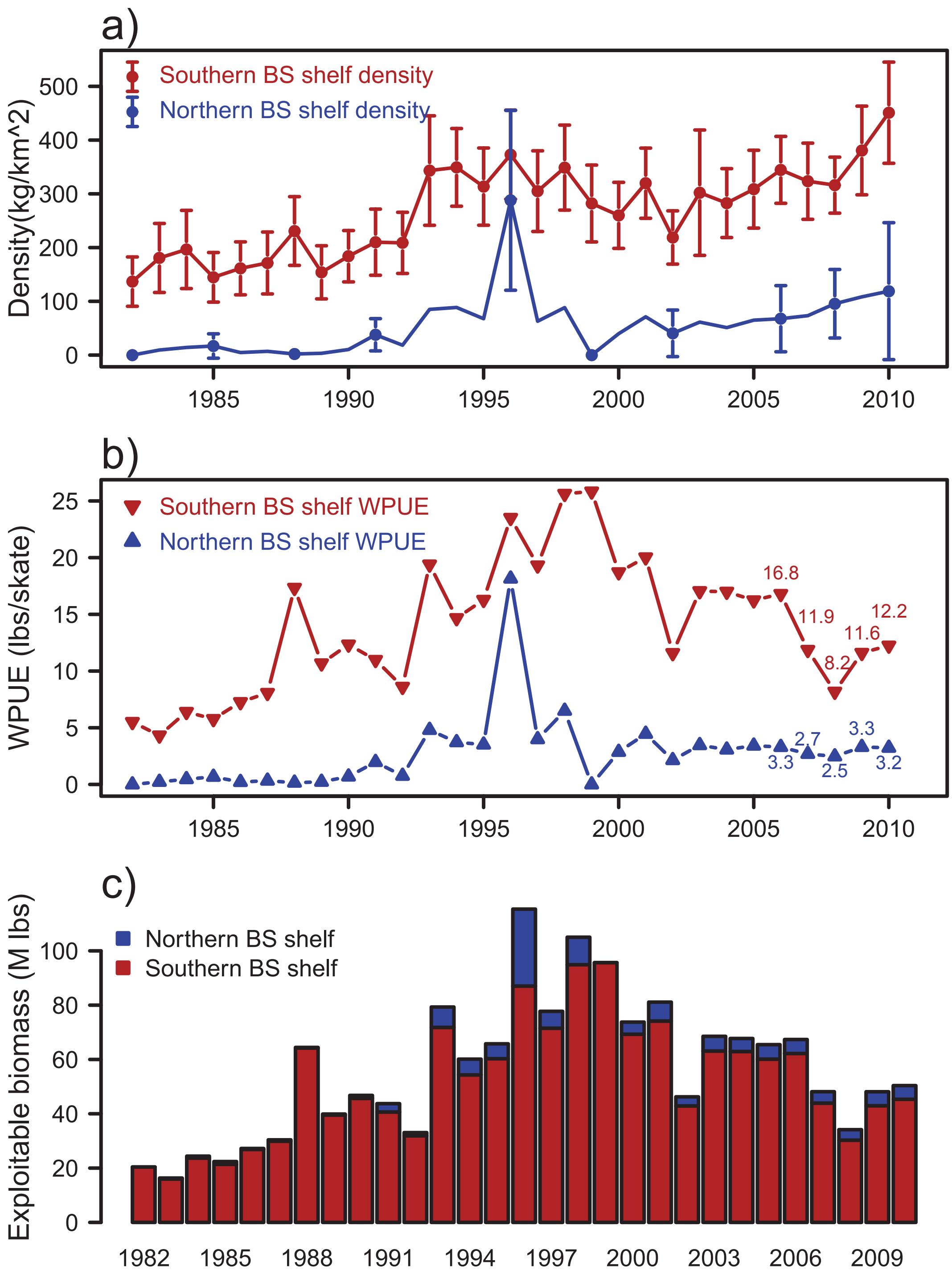


Figure 11. Time series used to construct an estimate of halibut biomass in the northern shelf region of Area 4CDE, termed Area 4N. See text for details.

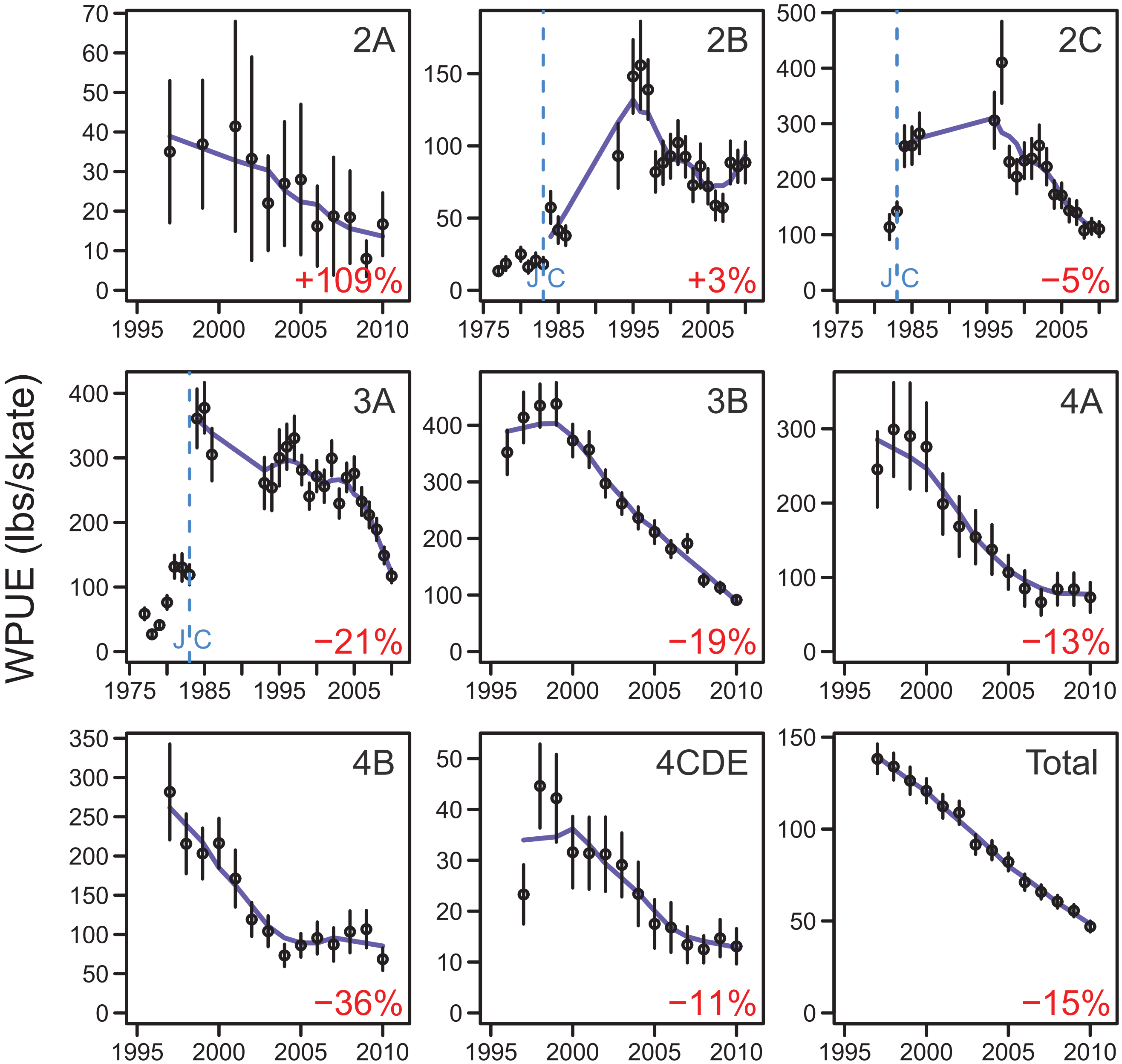


Figure 12. Survey WPUE (weight of O32 halibut per standardized skate of gear) by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The thick line is a smoother to illustrate trend; it is not an assessment model fitted to the WPUE data. The total is computed by area-weighting the individual area WPUE time series. Note that the timeline for Areas 2B, 2C, and 3A differ from the other areas and extends back to 1975. The data points prior to 1984 are from the "J" hook era. The percentages show the change in the index values from 2009 to 2010.

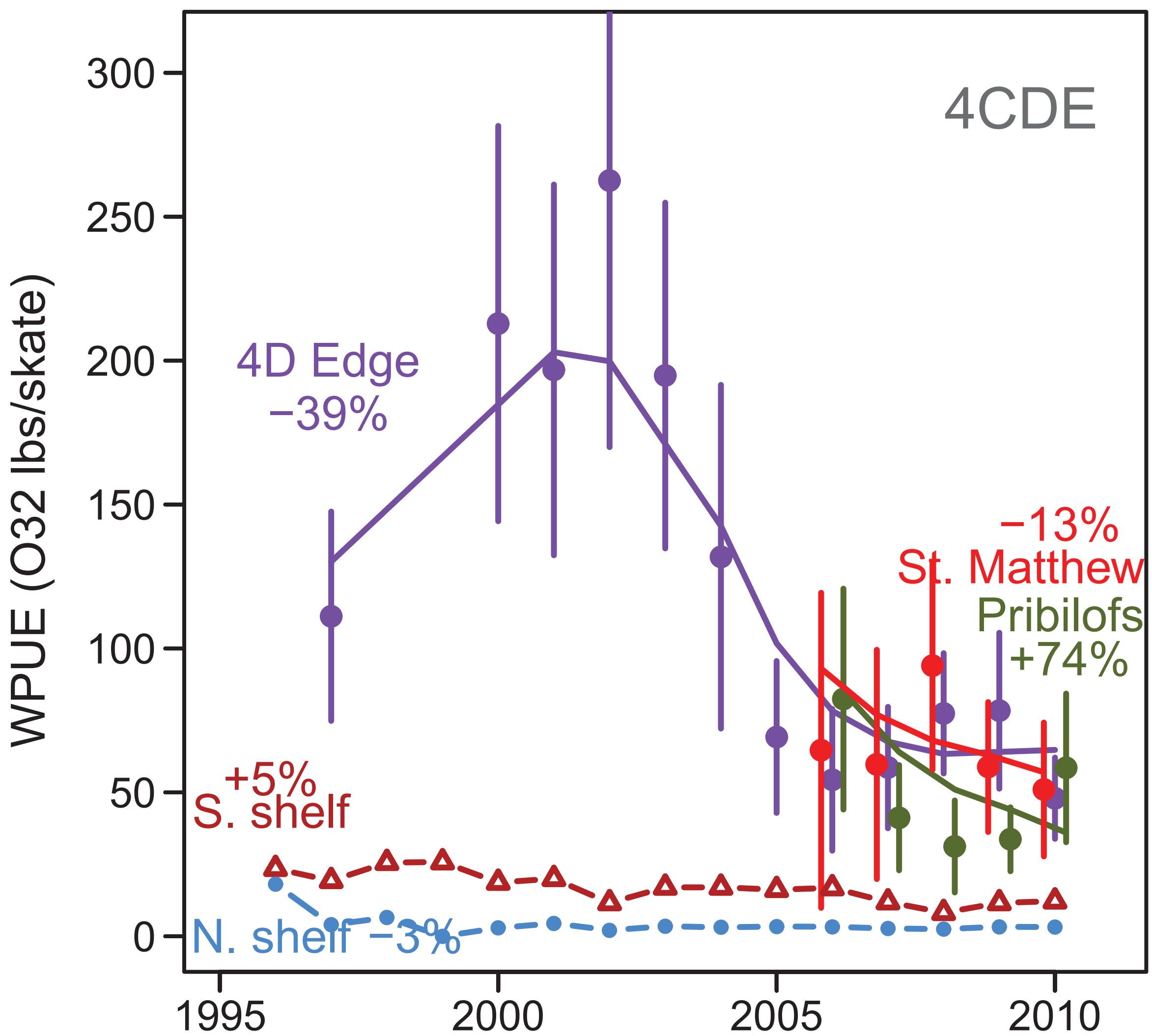


Figure 13. The five subarea components used to construct the WPUE survey index for Area 4CDE. The percentages show the change in the index values from 2009 to 2010.

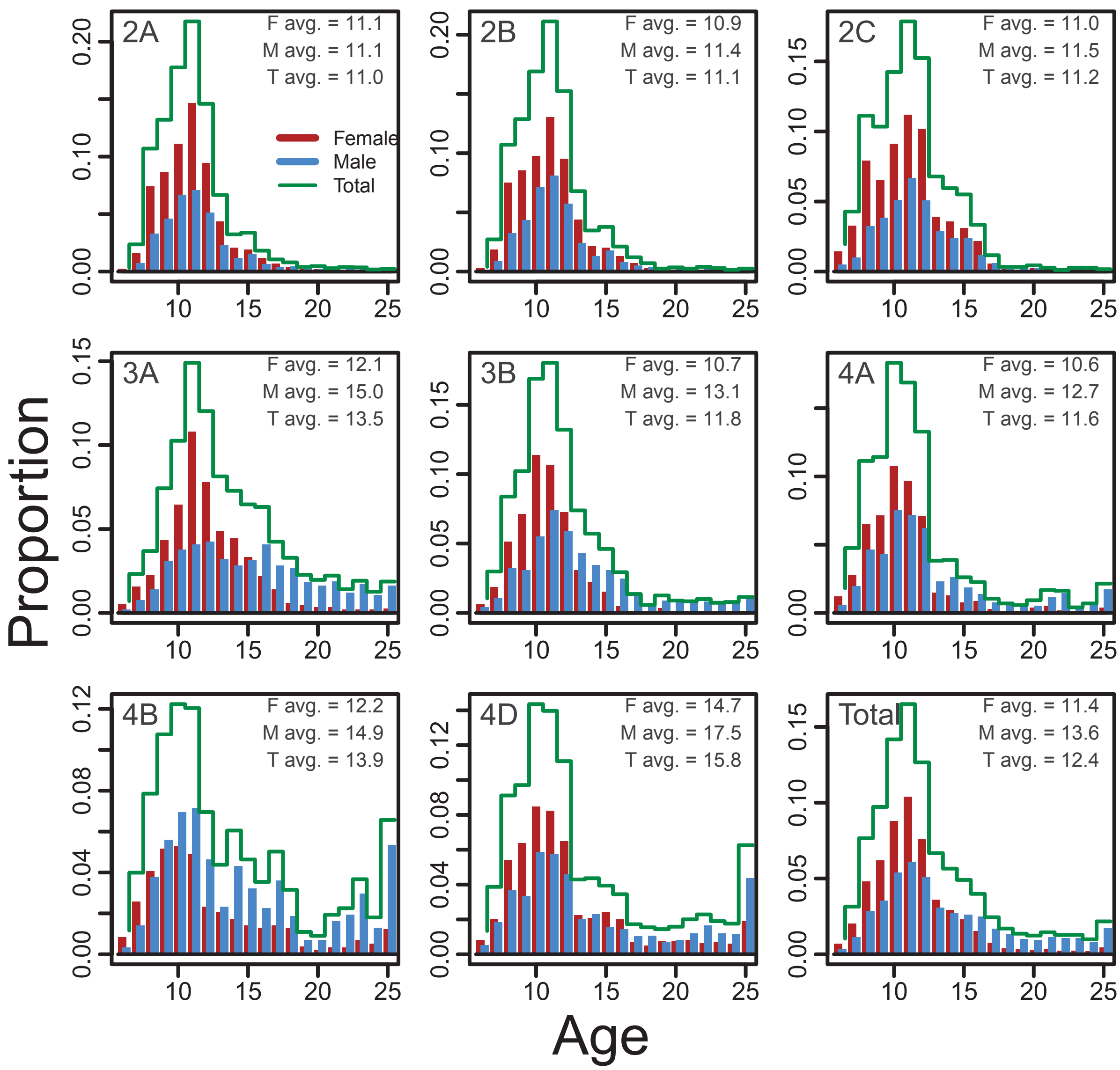


Figure 14. Regulatory area sex and age compositions from halibut taken in the 2010 IPHC stock assessment survey. Proportions are shown for females (red bars), males (blue bars) and sexes combined (green line). Average age is also shown, with "T" indicating Total (sexes combined).

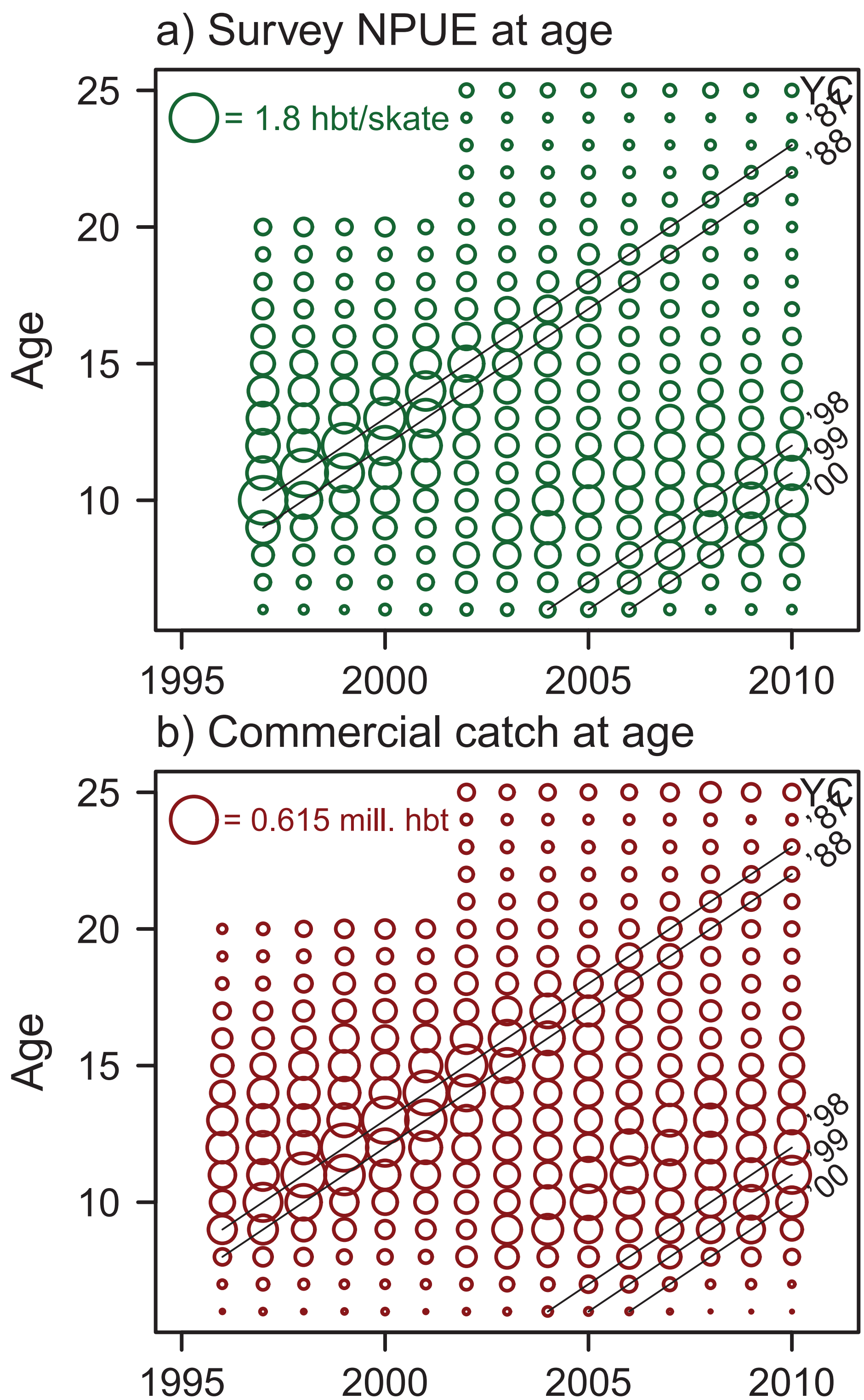


Figure 15. Bubble plots showing age-specific survey catch rate of halibut (both sexes combined, panel a), and catch at age (both sexes combined) in the commercial fishery (panel b).

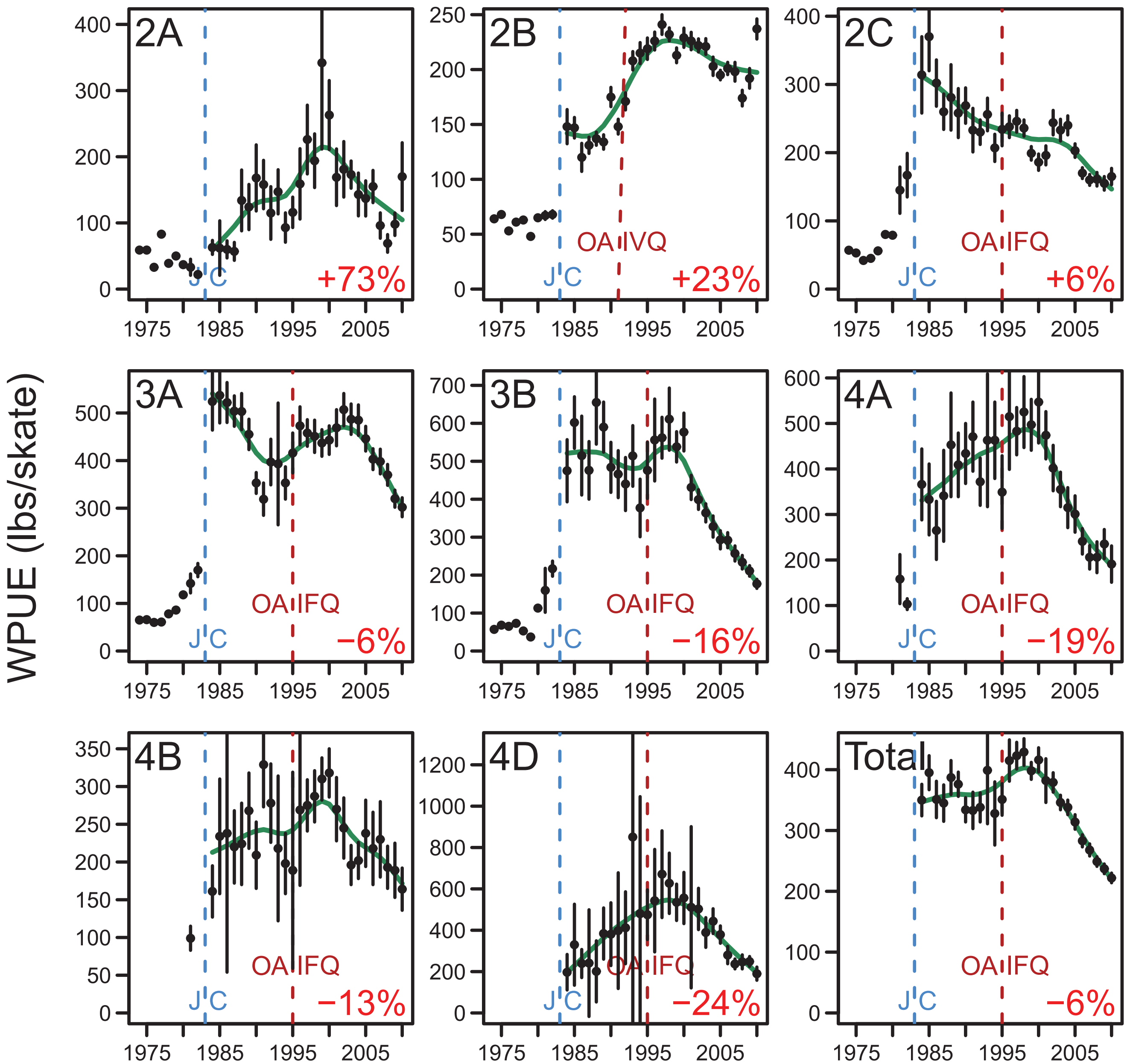


Figure 16. Commercial WPUE by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray/green line is a smoother to illustrate trend; it is not an assessment model fit to the CPUE data. The total is computed by area-weighting the individual area WPUE time series. The dashed vertical lines indicate transitions between J and C hook, between open access (OA) and Individual Vessel Quotas in Area 2B, and between open access and Individual Fishing Quotas in Areas 2C, 3 and 4. The percentages show the change in the index values from 2009 to 2010.

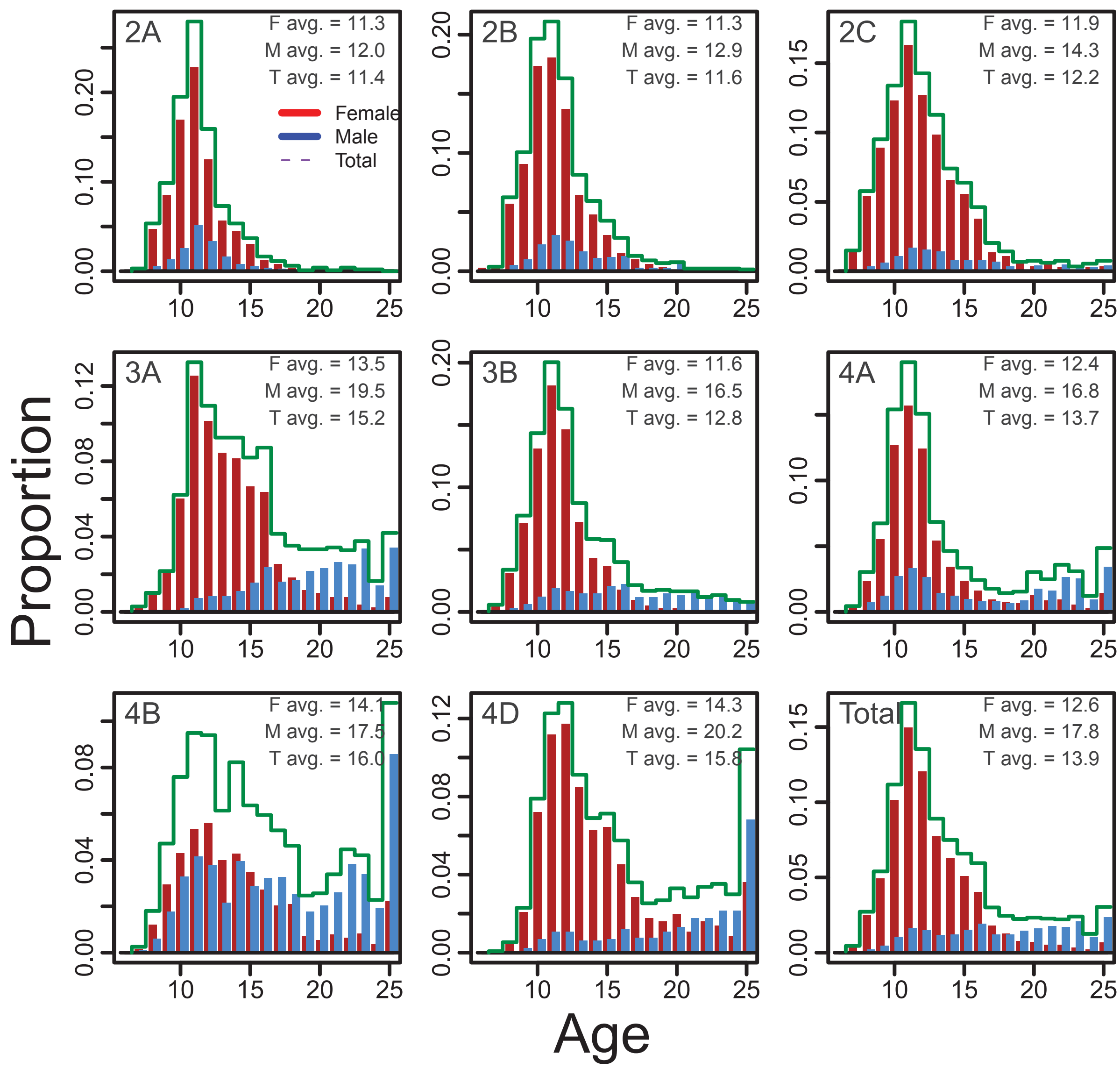


Figure 17. Regulatory area sex and age compositions from halibut sampled from commercial landings. Proportions are shown for females (red bars), males (blue bars) and sexes combined (green line). Average age is also shown, with "T" indicating Total (sexes combined).

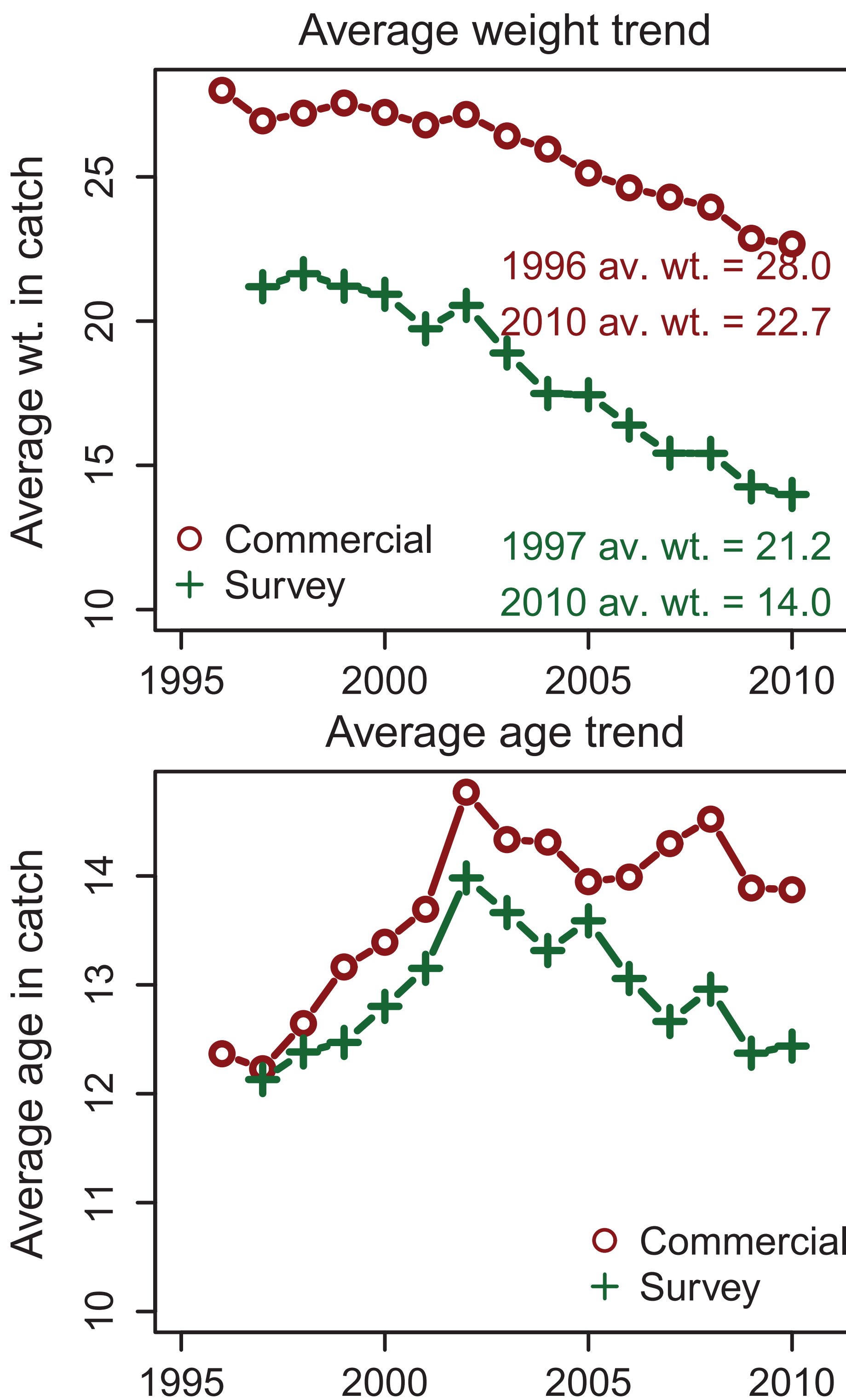


Figure 18. Average weight (panel a) and average weight (panel b) trends for the coastwide halibut stock for 1996 to 2010.

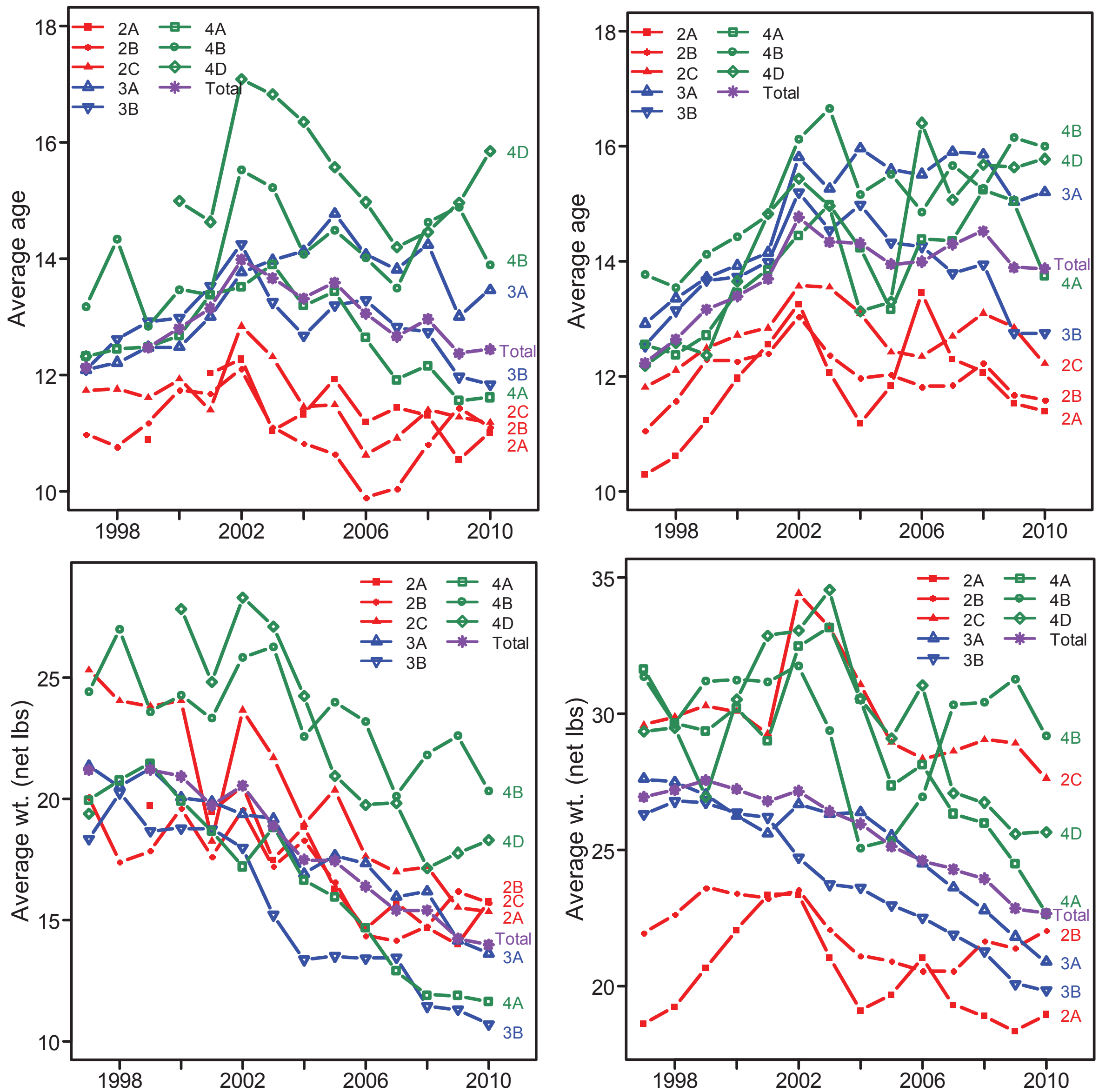


Figure 19. Trends in average age (top panels) and average weight (bottom panels) in survey catches (left panels) and commercial catches (right panels).

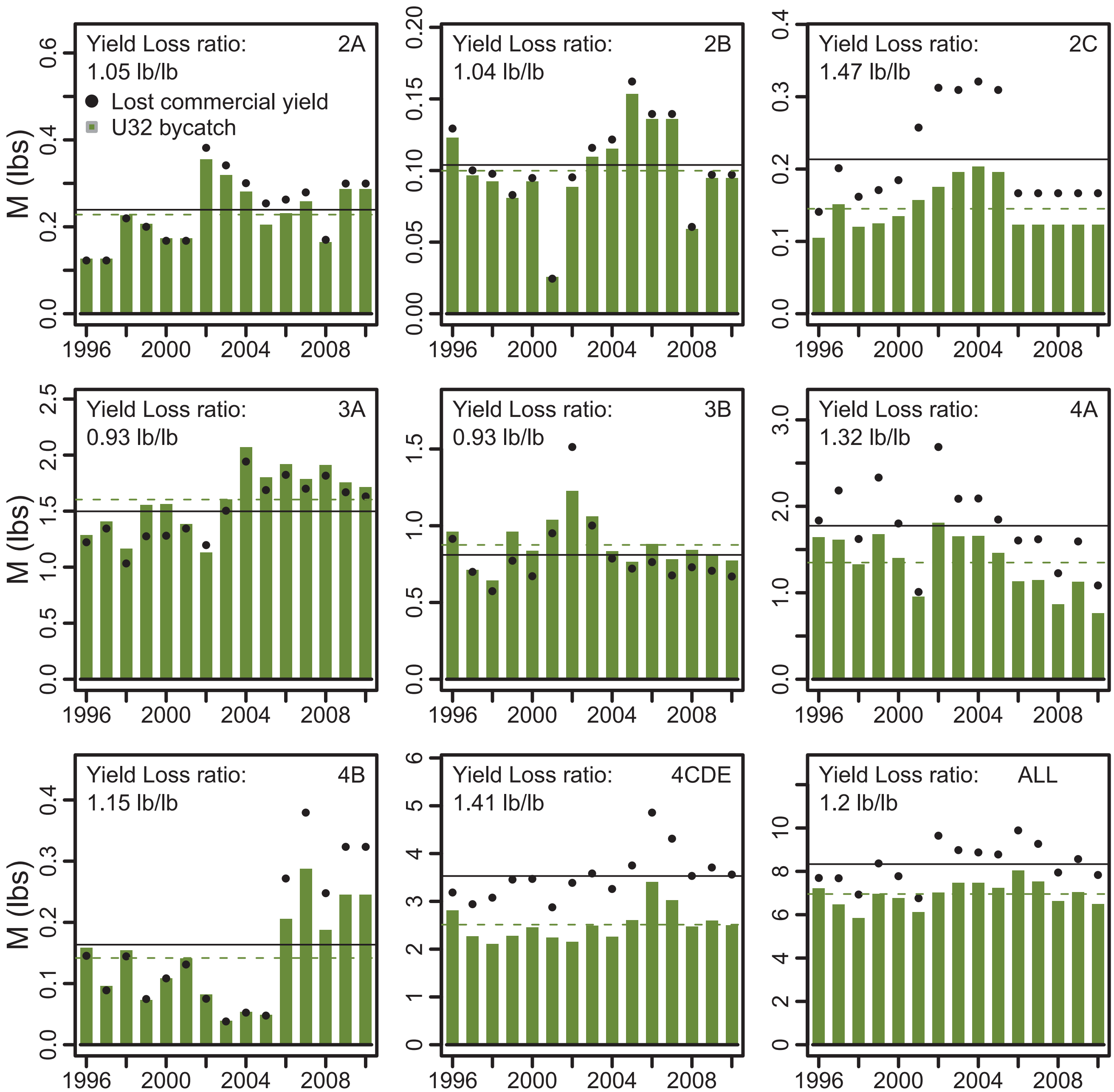


Figure 20. Illustration of impact of under-32 inch bycatch on future yield by regulatory area, without accounting for migration. The bars show estimated annual bycatch mortality, dots show estimated lost yield. Lost yield is estimated using growth models developed individually for each regulatory area. The dashed horizontal line is the average U32 bycatch over the 1996-2010 period; the solid horizontal line is the average yield loss over the same time frame.

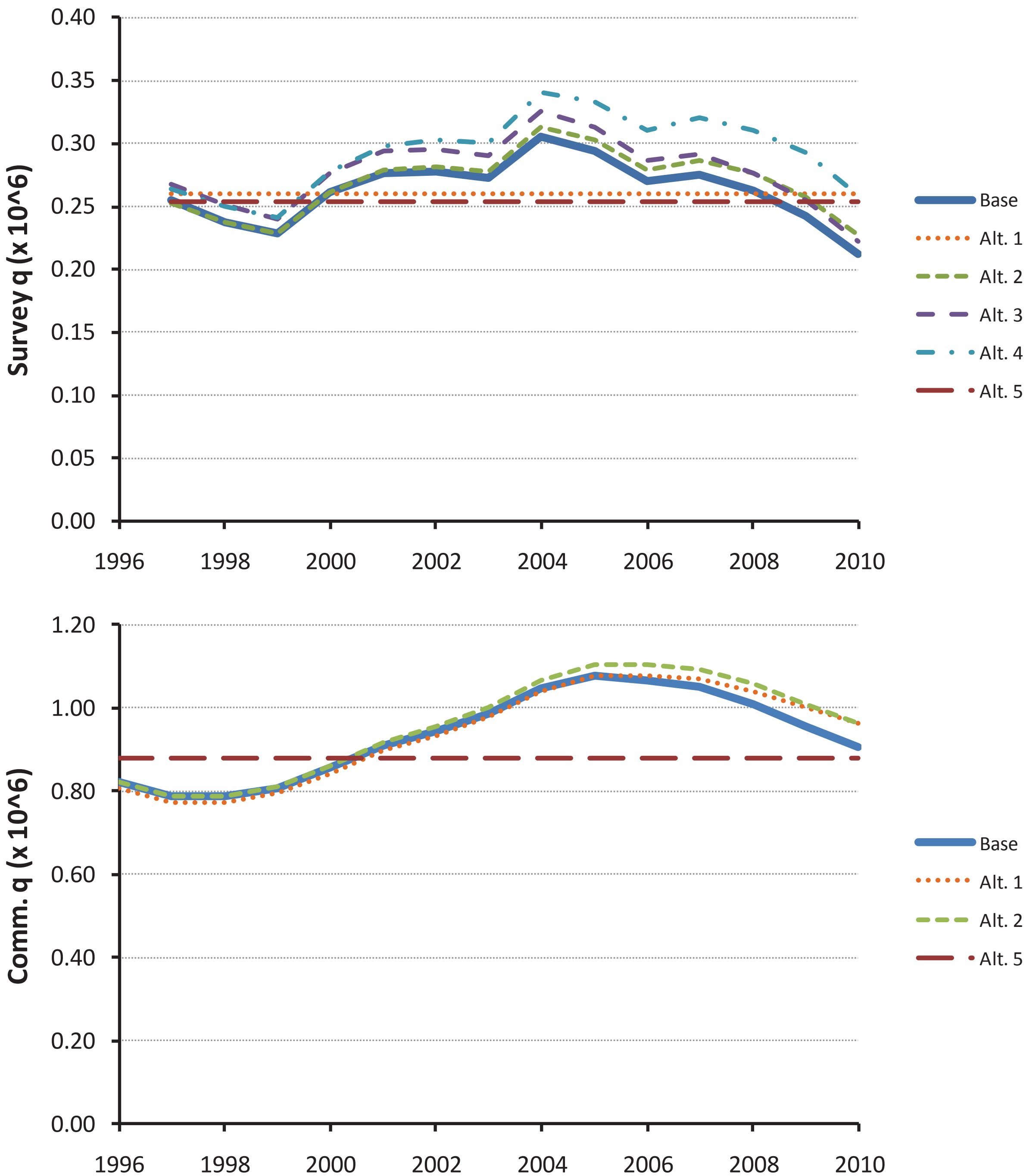


Figure 21. Illustration of time trends in survey and commercial “q” (catchability) among the Base and five Alternative assessment models. See text for details.

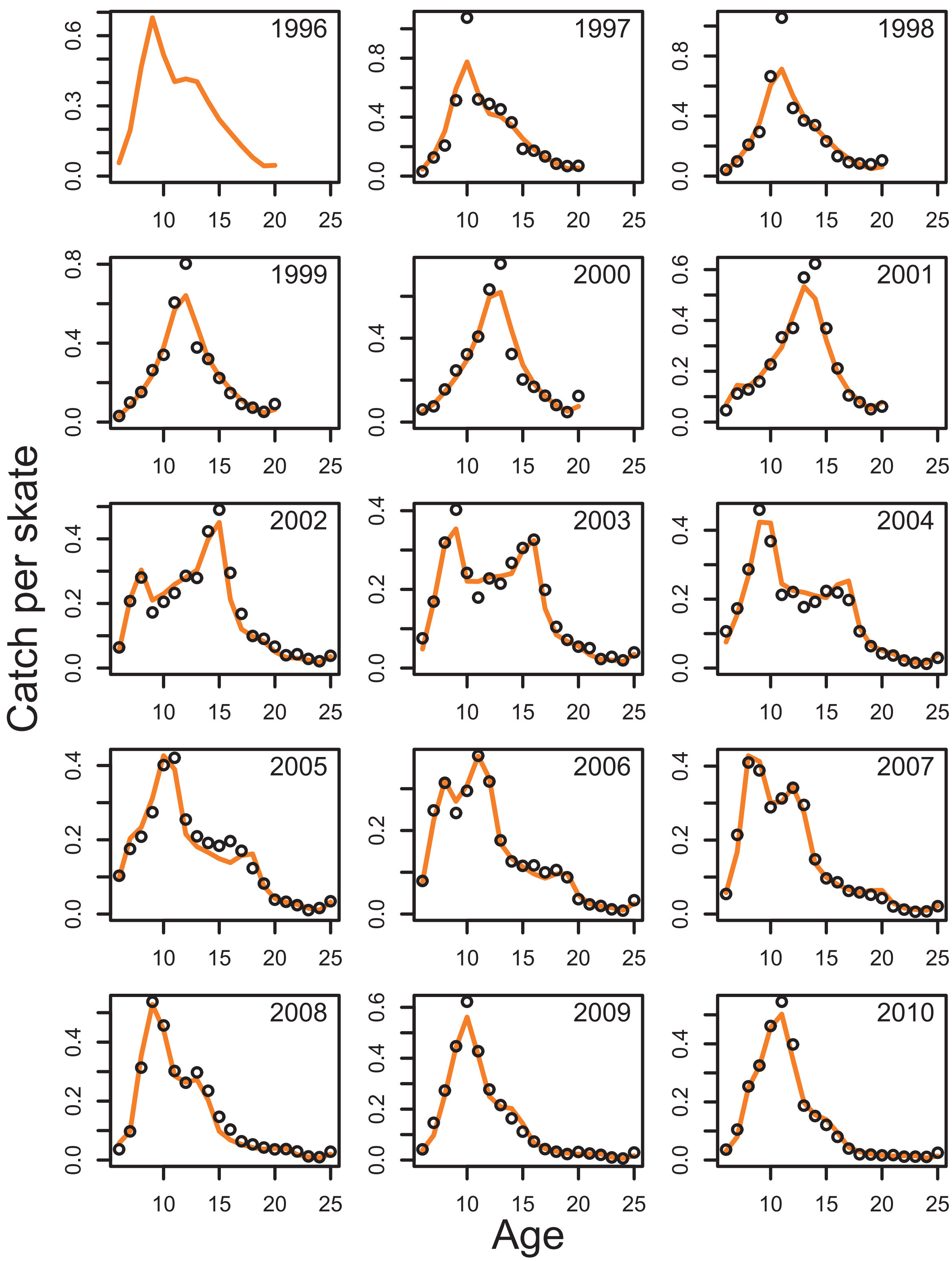


Figure 22a. Observed (points) and predicted (lines) survey NPUE at age of females in the 2010 coastwide model fit.

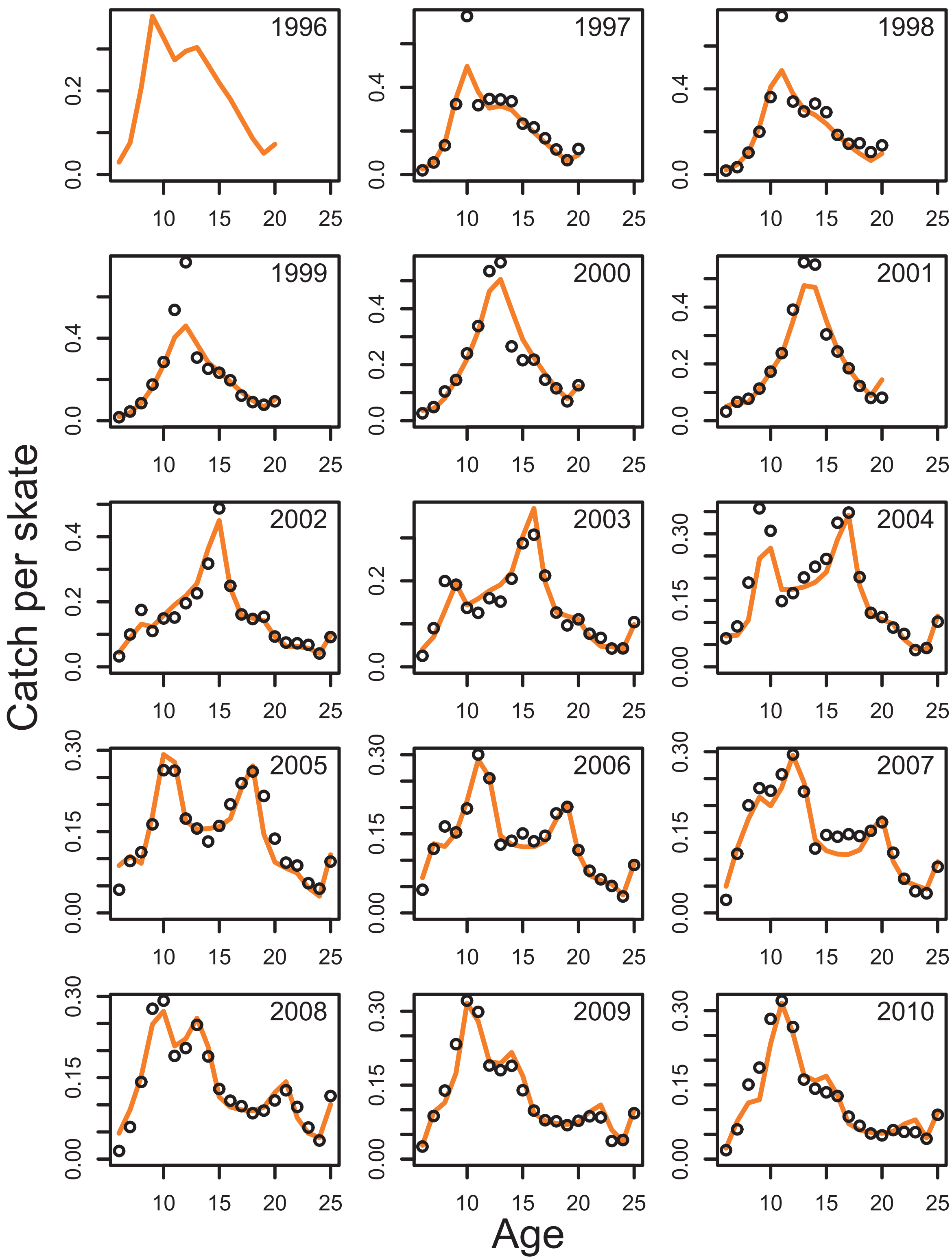


Figure 22b. Observed (points) and predicted (lines) survey NPUE at age of males in the 2010 coastwide model fit.

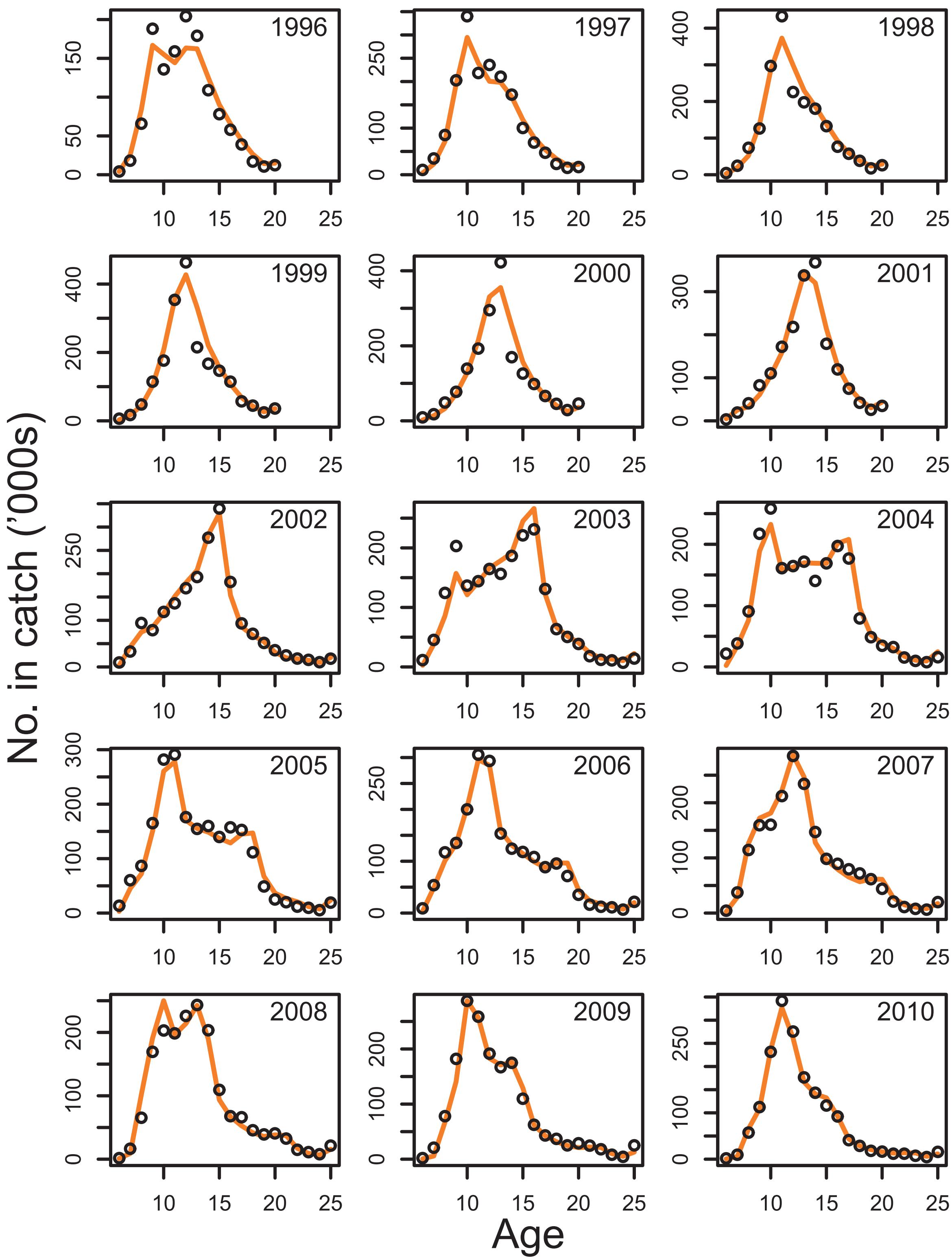


Figure 23a. Observed (points) and predicted (lines) commercial catch at age of females in the 2010 coastwide model fit.

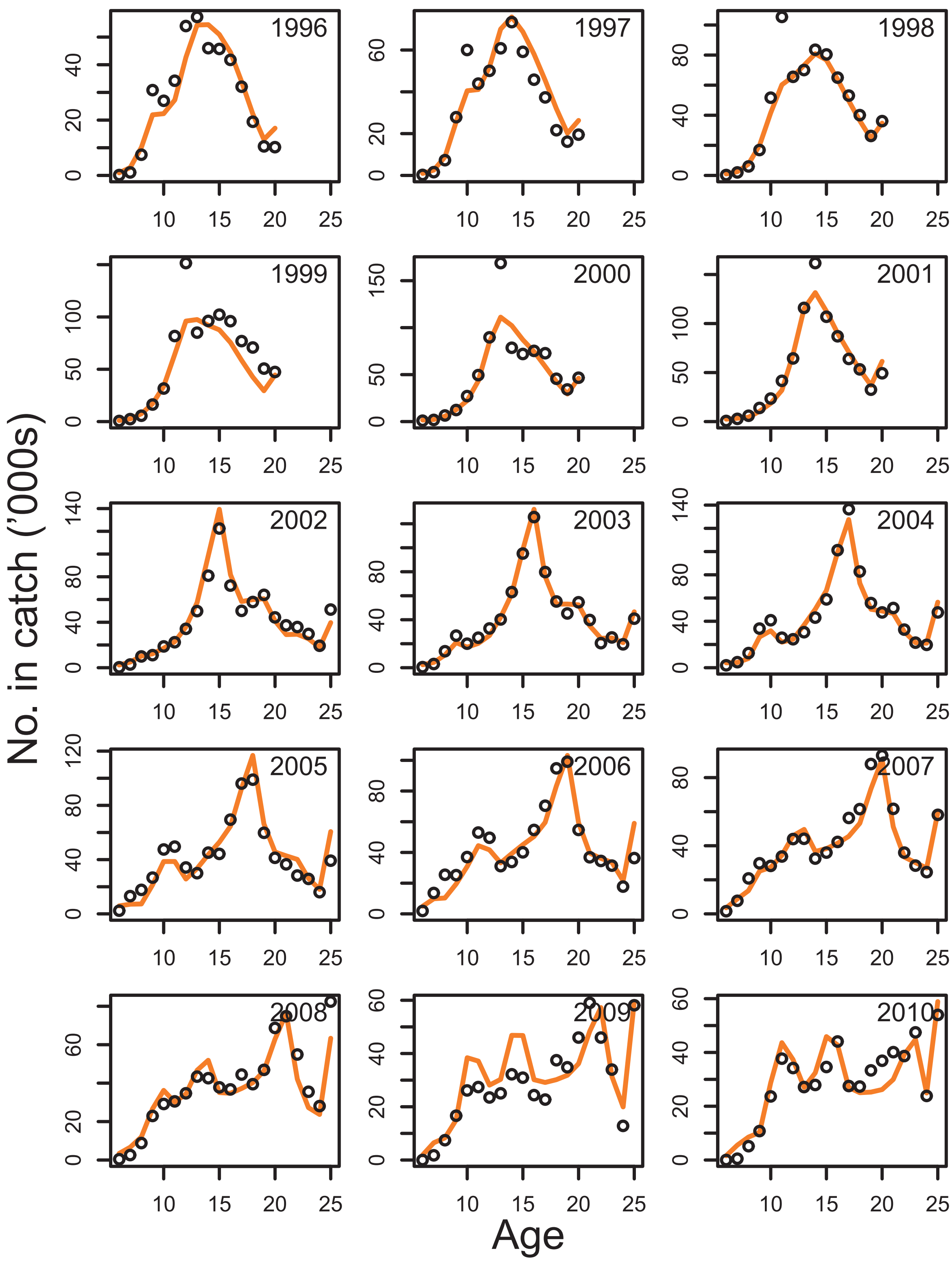


Figure 23b. Observed (points) and predicted (lines) commercial catch at age of males in the 2010 coastwide model fit.

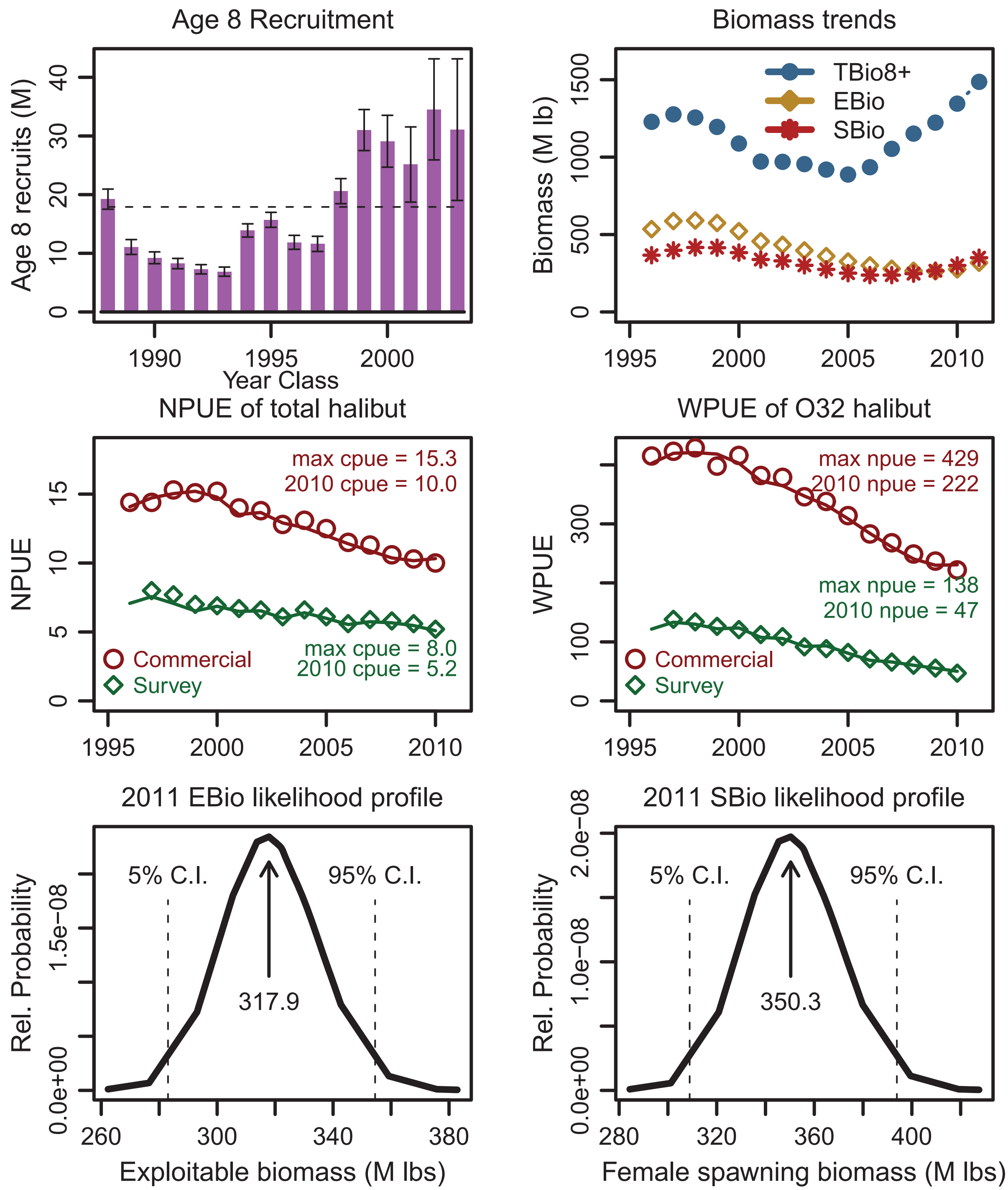


Figure 24. Features of the 2010 halibut coastwide assessment.

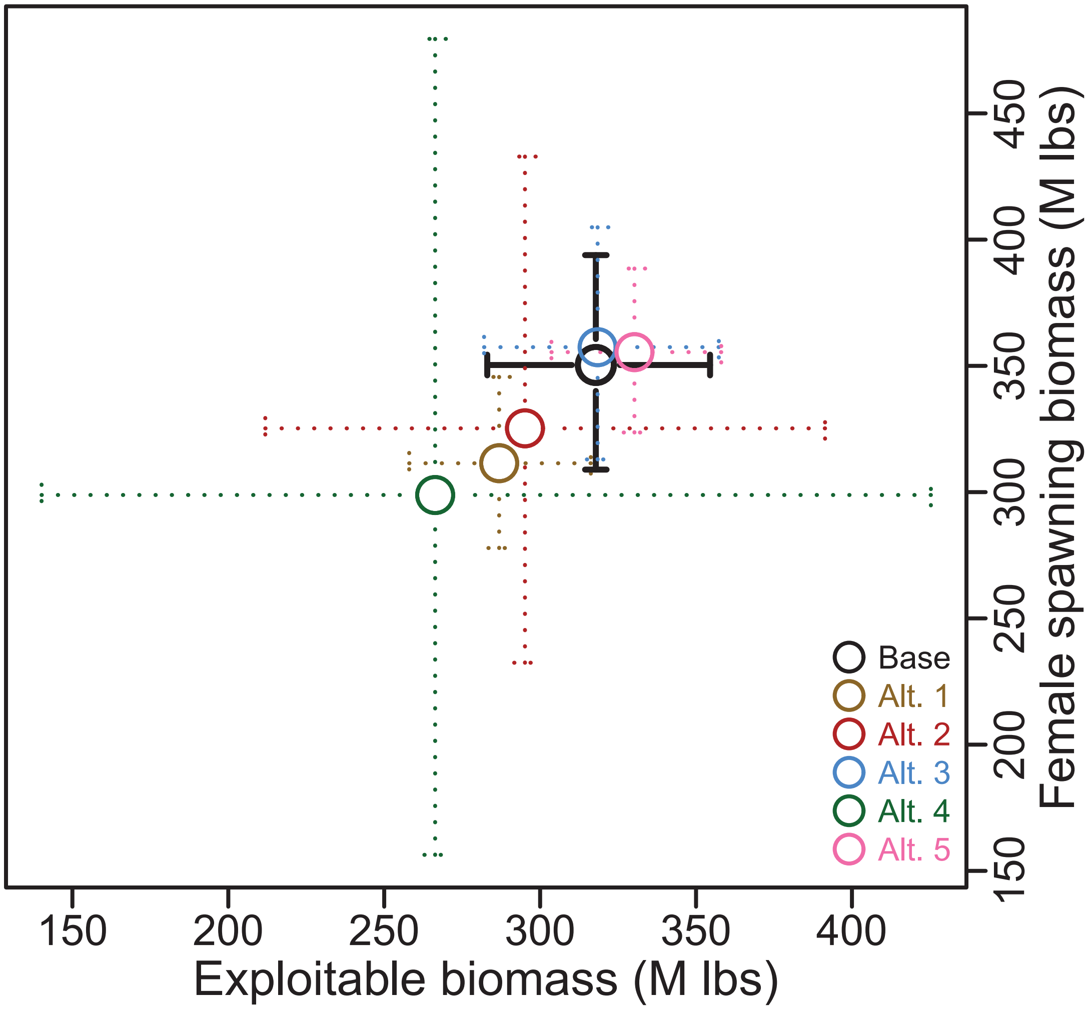


Figure 25. Illustration of maximum likelihood estimates (circles) for EBio and SBio for various model fits. The 95% percent asymptotic confidence intervals for the likelihood profiles are shown by the end caps of the horizontal and vertical bars extending from the circles.

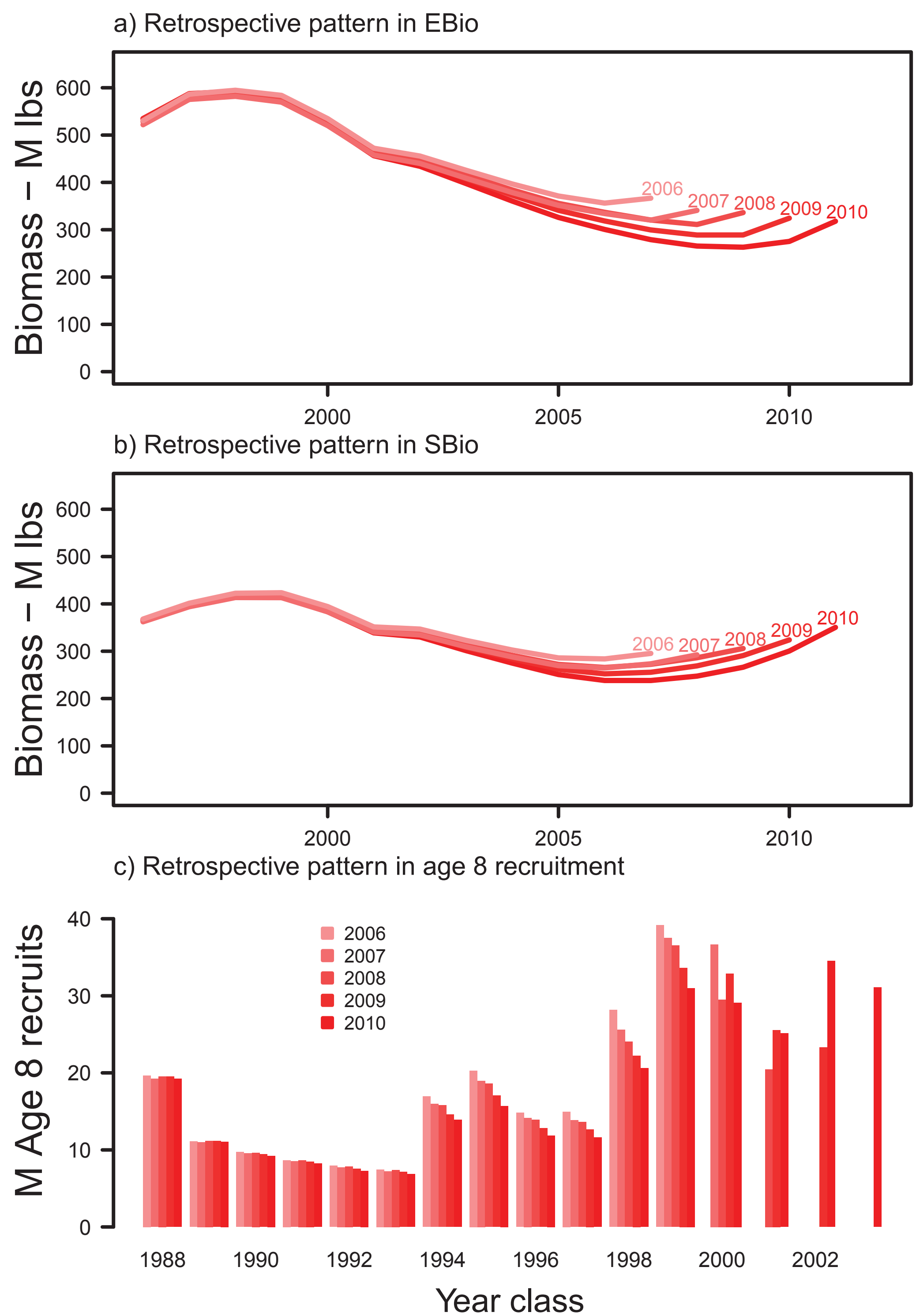


Figure 26. Retrospective behavior of the 2010 halibut assessment model. The top panel illustrates the effect on estimates of EBio by sequentially removing years of data. The middle panel illustrates the effect on estimation of female spawning biomass and the bottom panel illustrates the effect on age eight recruitment. Note that the most recent year class (2003) is only estimated in the 2010 assessment, the 2002 year class in the 2009 and 2010 assessments, and so on. The x-axis is year for the biomass plots and year class for the recruitment plot.

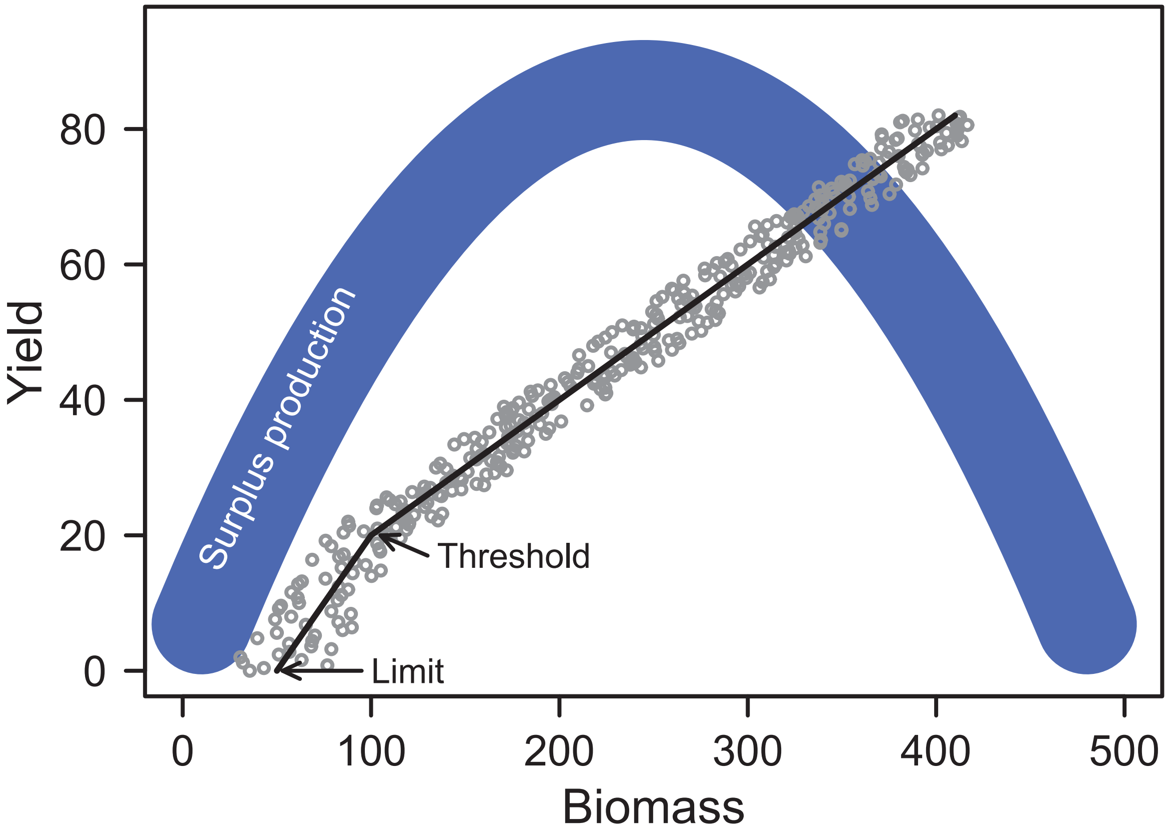


Figure 27. Representation of the IPHC harvest policy. The background curve illustrates theoretical relationship between biomass and surplus production, taken as yield. The slope of the straight line is a 20% harvest rate (Yield/Exploitable biomass), and the harvest rate deceases linearly to zero as the biomass approaches established reference points, termed the female spawning biomass threshold and limit. The scatter about the harvest rate indicates the effect of the "Slow Up Fast Down" adjustment to catch limits in terms of realized harvest rate.

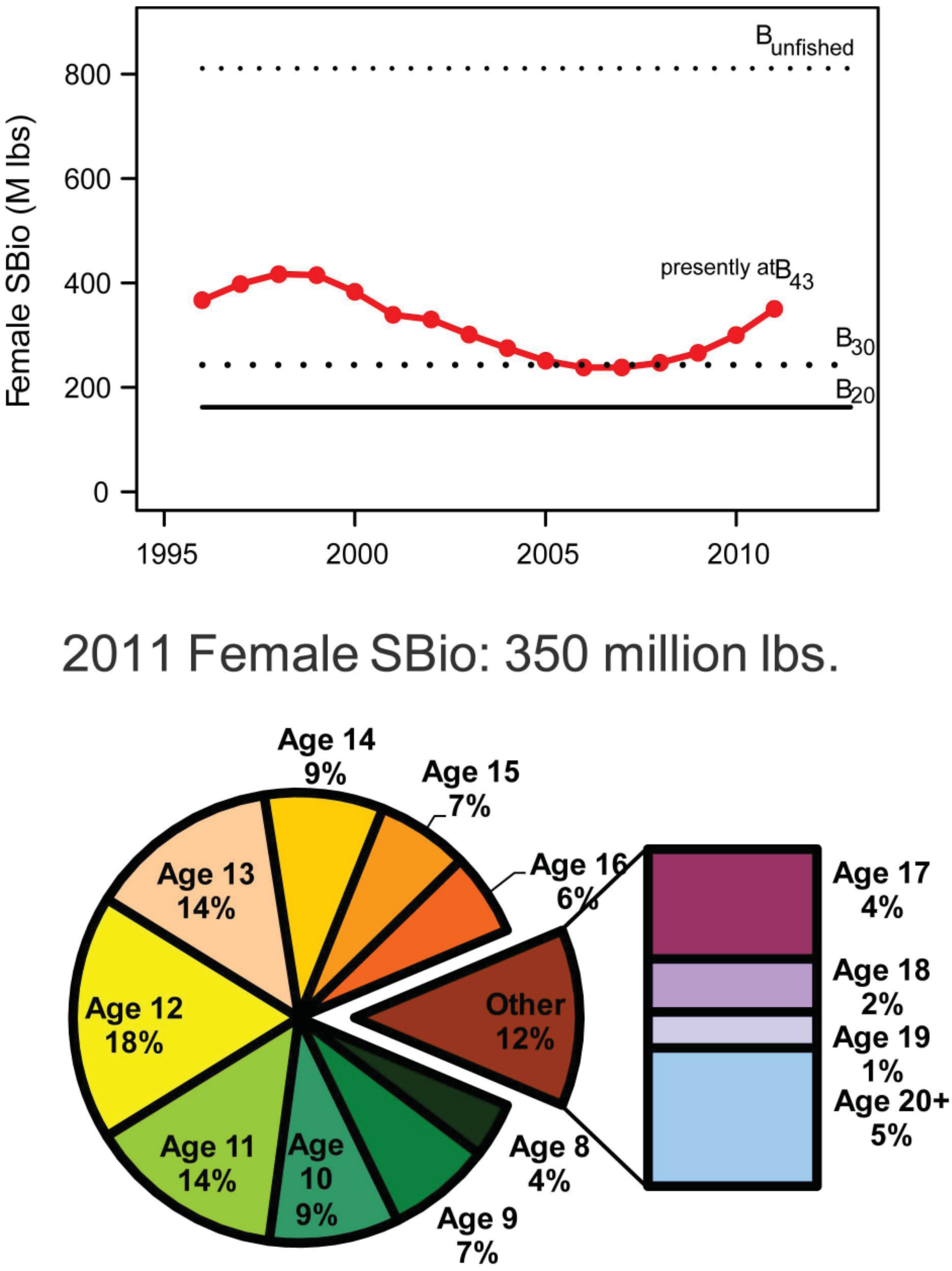


Figure 28. Status (top panel) and current age composition (bottom panel) of female spawning biomass. See text for details.

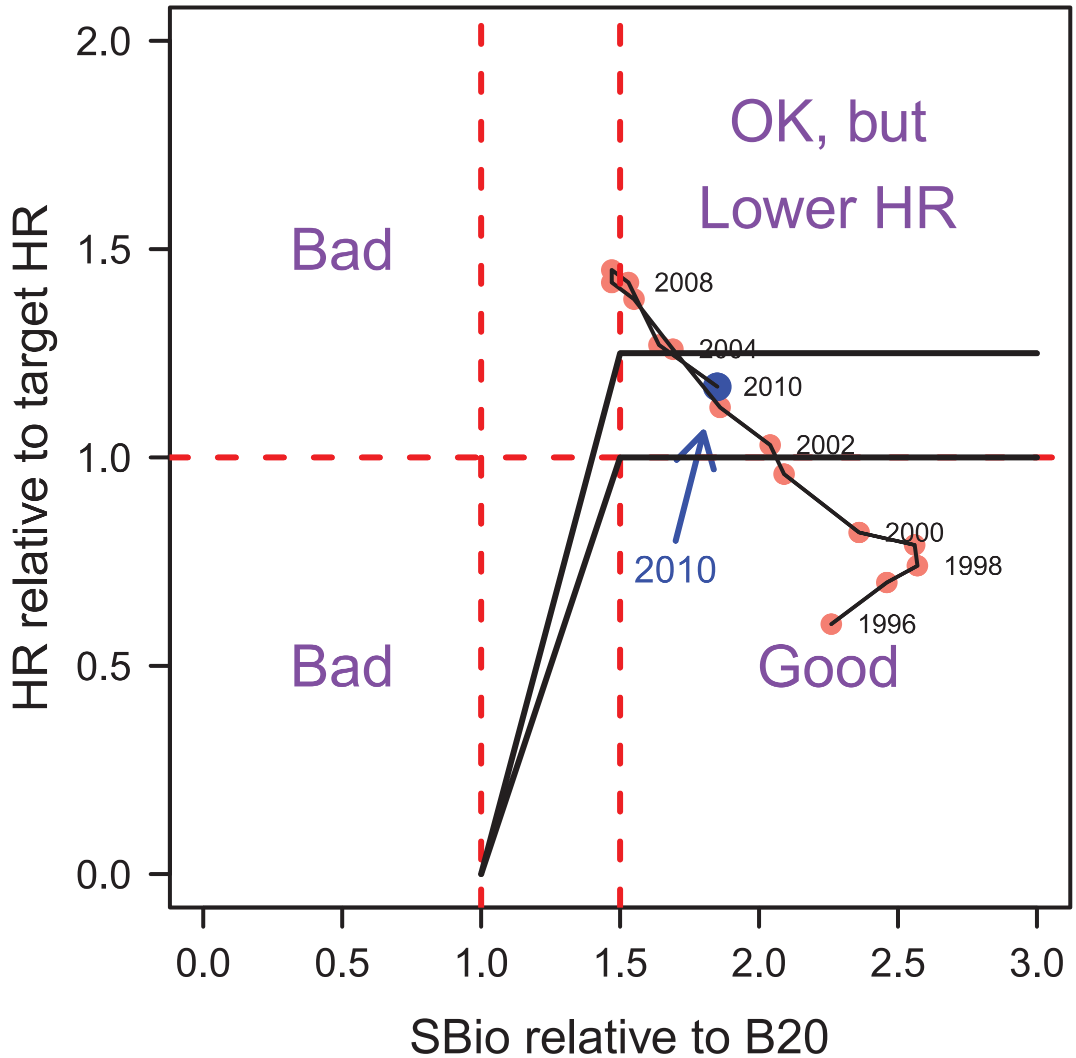


Figure 29. Trend and status of halibut management relative to reference points. Horizontal axis indicates female spawning biomass (SBio) relative to B_{20} (value of 1.0) and B_{30} (value of 1.5). Vertical axis illustrates realized harvest rate relative to a target harvest rate of 0.20 (value of 1.0) and the previous target harvest rate of 0.25 (value of 1.25).

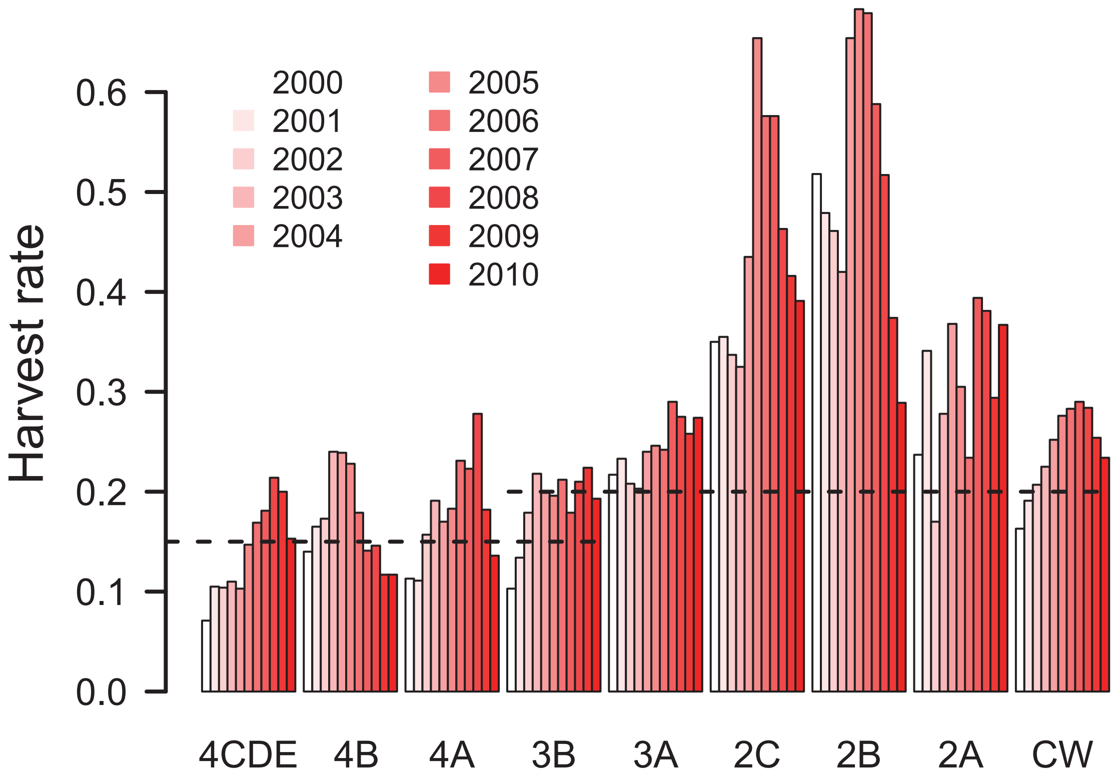
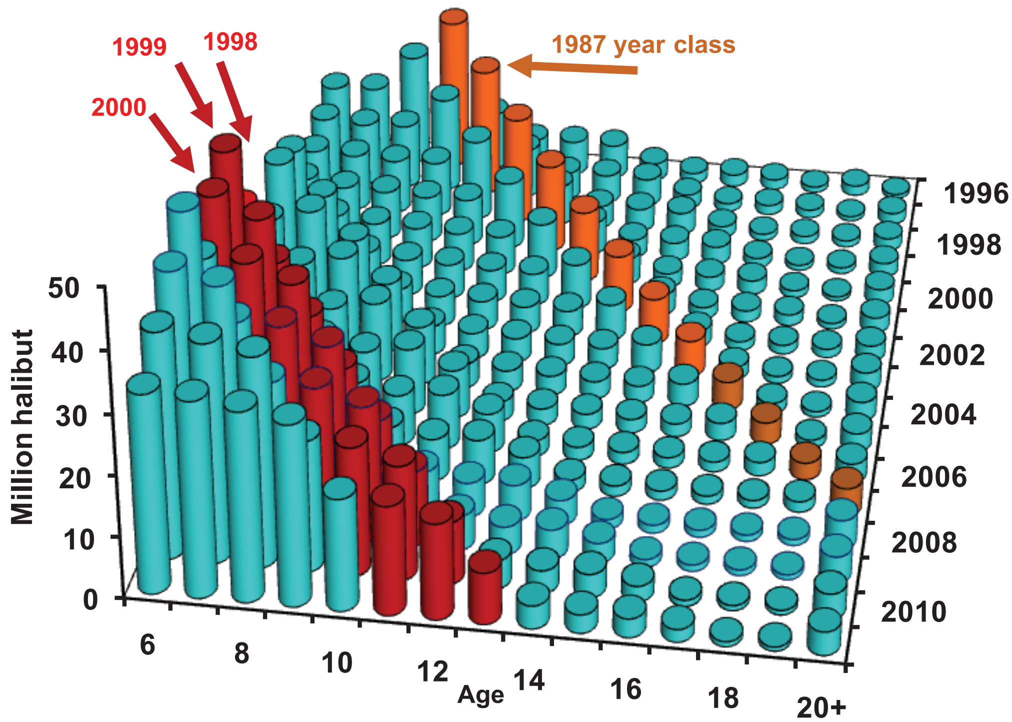


Figure 30. Summary of realized harvest rates from the coastwide assessment, using adjusted and weighted survey WPUE to partition biomass among areas.

a) Total numbers in the population



b) Exploitable biomass in the population

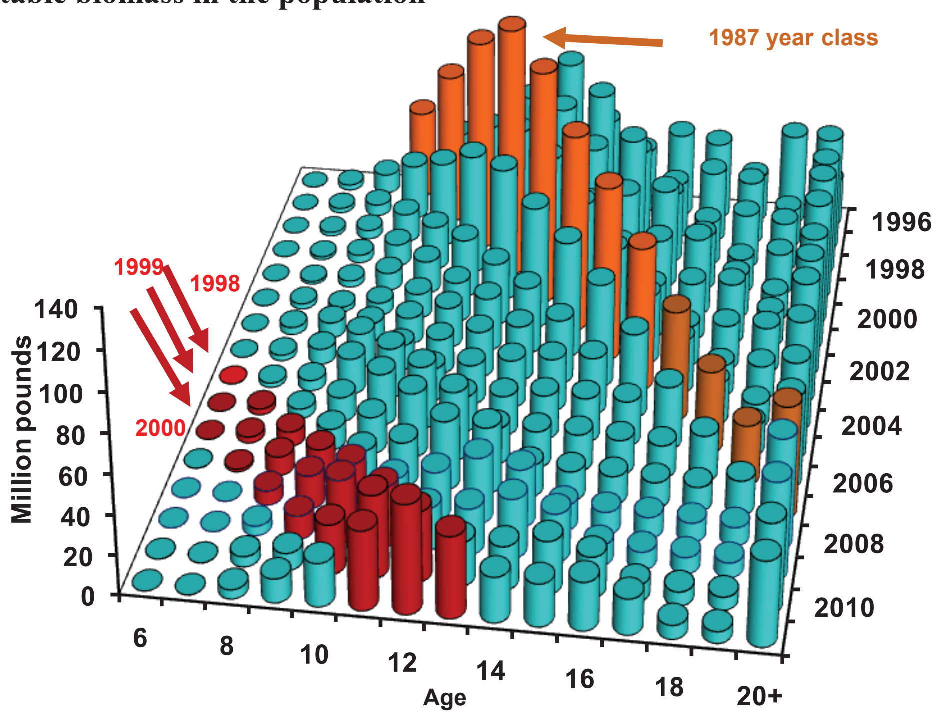


Figure 31. Coastwide population estimates in numbers of halibut (panel a) and as EBio (panel b). Several large year classes are highlighted.

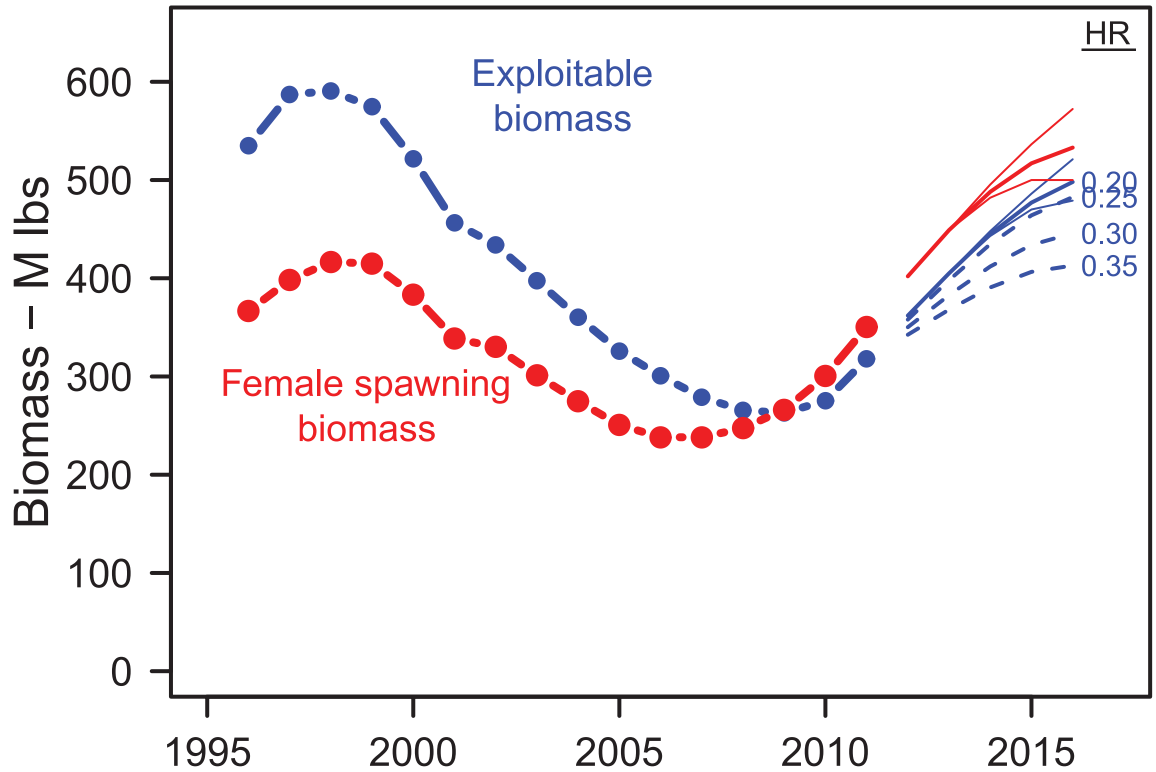


Figure 32. Projected exploitable and spawning biomasses for the coastwide population of halibut.

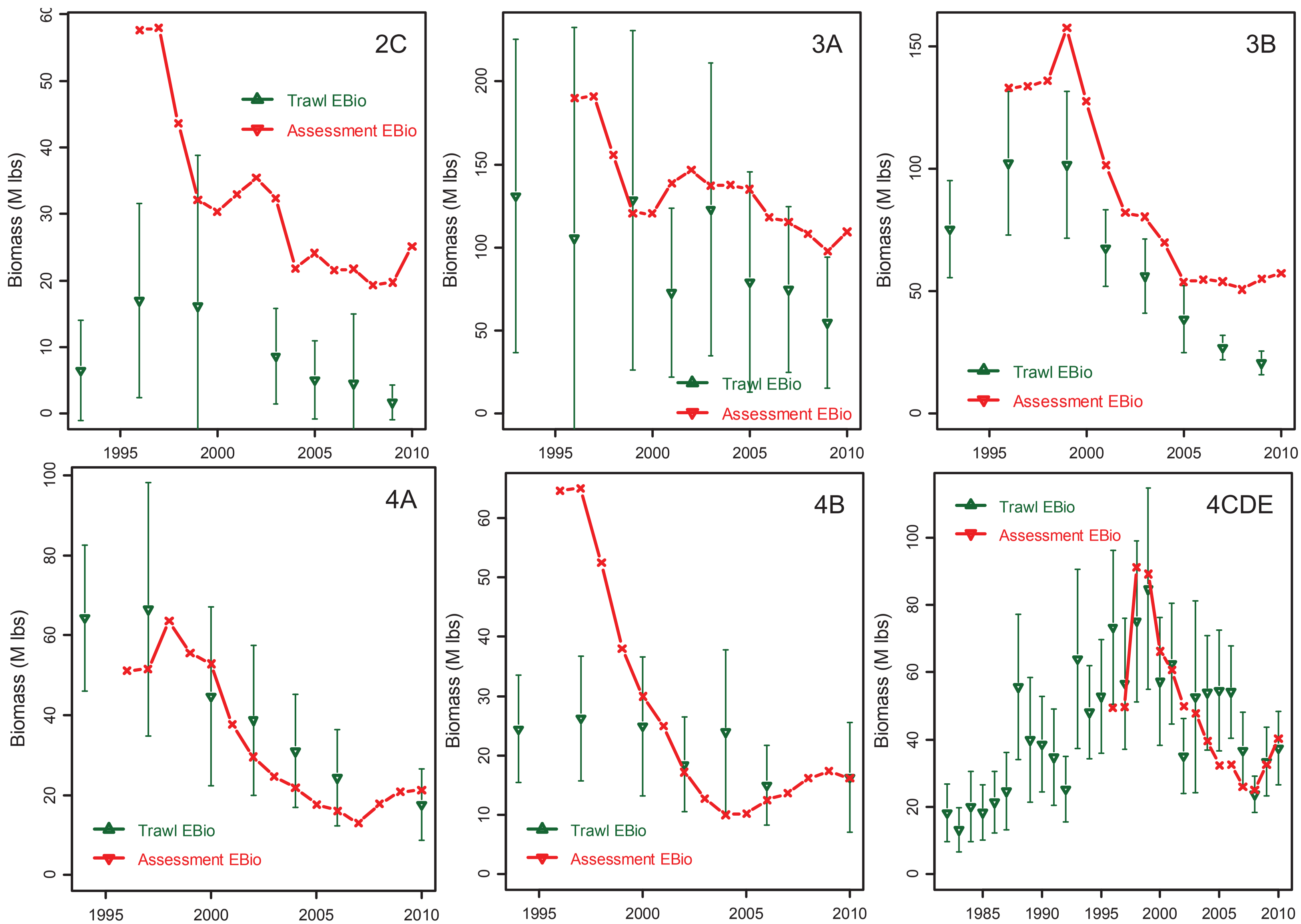


Figure 33. Comparison of IPHC assessment estimates (using adjusted survey WPUE) and NMFS swept area estimates of EBio.

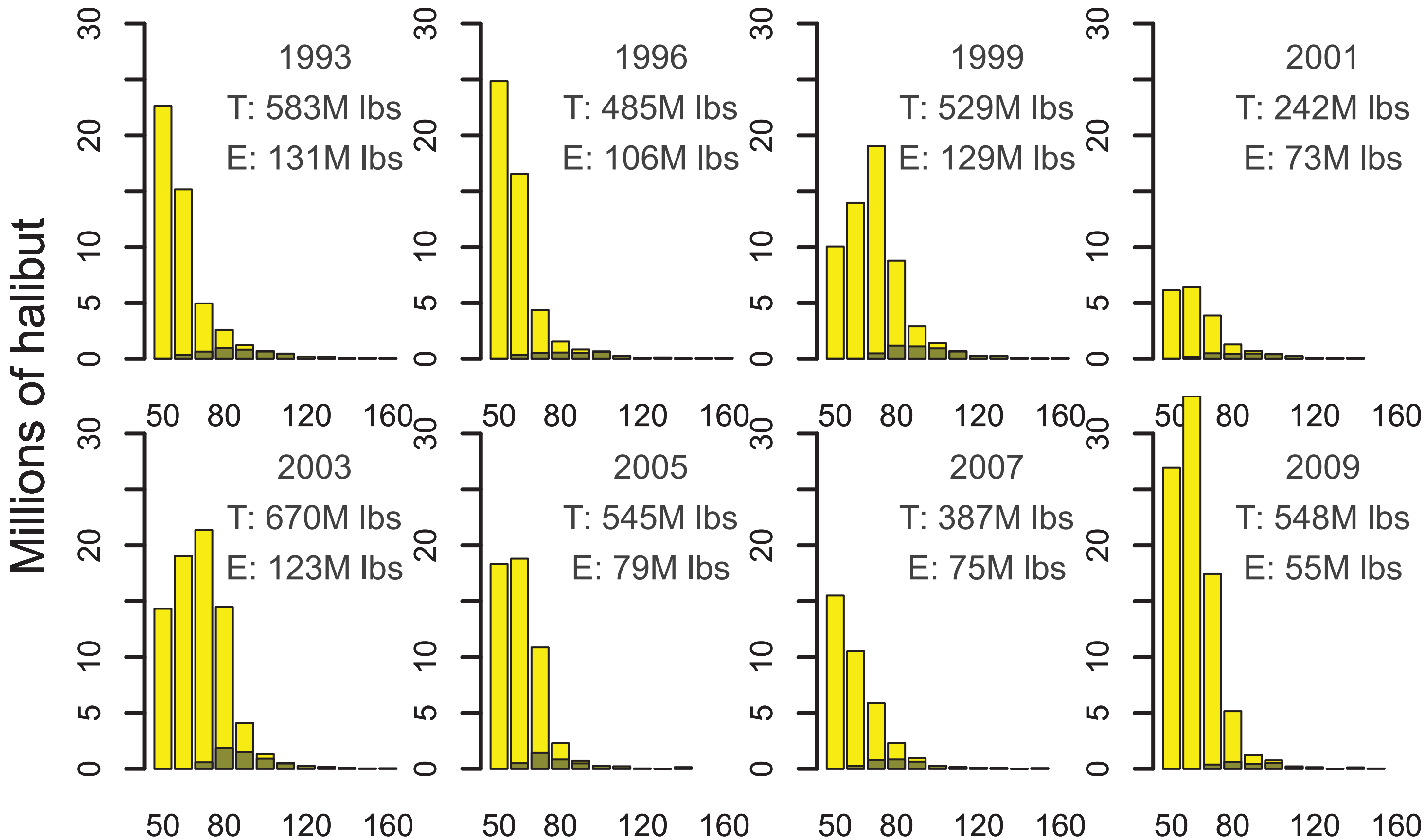


Figure 34. Swept area estimates of halibut in IPHC regulatory Area 3A, by 10-cm length interval, in the NMFS EBS trawl survey for the years 1993 to 2009. Values for total (T) and Exploitable (E) biomass estimated by the survey are also listed. Exploitable numbers of halibut are illustrated by the darker bars.

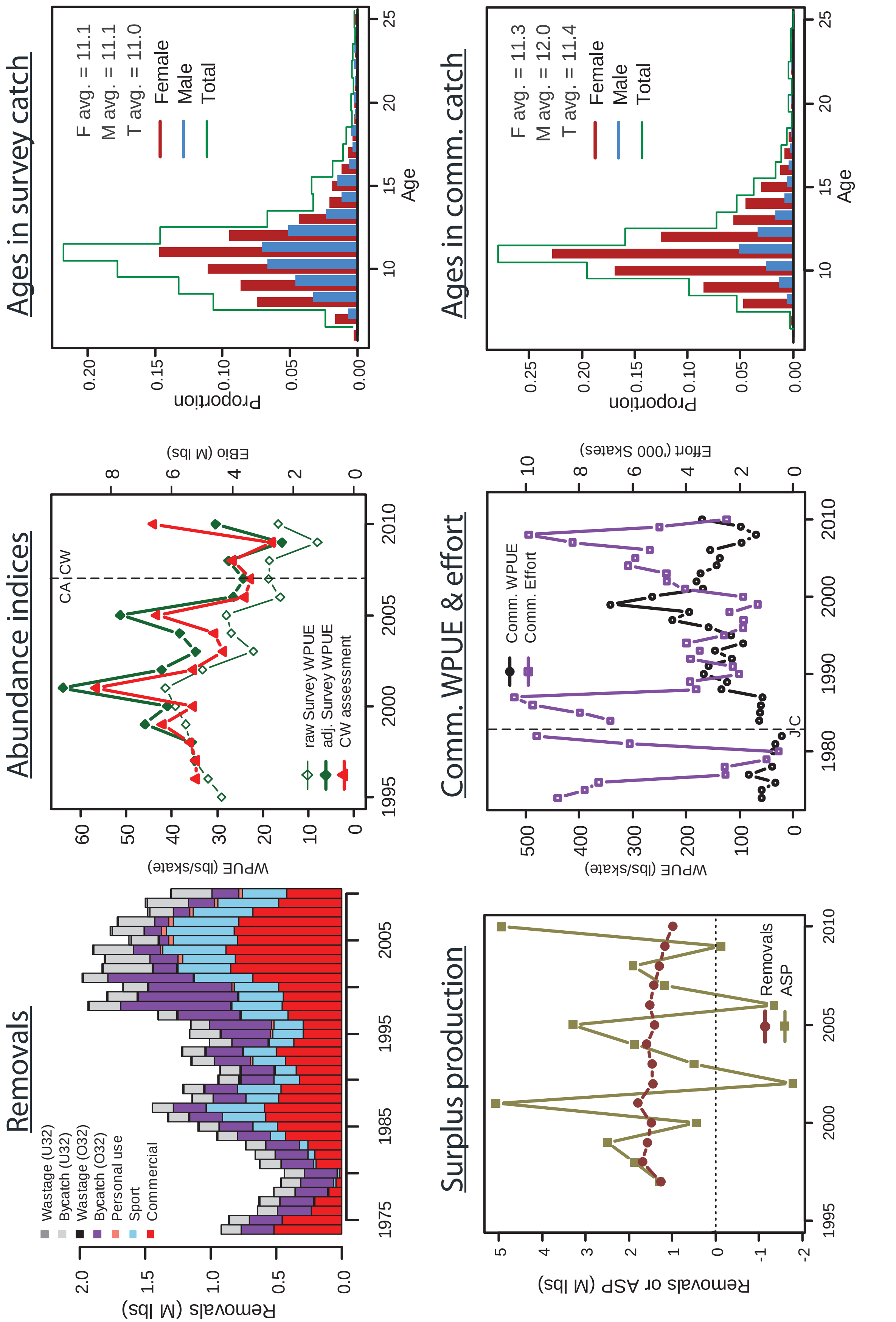


Figure 35. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 2A.

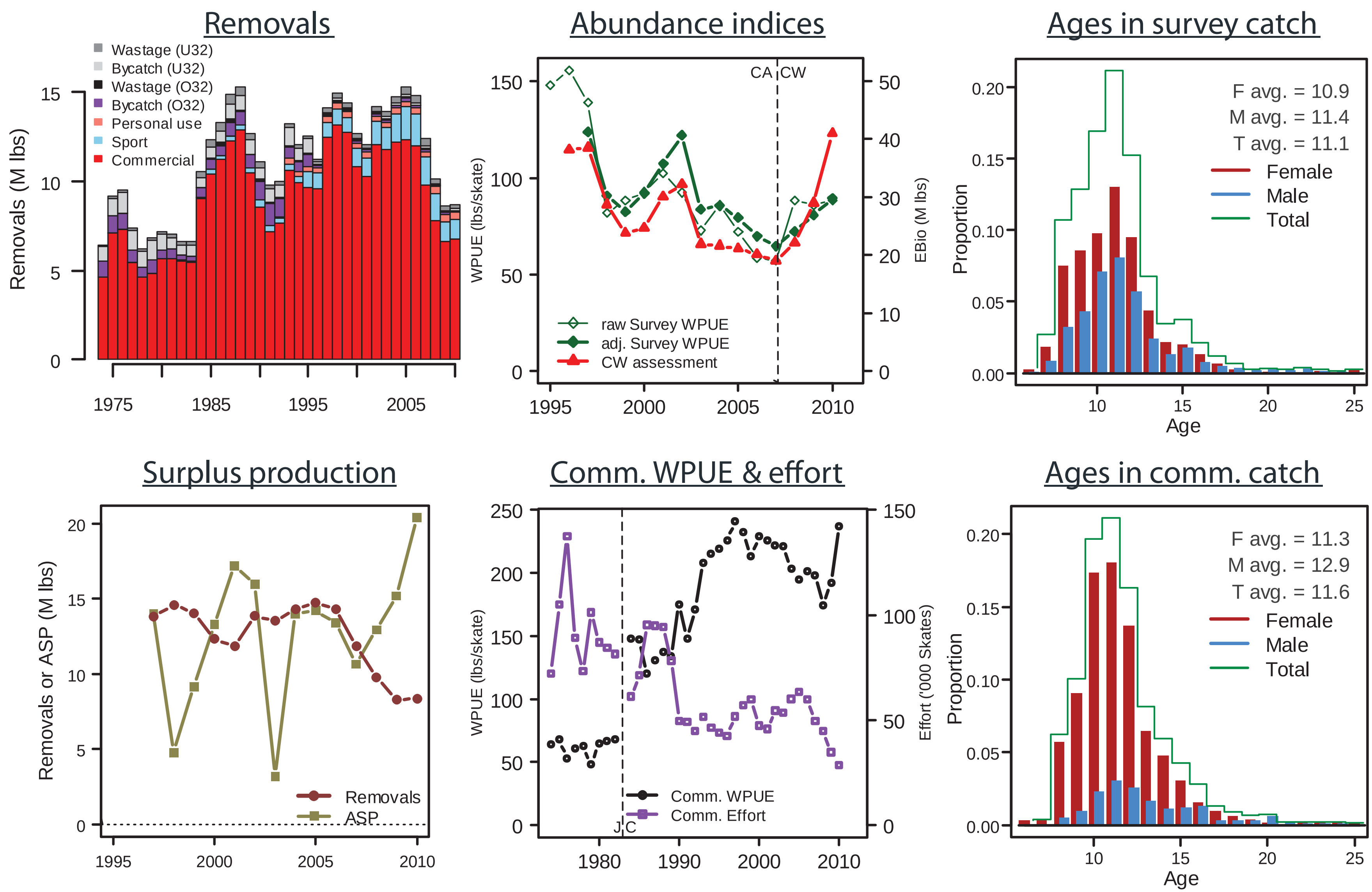


Figure 36. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 2B.

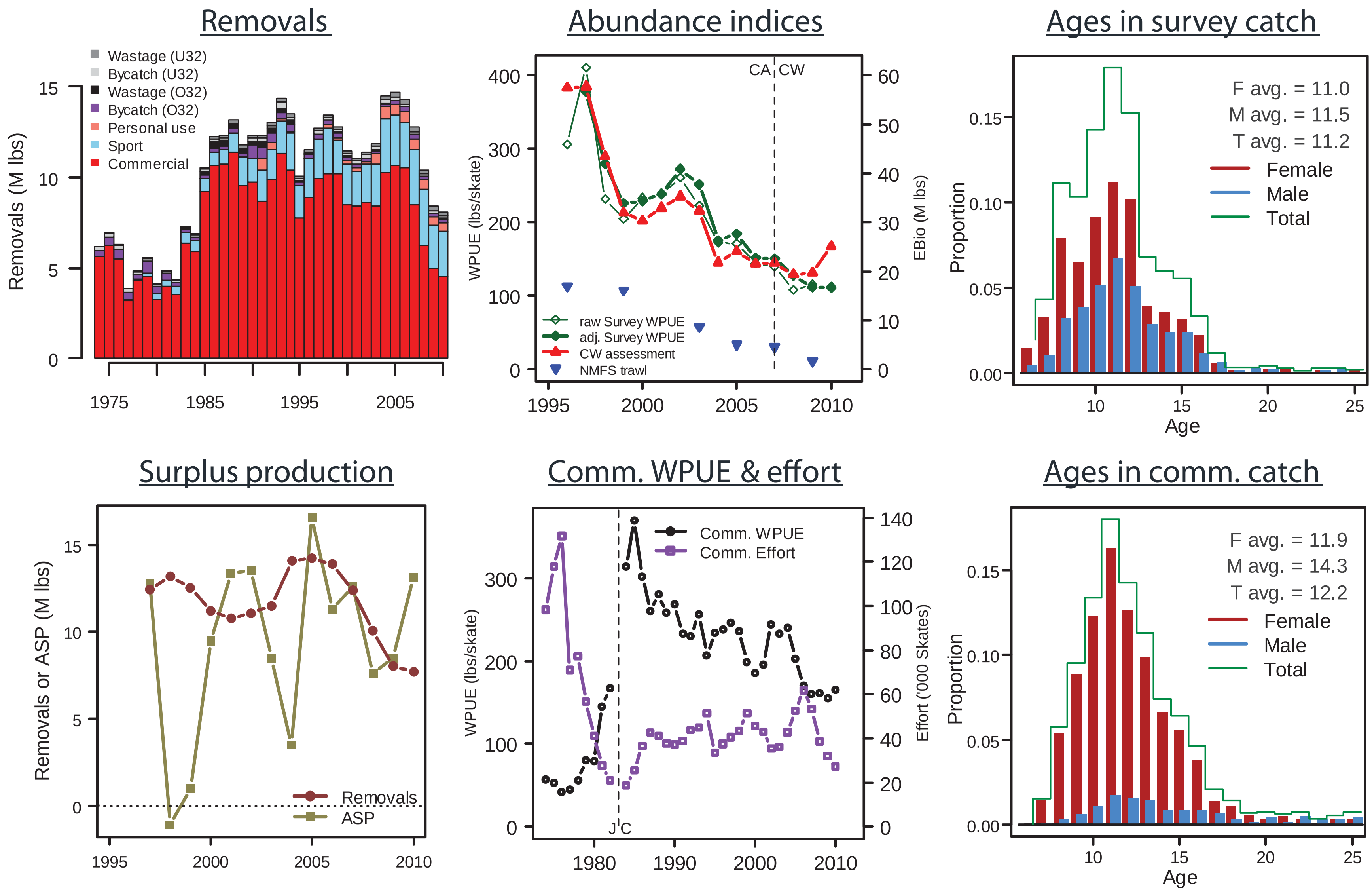


Figure 37. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 2C.

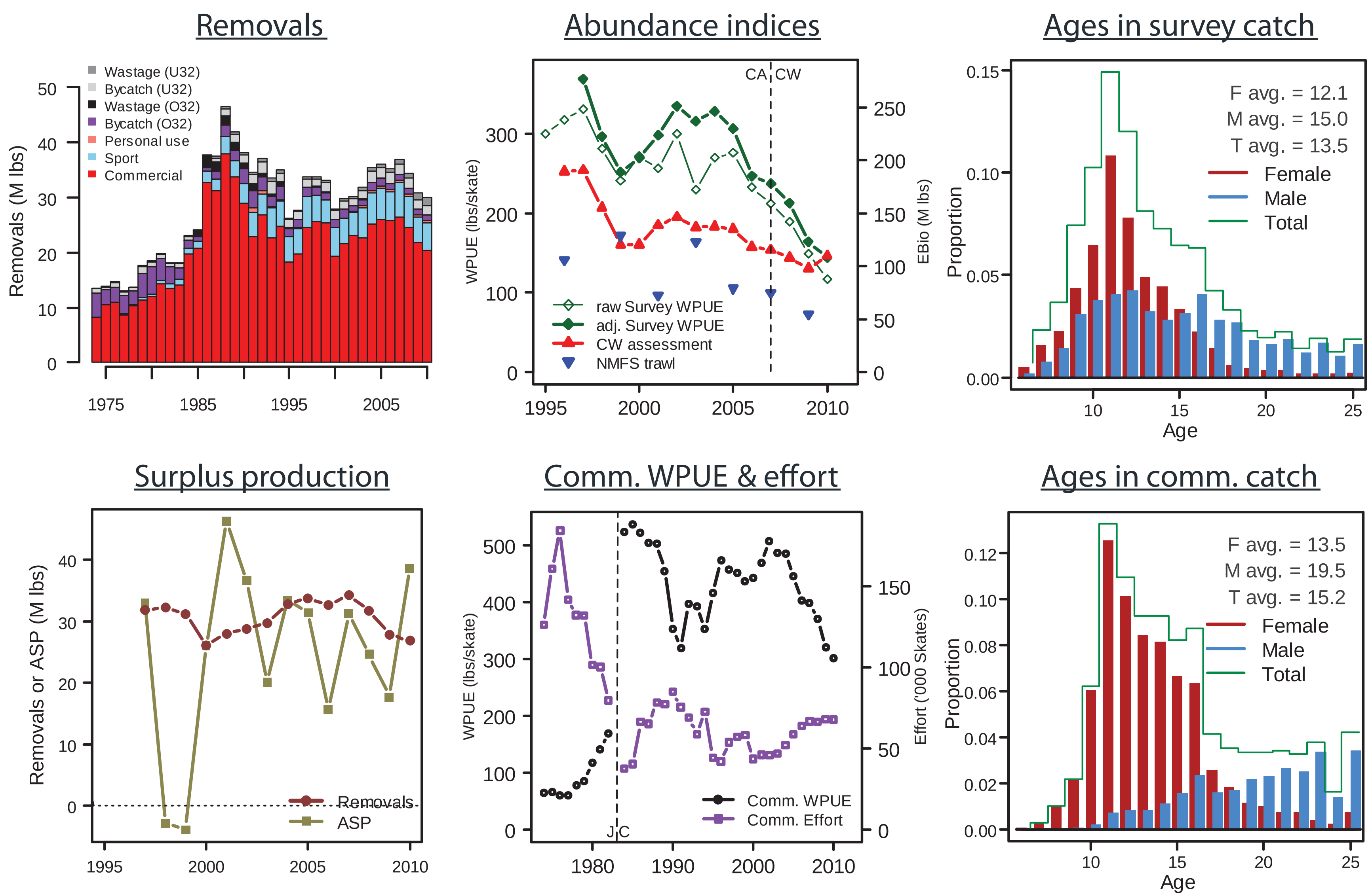


Figure 38. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 3A.

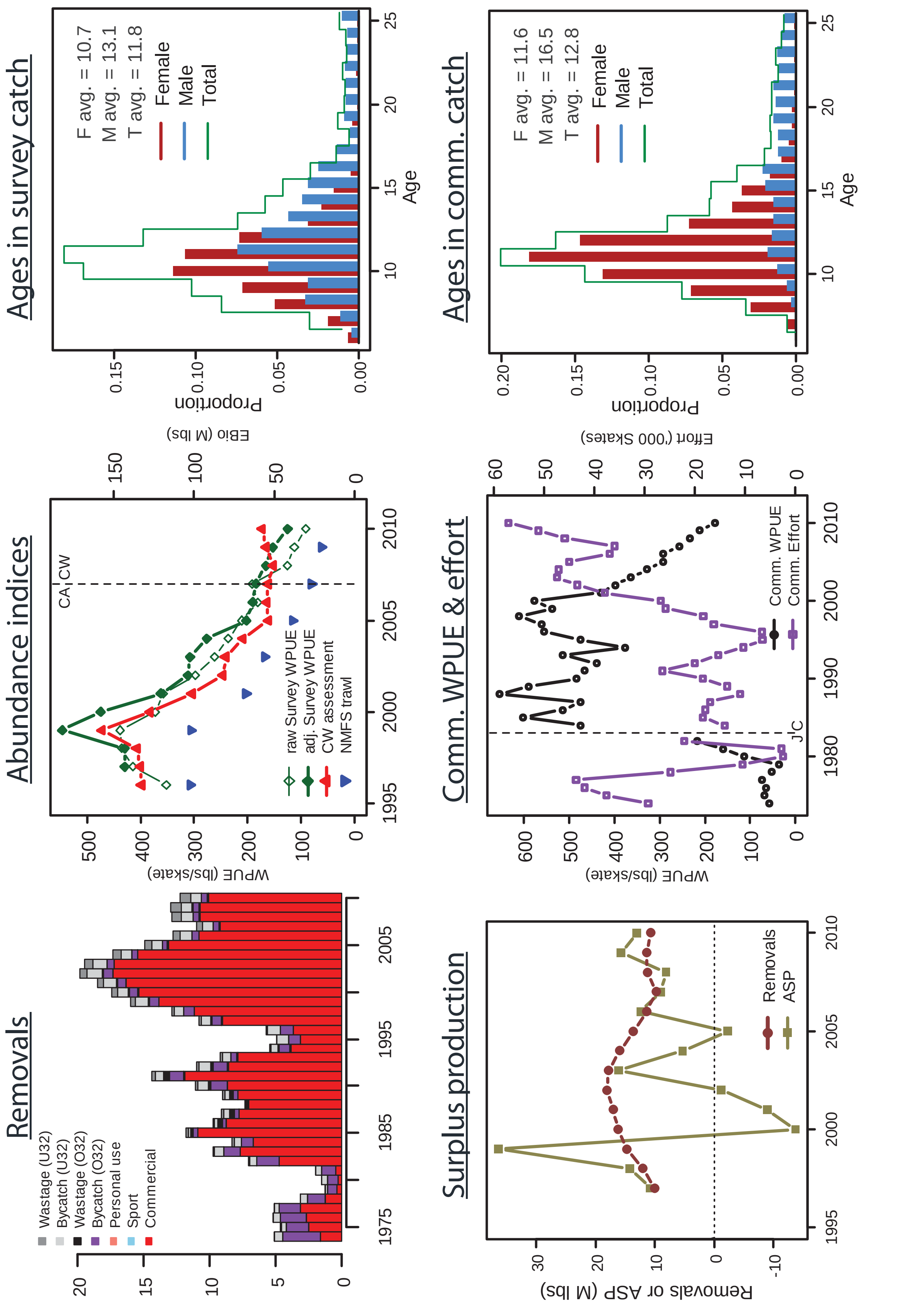


Figure 39. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 3B.

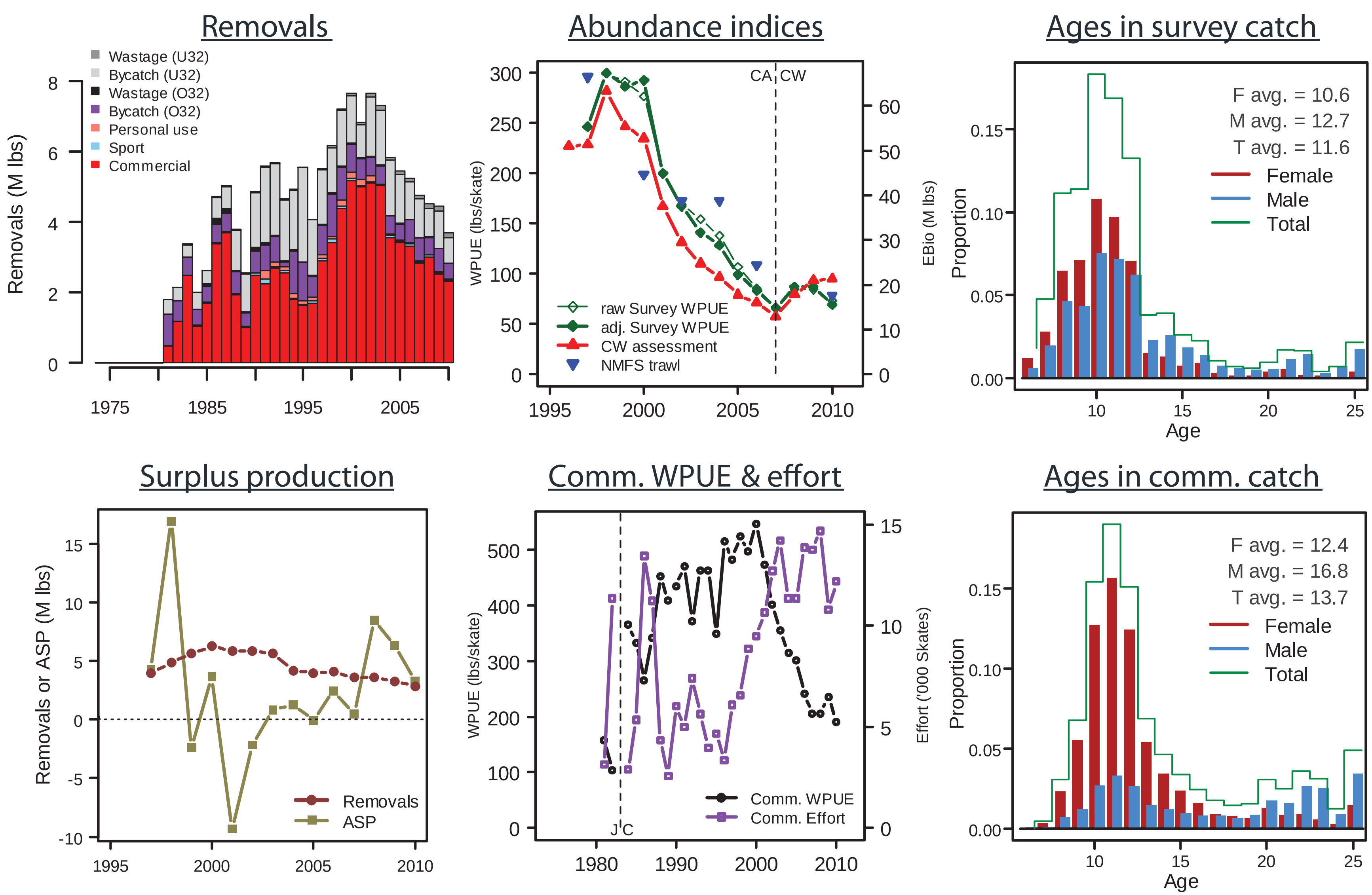


Figure 40. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 4A.

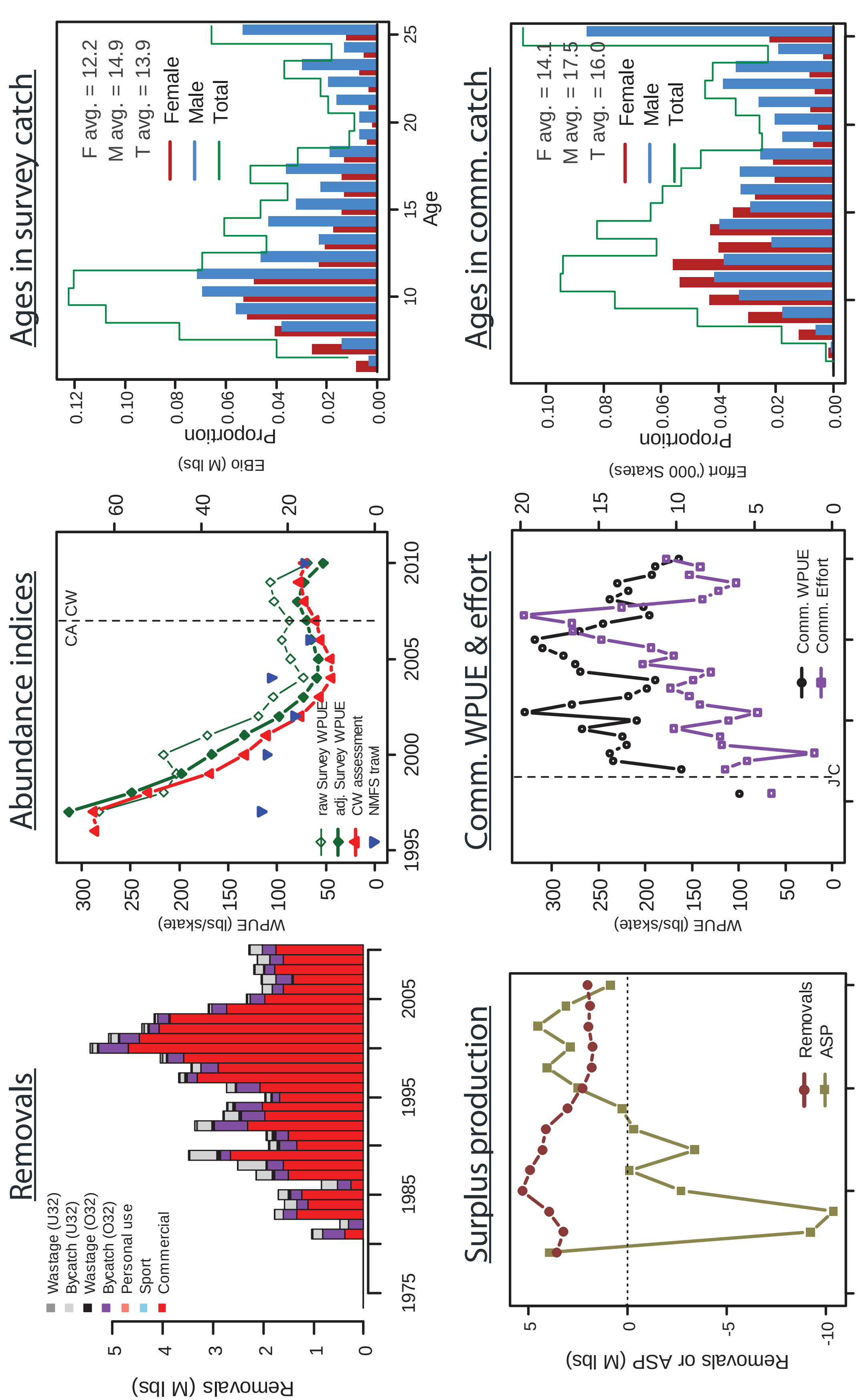


Figure 41. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 4B.

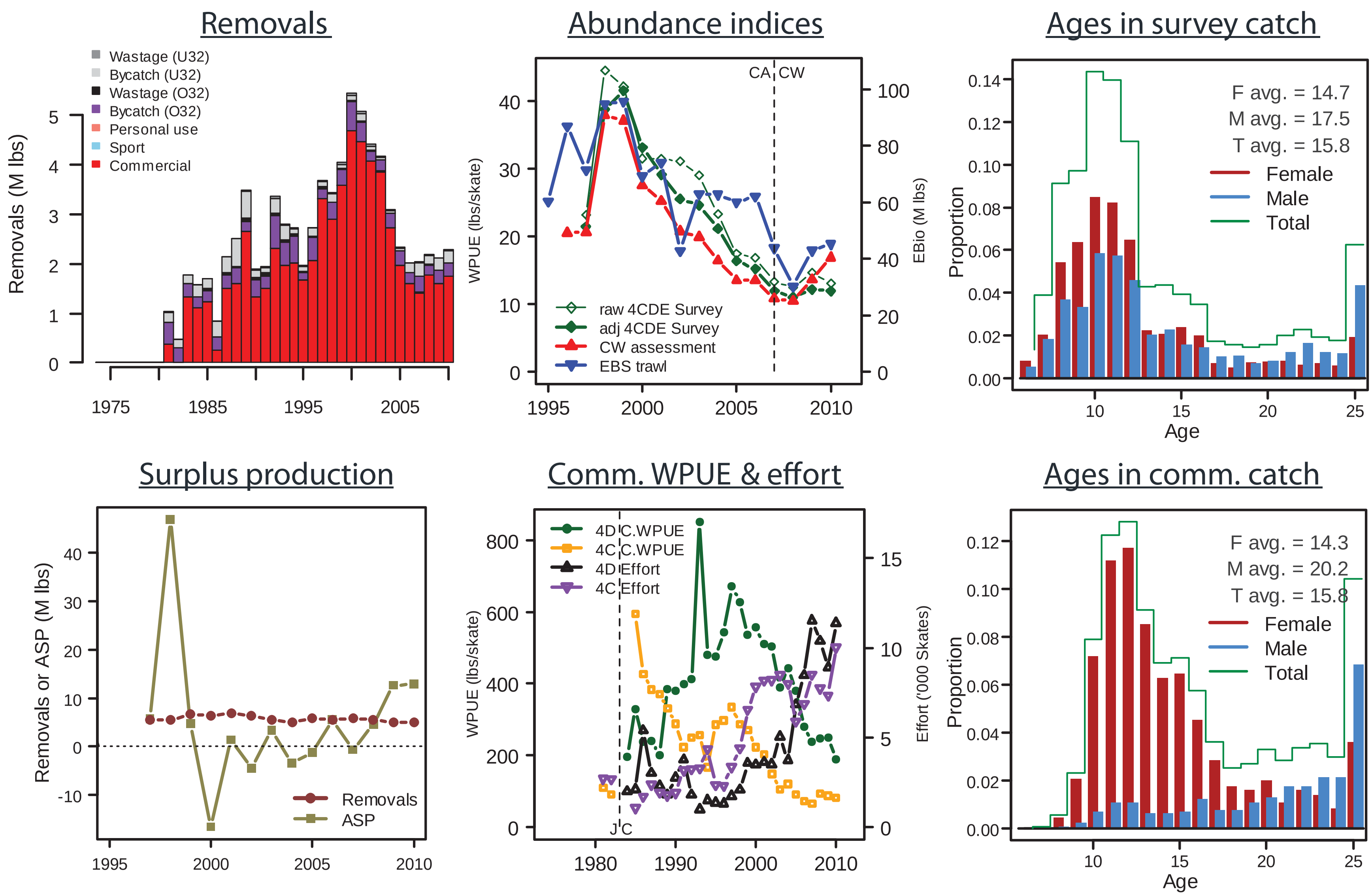


Figure 42. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 4CDE.

Appendix A. Selected fishery and survey data summaries

Table A1. Total removals (million pounds, net weight). Removals include commercial catch, IPHC survey catches, sport catch, personal use catch, O32 bycatch and O32 wastage. Removals do not include U32 bycatch or U32 wastage.

	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1974	0.77	5.52	5.97	12.67	4.49	2.61	---	---	---	32.03
1975	0.71	8.04	6.69	13.21	4.22	1.74	---	---	---	34.61
1976	0.49	8.22	6.03	13.78	4.68	1.90	---	---	---	35.10
1977	0.48	6.16	3.67	12.20	4.74	3.20	---	---	---	30.44
1978	0.36	5.17	4.62	13.03	2.63	4.75	---	---	---	30.55
1979	0.32	5.57	5.34	16.20	1.08	4.82	---	---	---	33.32
1980	0.29	6.17	3.99	17.39	1.15	6.45	---	---	---	35.44
1981	0.47	6.20	4.73	18.97	1.55	5.57	---	---	---	37.49
1982	0.51	5.87	4.19	17.44	6.48	4.40	---	---	---	38.89
1983	0.58	5.78	7.13	17.16	8.97	6.90	---	---	---	46.52
1984	0.80	9.63	6.70	22.31	7.61	5.48	---	---	---	52.53
1985	0.94	11.40	10.52	24.70	11.63	6.84	---	---	---	66.04
1986	1.18	12.37	12.41	39.10	9.82	8.83	---	---	---	83.71
1987	1.30	13.65	12.40	38.04	8.83	10.10	---	---	---	84.32
1988	0.99	13.98	13.06	46.26	7.37	8.07	---	---	---	89.72
1989	1.07	11.56	11.68	41.46	8.67	7.13	---	---	---	81.56
1990	0.81	10.22	12.22	37.35	10.34	---	3.39	1.78	4.11	80.22
1991	0.78	8.90	12.30	33.57	13.88	---	3.53	1.87	4.66	79.48
1992	0.99	9.14	12.92	35.10	10.16	---	3.68	3.06	3.59	78.65
1993	1.06	12.10	13.93	30.93	8.52	---	2.96	2.51	3.20	75.21
1994	0.85	11.25	13.34	33.71	4.87	---	3.24	2.63	3.44	73.32
1995	0.93	11.59	9.85	24.64	4.03	---	2.87	1.85	3.56	59.33
1996	1.02	10.96	11.32	26.29	4.73	---	2.51	2.59	4.53	63.93
1997	1.27	13.79	12.41	31.93	9.97	---	3.97	3.58	5.54	82.46
1998	1.69	14.58	13.19	32.28	12.06	---	4.84	3.26	5.51	87.40
1999	1.57	14.05	12.52	31.14	14.76	---	5.61	3.96	6.62	90.23
2000	1.49	12.32	11.20	26.06	16.21	---	6.25	5.32	6.35	85.20
2001	1.79	11.84	10.76	28.04	17.07	---	5.85	4.91	6.94	87.20
2002	1.45	13.86	11.08	28.76	18.13	---	5.88	4.31	6.28	89.74
2003	1.47	13.51	11.49	29.77	17.84	---	5.64	4.12	5.49	89.32
2004	1.59	14.29	14.06	32.85	15.92	---	4.19	3.04	4.92	90.87
2005	1.41	14.74	14.23	33.77	13.64	---	3.97	2.27	5.81	89.84
2006	1.52	14.30	13.87	32.64	11.38	---	4.08	1.83	5.47	85.09
2007	1.44	11.84	12.38	34.25	9.81	---	3.57	1.75	5.88	80.91
2008	1.29	9.79	10.05	31.70	11.31	---	3.59	1.99	5.55	75.28
2009	1.18	8.27	8.02	27.90	11.35	---	3.25	1.88	4.99	66.84
2010	1.00	8.38	7.73	26.84	10.65	---	2.85	2.03	5.00	64.47

Table A2. Commercial catch (million pounds, net weight). Figures include IPHC research catches.

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.52	4.62	5.60	8.19	1.67	0.71	---	---	---	---	---	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	---	---	---	---	---	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	---	---	---	---	---	27.54
1977	0.21	5.43	3.19	8.64	3.19	1.22	---	---	---	---	---	21.88
1978	0.10	4.61	4.32	10.30	1.32	1.35	---	---	---	---	---	22.00
1979	0.05	4.86	4.53	11.34	0.39	1.37	---	---	---	---	---	22.54
1980	0.02	5.65	3.24	11.97	0.28	0.71	---	---	---	---	---	21.87
1981	0.20	5.66	4.01	14.23	0.45	---	0.49	0.39	0.30	0.01	0.00	25.74
1982	0.21	5.54	3.50	13.52	4.80	---	1.17	0.01	0.24	0.00	0.01	29.01
1983	0.27	5.44	6.38	14.14	7.75	---	2.50	1.34	0.42	0.15	0.01	38.39
1984	0.43	9.05	5.87	19.77	6.69	---	1.05	1.10	0.58	0.39	0.04	44.97
1985	0.50	10.49	9.42	21.77	11.09	---	1.78	1.28	0.64	0.70	0.04	57.70
1986	0.59	11.43	11.04	34.66	9.22	---	3.56	0.28	0.72	1.29	0.05	72.83
1987	0.60	12.42	11.05	32.89	8.10	---	3.83	1.56	0.91	0.73	0.12	72.20
1988	0.49	12.91	11.57	39.36	7.20	---	1.96	1.62	0.72	0.46	0.01	76.29
1989	0.48	10.48	9.72	35.19	8.04	---	1.05	2.72	0.59	0.69	0.01	68.98
1990	0.34	8.69	9.97	29.96	8.91	---	2.61	1.39	0.55	1.05	0.06	63.54
1991	0.36	7.26	9.03	24.07	12.35	---	2.35	1.58	0.71	1.50	0.11	59.31
1992	0.44	7.68	10.06	27.43	8.80	---	2.75	2.36	0.81	0.74	0.07	61.15
1993	0.51	10.72	11.48	23.08	7.92	---	2.61	2.00	0.85	0.85	0.07	60.08
1994	0.37	9.98	10.61	25.69	3.90	---	1.84	2.06	0.73	0.73	0.12	56.02
1995	0.30	9.66	7.82	18.46	3.13	---	1.63	1.69	0.67	0.65	0.13	44.14
1996	0.30	9.57	8.92	19.87	3.69	---	1.72	2.10	0.69	0.72	0.12	47.69
1997	0.42	12.46	9.96	24.70	9.13	---	2.93	3.35	1.13	1.16	0.25	65.49
1998	0.46	13.23	10.24	25.85	11.22	---	3.44	2.92	1.26	1.32	0.19	70.12
1999	0.46	12.75	10.21	25.43	13.91	---	4.40	3.60	1.77	1.91	0.27	74.70
2000	0.49	10.84	8.48	19.33	15.47	---	5.18	4.72	1.75	1.94	0.35	68.55
2001	0.68	10.33	8.44	21.60	16.37	---	5.05	4.50	1.66	1.86	0.48	70.97
2002	0.86	12.11	8.63	23.27	17.35	---	5.11	4.10	1.22	1.76	0.56	74.95
2003	0.82	11.82	8.44	22.82	17.27	---	5.04	3.88	0.89	1.96	0.42	73.36
2004	0.88	12.20	10.27	25.24	15.48	---	3.58	2.73	0.96	1.66	0.32	73.31
2005	0.81	12.37	10.66	26.19	13.20		3.42	1.98	0.54	2.59	0.37	72.11
2006	0.83	12.04	10.51	25.77	10.80	---	3.34	1.59	0.49	2.37	0.37	68.12
2007	0.79	9.80	8.50	26.55	9.27	---	2.84	1.42	0.55	2.73	0.58	63.03
2008	0.68	7.78	6.22	24.58	10.75	---	3.03	1.77	0.73	2.56	0.60	58.70
2009	0.49	6.65	4.97	21.80	10.80	---	2.54	1.60	0.65	2.22	0.46	52.16
2010	0.42	6.76	4.50	20.45	10.12	---	2.33	1.75	0.82	2.16	0.41	49.71

Table A3. Sport catch (million pounds, net weight).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.01	0.01	0.07	0.20	0.00	0.00	0.00	0.00	0.01
1978	0.01	0.00	0.08	0.28	0.00	0.00	0.00	0.00	0.01
1979	0.02	0.01	0.17	0.37	0.00	0.00	0.00	0.00	0.02
1980	0.02	0.01	0.33	0.49	0.00	0.00	0.00	0.00	0.02
1981	0.02	0.01	0.32	0.75	0.00	0.01	0.00	0.00	0.02
1982	0.05	0.03	0.49	0.72	0.00	0.01	0.00	0.00	0.05
1983	0.06	0.05	0.55	0.95	0.00	0.00	0.00	0.00	0.06
1984	0.12	0.06	0.62	1.03	0.00	0.01	0.00	0.00	0.12
1985	0.19	0.26	0.68	1.21	0.00	0.01	0.00	0.00	0.19
1986	0.33	0.19	0.73	1.91	0.00	0.02	0.00	0.00	0.33
1987	0.45	0.26	0.78	1.99	0.00	0.03	0.00	0.00	0.45
1988	0.25	0.25	1.08	3.26	0.00	0.04	0.00	0.00	0.25
1989	0.33	0.32	1.56	3.01	0.00	0.02	0.00	0.00	0.33
1990	0.20	0.38	1.33	3.64	0.00	0.04	0.00	0.00	0.20
1991	0.16	0.29	1.65	4.26	0.01	0.13	0.00	0.00	0.16
1992	0.25	0.29	1.67	3.90	0.03	0.04	0.00	0.00	0.25
1993	0.25	0.33	1.81	5.27	0.02	0.06	0.00	0.00	0.25
1994	0.19	0.33	2.00	4.49	0.02	0.04	0.00	0.00	0.19
1995	0.24	0.89	1.76	4.49	0.02	0.06	0.00	0.00	0.24
1996	0.23	0.89	2.13	4.74	0.02	0.08	0.00	0.00	0.23
1997	0.36	0.89	2.17	5.51	0.03	0.07	0.00	0.00	0.36
1998	0.38	0.89	2.50	4.70	0.02	0.10	0.00	0.00	0.38
1999	0.34	0.86	1.84	4.23	0.02	0.09	0.00	0.00	0.34
2000	0.34	1.02	2.26	5.31	0.02	0.07	0.00	0.00	0.34
2001	0.45	1.02	1.93	4.68	0.02	0.03	0.00	0.00	0.45
2002	0.40	1.26	2.09	4.20	0.01	0.05	0.00	0.00	0.40
2003	0.40	1.22	2.26	5.43	0.01	0.03	0.00	0.00	0.40
2004	0.49	1.61	2.94	5.61	0.01	0.05	0.00	0.00	0.49
2005	0.48	1.84	2.80	5.67	0.01	0.05	0.00	0.00	0.48
2006	0.52	1.77	2.53	5.34	0.01	0.05	0.00	0.00	0.52
2007	0.50	1.56	3.05	6.28	0.03	0.04	0.00	0.00	0.50
2008	0.46	1.52	3.08	5.63	0.02	0.04	0.00	0.00	0.46
2009	0.46	1.10	2.37	4.76	0.03	0.02	0.00	0.00	0.46
2010	0.34	1.09	2.55	5.07	0.04	0.04	0.00	0.00	0.34

Table A4. Personal use (million pounds, net weight).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.01	0.05	0.72	0.96	0.06	0.23	0.00	0.00	2.03
1992	0.01	0.10	0.37	0.49	0.03	0.11	0.00	0.00	1.11
1993	0.02	0.30	0.11	0.33	0.06	0.12	0.00	0.00	0.94
1994	0.01	0.30	0.11	0.33	0.06	0.12	0.00	0.00	0.93
1995	0.01	0.30	0.00	0.10	0.04	0.09	0.00	0.00	0.54
1996	0.02	0.30	0.00	0.10	0.04	0.09	0.00	0.00	0.54
1997	0.02	0.30	0.00	0.10	0.04	0.09	0.00	0.00	0.54
1998	0.01	0.30	0.17	0.10	0.04	0.09	0.00	0.00	0.71
1999	0.01	0.30	0.17	0.07	0.02	0.17	0.00	0.00	0.74
2000	0.02	0.30	0.17	0.07	0.02	0.17	0.00	0.00	0.75
2001	0.02	0.30	0.17	0.07	0.02	0.17	0.00	0.00	0.75
2002	0.02	0.30	0.17	0.07	0.02	0.17	0.00	0.00	0.75
2003	0.03	0.30	0.63	0.28	0.03	0.02	0.00	0.10	1.38
2004	0.02	0.30	0.68	0.40	0.03	0.03	0.00	0.06	1.52
2005	0.04	0.30	0.60	0.43	0.05	0.04	0.00	0.09	1.54
2006	0.04	0.30	0.60	0.43	0.05	0.04	0.00	0.09	1.54
2007	0.04	0.30	0.58	0.38	0.05	0.03	0.00	0.11	1.48
2008	0.03	0.41	0.53	0.37	0.05	0.02	0.00	0.09	1.49
2009	0.03	0.41	0.46	0.33	0.03	0.03	0.00	0.03	1.31
2010	0.03	0.41	0.46	0.33	0.03	0.03	0.00	0.03	1.31

Table A5. O32 Bycatch (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1974	0.25	0.90	0.37	4.48	2.82	1.90	---	---	---	10.72
1975	0.25	0.91	0.45	2.61	1.66	1.11	---	---	---	6.99
1976	0.25	0.94	0.50	2.74	1.95	1.18	---	---	---	7.56
1977	0.25	0.72	0.41	3.37	1.55	1.98	---	---	---	8.27
1978	0.25	0.55	0.21	2.44	1.31	3.40	---	---	---	8.17
1979	0.25	0.70	0.64	4.49	0.69	3.45	---	---	---	10.22
1980	0.25	0.52	0.42	4.93	0.87	5.74	---	---	---	12.73
1981	0.25	0.53	0.40	3.99	1.10	4.37	---	---	---	10.64
1982	0.25	0.30	0.20	3.20	1.68	2.95	---	---	---	8.58
1983	0.25	0.29	0.20	2.08	1.22	2.47	---	---	---	6.52
1984	0.25	0.52	0.21	1.51	0.92	2.31	---	---	---	5.72
1985	0.25	0.55	0.20	0.80	0.34	2.25	---	---	---	4.38
1986	0.25	0.56	0.20	0.67	0.20	2.61	---	---	---	4.50
1987	0.25	0.79	0.20	1.59	0.39	2.67	---	---	---	5.89
1988	0.25	0.77	0.20	2.12	0.04	3.20	---	---	---	6.60
1989	0.25	0.72	0.20	1.80	0.44	1.91	---	---	---	5.33
1990	0.25	1.03	0.68	2.64	1.22	---	0.63	0.34	2.38	9.16
1991	0.25	1.22	0.55	3.13	1.04	---	0.73	0.24	2.25	9.41
1992	0.28	1.02	0.57	2.65	1.11	---	0.73	0.66	1.94	8.95
1993	0.28	0.65	0.33	1.91	0.47	---	0.13	0.48	1.41	5.65
1994	0.28	0.57	0.40	2.36	0.85	---	1.20	0.54	1.83	8.01
1995	0.38	0.71	0.22	1.46	0.83	---	1.09	0.15	2.11	6.95
1996	0.47	0.17	0.23	1.40	0.96	---	0.59	0.46	2.98	7.27
1997	0.47	0.11	0.24	1.55	0.73	---	0.85	0.20	2.97	7.11
1998	0.83	0.12	0.24	1.47	0.73	---	1.19	0.33	2.73	7.63
1999	0.76	0.11	0.23	1.28	0.74	---	0.91	0.34	2.64	7.01
2000	0.63	0.13	0.25	1.29	0.65	---	0.81	0.58	2.29	6.62
2001	0.65	0.15	0.18	1.62	0.63	---	0.57	0.39	2.92	7.11
2002	0.18	0.15	0.17	1.07	0.71	---	0.53	0.20	2.73	5.75
2003	0.22	0.13	0.14	1.18	0.50	---	0.52	0.22	2.11	5.02
2004	0.20	0.14	0.15	1.52	0.39	---	0.52	0.29	1.92	5.14
2005	0.07	0.19	0.14	1.32	0.36	---	0.46	0.28	2.21	5.04
2006	0.13	0.15	0.21	1.06	0.51	---	0.65	0.23	2.14	5.09
2007	0.10	0.15	0.22	0.99	0.45	---	0.66	0.33	1.90	4.79
2008	0.12	0.07	0.22	1.06	0.49	---	0.50	0.21	1.55	4.21
2009	0.20	0.11	0.22	0.97	0.47	---	0.65	0.28	1.63	4.52
2010	0.20	0.11	0.21	0.95	0.45	---	0.44	0.28	1.57	4.20

Table A6. O32 Commercial wastage (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.10	0.22	0.93	0.20	---	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.20	0.43	1.86	0.40	---	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.17	0.37	1.58	0.34	---	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.05	0.21	1.51	0.12	---	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.01	0.05	0.19	1.46	0.19	---	0.06	0.04	0.02	0.02	0.00	1.60
1990	0.02	0.12	0.24	1.11	0.22	---	0.18	0.01	0.04	0.07	0.00	3.20
1991	0.00	0.07	0.35	1.14	0.42	---	0.14	0.06	0.03	0.03	0.00	2.72
1992	0.01	0.05	0.25	0.64	0.18	---	0.03	0.02	0.01	0.01	0.00	1.95
1993	0.01	0.10	0.19	0.34	0.06	---	0.03	0.07	0.02	0.02	0.00	2.03
1994	0.00	0.07	0.23	0.85	0.04	---	0.11	0.06	0.02	0.04	0.00	1.94
1995	0.00	0.04	0.05	0.13	0.01	---	0.09	0.06	0.03	0.06	0.00	2.23
1996	0.00	0.03	0.04	0.18	0.02	---	0.05	0.04	0.02	0.01	0.00	1.25
1997	0.01	0.04	0.04	0.07	0.05	---	0.05	0.04	0.02	0.02	0.00	0.81
1998	0.00	0.05	0.04	0.15	0.06	---	0.04	0.04	0.01	0.01	0.00	1.29
1999	0.01	0.04	0.07	0.12	0.07	---	0.01	0.01	0.00	0.00	0.00	0.26
2000	0.01	0.03	0.04	0.06	0.06	---	0.02	0.03	0.01	0.01	0.00	0.35
2001	0.00	0.05	0.04	0.07	0.03	---	0.03	0.03	0.01	0.01	0.00	0.29
2002	0.01	0.04	0.03	0.14	0.03	---	0.02	0.02	0.01	0.01	0.00	0.36
2003	0.00	0.04	0.03	0.07	0.04	---	0.03	0.03	0.01	0.02	0.00	0.40
2004	0.00	0.04	0.03	0.08	0.02	---	0.03	0.02	0.01	0.01	0.00	0.26
2005	0.01	0.04	0.03	0.16	0.03	---	0.03	0.03	0.01	0.01	0.00	0.27
2006	0.00	0.04	0.02	0.05	0.01	---	0.02	0.02	0.01	0.01	0.00	0.29
2007	0.00	0.03	0.03	0.05	0.02	---	0.02	0.02	0.00	0.01	0.00	0.22
2008	0.00	0.02	0.01	0.06	0.00	---	0.02	0.01	0.00	0.01	0.00	0.20
2009	0.00	0.01	0.01	0.04	0.02	---	0.01	0.01	0.00	0.01	0.00	0.29
2010	0.00	0.01	0.01	0.04	0.02	---	0.01	0.00	0.00	0.01	0.00	0.14

Table A7-1. U32 Bycatch (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1974	0.15	0.83	0.16	0.77	0.60	5.72	---	---	---	8.24
1975	0.15	1.00	0.19	0.55	0.41	2.54	---	---	---	4.84
1976	0.15	1.12	0.21	0.76	0.50	3.38	---	---	---	6.12
1977	0.16	1.10	0.17	0.73	0.35	0.94	---	---	---	3.44
1978	0.16	0.92	0.16	0.61	0.53	1.62	---	---	---	4.00
1979	0.15	1.16	0.18	1.29	0.25	1.97	---	---	---	5.00
1980	0.15	0.86	0.10	0.92	0.38	3.50	---	---	---	5.91
1981	0.15	0.66	0.10	0.73	0.47	2.04	---	---	---	4.15
1982	0.15	0.57	0.10	0.60	0.49	1.80	---	---	---	3.72
1983	0.15	0.65	0.10	0.87	0.72	1.80	---	---	---	4.29
1984	0.15	0.56	0.09	0.63	0.59	2.39	---	---	---	4.40
1985	0.15	0.59	0.10	0.21	0.24	1.96	---	---	---	3.25
1986	0.15	0.60	0.10	0.16	0.21	2.96	---	---	---	4.20
1987	0.15	0.86	0.10	0.65	0.48	3.07	---	---	---	5.32
1988	0.15	0.84	0.10	1.24	0.01	5.66	---	---	---	8.00
1989	0.16	0.78	0.10	1.47	0.38	5.37	---	---	---	8.25
1990	0.16	0.65	0.18	1.47	0.83	---	1.54	0.15	3.55	8.53
1991	0.16	0.77	0.19	1.71	0.64	---	2.12	0.11	4.57	10.26
1992	0.17	0.73	0.16	2.02	0.87	---	2.04	0.31	5.05	11.34
1993	0.17	1.01	0.41	2.38	0.60	---	1.70	0.31	3.74	10.31
1994	0.17	0.65	0.13	1.55	0.54	---	1.71	0.12	4.08	8.93
1995	0.23	0.82	0.12	1.49	0.92	---	2.68	0.11	2.59	8.96
1996	0.14	0.13	0.11	1.29	0.97	---	1.58	0.16	2.72	7.11
1997	0.14	0.11	0.16	1.42	0.72	---	1.54	0.10	2.22	6.40
1998	0.25	0.10	0.12	1.19	0.66	---	1.30	0.16	2.03	5.80
1999	0.23	0.09	0.13	1.60	1.00	---	1.58	0.07	2.14	6.83
2000	0.19	0.10	0.14	1.61	0.87	---	1.34	0.11	2.32	6.67
2001	0.19	0.03	0.16	1.39	1.04	---	0.94	0.15	2.16	6.05
2002	0.38	0.09	0.17	1.12	1.21	---	1.70	0.08	2.04	6.78
2003	0.34	0.12	0.20	1.61	1.07	---	1.56	0.04	2.35	7.28
2004	0.30	0.12	0.20	2.08	0.84	---	1.57	0.05	2.14	7.30
2005	0.21	0.17	0.20	1.81	0.77	---	1.39	0.05	2.46	7.04
2006	0.24	0.14	0.13	1.91	0.89	---	1.06	0.19	3.22	7.79
2007	0.27	0.15	0.13	1.78	0.79	---	1.08	0.27	2.86	7.33
2008	0.18	0.06	0.13	1.91	0.85	---	0.81	0.18	2.34	6.46
2009	0.31	0.10	0.13	1.75	0.83	---	1.06	0.23	2.46	6.86
2010	0.31	0.10	0.13	1.71	0.78	---	0.72	0.23	2.36	6.34

Table A7-2. Break down of U32 Bycatch (million pounds, net weight) into U26 and U32/O26 components.

U26	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1996	0.01	0.02	0.03	0.58	0.44	0.75	0.04	1.16	3.02
1997	0.01	0.02	0.04	0.62	0.34	0.88	0.02	0.89	2.82
1998	0.01	0.02	0.03	0.43	0.24	0.59	0.05	1.03	2.40
1999	0.01	0.01	0.04	0.53	0.30	1.05	0.03	1.46	3.43
2000	0.01	0.02	0.04	0.53	0.26	0.81	0.04	1.50	3.21
2001	0.01	0.00	0.08	0.71	0.53	0.41	0.04	1.15	2.93
2002	0.08	0.02	0.10	0.63	0.66	1.17	0.02	1.25	3.92
2003	0.07	0.03	0.10	0.82	0.53	1.00	0.01	1.56	4.12
2004	0.07	0.03	0.10	1.05	0.42	1.01	0.01	1.42	4.11
2005	0.06	0.04	0.10	0.91	0.38	0.89	0.01	1.63	4.03
2006	0.08	0.02	0.04	1.05	0.42	0.74	0.13	2.08	4.55
2007	0.07	0.02	0.04	0.97	0.37	0.74	0.18	1.85	4.24
2008	0.02	0.01	0.04	1.04	0.40	0.56	0.11	1.51	3.70
2009	0.04	0.02	0.04	0.96	0.39	0.73	0.15	1.59	3.91
2010	0.04	0.02	0.04	0.94	0.37	0.50	0.15	1.53	3.57

O26/U32	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1996	0.14	0.11	0.08	0.72	0.53	0.83	0.13	1.56	4.09
1997	0.14	0.09	0.12	0.80	0.37	0.66	0.08	1.33	3.58
1998	0.24	0.08	0.09	0.77	0.42	0.71	0.11	1.00	3.40
1999	0.22	0.07	0.09	1.08	0.70	0.53	0.04	0.68	3.40
2000	0.18	0.09	0.10	1.08	0.60	0.52	0.07	0.82	3.46
2001	0.18	0.03	0.08	0.68	0.51	0.52	0.11	1.02	3.12
2002	0.29	0.07	0.08	0.49	0.56	0.53	0.06	0.78	2.86
2003	0.26	0.09	0.10	0.80	0.53	0.56	0.03	0.79	3.16
2004	0.24	0.10	0.10	1.03	0.42	0.56	0.04	0.72	3.19
2005	0.15	0.13	0.10	0.89	0.38	0.50	0.04	0.83	3.01
2006	0.16	0.12	0.09	0.87	0.48	0.33	0.07	1.14	3.25
2007	0.20	0.12	0.09	0.81	0.42	0.33	0.10	1.01	3.08
2008	0.16	0.05	0.09	0.87	0.45	0.25	0.06	0.83	2.76
2009	0.27	0.09	0.09	0.79	0.44	0.33	0.08	0.87	2.96
2010	0.27	0.09	0.09	0.78	0.42	0.22	0.08	0.83	2.78

Table A8. U32 Commercial wastage (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.00	0.08	0.04	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.20
1975	0.00	0.14	0.05	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.31
1976	0.00	0.16	0.04	0.11	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.34
1977	0.00	0.14	0.03	0.09	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.29
1978	0.00	0.11	0.04	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.28
1979	0.00	0.12	0.04	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
1980	0.00	0.14	0.03	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
1981	0.00	0.15	0.04	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.35
1982	0.00	0.16	0.03	0.12	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.40
1983	0.00	0.19	0.06	0.12	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.53
1984	0.01	0.36	0.07	0.16	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.72
1985	0.01	0.43	0.11	0.19	0.18	---	0.00	0.00	0.00	0.00	0.00	0.95
1986	0.01	0.47	0.13	0.34	0.15	---	0.01	0.00	0.00	0.00	0.00	1.15
1987	0.01	0.50	0.14	0.37	0.14	---	0.02	0.01	0.00	0.00	0.00	1.23
1988	0.01	0.50	0.16	0.51	0.13	---	0.01	0.01	0.01	0.00	0.00	1.36
1989	0.00	0.39	0.14	0.50	0.15	---	0.02	0.01	0.01	0.00	0.00	1.24
1990	0.00	0.31	0.15	0.48	0.18	---	0.04	0.00	0.01	0.00	0.00	1.17
1991	0.00	0.16	0.14	0.41	0.25	---	0.04	0.01	0.01	0.00	0.00	1.03
1992	0.00	0.16	0.17	0.53	0.19	---	0.02	0.02	0.01	0.00	0.00	1.13
1993	0.01	0.22	0.20	0.48	0.18	---	0.01	0.03	0.01	0.00	0.00	1.15
1994	0.00	0.20	0.19	0.56	0.09	---	0.03	0.01	0.01	0.00	0.00	1.11
1995	0.00	0.19	0.10	0.28	0.05	---	0.03	0.02	0.01	0.00	0.00	0.65
1996	0.00	0.18	0.12	0.32	0.06	---	0.04	0.03	0.01	0.00	0.00	0.73
1997	0.00	0.25	0.14	0.43	0.16	---	0.04	0.02	0.01	0.00	0.00	1.05
1998	0.00	0.28	0.15	0.47	0.22	---	0.03	0.02	0.01	0.00	0.00	1.20
1999	0.00	0.28	0.15	0.49	0.30	---	0.02	0.01	0.01	0.00	0.00	1.34
2000	0.00	0.24	0.14	0.39	0.37	---	0.02	0.02	0.01	0.00	0.00	1.29
2001	0.01	0.24	0.14	0.46	0.44	---	0.03	0.03	0.01	0.00	0.00	1.44
2002	0.01	0.29	0.16	0.52	0.53	---	0.04	0.03	0.01	0.00	0.00	1.66
2003	0.01	0.30	0.17	0.53	0.59	---	0.06	0.03	0.02	0.00	0.00	1.77
2004	0.01	0.34	0.23	0.61	0.60	---	0.07	0.04	0.02	0.00	0.01	1.93
2005	0.01	0.39	0.26	0.66	0.56	---	0.08	0.04	0.03	0.01	0.01	2.03
2006	0.01	0.41	0.28	0.67	0.51	---	0.09	0.03	0.02	0.01	0.01	2.05
2007	0.02	0.44	0.27	0.92	0.42	---	0.10	0.03	0.02	0.01	0.01	2.29
2008	0.02	0.26	0.21	0.92	0.68	---	0.09	0.02	0.02	0.01	0.01	2.34
2009	0.02	0.23	0.26	1.12	0.77	---	0.09	0.01	0.02	0.02	0.01	2.62
2010	0.01	0.23	0.24	1.42	0.89	---	0.10	0.01	0.02	0.03	0.01	3.04

Table A8-2. Break down of U32 Wastage (million pounds, net weight) into U26 and U32/O26 components.

U26	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1996	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.03
1997	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.03
1998	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.03
1999	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.04
2000	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.04
2001	0.00	0.00	0.01	0.01	0.02	0.01	0.00	0.00	0.05
2002	0.00	0.01	0.01	0.02	0.03	0.01	0.00	0.00	0.07
2003	0.00	0.01	0.00	0.02	0.03	0.01	0.00	0.00	0.08
2004	0.00	0.02	0.01	0.02	0.04	0.01	0.00	0.00	0.09
2005	0.00	0.02	0.02	0.03	0.04	0.01	0.00	0.00	0.11
2006	0.00	0.02	0.02	0.03	0.04	0.01	0.00	0.01	0.15
2007	0.00	0.02	0.01	0.04	0.04	0.02	0.00	0.01	0.16
2008	0.00	0.01	0.01	0.03	0.07	0.02	0.00	0.01	0.17
2009	0.00	0.01	0.01	0.05	0.07	0.02	0.00	0.01	0.17
2010	0.00	0.00	0.01	0.05	0.08	0.02	0.00	0.01	0.19

O26/U32	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1996	0.00	0.18	0.11	0.31	0.06	0.02	0.02	0.01	0.70
1997	0.00	0.24	0.13	0.42	0.16	0.03	0.03	0.02	1.02
1998	0.00	0.27	0.14	0.46	0.21	0.04	0.02	0.02	1.17
1999	0.00	0.27	0.15	0.48	0.29	0.05	0.03	0.03	1.29
2000	0.00	0.24	0.13	0.38	0.36	0.07	0.04	0.03	1.25
2001	0.01	0.23	0.14	0.45	0.43	0.08	0.04	0.04	1.39
2002	0.01	0.28	0.15	0.50	0.50	0.08	0.03	0.04	1.59
2003	0.01	0.29	0.16	0.51	0.56	0.10	0.03	0.04	1.69
2004	0.01	0.33	0.22	0.60	0.56	0.08	0.02	0.04	1.84
2005	0.01	0.37	0.25	0.63	0.52	0.09	0.01	0.04	1.92
2006	0.01	0.39	0.26	0.63	0.47	0.09	0.01	0.05	1.90
2007	0.02	0.42	0.26	0.88	0.38	0.11	0.02	0.07	2.13
2008	0.02	0.26	0.20	0.89	0.61	0.11	0.02	0.09	2.17
2009	0.02	0.23	0.25	1.07	0.71	0.12	0.01	0.07	2.46
2010	0.01	0.23	0.23	1.37	0.81	0.12	0.03	0.08	2.85

Table A9. IPHC setline survey WPUE of O32 fish in weight (net pounds per skate).

Figures refer to entire areas. For cases where only part of an area was fished (e.g., northern 2B, western 3A), the WPUE shown is an adjusted value. J-hook values are raw J-hook catch rates. Area 4CDE is constructed from five subareas: Area 4D Edge, Area 4IC (Pribilofs), 4ID (St. Matthew); Area 4S (southern Bering Sea shelf), and 4N (northern Bering Sea shelf. The 4N and 4S time series are constructed using trawl survey data (see text for full details). The bottom area (0-400fm) in thousands of nmi^2 is also listed for each area.

Bottom Area	2A	2B	2C	3A	3B	4A	4B	4D	4IC	4ID	4S	4N	4CDE	Total
	14.132	29.601	14.580	49.178	29.584	19.888	19.711	15.313	2.094	1.925	141.103	59.499	219.934	396.608
J-Hook WPUE:														
1974	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1976	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1977	---	13	---	58	---	---	---	---	---	---	---	---	---	---
1978	---	19	---	27	---	---	---	---	---	---	---	---	---	---
1979	---	---	---	41	---	---	---	---	---	---	---	---	---	---
1980	---	25	---	76	---	---	---	---	---	---	---	---	---	---
1981	---	16	---	131	---	---	---	---	---	---	---	---	---	---
1982	---	21	114	130	---	---	---	---	---	---	6	0	---	---
1983	---	18	142	119	---	---	---	---	---	---	4	0	---	---
C-Hook WPUE:														
1984	---	57	260	361	---	---	---	---	---	---	6	1	---	---
1985	---	42	261	378	---	---	---	---	---	---	6	1	---	---
1986	---	38	283	305	---	---	---	---	---	---	7	0	---	---
1987	---	---	---	---	---	---	---	---	---	---	8	0	---	---
1988	---	---	---	---	---	---	---	---	---	---	17	0	---	---
1989	---	---	---	---	---	---	---	---	---	---	11	0	---	---
1990	---	---	---	---	---	---	---	---	---	---	12	1	---	---
1991	---	---	---	---	---	---	---	---	---	---	11	2	---	---
1992	---	---	---	---	---	---	---	---	---	---	9	1	---	---
1993	---	93	---	261	---	---	---	---	---	---	19	5	---	---
1994	---	---	---	254	---	---	---	---	---	---	15	4	---	---
1995	29	148	---	300	---	---	---	---	---	---	16	4	---	---
1996	32	156	306	317	352	---	---	---	---	---	24	18	---	---
1997	35	139	411	331	414	245	282	111	111	111	19	4	23	138
1998	36	82	232	281	435	299	216	299	299	299	26	7	45	134
1999	37	88	205	241	438	290	203	290	290	290	26	0	42	126
2000	39	93	233	272	373	276	216	213	213	213	19	3	32	121
2001	41	102	237	256	357	199	171	197	197	197	20	5	31	112
2002	33	92	261	299	297	168	119	263	263	263	12	2	31	109
2003	22	73	223	229	262	154	104	195	195	195	17	4	29	92
2004	27	86	173	270	236	137	73	132	132	132	17	3	23	89
2005	28	72	171	276	211	107	86	69	69	69	16	3	18	82
2006	16	59	144	233	181	85	96	54	82	65	17	3	17	71
2007	19	57	140	212	191	67	87	59	41	60	12	3	13	66
2008	19	89	108	189	126	84	103	78	31	94	8	3	13	61
2009	8	86	115	149	113	84	107	78	34	59	12	3	15	56
2010	17	89	110	117	91	73	68	48	59	51	12	3	13	47

Table A10. Commercial WPUE (net pounds per skate).

Values before 1984 are raw J-hook catch rates, with no hook correction. 1983 is excluded because it consists of a mixture of J- and C-hook data. No value is shown for area/years after 1980 with fewer than 500 skates of reported catch/effort data. Total column recomputed in 2007 with new bottom area numbers.

	2A	2B	2C	3A	3B	4A	4B	4C	4D	4E	Total
J-hook CPUE:											
1974	59	64	57	65	57	---	---	---	---	---	---
1975	59	68	53	66	68	---	---	---	---	---	---
1976	33	53	42	60	65	---	---	---	---	---	---
1977	83	61	45	61	73	---	---	---	---	---	---
1978	39	63	56	78	53	---	---	---	---	---	---
1979	50	48	80	86	37	---	---	---	---	---	---
1980	37	65	79	118	113	---	---	---	---	---	---
1981	33	67	145	142	160	158	99	110	---	---	---
1982	22	68	167	170	217	103	---	91	---	---	---
1983	---	---	---	---	---	---	---	---	---	---	---
C-hook CPUE:											
1984	63	148	314	524	475	366	161	NA	197	---	350
1985	62	147	370	537	602	333	234	594	330	---	395
1986	60	120	302	522	515	265	238	427	239	---	351
1987	57	131	260	504	476	341	220	384	241	---	345
1988	134	137	281	503	655	453	224	371	201	---	387
1989	124	134	258	455	590	409	268	331	384	---	376
1990	168	175	269	353	484	434	209	288	381	---	334
1991	158	148	233	319	466	471	329	223	398	---	333
1992	115	171	230	397	440	372	278	249	412	---	338
1993	147	208	256	393	514	463	218	257	851	---	399
1994	93	215	207	353	377	463	198	167	480	---	328
1995	116	219	234	416	476	349	189	286	475	---	351
1996	159	226	238	473	556	515	269	297	543	---	415
1997	226	241	246	458	562	483	275	335	671	---	423
1998	194	232	236	451	611	525	287	287	627	---	429
1999	342	213	199	437	538	497	310	271	535	---	398
2000	263	229	186	443	577	547	318	223	556	---	416
2001	169	226	196	469	431	474	270	203	511	---	382
2002	181	222	244	507	399	402	245	148	503	---	379
2003	173	221	233	487	364	355	196	105	389	---	346
2004	143	203	240	485	328	315	202	120	444	---	338
2005	137	195	203	446	293	301	238	91	379	---	314
2006	155	201	170	403	292	241	218	72	280	---	283
2007	96	198	160	398	257	206	230	65	237	---	268
2008	69	174	161	370	234	206	193	94	247	---	249
2009	98	192	155	320	211	235	189	88	249	---	237
2010	170	237	165	302	177	191	164	82	190		222

Appendix B. Evolution of IPHC assessment methods, 1982-2007

From 1982 through 1994, the halibut stock assessment relied on CAGEAN, a simple age-structured model fitted to commercial catch-at-age and catch-per-effort data (Quinn et al. 1985). The constant age-specific commercial selectivities used in the model were fundamental model parameters, estimated directly.

Beginning in the late 1980s, halibut growth rates in Alaska declined dramatically. As a result, age-specific selectivity decreased. CAGEAN did not allow for that, and by the mid-1990s was seriously underestimating abundance. In effect, it interpreted lower catches as an indication of lower abundance, whereas the real cause was lower selectivity. Incoming year classes were initially estimated to be small, but in subsequent years' assessments those estimates would increase when unexpectedly large numbers of fish from those year classes appeared in the catches. The year-to-year changes in the stock trajectory shown by the assessment therefore developed a strong retrospective pattern. Each year's fit showed a steep decline toward the end, but each year the whole trajectory shifted upward.

The staff sought to remedy that problem by making selectivity a function of length in a successor model developed in 1995. It accounted not only for the age structure of the population, but also for the size distribution of each age group and the variations in growth schedule that had been observed. The fundamental selectivity parameters in this model were the two parameters of a function (the left limb of a normal density) by which the selectivity of an individual fish was determined from its length. The age-specific selectivity of an entire age group was calculated by integrating length-specific selectivity over the estimated length distribution of the age group, and that age-specific selectivity was used to calculate predicted catches. The new model was fitted to both commercial data and IPHC setline survey data, with separate length-specific selectivity functions. Commercial catchability and selectivity were allowed to drift slowly over time, while survey catchability and selectivity were held constant (Sullivan et al. 1999).

When this model was fitted to data from Area 2B and Area 3A, quite different length-specific selectivities were estimated, which suggested that fishery selectivity was not wholly determined by the properties of the gear and the size of the fish but also depended on fish behavior (e.g., migration). These behavioral elements are likely to be more related to age than size. The age of sexual maturity, for example, remained virtually the same in Alaska despite the tremendous decrease in growth, so the size at maturity is now much smaller than it was. While size must affect selectivity, it was thought that age was also influential.

To allow for that, the model was fitted in two ways. The original form was called the "length-specific" fit, because a single set of estimates of the two parameters of the length-based survey selectivity function was used in all years. In a second form, called the "age-specific" fit, the parameters were allowed to drift over time (like the commercial selectivity parameters), but they were required (by a heavy penalty) to vary in such a way that the integrated age-specific selectivities calculated in each year remained constant over time.

The usual diagnostics gave little reason to prefer one fit over the other. Goodness of fit was similar: good for both in 2B, not so good for either in 3A. The retrospective behavior of both fits was dramatically better than that of CAGEAN and quite satisfactory in all cases, although the length-specific fit was more consistent from year to year in 3A and the age-specific fit was more consistent in 2B (Clark and Parma 1999). The two fits produced very similar estimates of abundance in Areas 2B and 2C, but in 3A the length-specific estimates were substantially higher, so out of caution the staff catch limit recommendations were based on the age-specific fit through 1999.

The assessment model was simplified and recoded as a purely age-structured model in 2000 to eliminate some problems associated with the modeling of growth and the distribution of length at age. It retained the option of modeling survey selectivity as a function of mean length at age (observed not predicted), but the production fits continued to be based on constant age-specific survey selectivity, estimated directly as a vector of age-specific values rather than as a parametric function of age.

The fit of this model to Area 3A data in 2002 showed a dramatic retrospective pattern, similar to the pattern of successive CAGEAN fits in the mid-1990s. Treating setline survey selectivity as length-specific rather than age-specific largely eliminated the pattern. Accumulated data showing very similar trends in catch at length in IHPC setline surveys and NMFS trawl surveys provided further evidence that setline selectivity is, after all, determined mainly by size rather than by age (Clark and Hare 2003).

Another anomaly of the 3A model fit in 2002 was the unexpectedly large number of old fish (age 20+) in the last few years' catches. This was found to be the result of an increase in the proportion of otoliths read by the break-and-burn rather than surface method. Surface readings tend to understate the age of older fish, and IPHC age readers had been gradually doing more and more break-and-burn readings as the number of older fish in the catches increased. The poor model fit at these ages indicated a need to deal explicitly with the bias and variance of both kinds of age readings.

An entirely new model was written for the 2003 assessment (Clark and Hare 2004). Both commercial and survey selectivity were parameterized as piecewise linear functions of mean length at age in survey catches, and were required to reach an asymptote of one at or before a length of 130 cm. Because females are larger than males, all of the population accounting and predictions were done separately for each sex. (The age/sex/size composition of the commercial landings was estimated external to the assessment for this purpose.) The observed age compositions (surface or break-and-burn) were predicted by applying estimated misclassification matrices to the age distributions. Even in its most parsimonious form—with just one survey and one commercial selectivity schedule for both sexes in all years—this model achieved very good fits to the sex-specific observations and good retrospective performance. It also produced somewhat higher estimates of average recruitment and recruitment variability. With this simple model it was feasible do standalone analytical assessments of abundance in Areas 3B, 4A, and 4B for the first time, using data from 1996-2003.

Only two minor changes were made for the 2004 assessment, and neither had a significant effect on the estimates of abundance. First, both the 2004 PIT tag recoveries (Clark and Chen 2005) and a reanalysis of earlier wire tag data (Clark 2005) indicated that commercial selectivity is not always asymptotic; it appeared to be more dome-shaped in Area 2B and more ramp-shaped in Area 3A. Fitting the assessment model with free-form selectivity schedules showed much the same thing for commercial selectivity, namely an assortment of shapes beyond 120 cm. Nevertheless a schedule that reaches an asymptote of one at 120 cm is a good approximation to and compromise among the free estimates, and using an asymptotic commercial schedule is desirable for computing exploitable biomass and reporting harvest rates, so that it what was used in the assessment. All of the freely estimated survey selectivities either level out or increase after 120 cm. Freely estimated survey selectivities present no practical difficulties, so they were estimated that way in the assessment, and most of the estimates were ramp-shaped.

Apart from a few minor and inconsequential corrections and alterations, the 2005 analytical assessment was the same as the 2004 assessment. The only important change in procedure was the use of the NMFS trawl survey to estimate biomass in Area 4CDE where an analytical assessment was not done.

In 2006, growing concerns about migration of O32 fish from western to eastern areas led the staff to doubt the validity of the closed-area assessments that had been done for many years (Clark and Hare 2007a). The staff has estimated since 2006 coastwide abundance by fitting the model to a coastwide dataset, and estimated biomass in each area in accordance with survey estimates of relative abundance (Clark and Hare 2007b). U32 discard mortality in the halibut fishery was added to the removals beginning with the 2007 assessment; it had the effect of decreasing the present biomass estimate by less than 1%.

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Assessment of the Pacific halibut stock at the end of 2009

Steven R. Hare

Abstract

Since 2006, the IPHC stock assessment has been fitted to a coastwide dataset to estimate total exploitable biomass. Coastwide exploitable biomass at the beginning of 2010 is estimated to be 334 million pounds. The assessment revised last year's estimate of 325 million pounds at the start of 2009 downwards to 291 million pounds and projects an increase of 14% over that value to arrive at the 2010 value of 334 million pounds. The downward revision is part of a still present, but relatively modest, retrospective behavior shown in the model. At least part, if not most, of the downward revision for 2009 is believed to be caused by the ongoing decline in size at age, which continues for all ages in all areas. Just as last year, projections based on the currently estimated age compositions suggest that the exploitable and female spawning biomasses will increase over the next several years as a sequence of strong year classes recruit to the O32 component of the population. Trawl estimates of abundance were assembled this year and are comparable to the assessment estimates. The coastwide exploitable biomass was apportioned among regulatory areas in accordance with survey estimates of relative abundance, modified by 1) adjustment factors for hook competition, station depth distribution, and timing of the annual setline survey; 2) equal (1:1:1) and reverse (2:2:1) weighting of the three most recent survey years; and 3) weighting with historical shares in a 2:1 ratio with the survey index receiving the larger weight. These factors resulted in 32 different apportionment schemes.

Introduction

Each year the International Pacific Halibut Commission (IPHC) staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial and sport fisheries, other removals and scientific surveys (Appendix A). A biologically determined level for total removals from each regulatory area is calculated by applying a fixed harvest rate to the estimate of exploitable biomass in that area. This level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding level for catches in directed fisheries subject to allocation is called the fishery CEY. It comprises the commercial setline catch in all areas plus the sport catch in Area 2B, and the sport plus ceremonial and subsistence catches in Area 2A. It is calculated by subtracting from the total CEY an estimate of all unallocated removals—bycatch of halibut over 32 inches in length (hereafter, "O32"), wastage of O32 fish in the halibut fishery, fish taken for personal use, and sport catch except in Areas 2A and 2B. Staff recommendations for catch limits in each area are based on the estimates of fishery CEY but may be higher or lower depending on a number of statistical, biological, and policy considerations. Similarly, the Commission's final quota decisions form the management targets for the coming year and are based on the staff's recommendations but may be higher or lower.

For many years the staff assessed the stock in each regulatory area by fitting a model to the data from that area (Appendix B). This procedure relied on the assumption that the stock of fish of catchable size in each area was closed, meaning that net migration was negligible. A growing body of evidence from both the assessments (Clark and Hare 2007) and the ongoing mark-recapture experiment (Webster and Clark 2007, Webster 2010) shows that there is a continuing and predominantly eastward migration of catchable fish from the western area (Areas 3 and 4) to the eastern side (Area 2). The effect of this unaccounted for migration on the closed-area stock assessments was to produce underestimates of abundance in the western areas and overestimates in the eastern areas. To some extent this has almost certainly been the case for some time, meaning that exploitation rates were well above the target level in Area 2 and a disproportionate share of the catches have been taken from there.

In order to obtain an unbiased estimate of the total exploitable biomass (EBio) beginning with the 2006 assessment, the staff built a coastwide data set and fitted the model to it. Exploitable biomass in each regulatory area was estimated by partitioning, or apportioning, the total in proportion to an estimate of stock distribution derived from the setline survey catch rates (WPUE). Specifically, an index of abundance in each area was calculated by multiplying survey WPUE (running 3-year average) by total bottom area between 0 and 400 fm (Hare et al. 2010). The logic of this index is that survey WPUE can be regarded as an index of density, so multiplying it by bottom area gives a quantity proportional to total abundance. This year several adjustments to the index for each area, derived on the basis of hook competition, survey timing and depth distribution of survey stations were examined For apportionment purposes, the staff recommended that the survey index for each area be adjusted on the basis of hook competition and survey timing. The estimated proportion in each area is then the adjusted index value for that area divided by the sum of the adjusted index values.

Changes to the assessment and apportionment in 2009

The following is summary of changes, additions and updates to the 2009 assessment and apportionment procedures compared to the previous halibut assessment (Hare and Clark 2009)

- 2009 survey and commercial data added
- Regulatory area bottom area definitions expanded and revised
- The setline survey stations around the Pribilof Islands and St. Matthew island are used to index density for those regions
- The Norton Sound trawl survey data were assembled and a density index computed for Area 4CDE northern shelf
- Swept area estimates of Exploitable Biomass (EBio) from independent trawl surveys were assembled for all regulatory areas except 2B and 2A
- Three adjustment factors considered for the survey index - hook competition, bottom depth distribution, and timing of setline survey. The adjustments can be combined resulting in eight possible adjustment factors.
- The (possibly adjusted) survey indices are averaged over the past three years using both an equal weighted (1:1:1) and a reverse weighted (2:1:1) scheme to apportion 2010 beginning of year biomass
- The (possibly adjusted) and 3-year averaged survey indices are optionally weighted by a fixed 15-year (1993-2007) historical removals share
- The three factors (adjustment, time averaging, historical shares weighting) result in 32 possible apportionment schemes.
- The terms WPUE and NPUE replace the more generic CPUE to refer to Weight Per Unit Effort and Numbers Per Unit Effort, respectively.

- O32 (Over 32") and U32 (Under 32") replace the terms "legal-sized" and "sublegal-sized" when referring to halibut size.

Observations from the survey and commercial fishery

The IPHC collects data from a variety of sources to characterize the fishery, status and population trends in all regulatory areas, and assist in fitting a population assessment model. Some of the more important datasets are summarized herein.

Halibut removals

Total removals from the halibut populations come from seven categories: commercial catch (IPHC survey catch is included in this category), sport catch, O32 bycatch (from a variety of fisheries targeting species other than halibut), personal use, O32 wastage from the commercial fishery, sublegal-sized bycatch from non-target fisheries, and sublegal-sized wastage from the commercial fishery. Detailed descriptions of each category are contained in the Fishery Removals section of the annual Report of Assessment and Research Activities (Gilroy et al. 2010). The 2009 regulatory area total removals are illustrated in Figure 1, coastwide total removals from 1935 to 2009 are illustrated in Figure 2, and regulatory area total removals for 1974-2009 are illustrated in Figure 3 (and listed in Appendix Tables A1-A8). On a coastwide basis, total removals are at their lowest level since 1996 and third lowest total over the past 23 years. The pattern of changes between 1996 removals and 2009 removals has been quite different among regulatory areas, however.

Changes in definition of bottom area

The definition of halibut habitat is important to the process of apportioning coastwide biomass. It also plays a role in weighting various regulatory area datasets to construct the coastwide dataset used in fitting the stock assessment (Clark and Hare 2007). For the past several years, halibut habitat has been defined as all bottom area between 0 and 300 fathoms. While the setline survey restricts stations to a range of 20-275 fathoms, the mean density estimates are applied to the larger habitat definition. A recent review of commercial landings revealed that commercial fishing for halibut is increasingly operating in waters deeper than 300 fathoms (Hare et al. 2010). Correspondingly, we have expanded the definition of halibut habitat to 400 fathoms. In most areas, the additional habitat is minor with the largest increases realized by Areas 4A and 4B. An additional change in halibut habitat concerning Area 4CDE is elaborated upon in the next section. Additionally, a higher resolution digital bathymetry database has been made available thus we have recomputed the total amount of habitat (0-400 fm) in each regulatory area. The new computations and totals are described in Hare et al. (2010) and the square nautical miles of habitat are listed in Table A9.

Treatment of Area 4CDE

Due to its large size and relatively low density of halibut, Area 4CDE does not have a grid of setline survey stations across its entire range. Since 2000, the IPHC setline survey has included 48 stations along the 4D Edge at depths between 75 and 275 fathoms. Since 2006, 29 stations have been surveyed annually around the Pribilof Islands and St. Matthew Island. Finally, a unique grid survey, comprised of 82 stations was carried out in 2006 over the southern Eastern Bering

Sea shelf (Soderlund et al. 2007). Extensive use is also made of the data from the NMFS annual Eastern Bering Sea trawl survey.

In order to construct a more comprehensive and representative dataset for Area 4CDE, several changes and additions have been implemented this year. The 4D Edge, with the 48 stations, remains unchanged. The 4D Edge represents about 91,711 nmi^2. Beginning this year, the 4CDE islands surveyed as part of the survey now form an area operationally (though not officially) referred to as Area 4I and comprises about 4,019 nmi^2. Prior to this year, the habitat definition for Area 4CDE stopped at 61°N. A review of commercial landings showed that a not-insignificant amount of commercial landings were being taken north of 61°N, up to an including Norton Sound (Hare et al. 2010). To account for this area, we have expanded Area 4CDE northwards to 65.5°N - though constrained on the western boundary by the International dateline. This newly added region is operationally (again, not officially) referred to as Area 4N, and includes that part of Area 4E north of 61°N and Area 4D north of 62.5°N. The area represented by Area 4N is about 46,793 nmi^2. The reason for the differing southern boundaries is discussed later in the section on Bering Sea trawl surveys. South of Area 4N, that part of the shelf that is not part of the 4D Edge or Area 4I, is operationally termed Area 4S and comprises about 153,474 nmi^2. The boundaries for the four Area 4CDE areas are illustrated in Figure 4. Density estimates for the four areas all rely on surveys - Areas 4D Edge and 4I on the IPHC setline survey; Areas 4S and 4N on trawl surveys as discussed in the next section.

NMFS and ADFG Bering Sea trawl surveys

Every year, the IPHC places a sampler aboard the National Marine Fisheries Service (NMFS) Eastern Bering Sea (EBS) groundfish/crab trawl survey. The sampler collects biological data on the halibut catches, taking lengths of almost all halibut caught and selecting a subsample for aging. The 2009 effort is described in Sadorus and Lauth (2010). Due to the high cost, and very low catch rate, of setline surveying halibut in the EBS, the IPHC does not conduct the Standardized Stock Assessment (SSA) grid survey in that region. While the IPHC survey does operate along the Area 4D shelf edge, that region is not indicative of densities and trends across the broad shelf. For the purposes of apportionment, it is vital that a measure of density for the EBS shelf be derived each year, and the NMFS groundfish trawl survey is leveraged to allow just such an estimate. The NMFS survey generates swept area estimates of abundance for the southern part of the EBS shelf (equivalent to operational IPHC area 4S). In 2006, the IPHC added 100 extra stations to the SSA grid survey and placed these across the shelf to get an estimate of shelf-wide density (Soderlund et al. 2007). In that year, mean density was estimated to be 18.1 pounds per standardized survey skate. It is important to note that the value of 18.1 represented a weighted average of a value of 16.8 lbs for the shelf and 76 lbs/skate for the 4I stations. Beginning this year, we will use the value of 16.8 lbs/skate as the standard O32 halibut density for Area 4S in 2006. Area 4S comprises the part of the shelf south of 61N, not including the 4D Edge or Area 4I. We also decided to include the region between 61°N and 62.5°N as part of 4S. The reason for doing so is that, unlike the 4E region between 61°N and 62.5°N, about half of this region has NMFS trawl stations. As such, we felt that halibut density in this section of 4D is more similar to the density found on the south shelf than that found for the northern shelf (indexed by the Norton Sound survey discussed below).

The 2006 setline estimate of density is tied to the NMFS trawl survey to provide an annually varying estimate of density for 4S. We feel this method is valid for the following reason. From the NMFS trawl survey we actually obtain swept area estimates of abundance at length. We then apply the stock assessment estimated survey selectivity at length schedule to the full catch to provide an index of survey catch rate, comparable to the SSA survey fishing gear. Figure 5 illustrates how the length frequency distribution resulting from this treatment of trawl survey data compares to the actual length frequencies collected in the 2006 IPHC special EBS setline survey. In this manner we are able to obtain, for a tiny fraction of the cost it would take to survey the southern EBS with a setline survey, a highly reliable index of halibut abundance across the EBS flats. Figure 6 provides an illustration of the time trend in abundance estimated from the trawl survey. In 2008, the index was at its lowest point since the mid 1980s, but the 2009 value showed an increase of 40%. The 4S index has shown a strong decline in halibut abundance over the past decade, with an estimated decline of more than 50%. The index of total biomass, however, has not changed greatly and the length frequency data indicate very large numbers of U32 fish across the southern EBS shelf (Fig. 7).

As noted above, the shelf area north of 62.5°N (in 4D) and north of 61°N (in 4E) has been added to the definition of halibut habitat this year. In adding this area, however, we were concerned as to the validity of applying the south shelf density estimate from the NMFS trawl survey to the northern part of the shelf. Fortunately, there has been an approximately triennial trawl survey, conducted in a similar manner to the 4S survey with a similar net, in the greater Norton Sound area since 1976. The survey was conducted by NMFS until 1991 and since then by the Alaska Department of Fish and Game (ADFG). In all, there have been surveys conducted in 1976, 1979, 1982, 1985, 1988, 1991, 1996, 1999, 2002, 2006, and 2008). There has been no formal analysis of the halibut data from the survey; however, ADFG provided us with the raw catch rate (WPUE) data at all stations fished each year. The survey has been conducted each time in a core area (indicated by the Norton Sound outline in Figure 4) as well as opportunistic stations often well away from Norton Sound. In order to create a consistent index for Area 4N across years, we selected just the stations within the core area and calculated a simple mean value and its standard error (Fig. 8a). This index has units of kg. of halibut per km^2 area swept. As there are no sample data, we are unable to derive an O32 index similar to that derived from the NMFS trawl survey. To create a density index comparable to the other IPHC areas (i.e., O32 lbs/standard skate), we proceeded in the following manner.

1. Compute mean density (and standard error) for each Norton Sound ("Area 4N") survey year
2. Compute mean density in NMFS southern shelf trawl survey ("Area 4S") for the same years and in the same units.
3. Regress the square root transform of 4N density on the square root transform of the 4S density and use the regression parameters to estimate density in the unsurveyed years for 4N
4. Transform the estimates back to their original scale and retain the actual survey values in the years a survey was conducted in 4N (rather than use the predicted values)
5. Construct a standard IPHC density index (lbs/ skate) by multiplying the 4S index by the ratio of the 4N trawl density index to the 4S trawl density index.

This procedure makes several assumptions, most stringently that density trends in 4N and 4S vary synchronously. Consideration of the years with actual survey data shows this not to be that poor of an assumption and the square root transform downweights the single very large 4N data point of 1996 to achieve a closer match. The end result (Fig. 8b) is a density estimate comparable to the other IPHC areas. In general, 4N density averages 1/3rd to 1/10th of 4S density. As 4S is more than 3 times larger than 4N, the overall added biomass to 4S is relatively minor (Fig. 8c). More importantly though, all halibut are accounted for in Area 4CDE up to 65.5°N.

IPHC setline survey

The current SSA survey has been conducted since 1996 in almost all areas and in all years. The exceptions are the Eastern Bering Sea shelf which was surveyed only in 2006; Area 2A which was not surveyed in 1996, 1998, and 2000, the Area 4D edge which was not surveyed in 1996, 1998 and 1999, and Area 4A and 4B which were not surveyed in 1996. Stations are placed on a 10-nautical mile grid between depths of 20 and 275 fathoms, resulting in a total of approximately 1280 stations. The 2009 SSA survey is fully described in White et al. (2010). A key indicator of stock status in each regulatory area is the weight of O32 halibut caught per standardized skate, termed the survey WPUE (Fig. 9 and Appendix Table A9). Survey WPUE has declined by over 50% on a coastwide basis over the past 10 years. While the rate of decline has differed among areas, there has been a substantial decrease in WPUE in all areas, indicative of a consistent coastwide decline in exploitable biomass. As described earlier, Area 4CDE is assembled from four subareas. The derived WPUE indices from each of those areas are weighted by its respective bottom area to construct the single Area 4CDE WPUE time series shown in Figure 9. The component time series are illustrated in Figure 10, which gives a unified perspective on the relative densities of halibut in the different sub-areas of 4CDE.

The survey catch of halibut is sampled to obtain biological information about the stock including sex and age distribution and is described in Forsberg (2010a). The 2009 age distributions for males, females, and sexes combined for all regulatory areas are plotted in Figure 11. The age structure of the population is of considerable interest for a variety of reasons. These distributions indicate the relative abundance of fish available to the fishery, relative contributions to the female spawning biomass, etc. In 2009 as in 2008, there is a general tendency for an older age structure in the western areas, relative to the eastern areas. In particular, the lack of fish older than 20 years is noted for Area 2. Areas 3B and 4A present somewhat anomalous age distributions in that they more closely resemble Area 2 than Area 3A or most Area 4 distributions. The reasons for this are presently unclear although the estimated rate of fishing mortality is not excessive and there appears to be substantial recruitment into this area. The staff is recommending a reduction in the harvest rate in Area 3B in part based on the more truncated age distribution. Survey age-specific catch rates (Fig. 12) provide a means of gauging historic year class strength. Note that the age-specific catch rates are affected by the change in growth rate thus the survey indexes numbers of fish selected to the gear and not necessarily total numbers of fish in the population compared across years. The very strong 1987 and 1988 classes are readily apparent in Figure 12. Optimistically, it appears that the 1999 and 2000 year classes are now entering the survey catch at the larger rates the assessment model has been predicting the last few years. The declining growth is likely responsible for the delay in recruiting to the survey and it may still be a few years before these two year classes enter the commercial fishery in proportion to their overall numbers in the population.

Commercial fishery

The second major component of the annual IPHC data collection is sampling the commercial catch. The port sampling program is detailed in Erikson and MacTavish (2010) and age sampling in Forsberg (2010b). From commercial fishing logs, commercial CPUE is computed for each regulatory area (Fig. 13 and Appendix Table A10). As with the survey WPUE, there has been a consistent coastwide decline in commercial WPUE though not quite as pronounced. This is not unexpected however, as commercial fishers tend to move their effort to maintain their catch rate, whereas the survey maintains the same fishing locations every year. Approximately 1500 otoliths are collected and aged from each regulatory area (smaller samples in Areas 2A and 4B). Because commercially caught halibut are gutted at sea, the sex of halibut is unknown when sampled at the port of landing. A statistical methodology has been developed, based on sex ratio at length in survey catches, to parse out male and female proportions at age (see Clark 2004). The estimated sex and age composition of the commercial catch, by regulatory area, is illustrated in Figure 14. It is important to note that the distribution of ages for the total (sexes combined) is not statistically estimated (the distribution represents the otolith readings); it is the sex-specific distributions that are statistically derived. As with the survey age samples, the fish in Area 2 are, on average, several years younger than fish caught in Areas 3 and 4. Here, as well, Area 3B (but not Area 4A) is anomalous in that the average age of fish is closer to the Area 2 average.

Part of the coastwide decline in exploitable biomass can be attributed to a decline in size at age. For a given number of halibut in the population, a smaller size at age results in a smaller cumulative biomass. Figure 15a shows how the average weights of halibut in survey and commercial catches have changed over the past 12 years. Average weight has declined by 25% in the survey catches and 33% in the commercial catches. While the decline could be due to a decline in average age of the fish in the catches (since younger fish are smaller), Figure 15b shows this has not been the case as average age in both the survey and commercial catch has actually increased by a couple of years. Trends, by regulatory area, in average age and average weight are illustrated in Figure 16.

Description of the assessment model

The current halibut assessment model has remained essentially unchanged since 2003. It has been thoroughly described in an IPHC Scientific Report (Clark and Hare 2006) and was subjected to a peer review by two external scientists from the Center for Independent Experts (IPHC Staff 2008). Since the Commission's acceptance of a coastwide stock assessment model, much of the focus of the staff and the industry is now on how the coastwide estimate of exploitable biomass is apportioned among regulatory areas. For both these reasons, the assessment model for 2009 is identical to that used for the 2008 assessment. An extensive internal review of the assessment model is anticipated in the upcoming year. In the interest of brevity, little discussion is presented here of the model itself. Interested readers are referred to Clark and Hare (2006, 2007, 2008) for full details.

The IPHC assessment model is age- and sex-structured. Commercial and survey selectivities are both estimated as piecewise linear functions of observed mean length at age/sex in survey catches. (There is a 32-inch minimum size limit in the commercial fishery.) Commercial catchability is typically allowed to vary from year to year with a penalty of 0.03 on log differences. Some variation in survey catchability between years has been allowed in production fits since 2006. The model is fitted to commercial and survey catch at age/sex and CPUE.

Until 2006, estimates of halibut abundance were made using closed-area models for all areas except Areas 2A and 4CDE. Area 2A leveraged the Area 2B assessment and relative survey WPUE, while Area 4CDE relied upon the NMFS EBS trawl estimates of swept area abundance. The closed-area models are not considered reliable due to violation of the closed-population assumption. Beginning this year, we do not report on closed-area model fits nor biomass estimates from the models. The coastwide model has considerable more flexibility than the closed-area models, including sex-specific catchability, selectivity, and natural mortality parameters; it is fitted to CPUE (WPUE and NPUE) at age/sex (rather than just total CPUE), uses weaker selectivity smoothing and neutral data weighting. Finally, and perhaps most importantly, the coastwide data set is far less noisy than the closed area datasets and fits to the data provide more confidence in the results than was the case for closed-area model results. The closed area model fits are not discussed further.

Alternative model fits

As has been done the past few years, several versions of the basic assessment model were fitted. Differences among all the models concerned how survey and commercial catchability (generally termed "q") were parameterized. Two additional models were fitted that excluded commercial CPUE, and is considered similar to many of the NMFS groundfish assessment models. The models are summarized as such:

(Base) Survey q trendless drift: same as Survey q drift, but with the additional requirement that a regression of estimated survey catchability on year have zero slope. This means that survey catchability was allowed to vary but not to show any trend over time. This has been the selected production model since 2007.

(Alternative 1) Survey q constant: catchability is a single fixed (though estimated) value in all years.

(Alternative 2) Survey q drift: survey catchability estimated for each year, but with a penalty of 0.05 on log differences. This is similar to the treatment of commercial catchability.

(Alternative 3) Survey q trendless drift (i.e., Base model) but Commercial CPUE is not included in the likelihood.

(Alternative 4) Survey q drift (i.e., Alt. 2) but Commercial CPUE is not included in the likelihood.

(Alternative 5) Survey and commercial q both constant: this is similar to the old IPHC CAGEAN model

Table 1 shows features of the Base model as well as the alternatives. The best fit, indicated by a ΔAIC score of zero is Alternative 2 (survey q drift) model. Nearly as good a fit is provided by last year's production model, survey q trendless drift (Base) model. The four other model fits are significantly worse. The exploitable biomass estimate produced by five of the models is relatively narrow: between 312 and 358 M lbs. Alternative 4, which allows survey q to drift freely and is not fitted to commercial CPUE data produces a low estimate of exploitable biomass (267 M lbs). This occurs because Alternative 4 estimates survey q to be much higher than the other models. As has been the case the past two years, we select the base model (i.e., survey q trendless drift) as the production model and the coastwide exploitable biomass estimate of 334 million pounds forms the basis for apportionment among regulatory areas. Our preference for the Base model over Alternative 2, which is favored on the basis of the AIC criterion, has to do with the philosophy of the IPHC survey. A great deal of effort goes into standardizing the survey and we have no ancillary indications of long term changes in the catchability of the survey. We will continue to monitor and analyze potential catchability trends.

Effect of the 2009 data on abundance estimates

Coastwide survey WPUE declined by 3.5% and commercial WPUE declined by 6.5% from 2008 to 2009 (Figs. 9 and 13; Appendix A tables A9 and A10). As a result, the 2009 coastwide model fit is revised downwards, by about 10%, from the estimate of abundance at the beginning of 2009 made in the 2008 assessment (Table 2). On the other hand 2009 fit shows an increase in abundance, of about 14%, between the beginning of 2009 and the beginning of 2010. The net result is an estimated increase of 3% between the 2009 beginning of year exploitable biomass and the 2010 beginning of year exploitable biomass.

Evaluation of the assessment

Quality of fits

The model predicts survey NPUE at sex/age (Fig. 17) and commercial catch at age (Fig. 18) very well. There is no apparent pattern to the residuals from the fits, although the model initially underestimates slightly the early strength of the 1987 year class. The model is successfully predicting the increasing number of fish aged 25 and older, particularly males, which are appearing in both the survey and commercial catches. The very low growth rate for male halibut means that many are not recruiting to the fishery until they are older than 25. This "plus" group is poised to increase even more in the new few years as the remains of the very large 1987 and 1988 year classes reach 25 years of age. The series of total survey and commercial CPUE are also predicted closely (Fig. 19, middle panel).

Coastwide estimates of recruitment, exploitable biomass and spawning biomass

Exploitable biomass (EBio) at the beginning of 2010 is estimated to be 334 million pounds and female spawning biomass (SBio) is estimated to be 331 million pounds. EBio is up by about 3% from the beginning of year 2009, while SBio is a bit over 5% higher than the 2009 beginning of year value estimated in the 2008 assessment. EBio and SBio are both estimated to have declined continuously between 1998 and 2007 (Fig. 19, top right panel). EBio continued to decline in 2008, the model estimates that both are now on the increase, with SBio bottoming out in 2007 and EBio bottoming out in 2008. This matches the 2008 assessment in terms of when the turnarounds in decline for both EBio and SBio began. This point is discussed more fully in the Retrospective performance section. Recruitment (measured as age-eight fish in the year of assessment) has varied between 8 and 32 million halibut since the 1988 year class, with a mean of 17.3 million. The 1989 to 1997 year classes, presently 13 to 21 years old and the main target of the commercial fishery for the past several years, are all estimated to have been below average, several of the year classes substantially below average (Fig. 19, top left panel). The sharply declining biomass over the past decade has resulted from these small year classes replacing earlier year classes that were much larger, especially the 1987 and 1988 year classes. The projected increase in 2010 biomasses can be attributed, in large part, to the incoming 1998 through 2002 year classes that are estimated to be well above average, particularly the 1999 and 2000 year classes. The extent to which these year classes will contribute to EBio over the next few years depends on the growth rate which, as has been frequently noted, continues to decline.

Estimates of uncertainty

There are a number of ways of estimating the uncertainty associated with a given model fit and biomass estimate. They are all unsatisfactory in that they are conditioned on the correctness of the model when in fact it is the choice of one model rather than another that is the major source of uncertainty in assessments. This is well illustrated by the difference in area-specific biomass estimates between the coastwide and closed-area fits of the IPHC model as reported in past years. One standard method of illustrating uncertainty around an estimate, for a given model, is the likelihood profile. The bottom panels in Figure 19 show the likelihood profiles for both the exploitable biomass as well as the female spawning biomass. The 95% confidence interval (C.I.) for EBio is 295 to 374 million pounds, while the 95% C.I. for the female spawning biomass is 289 to 375 million pounds. Confidence intervals for the recruitment estimates were also computed and are plotted with the recruitment estimates (Fig. 19, top panel). For comparison purposes, the 95% C.I. for the alternative model fits described above are plotted in Fig. 20. The means of both EBio and SBio for all the alternative model fits, with the exception of Alternative 4, lie within the 95% C.I. of the Base (production) model estimates. Alternative 4, due to its unconstrained survey q parameter and non-use of commercial CPUE has very wide C.I.s, indicating relatively high uncertainty in the biomass estimates.

Retrospective performance

Each year's model fit estimates the abundance and other parameters for all years in the data series. One hopes that the present assessment will closely match the biomass trajectory estimated by the previous year's assessment. To the extent that it does not, the assessment is said to have poor retrospective performance.

Our assessment shows modest retrospective behavior for the last few years. Each year the assessment has revised downward the previous year's biomass estimates (Fig. 21a), meaning that biomass was overestimated then and may be overestimated now if the cause of the retrospective problem lies somewhere within the model. There is some precedent for that; the assessment models in use in the mid 1990s and the early 2000s showed strong retrospective patterns that turned out to be the result of misspecified selectivity (age- rather than length-based). There is also the possibility that the retrospective pattern is caused in some way by the external estimation of the sex composition of the commercial catch, or by the internal prediction of surface age compositions prior to 2002 through the application of an age misclassification matrix (Clark and Hare 2006).

Problems of this sort with the assessment machinery would manifest themselves as systematic revisions of the estimated relative strength of the year-classes present in the stock. That was true of the retrospective patterns caused by the misspecification of selectivity in the past: incoming year-classes would at first be estimated as weak because catch rates were low, but the real reason was low selectivity rather than low abundance. When they were later caught in large numbers, the estimates of relative year-class strength increased. The retrospective estimates of year class strength as plotted in Figure 21b. There is some evidence of a systematic revision of estimates of year class strength as the 1994 through 1998 year class have all trended downward for the last five assessments. The pattern does not hold for the 1999 year class strength estimates.

In 2007, a check was made using a blind projection of the assessment from 2004 to 2007. Year-class strengths and other parameters from the 2004 assessment, along with just the catches from 2005-2007 which are needed to estimate fishing mortality, were used to project the 2007 age structure and then compared to the 2007 observed age structure. That projection demonstrated that the retrospective behavior appears to be caused solely by the data and not by the assessment model (Clark and Hare 2008). We also note that the magnitude of the retrospective pattern from earlier assessments has lessened considerably over the last few years. The difference between the 2009 assessment of the last few EBios and the earlier assessments of the same EBios differ generally by less than 15%, which is generally within the error range of a good stock assessment.

Causes of retrospective behavior are notoriously difficult to diagnose. In the case of halibut, it appears to result from lower NPUE rates than expected, given the estimated mortality rate. This could be due, for example, to a trend in natural (or undocumented fishing) mortality, or a trend in catchability. The catchability explanation seems less likely, however, given that a model which allows catchability to have a trend produces assessment estimates that differ little from models with tightly constrained catchability. We consider it most likely that the retrospective behavior continues to derive in part, if not in whole, from the still declining growth rates. Each year, a new set of size at age data is collected and used to smooth earlier estimates of size at age. The addition of smaller sizes at age results in a reduction of the earlier estimated weights at age thus lowering EBio for the same number of fish. More important however is that as growth slows, fewer fish of the same age are selected to the gear and their lack of appearance in expected numbers forces the model to revise recruitment estimates to match the observed survey and commercial catch rates. To summarize, there is ongoing retrospective behavior in the halibut assessment. The magnitude of the behavior is modest and the trend of successively lowering all earlier EBio estimates has greatly tapered off. We do not feel the retrospective behavior weakens the assessment in any way, and analyses of the recognized patterns will continue.

Harvest policy, status relative to reference points and biomass projections

The IPHC has developed, refined, and utilized a constant harvest rate policy since the 1980's. The policy was fully described in Clark and Hare (2006) and further modified as described in Hare and Clark (2008). Stated succinctly, the policy is to harvest 20% of the coastwide exploitable biomass when the spawning biomass is estimated to be above 30% of the unfished level. The harvest rate is linearly decreased towards a rate of zero as the spawning biomass approaches 20% of the unfished level. This combination of harvest rate and precautionary levels of biomass protection have, in simulation studies, provided a large fraction of maximum available yield while minimizing risk to the spawning biomass. Since the early 2000s, and similar to many fisheries management agencies, the harvest policy has incorporated a measure designed to avoid rapid increases or decreases in catch limits, which can arise from a variety of factors including true changes in stock level as well as perceived changes resulting from changes in the assessment model. The adjustment, termed "Slow Up Fast Down (SUFD)" is based on a target harvest rate of 20% but a realized rate usually a bit different (Fig. 22). The SUFD approach is somewhat different from similar phased-change policies of other agencies in that it is asymmetric around the target value, i.e., the catch limit responds more strongly to estimated decreases in biomass than to estimated increases. This occurs for two reasons: first, the assessment generally has a better information base for estimating decreasing biomass compared with increasing biomass; and second, such an asymmetric policy follows the Precautionary Approach.

The unfished female spawning biomass ($B_{unfished}$) is computed by multiplying spawning biomass per recruit (SBR, from an unproductive regime) and average coastwide age-six recruitment (from an unproductive regime) The recruitment scaling uses the ratio of high to low recruitments based on long term recruitment estimates from Areas 2B, 2C and 3A and applied to the current coastwide average recruitment (Clark and Hare 2006) which we believe to represent a productive regime. The SBR value, computed from Area 2B/2C/3A size at age data from the 1960s and 1970s is 118.5 lbs per age-six recruit. Average coastwide recruitment for the 1990-2000 year classes (computed at age-six) is 23.4 million, and the estimate of unproductive regime average recruitment is 7.43 million recruits. This gives a $B_{unfished}$ of 880 million pounds, a B_{20} of 176 million, a B_{30} of 264 million pounds, and the 2010 female spawning biomass value of 331 million pounds establishes $B_{current}$ as 38% of $B_{unfished}$ (Fig. 23, top panel), up from the 2009 beginning of year estimate of $B_{current}$ of 35%. The revised trajectory of SBio suggests that the female spawning biomass did drop slightly below the B_{30} level which, had it been so estimated at the time, would have triggered a reduction in the harvest rate. On an annually estimated basis, however, the stock has not been that low; it is only retrospectively that we estimate the spawning biomass to have gone below to the reference point threshold. One problem with this method of establishing reference points is that the threshold and limit are dynamic, changing each year as the estimate of average recruitment changes. In this year's calculation the very strong 2000 year class was included among the year classes used to compute average recruitment. However, due to the downward revision of several year classes in this year's assessment, the estimate of $B_{unfished}$ changed very little from the 2008 estimates. Corresponding, B_{20} and B_{30} values also changed very little and the projected increase in the 2010 SBio results in the new determination that $B_{current}$ is around B_{38}. The estimated age composition of the coastwide spawning biomass shows a broad range of ages including 7% females age 20 and older (Fig. 23, bottom panel). While the age distribution is certainly truncated due to the size-selective effects of fishing, it is encouraging that production of eggs is not confined to a narrow range of ages and should ensure that adequate reproductive potential remains in the ocean for the foreseeable future. On an area by area basis, there are some departures from this pattern, particularly in Areas 2 and 3B which show a lower percentage of older females (See the Area summaries section).

In addition to monitoring the status of the female spawning biomass relative to reference points, success at achieving the harvest rate is also documented (Fig. 24). The harvest rate over the past decade for halibut has generally been 0.20. Exceptions include a briefly increased rate to 0.225 and 0.25 between 2004 and 2006, and a lower rate of 0.15 in Areas 4B and 4CDE. On a coastwide basis, however, recent realized harvest rates have hovered around 0.25. A sizable portion of this above-target harvest rate comes from the retrospective revision of exploitable biomass estimates. Thus, while the intended rate has been around 0.20, with catch limits based on such a rate, a retrospective revision of exploitable biomass, when combined with unchanged estimates of total removals generates higher realized harvest rates. Another portion of the above-target performance results from the SUFD adjustment which prevents catch limits dropping fully to the target level indicated by contemporary estimates of exploitable biomass. Estimates of realized harvest rate among individual regulatory areas require use of an apportionment method to calculate the underlying exploitable biomass. This year staff favors the use of survey timing and hook competition adjustments to the bottom area-weighted survey WPUE (discussed below) for apportionment purposes. However, we use the unadjusted WPUE values for virtually all other data comparisons, e.g., WPUE trends over time, comparisons with trawl estimates of abundance, etc. We are uncertain what adjustments will stand the test of time and there is the problem of comparing values year to year when different adjustments are used. The unadjusted, bottom-weighted, survey WPUEs are therefore used to apportion biomass to estimates historical realized harvest rates (Fig. 25). Realized harvest rates tend to increase from west (below or at the target harvest rate during the last decade) to east (high above target during the last decade) though the eastern area harvest rates have declined sharply towards the target harvest rate during the last few years, in part due to lower catch limits.

The annual stock assessment produces an estimate of the total number of male and female halibut, ages 6 and older, in the ocean (Fig. 26, top panel). With this set of numbers and assuming that life history parameters, such as size at age and maturity at age, remain close to what they are today, we can make biomass and yield projections for several years into the future. Because the age range of halibut in the catch is generally in the 10-20 year old range (9 to 15 for females constituting most of the catch), estimates of recruitment – which are often imprecise – should not much influence the projections. The time series of abundance shown in Figure 26 illustrate the strength of the celebrated 1987, and to a lesser extent 1988, year classes. As was true last year, the current assessment suggests that three large year classes – 1998, 1999, and 2000 – are poised to enter the exploitable biomass over the next few years. Presently, both year classes look to be larger – in terms of numbers – than the 1987 and 1988 year classes. However, it is important to note that size at age is much smaller now than it was 20 years ago. This has two important ramifications – first it means that the three strong year classes are only just beginning to reach the exploitable size range and, therefore, their true numbers in the population are still quite uncertain. Secondly, it also means that for a given number of halibut, their collective biomass will be lower (Fig. 26, bottom panel). Currently, a large fraction of males never reach the minimum size limit and thus never enter the exploitable biomass. It remains to be seen just how these year classes will develop into the exploitable component of the stock. If we assume that size at age remains at the values seen this year, then the projections for both the exploitable biomass and spawning biomass are very optimistic (Fig. 27) and indicate that the declines we have seen over the past decade are on the verge of reversing. It important to note that total removals should still remain at around 20% of the exploitable biomass and not be kept high in anticipation of future increases. As happened in the mid 1990s, when the biomass rises, higher catch limits will follow.

Comparison of assessment and trawl survey estimates of EBio

The National Marine Fisheries Service (NMFS) and Canadian Department of Fisheries and Oceans conduct bottom trawl surveys annually to triennially across most of the continental shelf of the U.S. west coast, British Columbia and Alaska. One possible method of possibly validating the coastwide assessment (and biomass partitioning) is to compare estimates produced by the two independent methods. We were able to obtain swept area estimates of abundance at length from trawl surveys that covered IPHC regulatory areas 2C westward to Area 4CDE. For Area 2B halibut are not sampled in the trawl survey and, in 2A too few halibut are caught to produce reliable estimates of abundance thus no comparisons are made for those two areas.

The NMFS conducts an annual survey on the Eastern Bering Sea shelf, a triennial survey in the Aleutian Islands and a biennial survey in the Gulf of Alaska. The NMFS trawl surveys do not precisely match IPHC regulatory areas. However, common areas can be generally defined:

Area 2C: NMFS GOA survey area Southeast matches IPHC Area 2C. Note that there is much rough/untrawlable ground in this region.

Area 3A: NMGS GOA regions Yakutat + Kodiak

Area 3B: NMFS GOA regions Chirikof + the eastern 70% of Shumagin

Area 4A: NMFS GOA Shumagin (western 30%) + AI region 799 + AI region 5699 (eastern 30%) + EBS region 50.

Area 4B: NMFS AI regions - 299 - 5699 (eastern 30%)

Area 4CDE: EBS regions - region 50.

Estimates of commercially exploitable biomass (i.e., the usual EBio) can be derived by applying the commercial selectivity curve to the swept area estimates of numbers at length and then applying the IPHC length weight relationship. For this comparison, the IPHC assessment estimates of EBio are partitioned among areas using the unadjusted bottom-weighted survey WPUE index. The results are illustrated in Figure 28.

The agreement between the trawl and assessment estimates of abundance is surprisingly good for most of the areas. Areas 4A, 4B and 4CDE are within a few percent of each other over the past few surveys. In Area 3A and 3B, the trends are generally captured though the trawl estimates of abundance tend to be lower by about a third. Area 2C, as anticipated provides the worst match. It is important to keep in mind the independence of the two estimates. The only commonality between them is use of a selectivity curve to derive EBio. The assessment estimates incorporate assumptions and estimates of factors such as catchability, natural mortality, survey apportionment, etc. The trawl estimates make an assumption about the effective area swept by the survey trawl and assumes a capture probability value of 1.0 for all sizes encountered. This latter assumption may be one reason the Area 3A and 3B trawl estimates are lower if larger halibut are able to escape the trawl and thus be under-represented in the swept area estimates.

Finally, the trawl data provide confirming evidence as regards the preponderance of smaller halibut. The large number of small halibut in the Bering Sea was earlier discussed and illustrated in Figure 7. In Figure 29, we show the swept area estimates of numbers by 10 cm length class in Area 3A. There is an unprecedented number of halibut in the 50-70 cm range. Thus, while the trawl estimate of EBio is not that large, the estimate of Total Biomass is near the top of the range over the past 15 years. As those millions of smaller halibut grow, we should see the steady increase in EBio predicted by the coastwide assessment.

Apportioning the coastwide biomass among regulatory areas

The staff believes that survey WPUE-based apportionment is the most objective and consistent method of estimating the biomass distribution among areas and therefore the best distribution of total CEY to achieve the IPHC's goal of proportional harvest among areas. The validity of the survey WPUE apportioning requires that survey catchability – the relationship between density and WPUE – be roughly equal among areas. Over the past few years, several checks for area differences in catchability were made (Clark 2008a, Clark 2008b, Clark 2008c, Webster 2009b) but results were inconclusive in determining differences. This year, three factors were considered for adjusting survey WPUE. Methodologies and analyses of all three factors - in isolation and in combination - is contained in Webster and Hare (2010). A brief summary of the rationale behind the three factors is presented below but details, and the adjustments themselves, are not repeated here - see Webster and Hare 2010. Following (potential) adjustment of the annual survey WPUE values, the IPHC has usually averaged the last few years to smooth out annual variation in the survey. This year, an alternate weighting scheme for the averaging was also investigated to compute apportionments. Also new this year, at the request of industry, is the addition of a historical removals shares weighting factor.

Adjustment factors

Station depth distribution. The IPHC survey stations are set on a fixed 10-nmi grid between the depths of 20 and 275 fathoms. Ideally, such an arrangement should lead to stations having the same physical and oceanic characteristics as the entire bottom area within each regulatory area. As WPUE is affected by a myriad of factors that vary with depth, a simple mean WPUE computed from all stations should be the same (on average) as one computed from a depth weighted WPUE. However, the match is not perfect, especially in Area 4B. To compute this adjustment, depth stratified WPUEs were weighted by bottom areas.

Hook competition. Catchability of halibut is affected by the presence of other bait takers, a process known as hook competition. If the average number of baits available to halibut varies substantially among regions, this might be a reason to adjust survey WPUE. To compute this adjustment, the return of baits by regulatory area is summed from survey data.

Timing of setline survey. The survey is designed to measure EBio at approximately the midpoint of the year in each regulatory area. Necessarily, the timing varies due to survey logistics. The timing of removals (commercial, sport and subsistence fishing, bycatch, wastage) also varies, even more substantially, among areas. It can be reasoned that an area where more of the annual removals are taken prior to our survey would "see" a smaller EBio than an otherwise identical situation where the other removals had not yet occurred. To compute this adjustment, we estimate the midpoint of the survey as well as fraction of removals prior to that time.

Time-averaging methods of (possibly adjusted) survey WPUE

We note here that the issue of time averaging of the survey WPUE values to smooth out annual variation will receive a closer look in the next year. There are many schemes used in different fisheries and even in different fields of science. We anticipate a report in next year's RARA with a formal evaluation of alternative weighting schemes.

Equal weighting (1:1:1). This has been the default method used by the IPHC for time weighting of various factors, including survey WPUE for apportionment purposes. Under this scheme, the three most recent WPUE values are averaged, with equal weight given to each year.

Reverse weighting (2:2:1). It can be argued that more recent data more accurately reflects current conditions and therefore should receive a higher weight than data 1-2 years old. Thus, we included a scheme this year that weights the two most recent survey values equally but assigns the data point from two years ago one half the weight.

Historical shares weight

No consideration of historical shares. Only the survey data, possibly adjusted and time averaged, is used to apportion biomass.

Inclusion of historical shares. Under this scheme, once the survey data have been possibly adjusted (hook, depth, survey timing) and then either equal or reverse weighted, they are combined with historical shares in a ratio of 2:1 survey to historical shares. At the request of industry, historical shares were computed from the 1993-2007 total removals data (Appendix A1) and have the following distribution by area:

2A	2B	2C	3A	3B	4A	4B	4CDE
1.7%	15.8%	15.1%	37.1%	14.5%	5.3%	3.9%	6.5%

Methods of apportioning biomass

Last year, the staff presented 10 methods of apportioning biomass and recommended the method that involved hook competition adjustment of bottom weighted survey WPUE, equally weighted over the prior three years. This year, the combination of adjustments and weighting described above results in 32 possible combinations. There are eight possible annual adjustments to the survey WPUE:

1. No adjustment
2. Hook competition (hereafter "hook")
3. Survey station bottom depth (hereafter "depth")
4. Timing of setline survey (hereafter "timing")
5. Hook + depth
6. Timing + hook
7. Timing + depth
8. Timing + hook + depth

For this year, the staff recommends the following

- Timing + hook adjustment
- Equal-weighting for time averaging
- No inclusion of historical shares

The staff recommendation is the line highlighted in all the tables referencing apportionment. The evaluation and rationale for the staff recommendation in described in the 2010 Staff Catch Limit Recommendation document.

Area-apportioned biomass, total and fishery constant exploitation yields

With the 32 different methods of apportioning biomass, 32 sets of area-apportioned exploitable biomass, total and fishery CEY can be computed. All of the methods utilize the same table of Other Removals – deducted from Total CEY to obtain Fishery CEY. The Other Removals are listed in Table 3. The staff recommended method of apportioning biomass, Method 2 – survey CPUE, adjusted for hook competition and survey timing, equal-weighted time averaging and no historical shares leads to the area-specific Exploitable Biomass, Total and Fishery CEY figures listed in Table 4. For comparison purposes, the corresponding 2008 estimates are shown in Table 5. There are two differences between 2008 and 2009 – only a hook competition correction was used in 2008 and the recommended harvest rate for Area 3B has been lowered from 0.20 to 0.15. The reasons for this recommendation are discussed in the Area Summary for 3B.

The area shares of Total Exploitable biomass for each of the 32 apportionment methods are listed in Table 6. The EBio totals for each area are listed in Table 7, Total CEYs are listed in Table 8, and Fishery CEYs are listed in Table 9. The harvest rates used to compute Total CEYs are 0.20 for Areas 2 and 3A and 0.15 for Area 3B and 4.

Area summaries

The coastwide assessment indicates that the exploitable biomass of halibut has declined approximately 50% over the past decade. This declining trend is seen in almost all of the area-specific survey and commercial WPUE indices, though with turnarounds apparently beginning in several areas. But the breadth and reasons behind the trends vary by area. The following is a region by region discussion of the trends and grouping of diagnostic plots to assess the past and present removals, stock trends, and prospects for each area. For each of the areas, six plots are illustrated. These include the following:

1. Total removals – illustrated by category (commercial catch, sport, etc.)
2. U32 bycatch – An estimate of lost commercial yield due to U32 bycatch is also given. Note that the lost yield from bycatch in any given year is an estimate of future lost yield summed across several years, and does not account for migration. Methodology for estimating U32 bycatch, lost production and computing surplus production is described in Hare (2010).
3. Surplus production. Stated simply, surplus production is the amount of total catch that, when taken exactly, keeps the exploitable biomass at the same level from one year to the next. If the biomass increases, then total catch (termed "removals") was less than surplus production. If the biomass declines, then removals were greater than surplus production. Removals exceeding surplus production can lead to long-term declines in biomass; stock building results from taking less than surplus production.
4. WPUE and effort – Long-term trends in commercial fishing effort and WPUE.
5. Abundance indices – these include the survey WPUE and the Coastwide assessment with unadjusted survey partitioning.
6. 2009 age structure of the survey catch.

Taken in total, these indicators convey a comprehensive picture for each area and serve as a helpful reference when discussing each regulatory area.

Area 2

Areas 2A, 2B and 2C indices are illustrated in Figures 30, 31 and 32, respectively. Between 1997 and 2006, total removals were stable in all three areas, averaging 1.6 million pounds in Area 2A, 13.5 million pounds in Area 2B and 12.4 million pounds in Area 2C. Removals declined sharply between 2007 and 2009, in response to the change from closed-area to coastwide assessment and the resultant revised view of relative halibut abundance in Area 2. Bycatch of U32 fish, and subsequent lost yield to constant Exploitation Yield (CEY), is estimated to be rather low, though O32 bycatch in Area 2A still represents a sizable portion of total removals. Surplus production estimates suggest that removals have exceeded surplus production in Area 2 for most of the past decade. Commercial effort has steadily increased in Area 2A for almost a decade but dropped sharply in 2009. In Areas 2B and 2C commercial WPUE has declined for the past three to four years. The main indices of abundance all suggest a steady decline in biomass from the mid 1990s to the late 2000s. Area 2A saw in 2009 a drop to the lowest survey WPUE on record, and a drop of 50% from 2008, to an average survey catch of 8 pounds of O32 halibut per standard skate. Area 2B had seen an increase in survey WPUE of 50% between 2007 and 2008; the 2009 value was nearly as strong as the 2008 value, suggesting a change in the declining trend in that area. For Area 2C, the increase in survey WPUE, while relatively minor, was the first in nearly a decade. Survey partitioning of the coastwide biomass suggests that the beginning of year 2010 EBio is down in 2A, up strongly in 2B, and up slightly in 2C from 2009 values. What is still a strong concern to staff is the generally much younger age structure of fish caught in Area 2. Mean age is around 11 years of age, with little difference between males and females. In particular, the catch of females is concentrated on ages where maturity at age is low thus removing females from the population before many have the opportunity to contribute to the spawning biomass.

All the indices are consistent with a picture of a steadily declining exploitable biomass up to at least 2007. The reasons for the decline are likely twofold. The first is the passing through of the two very large year classes of 1987 and 1988. Every assessment over the past decade has shown that those two year classes were very strong in comparison to the surrounding year classes. Now that those two year classes are 20 years old, their contribution to the exploitable biomass and catches has sharply declined and the drop in biomass is to be expected as they are replaced by year classes of lesser magnitude. Removals have been generally larger than surplus production and this prevents rebuilding of regional stocks. Our present view of Area 2 is that harvest rates have been much higher than the target rate of 0.20 over the past decade and are not sustainable, particularly with the passage of the 1987 and 1988 year classes. There are multiple signs that two or three large year classes are set to enter the exploitable biomass, however, the exploitable biomass will not increase strongly as long as harvest rates remain high. On that score, it is encouraging that removals have been brought down over the past few years. Realized harvest rates remain above target in all of Area 2 but are closer to target than at any time in the past decade. Finally, in 2009 Area 2 presently accounted for 26% of total removals coastwide but contributes just 20% to the female spawning biomass, a byproduct of their young age structure.

Area 3

Areas 3A and 3B indices are illustrated in Figures 33 and 34 respectively. While these two areas occupy the current central area of distribution of the halibut stock, they have substantially different exploitation and biomass histories over the past 10-20 years. Area 3A removals, both the total as well as the individual components (commercial, sport, bycatch) have been very stable over the past 10 years. Commercial effort has also seen relatively little variation. During the past decade when WPUE indices were falling sharply coastwide, Area 3A generally showed the most stability. That pattern has now changed as in 2009 Area 3A had the second largest decline from 2008 (after Area 2A). The WPUE indices are at about 71% (commercial) and 52% (survey) of their average values between 1997 and 1999. Biomass declined steadily in 3A between the late 1990’s and early 2000’s but then appeared to stabilize as surplus production basically matched removals. Area 3B saw a large increase in removals beginning in 1996 which peaked in 2002 and has dropped sharply since. Commercial fishing effort more than tripled in the seven years after 1996 and then declined modestly over the past four years before increasing again beginning in 2008. We estimate that removals greatly exceeded surplus production between 1998 and at least 2007. Commercial and survey WPUE are at 37% and 26%, respectively, of their average level between 1997 and 1999. Area 3A has a much broader spectrum of ages in the population than is seen in Area 2. Average age for females in survey catches is 13 and for males is 16 years of age. Area 3B, however, is more similar to Area 2 in age distribution than to Area 3A.

For a long time, Area 3A had the appearance of being the most stable of the IPHC regulatory areas. The area has been fully exploited for many decades and there is a wealth of data detailing its population dynamics. The area also sits at the current center of halibut distribution and it appears that emigration is roughly equal to immigration. Like Area 2, Area 3A benefited from the very large year classes of 1987 and 1988 and the slow decline in exploitable biomass is the result of those year classes dying off. The biomass does appear “healthy” as it was stated last year (Hare and Clark 2009) and it remains by far the largest of any regulatory area. The level of removals taken over the past several years appears appropriate as they have been near to (though above) the target harvest rate. Until the biomass decline has ended, it is likely removals will still trend downwards a bit in Area 3A.

The situation in Area 3B is one that has concerned us for several years. Area 3B was relatively lightly fished until the mid 1990s. With the introduction of a regular survey, quotas were incrementally increased from 4 million pounds to a high of 17 million pounds. Predictably, catch rates declined steadily. Our view of Area 3B was that the area had an accumulated "surplus" biomass that could be (and was) taken but the level of catches was not sustainable. Removals were brought down to around 10 million pounds however the WPUE indices continue to drop sharply. The level of commercial effort expended to take the CEY is at an all time high and increasing. The age distribution of the population is not broad and reflects one of an area fished at a much higher rate than is sustainable. Like Area 4, Area 3B is a net (though smaller) exporter of halibut as emigration is larger than immigration. For all of these reasons, we believe it prudent to reduce the harvest rate to a level of 0.15, as has been done for all of Area 4. It is paramount that the ongoing decline in Area 3B be arrested - until that is accomplished, the true level of productivity in Area 3B cannot be estimated. The harvest rate previously applied to Area 3B was adopted from Areas 2B, 2C, and 3A and that was determined on the basis of 60 years of productivity data (Clark and Hare 2006). Using a lower harvest rate in Area 3B is a precautionary move and one that has seen success in Area 4.

Area 4

Areas 4A, 4B and 4CDE indices are illustrated in Figures 35, 36 and 37, respectively. The three areas have roughly similar commercial exploitation histories over the past decade and show generally similar trends. In all three areas, commercial catches increased from around 1.5 million pounds to around 4-5 million pounds between 1996 and 2001. All three areas have since declined to 2-3 million pounds thought he trajectories differ. The target harvest rate is currently 0.15 in all of Area 4, with the change from 0.20 beginning in 2004 in 4B, 2006 in 4CDE and 2008 in 4A. Commercial effort mirrored the rise in removals from 1996-2001, however the drop in effort was not nearly as sharp as the drop in catches, and the drop in commercial WPUE is evident in the time series. Survey WPUE declined around 70% between the mid1990s and mid 2000s. All three areas have shown increases in recent years, with the turnarounds occurring immediately after the cut in the harvest rate in each area. The recent increases in WPUE, which reflect slow increases in EBio as estimated by the coastwide assessment, are evidence that the western portion of the stock, which is a net exporter of halibut, is best served by a lower harvest rate than that in the eastern areas. As the stock builds up, removals will also increase. There is evidence in both the assessment and the trawl surveys that extremely large numbers of halibut, in the 50-80 cm size range, are found in Area 4 and should continue to add substantially to the exploitable biomass over the next several years.

There are a couple of other observations that should be made about Area 4. The biggest concern, as regards productivity and sustainability of halibut, is the level of bycatch mortality. Most of the O32 bycatch in Area 4 most likely affects future yield within Area 4 itself. Over the past decade, O32 bycatch has averaged 3-4 million pounds resulting in an annual yield loss comparable to that level. On the other hand, U32 bycatch - which has also been on the order of 3-4 million pounds annually - results in a somewhat greater yield loss due to its smaller size and large numbers of killed halibut. Some potentially large fraction of yield loss, however is to areas "downstream" of Area 4 given migration of fish beyond at which they become vulnerable to fishing (Valero and Hare 2010). For most the 2000s, removals exceeded surplus production in all three subareas of Area 4. It would appear that situation has reversed though it is probably too early to make a definitive declaration. Encouragingly, the age distributions in Area 4 are the broadest of any of the IPHC regulatory areas. Thus, Area 4 not only contributes to the spawning biomass in a ratio exceeding its removals, it is also a reservoir of older females which are a valuable and necessary commodity for a fish population where individuals can live to 55 years of age.

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Table 1. Alternative coastwide model fits. The AIC value is in relative units compared to the model with the lowest AIC score.

Model	Number of parameters	Δ AIC	Exploitable Biomass (Mlb)
Base	172	+2	334
Alternative 1	160	+134	312
Alternative 2	172	+0	313
Alternative 3	158	+ 79	332
Alternative 4	158	+76	267
Alternative 5	147	+388	358

Table 2. Effect of the 2009 data on coastwide abundance estimates.

Area	2009 ebio 2008 assessment Data as of 11/08	2009 ebio 2008 assessment Data as of 11/09	2009 ebio 2009 assessment Data as of 11/09	2010 ebio 2009 assessment Data as of 11/09
Coastwide assessment:	325	326	293	334

Table 3. Other removals in detail. Sport catch figures for Areas 2C and 3A are actual catches not GHL levels as in Table 4.

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Sport catch	0.401	1.095	2.546	5.531	0.025	0.039	0.000	0.000	9.208
O32 bycatch	0.245	0.105	0.128	1.918	0.862	1.063	0.218	2.340	6.879
Personal use	0.029	0.405	0.458	0.337	0.042	0.020	0.005	0.046	1.342
O32 wastage	0.001	0.012	0.012	0.042	0.021	0.009	0.006	0.014	0.117
Total	0.676	1.617	3.144	7.828	0.950	1.131	0.229	2.400	16.606
Total excl.sport catch in Areas 2A and 2B	0.275	0.522	3.144	7.828	0.950	1.131	0.229	2.400	14.599
U32 discard mortality (shown for information; not taken off total CEY)	0.015	0.231	0.262	1.118	0.773	0.139	0.012	0.074	2.624
U32 bycatch mortality (shown for information; Not taken off total CEY)	0.138	0.105	0.128	1.918	0.862	1.063	0.218	2.340	6.772

Table 4. Estimates of 2010 exploitable biomass and CEY from the 2009 assessment

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2010 exploitable biomass	4.1	30.4	25.1	131.0	65.7	21.7	19.9	36.2	334
Proportion of total	0.012	0.091	0.075	0.392	0.197	0.065	0.059	0.108	1.000
Harvest rate	0.20	0.20	0.20	0.20	0.15	0.15	0.15	0.15	<0.20
Total CEY	0.819	6.076	5.020	26.192	9.859	3.251	2.979	5.431	59.627
Other removals [2, 3]	0.246	0.522	2.630	7.913	0.950	1.131	0.229	2.400	16.021
2010 fishery CEY [2]	0.573	5.554	2.390	18.279	8.909	2.120	2.750	3.031	43.606

Notes:

[1] "Coastwide assessment" refers to the coastwide model fit with survey apportionment of the total biomass estimate among regulatory areas, and corrected for estimated rates of hook competition.

[2] "Other removals" comprise O32 wastage, O32 bycatch, personal use, and in most areas sport catch. In Areas 2A and 2B sport catch is included in fishery CEY rather than in other removals.

[3] Assumes GHL of 0.788 M lbs. in Area 2C and 3.650 M lbs. in Area 3A.

Table 5. Estimates of 2009 exploitable biomass and CEY from the 2008 assessment (2009 RARA, p. 156).

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2009 exploitable biomass	3.2	27.0	27.9	140.0	68.8	18.5	15.4	24.2	325
Proportion of total	0.010	0.083	0.086	0.431	0.212	0.057	0.047	0.074	1.000
Harvest rate	0.20	0.20	0.20	0.20	0.20	0.15	0.15	0.15	<0.20
Total CEY	0.642	5.414	5.574	28.008	13.757	2.770	2.310	3.624	62.099
Other removals [2]	0.142	0.495	2.710	7.169	0.555	0.566	0.225	1.658	13.520
2009 fishery CEY [2]	0.500	4.919	2.864	20.839	13.202	2.204	2.085	1.966	48.579
2009 catch limit	**0.950**	**7.630**	**5.020**	**21.700**	**10.900**	**2.550**	**1.870**	**3.460**	**54.080**

Notes:

[1] "Coastwide assessment" refers to the coastwide model fit with survey apportionment of the total biomass estimate among regulatory areas. "Area assessments" are the closed-area model fits.

[2] "Other removals" comprise O32 wastage, O32 bycatch, personal use, and in most areas sport catch. In Areas 2A and 2B sport catch is included in fishery CEY rather than in other removals.

Table 6. Shares of total Exploitable biomass by area according to various apportionment methods.

3 year averages	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.9%	9.5%	7.3%	37.3%	17.6%	6.4%	8.1%	12.9%	100.0%
Hook AF	1.0%	9.0%	7.5%	38.9%	19.8%	6.8%	5.9%	11.1%	100.0%
Depth AF	0.7%	9.6%	7.4%	35.9%	17.7%	6.8%	9.5%	12.4%	100.0%
Timing AF	1.1%	9.6%	7.3%	37.7%	17.5%	6.2%	8.1%	12.6%	100.0%
Hook + Depth AFs	0.9%	9.2%	7.6%	37.5%	19.9%	7.2%	7.0%	10.7%	100.0%
Timing + Hook AFs	1.2%	9.1%	7.5%	39.2%	19.7%	6.5%	5.9%	10.8%	100.0%
Timing + Depth AFs	0.9%	9.8%	7.4%	36.2%	17.5%	6.6%	9.5%	12.1%	100.0%
Timing + Hook + Depth AFs	1.1%	9.3%	7.6%	37.9%	19.8%	6.9%	7.0%	10.4%	100.0%
Reverse weighted	2A	2B	22C	3A	3B	4A	4B	4CDE	Total
Survey only	0.8%	10.1%	7.2%	36.8%	16.7%	6.8%	8.4%	13.1%	100.0%
Hook AF	1.0%	9.4%	7.4%	37.8%	19.7%	7.3%	6.1%	11.3%	100.0%
Depth AF	0.7%	10.4%	7.2%	35.4%	16.8%	7.1%	9.8%	12.6%	100.0%
Timing AF	1.0%	10.2%	7.2%	37.2%	16.6%	6.5%	8.4%	12.8%	100.0%
Hook + Depth AFs	0.9%	9.7%	7.4%	36.5%	19.8%	7.7%	7.1%	11.0%	100.0%
Timing + Hook AFs	1.2%	9.5%	7.4%	38.3%	19.5%	6.9%	6.1%	11.1%	100.0%
Timing + Depth AFs	0.9%	10.5%	7.2%	35.8%	16.7%	6.9%	9.8%	12.3%	100.0%
Timing + Hook + Depth AFs	1.1%	9.8%	7.4%	36.9%	19.7%	7.3%	7.1%	10.7%	100.0%
Historical shares									
15 year (1993-2007) average	1.7%	15.8%	15.1%	37.1%	14.5%	5.3%	3.9%	6.5%	100.0%
3 year averages (2:1)	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	1.2%	11.6%	9.9%	37.3%	16.6%	6.1%	6.7%	10.7%	100.0%
Hook AF	1.3%	11.3%	10.0%	38.3%	18.0%	6.3%	5.3%	9.6%	100.0%
Depth AF	1.1%	11.7%	9.9%	36.3%	16.6%	6.3%	7.6%	10.4%	100.0%
Timing AF	1.3%	11.7%	9.9%	37.5%	16.5%	5.9%	6.7%	10.5%	100.0%
Hook + Depth AFs	1.1%	11.4%	10.1%	37.4%	18.1%	6.6%	6.0%	9.3%	100.0%
Timing + Hook AFs	1.4%	11.3%	10.0%	38.5%	18.0%	6.1%	5.3%	9.4%	100.0%
Timing + Depth AFs	1.2%	11.8%	9.9%	36.5%	16.5%	6.2%	7.6%	10.2%	100.0%
Timing + Hook + Depth AFs	1.3%	11.5%	10.1%	37.6%	18.1%	6.4%	6.0%	9.1%	100.0%
Reverse weighted (2:1)	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	1.1%	12.0%	9.8%	36.9%	16.0%	6.3%	6.9%	10.9%	100.0%
Hook AF	1.3%	11.6%	9.9%	37.6%	17.9%	6.6%	5.4%	9.7%	100.0%
Depth AF	1.1%	12.2%	9.8%	36.0%	16.0%	6.5%	7.8%	10.5%	100.0%
Timing AF	1.3%	12.1%	9.8%	37.2%	15.9%	6.1%	6.9%	10.7%	100.0%
Hook + Depth AFs	1.2%	11.7%	10.0%	36.7%	18.1%	6.9%	6.0%	9.5%	100.0%
Timing + Hook AFs	1.4%	11.6%	10.0%	37.9%	17.9%	6.4%	5.4%	9.5%	100.0%
Timing + Depth AFs	1.2%	12.3%	9.8%	36.2%	16.0%	6.3%	7.8%	10.4%	100.0%
Timing + Hook + Depth AFs	1.3%	11.8%	10.0%	37.0%	18.0%	6.7%	6.0%	9.3%	100.0%

Table 7. Exploitable biomass by area according to various apportionment methods.

3 year averages	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	2.938	31.592	24.453	124.739	58.774	21.503	27.047	42.954	334.000
Hook AF	3.399	30.021	25.021	129.818	66.144	22.630	19.825	37.142	334.000
Depth AF	2.453	32.227	24.558	120.030	58.958	22.811	31.662	41.302	334.000
Timing AF	3.571	32.011	24.492	125.771	58.387	20.669	27.079	42.021	334.000
Hook + Depth AFs	2.866	30.649	25.233	125.416	66.621	23.996	23.373	35.846	334.000
Timing + Hook AFs	4.094	30.382	25.101	130.962	65.723	21.673	19.858	36.207	334.000
Timing + Depth AFs	3.036	32.642	24.599	121.036	58.567	22.002	31.756	40.362	334.000
Timing + Hook + Depth AFs	3.530	31.005	25.313	126.517	66.190	23.082	23.463	34.899	334.000
Reverse weighted	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	2.831	33.831	24.111	122.959	55.852	22.563	28.201	43.652	334.000
Hook AF	3.398	31.454	24.635	126.319	65.646	24.239	20.406	37.902	334.000
Depth AF	2.401	34.715	24.058	118.253	56.118	23.822	32.609	42.024	334.000
Timing AF	3.399	34.225	24.090	124.267	55.458	21.603	28.183	42.776	334.000
Hook + Depth AFs	2.906	32.306	24.681	121.947	66.206	25.584	23.754	36.615	334.000
Timing + Hook AFs	4.039	31.797	24.663	127.755	65.238	23.138	20.374	36.997	334.000
Timing + Depth AFs	2.970	35.110	24.037	119.506	55.711	22.891	32.651	41.124	334.000
Timing + Hook + Depth AFs	3.568	32.648	24.707	123.308	65.776	24.534	23.776	35.683	334.000
Historical shares									
15 year (1993-2007) average	1.7%	15.8%	15.1%	37.1%	14.5%	5.3%	3.9%	6.5%	100.0%
3 year averages (2:1)	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	3.881	38.703	33.094	124.505	55.371	20.252	22.367	35.828	334.000
Hook AF	4.188	37.655	33.473	127.891	60.284	21.004	17.552	31.953	334.000
Depth AF	3.557	39.126	33.164	121.365	55.493	21.124	25.444	34.727	334.000
Timing AF	4.302	38.982	33.120	125.193	55.112	19.697	22.388	35.206	334.000
Hook + Depth AFs	3.833	38.074	33.614	124.956	60.602	21.914	19.917	31.089	334.000
Timing + Hook AFs	4.651	37.896	33.527	128.653	60.003	20.366	17.574	31.330	334.000
Timing + Depth AFs	3.946	39.403	33.192	122.036	55.233	20.585	25.506	34.100	334.000
Timing + Hook + Depth AFs	4.275	38.312	33.667	125.690	60.315	21.305	19.978	30.458	334.000
Reverse weighted (2:1)	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	3.809	40.196	32.866	123.318	53.422	20.959	23.136	36.293	334.000
Hook AF	4.187	38.611	33.216	125.558	59.952	22.077	17.939	32.460	334.000
Depth AF	3.522	40.785	32.831	120.181	53.600	21.799	26.074	35.208	334.000
Timing AF	4.188	40.458	32.852	124.190	53.160	20.319	23.124	35.709	334.000
Hook + Depth AFs	3.859	39.179	33.247	122.644	60.325	22.973	20.171	31.602	334.000
Timing + Hook AFs	4.614	38.839	33.234	126.516	59.680	21.342	17.918	31.857	334.000
Timing + Depth AFs	3.902	41.048	32.817	121.016	53.329	21.178	26.103	34.608	334.000
Timing + Hook + Depth AFs	4.300	39.407	33.263	123.551	60.039	22.273	20.186	30.981	334.000

Table 8. Total CEY by area according to various apportionment methods.

3 year averages	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.588	6.318	4.891	24.948	8.816	3.225	4.057	6.443	59.286
Hook AF	0.680	6.004	5.004	25.964	9.922	3.395	2.974	5.571	59.513
Depth AF	0.491	6.445	4.912	24.006	8.844	3.422	4.749	6.195	59.063
Timing AF	0.714	6.402	4.898	25.154	8.758	3.100	4.062	6.303	59.392
Hook + Depth AFs	0.573	6.130	5.047	25.083	9.993	3.599	3.506	5.377	59.308
Timing + Hook AFs	0.819	6.076	5.020	26.192	9.859	3.251	2.979	5.431	59.627
Timing + Depth AFs	0.607	6.528	4.920	24.207	8.785	3.300	4.763	6.054	59.166
Timing + Hook + Depth AFs	0.706	6.201	5.063	25.303	9.929	3.462	3.519	5.235	59.418
Reverse weighted	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.566	6.766	4.822	24.592	8.378	3.384	4.230	6.548	59.287
Hook AF	0.680	6.291	4.927	25.264	9.847	3.636	3.061	5.685	59.390
Depth AF	0.480	6.943	4.812	23.651	8.418	3.573	4.891	6.304	59.071
Timing AF	0.680	6.845	4.818	24.853	8.319	3.240	4.227	6.416	59.399
Hook + Depth AFs	0.581	6.461	4.936	24.389	9.931	3.838	3.563	5.492	59.192
Timing + Hook AFs	0.808	6.359	4.933	25.551	9.786	3.471	3.056	5.550	59.513
Timing + Depth AFs	0.594	7.022	4.807	23.901	8.357	3.434	4.898	6.169	59.181
Timing + Hook + Depth AFs	0.714	6.530	4.941	24.662	9.866	3.680	3.566	5.352	59.312
Historical shares									
15 year (1993-2007) average	1.7%	15.8%	15.1%	37.1%	14.5%	5.3%	3.9%	6.5%	100.0%
3 year averages (2:1)	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.776	7.741	6.619	24.901	8.306	3.038	3.355	5.374	60.109
Hook AF	0.838	7.531	6.695	25.578	9.043	3.151	2.633	4.793	60.260
Depth AF	0.711	7.825	6.633	24.273	8.324	3.169	3.817	5.209	59.961
Timing AF	0.860	7.796	6.624	25.039	8.267	2.955	3.358	5.281	60.180
Hook + Depth AFs	0.767	7.615	6.723	24.991	9.090	3.287	2.988	4.663	60.124
Timing + Hook AFs	0.930	7.579	6.705	25.731	9.001	3.055	2.636	4.699	60.336
Timing + Depth AFs	0.789	7.881	6.638	24.407	8.285	3.088	3.826	5.115	60.029
Timing + Hook + Depth AFs	0.855	7.662	6.733	25.138	9.047	3.196	2.997	4.569	60.197
Reverse weighted (2:1)	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.762	8.039	6.573	24.664	8.013	3.144	3.470	5.444	60.109
Hook AF	0.837	7.722	6.643	25.112	8.993	3.312	2.691	4.869	60.179
Depth AF	0.704	8.157	6.566	24.036	8.040	3.270	3.911	5.281	59.966
Timing AF	0.838	8.092	6.570	24.838	7.974	3.048	3.469	5.356	60.184
Hook + Depth AFs	0.772	7.836	6.649	24.529	9.049	3.446	3.026	4.740	60.046
Timing + Hook AFs	0.923	7.768	6.647	25.303	8.952	3.201	2.688	4.779	60.260
Timing + Depth AFs	0.780	8.210	6.563	24.203	7.999	3.177	3.915	5.191	60.039
Timing + Hook + Depth AFs	0.860	7.881	6.653	24.710	9.006	3.341	3.028	4.647	60.126

Table 9. Fishery CEY by area according to various apportionment methods.

3 year averages	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.342	5.796	2.261	17.035	7.866	2.094	3.828	4.043	43.265
Hook AF	0.434	5.482	2.374	18.051	8.972	2.264	2.745	3.171	43.492
Depth AF	0.245	5.923	2.282	16.093	7.894	2.291	4.520	3.795	43.042
Timing AF	0.468	5.880	2.268	17.241	7.808	1.969	3.833	3.903	43.371
Hook + Depth AFs	0.327	5.608	2.417	17.170	9.043	2.468	3.277	2.977	43.287
Timing + Hook AFs	0.573	5.554	2.390	18.279	8.909	2.120	2.750	3.031	43.606
Timing + Depth AFs	0.361	6.006	2.290	16.294	7.835	2.169	4.534	3.654	43.145
Timing + Hook + Depth AFs	0.460	5.679	2.433	17.390	8.979	2.331	3.290	2.835	43.397
Reverse weighted	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.320	6.244	2.192	16.679	7.428	2.253	4.001	4.148	43.266
Hook AF	0.434	5.769	2.297	17.351	8.897	2.505	2.832	3.285	43.369
Depth AF	0.234	6.421	2.182	15.738	7.468	2.442	4.662	3.904	43.050
Timing AF	0.434	6.323	2.188	16.940	7.369	2.109	3.998	4.016	43.378
Hook + Depth AFs	0.335	5.939	2.306	16.476	8.981	2.707	3.334	3.092	43.171
Timing + Hook AFs	0.562	5.837	2.303	17.638	8.836	2.340	2.827	3.150	43.492
Timing + Depth AFs	0.348	6.500	2.177	15.988	7.407	2.303	4.669	3.769	43.160
Timing + Hook + Depth AFs	0.468	6.008	2.311	16.749	8.916	2.549	3.337	2.952	43.291
Historical shares									
15 year (1993-2007) average	1.7%	15.8%	15.1%	37.1%	14.5%	5.3%	3.9%	6.5%	100.0%
3 year averages (2:1)	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.530	7.219	3.846	16.988	7.356	1.907	3.126	2.974	43.945
Hook AF	0.592	7.009	3.922	17.665	8.093	2.020	2.404	2.393	44.096
Depth AF	0.465	7.303	3.860	16.360	7.374	2.038	3.588	2.809	43.797
Timing AF	0.614	7.274	3.851	17.126	7.317	1.824	3.129	2.881	44.016
Hook + Depth AFs	0.521	7.093	3.950	17.078	8.140	2.156	2.759	2.263	43.960
Timing + Hook AFs	0.684	7.057	3.932	17.818	8.051	1.924	2.407	2.299	44.172
Timing + Depth AFs	0.543	7.359	3.865	16.494	7.335	1.957	3.597	2.715	43.865
Timing + Hook + Depth AFs	0.609	7.140	3.960	17.225	8.097	2.065	2.768	2.169	44.033
Reverse weighted (2:1)	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.516	7.517	3.800	16.751	7.063	2.013	3.241	3.044	43.945
Hook AF	0.591	7.200	3.870	17.199	8.043	2.181	2.462	2.469	44.015
Depth AF	0.458	7.635	3.793	16.123	7.090	2.139	3.682	2.881	43.802
Timing AF	0.592	7.570	3.797	16.925	7.024	1.917	3.240	2.956	44.020
Hook + Depth AFs	0.526	7.314	3.876	16.616	8.099	2.315	2.797	2.340	43.882
Timing + Hook AFs	0.677	7.246	3.874	17.390	8.002	2.070	2.459	2.379	44.096
Timing + Depth AFs	0.534	7.688	3.790	16.290	7.049	2.046	3.686	2.791	43.875
Timing + Hook + Depth AFs	0.614	7.359	3.880	16.797	8.056	2.210	2.799	2.247	43.962

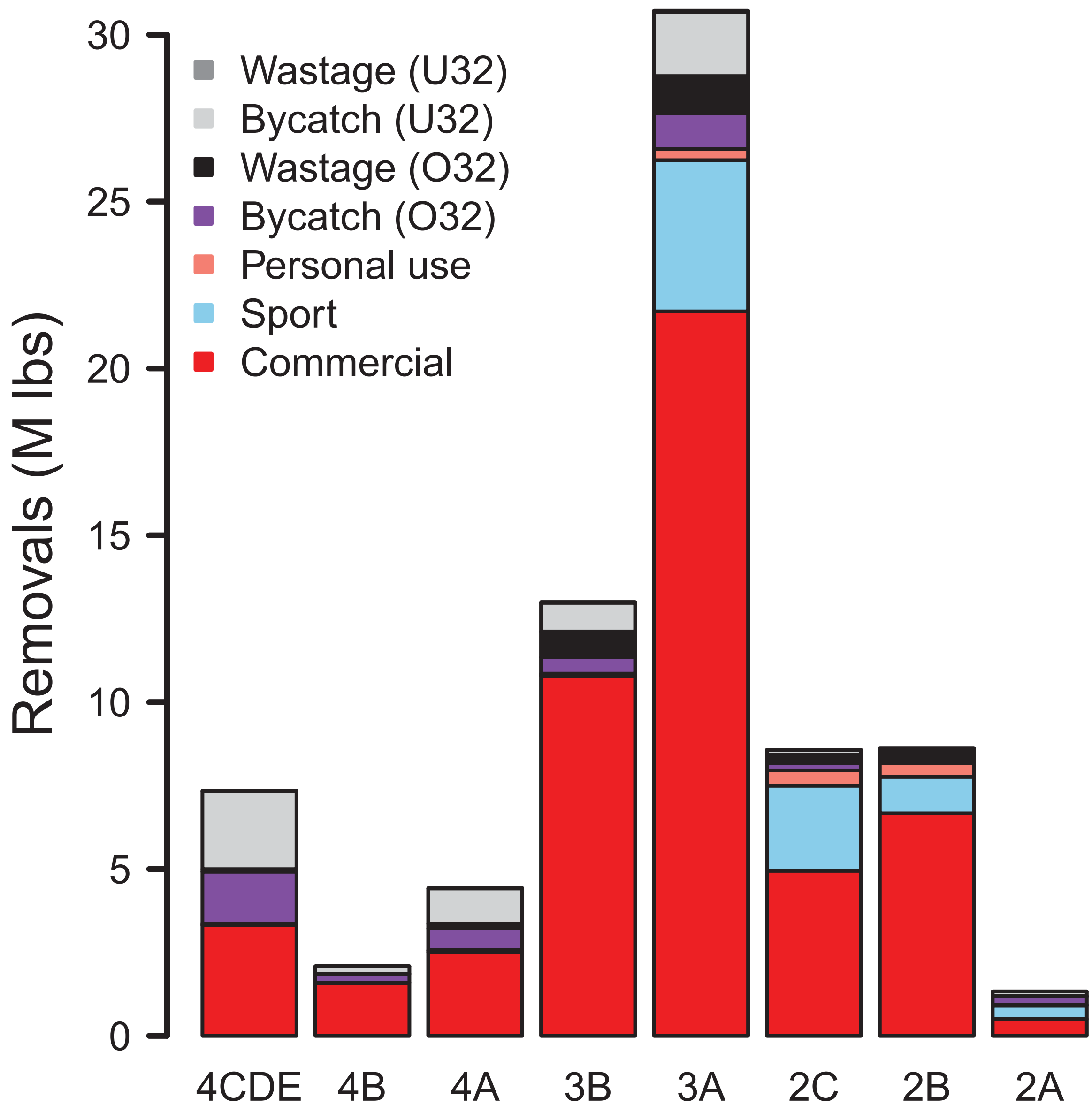


Figure 1. Total removals by type and regulatory area for 2009.

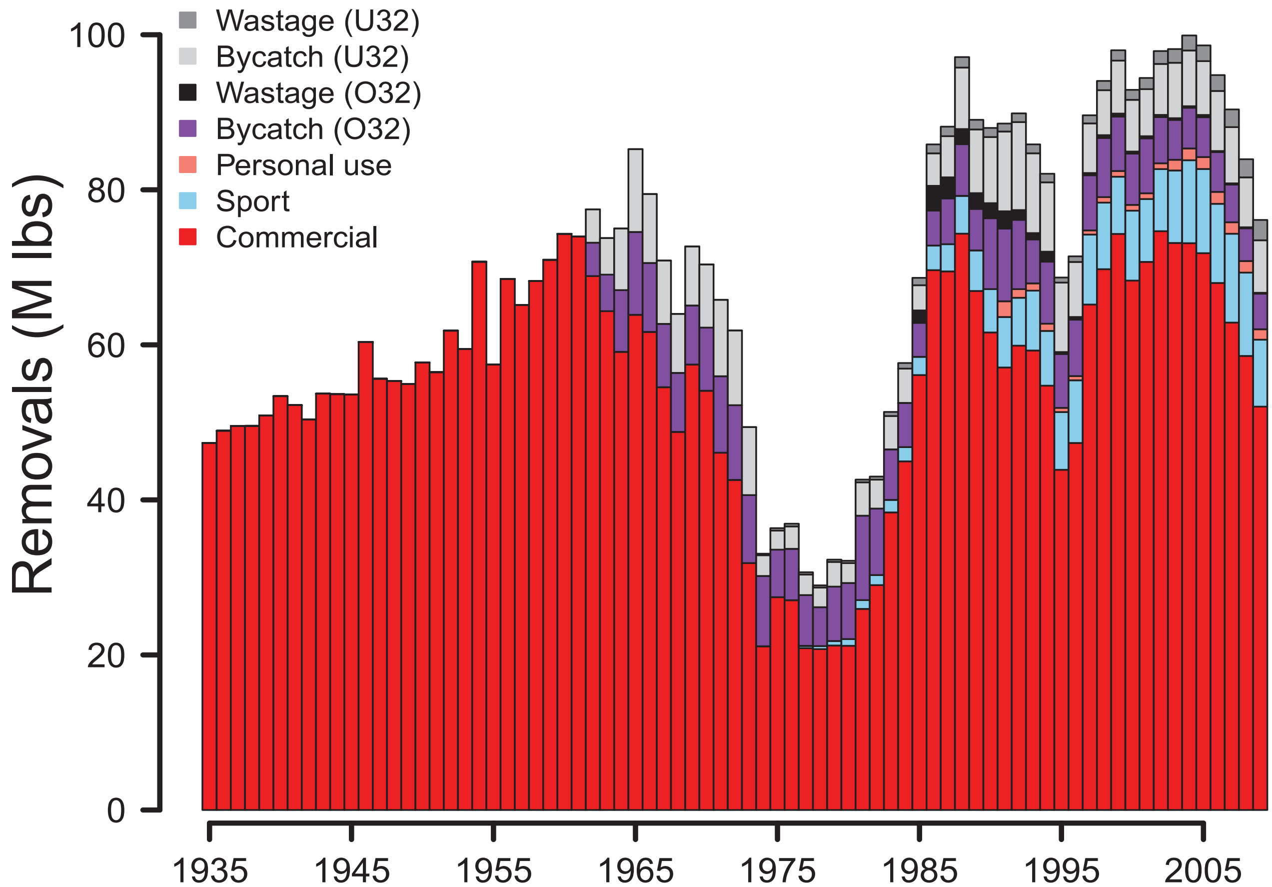


Figure 2. Total removals coastwide for the period 1935-2009.

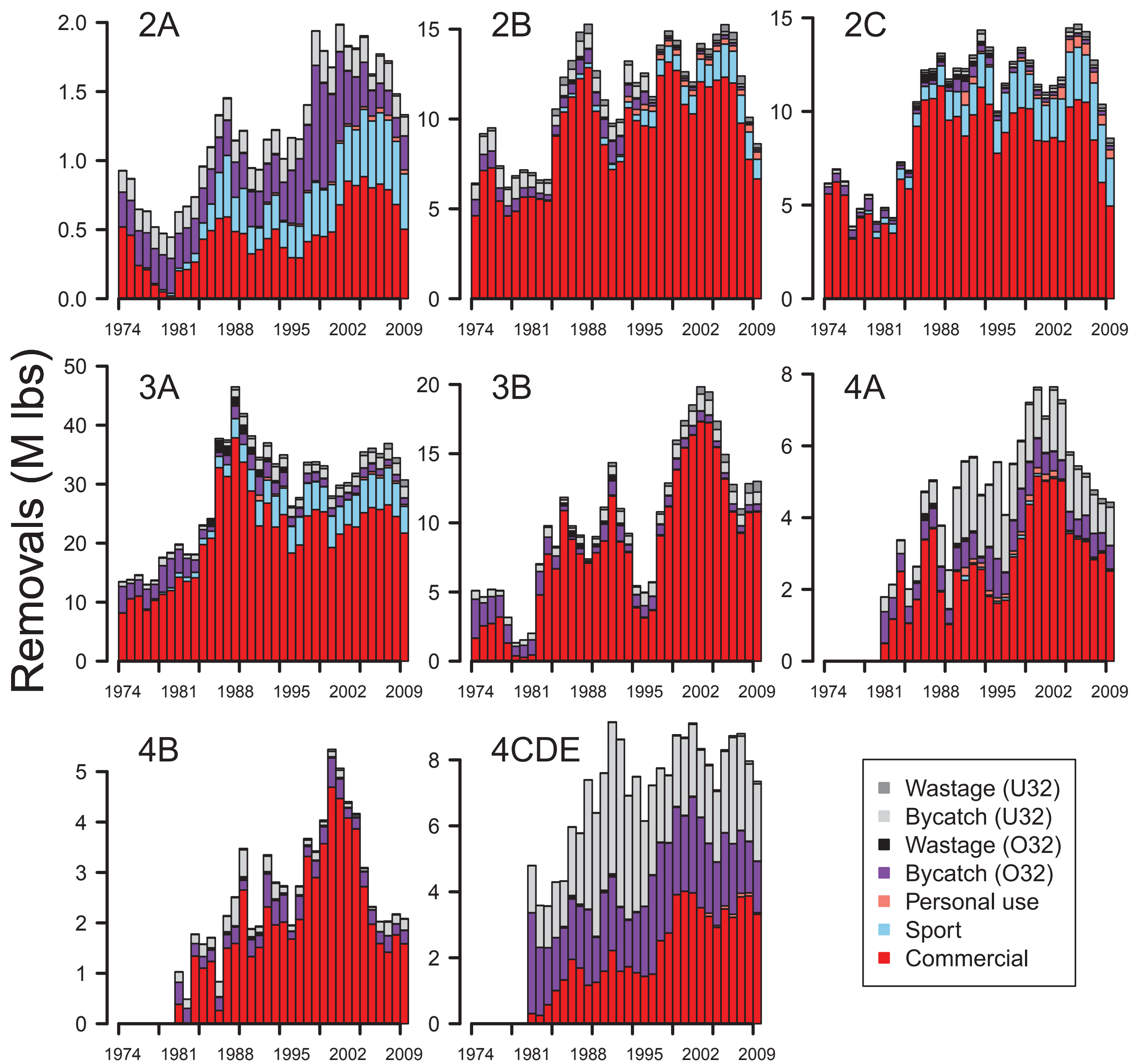


Figure 3. Total removals of halibut, by Regulatory Area, 1974-2009. The two U32 categories (bycatch and wastage, colored in gray) and not included in the total removals listed in Table A1).

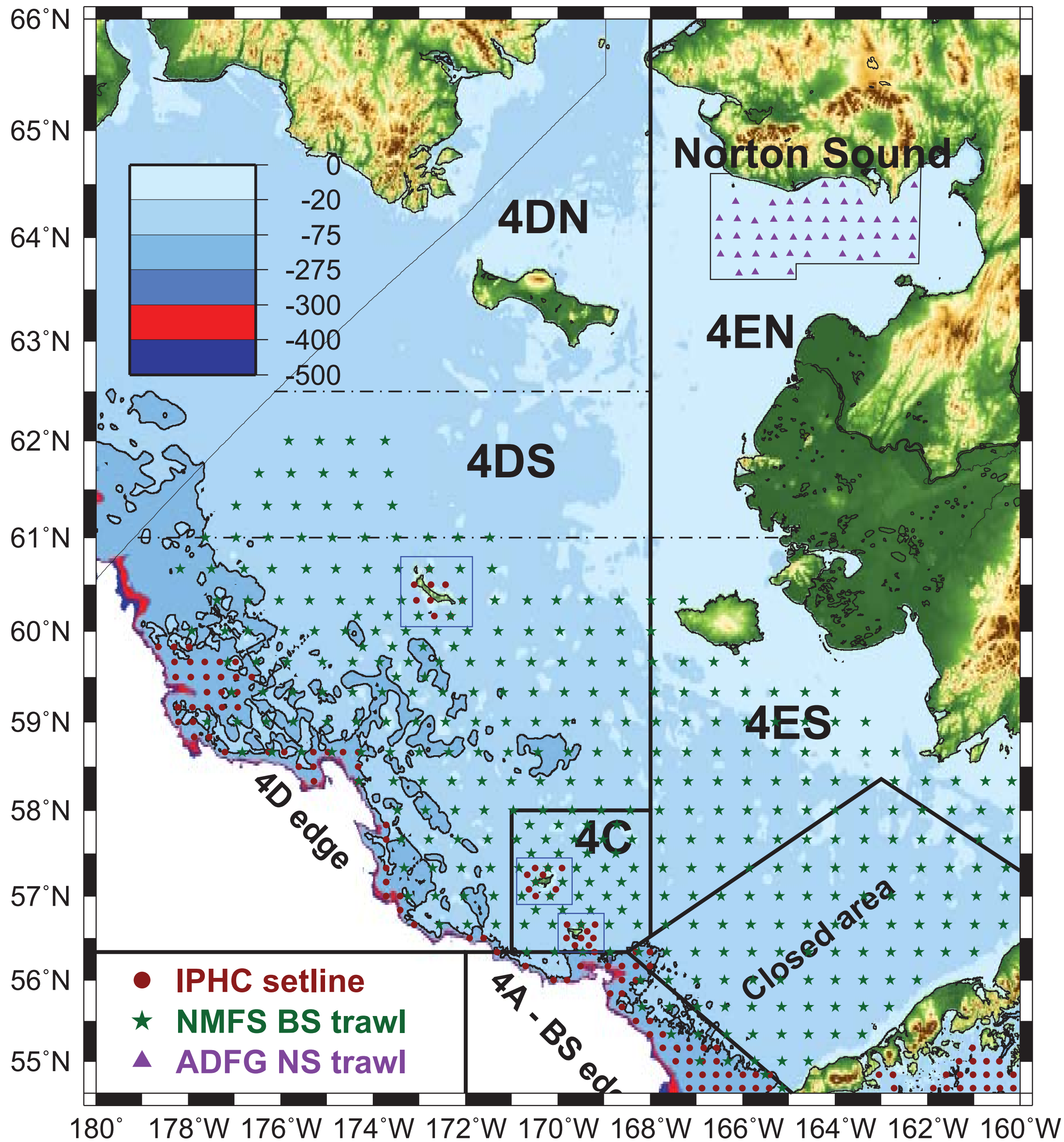


Figure 4. Summary of information sources and subareas utilized to construct a dataset for Area 4CDE. See text for details

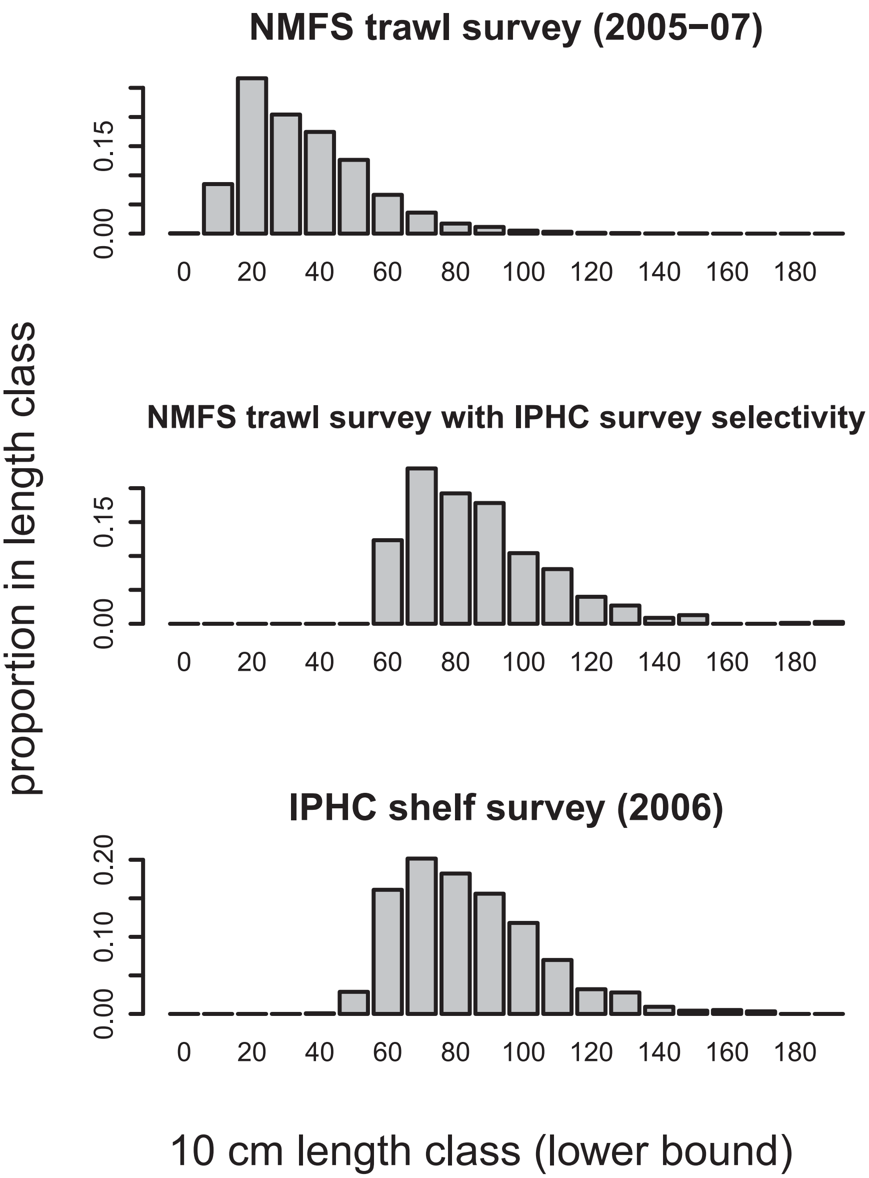


Figure 5. Comparison of NMFS trawl survey and IPHC length frequency compositions. The top panel shows the length frequency composition for all halibut caught by the NMFS trawl gear for years 2005-7. the middle panel shows the frequency distribution of lengths after the IPHC setline selectivity curve is applied to raw counts. The bottom panel illustrates the length composition of halibut in the 2006 IPHC shelf survey.

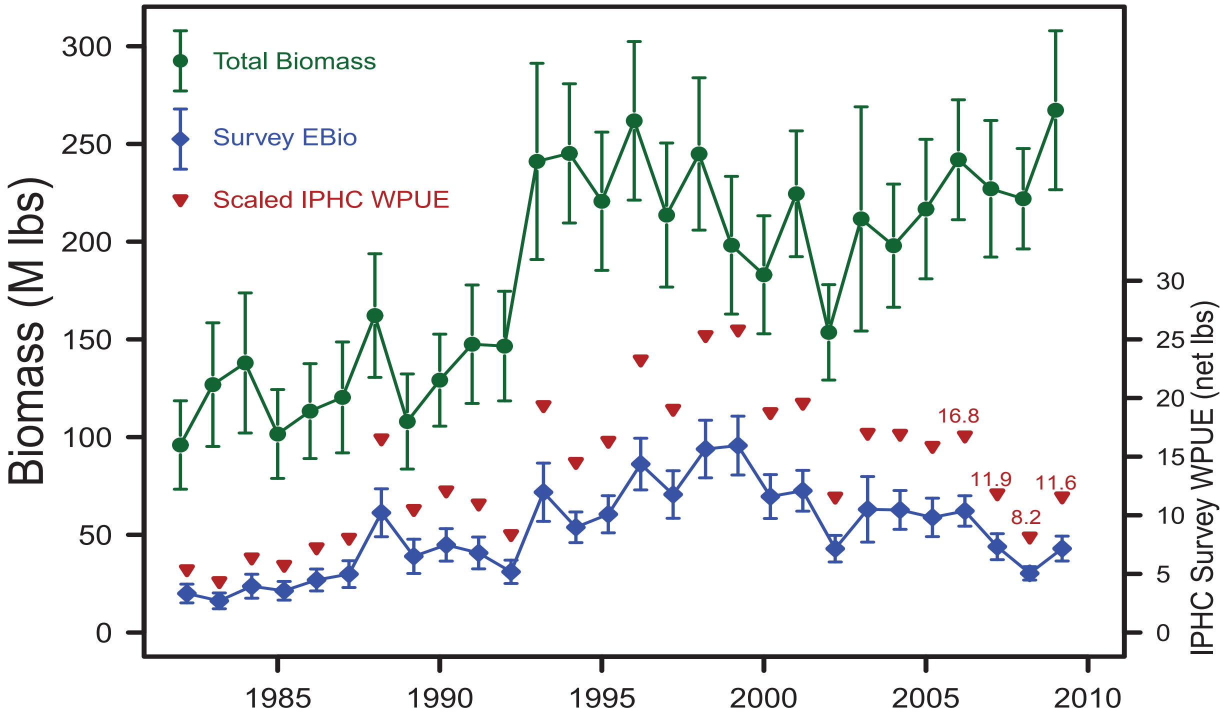


Figure 6. Swept-area estimates of halibut abundance from the NMFS EBS trawl survey. The red dots and error bars represent mean and 95% confidence interval for the total abundance; the blue diamonds are error bars represent mean and 95% confidence interval for abundance with survey selectivity applied to the total biomass (termed survey EBio). The inverted purple triangles represent the estimated density of O32 halibut (per standardized skate of gear) across the shelf; this index is scaled to the survey EBio trend (see text for full details).

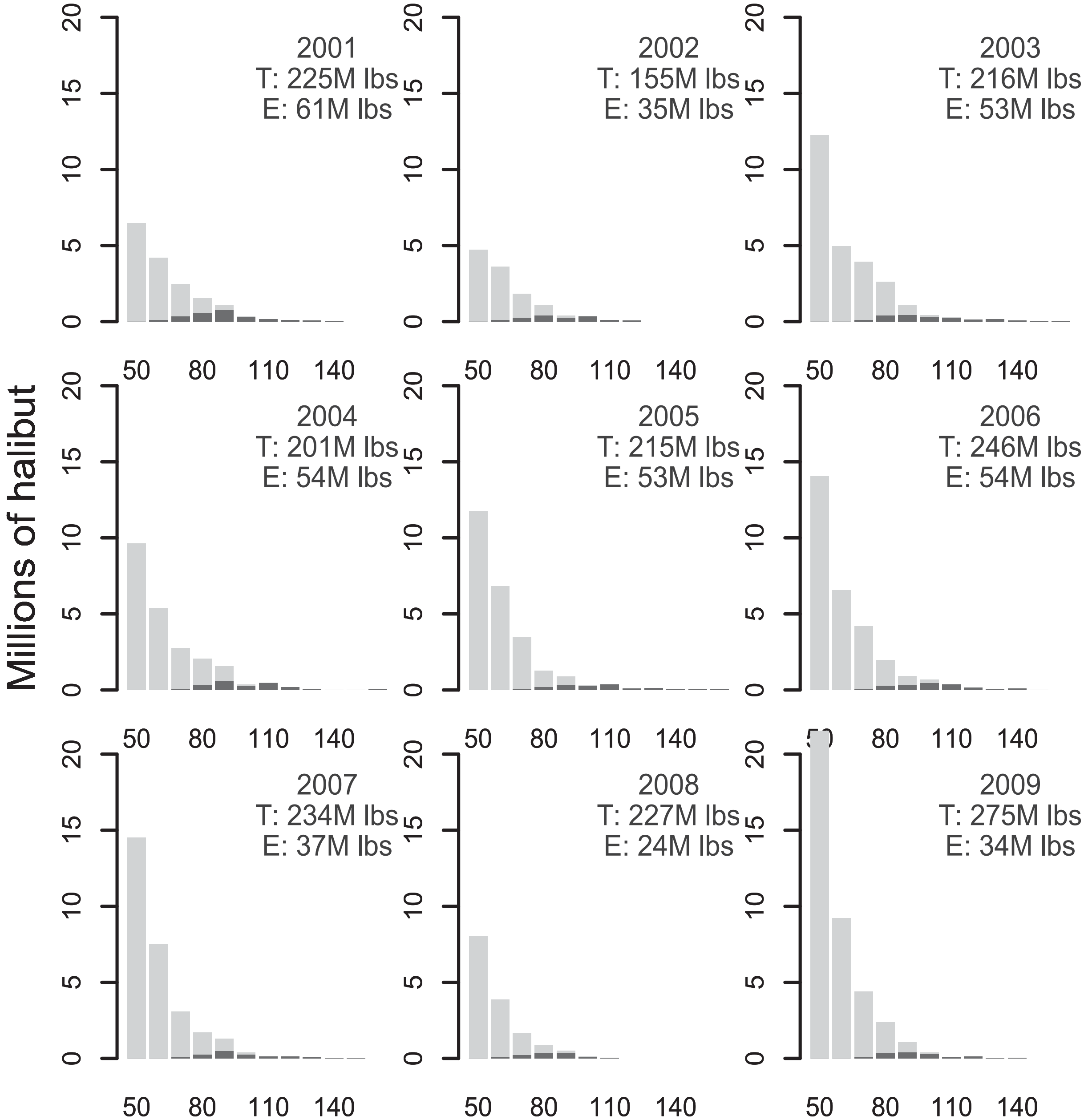


Figure 7. Swept area estimates of halibut, by 10-cm length interval, in the NMFS EBS trawl survey for the years 2001 to 2009. Values for total (T) and Exploitable (E) biomass estimated by the survey are also listed. Exploitable numbers of halibut are illustrated by the darker bars.

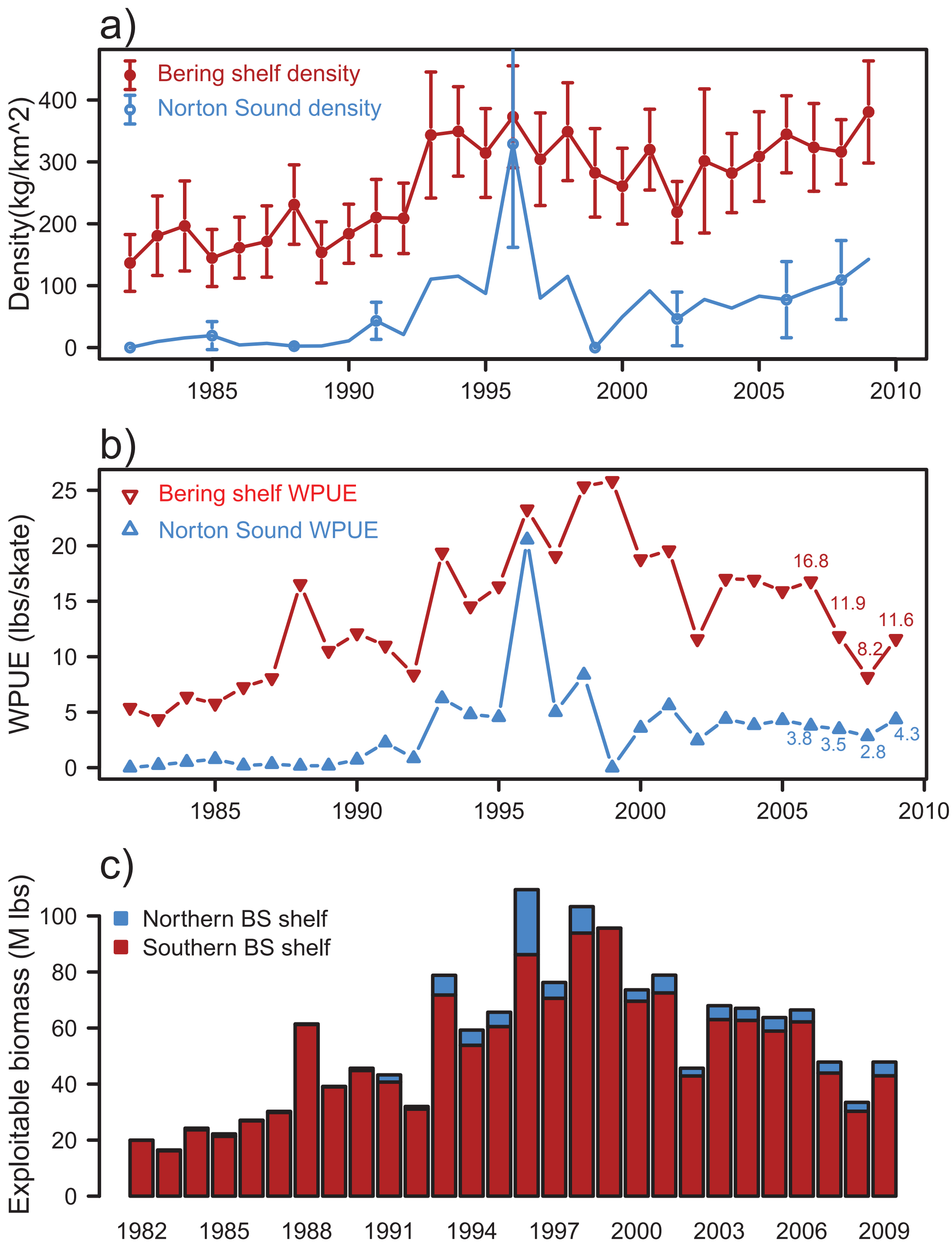


Figure 8. Time series used to construct an estimate of halibut biomass in the region north of 62.5°N in 4D and 61°N in Area 4E, together termed Area 4N. See text for details.

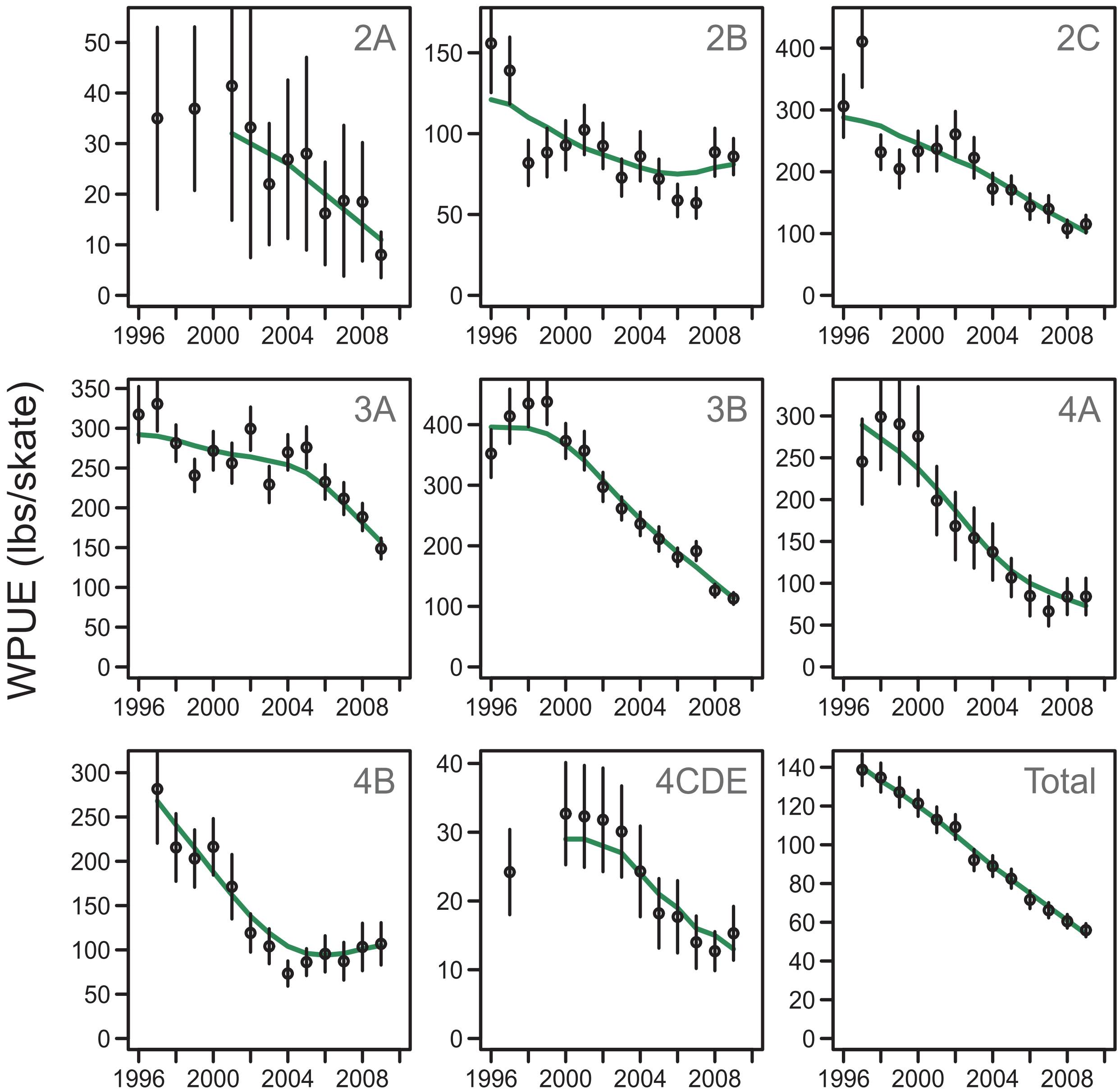


Figure 9. Survey WPUE (weight of O32 halibut per standardized skate of gear) by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray line is a smoother to illustrate trend; it is not an assessment model fitted to the WPUE data. The total is computed by area-weighting the individual area WPUE time series.

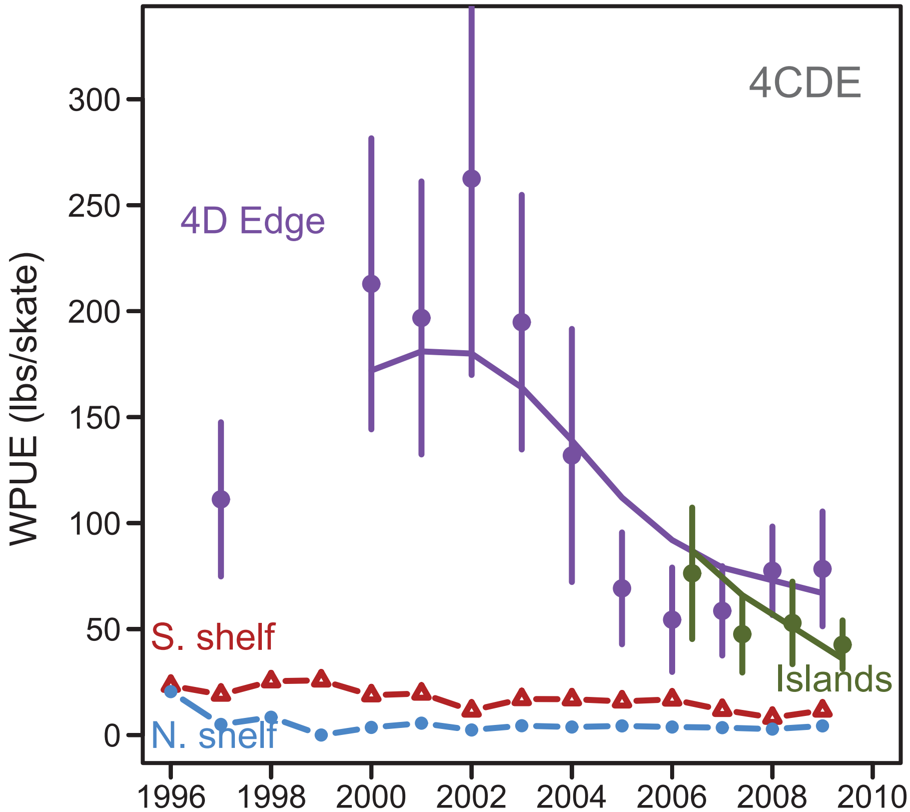


Figure 10. The four subarea components used to construct the WPUE survey index for Area 4CDE.

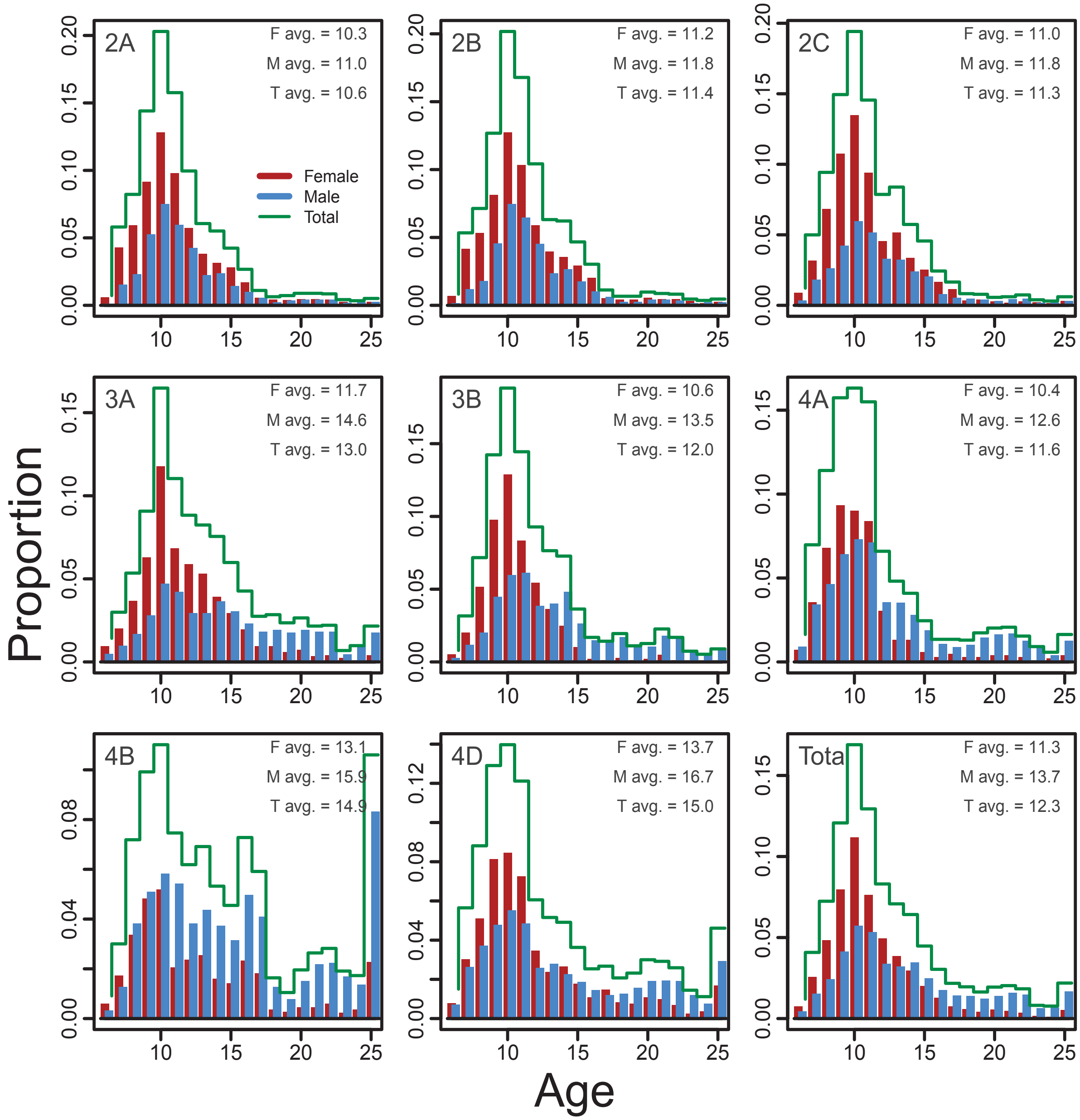


Figure 11. Regulatory area sex and age compositions from halibut taken in the 2009 IPHC stock assessment survey. Proportions are shown for females (red bars), males (blue bars) and sexes combined (green line). Average age is also shown, with "T" indicating Total (sexes combined).

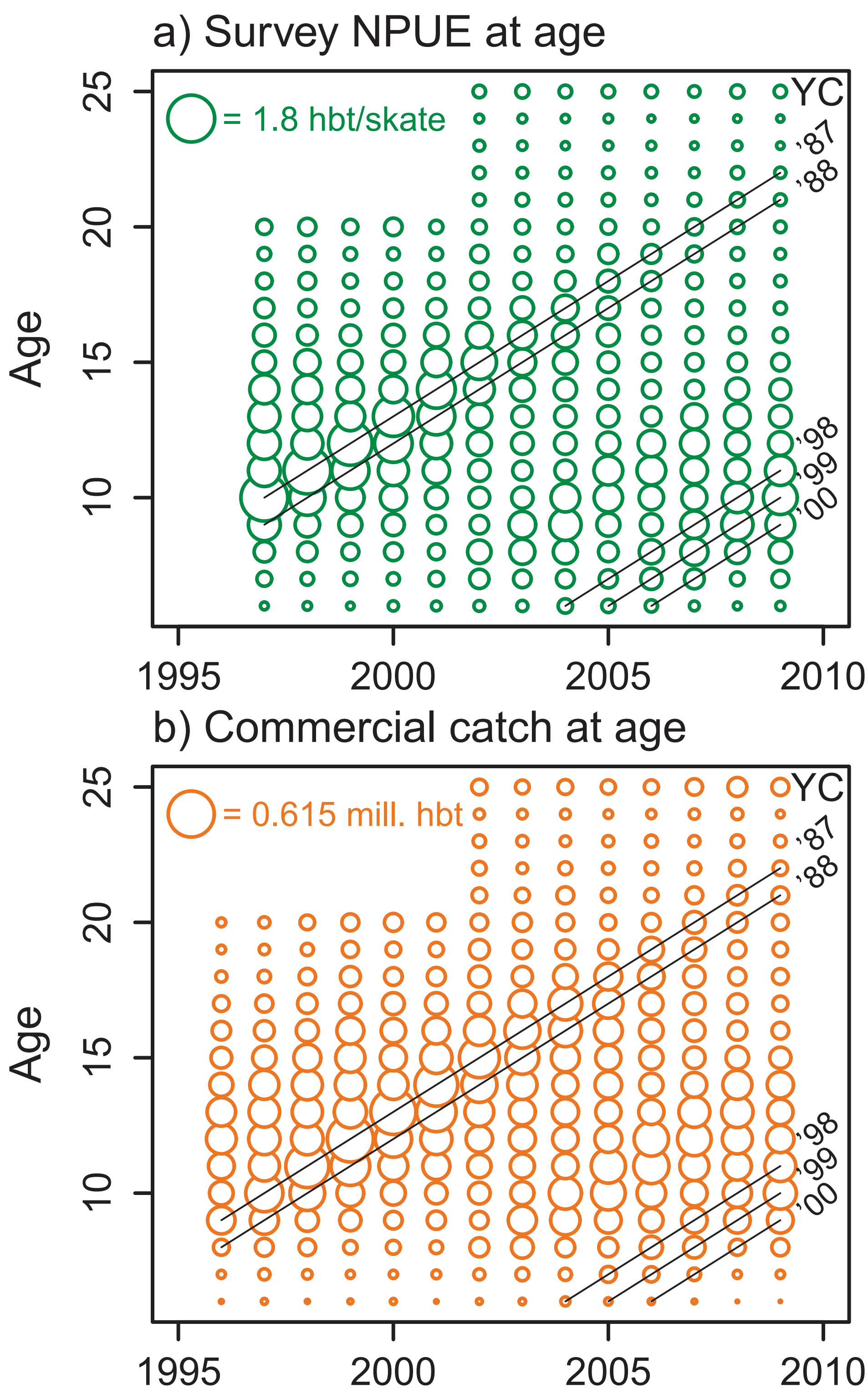


Figure 12. Bubble plots showing age-specific survey catch rate of halibut (both sexes combined, panel a), and catch at age (both sexes combined) in the commercial fishery (panel b).

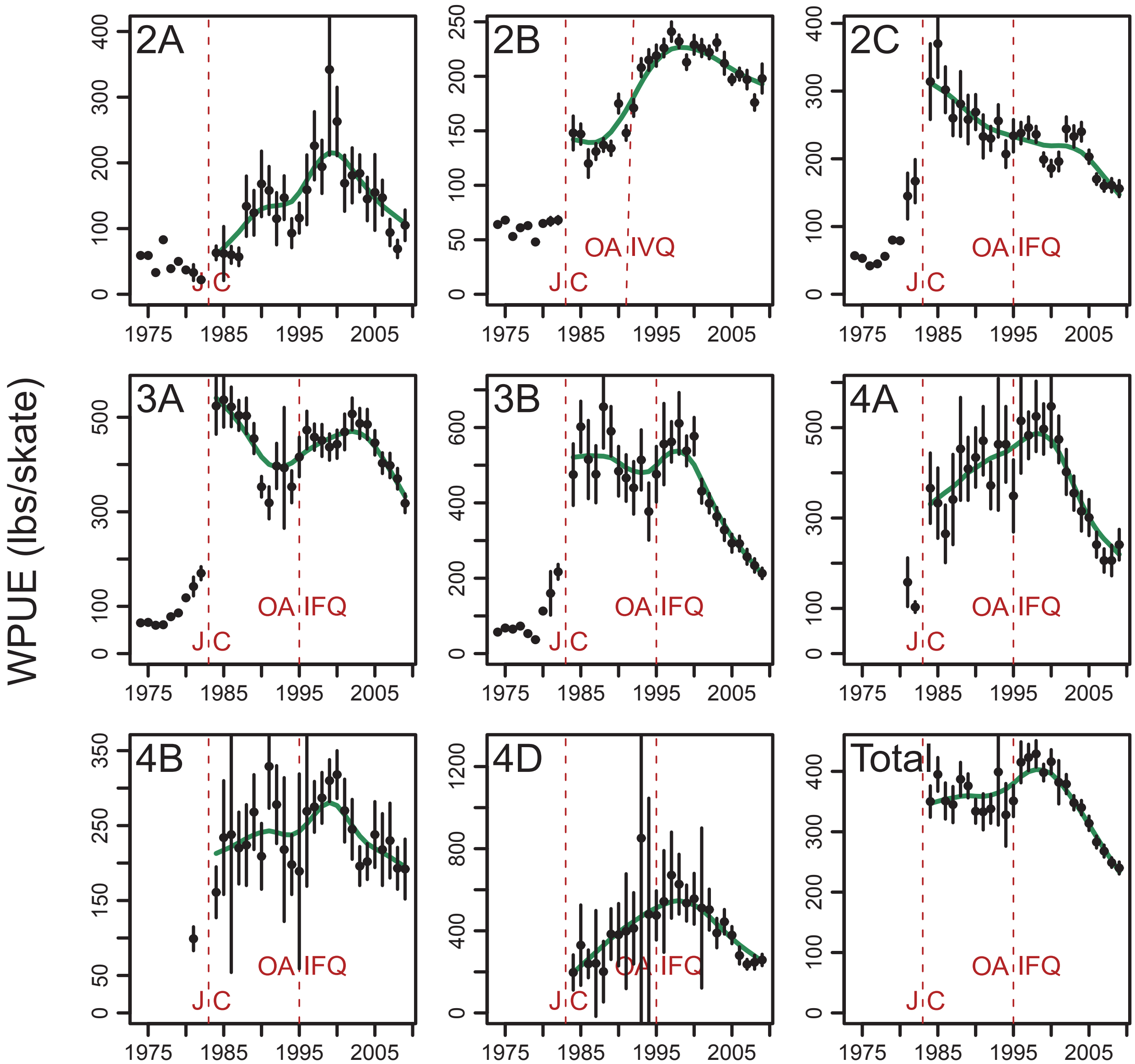


Figure 13. Commercial WPUE by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray line is a smoother to illustrate trend; it is not an assessment model fit to the CPUE data. The total is computed by area-weighting the individual area WPUE time series. The dashed vertical lines indicate transitions between J and C hook, between open access (OA) and Individual Vessel Quotas in Area 2B, and between open access and Individual Fishing Quotas in Areas 2C, 3 and 4.

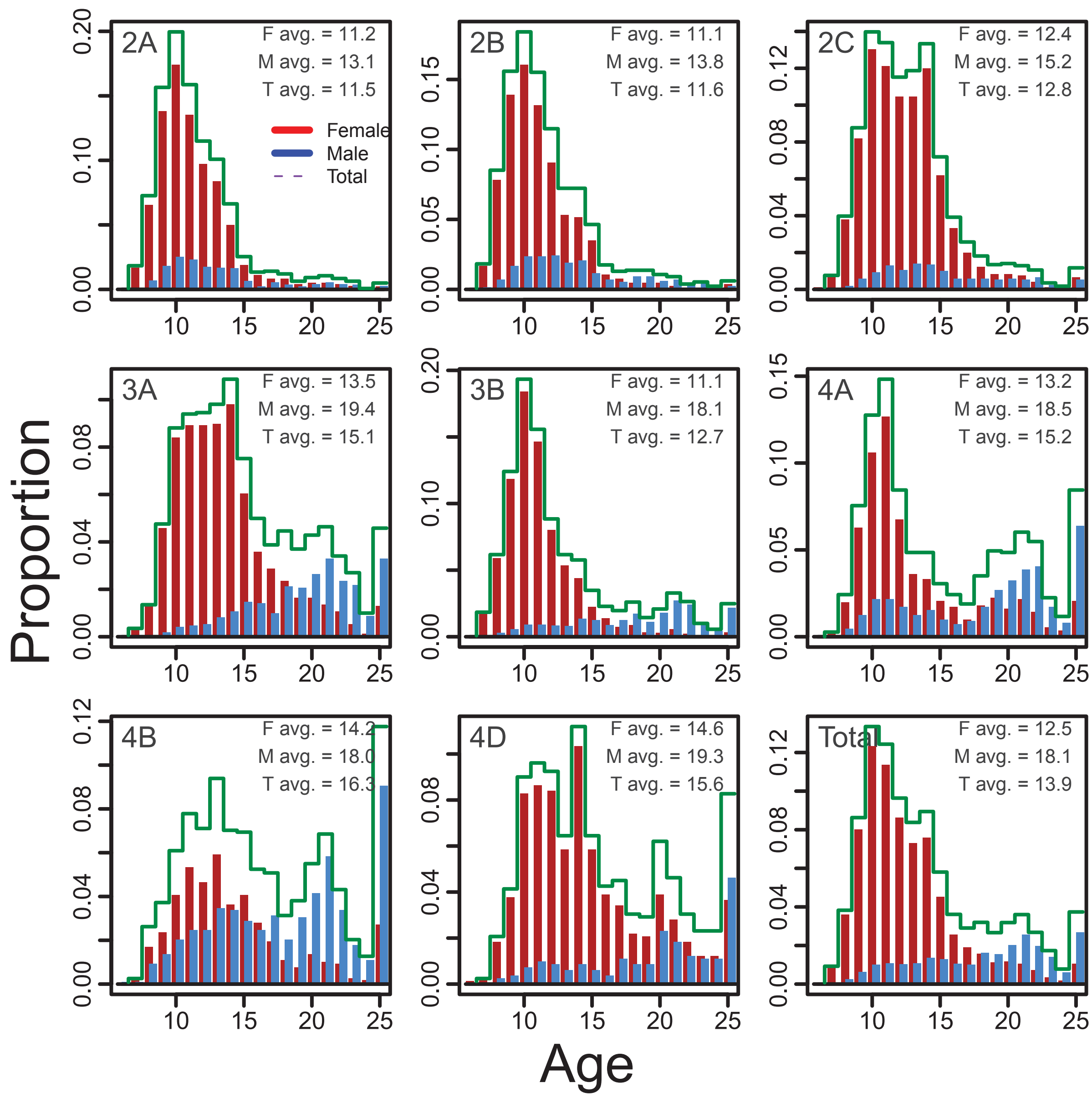


Figure 14. Regulatory area sex and age compositions from halibut sampled from commercial landings. Proportions are shown for females (red bars), males (blue bars) and sexes combined (green line). Average age is also shown, with "T" indicating Total (sexes combined).

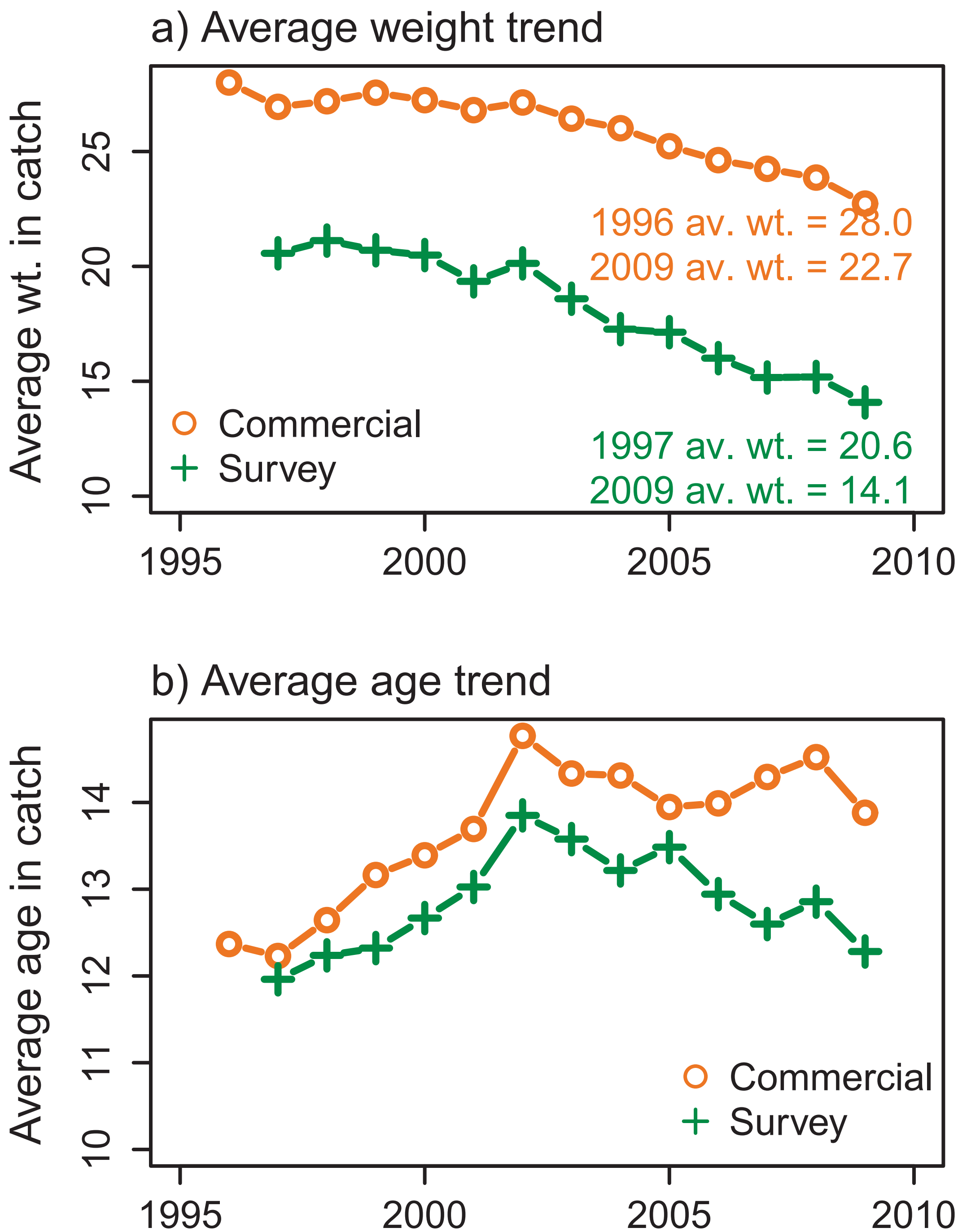


Figure 15. Average weight (panel a) and average weight (panel b) trends for the coastwide halibut stock for 1996 to 2009.

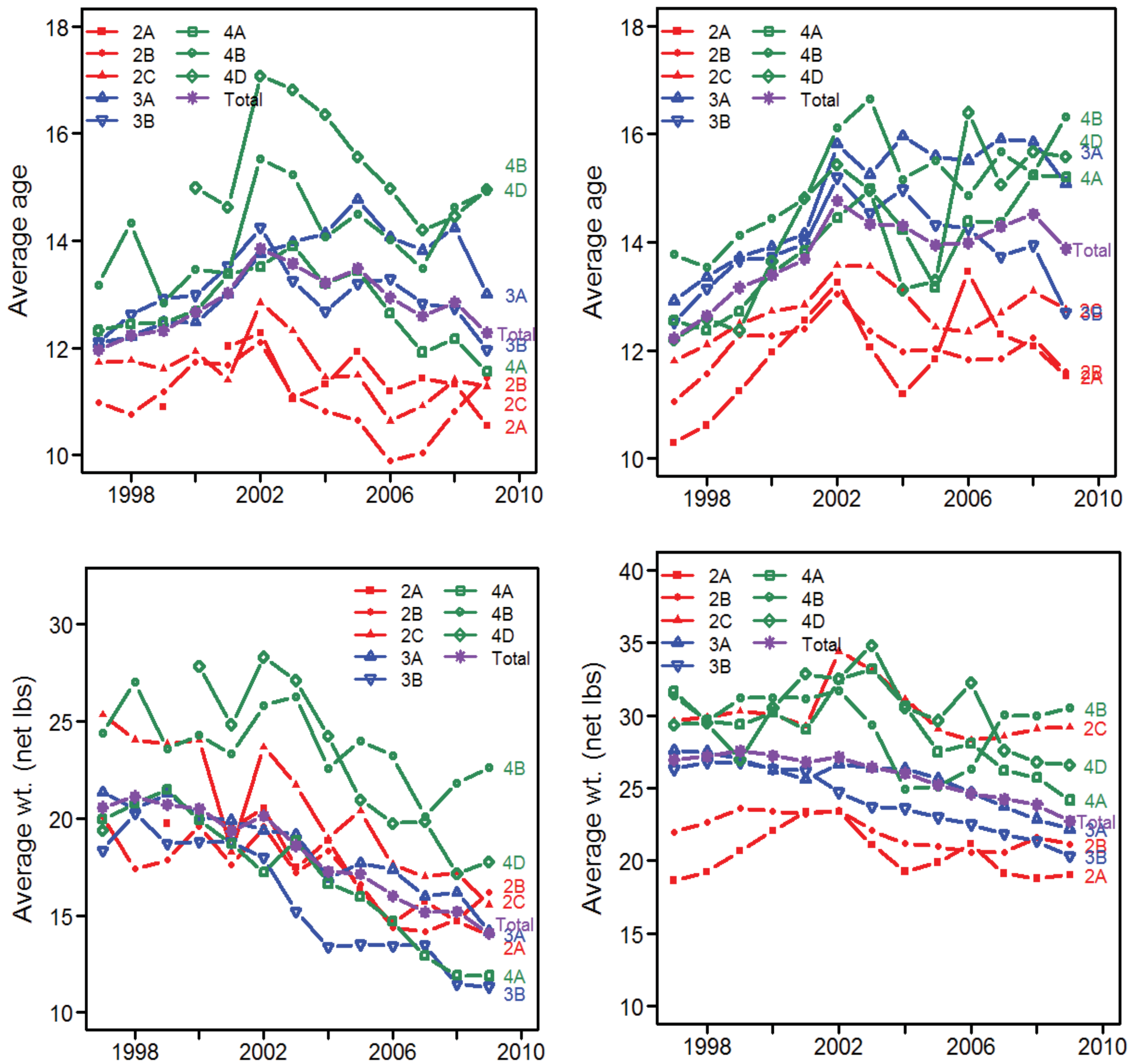


Figure 16. Trends in average age (top panels) and average weight (bottom panels) in survey catches (left panels) and commercial catches (right panels).

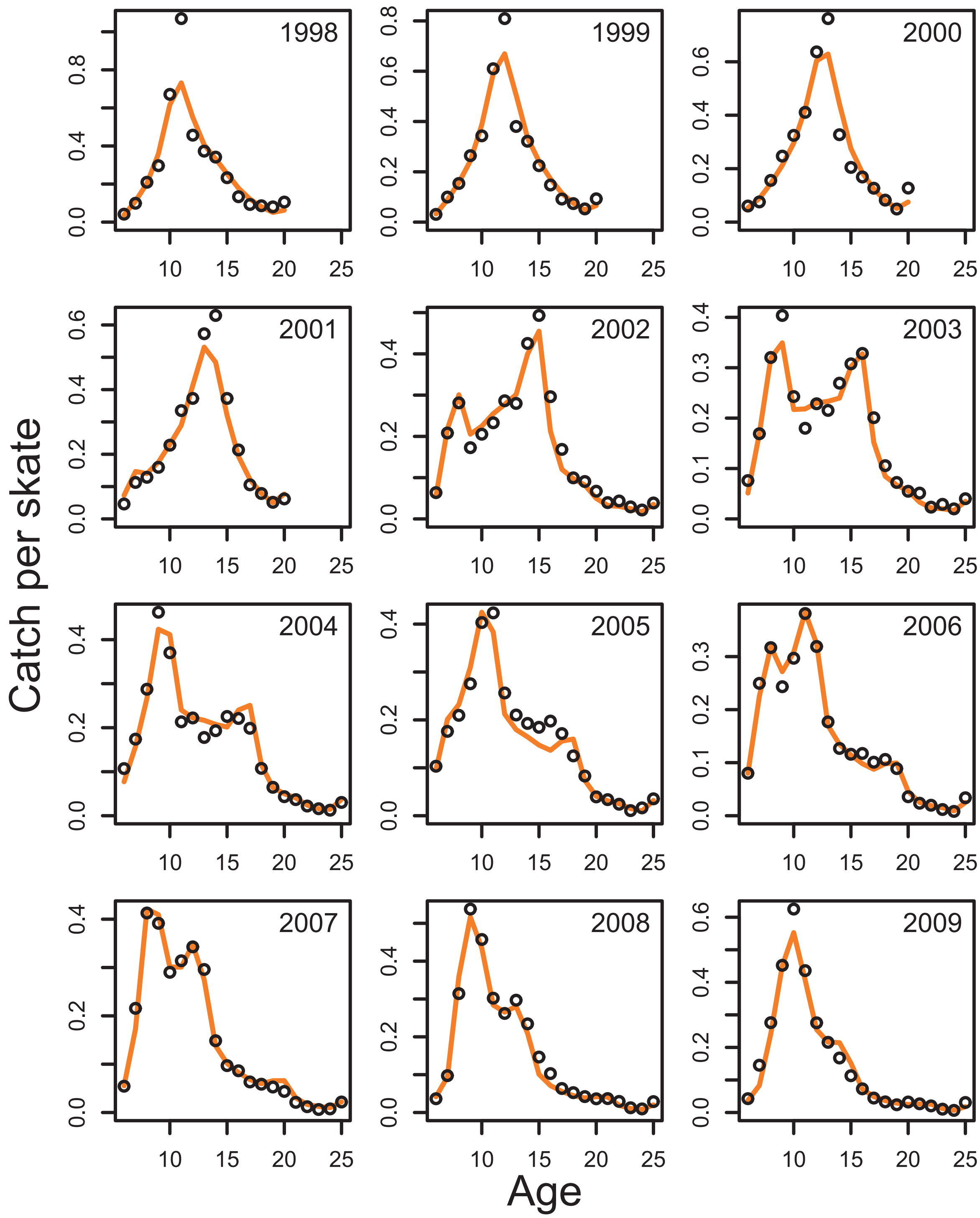


Figure 17a. Observed (points) and predicted (lines) survey NPUE at age of females in the 2009 coastwide model fit.

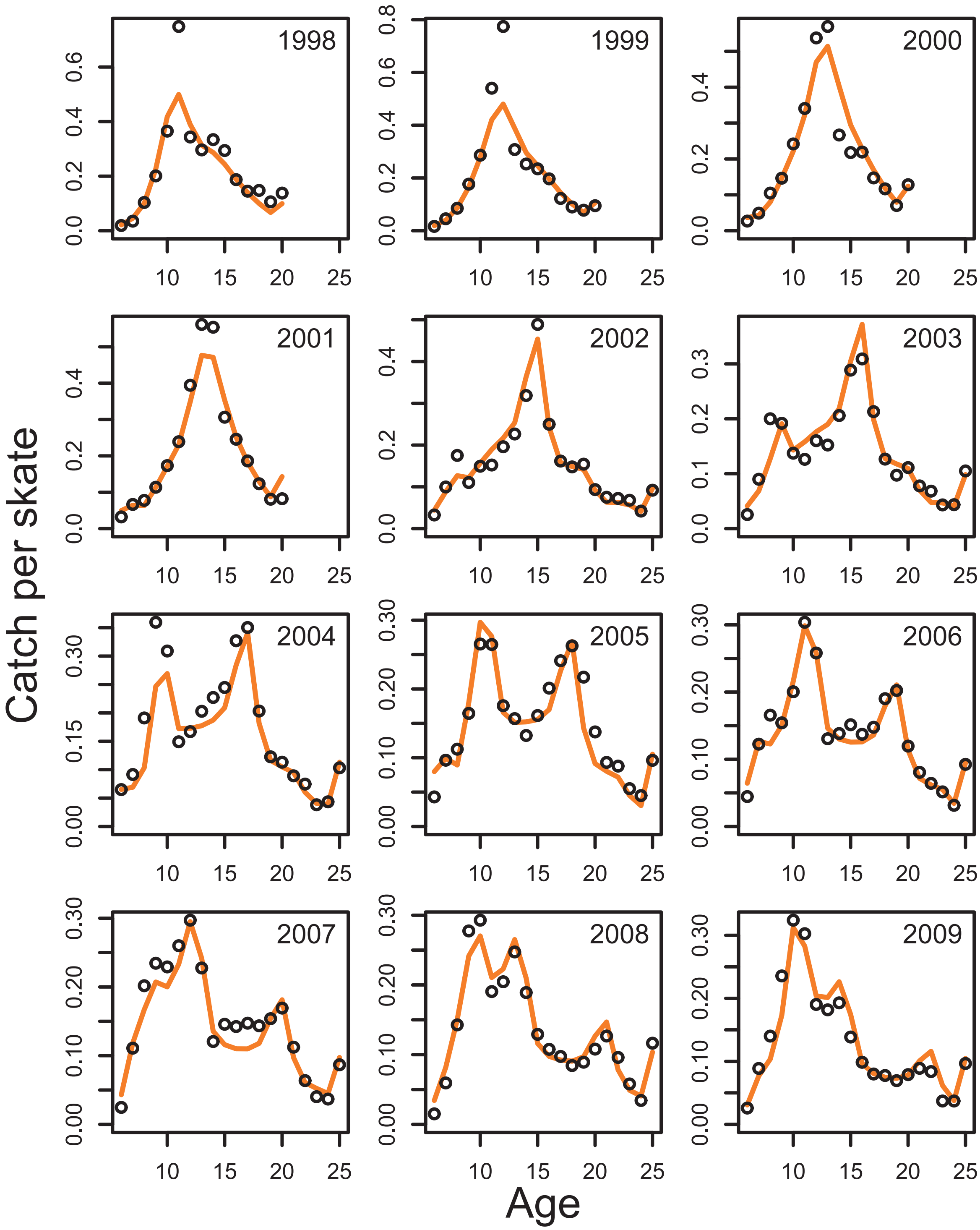


Figure 17b. Observed (points) and predicted (lines) survey NPUE at age of males in the 2009 coastwide model fit.

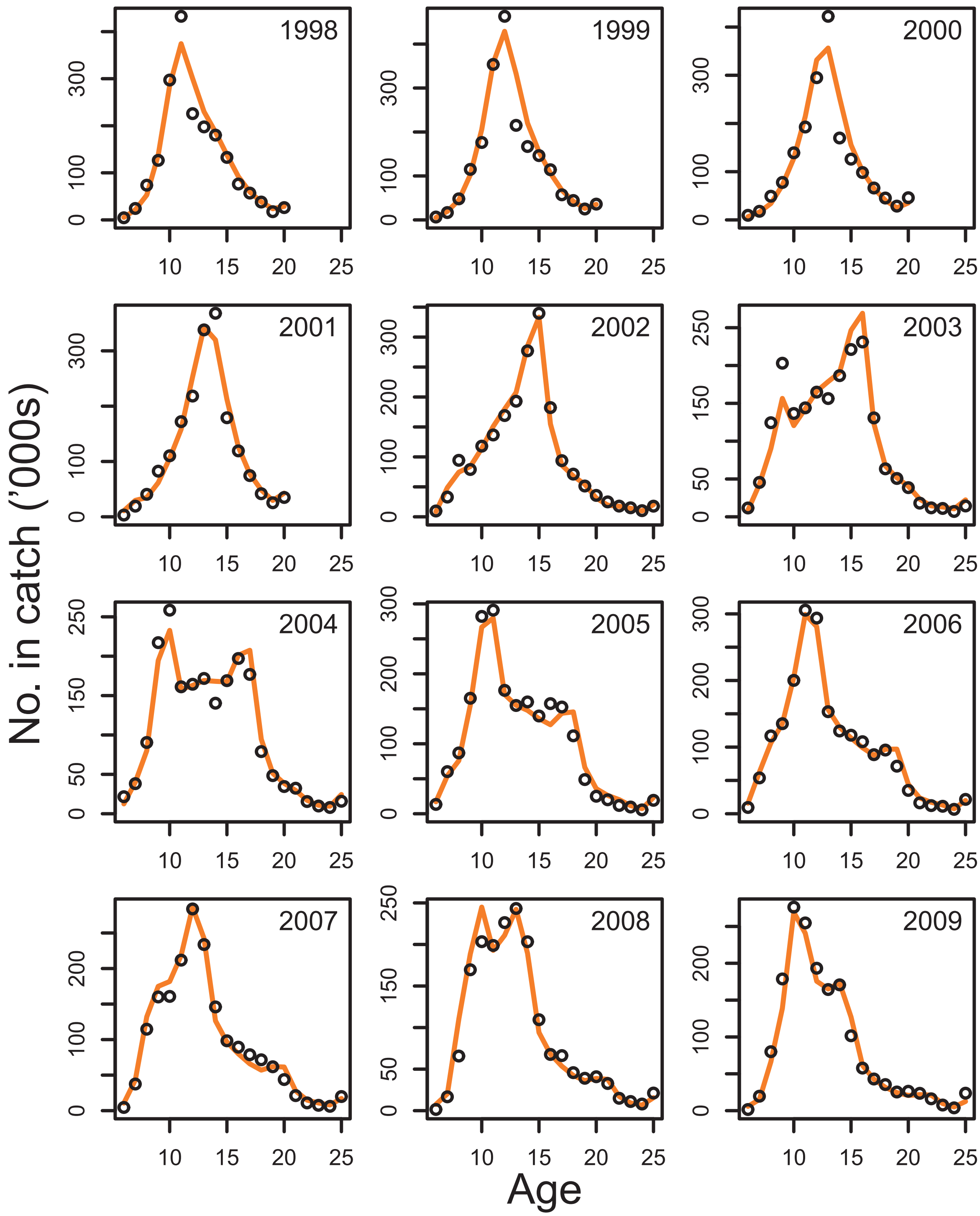


Figure 18a. Observed (points) and predicted (lines) commercial catch at age of females in the 2009 coastwide model fit.

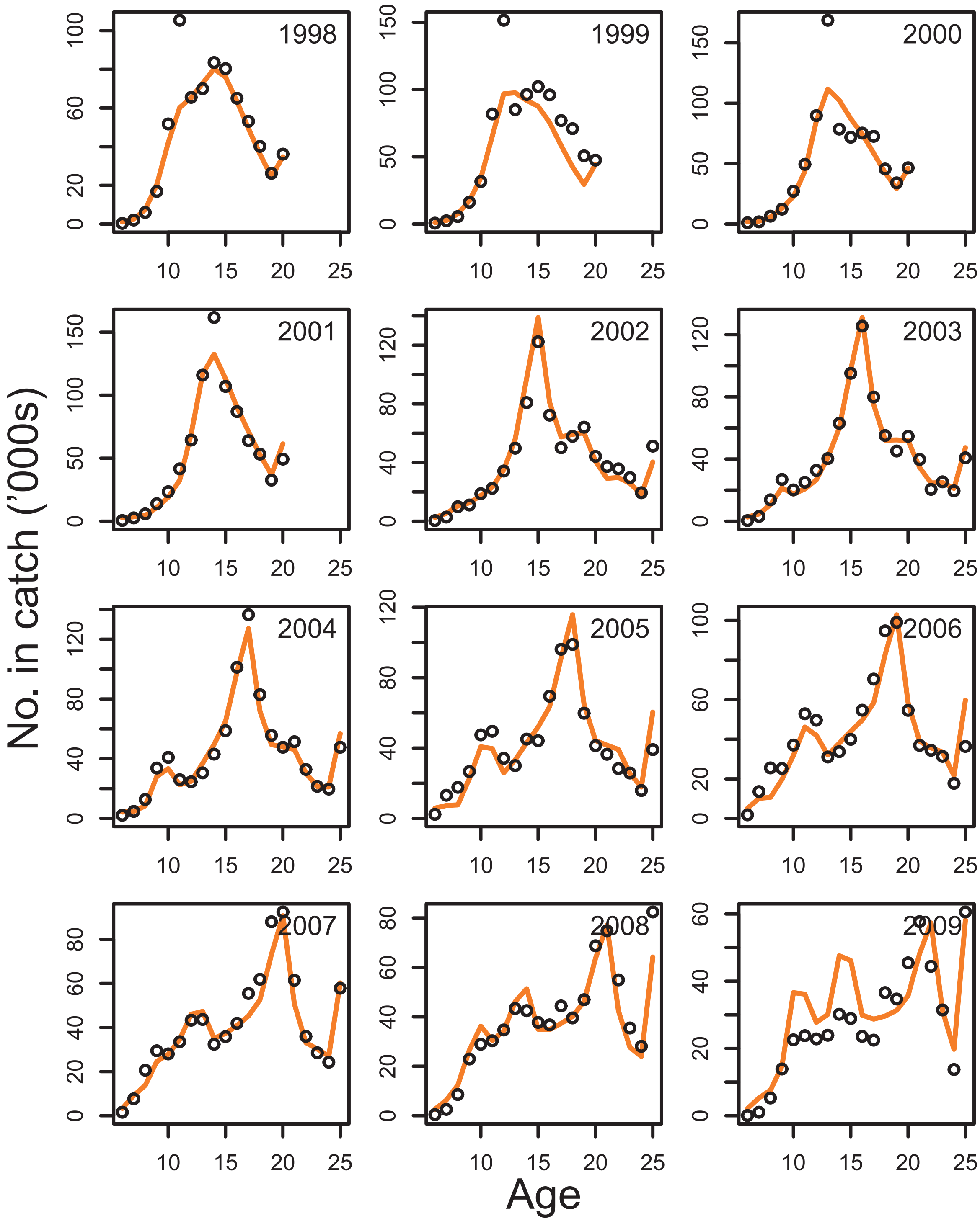


Figure 18b. Observed (points) and predicted (lines) commercial catch at age of males in the 2009 coastwide model fit.

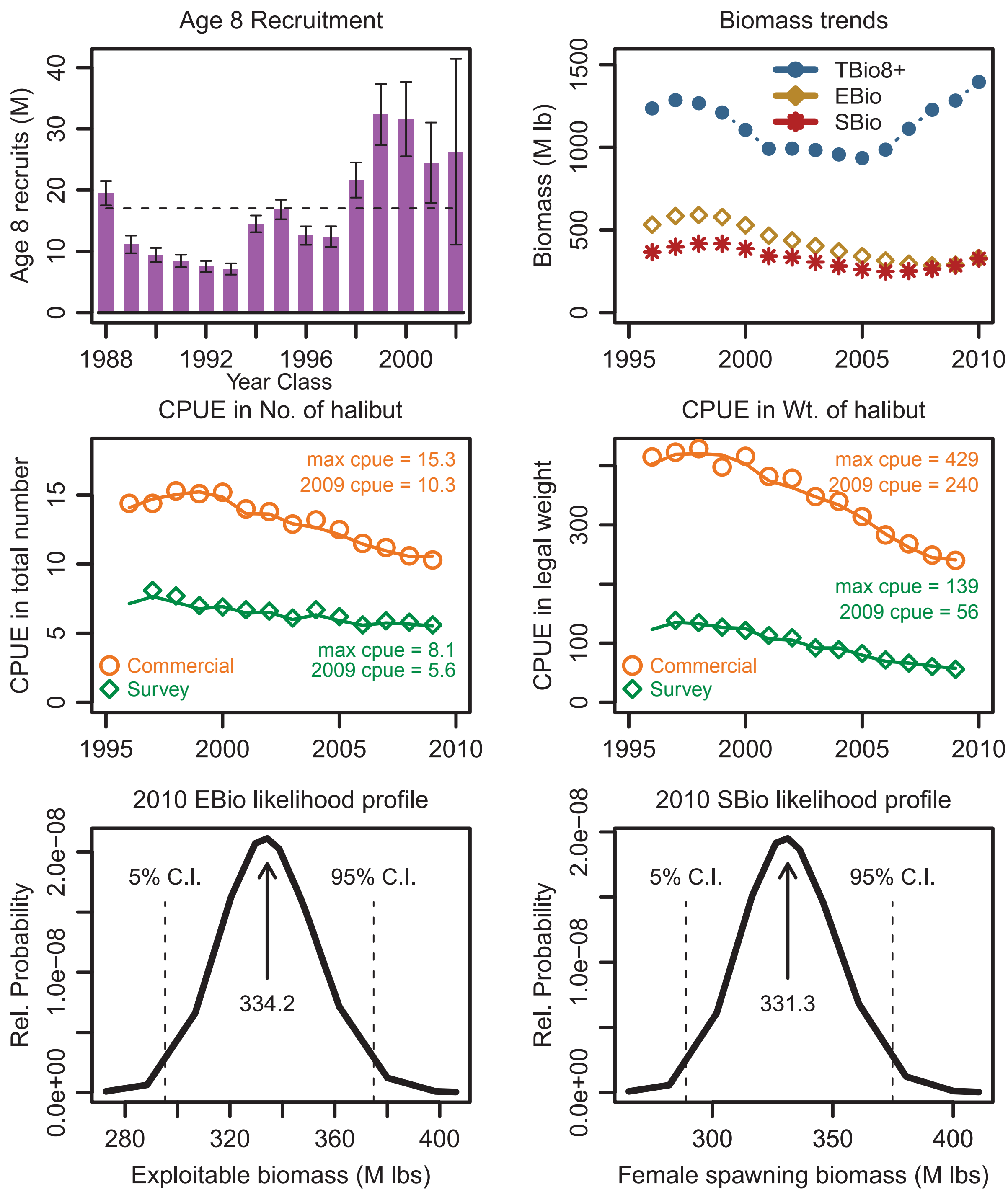


Figure 19. Features of the 2009 halibut coastwide assessment.

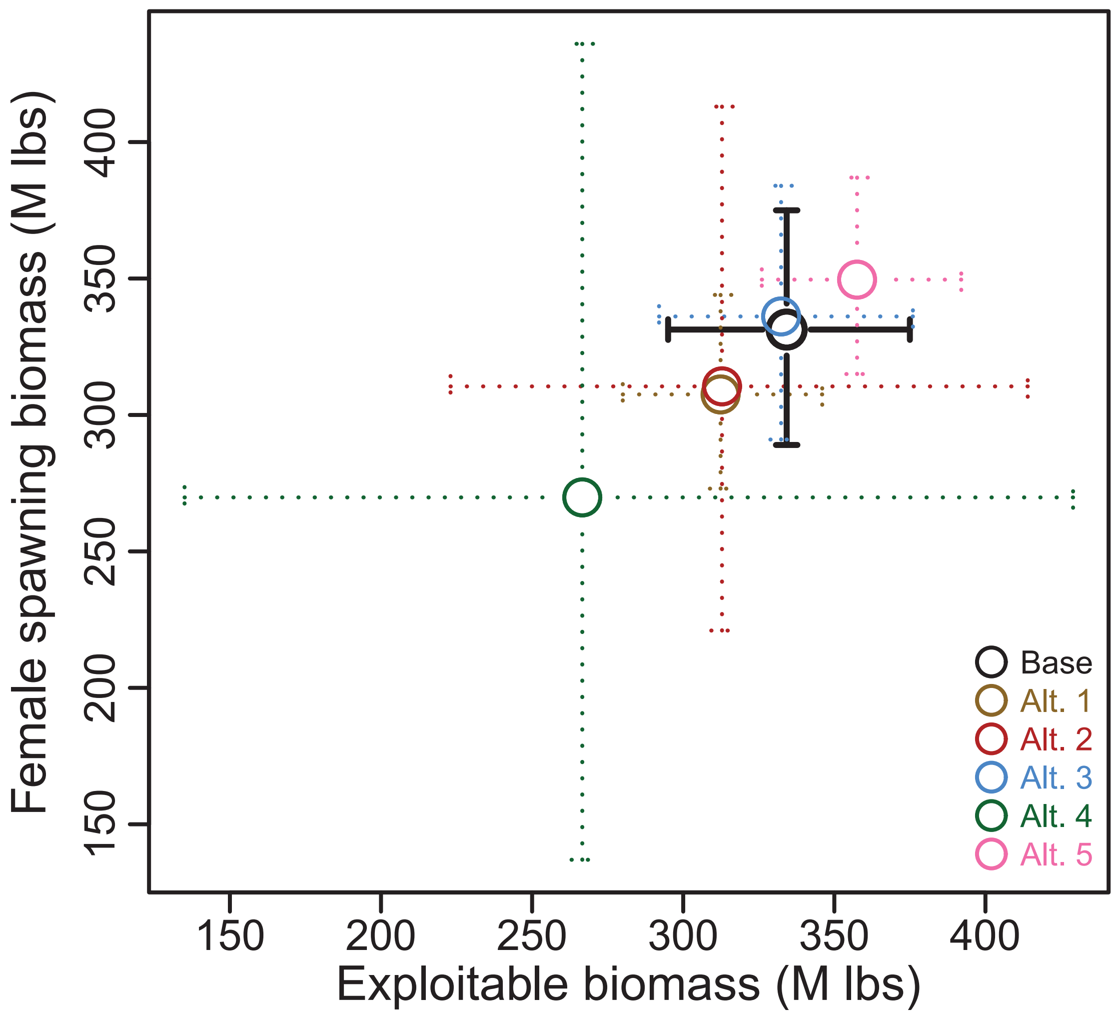
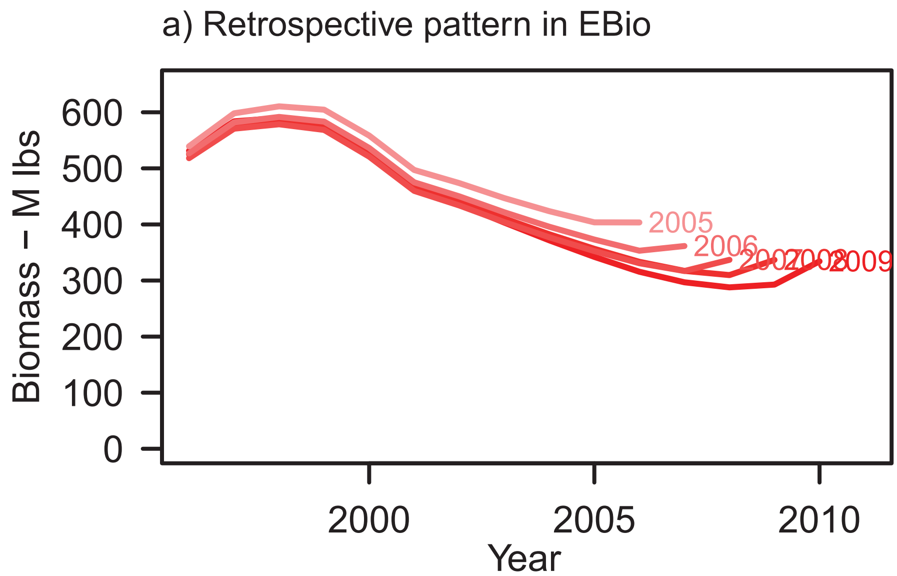


Figure 20. Illustration of maximum likelihood estimates (circles) for EBio and SBio for various model fits. The 95% percent confidence intervals for the likelihood profiles are shown by the end caps of the horizontal and vertical bars extending from the circles.



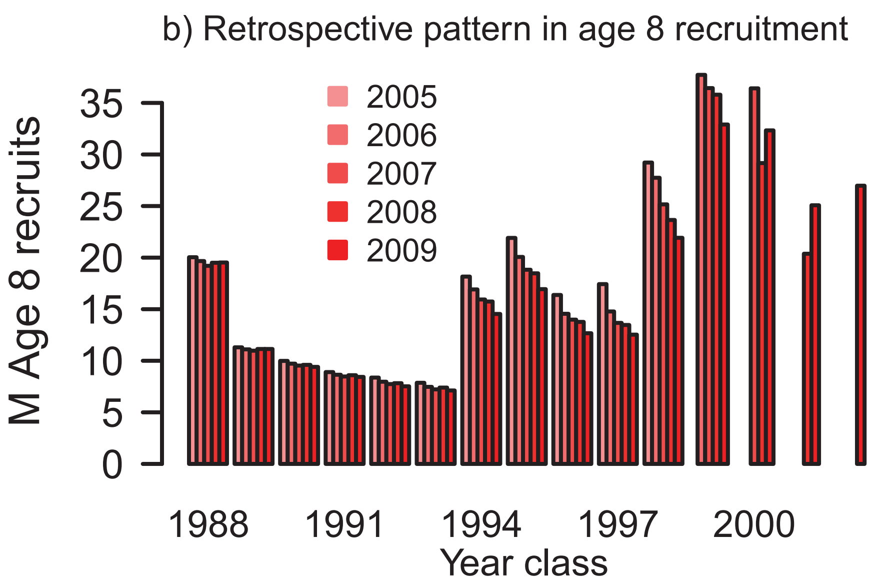


Figure 21. Retrospective behavior of the 2009 halibut assessment model. The top panel illustrates the effect on estimates of EBio by sequentially removing years of data. The bottom panel illustrates the efect on estimation of age eight recruitment. Note that the most recent year class (2002) is only estimated in the 2009 assessment, the 2001 year class in the 2008 and 2009 assessments, and so on.

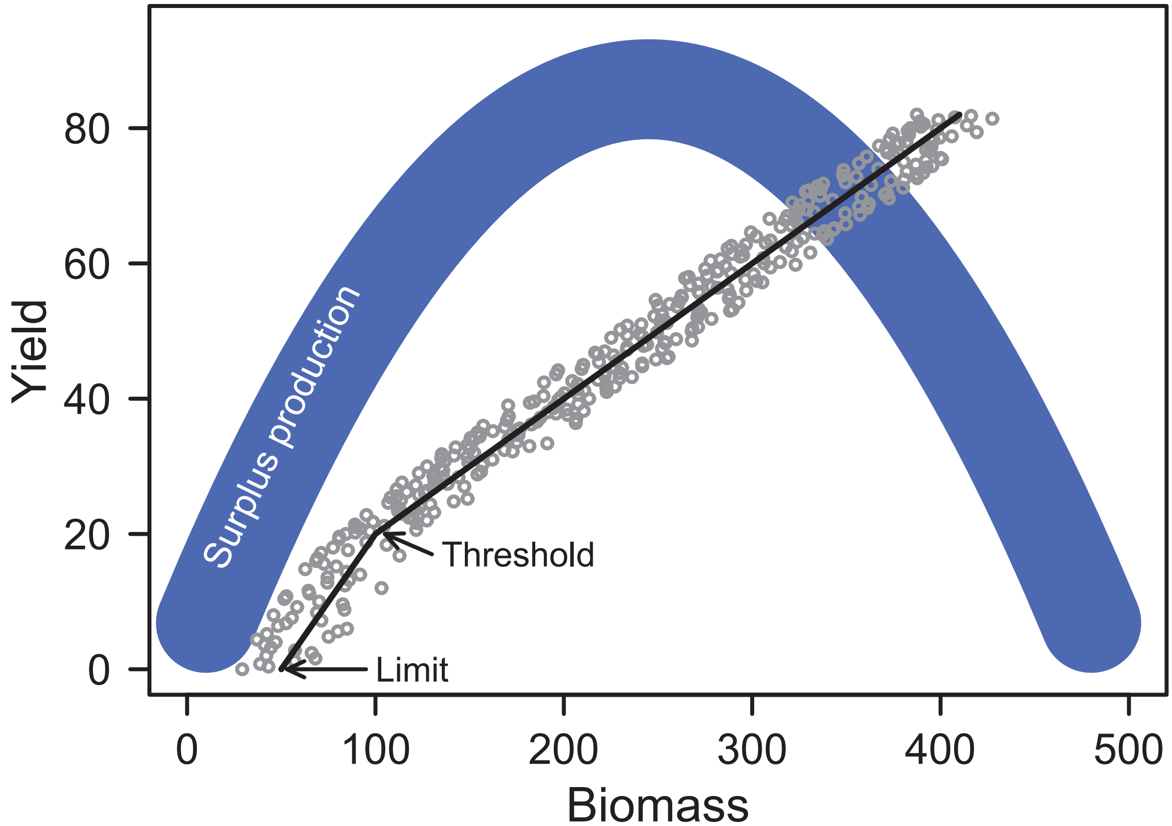


Figure 22. Representation of the IPHC harvest policy. The background curve illustrates theoretical relationship between biomass and surplus production, taken as yield. The slope of the straight line is a 20% harvest rate (Yield/Exploitable biomass), and the harvest rate deceases linearly to zero as the biomass approaches established reference points, termed the female spawning biomass threshold and limit. The scatter about the harvest rate indicates the effect of the "Slow Up Fast Down" adjustment to catch limits in terms of realized harvest rate.

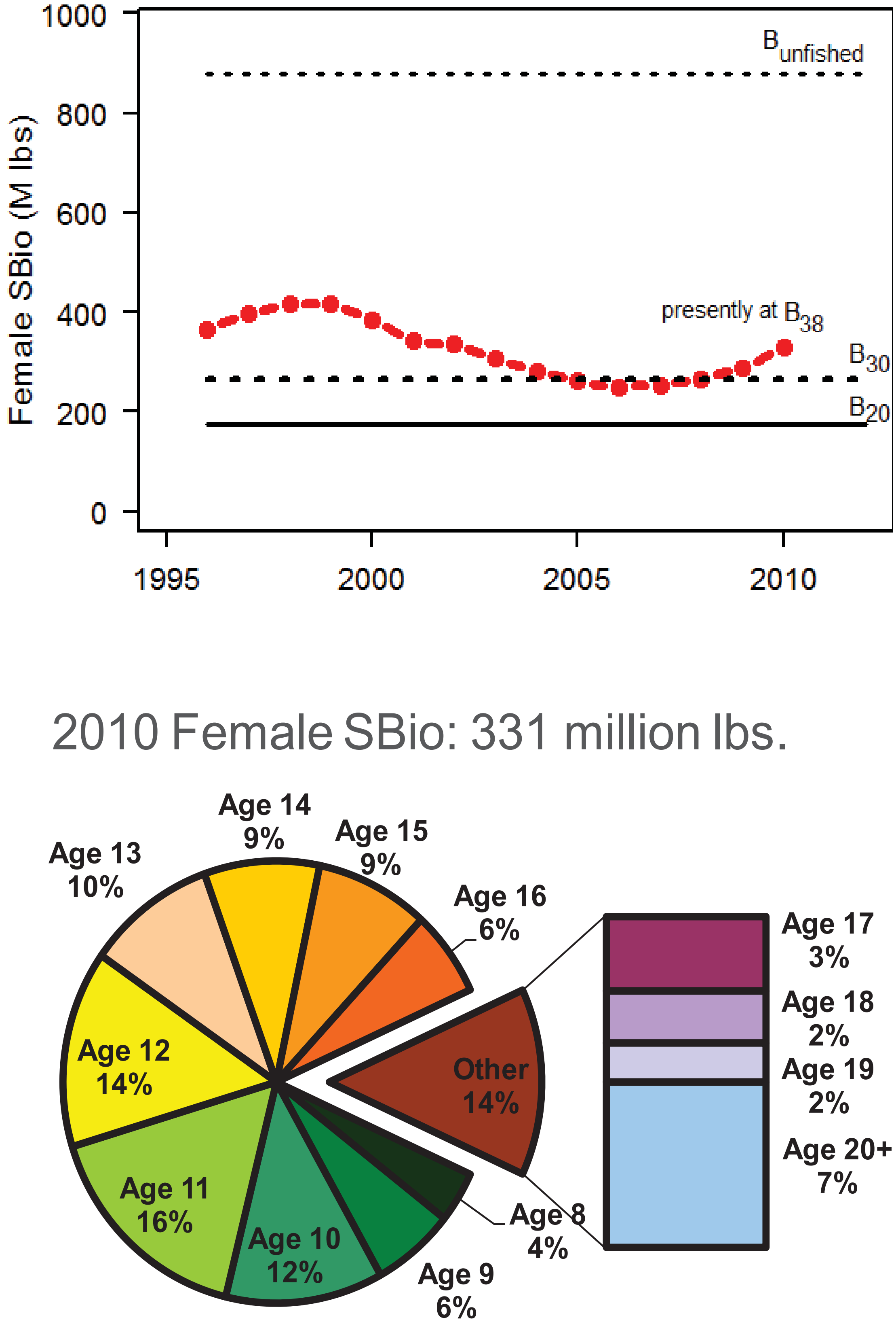


Figure 23. Status (top panel) and current age composition (bottom panel) of female spawning biomass. See text for details.

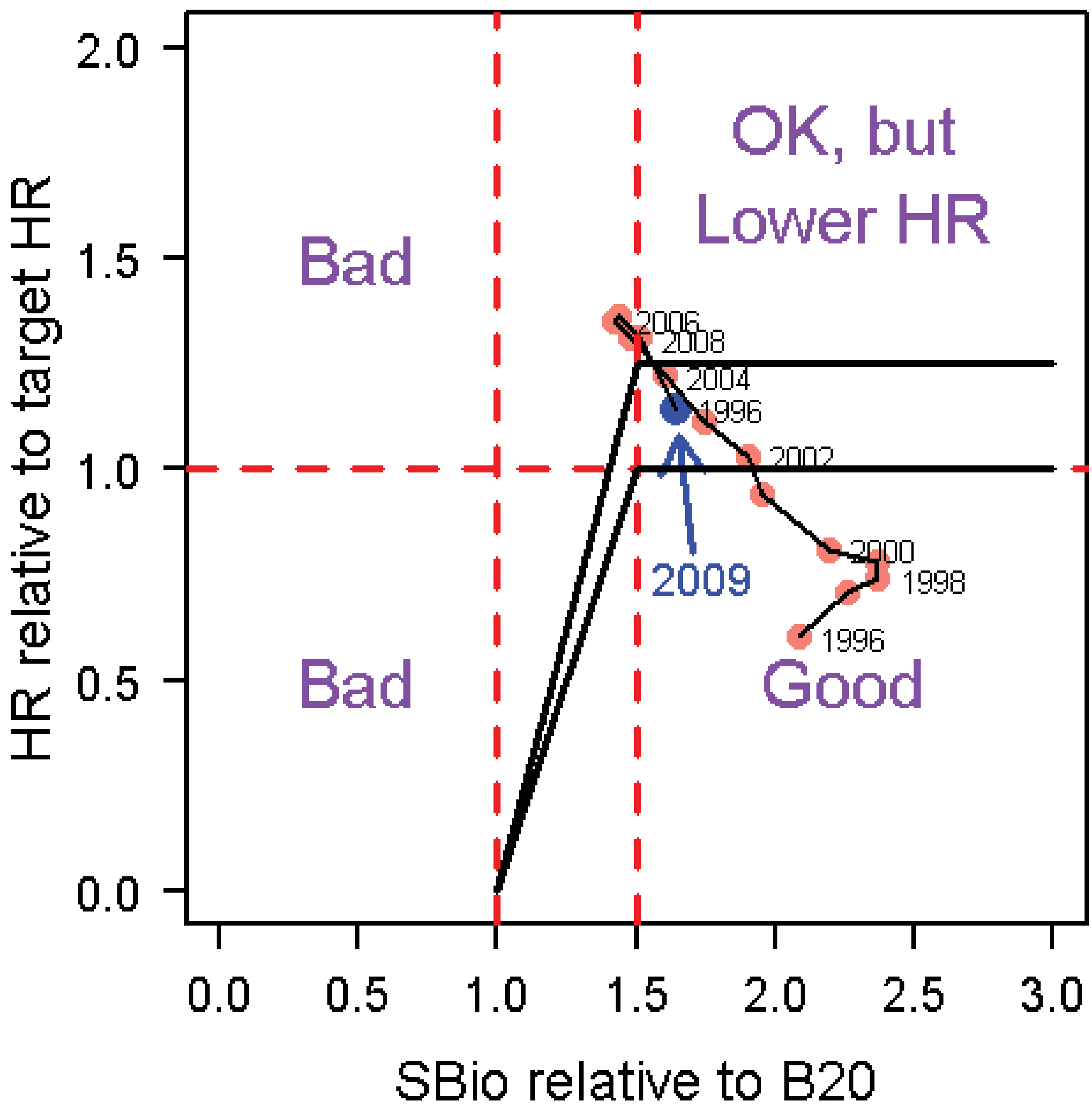


Figure 24. Trend and status of halibut management relative to reference points. Horizontal axis indicates female spawning biomass (SBio) relative to B_{20} (value of 1.0) and B_{30} (value of 1.5). Vertical axis illustrates realized harvest rate relative to a target harvest rate of 0.20 (value of 1.0) and the previous target harvest rate of 0.25 (value of 1.25).

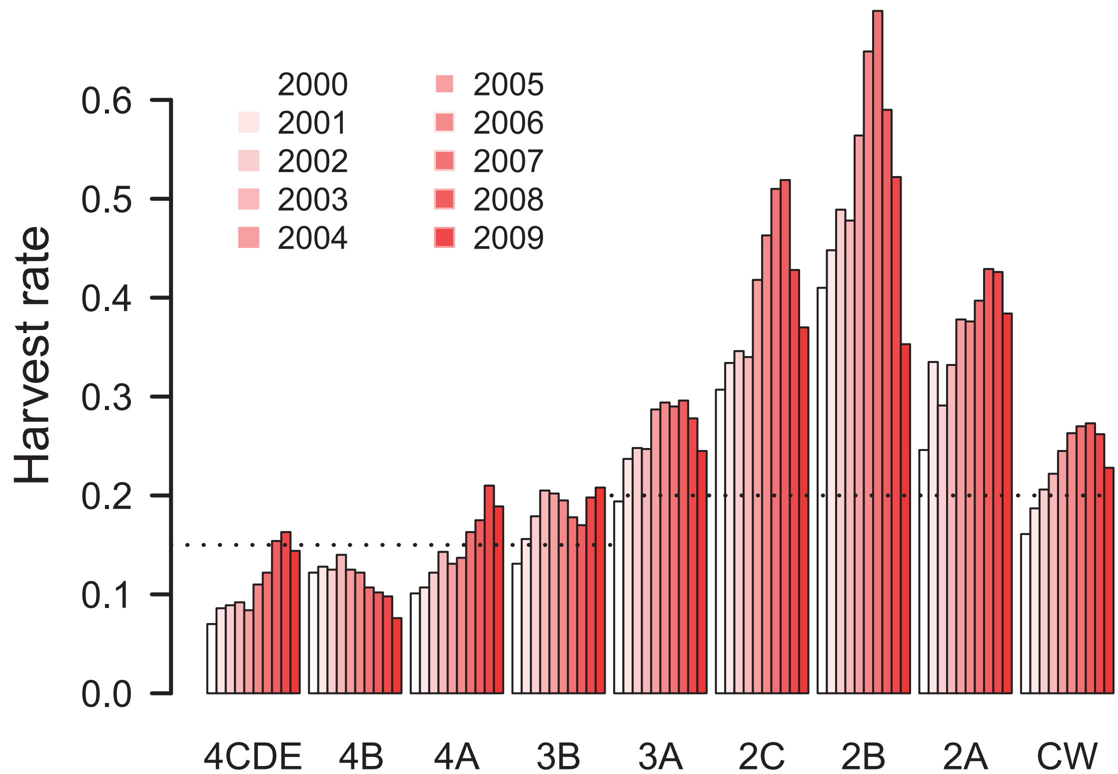
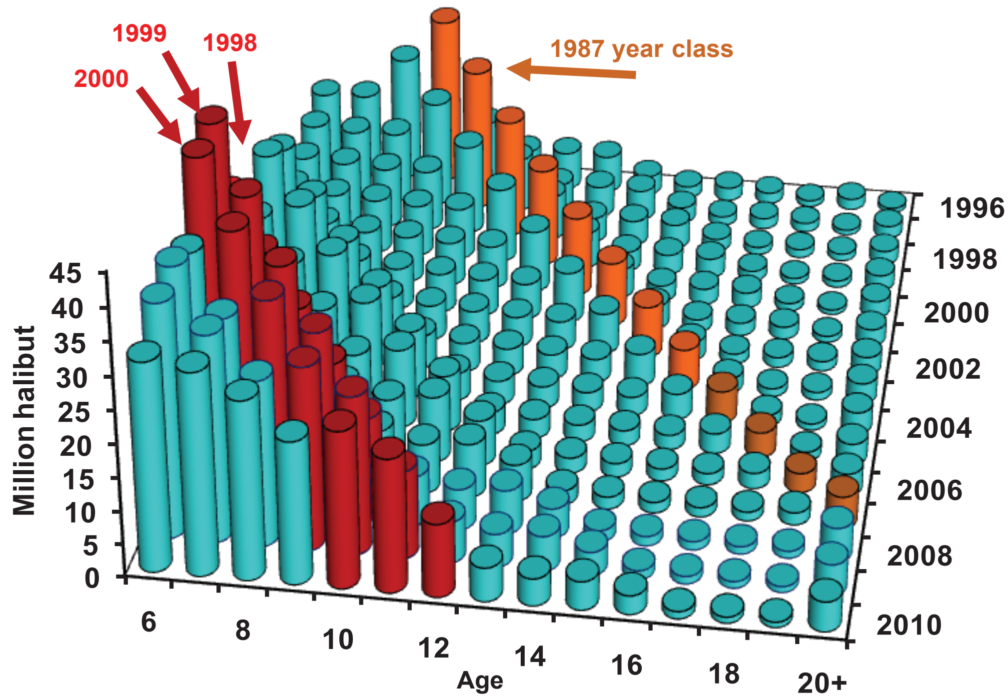


Figure 25. Summary of realized harvest rates from the coastwide assessment, using unadjusted survey WPUE to partition biomass among areas.

a) Total numbers in the population



b) Exploitable biomass in the population

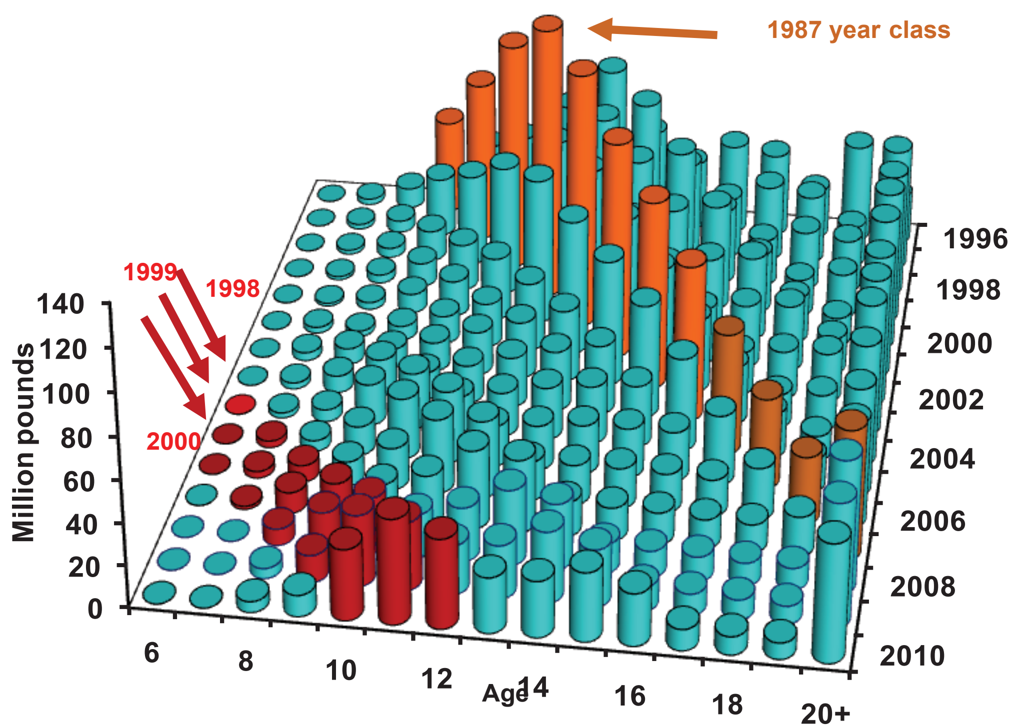


Figure 26. Coastwide population estimates in numbers of halibut (panel a) and as EBio (panel b). Several large year classes are highlighted.

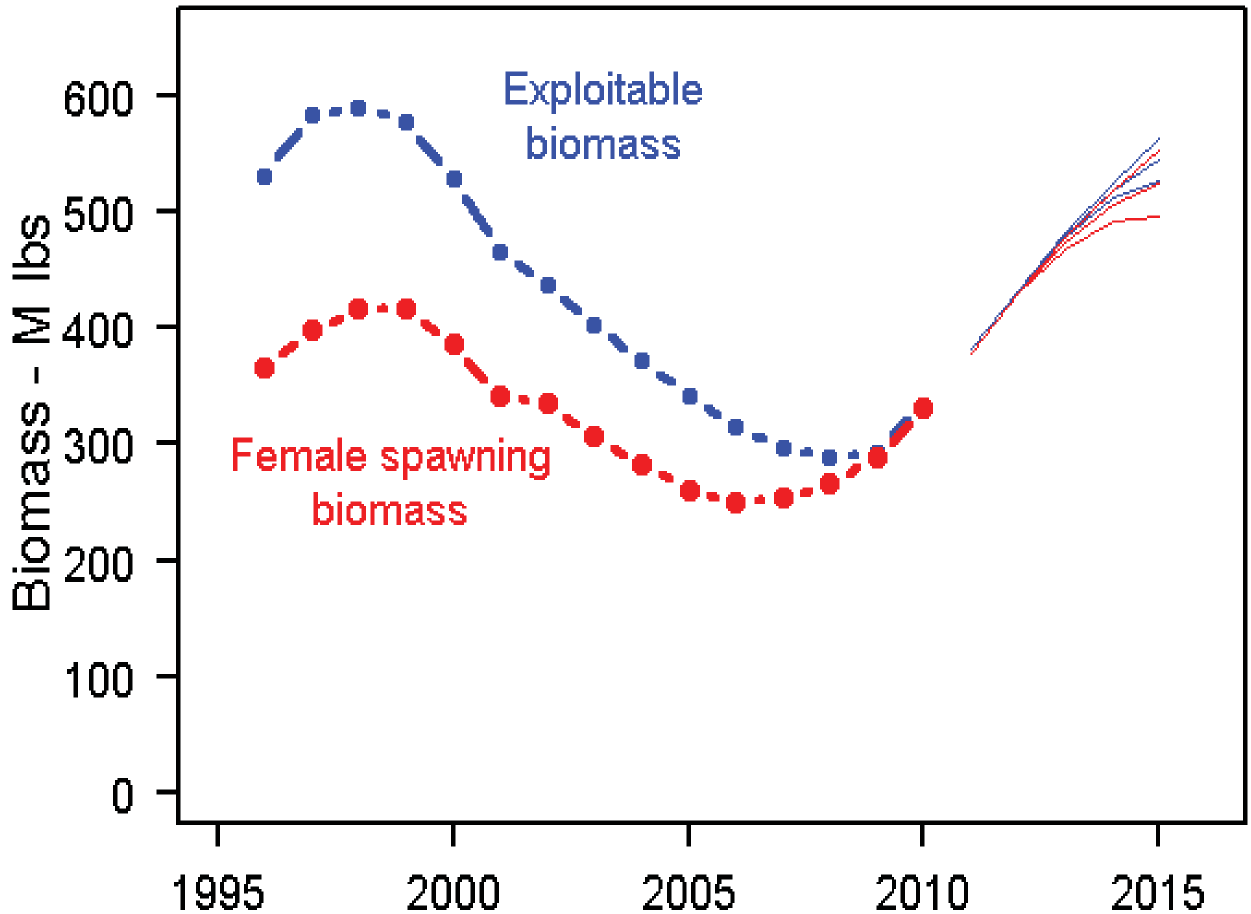


Figure 27. Projected exploitable and spawning biomasses for the coastwide population of halibut.

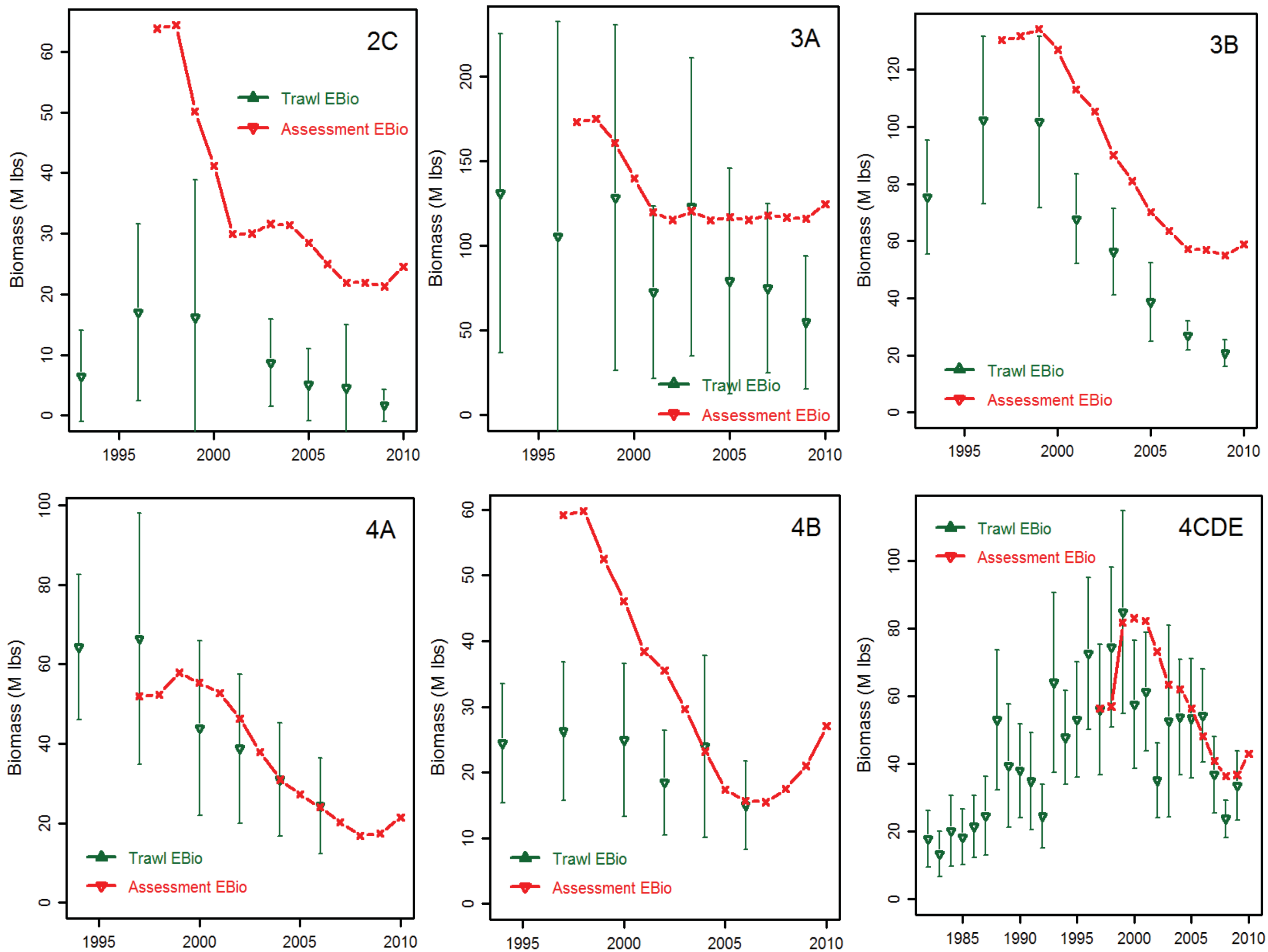


Figure 28. Comparison of IPHC assessment estimates (using unadjsuted survey WPUE) and NMFS swept area estimates of EBio.

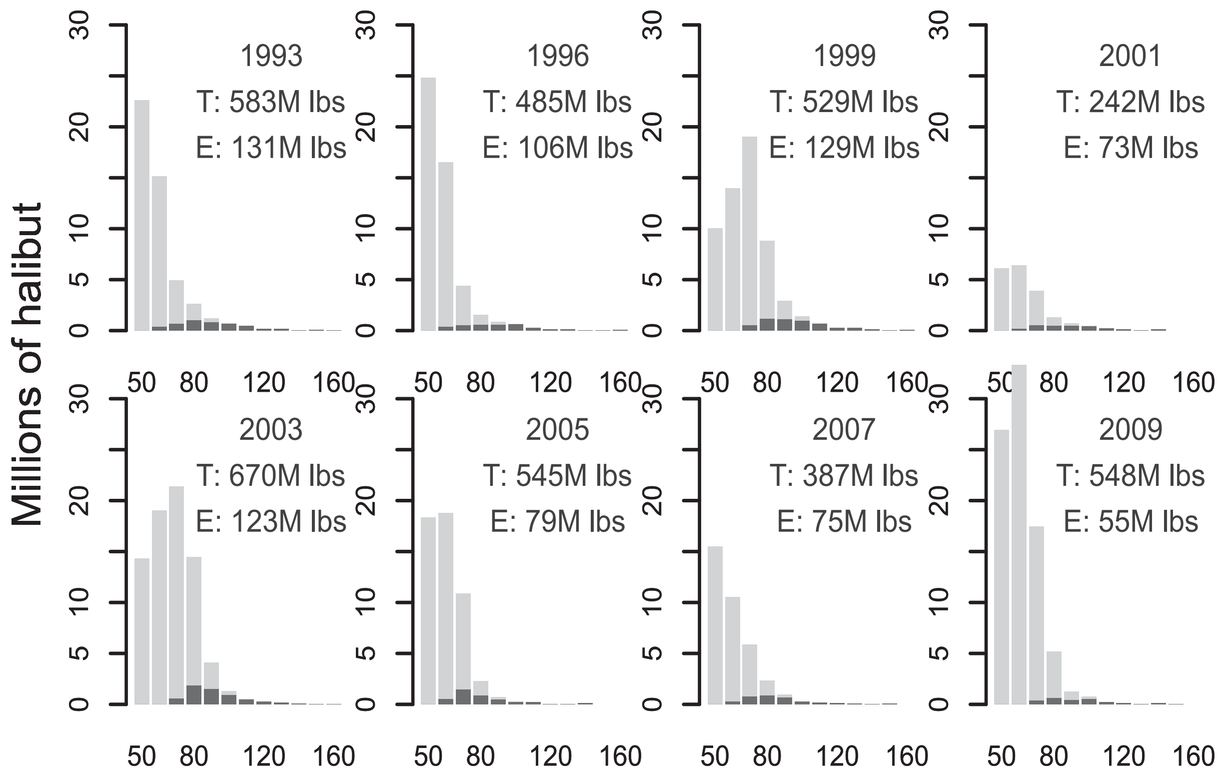


Figure 29. Swept area estimates of halibut in IPHC regulatory Area 3A, by 10-cm length interval, in the NMFS EBS trawl survey for the years 2001 to 2009. Values for total (T) and Exploitable (E) biomass estimated by the survey are also listed. Exploitable numbers of halibut are illustrated by the darker bars.

Area 2A summary

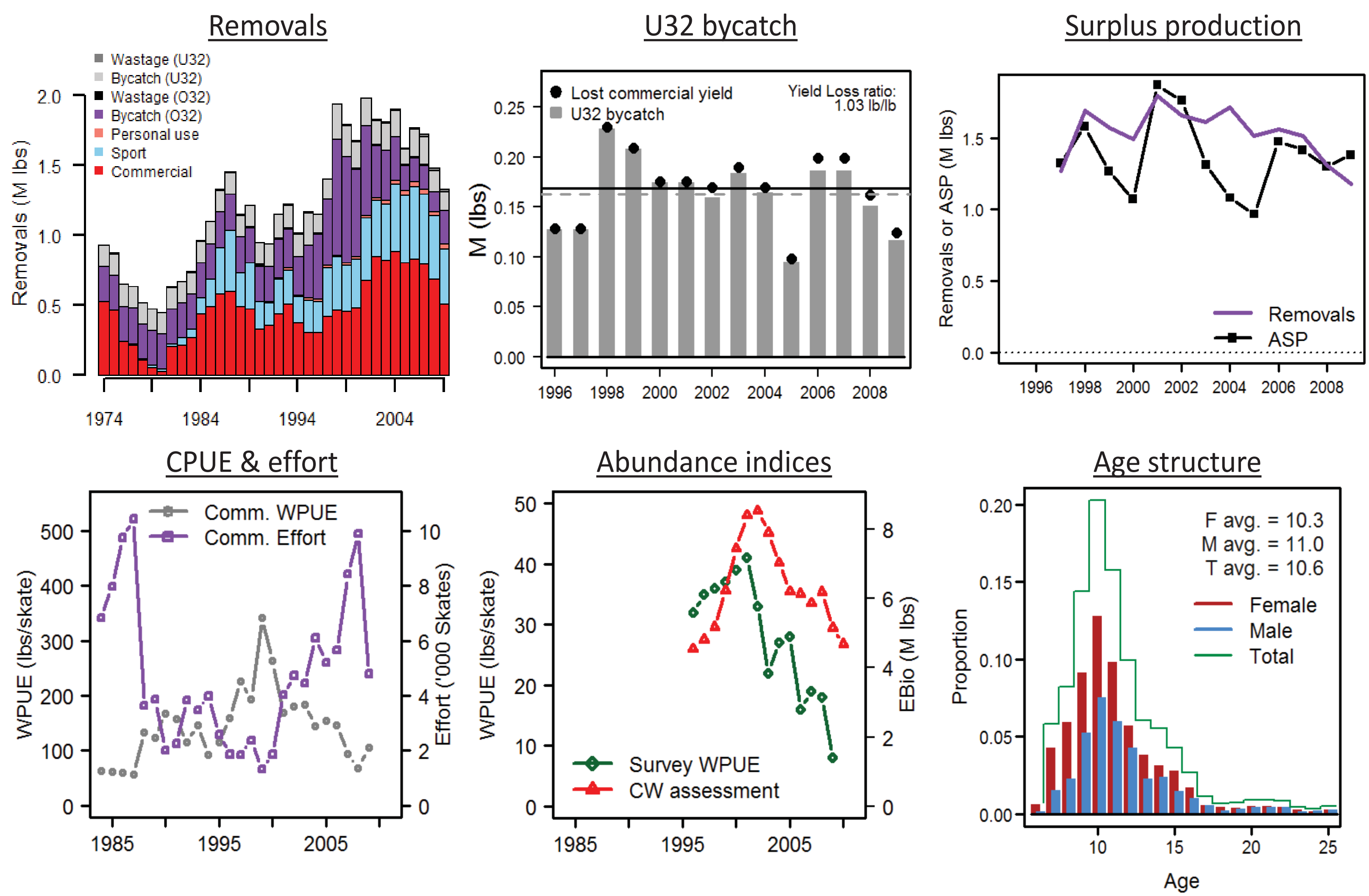


Figure 30. Summary of removals, production, effort, abundance indices and age structure for Area 2A.

Area 2B summary

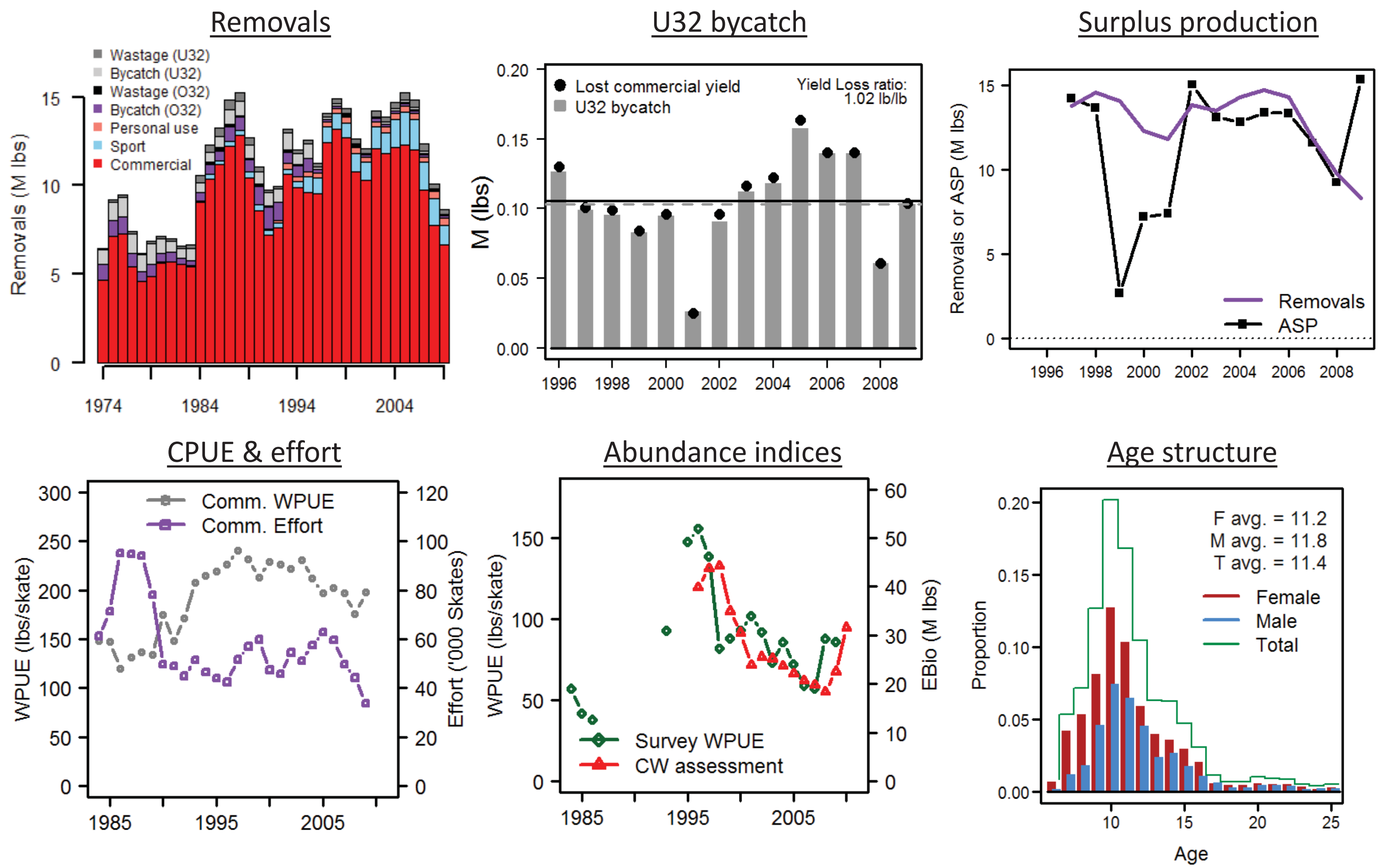


Figure 31. Summary of removals, production, effort, abundance indices and age structure for Area 2B.

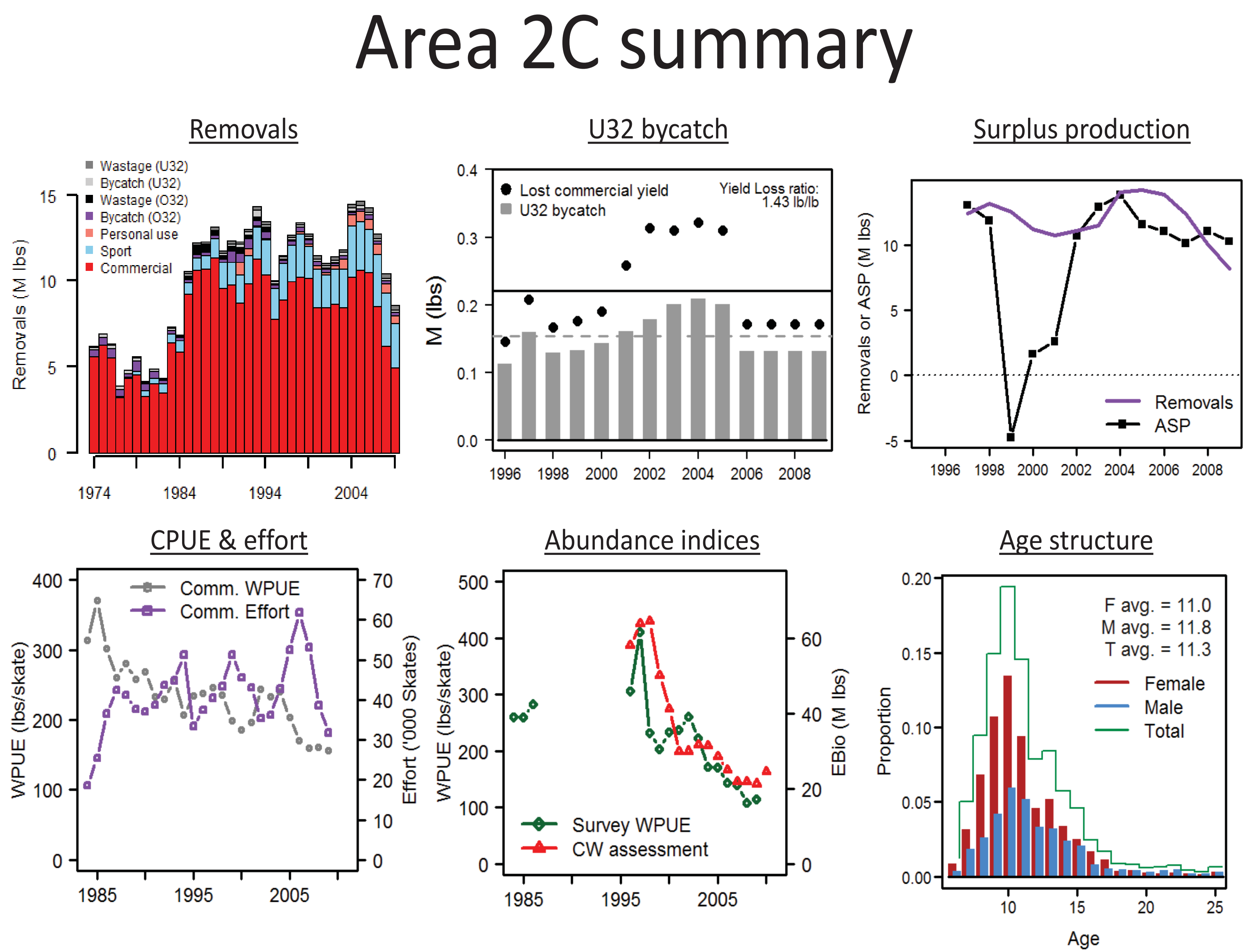


Figure 32. Summary of removals, production, effort, abundance indices and age structure for Area 2C.

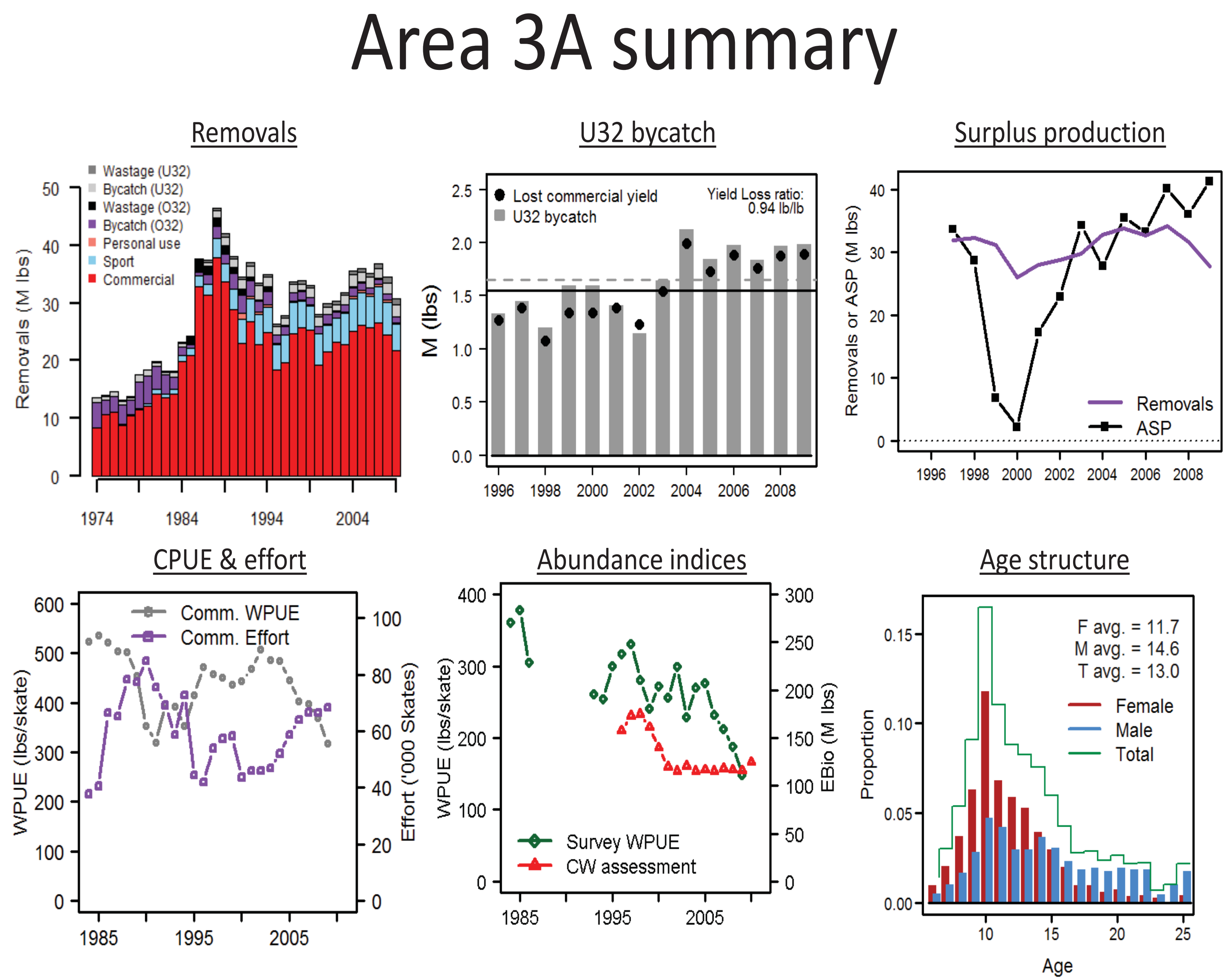


Figure 33. Summary of removals, production, effort, abundance indices and age structure for Area 3A.

Area 3B summary

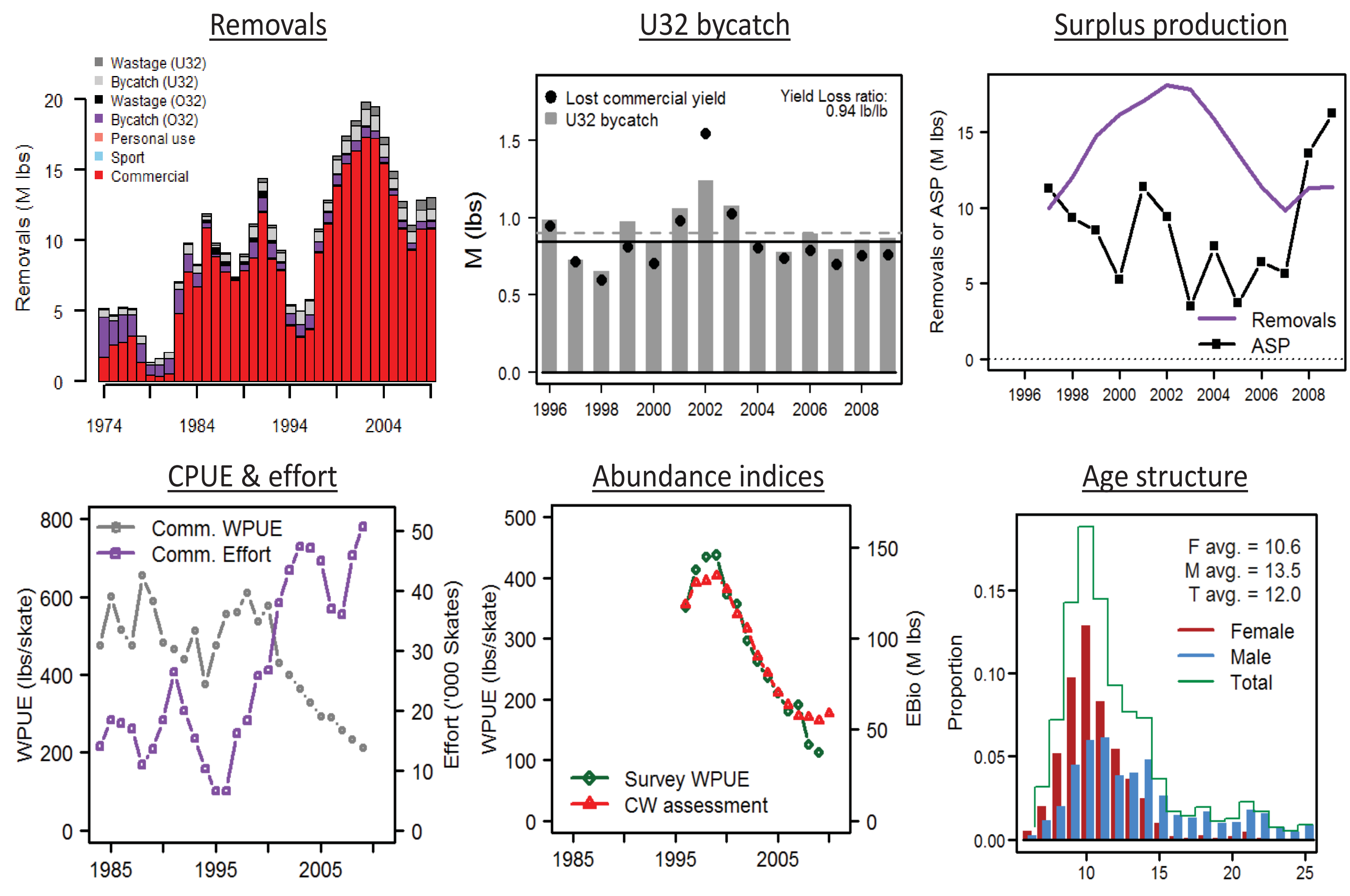


Figure 34. Summary of removals, production, effort, abundance indices and age structure for Area 3B.

Area 4A summary

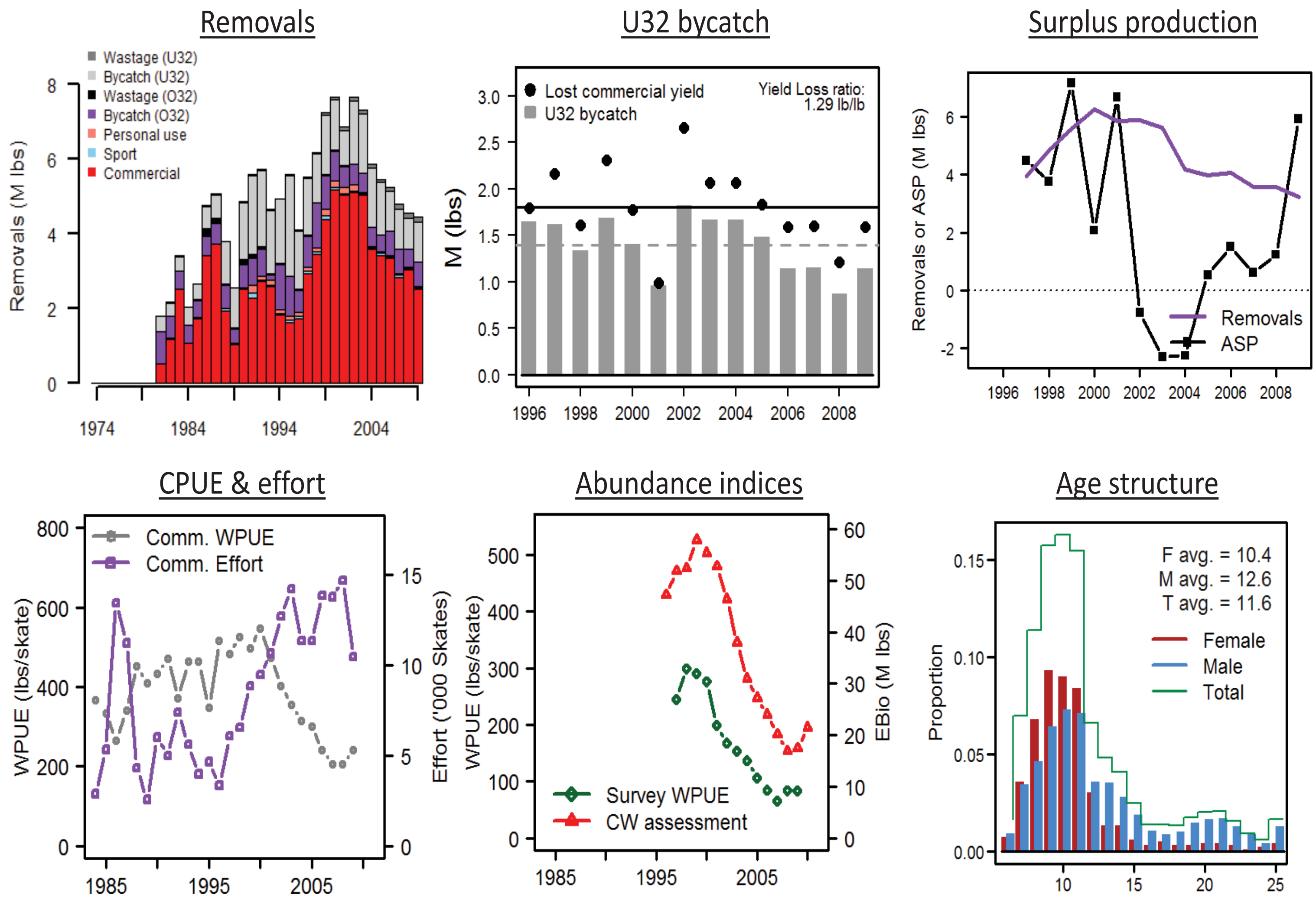


Figure 35. Summary of removals, production, effort, abundance indices and age structure for Area 4A

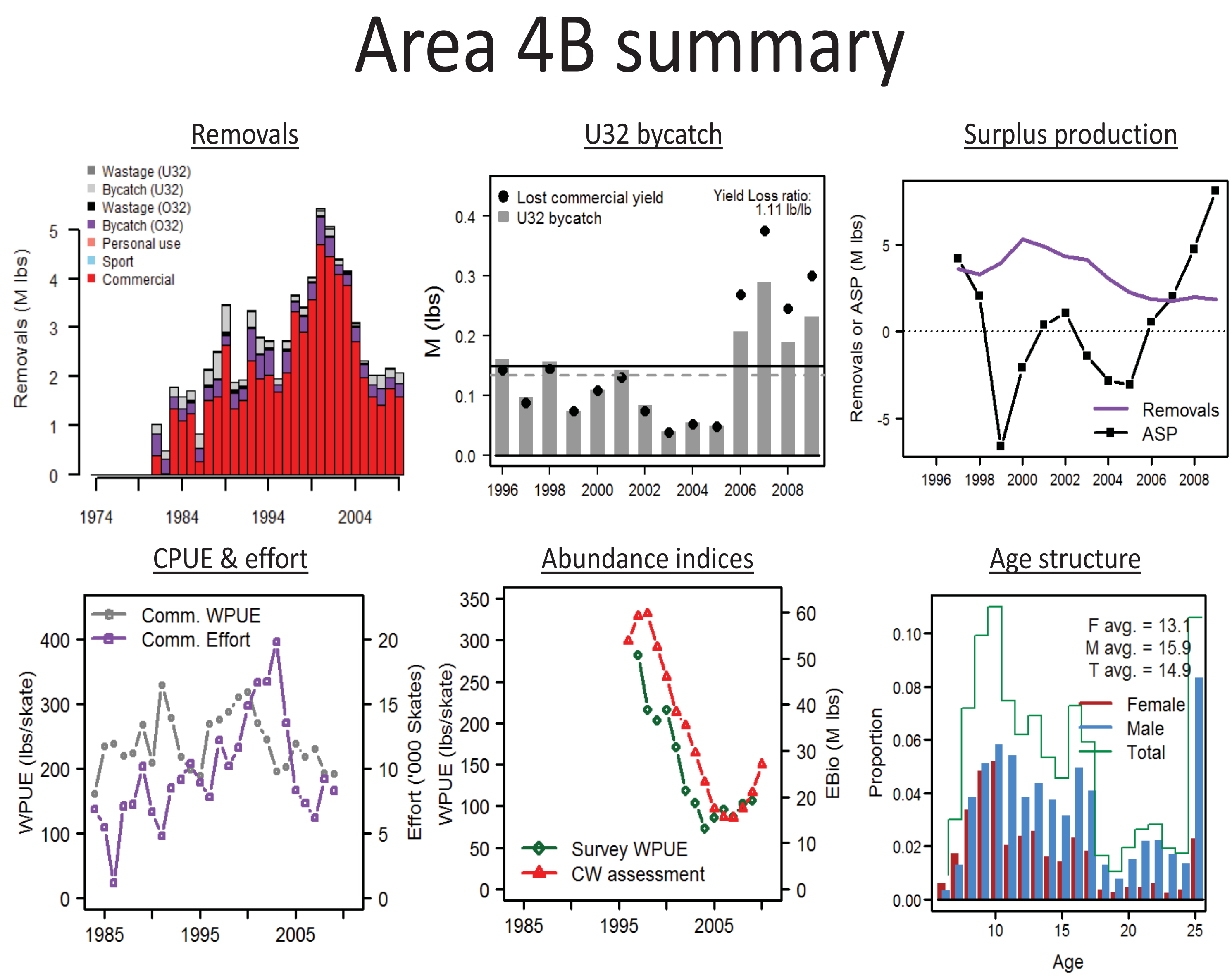


Figure 36. Summary of removals, production, effort, abundance indices and age structure for Area 4B.

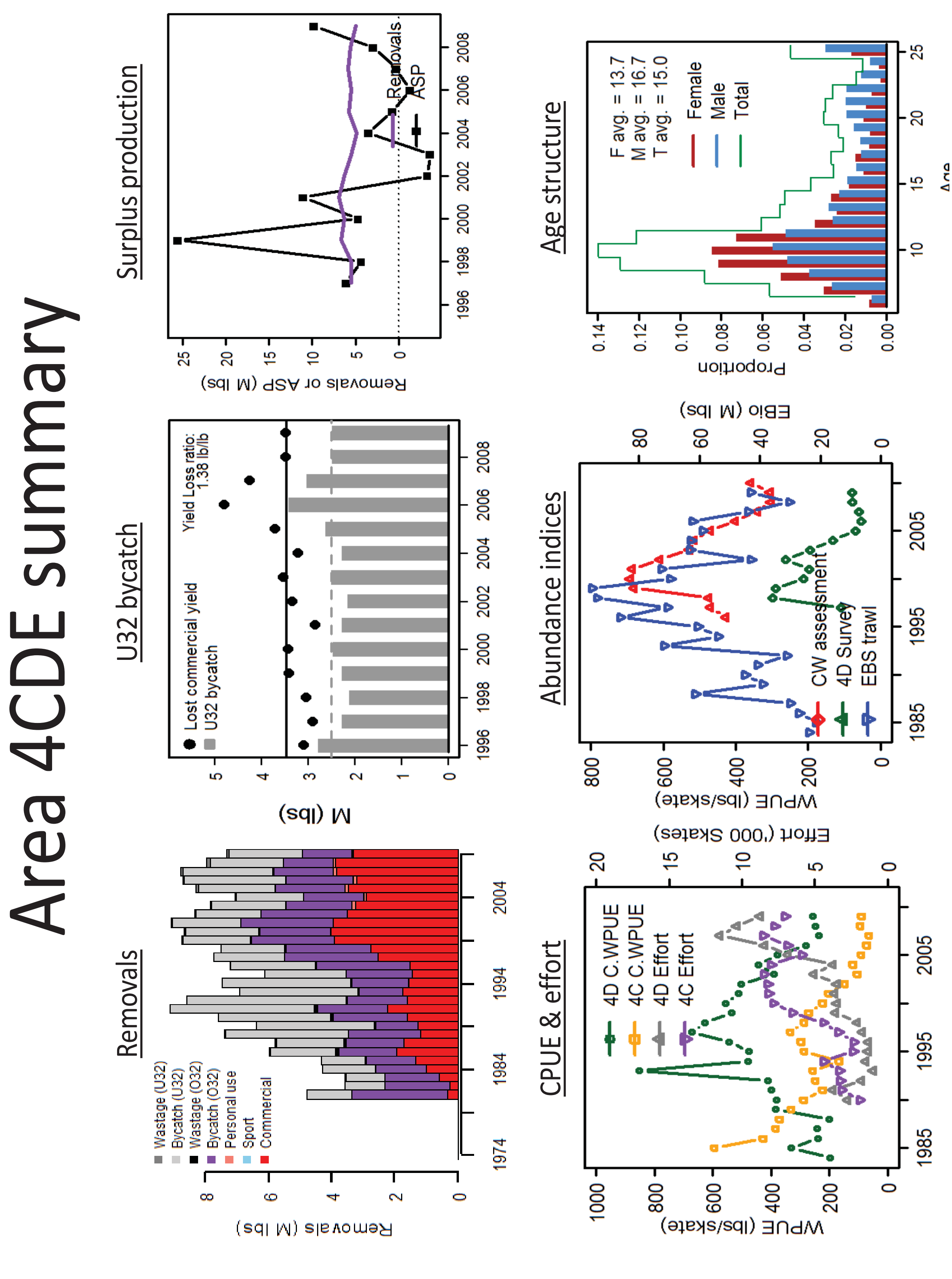


Figure 37. Summary of removals, production, effort, abundance indices and age structure for Area 4CDE.

Appendix A. Selected fishery and survey data summaries.

Table A1. Total removals (million pounds, net weight). Removals include commercial catch, IPHC survey catches, sport catch, personal use catch, O32 bycatch and O32 wastage. Removals do not include U32 bycatch or U32 wastage.

	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1974	0.77	5.52	5.97	12.67	4.49	2.60	---	---	---	32.02
1975	0.71	8.03	6.69	13.21	4.22	1.73	---	---	---	34.60
1976	0.49	8.22	6.03	13.78	4.67	1.90	---	---	---	35.10
1977	0.48	6.16	3.67	12.20	4.74	3.20	---	---	---	30.44
1978	0.36	5.17	4.62	13.02	2.63	4.75	---	---	---	30.54
1979	0.32	5.56	5.34	16.19	1.08	4.82	---	---	---	33.31
1980	0.29	6.17	3.99	17.39	1.15	6.42	---	---	---	35.41
1981	0.47	6.20	4.73	18.97	1.55	5.57	---	---	---	37.49
1982	0.51	5.87	4.19	17.44	6.48	4.39	---	---	---	38.88
1983	0.58	5.78	7.13	17.16	8.96	6.90	---	---	---	46.52
1984	0.80	9.63	6.70	22.30	7.61	5.47	---	---	---	52.51
1985	0.94	11.40	10.52	24.70	11.63	6.84	---	---	---	66.04
1986	1.18	12.38	12.41	39.10	9.82	8.83	---	---	---	83.71
1987	1.30	13.65	12.40	38.05	8.84	10.10	---	---	---	84.33
1988	0.99	13.98	13.05	46.26	7.37	8.13	---	---	---	89.79
1989	1.07	11.56	11.68	41.46	8.67	7.16	---	---	---	81.60
1990	0.81	10.22	12.22	37.34	10.34	2.60	---	---	---	80.21
1991	0.78	8.90	12.30	33.56	13.88	---	3.39	1.78	4.12	79.46
1992	0.99	9.14	12.92	35.10	10.16	---	3.53	1.87	4.64	78.64
1993	1.06	12.10	13.93	30.93	8.53	---	3.68	3.06	3.59	75.23
1994	0.85	11.25	13.34	33.70	4.87	---	2.97	2.51	3.20	73.30
1995	0.93	11.59	9.85	24.64	4.03	---	3.23	2.63	3.43	59.33
1996	1.02	10.96	11.32	26.29	4.73	---	2.87	1.85	3.57	63.94
1997	1.27	13.79	12.41	31.94	9.97	---	2.51	2.59	4.54	82.45
1998	1.69	14.58	13.19	32.28	12.06	---	3.97	3.58	5.53	87.40
1999	1.57	14.05	12.52	31.14	14.76	---	4.84	3.26	5.51	90.23
2000	1.49	12.32	11.20	26.06	16.21	---	5.61	3.96	6.62	85.19
2001	1.79	11.84	10.76	28.04	17.07	---	6.25	5.32	6.34	87.18
2002	1.66	13.86	11.08	28.76	18.13	---	5.85	4.91	6.92	89.95
2003	1.61	13.51	11.49	29.77	17.84	---	5.88	4.31	6.28	89.45
2004	1.71	14.29	14.06	32.85	15.92	---	5.63	4.12	5.49	90.98
2005	1.52	14.74	14.23	33.77	13.64	---	4.19	3.04	4.92	89.94
2006	1.56	14.30	13.87	32.64	11.38	---	3.97	2.27	5.81	85.14
2007	1.51	11.84	12.38	34.25	9.81	---	4.08	1.83	5.47	80.99
2008	1.31	9.79	10.05	31.70	11.31	---	3.57	1.75	5.88	75.30
2009	1.18	8.30	8.19	27.73	11.39	---	3.59	1.99	5.55	66.83

Table A2. Commercial catch (million pounds, net weight). Figures include IPHC research catches.

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.52	4.62	5.60	8.19	1.67	0.71	---	---	---	---	---	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	---	---	---	---	---	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	---	---	---	---	---	27.54
1977	0.21	5.43	3.19	8.64	3.19	1.22	---	---	---	---	---	21.88
1978	0.10	4.61	4.32	10.30	1.32	1.35	---	---	---	---	---	22.00
1979	0.05	4.86	4.53	11.34	0.39	1.37	---	---	---	---	---	22.54
1980	0.02	5.65	3.24	11.97	0.28	0.71	---	---	---	---	---	21.87
1981	0.20	5.66	4.01	14.23	0.45	---	0.49	0.39	0.30	0.01	0.00	25.74
1982	0.21	5.54	3.50	13.52	4.80	---	1.17	0.01	0.24	0.00	0.01	29.01
1983	0.27	5.44	6.38	14.14	7.75	---	2.50	1.34	0.42	0.15	0.01	38.39
1984	0.43	9.05	5.87	19.77	6.69	---	1.05	1.10	0.58	0.39	0.04	44.97
1985	0.50	10.49	9.42	21.77	11.09	---	1.78	1.28	0.64	0.70	0.04	57.70
1986	0.59	11.43	11.04	34.66	9.22	---	3.56	0.28	0.72	1.29	0.05	72.83
1987	0.60	12.42	11.05	32.89	8.10	---	3.83	1.56	0.91	0.73	0.12	72.20
1988	0.49	12.91	11.57	39.36	7.20	---	1.96	1.62	0.72	0.46	0.01	76.29
1989	0.48	10.48	9.72	35.19	8.04	---	1.05	2.72	0.59	0.69	0.01	68.98
1990	0.34	8.69	9.97	29.96	8.91	---	2.61	1.39	0.55	1.05	0.06	63.54
1991	0.36	7.26	9.03	24.07	12.35	---	2.35	1.58	0.71	1.50	0.11	59.31
1992	0.44	7.68	10.06	27.43	8.80	---	2.75	2.36	0.81	0.74	0.07	61.15
1993	0.51	10.72	11.48	23.08	7.92	---	2.61	2.00	0.85	0.85	0.07	60.08
1994	0.37	9.98	10.61	25.69	3.90	---	1.84	2.06	0.73	0.73	0.12	56.02
1995	0.30	9.66	7.82	18.46	3.13	---	1.63	1.69	0.67	0.65	0.13	44.14
1996	0.30	9.57	8.92	19.87	3.69	---	1.72	2.10	0.69	0.72	0.12	47.69
1997	0.42	12.46	9.96	24.70	9.13	---	2.93	3.35	1.13	1.16	0.25	65.49
1998	0.46	13.23	10.24	25.85	11.22	---	3.44	2.92	1.26	1.32	0.19	70.12
1999	0.46	12.75	10.21	25.43	13.91	---	4.40	3.60	1.77	1.91	0.27	74.70
2000	0.49	10.84	8.48	19.33	15.47	---	5.18	4.72	1.75	1.94	0.35	68.55
2001	0.68	10.33	8.44	21.60	16.37	---	5.05	4.50	1.66	1.86	0.48	70.97
2002	0.86	12.11	8.63	23.27	17.35	---	5.11	4.10	1.22	1.76	0.56	74.95
2003	0.82	11.82	8.44	22.82	17.27	---	5.04	3.88	0.89	1.96	0.42	73.36
2004	0.88	12.20	10.27	25.24	15.48	---	3.58	2.73	0.96	1.66	0.32	73.31
2005	0.81	12.37	10.66	26.19	13.20		3.42	1.98	0.54	2.59	0.37	72.11
2006	0.83	12.04	10.51	25.77	10.80	---	3.34	1.59	0.49	2.37	0.37	68.12
2007	0.79	9.80	8.50	26.55	9.27	---	2.84	1.42	0.55	2.73	0.58	63.03
2008	0.68	7.78	6.22	24.58	10.75	---	3.03	1.77	0.73	2.56	0.60	58.70
2009	.50	6.68	4.96	21.75	10.81	---	2.52	1.59	.63	2.26	.44	52.14

Table A3. Sport catch (million pounds, net weight).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.01	0.01	0.07	0.20	0.00	0.00	0.00	0.00	0.29
1978	0.01	0.00	0.08	0.28	0.00	0.00	0.00	0.00	0.38
1979	0.02	0.01	0.17	0.37	0.00	0.00	0.00	0.00	0.56
1980	0.02	0.01	0.33	0.49	0.00	0.00	0.00	0.00	0.85
1981	0.02	0.01	0.32	0.75	0.00	0.01	0.00	0.00	1.11
1982	0.05	0.03	0.49	0.72	0.00	0.01	0.00	0.00	1.30
1983	0.06	0.05	0.55	0.95	0.00	0.00	0.00	0.00	1.62
1984	0.12	0.06	0.62	1.03	0.00	0.01	0.00	0.00	1.84
1985	0.19	0.26	0.68	1.21	0.00	0.01	0.00	0.00	2.36
1986	0.33	0.19	0.73	1.91	0.00	0.02	0.00	0.00	3.18
1987	0.45	0.26	0.78	1.99	0.00	0.03	0.00	0.00	3.51
1988	0.25	0.25	1.08	3.26	0.00	0.04	0.00	0.00	4.88
1989	0.33	0.32	1.56	3.01	0.00	0.02	0.00	0.00	5.23
1990	0.20	0.38	1.33	3.64	0.00	0.04	0.00	0.00	5.59
1991	0.16	0.29	1.65	4.26	0.01	0.13	0.00	0.00	6.51
1992	0.25	0.29	1.67	3.90	0.03	0.04	0.00	0.00	6.18
1993	0.25	0.33	1.81	5.27	0.02	0.06	0.00	0.00	7.73
1994	0.19	0.33	2.00	4.49	0.02	0.04	0.00	0.00	7.07
1995	0.24	0.89	1.76	4.49	0.02	0.06	0.00	0.00	7.45
1996	0.23	0.89	2.13	4.74	0.02	0.08	0.00	0.00	8.08
1997	0.36	0.89	2.17	5.51	0.03	0.07	0.00	0.00	9.03
1998	0.38	0.89	2.50	4.70	0.02	0.10	0.00	0.00	8.59
1999	0.34	0.86	1.84	4.23	0.02	0.09	0.00	0.00	7.38
2000	0.34	1.02	2.26	5.31	0.02	0.07	0.00	0.00	9.02
2001	0.45	1.02	1.93	4.68	0.02	0.03	0.00	0.00	8.11
2002	0.40	1.26	2.09	4.20	0.01	0.05	0.00	0.00	8.01
2003	0.40	1.22	2.26	5.43	0.01	0.03	0.00	0.00	9.35
2004	0.49	1.61	2.94	5.61	0.01	0.05	0.00	0.00	10.70
2005	0.48	1.84	2.80	5.67	0.01	0.05	0.00	0.00	10.86
2006	0.52	1.77	2.53	5.34	0.01	0.05	0.00	0.00	10.21
2007	0.50	1.56	3.05	6.28	0.03	0.04	0.00	0.00	11.46
2008	0.46	1.52	3.08	5.63	0.02	0.04	0.00	0.00	10.75
2009	0.40	1.10	2.55	4.53	0.03	0.04	0.00	0.00	8.64

Table A4. Personal use (million pounds, net weight).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.01	0.05	0.72	0.96	0.06	0.23	0.00	0.00	2.03
1992	0.01	0.10	0.37	0.49	0.03	0.11	0.00	0.00	1.11
1993	0.02	0.30	0.11	0.33	0.06	0.12	0.00	0.00	0.94
1994	0.01	0.30	0.11	0.33	0.06	0.12	0.00	0.00	0.93
1995	0.01	0.30	0.00	0.10	0.04	0.09	0.00	0.00	0.54
1996	0.02	0.30	0.00	0.10	0.04	0.09	0.00	0.00	0.54
1997	0.02	0.30	0.00	0.10	0.04	0.09	0.00	0.00	0.54
1998	0.01	0.30	0.17	0.10	0.04	0.09	0.00	0.00	0.71
1999	0.01	0.30	0.17	0.07	0.02	0.17	0.00	0.00	0.74
2000	0.02	0.30	0.17	0.07	0.02	0.17	0.00	0.00	0.75
2001	0.02	0.30	0.17	0.07	0.02	0.17	0.00	0.00	0.75
2002	0.02	0.30	0.17	0.07	0.02	0.17	0.00	0.00	0.75
2003	0.03	0.30	0.63	0.28	0.03	0.02	0.00	0.10	1.38
2004	0.02	0.30	0.68	0.40	0.03	0.03	0.00	0.06	1.52
2005	0.04	0.30	0.60	0.43	0.05	0.04	0.00	0.09	1.54
2006	0.04	0.30	0.60	0.43	0.05	0.04	0.00	0.09	1.54
2007	0.04	0.30	0.58	0.38	0.05	0.03	0.00	0.11	1.48
2008	0.03	0.41	0.53	0.37	0.05	0.02	0.00	0.09	1.49
2009	0.03	0.41	0.46	0.34	0.04	0.02	0.01	0.05	1.34

Table A5. O32 Bycatch (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1974	0.25	0.90	0.37	4.48	2.82	1.89	---	---	---	10.71
1975	0.25	0.90	0.45	2.61	1.66	1.10	---	---	---	6.98
1976	0.25	0.94	0.50	2.74	1.94	1.18	---	---	---	7.56
1977	0.25	0.73	0.41	3.37	1.55	1.98	---	---	---	8.27
1978	0.25	0.55	0.21	2.44	1.31	3.40	---	---	---	8.17
1979	0.25	0.69	0.64	4.49	0.69	3.45	---	---	---	10.21
1980	0.25	0.51	0.42	4.93	0.87	5.71	---	---	---	12.70
1981	0.25	0.53	0.40	3.99	1.10	4.37	---	---	---	10.64
1982	0.25	0.30	0.20	3.20	1.68	2.95	---	---	---	8.58
1983	0.25	0.29	0.20	2.08	1.22	2.47	---	---	---	6.51
1984	0.25	0.52	0.21	1.51	0.92	2.29	---	---	---	5.70
1985	0.25	0.55	0.20	0.80	0.34	2.25	---	---	---	4.38
1986	0.25	0.56	0.20	0.67	0.20	2.62	---	---	---	4.50
1987	0.25	0.79	0.20	1.59	0.40	2.67	---	---	---	5.91
1988	0.25	0.77	0.20	2.13	0.04	3.27	---	---	---	6.67
1989	0.25	0.72	0.20	1.81	0.44	1.94	---	---	---	5.36
1990	0.25	1.03	0.68	2.63	1.22	---	0.63	0.34	2.38	9.15
1991	0.25	1.22	0.55	3.13	1.04	---	0.73	0.24	2.23	9.38
1992	0.28	1.02	0.58	2.65	1.12	---	0.73	0.66	1.94	8.95
1993	0.28	0.65	0.33	1.92	0.47	---	0.14	0.48	1.41	5.67
1994	0.28	0.57	0.40	2.35	0.85	---	1.20	0.54	1.82	8.00
1995	0.38	0.71	0.22	1.46	0.83	---	1.09	0.15	2.12	6.94
1996	0.47	0.17	0.23	1.40	0.96	---	0.59	0.46	2.99	7.28
1997	0.47	0.11	0.24	1.55	0.73	---	0.84	0.20	2.97	7.11
1998	0.84	0.12	0.24	1.47	0.73	---	1.19	0.33	2.73	7.64
1999	0.76	0.11	0.23	1.28	0.74	---	0.91	0.34	2.64	7.01
2000	0.63	0.13	0.25	1.29	0.65	---	0.81	0.58	2.28	6.62
2001	0.65	0.15	0.18	1.62	0.63	---	0.57	0.39	2.90	7.09
2002	0.38	0.15	0.17	1.07	0.72	---	0.53	0.20	2.73	5.95
2003	0.36	0.13	0.14	1.18	0.50	---	0.51	0.22	2.11	5.15
2004	0.32	0.14	0.15	1.52	0.39	---	0.52	0.29	1.92	5.25
2005	0.18	0.19	0.14	1.32	0.36	---	0.46	0.28	2.21	5.14
2006	0.18	0.15	0.21	1.06	0.51	---	0.65	0.23	2.14	5.13
2007	0.18	0.15	0.22	0.99	0.45	---	0.66	0.33	1.90	4.86
2008	0.14	0.07	0.22	1.06	0.49	---	0.50	0.21	1.55	4.23
2009	0.25	0.11	0.22	1.07	0.49	---	0.65	0.26	1.55	4.59

Table A6. O32 Commercial wastage (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.10	0.22	0.93	0.20	---	0.06	0.04	0.02	0.02	0.00	1.60
1986	0.00	0.20	0.43	1.86	0.40	---	0.18	0.01	0.04	0.07	0.00	3.20
1987	0.00	0.17	0.37	1.58	0.34	---	0.14	0.06	0.03	0.03	0.00	2.72
1988	0.00	0.05	0.21	1.51	0.12	---	0.03	0.02	0.01	0.01	0.00	1.95
1989	0.01	0.05	0.19	1.46	0.19	---	0.03	0.07	0.02	0.02	0.00	2.03
1990	0.02	0.12	0.24	1.11	0.22	---	0.11	0.06	0.02	0.04	0.00	1.94
1991	0.00	0.07	0.35	1.14	0.42	---	0.09	0.06	0.03	0.06	0.00	2.23
1992	0.01	0.05	0.25	0.64	0.18	---	0.05	0.04	0.02	0.01	0.00	1.25
1993	0.01	0.10	0.19	0.34	0.06	---	0.05	0.04	0.02	0.02	0.00	0.81
1994	0.00	0.07	0.23	0.85	0.04	---	0.04	0.04	0.01	0.01	0.00	1.29
1995	0.00	0.04	0.05	0.13	0.01	---	0.01	0.01	0.00	0.00	0.00	0.26
1996	0.00	0.03	0.04	0.18	0.02	---	0.02	0.03	0.01	0.01	0.00	0.35
1997	0.01	0.04	0.04	0.07	0.05	---	0.03	0.03	0.01	0.01	0.00	0.29
1998	0.00	0.05	0.04	0.15	0.06	---	0.02	0.02	0.01	0.01	0.00	0.36
1999	0.01	0.04	0.07	0.12	0.07	---	0.03	0.03	0.01	0.02	0.00	0.40
2000	0.01	0.03	0.04	0.06	0.06	---	0.03	0.02	0.01	0.01	0.00	0.26
2001	0.00	0.05	0.04	0.07	0.03	---	0.03	0.03	0.01	0.01	0.00	0.27
2002	0.01	0.04	0.03	0.14	0.03	---	0.02	0.02	0.01	0.01	0.00	0.29
2003	0.00	0.04	0.03	0.07	0.04	---	0.02	0.02	0.00	0.01	0.00	0.22
2004	0.00	0.04	0.03	0.08	0.02	---	0.02	0.01	0.00	0.01	0.00	0.20
2005	0.01	0.04	0.03	0.16	0.03	---	0.01	0.01	0.00	0.01	0.00	0.29
2006	0.00	0.04	0.02	0.05	0.01	---	0.01	0.00	0.00	0.01	0.00	0.14
2007	0.00	0.03	0.03	0.05	0.02	---	0.01	0.00	0.00	0.01	0.00	0.16
2008	0.00	0.02	0.01	0.06	0.00	---	0.01	0.01	0.00	0.01	0.00	0.13
2009	0.00	0.01	0.01	0.04	0.02	---	0.01	0.01	0.00	0.01	0.00	0.12

Table A7. U32 Bycatch (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1974	0.15	0.83	0.16	0.77	0.61	5.73	---	---	---	8.25
1975	0.15	1.01	0.19	0.55	0.41	2.55	---	---	---	4.86
1976	0.15	1.12	0.21	0.76	0.50	3.38	---	---	---	6.12
1977	0.16	1.09	0.17	0.73	0.35	0.94	---	---	---	3.44
1978	0.16	0.92	0.16	0.61	0.53	1.62	---	---	---	4.01
1979	0.15	1.16	0.18	1.29	0.25	1.98	---	---	---	5.01
1980	0.15	0.86	0.10	0.93	0.38	3.52	---	---	---	5.94
1981	0.15	0.66	0.10	0.73	0.47	2.04	---	---	---	4.15
1982	0.15	0.57	0.10	0.60	0.49	1.81	---	---	---	3.73
1983	0.15	0.65	0.10	0.87	0.72	1.80	---	---	---	4.30
1984	0.15	0.56	0.09	0.63	0.59	2.40	---	---	---	4.42
1985	0.15	0.59	0.10	0.21	0.24	1.96	---	---	---	3.25
1986	0.15	0.60	0.10	0.16	0.21	2.96	---	---	---	4.19
1987	0.15	0.86	0.10	0.65	0.48	3.07	---	---	---	5.31
1988	0.15	0.84	0.10	1.24	0.01	5.59	---	---	---	7.93
1989	0.16	0.78	0.10	1.46	0.38	5.34	---	---	---	8.22
1990	0.16	0.65	0.18	1.48	0.83	---	1.54	0.15	3.55	8.53
1991	0.16	0.77	0.19	1.72	0.64	---	2.12	0.11	4.59	10.29
1992	0.17	0.73	0.16	2.02	0.86	---	2.04	0.31	5.06	11.35
1993	0.17	1.01	0.41	2.37	0.60	---	1.69	0.31	3.74	10.29
1994	0.17	0.65	0.13	1.56	0.54	---	1.71	0.12	4.08	8.95
1995	0.23	0.82	0.12	1.50	0.92	---	2.68	0.11	2.58	8.96
1996	0.14	0.13	0.11	1.30	0.97	---	1.58	0.16	2.71	7.10
1997	0.14	0.11	0.16	1.42	0.71	---	1.54	0.10	2.23	6.40
1998	0.25	0.10	0.12	1.19	0.66	---	1.30	0.16	2.03	5.80
1999	0.23	0.09	0.13	1.60	0.99	---	1.59	0.07	2.14	6.83
2000	0.19	0.10	0.14	1.61	0.86	---	1.33	0.11	2.33	6.67
2001	0.19	0.03	0.16	1.39	1.04	---	0.93	0.15	2.18	6.07
2002	0.17	0.09	0.17	1.12	1.21	---	1.70	0.08	2.04	6.58
2003	0.20	0.12	0.20	1.61	1.06	---	1.57	0.04	2.35	7.15
2004	0.18	0.12	0.21	2.08	0.84	---	1.57	0.05	2.14	7.19
2005	0.10	0.17	0.20	1.81	0.77	---	1.39	0.05	2.46	6.95
2006	0.20	0.14	0.13	1.91	0.89	---	1.06	0.19	3.22	7.75
2007	0.20	0.15	0.13	1.78	0.79	---	1.08	0.27	2.86	7.25
2008	0.16	0.06	0.13	1.91	0.85	---	0.81	0.18	2.34	6.44
2009	0.14	0.11	0.13	1.92	0.86	---	1.06	0.22	2.34	6.77

Table A8. U32 Commercial wastage (million pounds, net weight).

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.00	0.08	0.04	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.20
1975	0.00	0.14	0.05	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.31
1976	0.00	0.16	0.04	0.11	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.34
1977	0.00	0.14	0.03	0.09	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.29
1978	0.00	0.11	0.04	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.28
1979	0.00	0.12	0.04	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
1980	0.00	0.14	0.03	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
1981	0.00	0.15	0.04	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.35
1982	0.00	0.16	0.03	0.12	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.40
1983	0.00	0.19	0.06	0.12	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.53
1984	0.01	0.36	0.07	0.16	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.72
1985	0.01	0.43	0.11	0.19	0.18	---	0.00	0.00	0.00	0.00	0.00	0.95
1986	0.01	0.47	0.13	0.34	0.15	---	0.01	0.00	0.00	0.00	0.00	1.15
1987	0.01	0.50	0.14	0.37	0.14	---	0.02	0.01	0.00	0.00	0.00	1.23
1988	0.01	0.50	0.16	0.51	0.13	---	0.01	0.01	0.01	0.00	0.00	1.36
1989	0.00	0.39	0.14	0.50	0.15	---	0.02	0.01	0.01	0.00	0.00	1.24
1990	0.00	0.31	0.15	0.48	0.18	---	0.04	0.00	0.01	0.00	0.00	1.17
1991	0.00	0.16	0.14	0.41	0.25	---	0.04	0.01	0.01	0.00	0.00	1.03
1992	0.00	0.16	0.17	0.53	0.19	---	0.02	0.02	0.01	0.00	0.00	1.13
1993	0.01	0.22	0.20	0.48	0.18	---	0.01	0.03	0.01	0.00	0.00	1.15
1994	0.00	0.20	0.19	0.56	0.09	---	0.03	0.01	0.01	0.00	0.00	1.11
1995	0.00	0.19	0.10	0.28	0.05	---	0.03	0.02	0.01	0.00	0.00	0.65
1996	0.00	0.18	0.12	0.32	0.06	---	0.04	0.03	0.01	0.00	0.00	0.73
1997	0.00	0.25	0.14	0.43	0.16	---	0.04	0.02	0.01	0.00	0.00	1.05
1998	0.00	0.28	0.15	0.47	0.22	---	0.03	0.02	0.01	0.00	0.00	1.20
1999	0.00	0.28	0.15	0.49	0.30	---	0.02	0.01	0.01	0.00	0.00	1.34
2000	0.00	0.24	0.14	0.39	0.37	---	0.02	0.02	0.01	0.00	0.00	1.29
2001	0.01	0.24	0.14	0.46	0.44	---	0.03	0.03	0.01	0.00	0.00	1.44
2002	0.01	0.29	0.16	0.52	0.53	---	0.04	0.03	0.01	0.00	0.00	1.66
2003	0.01	0.30	0.17	0.53	0.59	---	0.06	0.03	0.02	0.00	0.00	1.77
2004	0.01	0.34	0.23	0.61	0.60	---	0.07	0.04	0.02	0.00	0.01	1.93
2005	0.01	0.39	0.26	0.66	0.56	---	0.08	0.04	0.03	0.01	0.01	2.03
2006	0.01	0.41	0.28	0.67	0.51	---	0.09	0.03	0.02	0.01	0.01	2.05
2007	0.02	0.44	0.27	0.92	0.42	---	0.10	0.03	0.02	0.01	0.01	2.29
2008	0.02	0.26	0.21	0.92	0.68	---	0.09	0.02	0.02	0.01	0.01	2.34
2009	0.02	0.23	0.26	1.12	0.77	---	0.09	0.01	0.02	0.02	0.01	2.62

Table A9. IPHC setline survey WPUE of O32 fish in weight (net pounds per skate).

Figures refer to entire areas. For cases where only part of an area was fished (e.g., northern 2B, western 3A), the WPUE shown is an adjusted value. *No hook corrections* are applied; J-hook values are raw J-hook catch rates. Area 4CDE is constructed from four subareas: Area 4D Edge which is part of the annual setline survey; Area 4I which includes the survey stations around St. Paul, St. George and St. Matthew islands; Area 4S which is the southern Bering Sea shelf, and 4N which is the northern Bering Sea shelf. The 4N and 4S time series are constructed using trawl survey data (see text for full details). The bottom area (0-400fm) in thousands of nmi^2 is also listed for each area.

Bottom Area	2A 14.132	2B 29.601	2C 14.58	3A 49.178	3B 29.584	4A 19.889	4B 19.711	4D 15.313	4I 4.019	4S 153.474	4N 46.793	4CDE 219.599	Total 396.274
J-Hook WPUE:													
1974	---	---	---	---	---	---	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---	---	---	---	---	---	---
1976	---	---	---	---	---	---	---	---	---	---	---	---	---
1977	---	13	---	58	---	---	---	---	---	---	---	---	---
1978	---	18	---	27	---	---	---	---	---	---	---	---	---
1979	---	---	---	41	---	---	---	---	---	---	---	---	---
1980	---	25	---	76	---	---	---	---	---	---	---	---	---
1981	---	16	---	131	---	---	---	---	---	---	---	---	---
1982	---	21	114	130	---	---	---	---	---	5	0	---	---
1983	---	18	142	119	---	---	---	---	---	4	0	---	---
C-Hook WPUE:													
1984	---	57	260	361	---	---	---	---	---	6	0	---	---
1985	---	42	260	378	---	---	---	---	---	6	1	---	---
1986	---	38	283	305	---	---	---	---	---	7	0	---	---
1987	---	---	---	---	---	---	---	---	---	8	0	---	---
1988	---	---	---	---	---	---	---	---	---	17	0	---	---
1989	---	---	---	---	---	---	---	---	---	10	0	---	---
1990	---	---	---	---	---	---	---	---	---	12	1	---	---
1991	---	---	---	---	---	---	---	---	---	11	2	---	---
1992	---	---	---	---	---	---	---	---	---	8	1	---	---
1993	---	93	---	261	---	---	---	---	---	19	6	---	---
1994	---	---	---	254	---	---	---	---	---	14	5	---	---
1995	29	148	---	300	---	---	---	---	---	16	4	---	---
1996	32	156	306	317	352	---	---	---	---	23	20	---	---
1997	35	139	411	331	414	245	282	111	111	19	5	24	138
1998	36	82	232	281	435	299	216	299	299	25	8	45	134
1999	37	88	204	241	438	290	203	290	290	26	0	44	127
2000	39	93	233	272	373	276	216	213	213	19	4	33	121
2001	41	102	237	256	357	199	171	197	197	20	6	33	113
2002	33	92	261	299	297	168	119	262	262	12	2	32	109
2003	22	73	223	229	262	154	104	195	195	17	4	30	92
2004	27	86	172	270	236	137	73	132	132	17	4	24	89
2005	28	72	171	276	211	107	86	69	69	16	4	18	82
2006	16	59	144	232	181	85	96	54	76	17	4	18	72
2007	19	57	140	212	191	66	87	59	48	12	4	14	66
2008	18	88	108	188	126	84	103	78	53	8	3	13	60
2009	8	86	115	149	113	84	107	78	43	12	4	15	56

Table A10. Commercial WPUE (net pounds per skate).

Values before 1984 are raw J-hook catch rates, with no hook correction. 1983 is excluded because it consists of a mixture of J- and C-hook data. No value is shown for area/years after 1980 with fewer than 500 skates of reported catch/effort data. Total column recomputed in 2007 with new bottom area numbers.

	2A	2B	2C	3A	3B	4A	4B	4C	4D	4E	Total
J-hook CPUE:											
1974	59	64	57	65	57	---	---	---	---	---	---
1975	59	68	53	66	68	---	---	---	---	---	---
1976	33	53	42	60	65	---	---	---	---	---	---
1977	83	61	45	61	73	---	---	---	---	---	---
1978	39	63	56	78	53	---	---	---	---	---	---
1979	50	48	80	86	37	---	---	---	---	---	---
1980	37	65	79	118	113	---	---	---	---	---	---
1981	33	67	145	142	160	158	99	110	---	---	---
1982	22	68	167	170	217	103	---	91	---	---	---
1983	---	---	---	---	---	---	---	---	---	---	---
C-hook CPUE:											
1984	63	148	314	524	475	366	161	---	197	---	357
1985	62	147	370	537	602	333	234	---	330	---	400
1986	60	120	302	522	515	265	---	427	239	---	356
1987	57	131	260	504	476	341	220	384	---	---	349
1988	134	137	281	503	655	453	224	---	201	---	392
1989	124	134	258	455	590	409	268	331	384	---	376
1990	168	175	269	353	484	434	209	288	381	---	334
1991	158	148	233	319	466	471	329	223	398	---	328
1992	115	171	230	397	440	372	278	249	412	---	336
1993	147	208	256	393	514	463	218	257	851	---	392
1994	93	215	207	353	377	463	198	167	480	---	326
1995	116	219	234	416	476	349	189	---	475	---	351
1996	159	226	238	473	556	515	269	---	---	---	413
1997	226	241	246	458	562	483	275	335	671	---	419
1998	194	232	236	451	611	525	287	287	627	---	425
1999	---	213	199	437	538	500	310	270	535	---	394
2000	263	229	186	443	577	547	318	223	556	---	412
2001	169	226	196	469	431	474	270	203	511	---	379
2002	181	222	244	507	399	402	245	148	503	---	378
2003	184	231	233	487	364	355	196	105	389	---	349
2004	145	212	240	485	328	315	202	120	444	---	340
2005	155	197	203	446	293	301	238	91	379	---	314
2006	147	202	170	403	292	241	218	72	280	---	283
2007	94	197	160	398	257	206	230	65	237	---	268
2008	69	176	161	370	234	206	193	94	247	---	249
2009	105	198	156	318	213	241	192	90	258	---	240

Appendix B. Evolution of IPHC assessment methods, 1982-2007

From 1982 through 1994, the halibut stock assessment relied on CAGEAN, a simple age-structured model fitted to commercial catch-at-age and catch-per-effort data (Quinn et al. 1985). The constant age-specific commercial selectivities used in the model were fundamental model parameters, estimated directly.

Beginning in the late 1980s, halibut growth rates in Alaska declined dramatically. As a result, age-specific selectivity decreased. CAGEAN did not allow for that, and by the mid-1990s was seriously underestimating abundance. In effect, it interpreted lower catches as an indication of lower abundance, whereas the real cause was lower selectivity. Incoming year classes were initially estimated to be small, but in subsequent years' assessments those estimates would increase when unexpectedly large numbers of fish from those year classes appeared in the catches. The year-to-year changes in the stock trajectory shown by the assessment therefore developed a strong retrospective pattern. Each year's fit showed a steep decline toward the end, but each year the whole trajectory shifted upward.

The staff sought to remedy that problem by making selectivity a function of length in a successor model developed in 1995. It accounted not only for the age structure of the population, but also for the size distribution of each age group and the variations in growth schedule that had been observed. The fundamental selectivity parameters in this model were the two parameters of a function (the left limb of a normal density) by which the selectivity of an individual fish was determined from its length. The age-specific selectivity of an entire age group was calculated by integrating length-specific selectivity over the estimated length distribution of the age group, and that age-specific selectivity was used to calculate predicted catches. The new model was fitted to both commercial data and IPHC setline survey data, with separate length-specific selectivity functions. Commercial catchability and selectivity were allowed to drift slowly over time, while survey catchability and selectivity were held constant (Sullivan et al. 1999).

When this model was fitted to data from Area 2B and Area 3A, quite different length-specific selectivities were estimated, which suggested that fishery selectivity was not wholly determined by the properties of the gear and the size of the fish but also depended on fish behavior (e.g., migration). These behavioral elements are likely to be more related to age than size. The age of sexual maturity, for example, remained virtually the same in Alaska despite the tremendous decrease in growth, so the size at maturity is now much smaller than it was. While size must affect selectivity, it was thought that age was also influential.

To allow for that, the model was fitted in two ways. The original form was called the "length-specific" fit, because a single set of estimates of the two parameters of the length-based survey selectivity function was used in all years. In a second form, called the "age-specific" fit, the parameters were allowed to drift over time (like the commercial selectivity parameters), but they were required (by a heavy penalty) to vary in such a way that the integrated age-specific selectivities calculated in each year remained constant over time.

The usual diagnostics gave little reason to prefer one fit over the other. Goodness of fit was similar: good for both in 2B, not so good for either in 3A. The retrospective behavior of both fits was dramatically better than that of CAGEAN and quite satisfactory in all cases, although the length-specific fit was more consistent from year to year in 3A and the age-specific fit was more consistent in 2B (Clark and Parma 1999). The two fits produced very similar estimates of abundance in Areas 2B and 2C, but in 3A the length-specific estimates were substantially higher,

so out of caution the staff catch limit recommendations were based on the age-specific fit through 1999.

The assessment model was simplified and recoded as a purely age-structured model in 2000 to eliminate some problems associated with the modeling of growth and the distribution of length at age. It retained the option of modeling survey selectivity as a function of mean length at age (observed not predicted), but the production fits continued to be based on constant age-specific survey selectivity, estimated directly as a vector of age-specific values rather than as a parametric function of age.

The fit of this model to Area 3A data in 2002 showed a dramatic retrospective pattern, similar to the pattern of successive CAGEAN fits in the mid-1990s. Treating setline survey selectivity as length-specific rather than age-specific largely eliminated the pattern. Accumulated data showing very similar trends in catch at length in IHPC setline surveys and NMFS trawl surveys provided further evidence that setline selectivity is, after all, determined mainly by size rather than by age (Clark and Hare 2003).

Another anomaly of the 3A model fit in 2002 was the unexpectedly large number of old fish (age 20+) in the last few years' catches. This was found to be the result of an increase in the proportion of otoliths read by the break-and-burn rather than surface method. Surface readings tend to understate the age of older fish, and IPHC age readers had been gradually doing more and more break-and-burn readings as the number of older fish in the catches increased. The poor model fit at these ages indicated a need to deal explicitly with the bias and variance of both kinds of age readings.

An entirely new model was written for the 2003 assessment (Clark and Hare 2004). Both commercial and survey selectivity were parameterized as piecewise linear functions of mean length at age in survey catches, and were required to reach an asymptote of one at or before a length of 130 cm. Because females are larger than males, all of the population accounting and predictions were done separately for each sex. (The age/sex/size composition of the commercial landings was estimated external to the assessment for this purpose.) The observed age compositions (surface or break-and-burn) were predicted by applying estimated misclassification matrices to the age distributions. Even in its most parsimonious form—with just one survey and one commercial selectivity schedule for both sexes in all years—this model achieved very good fits to the sex-specific observations and good retrospective performance. It also produced somewhat higher estimates of average recruitment and recruitment variability. With this simple model it was feasible do standalone analytical assessments of abundance in Areas 3B, 4A, and 4B for the first time, using data from 1996-2003.

Only two minor changes were made for the 2004 assessment, and neither had a significant effect on the estimates of abundance. First, both the 2004 PIT tag recoveries (Clark and Chen 2005) and a reanalysis of earlier wire tag data (Clark 2005) indicated that commercial selectivity is not always asymptotic; it appeared to be more dome-shaped in Area 2B and more ramp-shaped in Area 3A. Fitting the assessment model with free-form selectivity schedules showed much the same thing for commercial selectivity, namely an assortment of shapes beyond 120 cm. Nevertheless a schedule that reaches an asymptote of one at 120 cm is a good approximation to and compromise among the free estimates, and using an asymptotic commercial schedule is desirable for computing exploitable biomass and reporting harvest rates, so that it what was used in the assessment. All of the freely estimated survey selectivities either level out or increase after 120 cm. Freely estimated survey

selectivities present no practical difficulties, so they were estimated that way in the assessment, and most of the estimates were ramp-shaped.

Apart from a few minor and inconsequential corrections and alterations, the 2005 analytical assessment was the same as the 2004 assessment. The only important change in procedure was the use of the NMFS trawl survey to estimate biomass in Area 4CDE where an analytical assessment was not done.

In 2006, growing concerns about migration of O32 fish from western to eastern areas led the staff to doubt the validity of the closed-area assessments that had been done for many years (Clark and Hare 2007a). The staff has estimated since 2006 coastwide abundance by fitting the model to a coastwide dataset, and estimated biomass in each area in accordance with survey estimates of relative abundance (Clark and Hare 2007b). U32 discard mortality in the halibut fishery was added to the removals beginning with the 2007 assessment; it had the effect of decreasing the present biomass estimate by less than 1%.

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Assessment of the Pacific halibut stock at the end of 2008

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Abstract

As has been done since 2006, the IPHC stock assessment was done by fitting the assessment model to a coastwide dataset to estimate total exploitable biomass. The coastwide exploitable biomass was then apportioned among regulatory areas in accordance with survey estimates of relative abundance, corrected for regional hook competition. Coastwide exploitable biomass in 2009 is estimated to be 325 million pounds, down from the 361 million estimated last year. Virtually all of the decrease is due to lower survey and commercial catch rates of legal-sized halibut. Projections based on the currently estimated age compositions suggest that the exploitable and female spawning biomasses will increase over the next several years as a sequence of strong year classes recruit to the legal-sized component of the population.

Introduction

Each year the International Pacific Halibut Commission (IPHC) staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). A biological target level for total removals from each regulatory area is calculated by applying a fixed harvest rate to the estimate of exploitable biomass in that area. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for catches in directed fisheries subject to allocation is called the fishery CEY. It comprises the commercial setline catch in all areas plus the sport catch in Area 2B, and the sport plus ceremonial and subsistence catches in Area 2A. It is calculated by subtracting from the total CEY an estimate of all unallocated removals—bycatch of legal-sized fish, wastage of legal-sized fish in the halibut fishery, fish taken for personal use, and sport catch except in Areas 2A and 2B. Staff recommendations for catch limits in each area are based on the estimates of fishery CEY but may be higher or lower depending on a number of statistical, biological, and policy considerations. Similarly, the Commission's final quota decisions are based on the staff's recommendations but may be higher or lower.

For many years the staff assessed the stock in each regulatory area by fitting a model to the data from that area (Appendix B). This procedure relied on the assumption that the stock of fish of catchable size in each area was closed, meaning that net migration was negligible. A growing body of evidence from both the assessments (Clark and Hare 2007a) and the ongoing mark-recapture experiment (Webster and Clark 2007, Webster 2008, Webster 2009a) shows that there is probably a continuing eastward net migration of catchable fish from the western Gulf of Alaska (Areas 3B and 4) to the eastern side (Area 2). The effect of this migration on the closed-area stock assessments was to produce underestimates of abundance in the western areas and overestimates in the eastern areas. To some extent this has almost certainly been the case for some time, meaning that exploitation rates were well above the target level in Area 2 and a disproportionate share of the catches have been taken from there.

In order to obtain an unbiased estimate of the coastwide stock beginning with the 2006 assessment, the staff built a coastwide data set and fitted the model to it. Exploitable biomass in each regulatory area was estimated by partitioning, or apportioning, the total in proportion to an estimate of stock distribution derived from the setline survey catch rates (CPUE). Specifically, an index of abundance in each area was calculated by multiplying survey CPUE (running 3-year average) by total bottom area between 0 and 300 fm (Hare 2008). The logic of this index is that survey CPUE can be regarded as an index of density, so multiplying it by bottom area gives a quantity proportional to total abundance. This year an adjustment to the index for each area, derived on the basis of hook competition, was applied. The estimated proportion in each area is then the adjusted index value for that area divided by the sum of the adjusted index values.

Observations from the survey and commercial fishery

The IPHC collects data from a variety of sources to characterize the status and population trends in all regulatory areas, and assist in fitting a population assessment model. Some of the more important datasets are summarized herein.

Total removals from the halibut populations come from seven categories: commercial catch (IPHC survey catch is included in this category), sport catch, legal-sized bycatch (from a variety of fisheries targeting species other than halibut), personal use, legal-sized wastage from the commercial fishery, sublegal-sized bycatch from non-target fisheries, and sublegal-sized wastage from the commercial fishery. Detailed descriptions of each category are contained in the Fishery Removals section of the annual Report of Assessment and Research Activities. The 2008 regulatory area total removals are illustrated in Figure 1, coastwide total removals from 1974 to 2008 are illustrated in Figure 2, and regulatory area total removals for 1974-2008 are illustrated in Figure 3 (and listed in Appendix Table A1). Commercial catch is separately listed in Appendix Table A2. On a coastwide basis, total removals are at their lowest level since 1996. The pattern of changes between 1996 removals and 2008 removals has been quite different among regulatory areas, however.

The current Standardized Stock Assessment (SSA) survey has been conducted since 1996 in almost all areas and in all years. The exceptions are the Eastern Bering Sea shelf which was surveyed only in 2006; Area 2A which was not surveyed in 1996, 1998, and 2000, the Area 4D edge which was not surveyed in 1996, 1998 and 1999, and Area 4A and 4B which were not surveyed in 1996. Stations are placed on a 10-nautical mile grid between depths of 20 and 275 fathoms, resulting in a total of approximately 1280 stations. The 2008 SSA survey is fully described in Soderland et al. (2009). A key indicator of stock status in each regulatory area is the weight of legal-sized (32 inch) halibut caught per standardized skate, termed the survey CPUE (Fig. 4 and Appendix Table A3). Survey CPUE has declined by over 50% on a coastwide basis over the past 10 years. While the rate of decline has differed among areas, there has been a substantial decrease in CPUE in all areas, indicative of a consistent coastwide decline in exploitable biomass.

The survey catch of halibut is sampled to obtain biological information about the stock including sex and age distribution and is described in Forsberg (2009a). The 2008 age distributions for males, females, and sexes combined for all regulatory areas are plotted in Figure 5. The age structure of the population is of considerable interest for a variety of reasons. These distributions indicate the relative abundance of fish available to the fishery, relative contributions to the female spawning biomass, etc. In 2008, there is a general tendency for an older age structure in the western areas, relative to the eastern areas. In particular, the lack of fish older than 20 years is noted for Area 2. Area 3B presents a somewhat anomalous age distribution in that it more closely resembles Area 2 than Area 3A or Area 4 distributions. The reasons for this are presently unclear although the estimated rate of fishing mortality is not excessive and there appears to be substantial recruitment into this area. The staff will be conducting an extensive investigation of this area in the 2009 assessment. Sex and age-specific catch rates are also computed; these are discussed and plotted in the section on Assessment model fit.

The second major component of the annual IPHC data collection is sampling the commercial catch. The port sampling program is detailed in Hutton and Gravel (2009) and age sampling in Forsberg (2009b). From commercial fishing logs, commercial CPUE is computed for each regulatory area (Fig. 6 and Appendix Table A4). As with the survey CPUE, there has been a consistent coastwide decline in commercial CPUE though not quite as pronounced. This is not unexpected however, as commercial fishers tend to move their effort to maintain their catch rate, whereas the survey maintains the same fishing locations every year. Approximately 1500 otoliths are collected and aged from each regulatory area (smaller samples in Areas 2A and 4B). Because commercially caught halibut are gutted at sea, the sex of halibut is unknown when sampled at the port of landing. A statistical methodology has been developed, based on sex ratio at length in survey catches, to parse out male and female proportions at age (see Clark 2004). The estimated sex and age composition of the commercial catch, by regulatory area, is illustrated in Figure 7. It is important to note that the distribution of ages for the total (sexes combined) is not statistically estimated (the distribution represents the otolith readings); it is the sex-specific distributions that are statistically derived. As with the survey age samples, the fish in Area 2 are, on average, several years younger than fish caught in Areas 3 and 4. Here, as well, Area 3B is anomalous in that the average age of fish is closer to the Area 2 average.

Every year, the IPHC places a sampler aboard the National Marine Fisheries Service (NMFS) Eastern Bering Sea (EBS) groundfish/crab trawl survey. The sampler collects biological data on the halibut catches, taking lengths of almost all halibut caught and selecting a subsample for aging. The 2008 effort is described in Sadorus and Lauth (2009). Due to the high cost, and very low catch rate, of setline surveying halibut in the EBS, the IPHC does not conduct the SSA grid survey in that region. While the IPHC survey does operate along the Area 4D edge, that region is not indicative of densities and trends across the broad shelf. For the purposes of apportionment, it is vital that a measure of density for the EBS shelf be derived each year, and the NMFS groundfish trawl survey is leveraged to allow just such an estimate. The NMFS survey generates swept area estimates of abundance for the entire shelf (Fig. 8). In 2006, the IPHC added 100 extra stations to the SSA grid survey and placed these across the shelf to get an estimate of shelf-wide density (Soderlund et al. 2007). In that year, mean density was estimated to be 18.1 pounds per standardized survey skate. That estimate of density is tied to the NMFS trawl survey to provide the annually varying estimate of density. We feel this method is valid for the following reason. From the NMFS trawl survey we actually obtain swept area estimates of abundance at length. We then apply the stock assessment estimated survey selectivity at length schedule to the full catch to provide an index of survey catch rate, comparable to the SSA survey fishing gear. Figure 9 illustrates how the length frequency distribution resulting from this treatment of trawl survey data compares to the actual length frequencies collected in the 2006 IPHC special EBS setline survey. In this manner, we are able to obtain, for a tiny fraction of the cost it would take to survey the EBS with a setline survey, a highly reliable index of halibut abundance across the EBS flats. As can be noted from the time series, the EBS is also showing a strong decline in halibut abundance over the past decade, with an estimated decline of more than 50%.

Part of the coastwide decline in exploitable biomass can be attributed to a decline in size at age. For a given number of halibut in the population, a smaller size at age results in a smaller cumulative biomass. Figure 10a shows how the average weights of halibut in survey and commercial catches have changed over the past 12 years. Average weight has declined by 25% in the survey catches and 33% in the commercial catches. While the decline could be due to a decline in average age of the fish in the catches (since younger fish are smaller), Figure 10b shows this has not been the case as average age in both the survey and commercial catch has actually increased by several years. Trends, by regulatory area, in average age and average weight are illustrated in Figure 11.

Description of the assessment model

For the first time in ten years, a new lead analyst (author SRH) has taken over the assessment (from author WGC, who retired in 2008 and had been the lead analyst). In addition, since last year's acceptance of a coastwide stock assessment model, much of the focus of the staff and the industry is now on how the coastwide estimate of exploitable biomass is apportioned among regulatory areas. For both these reasons, the assessment model for 2008 is identical to that used for the 2007 assessment. This model has been essentially unchanged since 2003. It has been thoroughly described in an IPHC Scientific Report (Clark and Hare 2006) and was subjected to an external peer review by two external scientists from the Center for Independent Experts (IPHC Staff 2008). In the interest of brevity, little discussion is presented here of the model itself. Interested readers are referred to Clark and Hare (2006, 2007b, 2008) for full details.

The IPHC assessment model is age- and sex-structured. Commercial and survey selectivity are both estimated as piecewise linear functions of observed mean length at age/sex in survey catches. (There is a 32-inch minimum size limit in the commercial fishery.) Commercial catchability is normally allowed to vary from year to year with a penalty of 0.03 on log differences. Survey catchability is normally held constant, although some variation was allowed in both this year's and last year's production fits. The model is fitted to commercial and survey catch at age/sex and CPUE.

Until 2006, estimates of halibut abundance were made using closed area models for all areas except Areas 2A and 4CDE. Area 2A leveraged the Area 2B assessment and relative survey CPUE, while Area 4CDE relied upon the NMFS EBS trawl estimates of swept area abundance. The closed area models are no longer considered reliable but for the sake of comparison they are still fitted to data and provide abundance estimates. The closed-area and coastwide model fits differ in parameterization and likelihood. Some of the closed-area data sets are quite noisy, so the closed-area version is more parsimonious and it is weighted. Specifically, the catchability, selectivity and natural mortality parameters are all unisex; the estimated selectivity schedules are strongly smoothed; the model is fitted only to total CPUE (rather than CPUE at age/sex); and a heavy weight is placed on the CPUE data series to assure satisfactory agreement. The coastwide data are not noisy, so the coastwide version of the model can have sex-specific parameters, weaker selectivity smoothing, and neutral data weighting. It is fitted to CPUE at age/sex as well as total CPUE. The closed area model fits are not discussed further. The EBio estimates produced by the closed area fits are contained in the summary tables listed in the section on coastwide abundance apportionment.

Alternative model fits

As was done in 2007, four versions of the basic assessment model were fitted. The main difference for three of the models concerned how survey selectivity (which is referred to as "q" below) was parameterized. The fourth variant excluded commercial CPUE from the model fit and is considered to be similar to many of the NMFS groundfish assessment models. The models are summarized as such:

(i) Survey q constant: catchability is a single fixed (though estimated) value in all years.

(ii) Survey q drift: survey catchability estimated for each year, but with a penalty of 0.05 on log differences. This is similar to the treatment of commercial catchability.

(iii) Survey q trendless drift: same as Survey q drift, but with the additional requirement that a regression of estimated survey catchability on year have zero slope. This means that survey catchability was allowed to vary but not to show any trend over time. This was last year's production model.

(iv) No commercial CPUE: Commercial CPUE is not included in the likelihood.

Table 1 shows features of the candidate model fits and some others. The best fit, indicated by a delta AIC score of zero is the survey q drift model. Nearly as good a fit is provided by last year's production model, survey q trendless drift. The two other model fits are significantly worse. The exploitable biomass estimate produced by all four models covers a very narrow range. As in 2007, the survey q trendless drift model is selected as the production model and the coastwide exploitable biomass estimate of 325 million pounds forms the basis for apportionment among regulatory areas.

Effect of the 2008 data on abundance estimates

Coastwide survey CPUE declined by 9% and commercial CPUE declined by 8% from 2007 to 2008 (Figs. 4 and 6; Appendix A tables A3 and A4). As a result, the 2008 coastwide model fit is revised downwards, by about 20%, from the estimate of abundance at the beginning of 2008 made in the 2007 assessment (Table 2). At the same time the 2008 fit shows an increase in abundance, of about 12%, between the beginning of 2008 and the beginning of 2009. The net result is an estimated decline of 10% between the 2008 beginning of year exploitable biomass and the 2009 beginning of year exploitable biomass.

Evaluation of the assessment

Quality of fits

The model predicts survey CPUE at sex/age (Fig. 12) and commercial catch at age (Fig. 13) very well. That is not true for many of the closed area model fits (not shown). There is no apparent pattern to the residuals from the fits, although the model initially underestimates slightly the early strength of the 1987 year class. The model is successfully predicting the increasing number of fish aged 25 and older, particularly males, which are appearing in both the survey and commercial catches. The very low growth rate for male halibut means that many are not recruiting to the fishery until they are older than 25. This "plus" group is poised to increase even more in the new few years as the remains of the very large 1987 and 1988 year classes reach 25 years of age. The series of total survey and commercial CPUE are also predicted closely (Fig. 13, middle panel).

Estimates of recruitment, exploitable biomass and spawning biomass

Exploitable biomass (EBio) at the beginning of 2009 is estimated to be 325 million pounds and female spawning biomass (SBio) is estimated to be 315 million pounds. EBio is down by about 10% from the beginning of year 2008, while SBio is a bit over 3% higher than the 2008 beginning of year value estimated in the 2007 assessment. EBio and SBio are both estimated to have declined continuously between 1998 and 2007. EBio continued to decline in 2008, the model estimates that both are now on the increase, with SBio bottoming out in 2007 and EBio bottoming out in 2008. However, the 2007 assessment estimated that the low point for both was reached in 2007 and 2008 was the beginning of the turn around. This point is discussed more fully in the Retrospective performance section. Recruitment (measured as age-eight fish in the year of assessment) has varied between 8 and 40 million halibut since the 1988 year class, with a mean of 17.4 million. The 1989 to 1993 year classes, presently 15 to 19 years old and the main target of the commercial fishery for the past several years, are all estimated to have been well below average. The sharply declining biomass over the past decade has resulted from these small year classes replacing earlier year classes that were much larger, especially the 1987 and 1988 year classes. A hopeful sign, and the explanation for the projected increase in 2009 biomasses, is the estimation that the 1998, 1999 and 2000 year classes all appear well above average. The extent to which these year classes will contribute to EBio over the next few years depends on the growth rate which, as has been frequently noted, continues to decline. Figure 14 (top panels) illustrates estimated recruitment and biomass trends since 1996.

Estimates of uncertainty

There are a number of ways of estimating the uncertainty associated with a given model fit and biomass estimate. They are all unsatisfactory in that they are conditioned on the correctness of the model, and in fact it is the choice of one model rather than another that is the major source of uncertainty in assessments. This is well illustrated by the difference in area-specific biomass estimates between the coastwide and closed-area fits of the IPHC model. One standard method of illustrating uncertainty around an estimate, for a given model, is the likelihood profile. The bottom panels in Figure 14 show the likelihood profile for both the exploitable biomass as well as the female spawning biomass. The 95% confidence interval (C.I.) for EBio is 286 to 368 million pounds, while the 95% C.I. for the female spawning biomass is 274 to 359 million pounds. Confidence intervals for the recruitment estimates were also computed and are plotted with the recruitment estimates (Fig. 14, top panel).

Retrospective performance

Each year's model fit estimates the abundance and other parameters for all years in the data series. One hopes that the present assessment will closely match the biomass trajectory estimated by the previous year's assessment. To the extent that it does not, the assessment is said to have poor retrospective performance.

Our assessment has not tracked very well for the last few years. Each year the assessment has revised downward the previous year's biomass estimates (Fig. 15a), meaning that biomass was overestimated then and may be overestimated now if the cause of the retrospective problem lies somewhere within the model. There is some precedent for that; the assessment models in use in the mid 1990s and the early 2000s showed strong retrospective patterns that turned out to be the result of misspecified selectivity (age- rather than length-based). There is also the possibility that the retrospective pattern is caused in some way by the external estimation of the sex composition of the commercial catch, or by the internal prediction of surface age compositions prior to 2002 through the application of an age misclassification matrix (Clark and Hare 2006).

Problems of this sort with the assessment machinery would manifest themselves as systematic revisions of the estimated relative strength of the year-classes present in the stock. That was true of the retrospective patterns caused by the misspecification of selectivity in the past: incoming year-classes would at first be estimated as weak because catch rates were low, but the real reason was low selectivity rather than low abundance. When they were later caught in large numbers, the estimates of relative year-class strength increased. The retrospective estimates of year class strength as plotted in Figure 15b. There is some evidence of a systematic revision of estimates of year class strength as the 1994 through 1998 year class have all trended downward for the last five assessments. The pattern does not hold for the 1999 year class strength estimates.

In 2007, a check was made using a blind projection of the assessment from 2004 to 2007. Year-class strengths and other parameters from the 2004 assessment, along with just the catches from 2005-2007 which are needed to estimate fishing mortality, were used to project the 2007 age structure and then compared to the 2007 observed age structure. That projection demonstrated that the retrospective behavior appears to be caused solely by the data and not by the assessment model (Clark and Hare 2008). We also note that the retrospective pattern has changed this year compared to the past several years. The 2008 EBio trajectory essentially overlays the 2007 EBio trajectory, with the exception of the 2007 estimate which again showed a decline. Also, the span of the revised estimates has narrowed. The difference between the 2005 EBio, as estimated using data up to 2004, and the 2008 assessment estimate of the 2005 EBio differ by just 15%, which is generally within the error range of a good stock assessment.

Causes of retrospective behavior are notoriously difficult to diagnose. In the case of halibut it appears to result from lower CPUE rates than expected, given the estimated mortality rate. This could be due, for example, to a trend in natural (or undocumented fishing) mortality, or a trend in catchability. The catchability explanation is unlikely, however, given that a model which permits catchability to show a trend produces assessment estimates that differ little from models with tightly constrained catchability. To summarize, there is ongoing retrospective behavior in the halibut assessment. The magnitude of the behavior is relatively small and the trend of successively lowering all earlier EBio estimates essentially ended this year. We do not feel the retrospective behavior weakens the assessment in any way, and analyses of the recognized patterns will be ongoing.

Harvest policy, status relative to reference points and biomass projections

The IPHC has developed, refined and utilized a constant harvest rate policy since the 1980's. The policy was fully described in Clark and Hare (2006) and further modified as described in Hare and Clark (2008). Stated succinctly, the policy is to harvest 20% of the coastwide exploitable biomass when the spawning biomass is estimated to be above 30% of the unfished level. The harvest rate is linearly decreased towards a rate of zero as the spawning biomass approaches 20% of the unfished level. This combination of harvest rate and precautionary levels of biomass protection have, in simulation studies, provided a large fraction of maximum available yield while minimizing risk to the spawning biomass. Since the early 2000s, and in common with many fisheries management agencies, the harvest policy has incorporated a measure designed to avoid rapid increases or decreases in catch limits, which can arise from a variety of factors including true changes in stock level as well as perceived changes resulting from changes in the assessment model. The adjustment, termed "Slow Up Fast Down (SUFD)" results in a target harvest rate of 20% but a realized rate usually a bit different (Fig. 16). The SUFD approach is somewhat different from other agencies in that it is asymmetric around the target value, i.e., the catch limit responds more strongly to estimated decreases in biomass than to estimated increases. This occurs for two reasons: first, the assessment generally has a better information base for estimating decreasing biomass compared with increasing biomass; and second, such an asymmetric policy follows the Precautionary Approach.

The unfished female spawning biomass ($B_{unfished}$) is computed by multiplying spawning biomass per recruit (SBR, from an unproductive regime) and average coastwide age-six recruitment (excluding the four most recent years). The SBR value, computed from Area 2B/2C/3A size at age data from the 1960s and 1970s is 118.5 lbs per age-six recruit. Average coastwide recruitment for the 1990-1999 year classes (computed at age-six) is 23.3 million. This gives a $B_{unfished}$ of 878 million pounds, a B_{20} of 176 million, a B_{30} of 263 million pounds, and the 2009 female spawning biomass value of 315 million pounds establishes $B_{current}$ as 35% of $B_{unfished}$ (Fig. 17, top panel), down from the 2008 beginning of year estimate of $B_{current}$ of 40%. The revised trajectory of SBio suggests that the female spawning biomass has been very close to the B_{30} level, the point at which the harvest rate would start being curtailed. On an annually estimated basis, however, the stock has not been that low; it is only retrospectively that we estimate the spawning biomass to have gotten so close to the reference point threshold. One problem with this method of establishing reference points is that the threshold and limit are dynamic, changing each year as the estimate of average recruitment changes. In this year's calculation the very strong 1999 year class was included among the year classes used to compute average recruitment, hence $B_{unfished}$ increased from the 2008 estimate of 748 million pounds to this year's estimate of 878 million pounds. The corresponding B_{20} and B_{30} values also increased, thus even though SBio is estimated to have increased between 2008 and 2009, the $B_{current}$ value declined. This situation will exacerbate next year if the 2000 year class, which presently appears to be almost as large as the 1999 year class enters the calculation. This seems paradoxical that an increasing SBio appears to be dropping closer to the reference point threshold. One solution to this paradox is to use a fixed set of year classes to estimate average recruitment, in the same way that SBR is computed from a set of size at age estimates. Staff will explore modifications to the determination of reference points in the next year. The estimated age composition of the spawning biomass shows that contributions come from a broad range of ages including an 8% contribution from females age 20 and older (Fig. 17, bottom panel). While the age distribution is certainly truncated due to the size-selective effects of fishing, it is encouraging that production of eggs is not confined to a narrow range of ages and should ensure that adequate reproductive potential remains in the ocean for the foreseeable future.

In addition to monitoring the status of the female spawning biomass relative to reference points, success at achieving the target harvest rate is also documented (Fig. 18). The target harvest rate over the past decade for halibut has generally been 0.20. Exceptions include a briefly increased rate to 0.225 and 0.25 between 2004 and 2006, and a lower rate of 0.15 in Areas 4B and 4CDE. On a coastwide basis, however, recent realized harvest rates have hovered around 0.25. A sizable portion of this above target harvest rate comes from the retrospective revision of exploitable biomass estimates. Thus, while the intended target rate has been around 0.20, with catch limits based on such a rate, a retrospective revision of exploitable biomass, when combined with unchanged estimates of total removals generates the higher estimated harvest rates. A smaller portion of the above target results from the SUFD adjustment which prevents catch limits dropping fully to the target level indicated by contemporary estimates of exploitable biomass. Estimates of realized harvest rate among individual regulatory areas require use of an apportionment method. The staff favors use of bottom area-weighted survey CPUE adjusted for hook competition (discussed below). Using this apportionment method, regulatory area realized harvest rates are illustrated in Figure 19. Realized harvest rates are estimated to be at, or above target in Area 4 (where target harvest rate is 0.15), at target in Area 3, and substantially above target in Area 2.

The annual stock assessment produces an estimate of the total number of male and female halibut, ages 6 and older, in the ocean (Fig. 20). With this set of numbers and assuming that life history parameters, such as size at age and maturity at age, remain close to what they are today, we can make biomass and yield projections for several years into the future. Because the age range of halibut in the catch is generally in the 10-20 year old range, estimates of recruitment – which are often imprecise – do not much influence the projections. The time series of abundance shown in Figure 19 illustrate the strength of the celebrated 1987, and to a lesser extent 1988, year classes. As was true last year, the current assessment suggests that two extremely large year classes – 1999 and 2000 – are poised to enter the exploitable biomass over the next few years. Presently, both year classes look to be larger – in terms of numbers – than the 1987 and 1988 year classes. However, it is important to note that size at age is much smaller now than it was 20 years ago. This has two important ramifications – first it means that the 1999 and 2000 year classes are only just beginning to reach the exploitable size range and, therefore, their true numbers in the population are still quite uncertain. Secondly, it also means that for a given number of halibut, their collective biomass will be lower. Currently, a large fraction of males never reach the minimum size limit and thus never enter the exploitable biomass. It remains to be seen just how these year classes will develop. If we assume that size at age remains at the values seen this year, then the projections for both the exploitable biomass and spawning biomass are very optimistic (Fig. 21) and indicate that the declines we have seen over the past decade are on the verge of reversing. It important to note that total removals should still remain at around 20% of the exploitable biomass and not be kept high in anticipation of future increases. As happened in the mid 1990s, when the biomass rises, higher catch limits will follow.

Apportioning the coastwide biomass among regulatory areas

The staff believes that survey CPUE-based apportionment is the most objective and consistent method of estimating the biomass distribution among areas and therefore the best distribution of total CEY, if the aim is proportional harvest. The validity of the survey CPUE apportioning requires that survey catchability – the relationship between density and CPUE – be roughly equal among areas. In 2007, several checks for area differences in catchability were made (Clark 2008a, Clark 2008b, Clark 2008c, Webster 2009b) but little compelling evidence suggesting significant differences was found. The exception was in Area 2A where a preliminary analysis suggested that uneven station distribution, in relation to bottom depth, resulted in a 40% lower catchability. The other factor that indicated potential area differences concerned hook competition and whether areas had different catchabilities as a result of fewer baited hooks being available to halibut. Both of those factors have been reconsidered for this year.

Station depth distribution

The IPHC survey stations are set on a 10-nmi grid between the depths of 20 and 275 fathoms. Ideally, such an arrangement should lead to stations having the same physical and oceanic characteristics as the entire bottom area within each regulatory area. As CPUE is affected by a myriad of factors that vary with depth, a simple mean CPUE computed from all stations should be the same as one computed from a depth weighted CPUE. Figure 22 illustrates how closely survey station depths relate to the cumulative bottom depth distribution. With the exception of Area 4B where survey stations are disproportionally deep, station depth distribution closely matches bottom depth distribution. Minor differences are also noted in Area 2C, which has a slight surplus of deep stations and Area 4A which has a slight surplus of shallow stations. Survey stations were stratified by depth interval and mean CPUE values were computed for each interval. These depth-stratified CPUEs were weighted by the amount of bottom area to compute a depth stratified mean CPUE (Fig. 23) In computing the stratified means, it was necessary to find depth ranges such that adequate numbers of stations contributed to the mean calculation, otherwise a biased computation could occur from undue influence of a small number of stations. In fact, this is what occurred in Area 2A when depth stratified means were computed. This year, the depth intervals were chosen such that 10 stations were included in each depth stratum. The resultant depth stratified means are very close to the simple survey means. The largest difference is in Area 4B but the difference is not statistically meaningful. Thus, for 2008, no depth correction is made to the survey CPUE.

Hook competition

Catchability of halibut is affected by the presence of other bait takers, a process known as hook competition. If the average number of baits available to halibut varies substantially among regions, this would be reason to adjust survey CPUE. An analytical method for determining the level of hook competition and a correction factor for such competition was presented in 2007 (Clark 2008a). The following section is reprinted from Clark (2008a):

> Mathematically the process of baits being removed from a longline by different species is the same as the process of fish being removed from a population by different fisheries and natural predators. We can represent each kind of bait taker as removing a certain proportion of the baits per unit time, so that the number of baits B_i taken by a given species *i* during a soak time *T* is given by the familiar catch equation:
>
> $$B_i = F_i \cdot B_0 \cdot \left(1 - \exp\left(-Z \cdot T\right)\right) / Z$$
>
> where F_i is the instantaneous rate of bait removal by species *i*, B_0 is the initial number of baited hooks, and $Z = \sum_j F_j$ is the sum of the instantaneous rates applied by all bait takers.
>
> The instantaneous rate of bait removal by halibut can be taken to be proportional to the local density of halibut, and depending on size and gear selectivity some proportion of halibut that take a bait will also be hooked and caught, so the catch per skate of halibut C_h will be proportional to the density of halibut D_h multiplied by the last term in the bait removal equation:

$$C_h = k \cdot B_h = k \cdot F_h \cdot B_0 \cdot \left(1-\exp\left(-Z\right)\right)\big/ Z = k' \cdot D_h \cdot B_0 \cdot \left(1-\exp\left(-Z\right)\right)\big/ Z$$

where k and k' are constants of proportionality. In this equation, $\left(1-\exp\left(-Z\right)\right)$ is the fraction of baits removed by all takers during the active period, and $\left(1-\exp\left(-Z\right)\right)\big/ Z$ is the average number of baits remaining over the course of the active period as a proportion of the initial number. If this term is the same in all areas, then survey CPUE is a consistent index of density across areas. Otherwise survey CPUE does not index density consistently across areas. Equivalently, if the fraction of baits taken is the same in all areas, then survey CPUE is a consistent index of density.

It is interesting to note that the effect of hook competition on the comparability of survey CPUE is wholly determined by the total bait removal rate *Z*. The species composition of the bait takers makes no difference. If 80% of the baits are taken in both Area X and Area Y (meaning that *Z* is the same), and the catch in Area X is all halibut and the catch in Area Y is half halibut and half dogfish, the survey CPUEs of halibut in the two areas will accurately reflect the relative densities of halibut.

Figure 24 shows hook occupancy rates for years 2006-2008. The catch rate (hook occupancy) varies widely for different species among the areas. The important rate however is the number of baits remaining. It is this amount, and assuming an instantaneous rate of removal, that determines average number of baits available to halibut. Areas where the number of baits remaining is higher than the Coastwide total have higher catchability while areas with fewer baits remaining have lower catchability. A hook competition correction factor is computed by dividing the coastwide value of average baits (1-exp(-Z)/Z) by the area-specific value of average baits. Thus lower catchability will result in a correction factor greater than 1 (survey CPUE is increased) while higher catchability has the opposite result. Figure 25 shows the range of hook correction factors by area from 1996 to 2008. Areas 2A, 4B, and 4D are significantly different than 1.0 while the other regions range slightly above and below 1.0.

For this year, staff recommends adopting the hook correction factor as a means of adjusting survey CPUE within each regulatory area. A running three-year mean is used so that trends in competition can be tracked. The correction factors used for weighting survey CPUE in 2008 are listed in Table 3.

Methods of apportioning biomass

Last year, staff recommended apportioning the coastwide biomass using area weighted survey CPUE. This year, staff recommends the same method though with a hook competition correction factor applied. The staff examined several candidate methods, including those brought forward in various meetings, as well as via email, for apportioning the biomass and determining Total and Fishery CEY using these alternative methods. The full complement of apportionment methods for which staff compiled CEY estimates are as follows:

1. Survey CPUE x Bottom Area. This method uses a three-year average of survey CPUE multiplied by bottom area to develop an index of relative abundance. Each area's portion of the coast wide biomass is its index divided by the coastwide sum of the indices.

2. Survey CPUE x Bottom Area, hook competition correction applied. Same as above but regulatory area survey CPUE average is multiplied by the hook competition correction factor listed in Table 3.
3. 2008 Closed-Area Assessment proportions applied to Coastwide Total EBio. The relative area abundances as computed in the closed-area assessment are applied to the coastwide estimate of Exploitable Biomass. Relative abundance estimate for Area 2A leverages Area 2B using relative survey CPUE while Area 4CDE biomass is computed using NMFS swept area estimates of abundance.
4. 2008 Closed-Area Assessment proportions applied to Closed Area Total EBio. This is the method used up until 2006 and is the only method that doesn't use the Coastwide Total of EBio.
5. Relative Proportion of age-eight halibut as estimated in the closed area assessments. The logic is that this represents numbers of fish that would have eventually ended up in each area even though they may have been elsewhere at age-eight.
6. Share of Total Removals (3-year average). This method averages removals by area for the past three years and each regulatory area's biomass is average removals divided by coastwide average removals.
7. Share of Total Removals (10-year average). Same as above but using a 10-year average.
8. Share of Total Removals (15-year average). Same as above but using a 15-year average.
9. Share of Bottom Area. Bottom area is computed for each regulatory area (0-300 fathoms) and biomass is apportioned according to each area's share of bottom area. This method excludes the EBS outside of Area 4C.
10. Commercial CPUE x Bottom Area. Same as method 1, but using commercial CPUE instead of survey CPUE.

Area-apportioned biomass, total and fishery constant exploitation yields

With the 10 different methods of apportioning biomass, 10 sets of area-apportioned exploitable biomass, total and fishery CEY can be computed. All of the methods utilize the same table of Other Removals – deducted from Total CEY to obtain Fishery CEY. The Other Removals are listed in Table 4. The staff recommended method of apportioning biomass, Method 2 – survey CPUE, adjusted for hook competition and area-weighted leads to the area-specific Exploitable Biomass, Total and Fishery CEY figures listed in Table 5. For comparison purposes, the corresponding 2007 estimates are shown in Table 6. There are two differences between 2007 and 2008 – no hook competition correction was used in 2007, though a depth correction was applied to Area 2A and which has now been removed. Also, the recommended target harvest rate for Area 4A has been lowered from 0.20 to 0.15. The reasons for this recommendation are discussed in the Area Summary for 4A.

The area shares for each of the 10 apportionment methods are listed in Table 7. The EBio totals for each area are listed in Table 8, Total CEYs are listed in Table 9, and Fishery CEYs are listed in Table 10. The target harvest rates used to compute Fishery CEYs are 0.20 for Areas 2 and 3 and 0.15 for all of Area 4. Within the tables, apportionment method No. 4, which solely relies upon the closed area assessments, has a different EBio (and 28 million pounds higher) total that the other 9 methods.

Area summaries

The coastwide assessment indicates that the exploitable biomass of halibut has declined approximately 50% over the past decade. This declining trend is seen almost all of the area-specific survey and commercial CPUE indices. But the breadth and reasons behind the declines vary by area. The following is a region by region discussion of the trends and grouping of diagnostic plots to assess the past and present removals, stock trends, and prospects for each area. For each of the areas, six plots are illustrated. These include the following:

1. Total removals – illustrated by category (commercial catch, sport, etc.)
2. Sublegal bycatch – An estimate of lost commercial yield due to sublegal bycatch is also given. Note that the lost yield from bycatch in any given year is an estimate of future lost yield summed across several years. Methodology for estimating sublegal bycatch, lost production and computing surplus production are in the process of being documented (Hare, in prep.).
3. Surplus production. Stated simply, surplus production is the amount of total catch that, when taken exactly, keeps the exploitable biomass at the same level from one year to the next. If the biomass increases, then total catch (termed "removals") was less than surplus production. If the biomass declines, then removals were greater than surplus production. Long term declines in biomass result from removals exceeding surplus production; stock building results from taking less than surplus production.
4. CPUE and effort – Long term trends in commercial fishing effort and CPUE.
5. Abundance indices – these include survey CPUE, Coastwide assessment with survey partitioning and closed area assessments.
6. 2008 age structure of the population.

Taken in total, these indicators convey a comprehensive picture for each area and serve as a helpful reference when discussing each regulatory area.

Area 2

Area 2A, 2B and 2C indices are illustrated in Figures 26, 27 and 28, respectively. Between 1997 and 2006, total removals were stable in all three areas, averaging 1.6 million pounds in Area 2A, 13.5 million pounds in Area 2B and 12.4 million pounds in Area 2C. Removals declined sharply in 2007 and 2008, in response to the revised view of relative halibut abundance in Area 2. Sublegal bycatch, and subsequent lost yield to the sport and commercial fisheries, is estimated to be rather low, though legal-sized bycatch in Area 2A still represents a sizable portion of total removals. Surplus production estimates suggest that removals have exceeded surplus production in Area 2 for most of the past decade. Commercial effort has steadily increased in Area 2A for almost a decade but was relatively level in Areas 2B and 2C, and in fact declined over the past two years. Indices of abundance all suggest a steady decline in biomass in all three areas, though the Area 2B survey setline CPUE increased nearly 50% in 2008. All three areas saw decline of more than 50% in survey CPUE between 1996 and 2007, and declines continued for 2A and 2C. As is the case with the coastwide estimate of abundance, a small increase in EBio is projected for the beginning of 2009. The age structure of fish caught in Area 2 is noticeably younger than in Areas 3 and 4. Mean age is around 11 years of age, with little difference between males and females.

All the indices are consistent with a picture of a steadily declining exploitable biomass in Area 2. The reasons for the decline are likely twofold. The first is the passing through of the two very large year classes of 1987 and 1988. Every assessment over the past decade has shown that those two year classes were very strong in comparison to the surrounding year classes. Now that those two year classes are 20 years old, their contribution to the exploitable biomass and catches has sharply declined and the drop in biomass is to be expected as they are replaced by year classes of lesser magnitude. Removals have been generally larger than surplus production and this prevents rebuilding of regional stocks. Our present view of Area 2 is that harvest rates have been much higher than the target rate of 0.20 over the past decade and are not sustainable, particularly with the passage of the 1987 and 1988 year classes. There are signs that two or three large year classes are set to enter the exploitable biomass, however, the exploitable biomass will not increase as long as harvest rates remain high. Finally, Area 2 presently accounts for 28% of total removals coastwide but contributes just 17% to the female spawning biomass, a byproduct of the young age of the resident population.

Area 3

Area 3A and 3B indices are illustrated in Figures 29 and 30 respectively. While these two areas occupy the central area of distribution of the halibut stock, they have substantially different exploitation histories over the past 10-20 years. Area 3A removals, both the total as well as the individual components (commercial, sport, bycatch) have been very stable over the past 10 years. Commercial effort has also seen relatively little variation. The CPUE indices show a slow decline with a drop of 20% in the commercial and 33% in the survey between 1998 and 2008. Removals have been very close to estimated surplus production when averaged over the past seven years, although there has been large annual variation in the proportion of the surplus production removed. The coastwide assessment estimates a decline of 16% in the EBio over the past 10 years. Area 3B saw a large increase in removals beginning in 1996 which peaked in 2002 and has dropped sharply since. Commercial fishing effort more than tripled in the seven years after 1996 and then declined modestly over the past four years before increasing again in 2008. We estimate that removals greatly exceeded surplus production between 1998 and at least 2006. Commercial and survey CPUE both dropped by a bit more than 50% between 1998 and 2008. The coastwide assessment suggests biomass dropped by 55% between 1998 and 2008. Area 3A has a much broader spectrum of ages in the population than is seen in Area 2. Average age for females in survey catches is 13 and for males is 16 years of age. Area 3B, however, is more similar to Area 2 in age distribution than to Area 3A.

Area 3A has the appearance of being the most stable of the IPHC regulatory areas. The area has been fully exploited for many decades and there is a wealth of data detailing the population dynamics. The area also sits at the center of halibut distribution and it appears that emigration is roughly equal to immigration resulting in an effectively closed population. Like Area 2, Area 3A benefited from the very large year classes of 1987 and 1988 and the slow decline in exploitable biomass is the result of those year classes dying off. The biomass remains in a healthy state and will continue to support removals of the size seen over the past 2-3 decades. The situation in Area 3B is different. Area 3B was relatively lightly fished until the mid 1990s. With the introduction of a regular survey, quotas were incrementally increased from 4 million pounds to a high of 17 million pounds. Predictably, catch rates declined steadily. Our view of Area 3B is that the area had an accumulated "surplus" biomass that could be (and was) taken but the level of catches was not sustainable. The area has now been fished down and the average annual yield will be somewhere in between the low levels of the mid 1990s and the high levels of 5-6 years ago. As the area is also centrally located, we apply the dynamics of Areas 2 and 3A and believe that a constant harvest rate of 0.20 is appropriate for the region. The coastwide assessment suggests that harvests have been in the 0.15 to 0.20 range over the past six years.

Area 4

Area 4A, 4B and 4CDE indices are illustrated in Figures 31, 32 and 33, respectively. The three areas have roughly similar commercial exploitation histories over the past decade and show similar trends. In all three areas, commercial catches increased from around 1.5 million pounds to around 4-5 million pounds between 1996 and 2001. Catches have since declined in all three areas, most strongly in Areas 4B and 4CDE where a lower target harvest rate of 0.15 was applied the past few years. Commercial effort mirrored the rise in removals from 1996-2001, however the drop in effort was not nearly as sharp as the drop in catches, and the drop in commercial CPUE is evident in the time series. Survey CPUE in Area 4A has declined around 70% over the past decade while Area 4B is down 50% over the same time period; the decline in Area 4D survey CPUE is around 40% (there is no survey index for 4C or 4E). The coastwide assessment indicates an exploitable biomass decline of 61% for Area 4A, 68% for Area 4B, and 43% for Area 4CDE.

The situation in Area 4 is somewhat like Area 3B only more exaggerated. Area 4 was very lightly exploited up until the mid 1990s. With the onset of surveys, quotas were quickly increased and the accumulated surplus biomass quickly removed. Catches of 4-5 million pounds in each area are clearly not sustainable, as was stated by the IPHC staff when higher catch limits were recommended. In Area 4B, where catch limits were dropped most strongly, there is evidence of a reversal in the strong biomass decline. Over the past three years, the CPUE indices have actually increased slightly and the two assessments estimate a level time trend in exploitable biomass. The target harvest rate was reduced to 0.15 in Area 4CDE in 2004 and in Area 4B in 2005. While Area 4CDE still shows continuing signs of decline, the situation in Area 4B is much more promising. The Area 4B survey CPUE increased for the fourth consecutive year and total removals now appear to be less than surplus production.

This year, staff is recommending lowering the target harvest rate for Area 4A to 0.15, in line with the rest of Area 4. Sublegal bycatch remains very large relative to removals and lost annual yield to the commercial fishery is on the order of 1.5 million pounds. Additionally, Area 4A is a net exporter of fish, likely receiving little emigration from the rest of Area 4 while immigration has been seen to be quite large (Webster 2009). Yield per recruit calculations for Area 4A, based on estimated average recruitment suggest sustainable yield is no greater than 3 million pounds; an F_{40} harvest policy for Area 4A gives a recommended harvest rate of 0.15. All of these factors together suggest that removals continue to be too high in Area 4A and a lower target harvest rate is required. The hope is that Area 4A will respond as Area 4B has and the stock will curtail its steep decline and begin to increase, perhaps with assistance from the anticipated large 1999 and 2000 year classes and removals will then increase commensurately.

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Table 1. Alternative coastwide model fits. The AIC value is relative units compared to the model with the lowest AIC scare.

Model	Number of parameters	Deviance	Δ AIC	Exploitable biomass
Survey q constant	153	534	+ 82	320
Survey q drift	164	512	0	322
Survey q trendless drift	164	513	+ 3	325
No fit to commercial CPUE	153	530	+ 65	316

Table 2. Effect of the 2008 data on closed-area and coastwide abundance estimates.

Area	2008 ebio 2007 assessment Data as of 11/07	2008 ebio 2007 assessment Data as of 11/08	2008 ebio 2008 assessment Data as of 11/08	2009 ebio 2008 assessment Data as of 11/08
Coastwide assessment:	361	360	290	325

Table 3. Hook correction factors applied to survey CPUE in partitioning coastwide biomass among regulatory areas. The factors represent 2006-2008 hook occupancy data.

2A	2B	2C	3A	3B	4A	4B	4CDE
1.112	1.009	1.050	1.048	1.087	1.024	0.845	0.732

Table 4. Other removals in detail. Sport catch figures for Areas 2C and 3A are actual catches not GHL levels as in Table 5.

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Sport catch	0.457	1.520	3.083	5.629	0.018	0.043	0.000	0.000	10.750
Legal-sized bycatch	0.141	0.067	0.216	1.058	0.485	0.496	0.211	1.552	4.226
Personal use	0.030	0.405	0.525	0.372	0.048	0.015	0.002	0.092	1.489
Legal-sized wastage	0.001	0.023	0.012	0.063	0.004	0.012	0.012	0.014	0.141
Total	0.629	2.015	3.836	7.122	0.555	0.566	0.225	1.658	16.606
Total excl.sport catch in Areas 2A and 2B	0.142	0.495	3.836	7.122	0.555	0.566	0.225	1.658	14.599
Sublegal discard mortality (shown for information; not taken off total CEY)	0.015	0.262	0.212	0.924	0.681	0.133	0.019	0.091	2.337
Sublegal bycatch mortality (shown for information; Not taken off total CEY)	0.157	0.064	0.128	1.905	0.852	0.814	0.176	2.337	6.432

Table 5. Estimates of 2009 exploitable biomass and CEY from the 2008 assessment.

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2009 exploitable biomass	3.2	27.0	27.9	140.0	68.8	18.5	15.4	24.2	325
Proportion of total	0.010	0.083	0.086	0.431	0.212	0.057	0.047	0.074	1.000
Target harvest rate	0.20	0.20	0.20	0.20	0.20	0.15	0.15	0.15	<0.20
Total CEY	0.642	5.414	5.574	28.008	13.757	2.770	2.310	3.624	62.099
Other removals [2,3]	0.142	0.495	2.710	7.169	0.555	0.567	0.225	1.658	13.520
2009 fishery CEY [2]	0.500	4.919	2.864	20.839	13.202	2.204	2.085	1.966	48.579

Notes:
[1] "Coastwide assessment" refers to the coastwide model fit with survey apportionment of the total biomass estimate among regulatory areas, and corrected for estimated rates of hook competition.
[2] "Other removals" comprise legal-sized wastage, legal-sized bycatch, personal use, and in most areas sport catch. In Areas 2A and 2B sport catch is included in fishery CEY rather than in other removals.
[3] Assumes GHL of 0.788 M lbs. in Area 2C and 3.650 M lbs. in Area 3A.

Table 6. Estimates of 2008 exploitable biomass and CEY from the 2007 assessment (2008 RARA, p. 185).

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2008 exploitable biomass	4.7	25.6	32.5	144.8	74.0	21.3	20.2	37.9	361
Proportion of total	0.013	0.071	0.090	0.401	0.205	0.059	0.056	0.105	1.000
Target harvest rate	0.20	0.20	0.20	0.20	0.20	0.20	0.15	0.15	<0.20
Total CEY	0.94	5.12	6.50	28.96	14.80	4.26	3.03	5.69	69.30
Other removals [2]	0.29	0.47	2.59[3]	6.71[3]	0.53	0.75	0.33	2.01	13.68
2008 fishery CEY [2]	0.65	4.65	3.92	22.25	14.27	3.51	2.71	3.68	55.62
2008 catch limit	1.22	9.00	6.21	24.22	10.90	3.10	1.86	3.89	60.40

Notes:
[1] "Coastwide assessment" refers to the coastwide model fit with survey apportionment of the total biomass estimate among regulatory areas. "Area assessments" are the closed-area model fits.
[2] "Other removals" comprise legal-sized wastage, legal-sized bycatch, personal use, and in most areas sport catch. In Areas 2A and 2B sport catch is included in fishery CEY rather than in other removals.

Table 7. Shares of total CEY by area according to various apportionment methods.

Rule	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Survey apportionment (CPUE x bottom area)	0.009	0.083	0.082	0.415	0.196	0.056	0.057	0.102	1.000
Survey apportionment (with hook correction)	0.010	0.083	0.086	0.431	0.212	0.057	0.047	0.074	1.000
2009 exploitable biomass from 2008 closed-area assessments (CW assessment sum)	0.012	0.114	0.123	0.449	0.107	0.027	0.063	0.104	1.000
2009 exploitable biomass from 2008 closed-area assessments (CA assessment sum)	0.012	0.114	0.123	0.449	0.107	0.027	0.063	0.104	1.000
Historical recruitment from 2007 closed-area assessments (1987-1996)	0.013	0.118	0.106	0.483	0.122	0.049	0.024	0.085	1.000
Share of total removals (3 year avg.)	0.018	0.149	0.151	0.408	0.135	0.047	0.023	0.070	1.000
Share of total removals (10 year avg.)	0.018	0.151	0.141	0.357	0.169	0.056	0.039	0.069	1.000
Share of total removals (15 year avg.)	0.018	0.157	0.148	0.371	0.148	0.054	0.038	0.067	1.000
Share of bottom 0-300 fm (excl. EBS shelf outside 4C)	0.066	0.159	0.082	0.256	0.154	0.094	0.078	0.111	1.000
Commercial apportionment (CPUE x bottom area)	0.028	0.123	0.055	0.401	0.162	0.082	0.069	0.080	1.000

Table 8. Exploitable biomass by area according to various apportionment methods.

Rule	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Survey apportionment (CPUE x bottom area)	2.911	27.071	26.778	134.822	63.845	18.193	18.389	32.992	325.000
Survey apportionment (with hook correction)	3.208	27.072	27.868	140.041	68.784	18.465	15.401	24.162	325.000
2009 exploitable biomass from 2008 closed-area assessments (CW assessment sum)	3.975	36.966	40.053	145.858	34.928	8.851	20.468	33.901	325.000
2009 exploitable biomass from 2008 closed-area assessments (CA assessment sum)	4.316	40.138	43.490	158.374	37.926	9.610	22.225	36.810	353.000
Historical recruitment from 2007 closed-area assessments (1987-1996)	4.140	38.502	34.587	156.928	39.662	15.767	7.657	27.758	325.000
Share of total removals (3 year avg.)	5.946	48.361	48.916	132.471	43.951	15.123	7.498	22.732	325.000
Share of total removals (10 year avg.)	5.933	49.092	45.755	116.099	55.005	18.260	12.575	22.281	325.000
Share of total removals (15 year avg.)	5.694	50.941	48.002	120.731	48.082	17.429	12.495	21.626	325.000
Share of bottom 0-300 fm (excl. EBS shelf outside 4C)	21.446	51.820	26.676	83.174	50.064	30.492	25.196	36.133	325.000
Commercial apportionment (CPUE x bottom area)	8.967	40.109	17.744	130.376	52.771	26.778	22.409	25.845	325.000

Table 9. Total CEY by area according to various apportionment methods.

Rule	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Survey apportionment (CPUE x bottom area)	0.58	5.41	5.36	26.96	12.77	2.73	2.76	4.95	61.52
Survey apportionment (with hook correction)	0.64	5.41	5.57	28.01	13.76	2.77	2.31	3.62	62.10
2009 exploitable biomass from 2008 closed-area assessments (CW assessment sum)	0.79	7.39	8.01	29.17	6.99	1.33	3.07	5.09	61.84
2009 exploitable biomass from 2008 closed-area assessments (CA assessment sum)	0.86	8.03	8.70	31.67	7.59	1.44	3.33	5.52	67.15
Historical recruitment from 2007 closed-area assessments (1987-1996)	0.83	7.70	6.92	31.39	7.93	2.36	1.15	4.16	62.44
Share of total removals (3 year avg.)	1.18	9.60	9.81	26.54	8.76	2.27	1.14	3.43	62.72
Share of total removals (10 year avg.)	1.18	9.80	9.16	23.23	10.99	2.74	1.89	3.35	62.34
Share of total removals (15 year avg.)	1.14	10.18	9.61	24.15	9.61	2.61	1.88	3.25	62.42
Share of bottom 0-300 fm (excl. EBS shelf outside 4C)	4.29	10.36	5.34	16.63	10.01	4.57	3.78	5.42	60.41
Commercial apportionment (CPUE x bottom area)	1.79	8.02	3.55	26.08	10.55	4.02	3.36	3.88	61.25

Table 10. Fishery CEY by area according to various apportionment methods.

Rule	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Survey apportionment (CPUE x bottom area)	0.404	4.919	2.448	19.787	12.212	2.150	2.482	3.273	47.675
Survey apportionment (with hook correction)	0.464	4.919	2.666	20.831	13.200	2.191	2.034	1.948	48.253
2009 exploitable biomass from 2008 closed-area assessments (CW assessment sum)	0.617	6.898	5.103	21.995	6.429	0.749	2.794	3.409	47.993
2009 exploitable biomass from 2008 closed-area assessments (CA assessment sum)	0.685	7.533	5.790	24.498	7.028	0.863	3.058	3.846	53.300
Historical recruitment from 2007 closed-area assessments (1987-1996)	0.650	7.205	4.009	24.209	7.375	1.786	0.873	2.488	48.595
Share of total removals (3 year avg.)	0.999	9.110	6.904	19.366	8.200	1.687	0.861	1.750	48.877
Share of total removals (10 year avg.)	1.005	9.305	6.250	16.052	10.438	2.160	1.615	1.671	48.495
Share of total removals (15 year avg.)	0.958	9.681	6.698	16.976	9.054	2.035	1.601	1.571	48.574
Share of bottom 0-300 fm (excl. EBS shelf outside 4C)	4.111	9.869	2.427	9.458	9.456	3.995	3.503	3.744	46.563
Commercial apportionment (CPUE x bottom area)	1.615	7.527	0.000	18.898	9.997	3.438	3.085	2.201	46.762

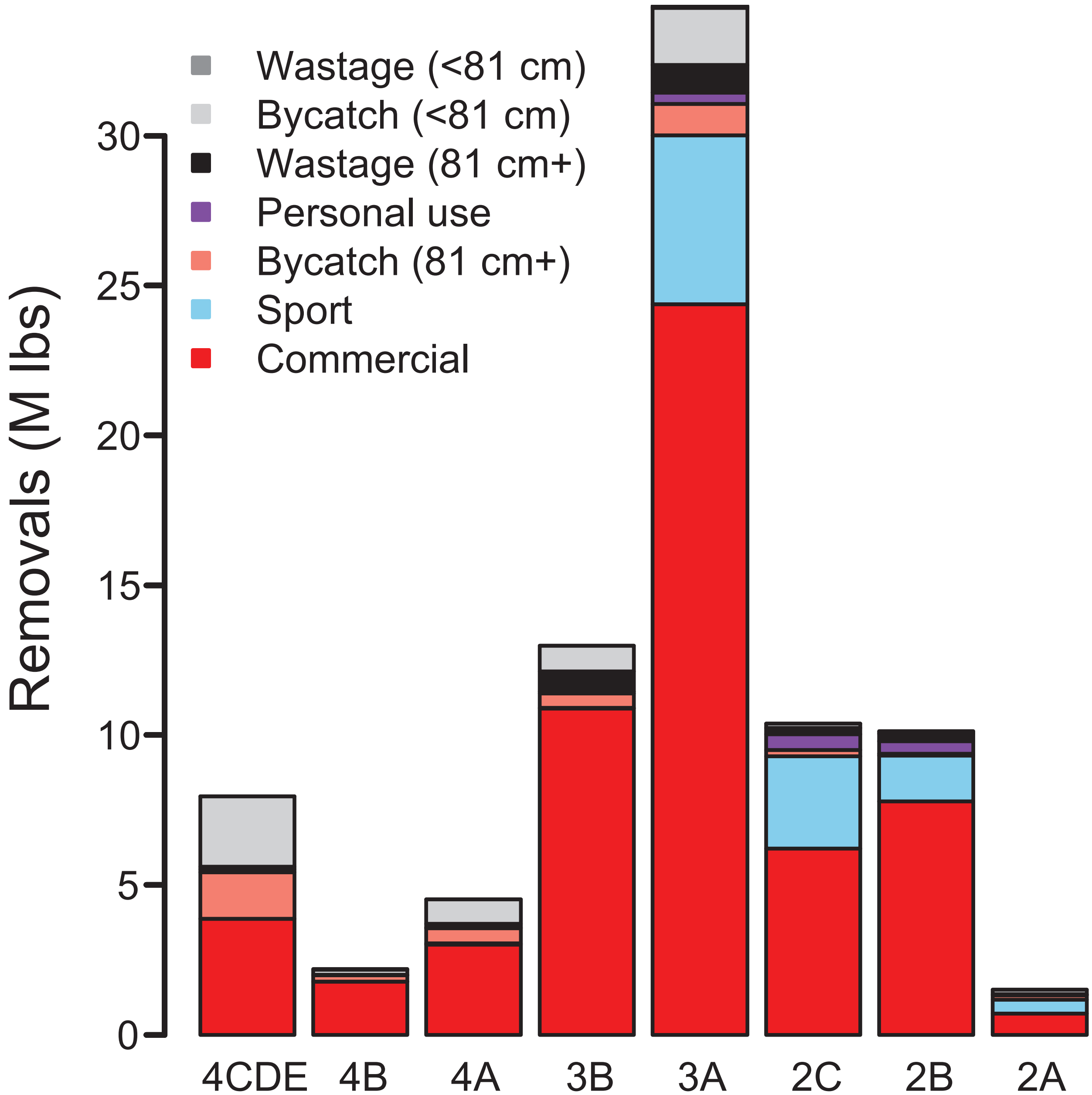


Figure 1. Total removals by type and regulatory area for 2008.

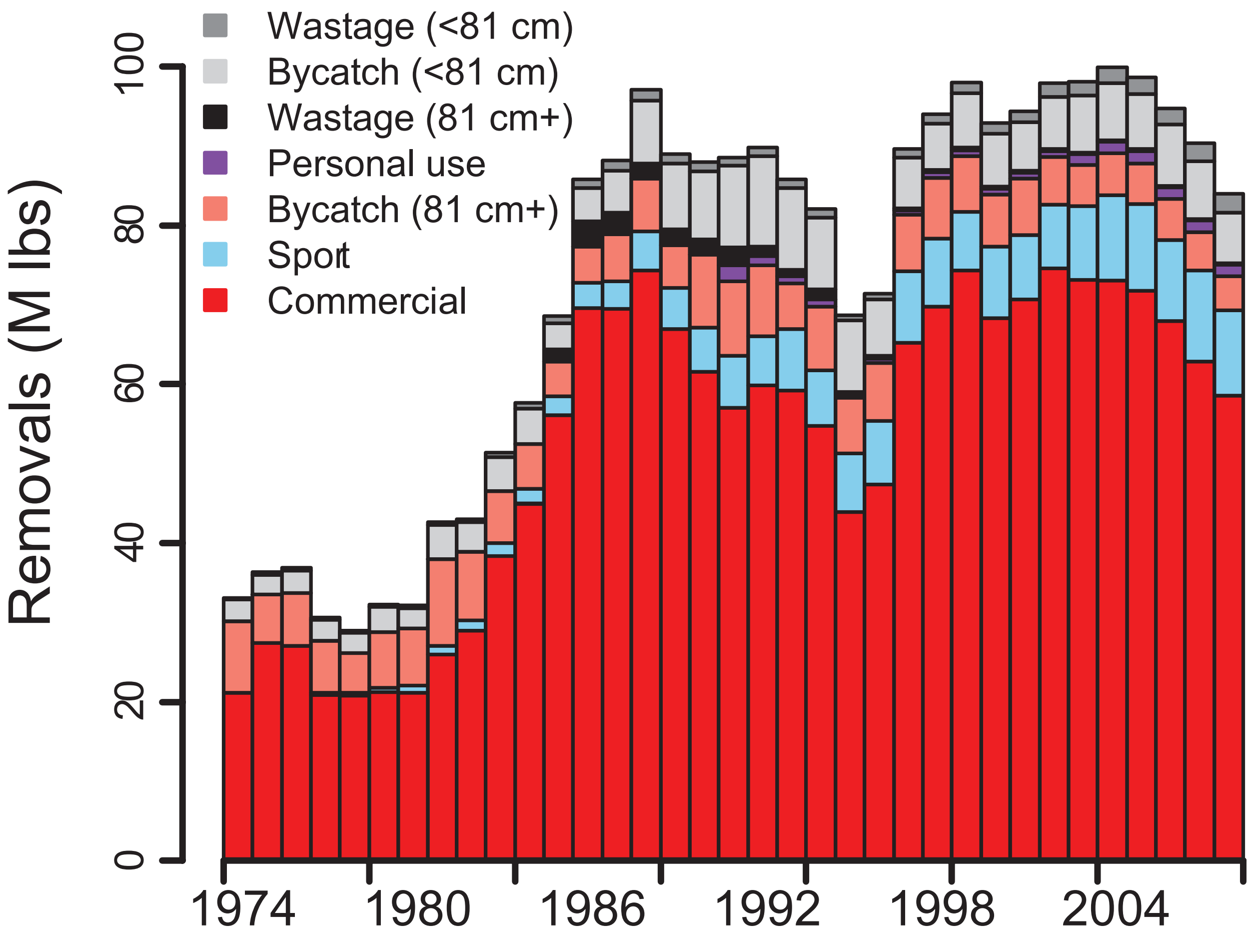


Figure 2. Total removals coastwide for the period 1974-2008.

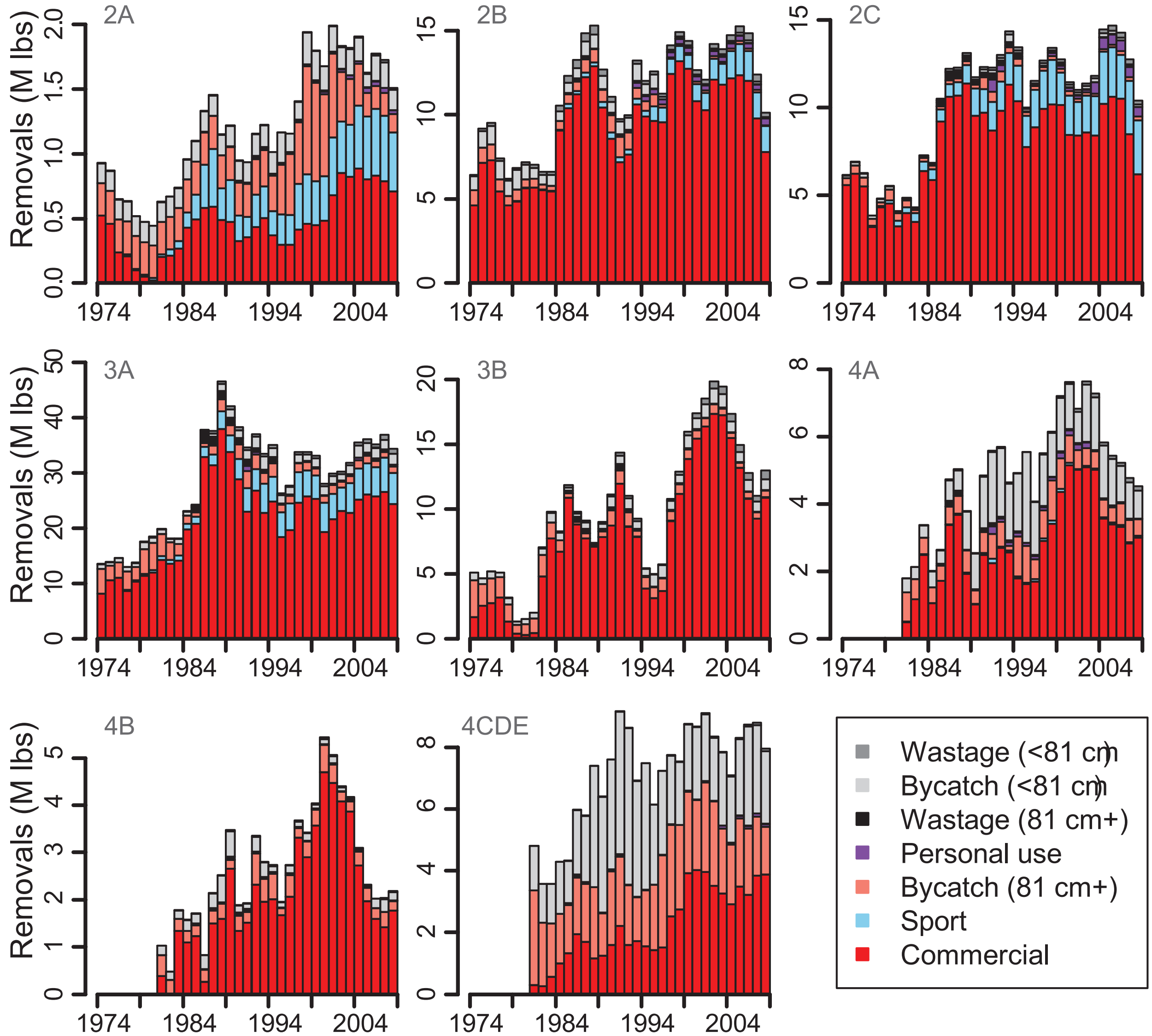


Figure 3. Total removals of halibut, by Regulatory Area, 1974-2008. The two sublegal categories (bycatch and wastage, colored in gray) and not included in the total removals listed in Table A1).

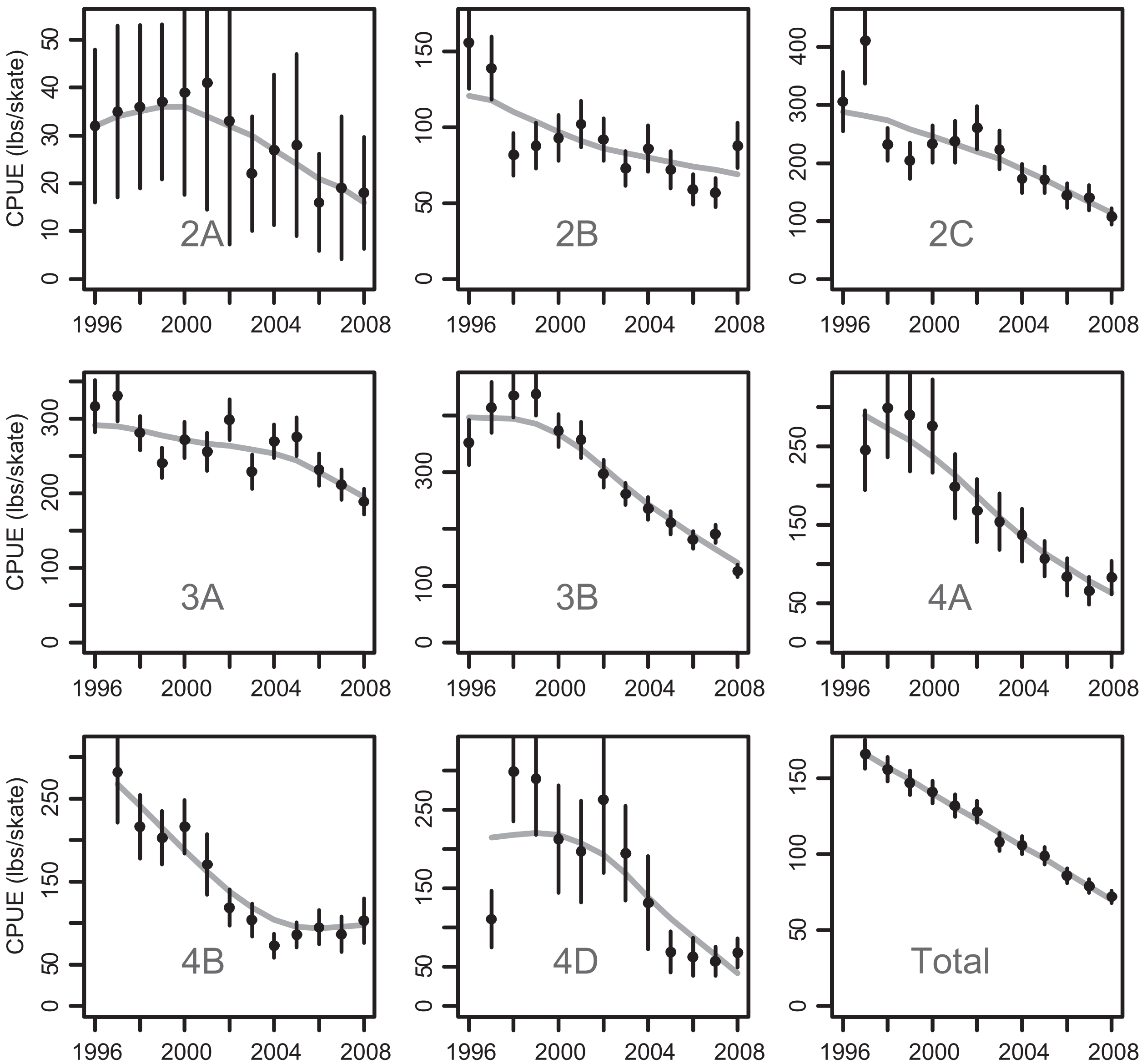


Figure 4. Survey CPUE (weight of legal-sized halibut per standardized skate of gear) by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray line is a smoother to illustrate trend; it is not an assessment model fit to the CPUE data. The total is computed by area-weighting the individual area CPUE time series.

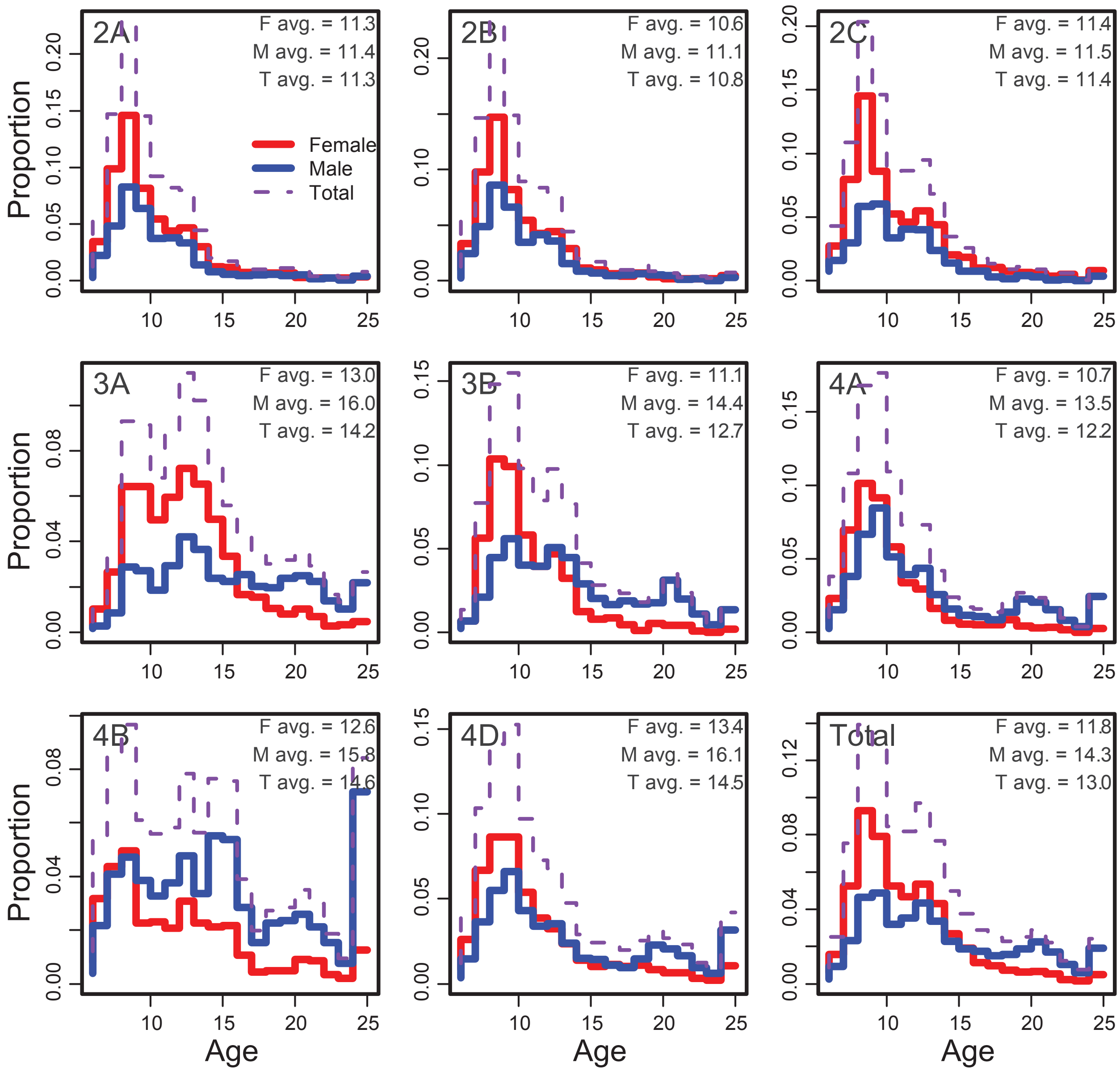


Figure 5. Regulatory area sex and age compositions from halibut taken in the 2008 IPHC stock assessment survey. Proportions are shown for females (red lines), males (blue line) and sexes combined (purple dashed line). Average age is also shown, with "T" indicating Total (sexes combined).

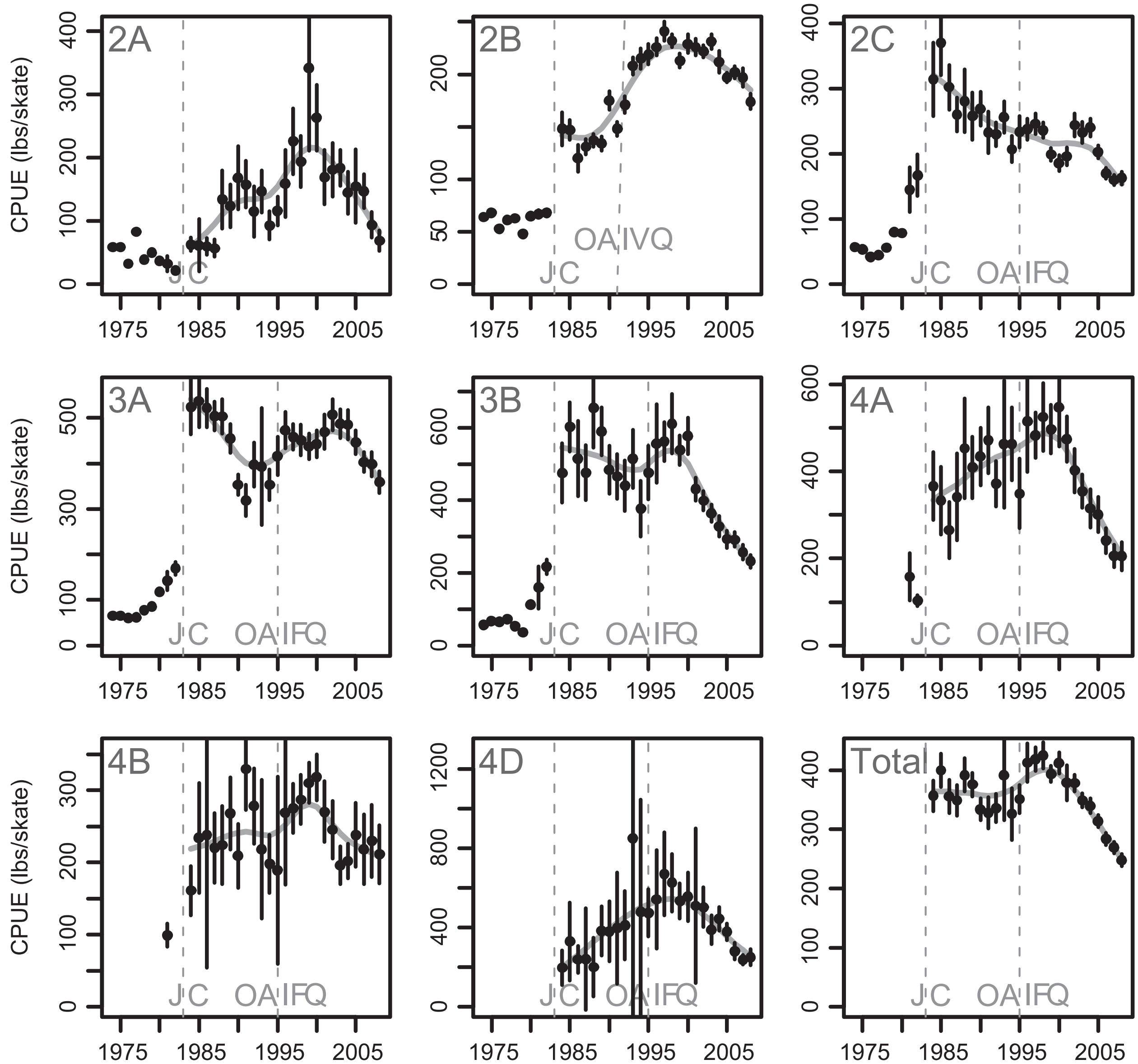


Figure 6. Commercial CPUE by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray line is a smoother to illustrate trend; it is not an assessment model fit to the CPUE data. The total is computed by area-weighting the individual area CPUE time series. The dashed vertical lines indicate transitions between J and C hook, between open access (OA) and Individual Vessel Quotas in Area 2B, and between open access and Individual Fishing Quotas in Areas 2C, 3 and 4.

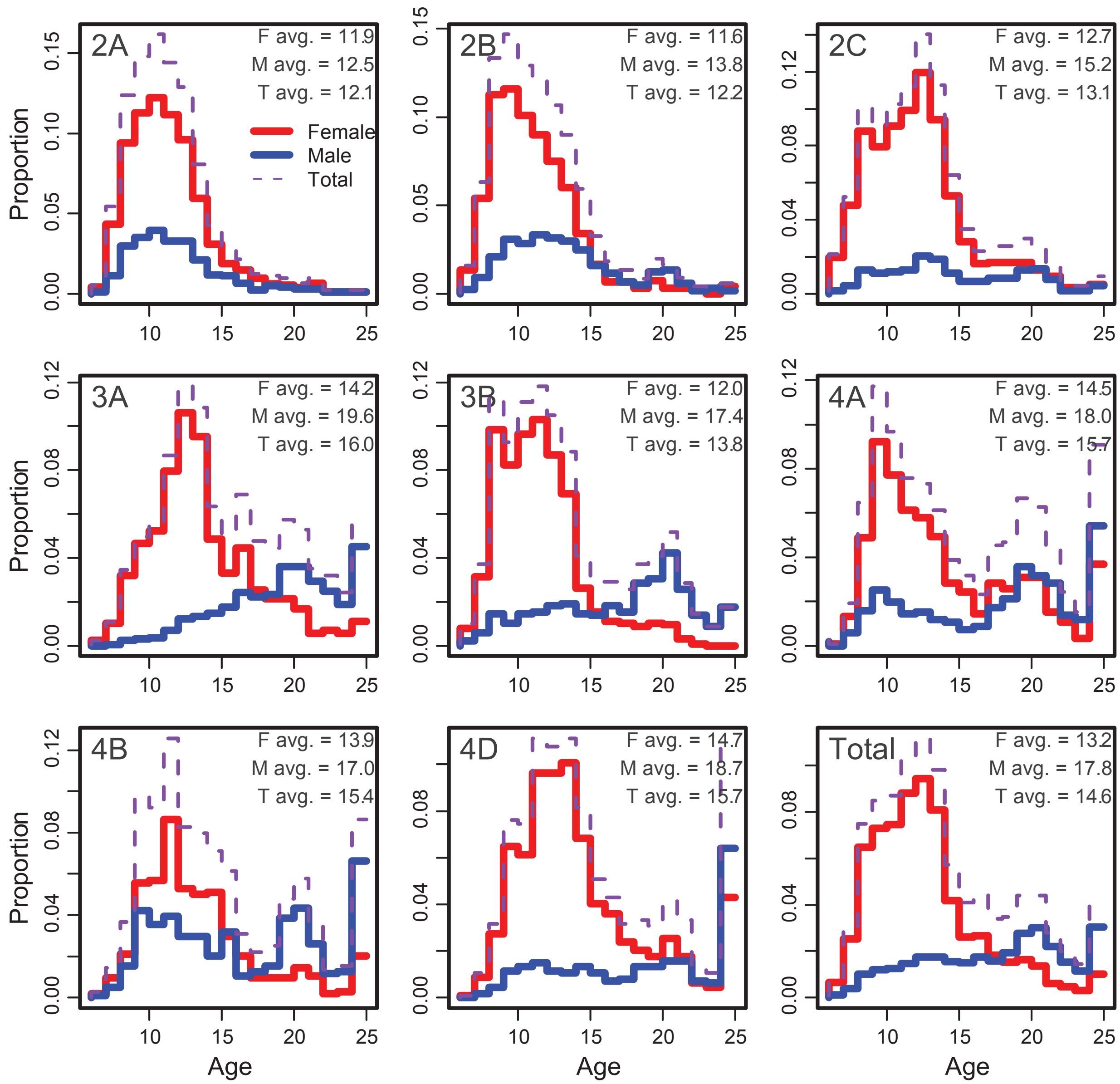


Figure 7. Regulatory area sex and age compositions from halibut sampled from commercial landings. Proportions are shown for females (red line), males (blue line) and sexes combined (purple dashed line). Average age is also shown, with "T" indicating Total (sexes combined).

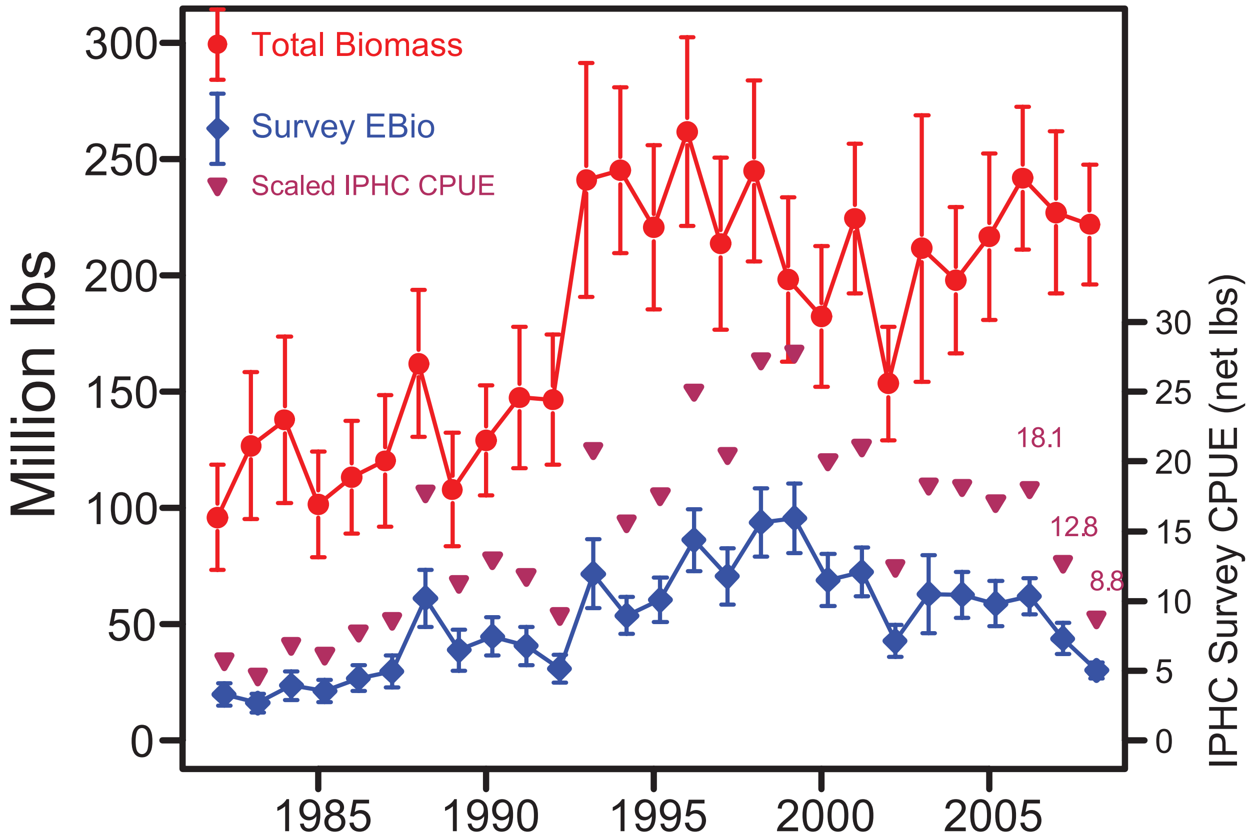


Figure 8. Swept-area estimates of halibut abundance from the NMFS EBS trawl survey. The red dots and error bars represent mean and 95% confidence interval for the total abundance; the blue diamonds are error bars represent mean and 95% confidence interval for abundance with survey selectivity applied to the total biomass (termed survey EBio). The inverted purple triangles represent the estimated density of legal-sized halibut (per standardized skate of gear) across the shelf; this index is scaled to the survey EBio trend (see text for full details).

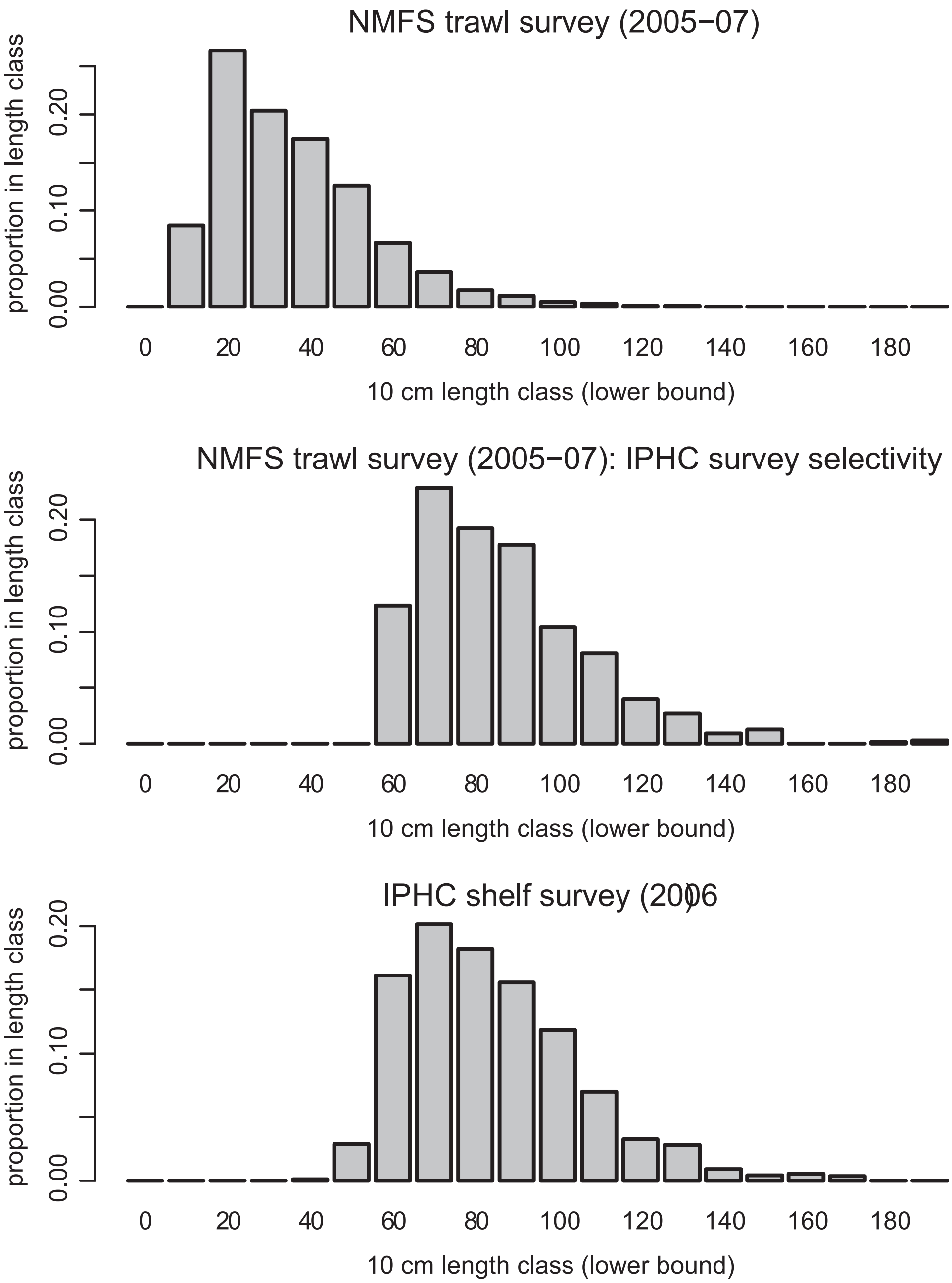


Figure 9. Comparison of NMFS trawl survey and IPHC length frequency compositions. The top panel shows the length frequency composition for all halibut caught by the NMFS trawl gear for years 2005-7. the middle panel shows the frequency distribution of lengths after the IPHC setline selectivity curve is applied to raw counts. The bottom panel illustrates the length composition of halibut in the 2006 IPHC shelf survey.

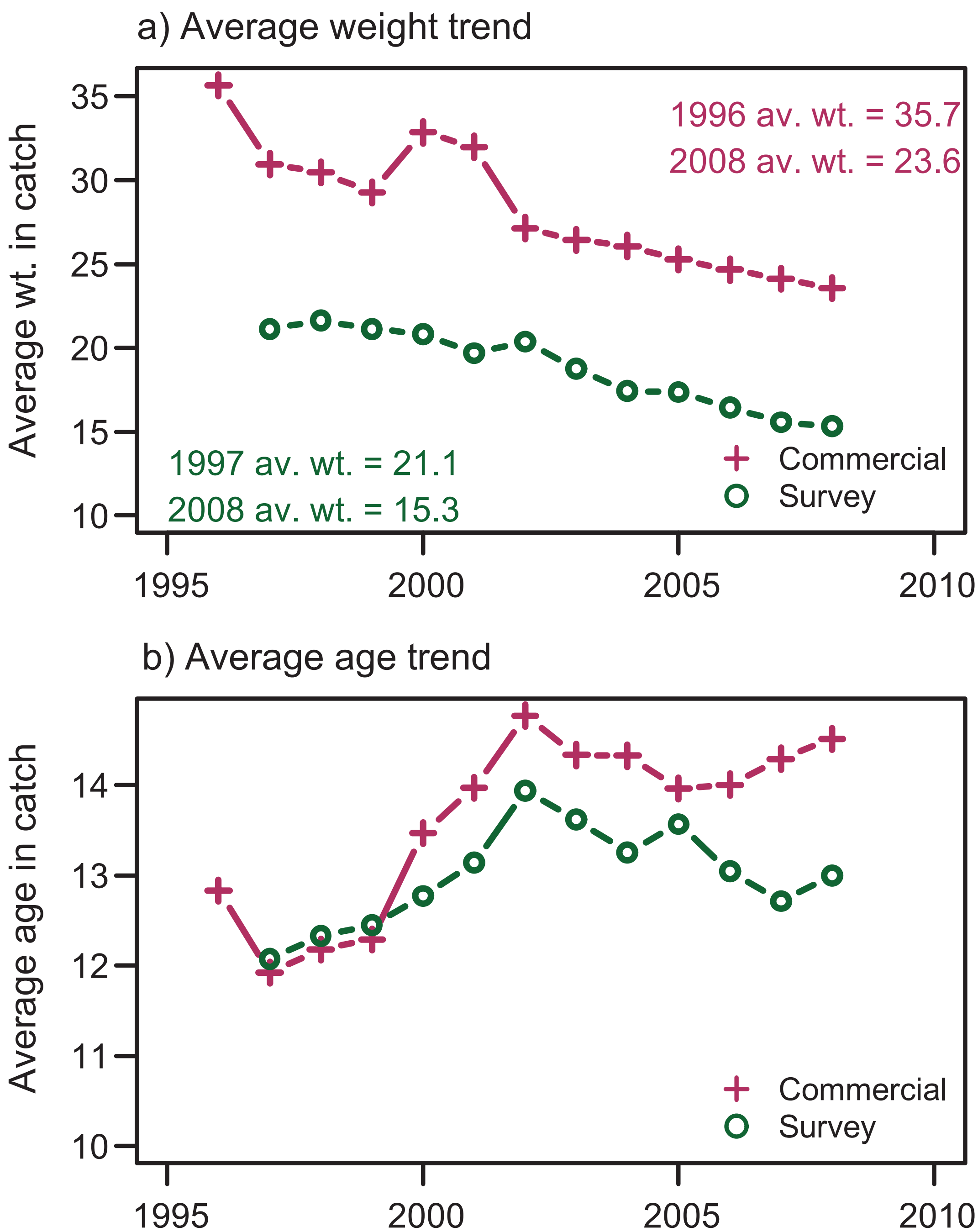


Figure 10. Average weight (panel a) and average weight (panel b) trends for the coastwide halibut stock for 1996 to 2008.

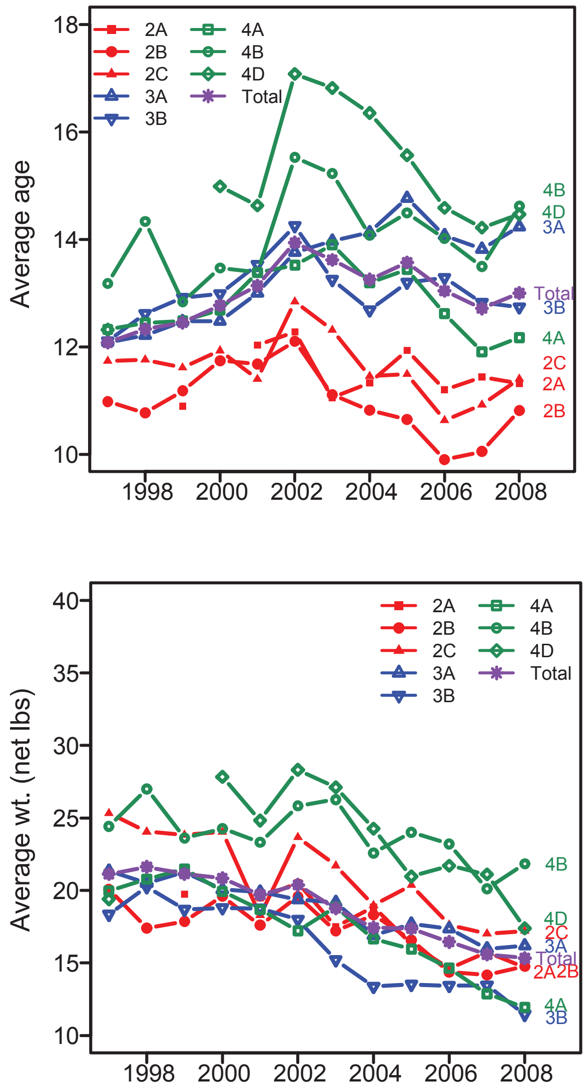


Figure 11. Trends in average age (top panels) and average weight (bottom panels) in survey catches (left panels) and commercial catches (right panels).

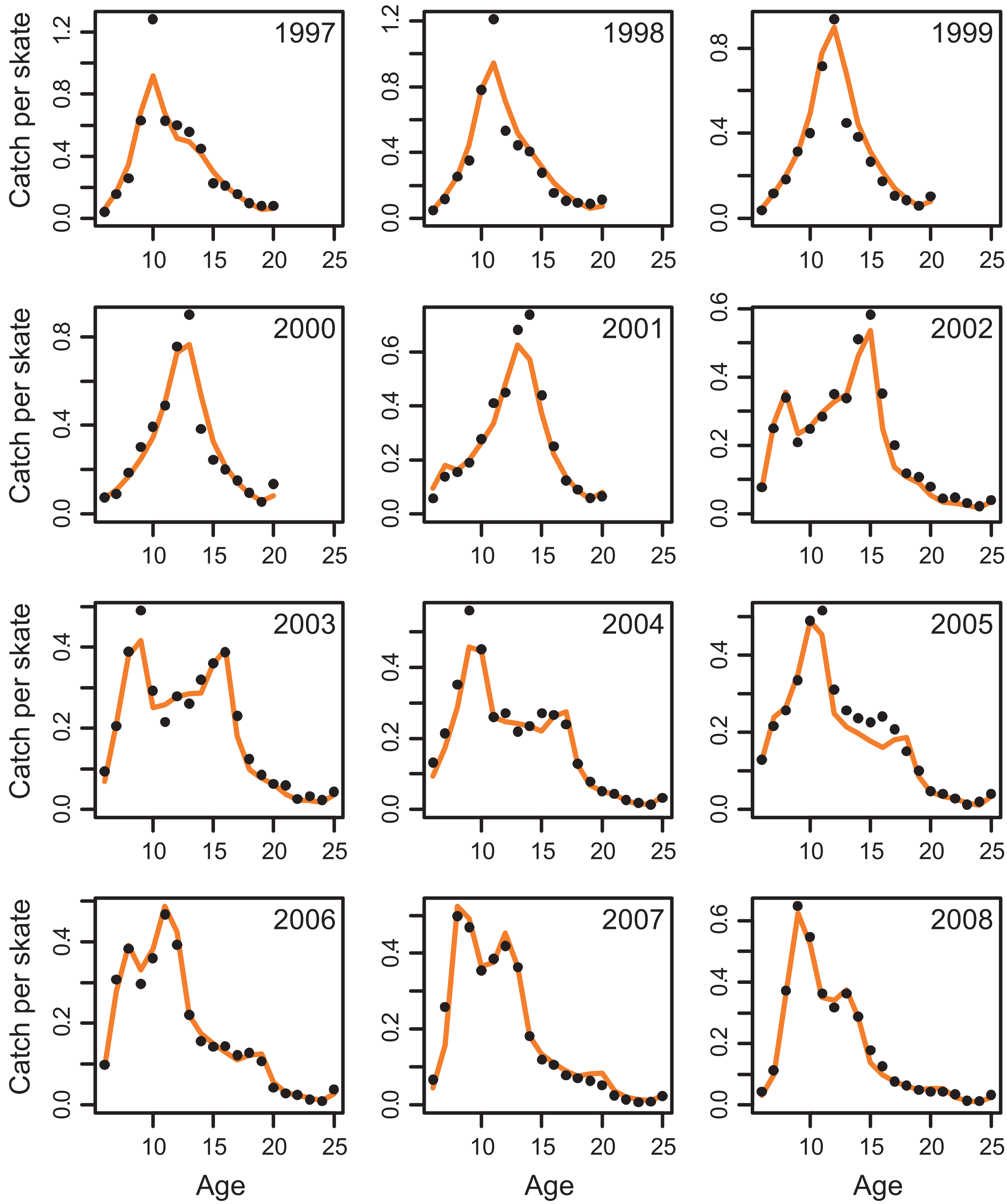


Figure 12a. Observed (points) and predicted (lines) survey CPUE at age of females in the 2008 coastwide model fit.

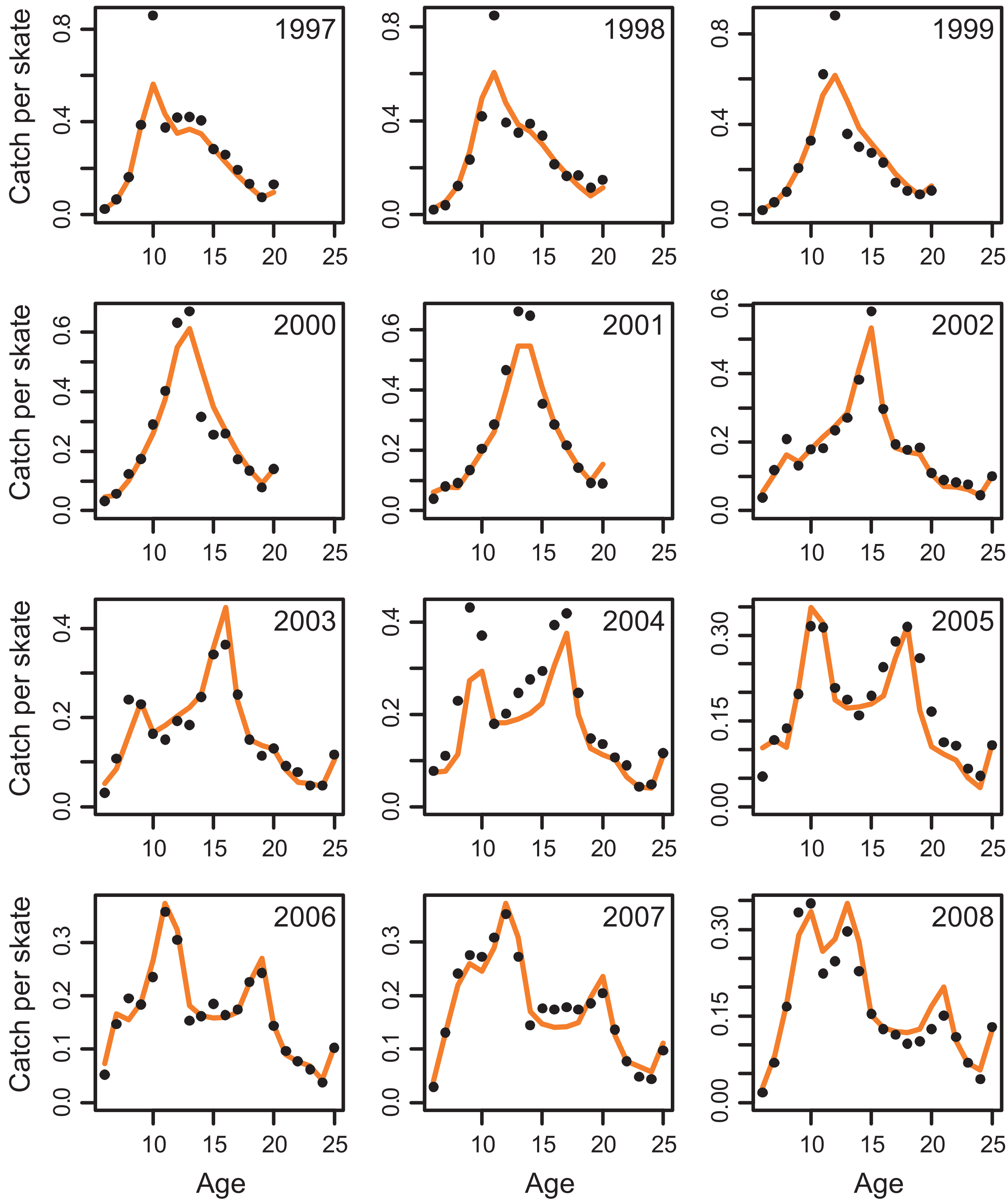


Figure 12b. Observed (points) and predicted (lines) survey CPUE at age of males in the 2008 coastwide model fit.

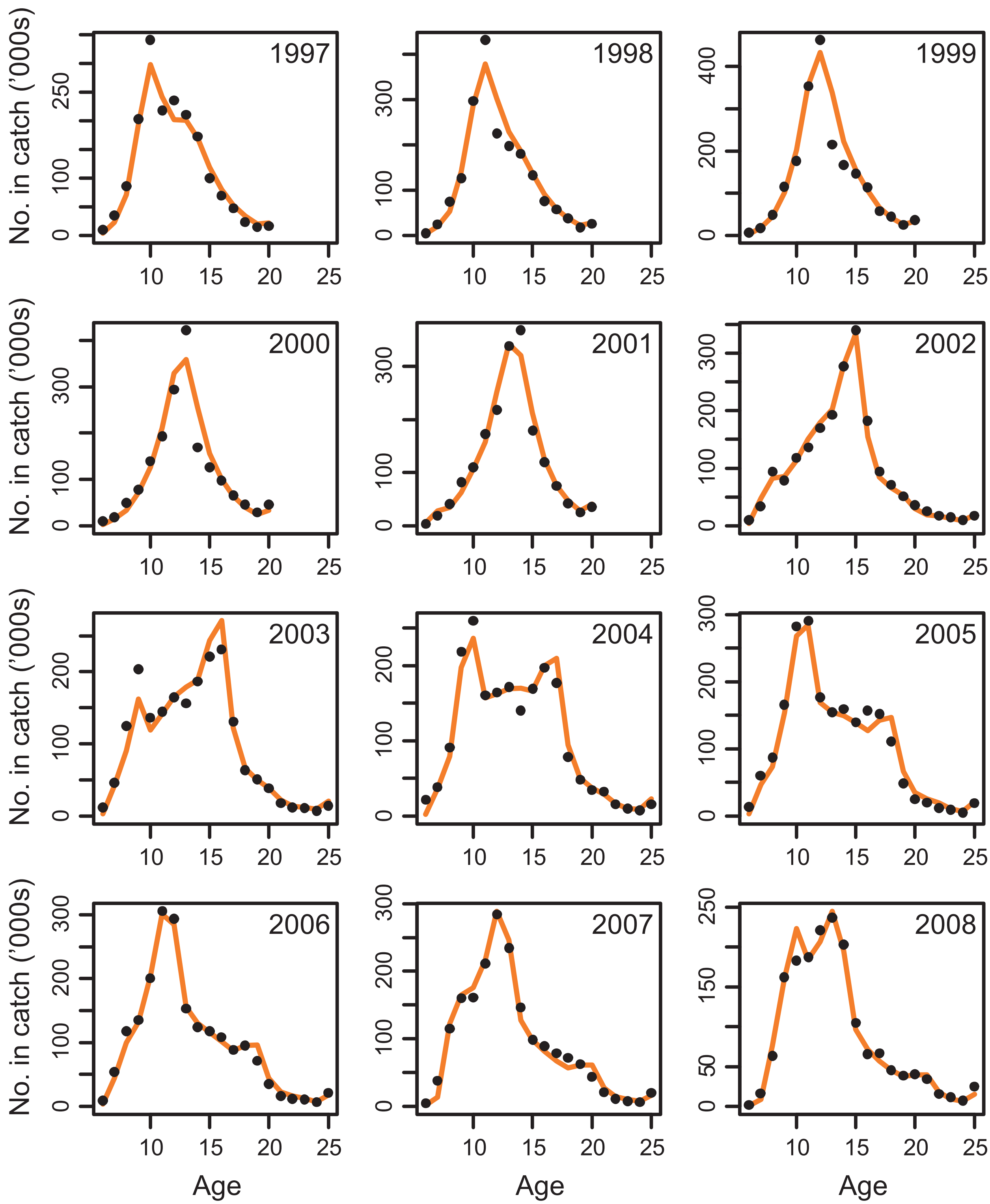


Figure 13a. Observed (points) and predicted (lines) commercial catch at age of females in the 2008 coastwide model fit.

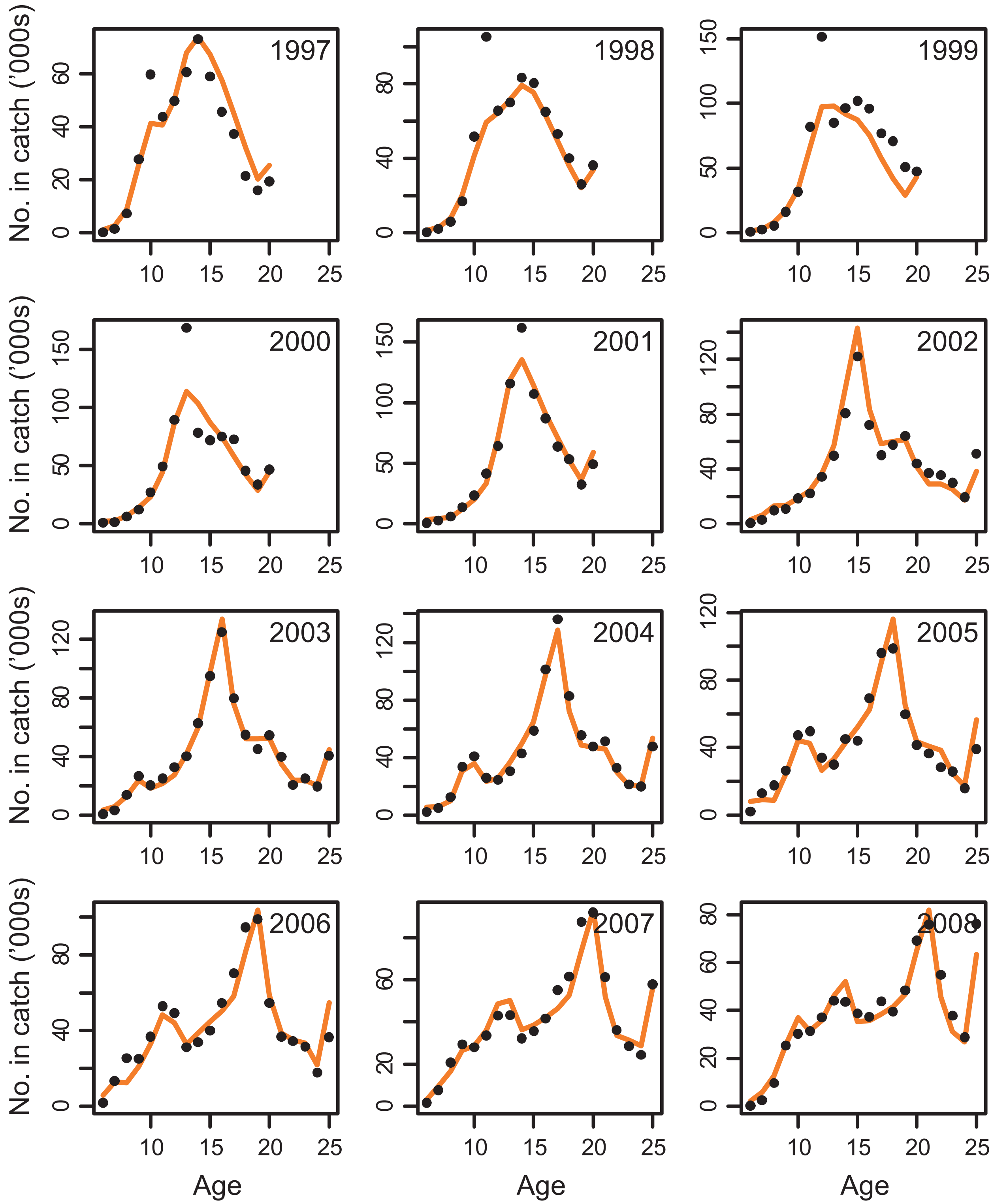


Figure 13b. Observed (points) and predicted (lines) commercial catch at age of males in the 2008 coastwide model fit.

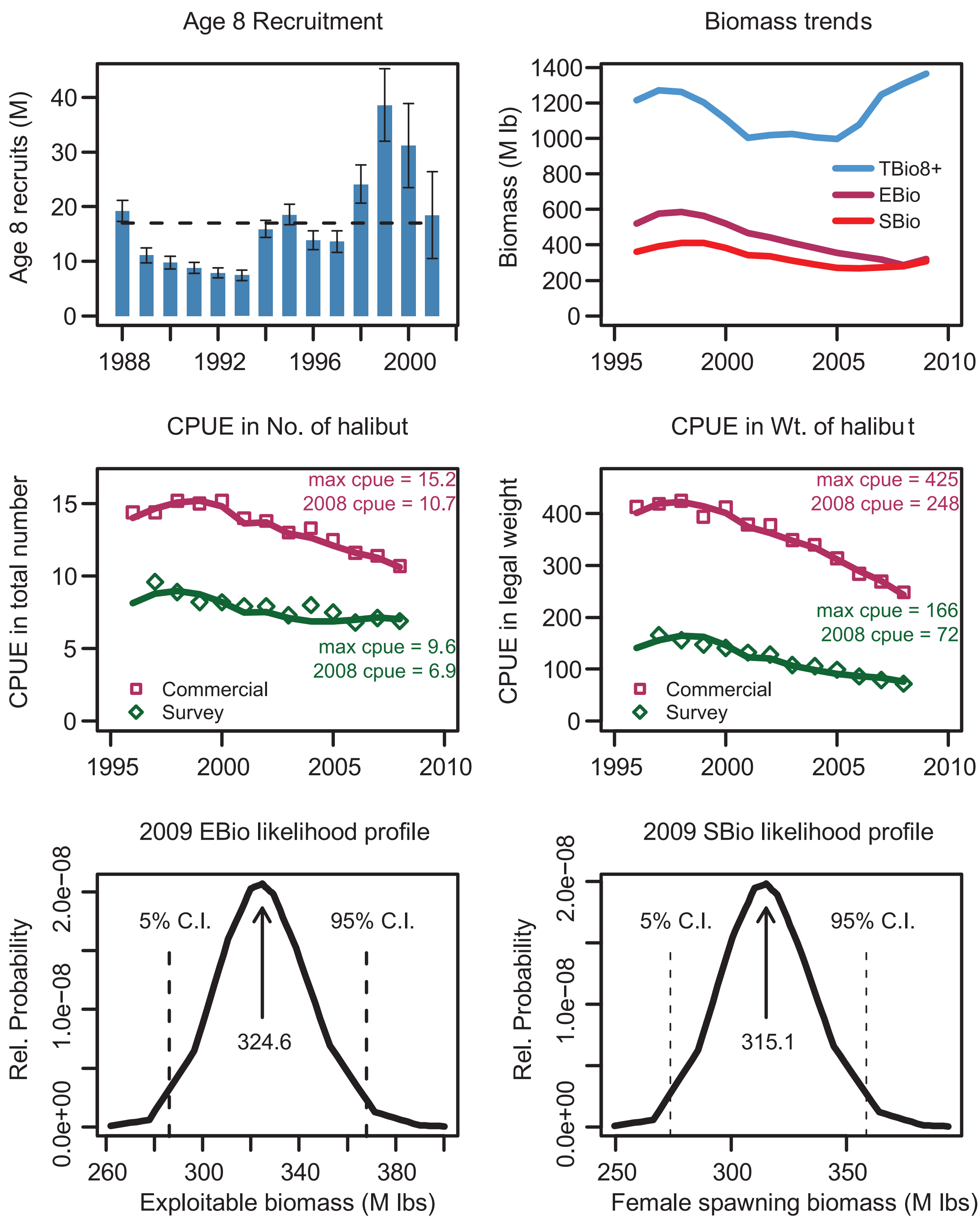
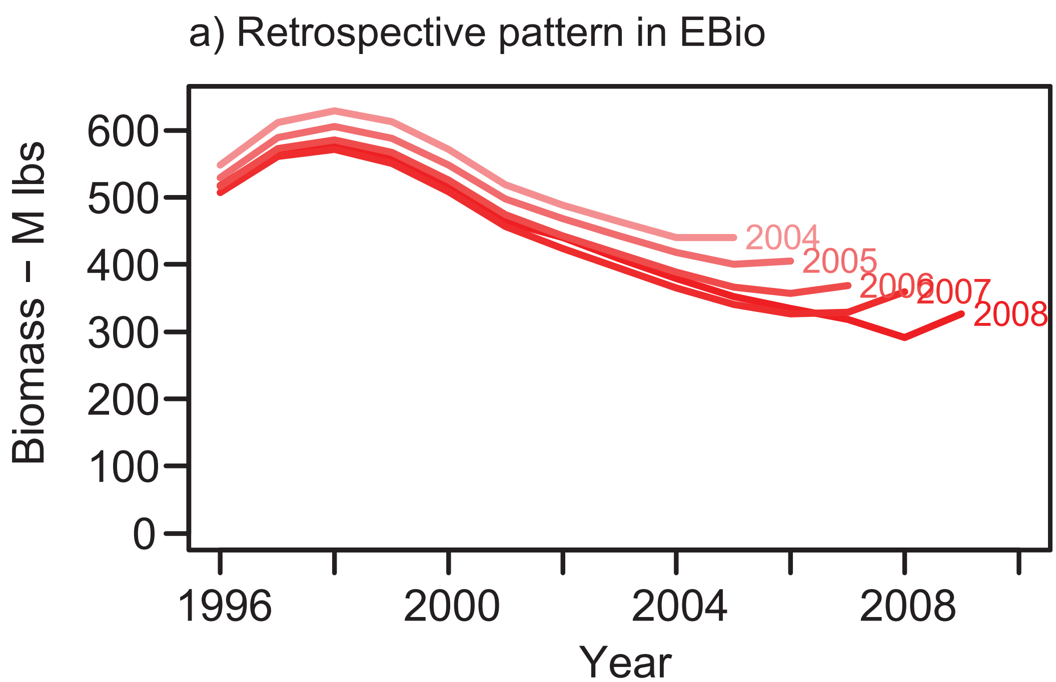


Figure 14. Features of the 2008 halibut coastwide assessment.



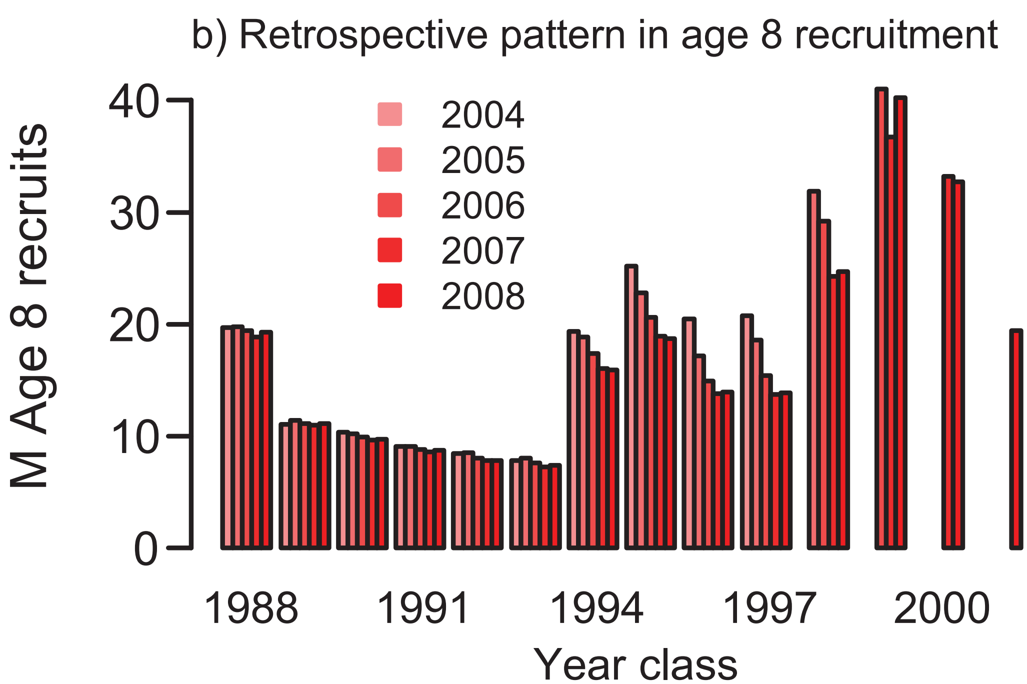


Figure 15. Retrospective behavior of 2008 halibut assessment model. The top panel illustrates the effect on estimates of EBio by sequentially removing years of data. The bottom panel illustrates the efect on estimation of age eight recruitment. Note that the most recent year class (2001) is only estimated in the 2008 assessment, the 2000 year class in the 2007 and 2008 assessments, and so on.

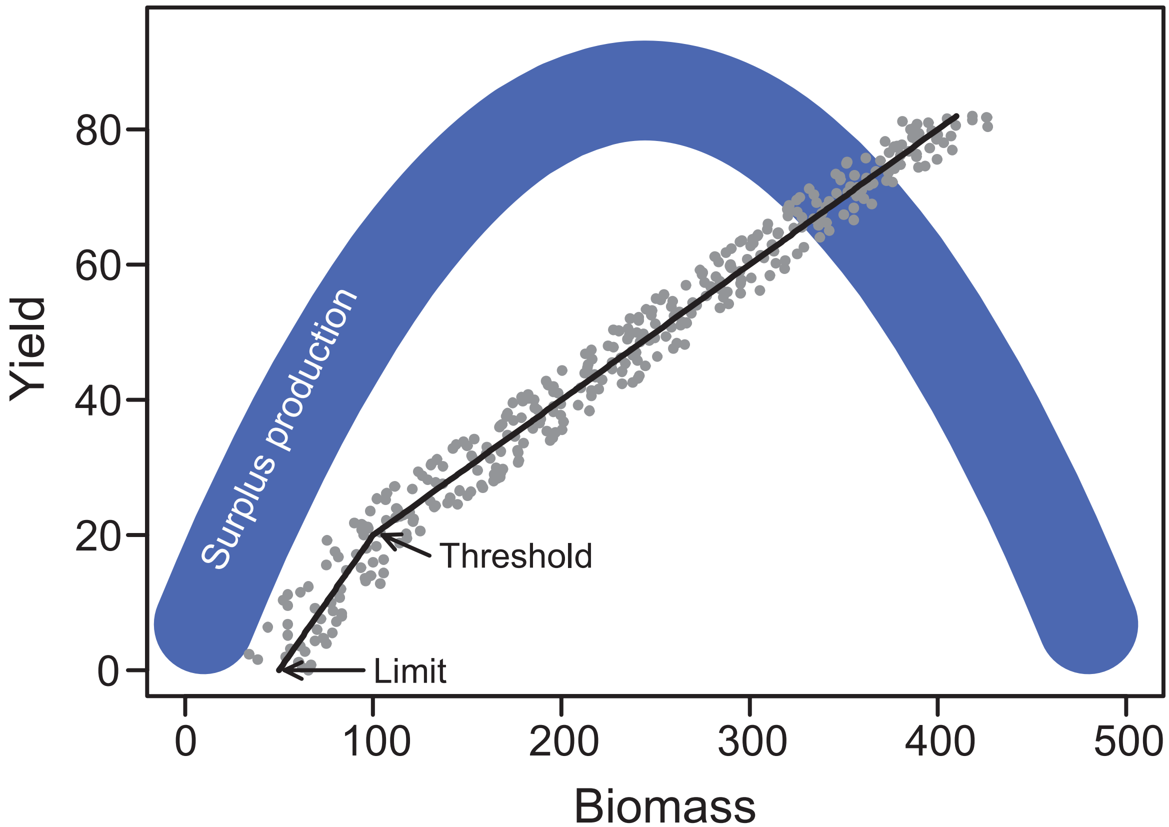
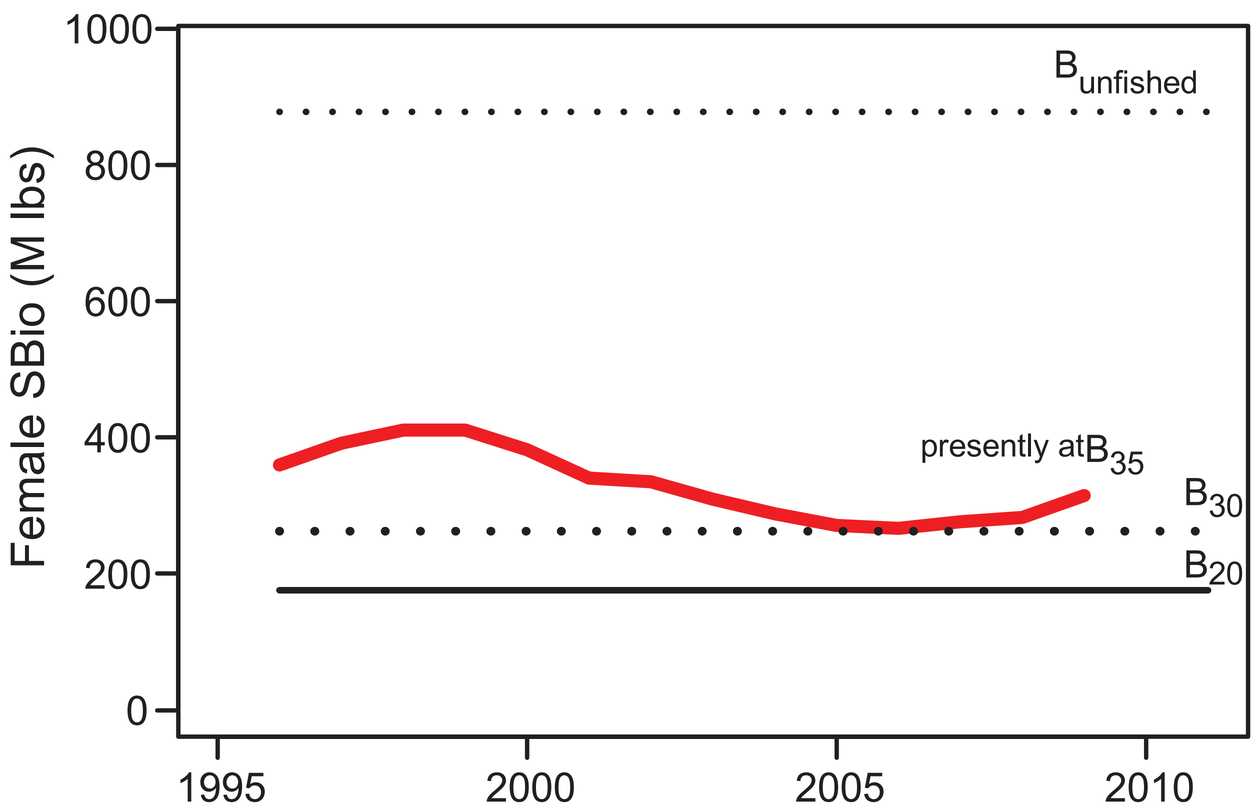


Figure 16. Representation of the IPHC harvest policy. The background curve illustrates theoretical relationship between biomass and surplus production, taken as yield. The slope of the straight line is a 20% harvest rate (Yield/Exploitable biomass), and the harvest rate deceases linearly to zero as the biomass approaches established reference points, termed the female spawning biomass threshold and limit. The scatter about the harvest rate indicates the effect of the "Slow Up Fast Down" adjustment to catch limits in terms of realized harvest rate.



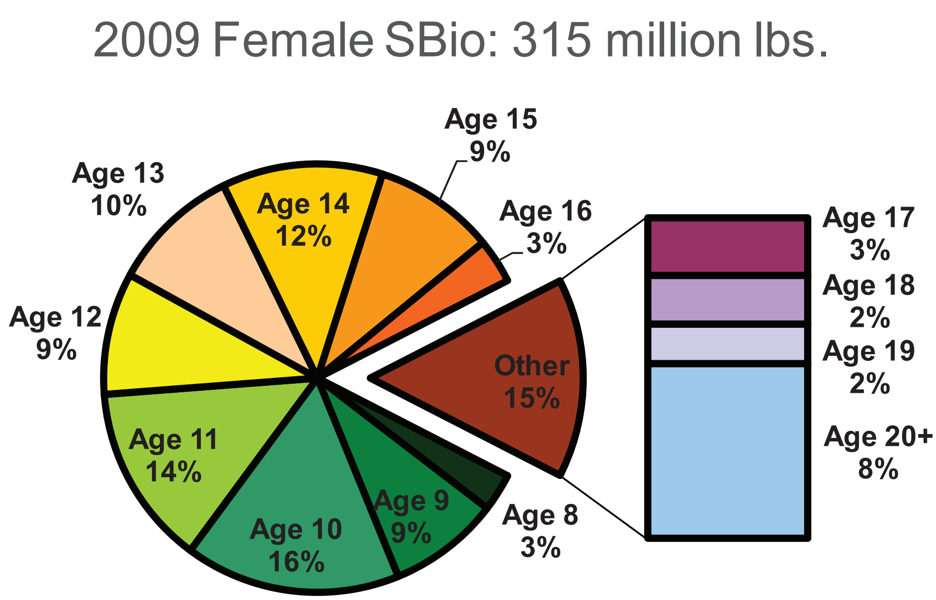


Figure 17. Status (top panel) and current age composition (bottom panel) of female spawning biomass. See text for details.

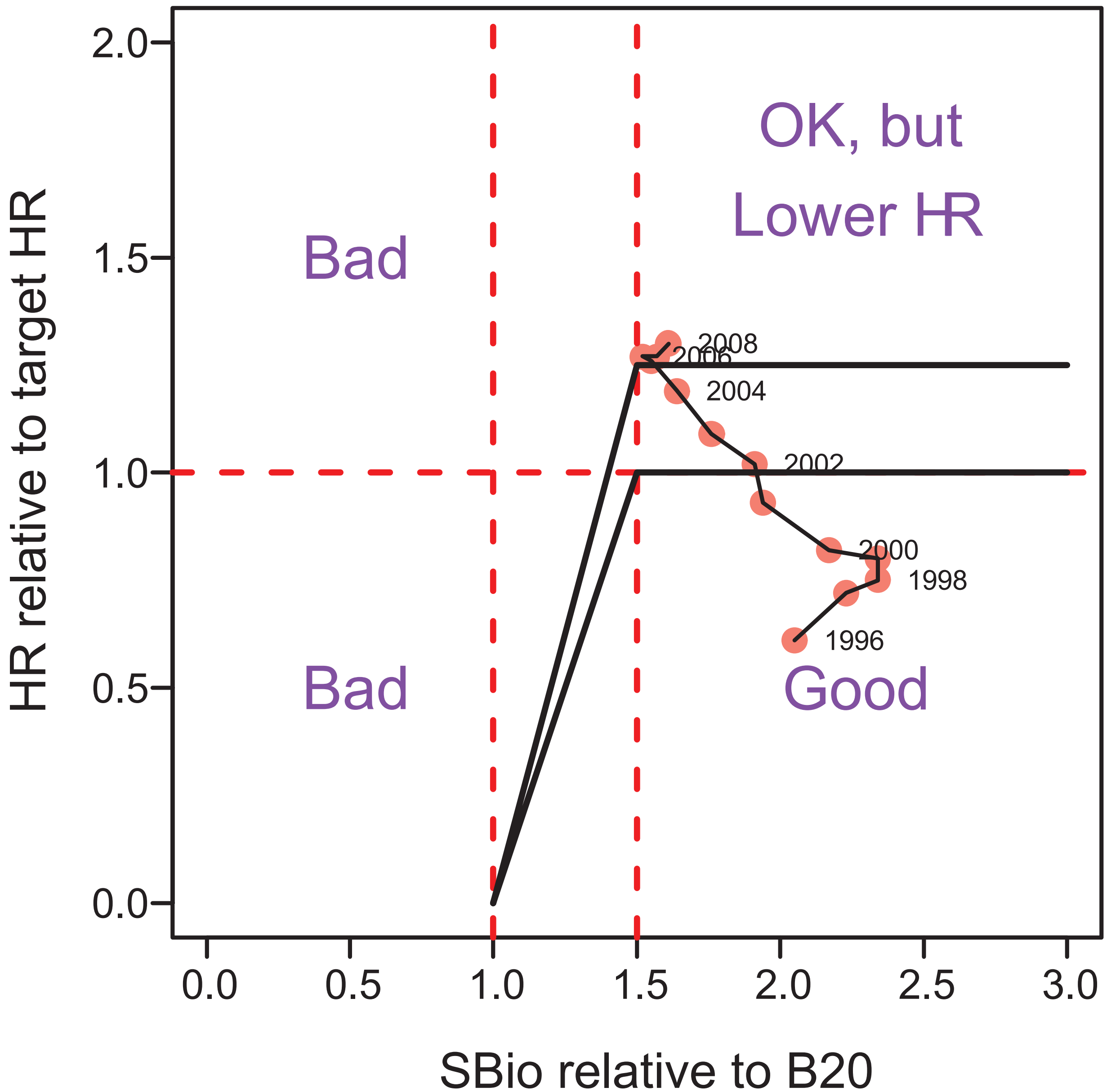


Figure 18. Trend and status of halibut management relative to reference points. Horizontal axis indicates female spawning biomass (SBio) relative to B_{20} (value of 1.0) and B_{30} (value of 1.5). Vertical axis illustrates realized harvest rate relative to a target harvest rate of 0.20 (value of 1.0) and the previous target harvest rate of 0.25 (value of 1.25).

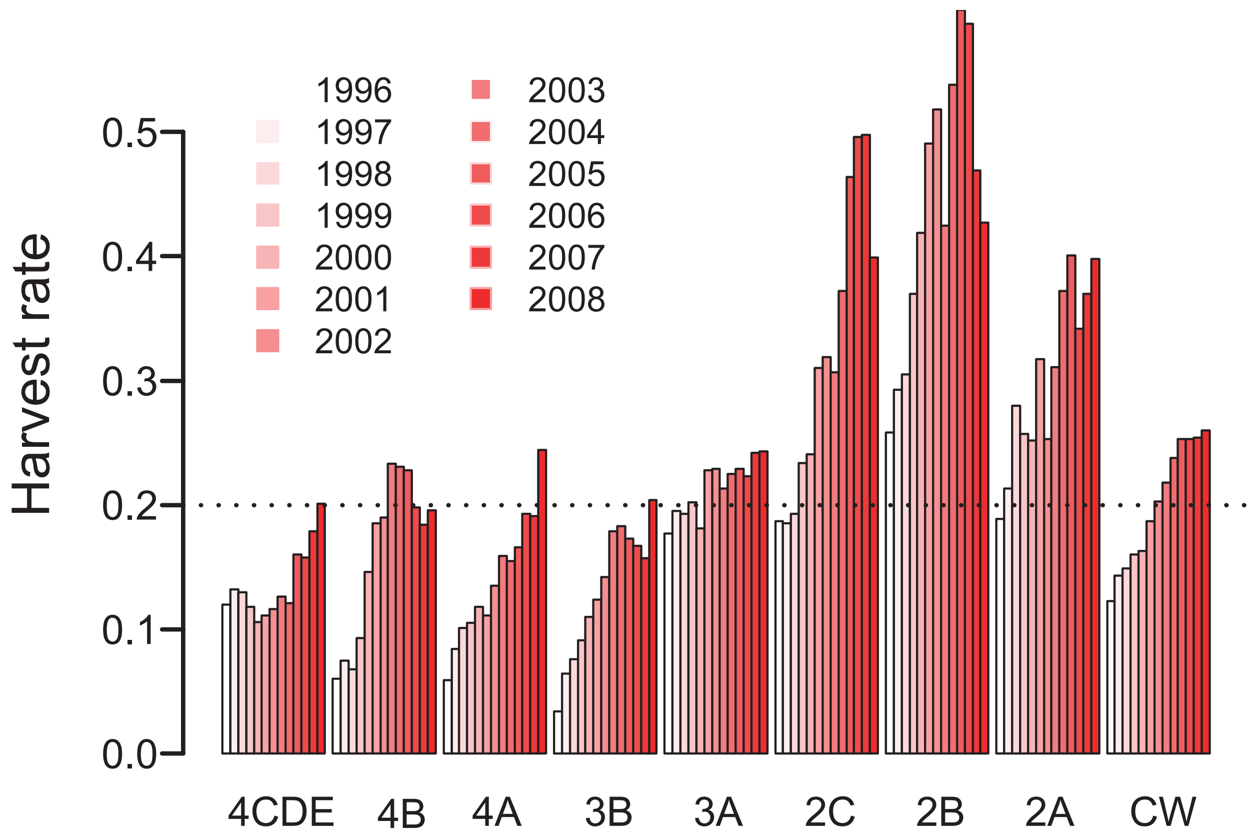


Figure 19. Summary of realized harvest rates from the coastwide assessment, using survey CPUE weighted by hook competition to partition biomass among areas.

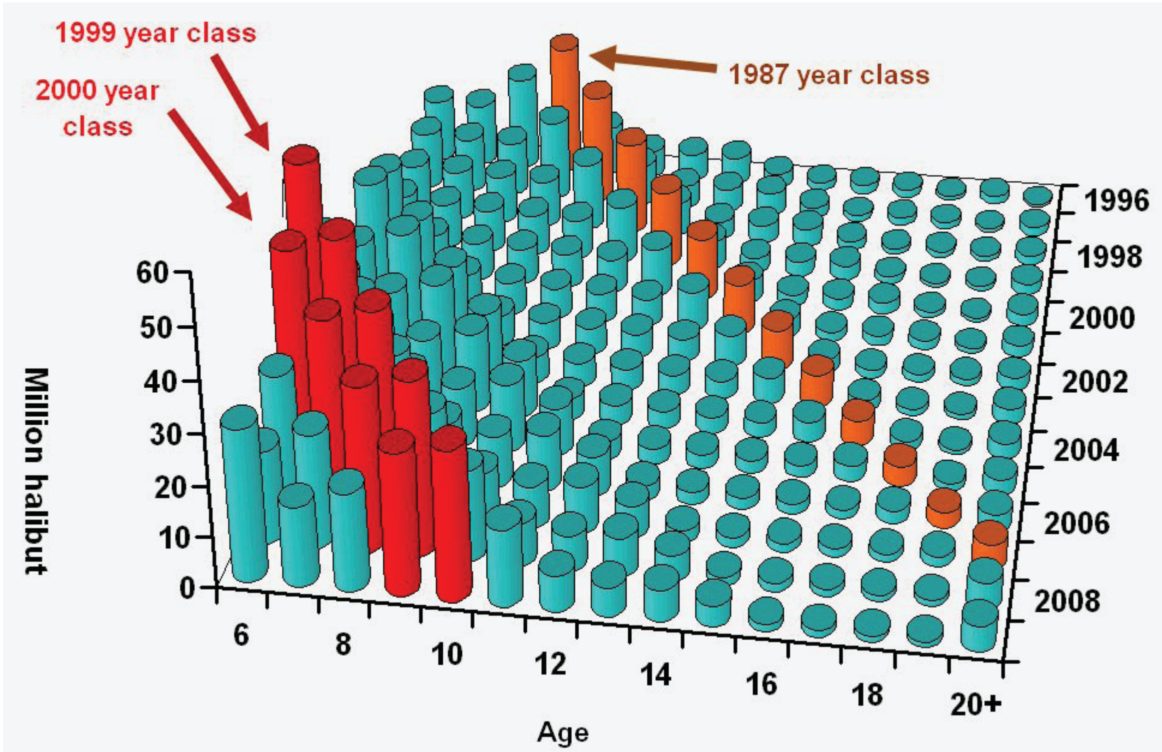


Figure 20. Coast population estimates of halibut. Several large year classes are highlighted.

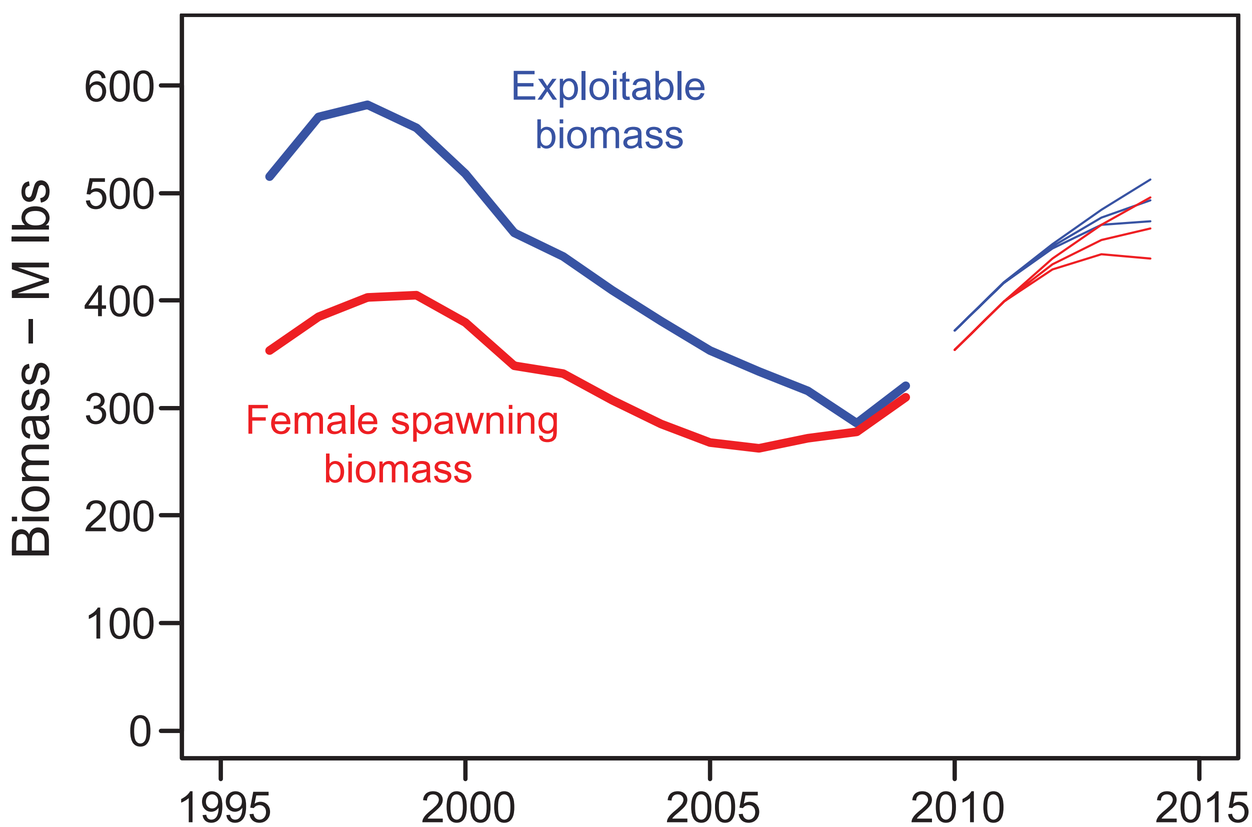


Figure 21. Projected exploitable and spawning biomasses for the coastwide population of halibut.

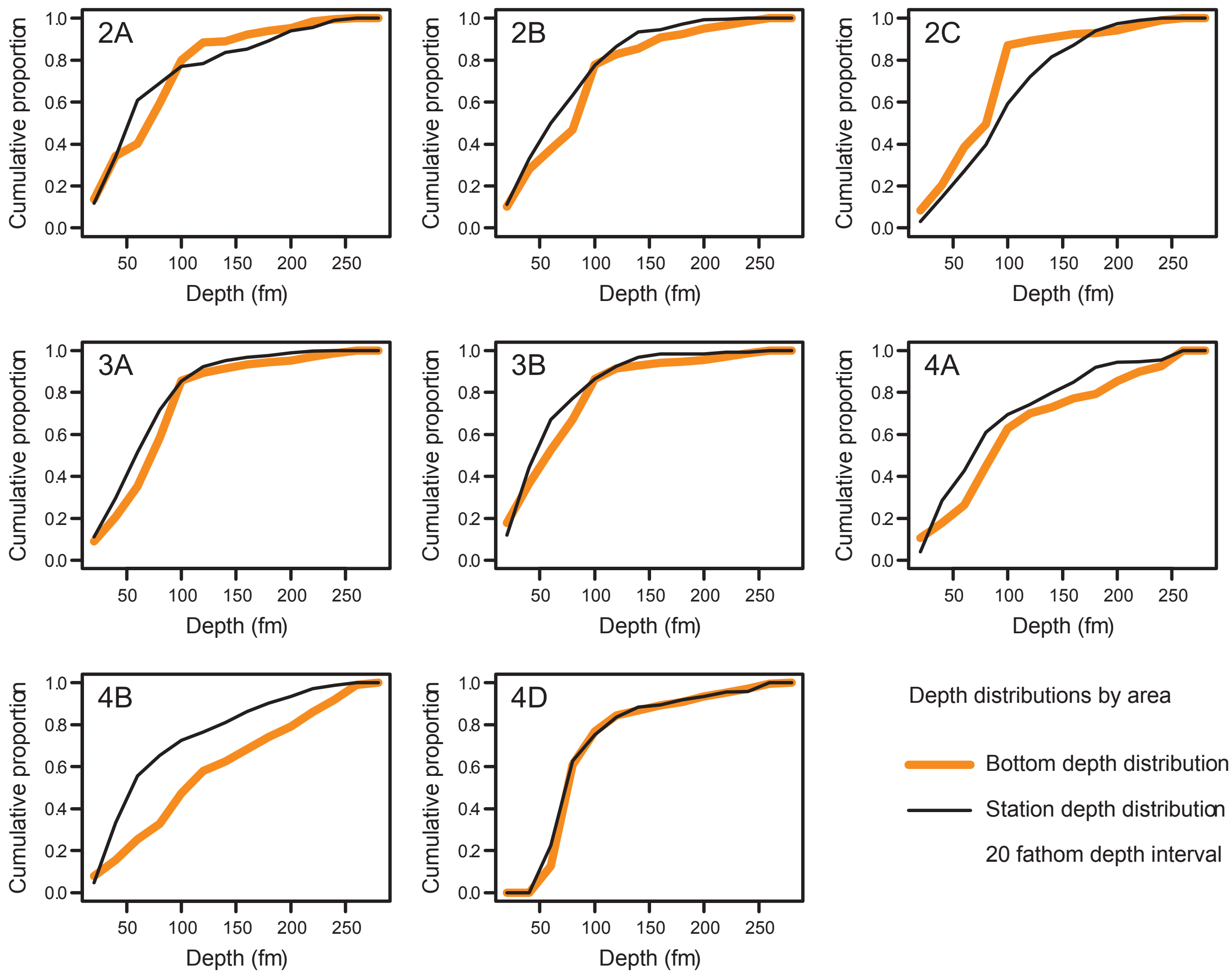


Figure 22. Cumulative distribution of bottom depth and survey station depth by regulatory area.

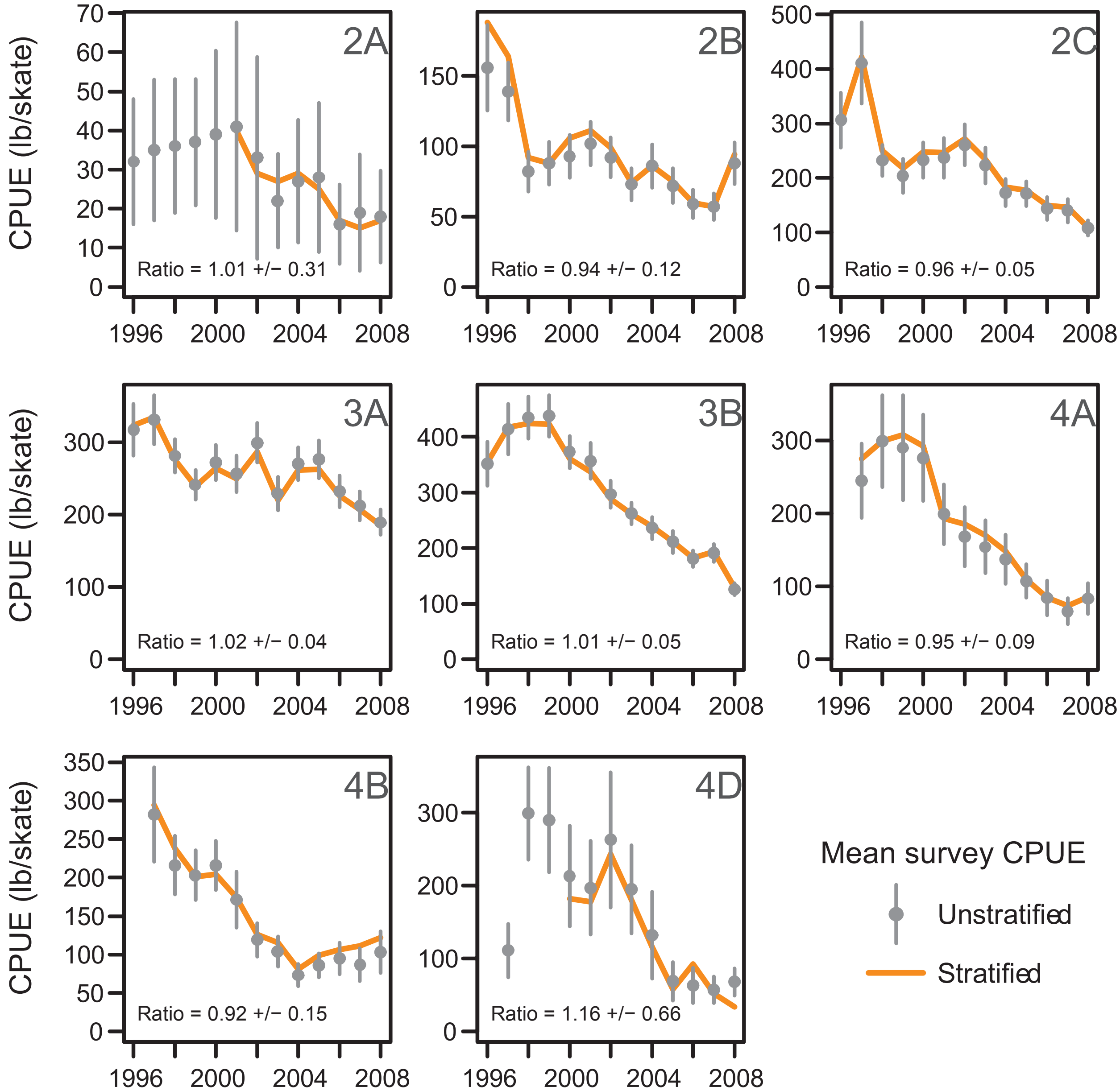


Figure 23. Survey CPUE plotted as simple mean (unstratified, gray dots) and depth-stratified CPUE (yellow line). The errors bars are +/- two standard errors of the mean for the unstratified mean

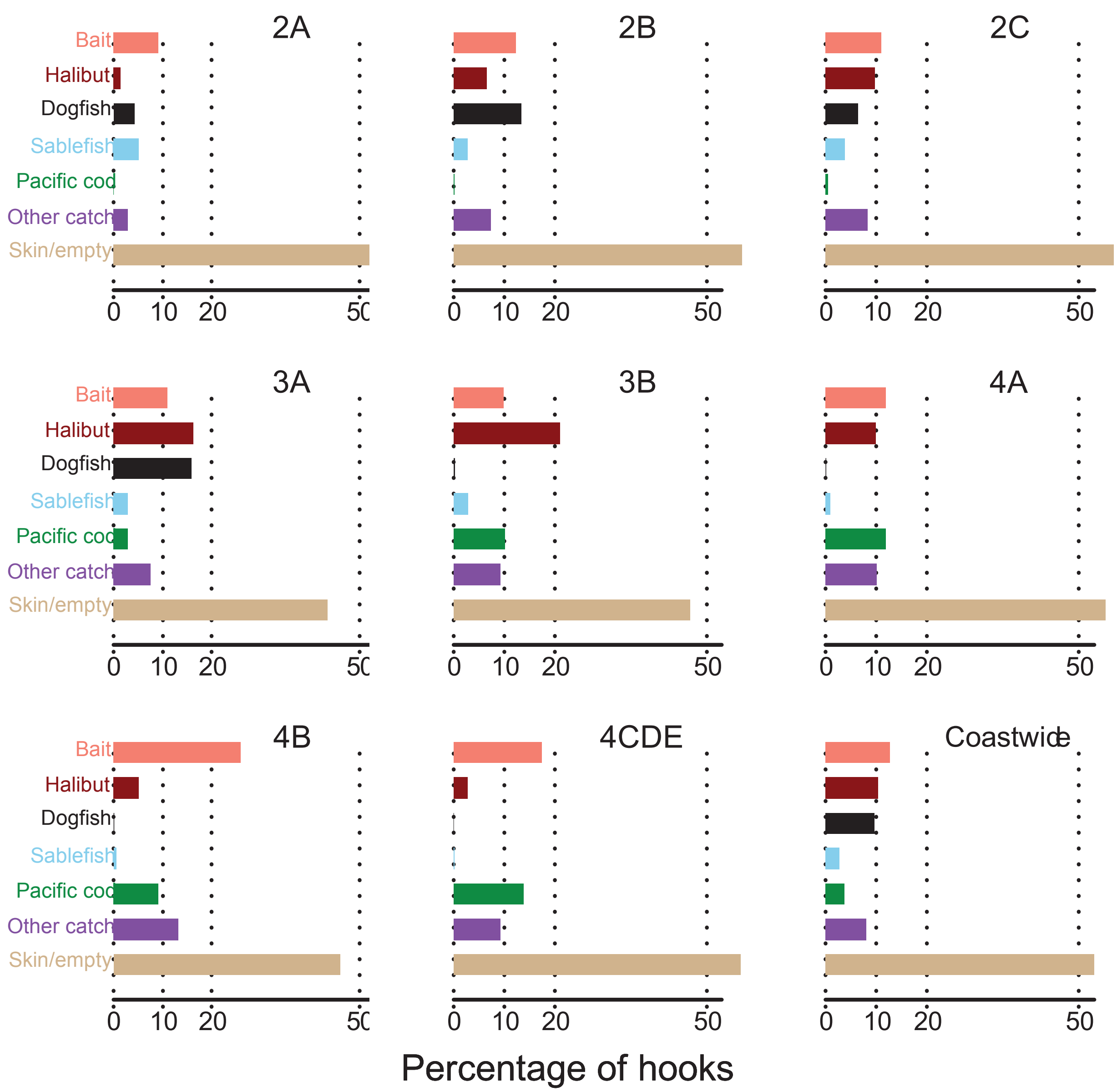


Figure 24. Hook occupancy by regulatory area, 2006-2008 data combined.

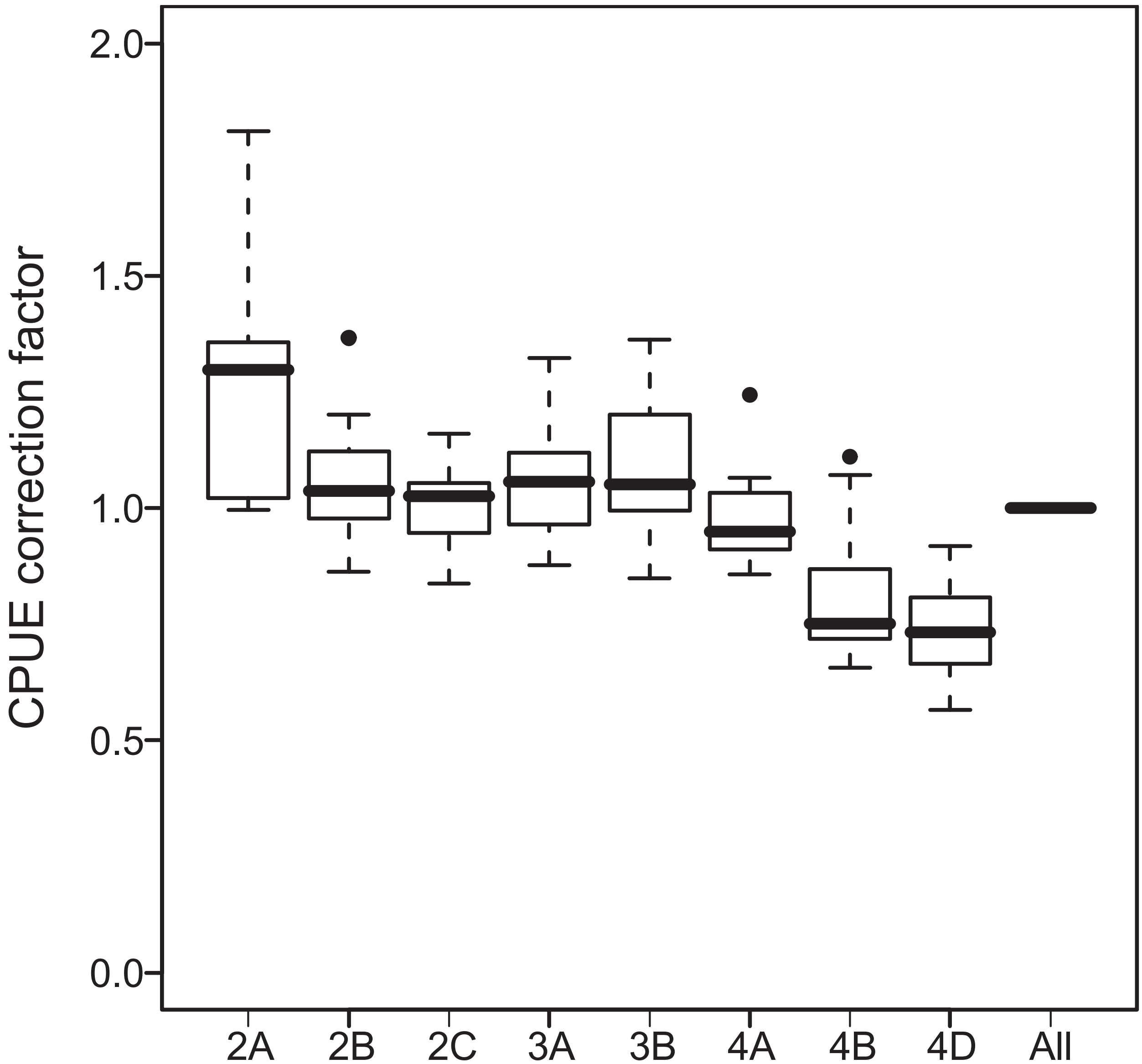


Figure 25. Boxplot of hook competition correction factors for the period 1996-2008. Correction factors were computed for each year of survey data for a maximum of 13 values for any regulatory area.

Area 2A summary

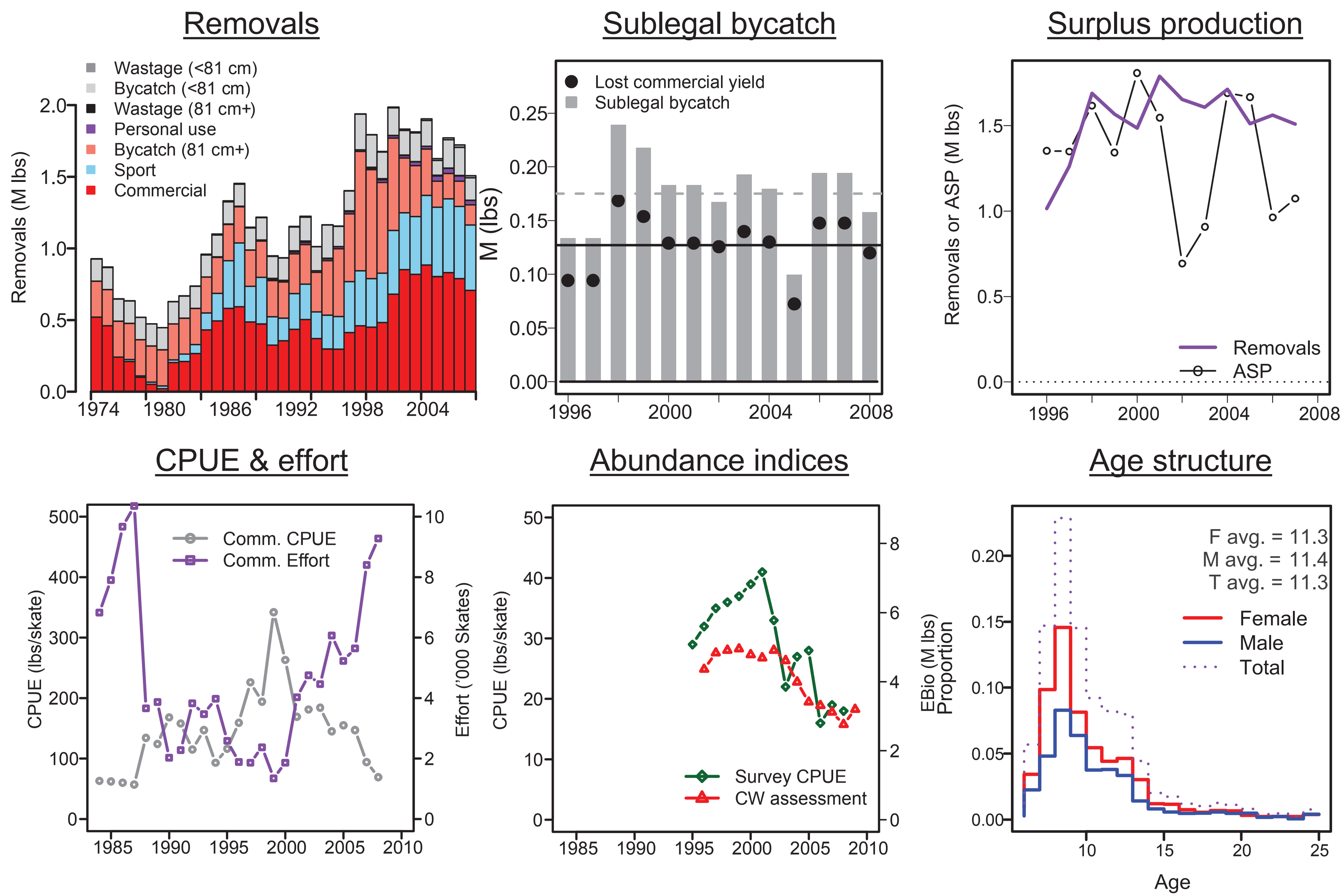


Figure 26. Summary of removals, production, effort, abundance indices and age structure for Area 2A.

Area 2B summary

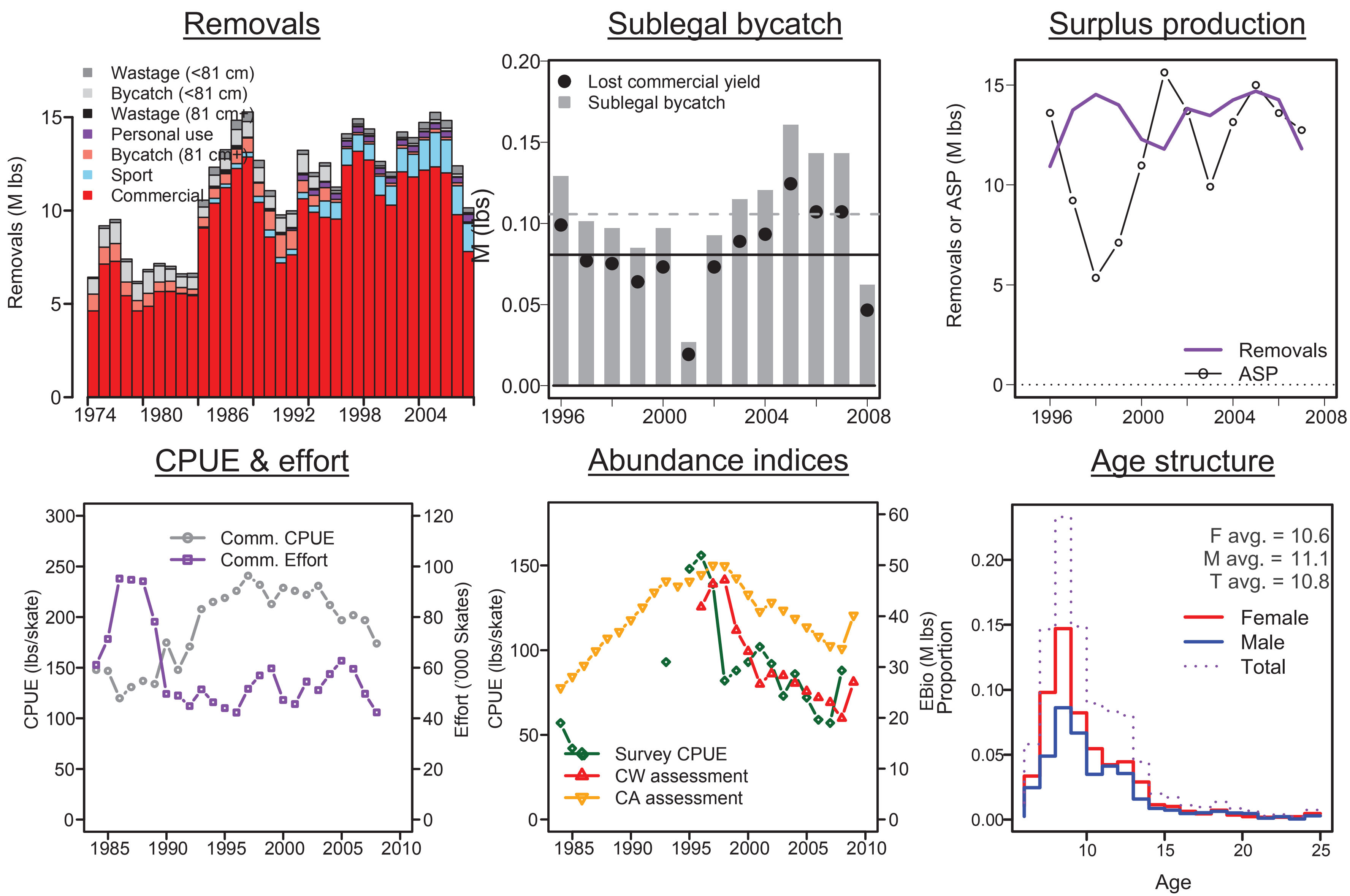


Figure 27. Summary of removals, production, effort, abundance indices and age structure for Area 2B.

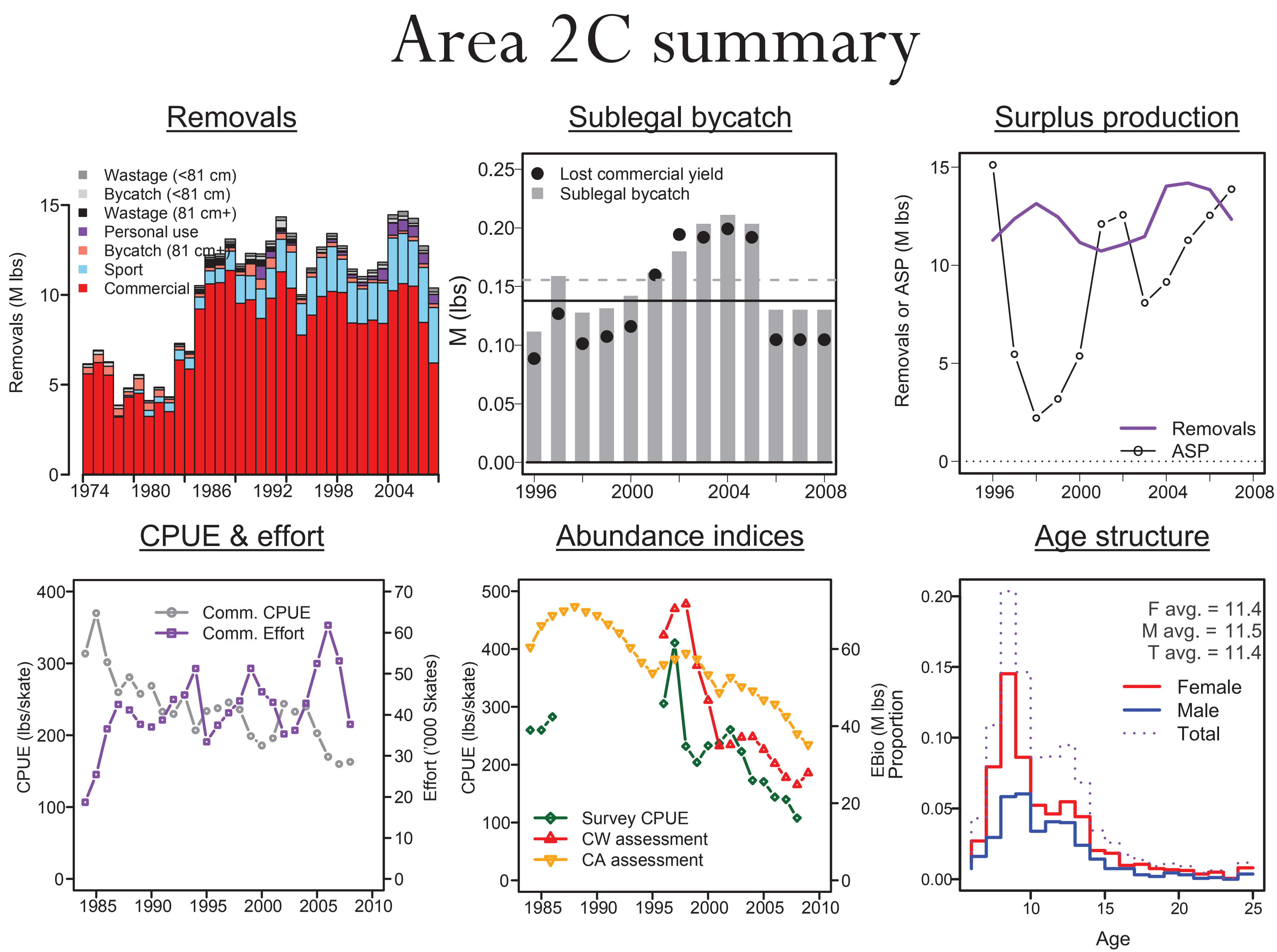


Figure 28. Summary of removals, production, effort, abundance indices and age structure for Area 2C.

Area 3A summary

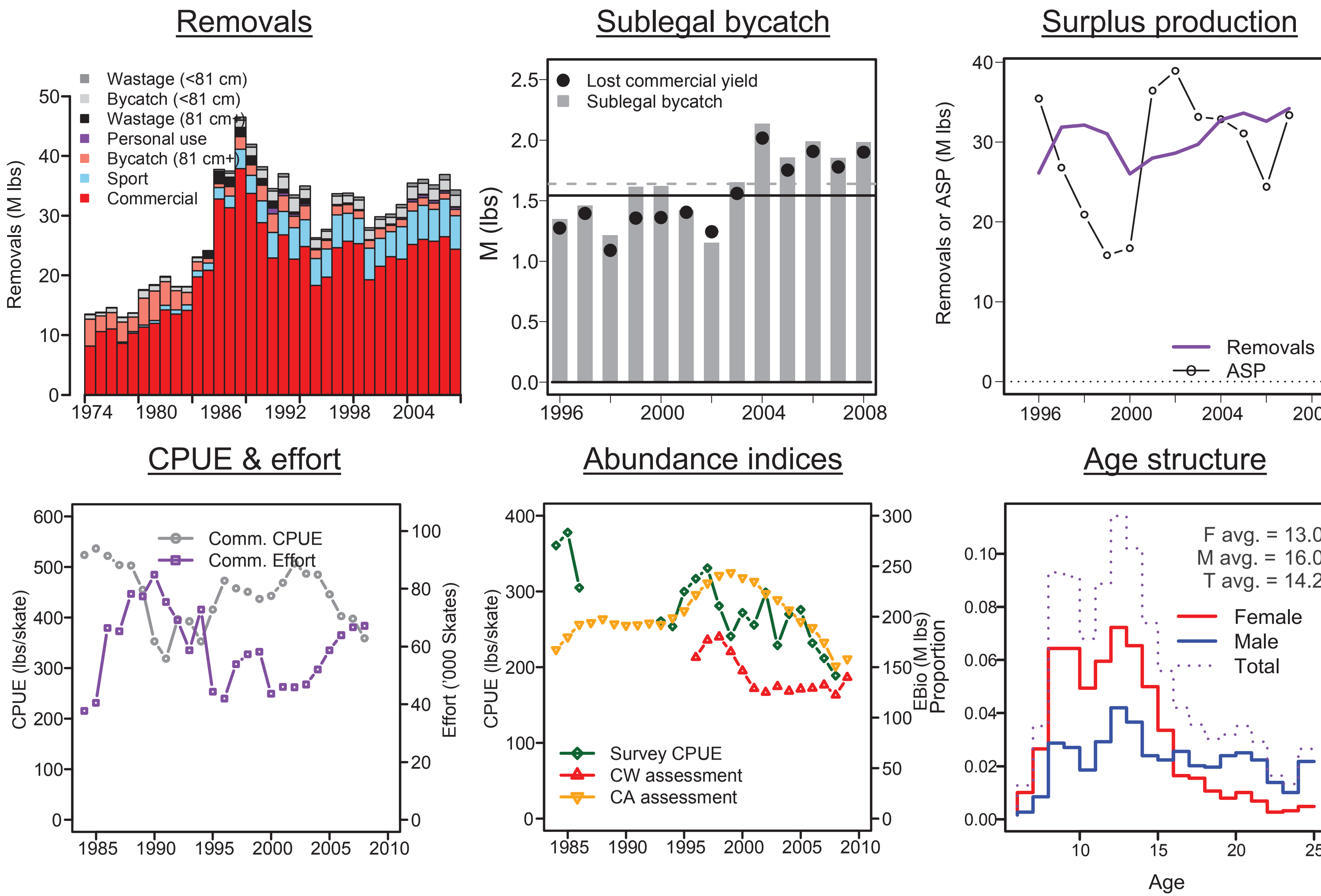


Figure 29. Summary of removals, production, effort, abundance indices and age structure for Area 3A.

Area 3B summary

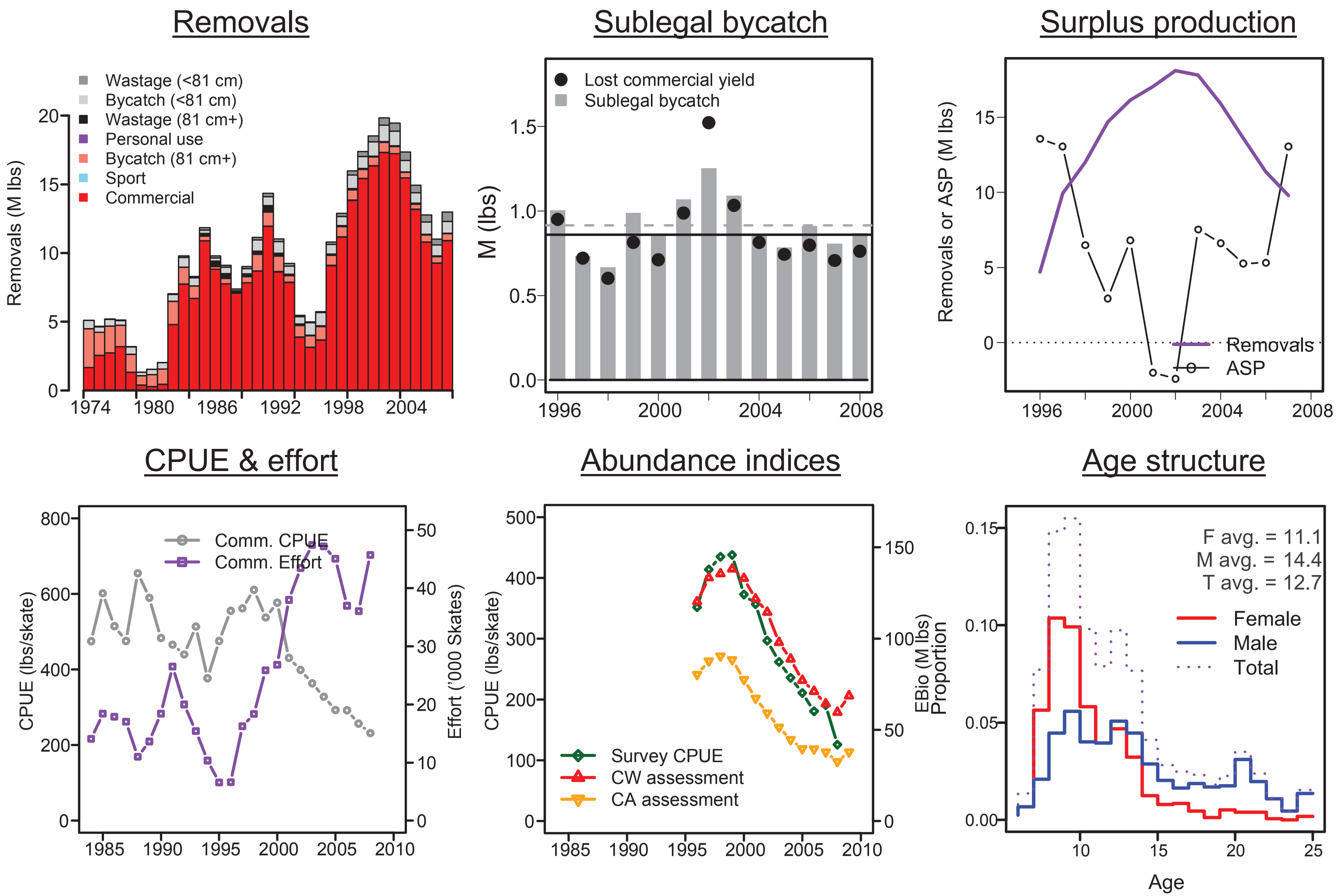


Figure 30. Summary of removals, production, effort, abundance indices and age structure for Area 3B.

Area 4A summary

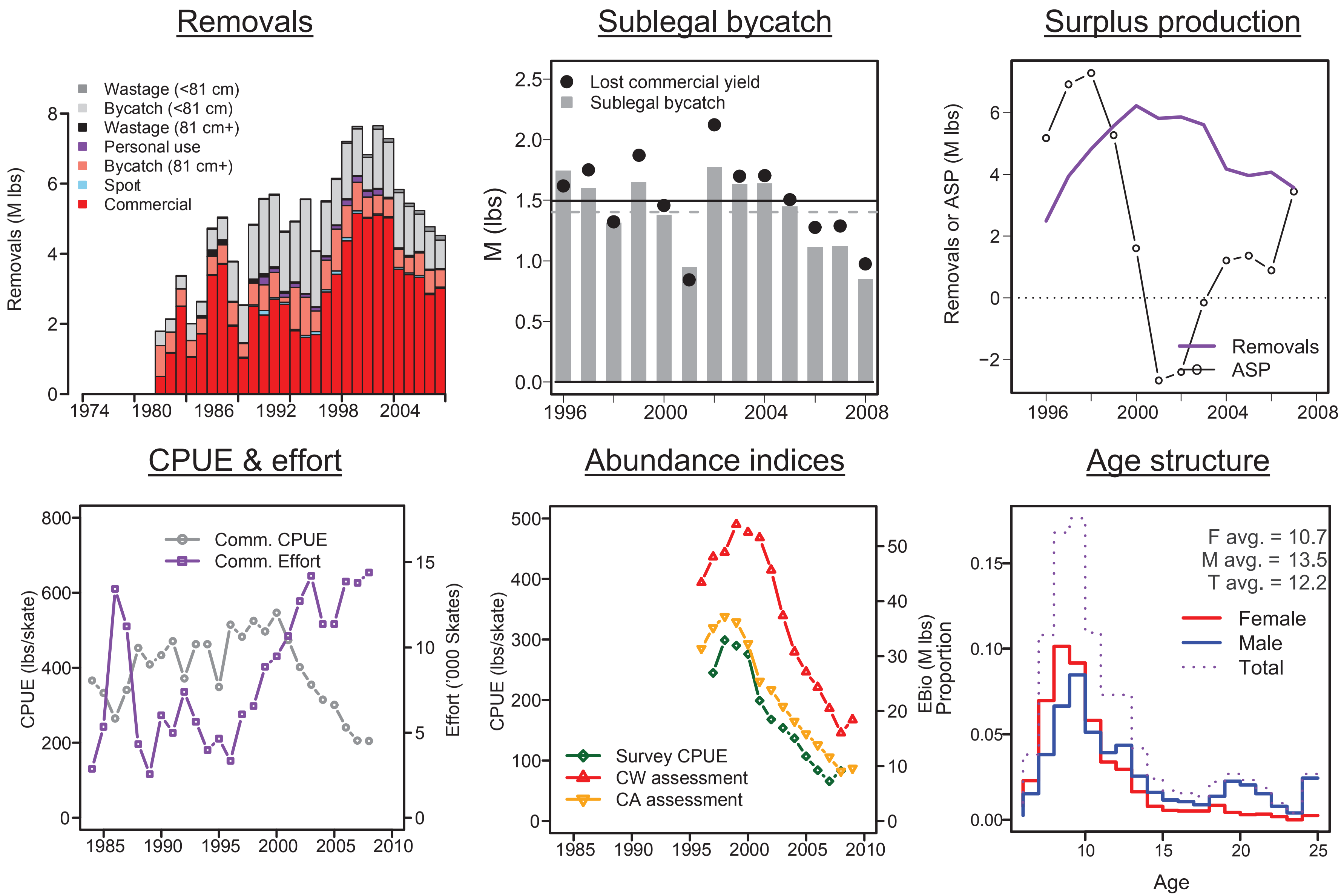


Figure 31. Summary of removals, production, effort, abundance indices and age structure for Area 4A

Area 4B summary

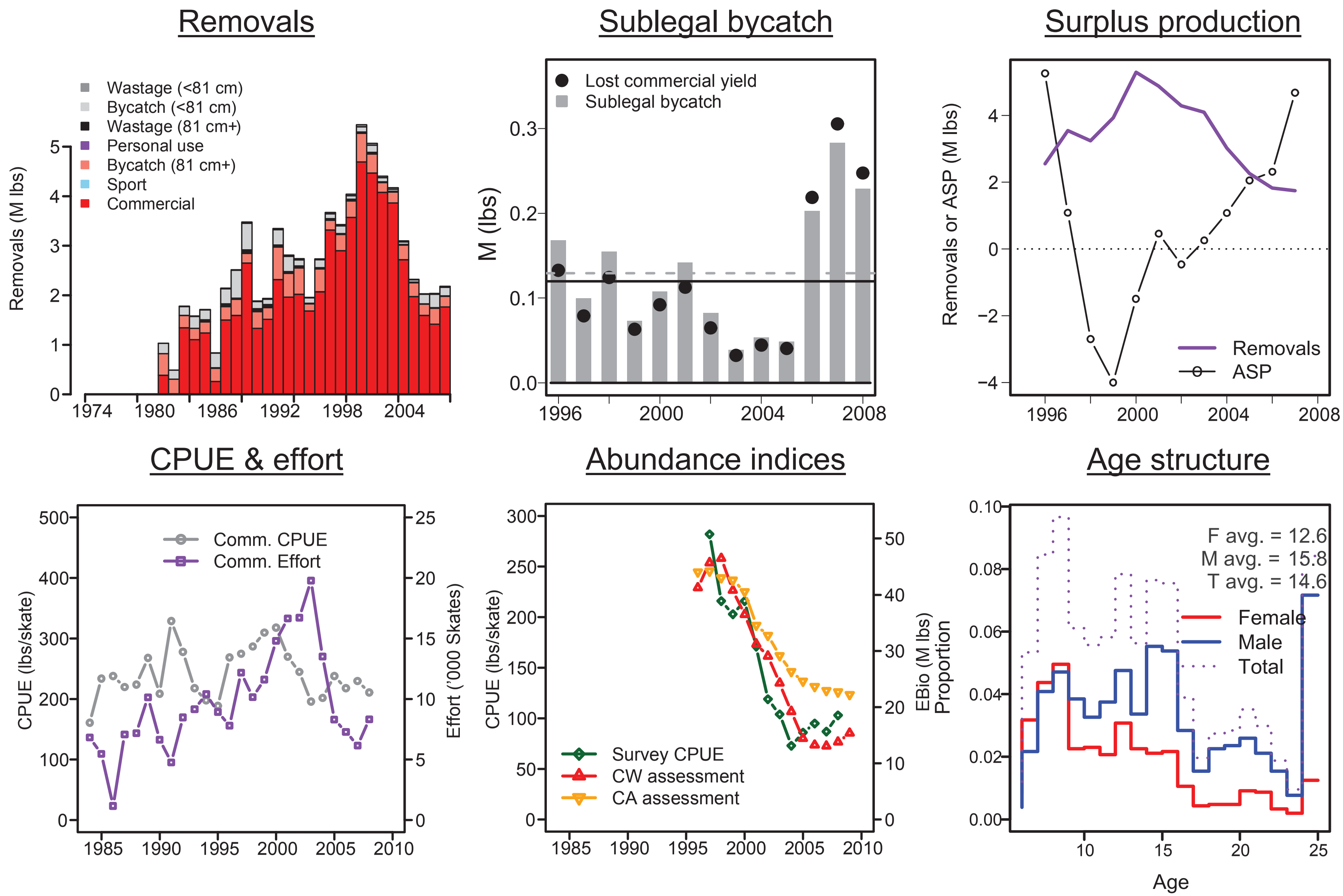


Figure 32. Summary of removals, production, effort, abundance indices and age structure for Area 4B.

Area 4CDE summary

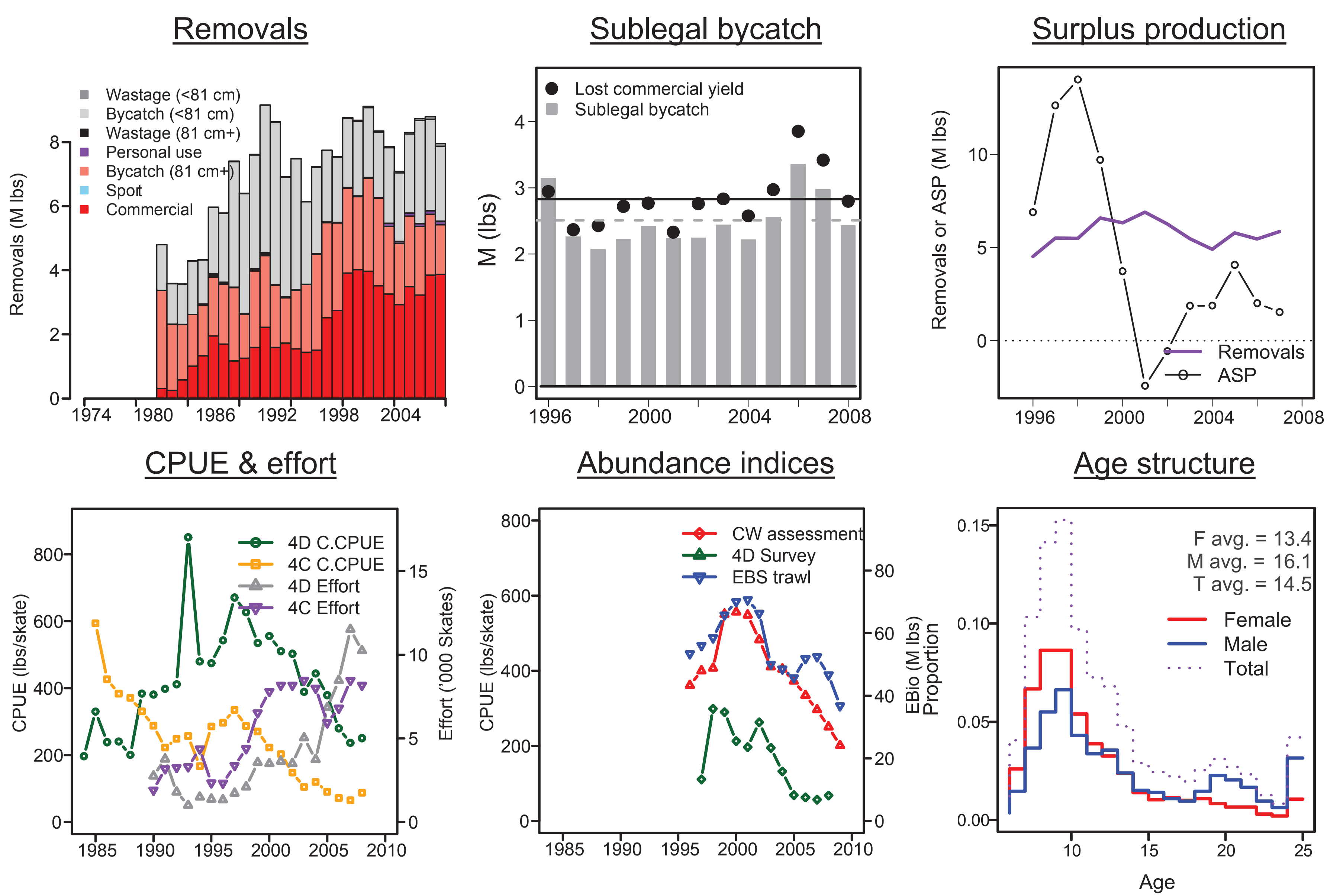


Figure 33. Summary of removals, production, effort, abundance indices and age structure for Area 4CDE.

Appendix A. Selected fishery and survey data summaries.

Table A1. Total removals (million pounds, net weight). Removals include commercial catch, IPHC survey catches, sport catch, personal use catch, legal-size bycatch and legal-sized wastage. Removals do not include sublegal-sized bycatch or sublegal-sized wastage.

	2A	2B	2C	3A	3B	4	4A	4B	4CDE	Total
1974	0.77	5.52	5.97	12.67	4.49	2.60				32.02
1975	0.71	8.03	6.69	13.21	4.22	1.73				34.59
1976	0.49	8.22	6.03	13.78	4.67	1.90				35.10
1977	0.48	6.16	3.67	12.20	4.73	3.20				30.44
1978	0.36	5.17	4.62	13.02	2.63	4.75				30.54
1979	0.32	5.56	5.34	16.19	1.08	4.82				33.31
1980	0.29	6.17	3.99	17.39	1.15	6.42				35.41
1981	0.47	6.20	4.73	18.97	1.55		1.55	0.94	3.08	37.49
1982	0.51	5.87	4.19	17.44	6.48		1.89	0.38	2.12	38.88
1983	0.58	5.78	7.13	17.16	8.96		3.10	1.66	2.14	46.52
1984	0.80	9.63	6.70	22.30	7.61		1.61	1.40	2.46	52.51
1985	0.94	11.30	10.31	23.78	11.43		2.32	1.57	2.75	64.40
1986	1.17	12.17	11.98	37.24	9.42		4.21	0.61	3.61	80.41
1987	1.29	13.48	12.04	36.47	8.50		4.50	1.90	3.39	81.55
1988	0.99	13.93	12.85	44.75	7.25		2.78	2.03	3.24	87.82
1989	1.06	11.52	11.49	40.00	8.47		1.54	2.97	2.49	79.54
1990	0.79	10.10	11.98	36.23	10.13		3.28	1.73	3.98	78.21
1991	0.78	8.83	11.95	32.42	13.46		3.44	1.81	4.46	77.15
1992	0.98	9.09	12.68	34.46	9.98		3.63	3.02	3.53	77.35
1993	1.05	12.00	13.74	30.59	8.46		2.92	2.48	3.14	74.38
1994	0.84	11.18	13.11	32.86	4.83		3.20	2.59	3.37	71.98
1995	0.93	11.55	9.80	24.51	4.02		2.86	1.84	3.56	59.06
1996	1.01	10.93	11.28	26.11	4.70		2.49	2.56	4.50	63.58
1997	1.26	13.75	12.37	31.86	9.92		3.94	3.55	5.49	82.14
1998	1.69	14.53	13.15	32.12	12.00		4.82	3.25	5.48	87.03
1999	1.57	14.01	12.45	31.02	14.69		5.57	3.94	6.56	89.80
2000	1.49	12.29	11.17	26.00	16.15		6.23	5.30	6.30	84.91
2001	1.79	11.80	10.72	27.97	17.04		5.82	4.88	6.87	86.89
2002	1.65	13.82	11.05	28.62	18.10		5.86	4.29	6.26	89.65
2003	1.61	13.48	11.47	29.70	17.80		5.61	4.10	5.46	89.22
2004	1.71	14.25	14.03	32.77	15.91		4.17	3.03	4.90	90.77
2005	1.51	14.70	14.20	33.61	13.62		3.96	2.26	5.78	89.64
2006	1.56	14.27	13.85	32.59	11.37		4.07	1.83	5.46	84.99
2007	1.51	11.81	12.35	34.20	9.79		3.56	1.75	5.85	80.82
2008	1.34	9.81	10.10	31.51	11.45		3.59	1.99	5.54	75.33

Table A2. Commercial catch (million pounds, net weight). Figures include IPHC research catches. Sport catch in Areas 2A and 2B is *not* included in this table.

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.52	4.62	5.60	8.19	1.67	0.71	---	---	---	---	---	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	---	---	---	---	---	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	---	---	---	---	---	27.54
1977	0.21	5.43	3.19	8.64	3.19	1.22	---	---	---	---	---	21.88
1978	0.10	4.61	4.32	10.30	1.32	1.35	---	---	---	---	---	22.00
1979	0.05	4.86	4.53	11.34	0.39	1.37	---	---	---	---	---	22.54
1980	0.02	5.65	3.24	11.97	0.28	0.71	---	---	---	---	---	21.87
1981	0.20	5.66	4.01	14.23	0.45	---	0.49	0.39	0.30	0.01	0.00	25.74
1982	0.21	5.54	3.50	13.52	4.80	---	1.17	0.01	0.24	0.00	0.01	29.01
1983	0.26	5.44	6.38	14.14	7.75	---	2.50	1.34	0.42	0.15	0.01	38.39
1984	0.43	9.05	5.87	19.77	6.69	---	1.05	1.10	0.58	0.39	0.04	44.97
1985	0.49	10.39	9.21	20.84	10.89	---	1.72	1.24	0.62	0.67	0.04	56.10
1986	0.58	11.22	10.61	32.80	8.82	---	3.38	0.26	0.69	1.22	0.04	69.63
1987	0.59	12.25	10.68	31.31	7.76	---	3.69	1.50	0.88	0.70	0.11	69.47
1988	0.49	12.86	11.36	37.86	7.08	---	1.93	1.59	0.71	0.45	0.01	74.34
1989	0.47	10.43	9.53	33.74	7.84	---	1.02	2.65	0.57	0.67	0.01	66.95
1990	0.32	8.57	9.73	28.85	8.69	---	2.50	1.33	0.53	1.00	0.06	61.60
1991	0.36	7.19	8.69	22.93	11.93	---	2.26	1.51	0.68	1.44	0.10	57.08
1992	0.44	7.63	9.82	26.78	8.62	---	2.70	2.32	0.79	0.73	0.07	59.89
1993	0.50	10.63	11.29	22.74	7.86	---	2.56	1.96	0.83	0.84	0.06	59.27
1994	0.37	9.91	10.38	24.84	3.86	---	1.80	2.02	0.72	0.71	0.12	54.73
1995	0.30	9.62	7.77	18.34	3.12	---	1.62	1.68	0.67	0.64	0.13	43.88
1996	0.30	9.54	8.87	19.69	3.66	---	1.70	2.07	0.68	0.71	0.12	47.34
1997	0.41	12.42	9.92	24.63	9.07	---	2.91	3.32	1.12	1.15	0.25	65.20
1998	0.46	13.17	10.20	25.70	11.16	---	3.42	2.90	1.26	1.31	0.19	69.76
1999	0.45	12.70	10.14	25.32	13.84	---	4.37	3.57	1.76	1.89	0.26	74.31
2000	0.48	10.81	8.44	19.27	15.41	---	5.16	4.69	1.74	1.93	0.35	68.29
2001	0.68	10.29	8.40	21.54	16.34	---	5.01	4.47	1.65	1.84	0.48	70.70
2002	0.85	12.07	8.60	23.13	17.31	---	5.09	4.08	1.21	1.75	0.56	74.66
2003	0.82	11.79	8.41	22.75	17.23	---	5.02	3.86	0.89	1.96	0.42	73.19
2004	0.88	12.16	10.23	25.17	15.46	---	3.56	2.72	0.95	1.66	0.31	73.11
2005	0.80	12.33	10.63	26.03	13.17		3.40	1.98	0.53	2.58	0.37	71.82
2006	0.83	12.01	10.49	25.71	10.79	---	3.33	1.59	0.49	2.37	0.37	67.98
2007	0.79	9.77	8.47	26.49	9.25	---	2.83	1.42	0.55	2.72	0.58	62.87
2008	0.71	7.79	6.21	24.38	10.89	---	3.01	1.77	0.72	2.56	0.59	58.63

Table A3. IPHC setline survey CPUE of legal sized fish in weight (net pounds per skate).

Figures refer to entire areas. For cases where only part of an area was fished (e.g., northern 2B, western 3A), the CPUE shown is an adjusted value. *No hook corrections* are applied; J-hook values are raw J-hook catch rates. Area 4EBS is the eastern Bering Sea shelf, first surveyed in 2006. For other years, the 4EBS CPUE is a constructed value based on the NMFS trawl survey and the single 2006 setline data point.

	2A	2B	2C	3A	3B	4A	4B	4C	4D	4EBS	Total
J-hook surveys:											
1974	---	---	---	---	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---	---	---	---	---
1976	---	---	---	---	---	---	---	---	---	---	---
1977	---	13	---	58	---	---	---	---	---	---	---
1978	---	18	---	27	---	---	---	---	---	---	---
1979	---	NA	---	41	---	---	---	---	---	---	---
1980	---	25	---	76	---	---	---	---	---	---	---
1981	---	16	---	131	---	---	---	---	---	---	---
1982	---	21	114	130	---	---	---	---	---	---	---
1983	---	18	142	119	---	---	---	---	---	---	---
1984	---	25	---	176	---	---	---	---	---	---	---
C-hook surveys:											
1984	---	57	260	361	---	---	---	---	---	7	---
1985	---	42	260	378	---	---	---	---	---	8	---
1986	---	38	283	305	---	---	---	---	---	9	---
1987	---	NA	---	---	---	---	---	---	---	10	---
1988	---	NA	---	---	---	---	---	---	---	20	---
1989	---	NA	---	---	---	---	---	---	---	13	---
1990	---	NA	---	---	---	---	---	---	---	14	---
1991	---	NA	---	---	---	---	---	---	---	12	---
1992	---	NA	---	---	---	---	---	---	---	11	---
1993	---	93	---	261	---	---	---	---	---	22	---
1994	---	NA	---	254	---	---	---	---	---	17	---
1995	29	148	---	300	---	---	---	---	---	20	---
1996	---	156	306	317	352	---	---	---	---	25	---
1997	35	139	411	331	414	245	282	71	111	23	166
1998	---	82	232	281	435	299	216	---	---	30	157
1999	37	88	204	241	438	290	203	---	---	27	147
2000	---	93	233	272	373	276	216	---	213	20	142
2001	41	102	237	256	357	199	171	---	197	21	133
2002	33	92	261	299	297	168	119	---	263	13	128
2003	22	73	223	229	262	154	104	---	195	18	108
2004	27	86	173	270	236	137	73	---	132	18	106
2005	28	72	171	276	211	107	86	---	69	17	99
2006	16	59	144	232	181	84	95	---	63	18	86
2007	19	57	140	212	191	66	87	---	57	13	79
2008	18	88	108	189	126	83	103	---	68	9	72

Table A4. Commercial CPUE (net pounds per skate).

Values before 1984 are raw J-hook catch rates, with no hook correction. 1983 is excluded because it consists of a mixture of J- and C-hook data. No value is shown for area/years after 1980 with fewer than 500 skates of reported catch/effort data. Total column recomputed in 2007 with new bottom area numbers.

	2A	2B	2C	3A	3B	4A	4B	4C	4D	4E	Total
J-hook CPUE:											
1974	59	64	57	65	57	---	---	---	---	---	---
1975	59	68	53	66	68	---	---	---	---	---	---
1976	33	53	42	60	65	---	---	---	---	---	---
1977	83	61	45	61	73	---	---	---	---	---	---
1978	39	63	56	78	53	---	---	---	---	---	---
1979	50	48	80	86	37	---	---	---	---	---	---
1980	37	65	79	118	113	---	---	---	---	---	---
1981	33	67	145	142	160	158	99	110	---	---	---
1982	22	68	167	170	217	103	---	91	---	---	---
1983	---	---	---	---	---	---	---	---	---	---	---
C-hook CPUE:											
1984	63	148	314	524	475	366	161	---	197	---	357
1985	62	147	370	537	602	333	234	---	330	---	400
1986	60	120	302	522	515	265	---	427	239	---	356
1987	57	131	260	504	476	341	220	384	---	---	349
1988	134	137	281	503	655	453	224	---	201	---	392
1989	124	134	258	455	590	409	268	331	384	---	376
1990	168	175	269	353	484	434	209	288	381	---	334
1991	158	148	233	319	466	471	329	223	398	---	328
1992	115	171	230	397	440	372	278	249	412	---	336
1993	147	208	256	393	514	463	218	257	851	---	392
1994	93	215	207	353	377	463	198	167	480	---	326
1995	116	219	234	416	476	349	189	---	475	---	351
1996	159	226	238	473	556	515	269	---	---	---	413
1997	226	241	246	458	562	483	275	335	671	---	419
1998	194	232	236	451	611	525	287	287	627	---	425
1999	---	213	199	437	538	500	310	270	535	---	394
2000	263	229	186	443	577	547	318	223	556	---	412
2001	169	226	196	469	431	474	270	203	511	---	379
2002	181	222	244	507	399	402	245	148	503	---	378
2003	184	231	233	487	364	355	196	105	389	---	349
2004	145	212	240	485	328	315	202	120	444	---	340
2005	155	197	203	446	293	301	238	91	379	---	314
2006	147	202	170	403	292	241	218	72	280	---	284
2007	94	197	160	398	257	206	230	65	237	---	269
2008	69	174	163	359	232	205	211	88	251	---	248

Appendix B. Evolution of IPHC assessment methods, 1982-2007

From 1982 through 1994, the halibut stock assessment relied on CAGEAN, a simple age-structured model fitted to commercial catch-at-age and catch-per-effort data (Quinn et al. 1985). The constant age-specific commercial selectivities used in the model were fundamental model parameters, estimated directly.

Beginning in the late 1980s, halibut growth rates in Alaska declined dramatically. As a result, age-specific selectivity decreased. CAGEAN did not allow for that, and by the mid-1990s was seriously underestimating abundance. In effect, it interpreted lower catches as an indication of lower abundance, whereas the real cause was lower selectivity. Incoming year classes were initially estimated to be small, but in subsequent years' assessments those estimates would increase when unexpectedly large numbers of fish from those year classes appeared in the catches. The year-to-year changes in the stock trajectory shown by the assessment therefore developed a strong retrospective pattern. Each year's fit showed a steep decline toward the end, but each year the whole trajectory shifted upward.

The staff sought to remedy that problem by making selectivity a function of length in a successor model developed in 1995. It accounted not only for the age structure of the population, but also for the size distribution of each age group and the variations in growth schedule that had been observed. The fundamental selectivity parameters in this model were the two parameters of a function (the left limb of a normal density) by which the selectivity of an individual fish was determined from its length. The age-specific selectivity of an entire age group was calculated by integrating length-specific selectivity over the estimated length distribution of the age group, and that age-specific selectivity was used to calculate predicted catches. The new model was fitted to both commercial data and IPHC setline survey data, with separate length-specific selectivity functions. Commercial catchability and selectivity were allowed to drift slowly over time, while survey catchability and selectivity were held constant (Sullivan et al. 1999).

When this model was fitted to data from Area 2B and Area 3A, quite different length-specific selectivities were estimated, which suggested that fishery selectivity was not wholly determined by the properties of the gear and the size of the fish but also depended on fish behavior (e.g., migration). These behavioral elements are likely to be more related to age than size. The age of sexual maturity, for example, remained virtually the same in Alaska despite the tremendous decrease in growth, so the size at maturity is now much smaller than it was. While size must affect selectivity, it was thought that age was also influential.

To allow for that, the model was fitted in two ways. The original form was called the "length-specific" fit, because a single set of estimates of the two parameters of the length-based survey selectivity function was used in all years. In a second form, called the "age-specific" fit, the parameters were allowed to drift over time (like the commercial selectivity parameters), but they were required (by a heavy penalty) to vary in such a way that the integrated age-specific selectivities calculated in each year remained constant over time.

The usual diagnostics gave little reason to prefer one fit over the other. Goodness of fit was similar: good for both in 2B, not so good for either in 3A. The retrospective behavior of both fits was dramatically better than that of CAGEAN and quite satisfactory in all cases, although the length-specific fit was more consistent from year to year in 3A and the age-specific fit was more consistent in 2B (Clark and Parma 1999). The two fits produced very similar estimates of abundance in Areas 2B and 2C, but in 3A the length-specific estimates were substantially higher,

so out of caution the staff catch limit recommendations were based on the age-specific fit through 1999.

The assessment model was simplified and recoded as a purely age-structured model in 2000 to eliminate some problems associated with the modeling of growth and the distribution of length at age. It retained the option of modeling survey selectivity as a function of mean length at age (observed not predicted), but the production fits continued to be based on constant age-specific survey selectivity, estimated directly as a vector of age-specific values rather than as a parametric function of age.

The fit of this model to Area 3A data in 2002 showed a dramatic retrospective pattern, similar to the pattern of successive CAGEAN fits in the mid-1990s. Treating setline survey selectivity as length-specific rather than age-specific largely eliminated the pattern. Accumulated data showing very similar trends in catch at length in IHPC setline surveys and NMFS trawl surveys provided further evidence that setline selectivity is, after all, determined mainly by size rather than by age (Clark and Hare 2003).

Another anomaly of the 3A model fit in 2002 was the unexpectedly large number of old fish (age 20+) in the last few years' catches. This was found to be the result of an increase in the proportion of otoliths read by the break-and-burn rather than surface method. Surface readings tend to understate the age of older fish, and IPHC age readers had been gradually doing more and more break-and-burn readings as the number of older fish in the catches increased. The poor model fit at these ages indicated a need to deal explicitly with the bias and variance of both kinds of age readings.

An entirely new model was written for the 2003 assessment (Clark and Hare 2004). Both commercial and survey selectivity were parameterized as piecewise linear functions of mean length at age in survey catches, and were required to reach an asymptote of one at or before a length of 130 cm. Because females are larger than males, all of the population accounting and predictions were done separately for each sex. (The age/sex/size composition of the commercial landings was estimated external to the assessment for this purpose.) The observed age compositions (surface or break-and-burn) were predicted by applying estimated misclassification matrices to the age distributions. Even in its most parsimonious form—with just one survey and one commercial selectivity schedule for both sexes in all years—this model achieved very good fits to the sex-specific observations and good retrospective performance. It also produced somewhat higher estimates of average recruitment and recruitment variability. With this simple model it was feasible do standalone analytical assessments of abundance in Areas 3B, 4A, and 4B for the first time, using data from 1996-2003.

Only two minor changes were made for the 2004 assessment, and neither had a significant effect on the estimates of abundance. First, both the 2004 PIT tag recoveries (Clark and Chen 2005) and a reanalysis of earlier wire tag data (Clark 2005) indicated that commercial selectivity is not always asymptotic; it appeared to be more dome-shaped in Area 2B and more ramp-shaped in Area 3A. Fitting the assessment model with free-form selectivity schedules showed much the same thing for commercial selectivity, namely an assortment of shapes beyond 120 cm. Nevertheless a schedule that reaches an asymptote of one at 120 cm is a good approximation to and compromise among the free estimates, and using an asymptotic commercial schedule is desirable for computing exploitable biomass and reporting harvest rates, so that it what was used in the assessment. All of the freely estimated survey selectivities either level out or increase after 120 cm. Freely estimated survey

selectivities present no practical difficulties, so they were estimated that way in the assessment, and most of the estimates were ramp-shaped.

Apart from a few minor and inconsequential corrections and alterations, the 2005 analytical assessment was the same as the 2004 assessment. The only important change in procedure was the use of the NMFS trawl survey to estimate biomass in Area 4CDE where an analytical assessment was not done.

In 2006, growing concerns about migration of legal-sized fish from western to eastern areas led the staff to doubt the validity of the closed-area assessments that had been done for many years (Clark and Hare 2007a). The staff therefore estimated coastwide abundance by fitting the model to a coastwide dataset, and estimated biomass in each area in accordance with survey estimates of relative abundance (Clark and Hare 2007b). The 2007 and 2008 assessments followed the same procedure. Sublegal discard mortality in the halibut fishery was added to the removals beginning with the 2007 assessment; it had the effect of decreasing the present biomass estimate by less than 1%.

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Assessment of the Pacific halibut stock at the end of 2007

William G. Clark and Steven R. Hare

Abstract

As in 2006, the stock assessment was done by fitting the assessment model to a coastwide dataset to estimate total biomass, and then apportioning the total among regulatory areas in accordance with survey estimates of relative abundance. Coastwide exploitable biomass in 2008 is estimated to be 361 million pounds, down from the 414 million estimated last year. About half of the decrease is due to a change in the parameterization of survey catchability in the model, and the other half to lower commercial and survey catch rates in 2007. Total CEY is 69 million pounds.

Introduction

Each year the International Pacific Halibut Commission (IPHC) staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). A biological target level for total removals from each regulatory area is calculated by applying a fixed harvest rate to the estimate of exploitable biomass in that area. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for catches in directed fisheries subject to allocation is called the fishery CEY. It comprises the commercial setline catch in all areas plus the sport catch in Areas 2A and 2B. It is calculated by subtracting from the total CEY an estimate of all unallocated removals—bycatch of legal-sized fish, wastage of legal-sized fish in the halibut fishery, fish taken for personal use, and sport catch except in Areas 2A and 2B. Staff recommendations for catch limits in each area are based on the estimates of fishery CEY but may be higher or lower depending on a number of statistical, biological, and policy considerations. Similarly, the Commission's final quota decisions are based on the staff's recommendations but may be higher or lower.

For many years the staff assessed the stock in each regulatory area by fitting a model to the data from that area (Appendix B). This procedure relied on the assumption that the stock of fish of catchable size in each area was closed, meaning that net migration was negligible. A growing body of evidence from both the assessments (Clark and Hare 2007a) and the ongoing mark-recapture experiment (Webster and Clark 2007) shows that there is probably a continuing eastward net migration of catchable fish from the western Gulf of Alaska (Areas 3B and 4) to the eastern side (Area 2). The effect of this migration on the closed-area stock assessments was to produce underestimates of abundance in the western areas and overestimates in the eastern areas. To some extent this has almost certainly been the case for some time, meaning that exploitation rates were well above the target level in Area 2 and a disproportionate share of the catches have been taken from there.

In order to obtain an unbiased estimate of the coastwide stock in the 2006 assessment, the staff built a coastwide data set and fitted the model to it. Exploitable biomass in each regulatory area was estimated by apportioning the total in proportion to an estimate of stock distribution derived from the setline survey catch rates (CPUE). Specifically, an index of abundance in each area was calculated by multiplying survey CPUE (running 3-year average) by total bottom area between 0 and 300 fm. The logic of this index is that survey CPUE can be regarded as an index of density, so multiplying it by bottom area gives a quantity proportional to total abundance. The estimated proportion in each area is then the index value for that area divided by the sum of the index values. This year's assessment uses the same procedure.

Description of the assessment model

The IPHC assessment model is age- and sex-structured. Commercial and survey selectivity are both estimated as piecewise linear functions of observed mean length at age/sex in survey catches. (There is a 32" minimum size limit in the commercial fishery.) Commercial catchability is normally allowed to vary from year to year with a penalty of 0.03 on log differences. Survey catchability is normally held constant, although some variation was allowed in both this year's and last year's production fits. The model is fitted to commercial and survey catch at age and CPUE. Clark and Hare (2006) provide a full account of model structure and fitting procedures.

The closed-area and coastwide model fits differ in parameterization and likelihood. Some of the closed-area data sets are quite noisy, so the closed-area version is more parsimonious and it is weighted. Specifically, the catchability, selectivity and natural mortality parameters are all unisex; the estimated selectivity schedules are strongly smoothed; the model is fitted only to total CPUE (rather than CPUE at age/sex); and a heavy weight is placed on the CPUE data series to assure satisfactory agreement. The coastwide data are not noisy, so the coastwide version of the model can have sex-specific parameters, weaker selectivity smoothing, and neutral data weighting. It is fitted to CPUE at age/sex as well as total CPUE.

Alternative model fits

In the 2006 coastwide assessment (Clark and Hare 2007b), estimated survey catchability was allowed to vary somewhat because it was found that actual survey catchability had varied substantially. This was shown by model fits in which present abundance was fixed at a range of levels by fixing the terminal fishing mortality rate as in a virtual population analysis (VPA) and then estimating survey catchability as a free parameter in each year (Fig. 1). These fits showed that survey catchability happened to be high in the first year of the data (1997) and low in the last year (2006), resulting in a spurious appearance of a decline in abundance. To neutralize that feature, survey catchability was estimated independently for the first and last years, which effectively meant disregarding those data points and estimating a constant survey catchability from the remaining data (1998-2005).

In this year's assessment some other ways of dealing with variable survey catchability were considered. The candidate models were:

(i) Vanilla: the conventional model, with constant survey catchability in all years.

(ii) HiLoSQ: last year's production model, with three values of survey catchability estimated (1997, 1998-2005, 2006-2007).

(iii) WobbleSQ: survey catchability estimated for each year, but with a penalty of 0.05 on log differences. This is similar to the treatment of commercial catchability.

(iv) TrendlessSQ: same as WobbleSQ, but with the additional requirement that a regression of estimated survey catchability on year have zero slope. This means that survey catchability was allowed to vary but not to show any trend over time.

Table 1 shows features of the candidate model fits and some others. WobbleSQ has the lowest AIC score, but TrendlessSQ is nearly as good, and we think it is appropriate to disallow trends in survey catchability over time, so that is our chosen production model.

The last two fits in Table 1 show the effect of commercial CPUE on the biomass estimate. "No commercial CPUE" is a fit in which commercial CPUE is disregarded, and "CAGEAN" is a fit in which commercial catchability is held constant, so that commercial and survey CPUE are given equal influence. Evidently commercial CPUE tends to increase the biomass estimate, but not greatly.

Effect of the 2007 data on abundance estimates

Coastwide commercial and survey CPUE both declined by 5-10% from 2006 to 2007 (Fig. 2; Appendix A tables A2 and A3). As a result the 2007 coastwide and closed-area model fits mostly revise downward the estimates of abundance at the beginning of 2007 made in the 2006 assessment (Table 2). At the same time the 2007 fits show an increase in abundance between the beginning of 2007 and the beginning of 2008, so last year's estimates of 2007 biomass and this year's estimates of 2008 biomass are not very different in most cases. Exceptions are Areas 2C and 4A where the closed-area estimates decrease significantly.

The coastwide estimate of exploitable biomass in 2008 is 361 M lb compared with 414 last year. About half of this difference is due to the change from the HiLoSQ to the TrendlessSQ model fit. The HiLoSQ biomass estimate in 2008 is 386 M lb.

Area-specific biomass and CEY estimates

Area-specific estimates of biomass are calculated by survey apportionment as they were last year, with the difference that this year a depth-stratified mean survey CPUE has been used, which results in about a 40% increase in the Area 2A apportionment, about a 5% decrease in the Area 3A apportionment, and very small increases in most other apportionments. The area-specific estimates from last year's and this year's coastwide and closed-area assessments are shown in Tables 3 and 4.

The staff believes that survey apportionment is the most objective and consistent method of estimating the biomass distribution among areas and therefore the best distribution of total CEY, if the aim is proportional harvest. A disproportionate share of the harvest has been taken from Area 2 for decades, so some level of disproportionality was clearly sustainable by the stock with the exploitation pattern that prevailed during that period. Increasing catches from the western portion of the stock in the last decade have altered the exploitation pattern, so the historical high levels of removals from Area 2 may no longer be sustainable. Alternative CEY apportionments under a variety of rules are shown for information in Table 6. The staff does not advocate any of them and would in fact oppose some, such as apportionment on the basis of bottom area alone or an index incorporating commercial CPUE.

Evaluation of the assessment

Quality of fits

The assessment model fits the coastwide data very well. (That is not true of some of the closed-area data sets.) The series of total survey and commercial CPUE are predicted closely (Fig.

3, bottom panels), and so are the commercial catch and survey CPUE at age/sex (Figs. 4a and 4b).

Retrospective performance

Each year's model fit estimates the abundance and other parameters for all years in the data series. One hopes that the present assessment will closely match the biomass trajectory estimated by the previous year's assessment. To the extent that it does not, the assessment is said to have poor retrospective performance.

Our assessment has not tracked very well for the last few years. Each year the assessment has revised downward the previous year's biomass estimates (Fig. 5), meaning that biomass was overestimated then and may be overestimated now if the cause of the retrospective problem lies somewhere within the model. There is some precedent for that; the assessment models in use in the mid 1990s and the early 2000s showed strong retrospective patterns that turned out to be the result of misspecified selectivity (age- rather than length-based). There is also the possibility that the retrospective pattern is caused in some way by the external estimation of the sex composition of the commercial catch, or by the internal prediction of surface age compositions prior to 2002 through the application of an age misclassification matrix (Clark and Hare 2006).

Problems of this sort with the assessment machinery would manifest themselves as systematic revisions of the estimated relative strength of the year-classes present in the stock. That was true of the retrospective patterns caused by the misspecification of selectivity in the past: incoming year-classes would at first be estimated as weak because catch rates were low, but the real reason was low selectivity rather than low abundance. When they were later caught in large numbers, the estimates of relative year-class strength increased.

We can check for patterns of this sort by doing a blind projection of the assessment from, say, 2004 to 2007. This means using the estimates of year-class strength and other parameters from the 2004 assessment and projecting forward to 2007 without benefit of the 2005-2007 data (except for the total catch in number in each year, which determines the annual fishing mortality rate). If there were some problem with the model, the projected age compositions of the survey and commercial catches would differ systematically from the predictions of the 2007 assessment incorporating the 2005-2007 data. But they do not; the two sets of predicted age compositions are nearly the same (Fig. 6a). This is not surprising, given the simplicity of the model and the very good fits to the data.

What the projection from 2004 fails to predict is the commercial and survey CPUE in 2005-2007 (Fig. 6b). Given the estimates of year-class strength and catchability in 2004, the blind projection shows CPUE bottoming out in 2005 and increasing thereafter. In actuality both declined in 2006 and again in 2007, with the result that the present abundances of all of the year-classes in the stock were revised downward proportionally in the subsequent assessments. So this is a retrospective pattern caused by the data, not by the model.

To some extent the pattern results from the decline in survey catchability mentioned above. VPA-like fits in 2007 show that survey catchability declined every year from 2005 through 2007, by some 20% in total. This is by no means unprecedented, but the run of three declines in a row inevitably affects the biomass estimates. This year's production model ("Trendless") is less affected than a conventional model ("Vanilla") because it allows survey catchability to vary from year to year, but it is affected.

Estimates of uncertainty

There are a number of ways of estimating the uncertainty associated with a given model fit and biomass estimate. They are all unsatisfactory in that they are conditioned on the correctness of the model, and in fact it is the choice of one model rather than another that is the major source of uncertainty in assessments. This is well illustrated by the difference in area-specific biomass estimates between the coastwide and closed-area fits of the IPHC model.

Figure 7 shows probability distributions of the 2008 exploitable biomass obtained in various ways. The Hessian-based estimate of standard deviation is about 20 M lb, and a normal distribution with this amount of dispersion closely approximates a calculated likelihood profile. A straightforward measure of uncertainty is the spread of biomass estimates among plausible models. All of the fits in Table 1 are at least plausible, and they range from 320 to 400 M lb, similar to the Hessian-based normal approximation.

Treatment of process error

The likelihood used in fitting the model is the MULTIFAN scheme developed by Fournier et al. (1990). All errors are treated as being normally distributed, so the likelihood is a sum of squared deviations, each weighted by the inverse of a scaled variance. The variances are the external estimates of sampling variance of each observation, and the scalers are just the root mean squared errors associated with each data type in unscaled fits. This amounts to a one-step reweighting of the data. It succeeds in producing distributions of residuals that are very close to standard normals. The scalers are mostly in the range 4-9, meaning that sampling variance accounts for only a small fraction of the total error variance. The remainder is process error, the result of model misspecification or parameter variation

While the MULTIFAN procedure is clearly effective in standardizing the variances in the halibut assessment, it is somewhat puzzling that process error can be successfully treated as a multiple of sampling error. They arise from different sources and there is really no reason to expect them to be related. One suggestion made during an external review in 2007 was that we consider an additive rather than a multiplicative model of process error. The multiplicative model is $\sigma_p^2 = \left(\tau^2 - 1\right) \cdot \sigma_s^2$, where σ_p^2 is process variance, σ_s^2 is sampling variance, and τ^2 is a scaler. Total variance σ_t^2 is then given by $\sigma_t^2 = \tau^2 \cdot \sigma_s^2$. The additive model is $\sigma_t^2 = \sigma_s^2 + \sigma_p^2$ where σ_p^2 is process error. The suggestion was to estimate a process coefficient of variation (CV) for each data type, so $\sigma_p^2 = \delta^2 \cdot y^2$ where y is the observed value and δ is the CV.

The amount of process error associated with each data point can be estimated as the squared deviation (in an unscaled fit) minus the estimated sampling variance. If the multiplicative model is appropriate, process error should increase with sampling variance, and it does (Fig. 8a). If the additive model is appropriate, process error should increase with the square of the observed value, and it does (Fig. 8b). The reason that both models are appropriate is that most of the observations (commercial and survey catch and CPUE at age/sex) have multinomial sampling variances, so the sampling variances are proportional to the expected values. So while equally appropriate, the additive model would not improve on the multiplicative model.

Use of PIT tag estimates of commercial selectivity in the assessment

Estimates of fishing mortality from the ongoing PIT tag experiment (Webster 2008) are so different from the stock assessment as to be simply incredible, but that is not true of the selectivity estimates. Even when mark-recapture data are not usable for estimating fishing mortality or abundance or migration rates, they can still provide useful estimates of selectivity (Myers and Hoenig 1997, Clark and Kaimmer 2006).

In the stock assessment, commercial selectivity is required to reach 100% at a length of 120 cm and remain there (i.e., commercial selectivity is asymptotic). In model fits, commercial selectivity increases gradually between 80 and 120 cm. At 100 cm it is estimated to be 0.56. The PIT tag data show full commercial selection occurring at a smaller size than the assessment. When a coastwide commercial selectivity is estimated freely from the PIT tag data, it reaches 100% at 100 cm and stays close to that level thereafter (Ray Webster, IPHC, pers. comm.).

The assessment can be made to conform to the PIT tag results by requiring full commercial selection at 100 cm. When that is done, the fit is much worse (AIC = 850 vs 790 for the production model). The exploitable biomass estimate is nearly the same (373 M lb vs 361).

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Table 1. Alternative coastwide model fits. The first two are coastwide fits that have the same parameterization as the closed-area fits.

Model	Number of parameters	Deviance	AIC	Exploitable biomass
Closed-area parameters Closed-area likelihood	121	NA	NA	321
Closed-area parameters Coastwide likelihood	121	716	958	341
Vanilla	136	524	796	337
WobbleSQ	155	479	789	338
HiLoSQ	138	520	796	386
TrendlessSQ	155	480	790	361
No commercial CPUE	145	504	794	344
CAGEAN	134	553	821	400

Table 2. Effect of the 2007 data on closed-area and coastwide abundance estimates.

Area	2007 ebio 2006 assessment Data as of 11/06	2007 ebio 2006 assessment Data as of 11/07	2007 ebio 2007 assessment Data as of 11/07	2008 ebio 2007 assessment Data as of 11/07
Closed-area assessments:				
2A	4.9	5.1	4.0	4.6
2B	39	41	33	37
2C	57	55	45	49
3A	174 [1]	170	169	169
3B	52	53	47	54
4A	17	14	11	11
4B	10	12	15	14
2A-4B sum	354	350	324	339
4CDE	58	52	52	52
Total	412	402	376	391
Coastwide assessment:				
2A-4B sum (90% of total)	339	333	297	325
4CDE	38	37	33	36
Total	377	370	330	361

Notes:

[1] Recalculated to be consistent with present treatment of Area 3A survey CPUE (full-area CPUE = 81% of partial-area CPUE rather than 75%). Value reported last year was 186.

Table 3. Estimates of 2007 exploitable biomass and CEY from the 2006 assessment (2006 RARA, p. 107).

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2007 exploitable biomass	3.7	27	33	176	86	29	19	41	414
Proportion of total	0.009	0.065	0.080	0.423	0.208	0.069	0.045	0.101	1.000
Target harvest rate	0.25	0.25	0.25	0.20	0.20	0.20	0.15	0.15	~0.20
Total CEY	0.93	6.75	8.25	35.20	17.20	5.80	2.85	6.15	83.13
Other removals [2]	0.27	0.53	3.79	7.89	0.43	0.57	0.29	2.30	16.07
2007 fishery CEY [2]	0.66	6.22	4.46	27.31	16.77	5.23	2.56	3.85	67.06
Area assessments [1]									
2007 exploitable biomass	4.9	39	57	186	52	17	10	50	416
Proportion of total	0.012	0.094	0.137	0.447	0.125	0.041	0.024	0.120	1.000
Target harvest rate	0.20	0.20	0.20	0.20	0.20	0.20	0.15	0.15	~0.20
Total CEY	1.00	7.80	11.40	37.20	10.40	3.40	1.50	7.50	80.20
Other removals [2]	0.27	0.53	3.79	7.89	0.43	0.57	0.29	2.30	16.07
2007 fishery CEY [2]	0.73	7.27	7.61	29.31	9.97	2.83	1.21	5.20	64.13
2007 catch limit [3]	1.34	11.47	8.51	26.20	9.22	2.89	1.44	4.10	65.17

Notes:

[1] "Coastwide assessment" refers to the coastwide model fit with survey apportionment of the total biomass estimate among regulatory areas. "Area assessments" are the closed-area model fits.

[2] "Other removals" comprise legal-sized wastage, legal-sized bycatch, personal use, and in most areas sport catch. In Areas 2A and 2B sport catch is included in fishery CEY rather than in other removals.

[3] "Catch limit" includes sport as well as commercial catch in Areas 2A and 2B.

Table 4. Estimates of 2008 exploitable biomass and CEY from the 2007 assessment.

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2008 exploitable biomass	4.7	25.6	32.5	144.8	74.0	21.3	20.2	37.9	361
Proportion of total	0.013	0.071	0.090	0.401	0.205	0.059	0.056	0.105	1.000
Target harvest rate	0.20	0.20	0.20	0.20	0.20	0.20	0.15	0.15	<0.20
Total CEY	0.94	5.12	6.50	28.96	14.80	4.26	3.03	5.69	69.30
Other removals [2]	0.29	0.47	2.59[3]	6.71[3]	0.53	0.75	0.33	2.01	13.68
2008 fishery CEY [2]	0.65	4.65	3.92	22.25	14.27	3.51	2.71	3.68	55.62
Area assessments [1]									
2008 exploitable biomass	4.6	37	49	169	54	11	14	52	391
Proportion of total	0.012	0.095	0.125	0.432	0.138	0.028	0.036	0.133	0.999
Target harvest rate	0.20	0.20	0.20	0.20	0.20	0.20	0.15	0.15	<0.20
Total CEY	0.92	7.40	9.80	33.80	10.80	2.20	2.10	7.80	74.82
Other removals [2]	0.29	0.47	2.59[3]	6.71[3]	0.53	0.75	0.33	2.01	13.68
2008 fishery CEY [2]	0.63	6.93	7.21	27.09	10.27	1.45	1.77	5.79	61.14

Notes:

[1] "Coastwide assessment" refers to the coastwide model fit with survey apportionment of the total biomass estimate among regulatory areas. "Area assessments" are the closed-area model fits.

[2] "Other removals" comprise legal-sized wastage, legal-sized bycatch, personal use, and in most areas sport catch. In Areas 2A and 2B sport catch is included in fishery CEY rather than in other removals.

[3] The sport catch component in these figures is the adopted guideline harvest level (GHL), which is lower than the actual 2007 catch in Area 2C and higher in Aea 3A.

Table 5. Other removals in detail. Sport catch figures for Areas 2C and 3A are actual catches not GHL levels as in Table 4.

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Sport catch	0.52	1.75	2.55	5.05	0.01	0.05	0.00	0.00	9.93
Legal-sized bycatch	0.25	0.15	0.21	0.99	0.45	0.66	0.32	1.90	4.93
Pesonal use	0.04	0.30	0.58	0.38	0.05	0.03	0.00	0.11	1.49
Legal-sized wastage	0.00	0.02	0.02	0.05	0.02	0.01	0.01	0.00	0.13
Total	0.81	2.22	3.36	6.47	0.53	0.75	0.33	2.01	16.48
Total excl.sport catch in Areas 2A and 2B	0.29	0.47	3.36	6.47	0.53	0.75	0.33	2.01	14.21
Sublegal discard mortality (shown for information; not taken off total CEY)	0.02	0.44	0.27	0.92	0.42	0.13	0.02	0.07	2.29

Table 6. Shares of total CEY by area according to various apportionment rules.

Rule	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Survey apportionment (CPUE x bottom area)	0.013	0.071	0.090	0.401	0.205	0.059	0.056	0.105	1.000
2008 exploitable biomass from 2007 closed-area assessments	0.012	0.095	0.125	0.432	0.138	0.028	0.036	0.133	0.999
Historical recruitment from 2007 closed-area assessments (1987-1996)	0.02?	0.107	0.098	0.451	0.161	0.046	0.018	0.10?	1.001
Share of total catch (1990-2007)	0.017	0.144	0.140	0.366	0.142	0.065	0.035	0.091	1.000
Share of bottom 0-300 fm (excl. EBS shelf outside 4C)	0.066	0.160	0.082	0.256	0.154	0.094	0.078	0.111	1.001
Commercial apportionment (CPUE x bottom area)	0.035	0.113	0.055	0.401	0.162	0.088	0.066	0.080	1.000

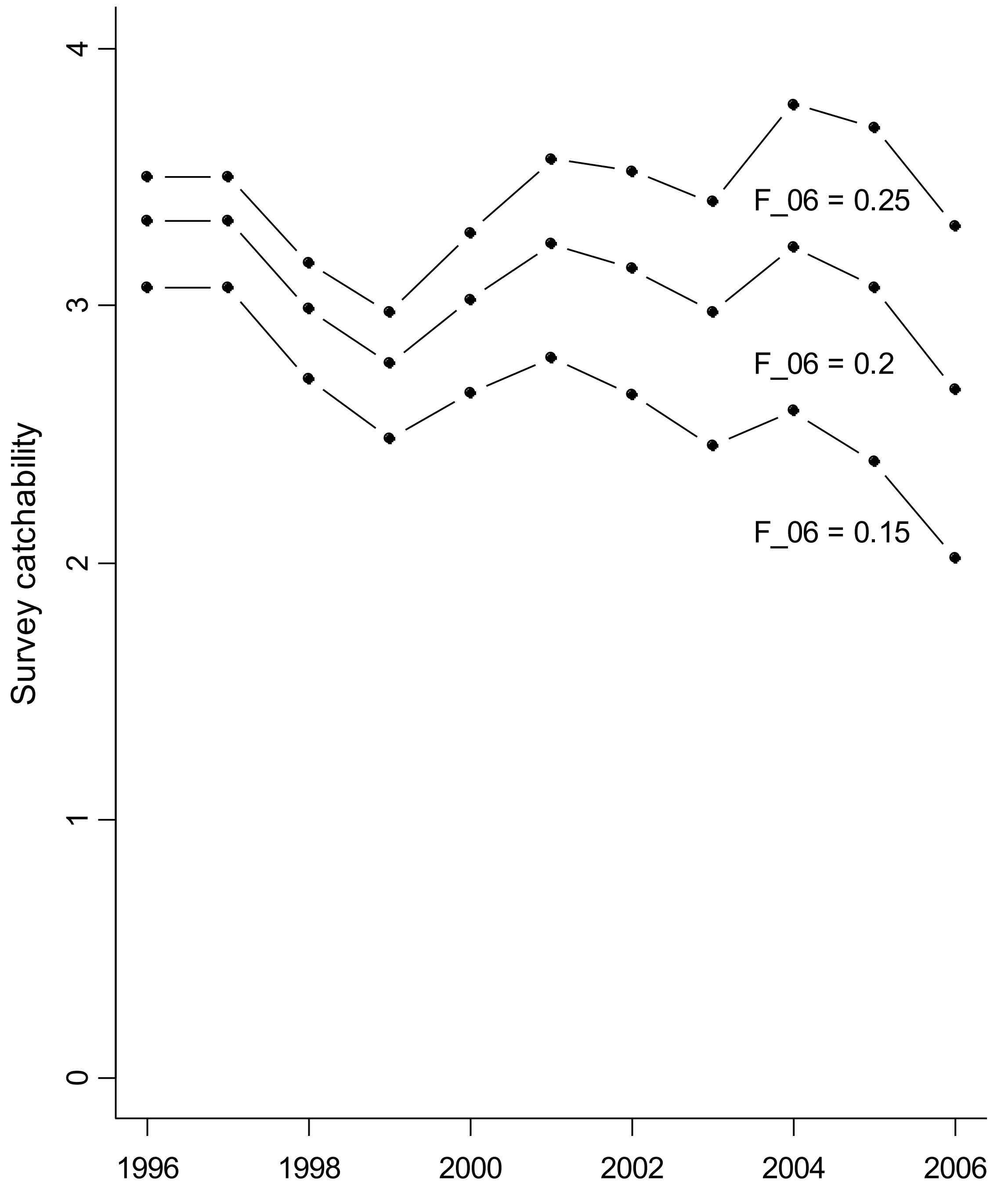

Figure 1. Calculated values of survey catchability in VPA-like fits of the model in the 2006 assessment. The labels refer to the value of the fixed terminal fishing mortality rate; e.g. "F_06 = 0.2" means that the fishing mortality rate in 2006 was set to 0.20.

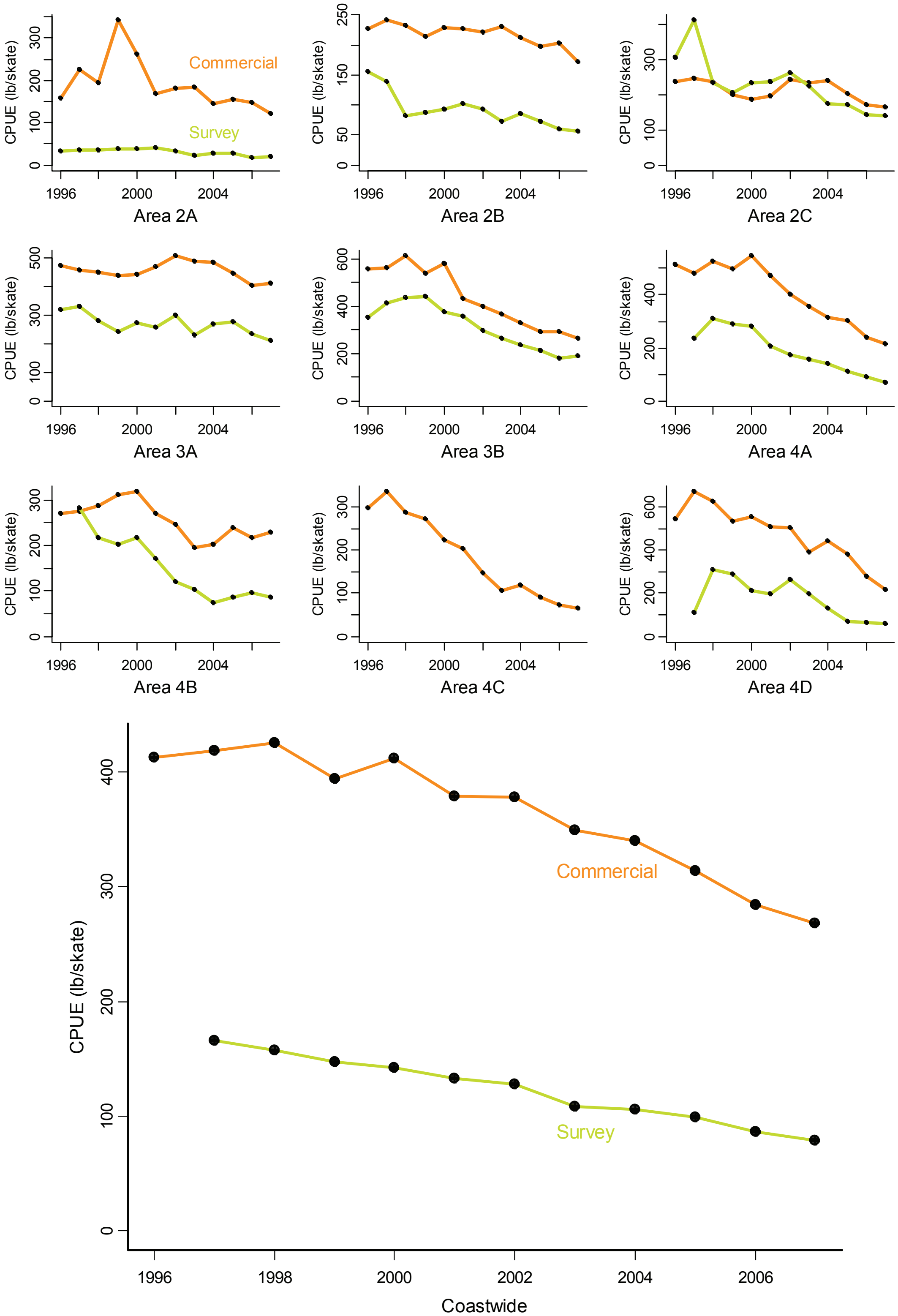

Figure 2. Commercial and survey CPUE by area (above) and coastwide (below).

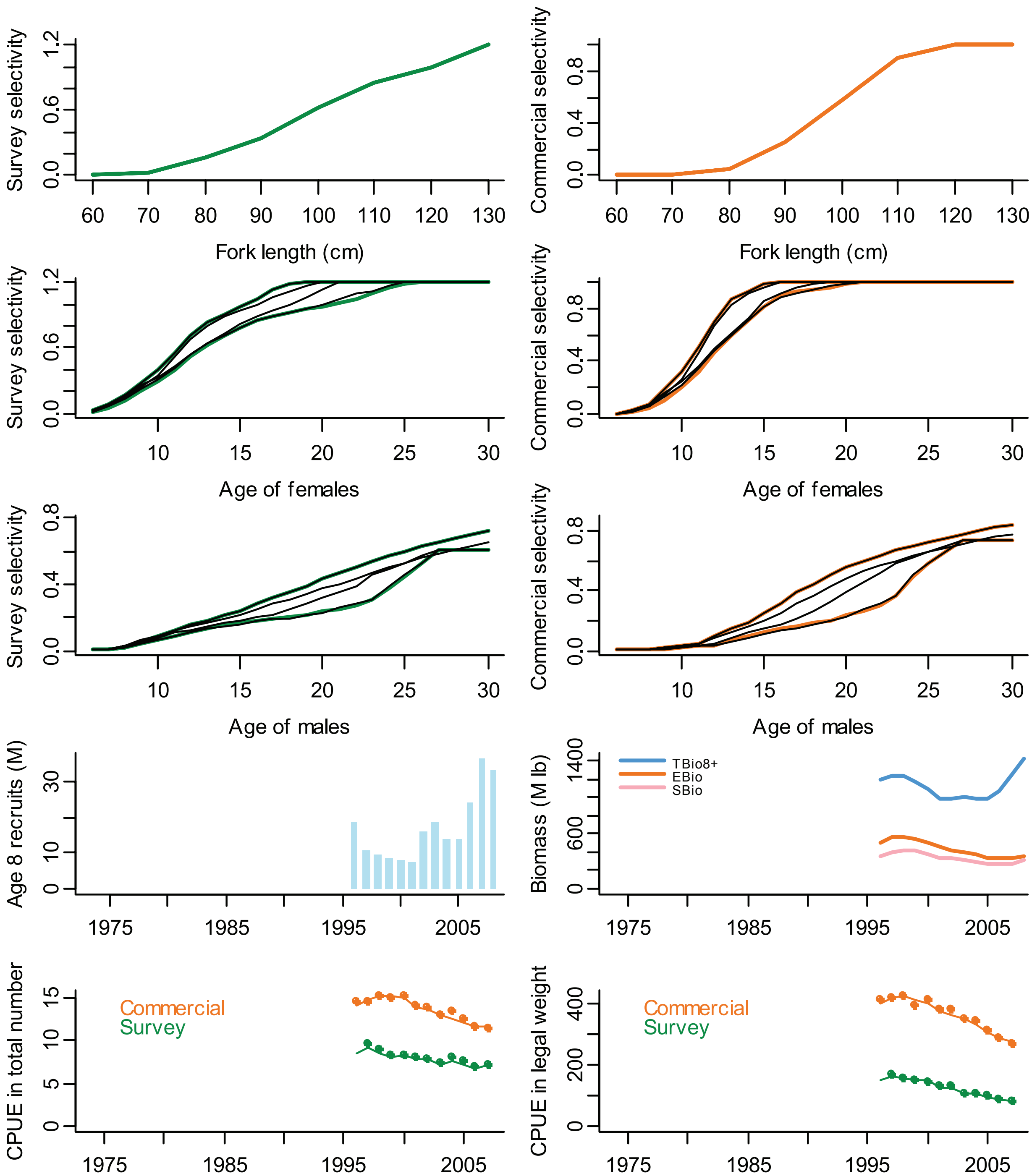

Figure 3. Features of the 2007 coastwide assessment. Age-specific selectivities are plotted for every third year plus the last.

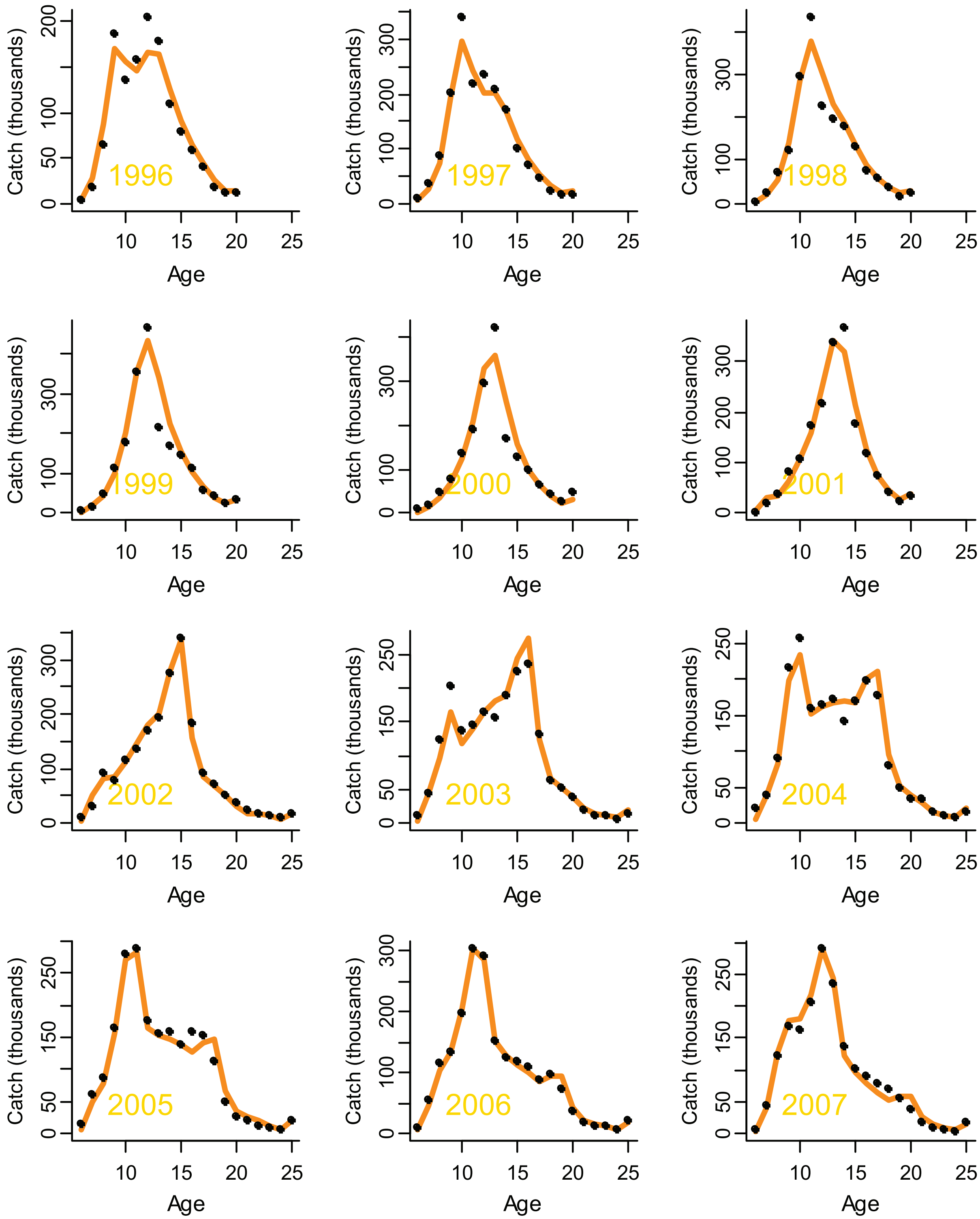

Figure 4a. Observed (points) and predicted (lines) commercial catch at age of females in the 2007 coastwide model fit.

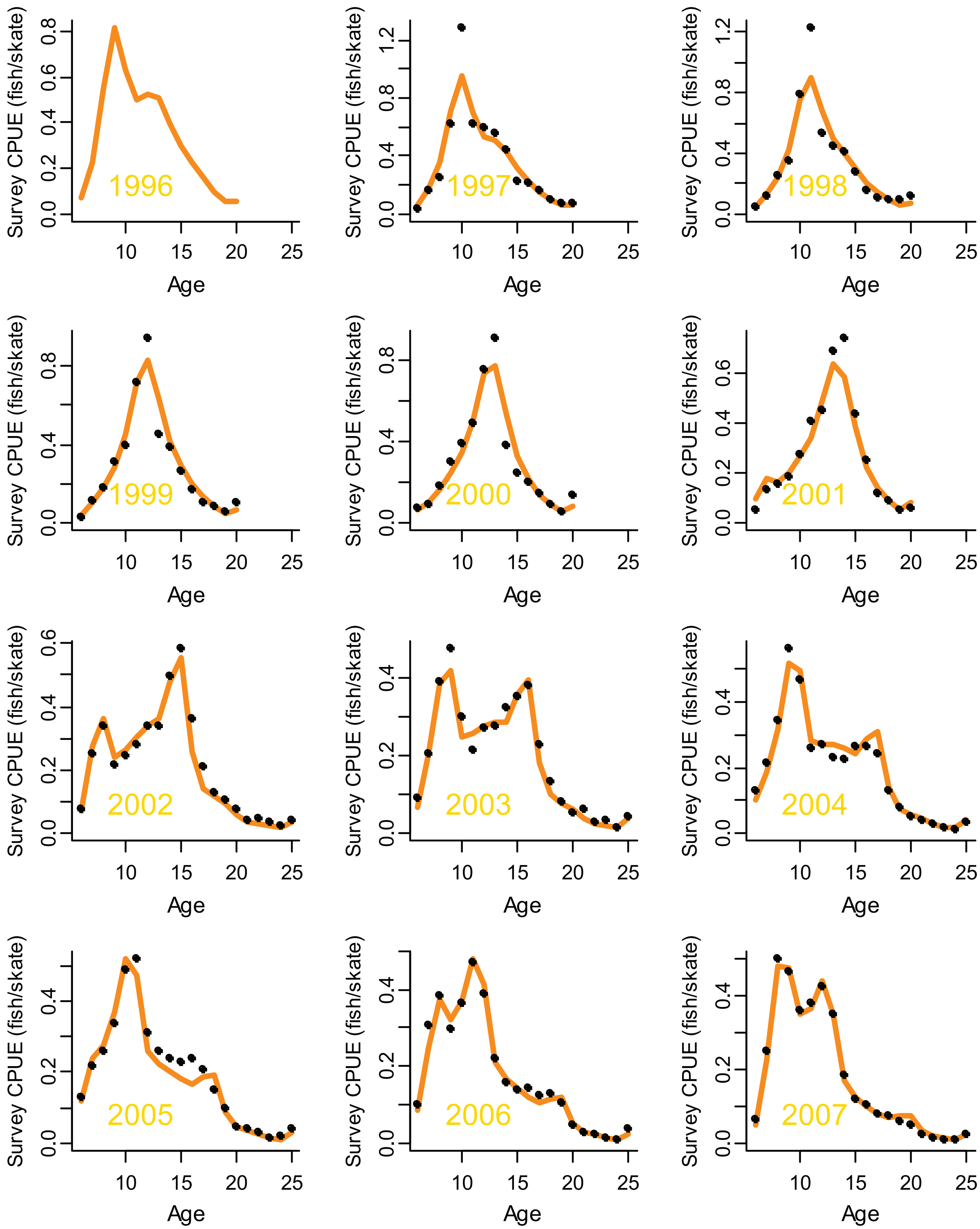

Figure 4b. Observed (points) and predicted (lines) survey CPUE at age of females in the 2007 coastwide model fit.

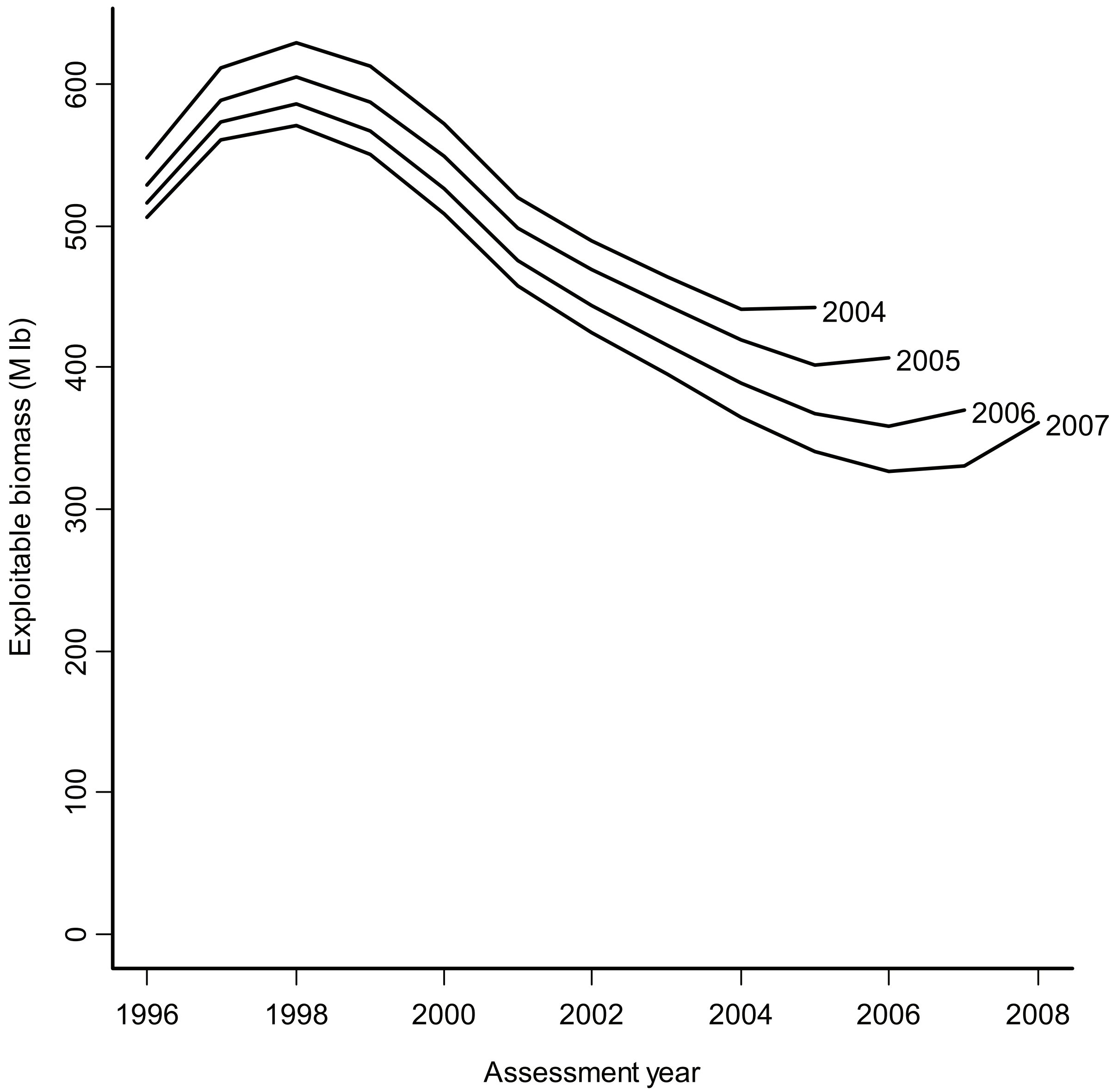

Figure. 5. Retrospective performance of the assessment. Each line is the biomass trajectory estimated by the model fitted to data from 1996 through the labeled last year.

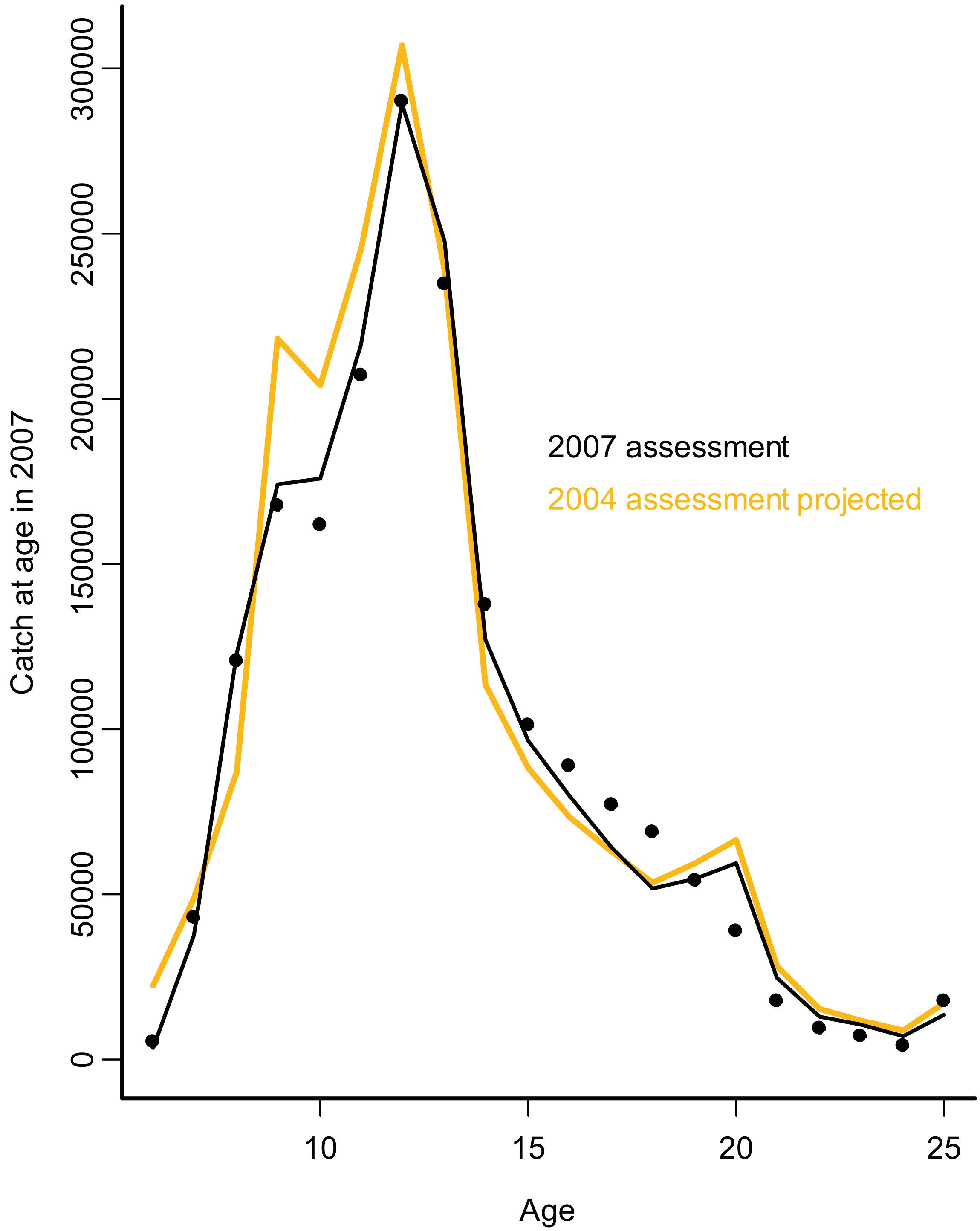

Figure 6a. Observed commercial catch at age of females in 2007 (points) and predicted catch at age from the 2007 assessment and from a blind projection of the 2004 assessment.

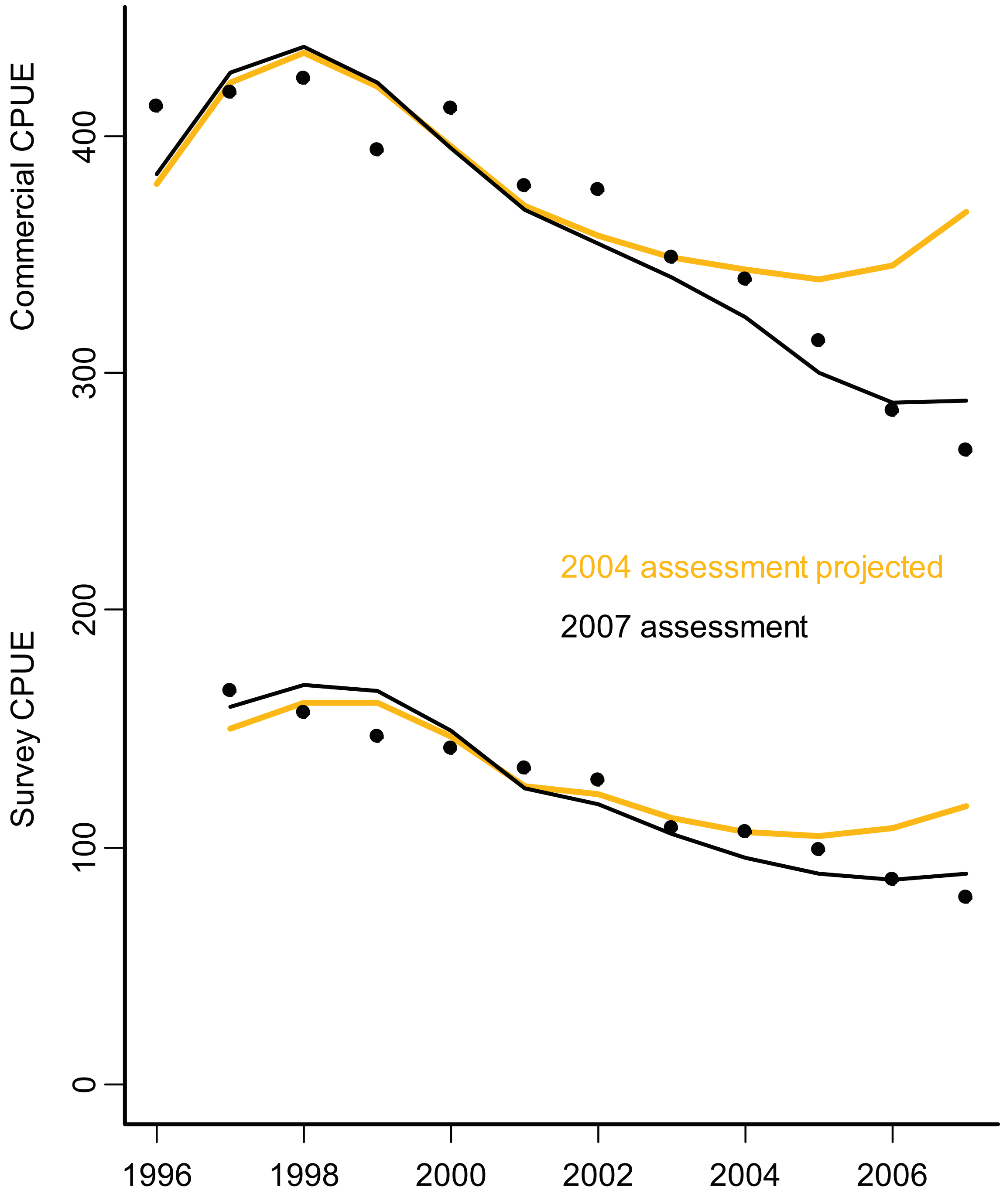

Figure 6b. Points are observed commercial (above) and survey (below) CPUE. Lines are predicted values from the 2007 assessment and a blind projection of the 2004 assessment.

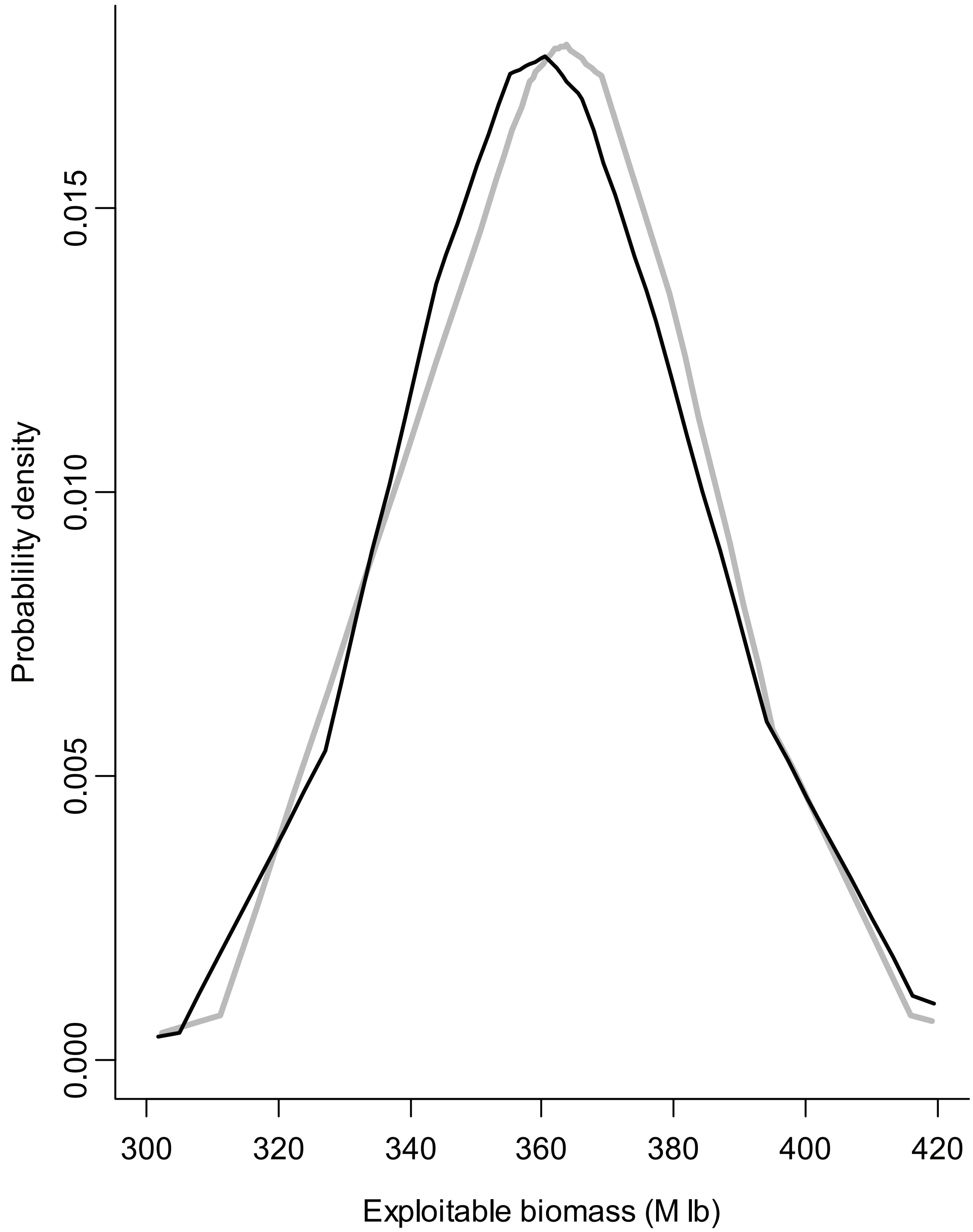

Figure 7. Estimates of uncertainty in the estimate of 2008 exploitable biomass: normal approximation based on the Hessian (gray line) and calculated likelihood profile (black line).

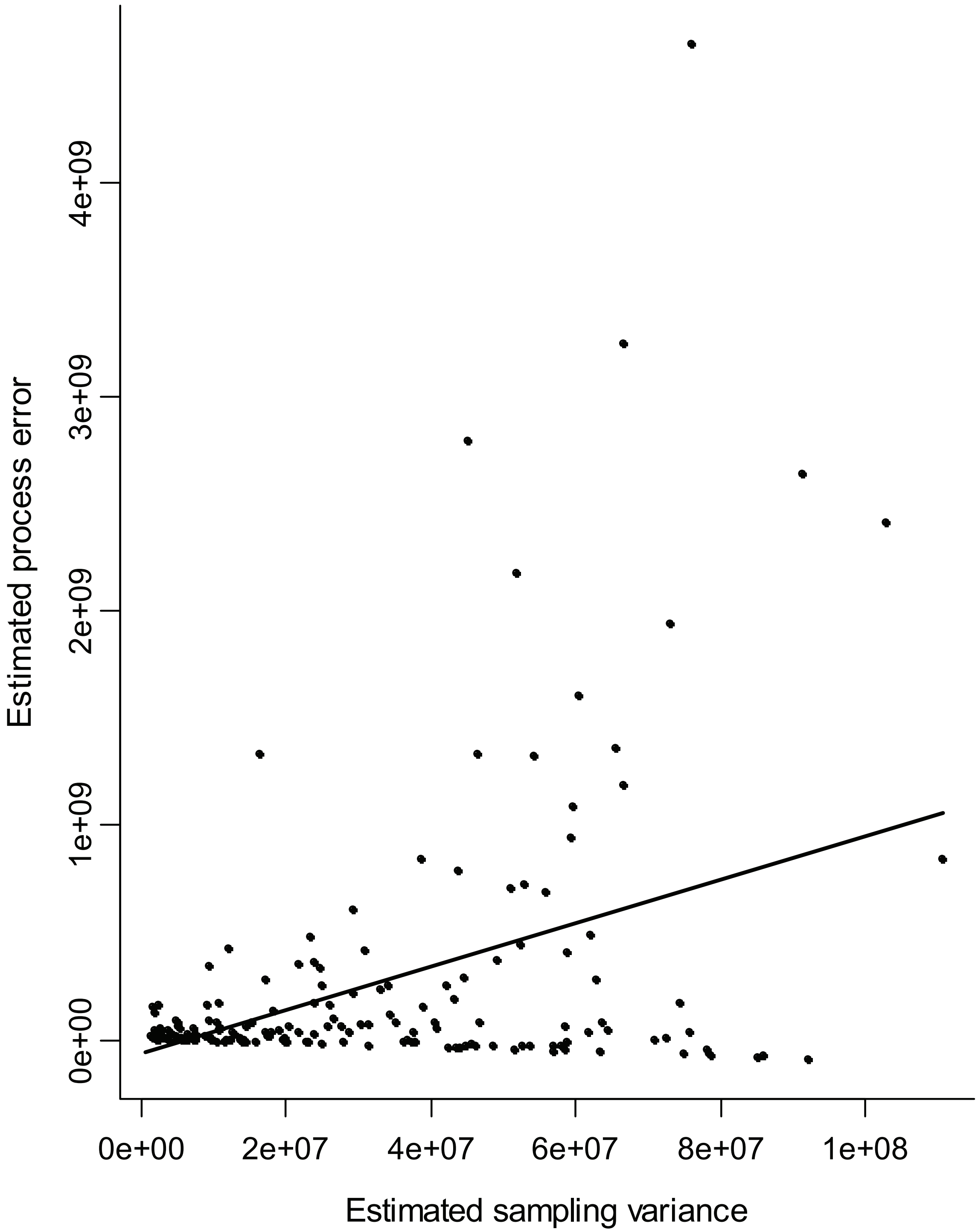

Figure 8a. Estimated process error (squared deviation minus estimated sampling variance) plotted against estimated sampling variance of female catch at age.

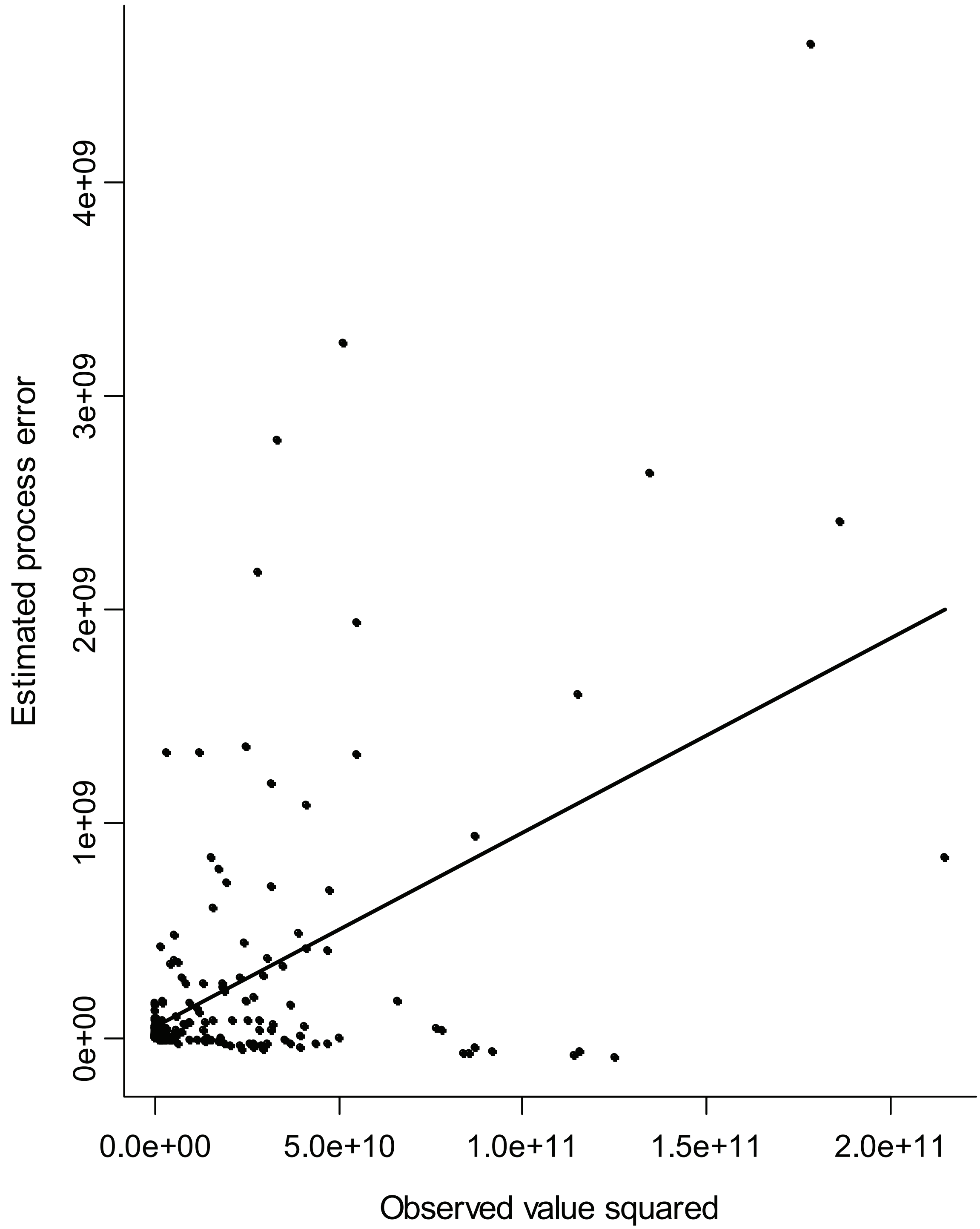

Figure 8b. Estimated process error (squared deviation minus estimated sampling variance) plotted against the square of the observed value of female catch at age.

Appendix A. Selected fishery and survey data summaries.

Table A1. Commercial catch (million pounds, net weight). Figures include IPHC research catches. Sport catch in Areas 2A and 2B is *not* included in this table.

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.52	4.62	5.60	8.19	1.67	0.71	---	---	---	---	---	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	---	---	---	---	---	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	---	---	---	---	---	27.54
1977	0.21	5.43	3.19	8.64	3.19	1.22	---	---	---	---	---	21.88
1978	0.10	4.61	4.32	10.30	1.32	1.35	---	---	---	---	---	22.00
1979	0.05	4.86	4.53	11.34	0.39	1.37	---	---	---	---	---	22.54
1980	0.02	5.65	3.24	11.97	0.28	0.71	---	---	---	---	---	21.87
1981	0.20	5.66	4.01	14.23	0.45	---	0.49	0.39	0.30	0.01	0.00	25.74
1982	0.21	5.54	3.50	13.52	4.80	---	1.17	0.01	0.24	0.00	0.01	29.01
1983	0.26	5.44	6.38	14.14	7.75	---	2.50	1.34	0.42	0.15	0.01	38.39
1984	0.43	9.05	5.87	19.77	6.69	---	1.05	1.10	0.58	0.39	0.04	44.97
1985	0.49	10.39	9.21	20.84	10.89	---	1.72	1.24	0.62	0.67	0.04	56.10
1986	0.58	11.22	10.61	32.80	8.82	---	3.38	0.26	0.69	1.22	0.04	69.63
1987	0.59	12.25	10.68	31.31	7.76	---	3.69	1.50	0.88	0.70	0.11	69.47
1988	0.49	12.86	11.36	37.86	7.08	---	1.93	1.59	0.71	0.45	0.01	74.34
1989	0.47	10.43	9.53	33.74	7.84	---	1.02	2.65	0.57	0.67	0.01	66.95
1990	0.32	8.57	9.73	28.85	8.69	---	2.50	1.33	0.53	1.00	0.06	61.60
1991	0.36	7.19	8.69	22.93	11.93	---	2.26	1.51	0.68	1.44	0.10	57.08
1992	0.44	7.63	9.82	26.78	8.62	---	2.70	2.32	0.79	0.73	0.07	59.89
1993	0.50	10.63	11.29	22.74	7.86	---	2.56	1.96	0.83	0.84	0.06	59.27
1994	0.37	9.91	10.38	24.84	3.86	---	1.80	2.02	0.72	0.71	0.12	54.73
1995	0.30	9.62	7.77	18.34	3.12	---	1.62	1.68	0.67	0.64	0.13	43.88
1996	0.30	9.54	8.87	19.69	3.66	---	1.70	2.07	0.68	0.71	0.12	47.34
1997	0.41	12.42	9.92	24.63	9.07	---	2.91	3.32	1.12	1.15	0.25	65.20
1998	0.46	13.17	10.20	25.70	11.16	---	3.42	2.90	1.26	1.31	0.19	69.76
1999	0.45	12.70	10.14	25.32	13.84	---	4.37	3.57	1.76	1.89	0.26	74.31
2000	0.48	10.81	8.44	19.27	15.41	---	5.16	4.69	1.74	1.93	0.35	68.29
2001	0.68	10.29	8.40	21.54	16.34	---	5.01	4.47	1.65	1.84	0.48	70.70
2002	0.85	12.07	8.60	23.13	17.31	---	5.09	4.08	1.21	1.75	0.56	74.66
2003	0.82	11.79	8.41	22.75	17.23	---	5.02	3.86	0.89	1.96	0.42	73.19
2004	0.88	12.16	10.23	25.17	15.46	---	3.56	2.72	0.95	1.66	0.31	73.11
2005	0.80	12.33	10.63	26.03	13.17		3.40	1.98	0.53	2.58	0.37	71.82
2006	0.83	12.01	10.49	25.71	10.79	---	3.33	1.59	0.49	2.37	0.37	67.98
2007	0.78	9.74	8.49	26.31	9.42	---	2.81	1.41	0.55	2.72	0.58	62.81

Table A2. Commercial CPUE (net pounds per skate).

Values before 1984 are raw J-hook catch rates, with no hook correction. 1983 is excluded because it consists of a mixture of J- and C-hook data. No value is shown for area/years after 1980 with fewer than 500 skates of reported catch/effort data. Total column recomputed in 2007 with new bottom area numbers.

	2A	2B	2C	3A	3B	4A	4B	4C	4D	4E	Total
J-hook CPUE:											
1974	59	64	57	65	57	---	---	---	---	---	---
1975	59	68	53	66	68	---	---	---	---	---	---
1976	33	53	42	60	65	---	---	---	---	---	---
1977	83	61	45	61	73	---	---	---	---	---	---
1978	39	63	56	78	53	---	---	---	---	---	---
1979	50	48	80	86	37	---	---	---	---	---	---
1980	37	65	79	118	113	---	---	---	---	---	---
1981	33	67	145	142	160	158	99	110	---	---	---
1982	22	68	167	170	217	103	---	91	---	---	---
1983	---	---	---	---	---	---	---	---	---	---	---
C-hook CPUE:											
1984	63	148	314	524	475	366	161	---	197	---	357
1985	62	147	370	537	602	333	234	---	330	---	400
1986	60	120	302	522	515	265	---	427	239	---	356
1987	57	131	260	504	476	341	220	384	---	---	349
1988	134	137	281	503	655	453	224	---	201	---	392
1989	124	134	258	455	590	409	268	331	384	---	376
1990	168	175	269	353	484	434	209	288	381	---	334
1991	158	148	233	319	466	471	329	223	398	---	328
1992	115	171	230	397	440	372	278	249	412	---	336
1993	147	208	256	393	514	463	218	257	851	---	392
1994	93	215	207	353	377	463	198	167	480	---	326
1995	116	219	234	416	476	349	189	---	475	---	351
1996	159	226	238	473	556	515	269	---	---	---	413
1997	226	241	246	458	562	483	275	335	671	---	419
1998	194	232	236	451	611	525	287	287	627	---	425
1999	---	213	199	437	538	500	310	270	535	---	394
2000	263	229	186	443	577	547	318	223	556	---	412
2001	169	226	196	469	431	474	270	203	511	---	379
2002	181	222	244	507	399	402	245	148	503	---	378
2003	184	231	233	487	364	355	196	105	389	---	349
2004	145	212	240	485	328	315	202	120	444	---	340
2005	155	197	203	446	293	301	238	91	379	---	314
2006	147	202	170	403	292	241	218	72	280	---	284
2007	121	172	164	410	261	213	230	66	216	---	268

Table A3. IPHC setline survey CPUE of legal sized fish in weight (net pounds per skate).

Figures refer to entire areas. For cases where only part of an area was fished (e.g., northern 2B, western 3A), the CPUE shown is an adjusted value. *No hook corrections* are applied; J-hook values are raw J-hook catch rates. Area 4EBS is the eastern Bering Sea shelf, first surveyed in 2006. For other years, the 4EBS CPUE is a constructed value based on the NMFS trawl survey and the single 2006 setline data point.

	2A	2B	2C	3A	3B	4A	4B	4C	4D	4EBS	Total
J-hook surveys:											
1974	---	---	---	---	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---	---	---	---	---
1976	---	---	---	---	---	---	---	---	---	---	---
1977	---	13	---	58	---	---	---	---	---	---	---
1978	---	18	---	27	---	---	---	---	---	---	---
1979	---	NA	---	41	---	---	---	---	---	---	---
1980	---	25	---	76	---	---	---	---	---	---	---
1981	---	16	---	131	---	---	---	---	---	---	---
1982	---	21	114	130	---	---	---	---	---	---	---
1983	---	18	142	119	---	---	---	---	---	---	---
1984	---	25	---	176	---	---	---	---	---	---	---
C-hook surveys:											
1984	---	57	260	361	---	---	---	---	---	7	---
1985	---	42	260	378	---	---	---	---	---	8	---
1986	---	38	283	305	---	---	---	---	---	9	---
1987	---	NA	---	---	---	---	---	---	---	10	---
1988	---	NA	---	---	---	---	---	---	---	20	---
1989	---	NA	---	---	---	---	---	---	---	13	---
1990	---	NA	---	---	---	---	---	---	---	14	---
1991	---	NA	---	---	---	---	---	---	---	12	---
1992	---	NA	---	---	---	---	---	---	---	11	---
1993	---	93	---	261	---	---	---	---	---	22	---
1994	---	NA	---	254	---	---	---	---	---	17	---
1995	29	148	---	300	---	---	---	---	---	20	---
1996	---	156	306	317	352	---	---	---	---	25	---
1997	35	139	411	331	414	237	282	71	111	23	166
1998	---	82	232	281	435	310	216	---	---	30	157
1999	37	88	204	241	438	290	203	---	---	27	147
2000	---	93	233	272	373	282	216	---	215	20	142
2001	41	102	237	256	357	205	171	---	197	21	133
2002	33	92	261	299	297	174	119	---	263	13	128
2003	22	73	223	229	262	158	104	---	195	18	108
2004	27	86	173	270	236	142	73	---	132	18	106
2005	28	72	171	276	211	111	86	---	69	17	99
2006	16	59	144	232	181	88	95	---	63	18	86
2007	19	57	140	212	191	69	87	---	57	13	79

Appendix B. Evolution of IPHC assessment methods, 1982-2007

From 1982 through 1994, the halibut stock assessment relied on CAGEAN, a simple age-structured model fitted to commercial catch-at-age and catch-per-effort data (Quinn et al. 1985). The constant age-specific commercial selectivities used in the model were fundamental model parameters, estimated directly.

Beginning in the late 1980s, halibut growth rates in Alaska declined dramatically. As a result, age-specific selectivity decreased. CAGEAN did not allow for that, and by the mid-1990s was seriously underestimating abundance. In effect, it interpreted lower catches as an indication of lower abundance, whereas the real cause was lower selectivity. Incoming year classes were initially estimated to be small, but in subsequent years' assessments those estimates would increase when unexpectedly large numbers of fish from those year classes appeared in the catches. The year-to-year changes in the stock trajectory shown by the assessment therefore developed a strong retrospective pattern. Each year's fit showed a steep decline toward the end, but each year the whole trajectory shifted upward.

The staff sought to remedy that problem by making selectivity a function of length in a successor model developed in 1995. It accounted not only for the age structure of the population, but also for the size distribution of each age group and the variations in growth schedule that had been observed. The fundamental selectivity parameters in this model were the two parameters of a function (the left limb of a normal density) by which the selectivity of an individual fish was determined from its length. The age-specific selectivity of an entire age group was calculated by integrating length-specific selectivity over the estimated length distribution of the age group, and that age-specific selectivity was used to calculate predicted catches. The new model was fitted to both commercial data and IPHC setline survey data, with separate length-specific selectivity functions. Commercial catchability and selectivity were allowed to drift slowly over time, while survey catchability and selectivity were held constant (Sullivan et al. 1999).

When this model was fitted to data from Area 2B and Area 3A, quite different length-specific selectivities were estimated, which suggested that fishery selectivity was not wholly determined by the properties of the gear and the size of the fish but also depended on fish behavior (e.g., migration). These behavioral elements are likely to be more related to age than size. The age of sexual maturity, for example, remained virtually the same in Alaska despite the tremendous decrease in growth, so the size at maturity is now much smaller than it was. While size must affect selectivity, it was thought that age was also influential.

To allow for that, the model was fitted in two ways. The original form was called the "length-specific" fit, because a single set of estimates of the two parameters of the length-based survey selectivity function was used in all years. In a second form, called the "age-specific" fit, the parameters were allowed to drift over time (like the commercial selectivity parameters), but they were required (by a heavy penalty) to vary in such a way that the integrated age-specific selectivities calculated in each year remained constant over time.

The usual diagnostics gave little reason to prefer one fit over the other. Goodness of fit was similar: good for both in 2B, not so good for either in 3A. The retrospective behavior of both fits was dramatically better than that of CAGEAN and quite satisfactory in all cases, although the length-specific fit was more consistent from year to year in 3A and the age-specific fit was more consistent in 2B (Clark and Parma 1999). The two fits produced very similar estimates of abundance in Areas 2B and 2C, but in 3A the length-specific estimates were substantially higher,

so out of caution the staff catch limit recommendations were based on the age-specific fit through 1999.

The assessment model was simplified and recoded as a purely age-structured model in 2000 to eliminate some problems associated with the modeling of growth and the distribution of length at age. It retained the option of modeling survey selectivity as a function of mean length at age (observed not predicted), but the production fits continued to be based on constant age-specific survey selectivity, estimated directly as a vector of age-specific values rather than as a parametric function of age.

The fit of this model to Area 3A data in 2002 showed a dramatic retrospective pattern, similar to the pattern of successive CAGEAN fits in the mid-1990s. Treating setline survey selectivity as length-specific rather than age-specific largely eliminated the pattern. Accumulated data showing very similar trends in catch at length in IHPC setline surveys and NMFS trawl surveys provided further evidence that setline selectivity is, after all, determined mainly by size rather than by age (Clark and Hare 2003).

Another anomaly of the 3A model fit in 2002 was the unexpectedly large number of old fish (age 20+) in the last few years' catches. This was found to be the result of an increase in the proportion of otoliths read by the break-and-burn rather than surface method. Surface readings tend to understate the age of older fish, and IPHC age readers had been gradually doing more and more break-and-burn readings as the number of older fish in the catches increased. The poor model fit at these ages indicated a need to deal explicitly with the bias and variance of both kinds of age readings.

An entirely new model was written for the 2003 assessment (Clark and Hare 2004). Both commercial and survey selectivity were parameterized as piecewise linear functions of mean length at age in survey catches, and were required to reach an asymptote of one at or before a length of 130 cm. Because females are larger than males, all of the population accounting and predictions were done separately for each sex. (The age/sex/size composition of the commercial landings was estimated external to the assessment for this purpose.) The observed age compositions (surface or break-and-burn) were predicted by applying estimated misclassification matrices to the age distributions. Even in its most parsimonious form—with just one survey and one commercial selectivity schedule for both sexes in all years—this model achieved very good fits to the sex-specific observations and good retrospective performance. It also produced somewhat higher estimates of average recruitment and recruitment variability. With this simple model it was feasible do standalone analytical assessments of abundance in Areas 3B, 4A, and 4B for the first time, using data from 1996-2003.

Only two minor changes were made for the 2004 assessment, and neither had a significant effect on the estimates of abundance. First, both the 2004 PIT tag recoveries (Clark and Chen 2005) and a reanalysis of earlier wire tag data (Clark 2005) indicated that commercial selectivity is not always asymptotic; it appeared to be more dome-shaped in Area 2B and more ramp-shaped in Area 3A. Fitting the assessment model with free-form selectivity schedules showed much the same thing for commercial selectivity, namely an assortment of shapes beyond 120 cm. Nevertheless a schedule that reaches an asymptote of one at 120 cm is a good approximation to and compromise among the free estimates, and using an asymptotic commercial schedule is desirable for computing exploitable biomass and reporting harvest rates, so that it what was used in the assessment. All of the freely estimated survey selectivities either level out or increase after 120 cm. Freely estimated survey

selectivities present no practical difficulties, so they were estimated that way in the assessment, and most of the estimates were ramp-shaped.

Apart from a few minor and inconsequential corrections and alterations, the 2005 analytical assessment was the same as the 2004 assessment. The only important change in procedure was the use of the NMFS trawl survey to estimate biomass in Area 4CDE where an analytical assessment was not done.

In 2006, growing concerns about migration of legal-sized fish from western to eastern areas led the staff to doubt the validity of the closed-area assessments that had been done for many years (Clark and Hare 2007a). The staff therefore estimated coastwide abundance by fitting the model to a coastwide dataset, and estimated biomass in each area in accordance with survey estimates of relative abundance (Clark and Hare 2007b). The 2007 assessment followed the same procedure. Sublegal discard mortality in the halibut fishery was added to the removals included in the assessment; it had the effect of decreasing the present biomass estimate by less than 1%.

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Assessment of the Pacific halibut stock at the end of 2006

William G. Clark and Steven R. Hare

Abstract

Growing concerns about net migration from the western to the eastern Gulf of Alaska have led the staff to doubt the accuracy of the closed-area assessments that have been done for many years. A coastwide assessment with survey apportionment was therefore done in addition to the closed-area assessments this year, and was used to calculate the available yield in each area. The two kinds of assessments produced very similar estimates of total abundance (total exploitable biomass about 400 M lb, total available yield about 80 M lb) but the distribution among areas was quite different, with the coastwide assessment showing more biomass and available yield in Areas 3B and 4 than the closed-area assessments and less in Area 2. Area 3A is about the same in both assessments.

Introduction

Each year the International Pacific Halibut Commission (IPHC) staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). A biological target level for total removals from each regulatory area is calculated by applying a fixed harvest rate to the estimate of exploitable biomass in that area. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for catches in directed fisheries subject to allocation is called the fishery CEY. It comprises the commercial setline catch in all areas plus the sport catch in Areas 2A and 2B. It is calculated by subtracting from the total CEY an estimate of all unallocated removals—bycatch of legal-sized fish, wastage of legal-sized fish in the halibut fishery, fish taken for personal use, and sport catch except in Areas 2A and 2B. Staff recommendations for catch limits in each area are based on the estimates of fishery CEY but may be higher or lower depending on a number of statistical, biological, and policy considerations. Similarly, the Commission's final quota decisions are based on the staff's recommendations but may be higher or lower.

For many years the staff has assessed the stock in each regulatory area by fitting a model to the data from that area (Appendix B). This procedure relied on the assumption that the stock of fish of catchable size in each area was closed, meaning that net migration was negligible. A growing body of evidence from both the assessments (Clark and Hare 2007) and the ongoing mark-recapture experiment (Webster and Clark 2007) shows that there is probably a continuing eastward net migration of catchable fish from the western Gulf of Alaska (Areas 3B and 4) to the eastern side (Area 2). The effect of this migration on the closed-area stock assessments is to produce underestimates of abundance in the western areas and overestimates in the eastern areas. To some extent this has almost certainly been the case for some time, meaning that exploitation rates have been well above the target level in Area 2 and a disproportionate share of the catches have been taken from there.

In order to obtain an unbiased estimate of the coastwide stock this year, the staff built a coastwide data set and fitted the model to it. The coastwide estimate of exploitable biomass (414 M lb) is close to the sum of the closed-area estimates. To estimate the exploitable biomass in each regulatory area, the staff apportioned the coastwide total according to the setline survey index of exploitable biomass in each area (survey CPUE of legal-sized fish multiplied by bottom area). Comparison of this distribution to the closed-area assessments shows that the closed-area assessments were too high by 50-100% in Area 2, meaning that the actual harvest rates there have been 50-100% above the coastwide target.

The closed-area assessments overestimate present abundance in Area 2 because in effect they include fish that are migrating to Area 2 from areas to westward. It could be fairly argued that these really are Area 2 fish, so apportioning yield on the basis of the closed-area assessments is appropriate. And it would certainly be feasible. According to the present estimates, it would mean taking 25% of the coastwide yield from Area 2, which contains 16% of the coastwide biomass. This would not be a conservation issue for the stock as a whole. The fishery has been prosecuted in that fashion for decades, and it is probably sustainable, although harvest rates in the western areas (the source of the migrating fish) have been higher since 1996 than in previous years.

On the other hand, the general practice and the stated policy of the Commission is to harvest in proportion to actual abundance in each area, which means reducing the exploitation rate in Area 2 to the target level, now 20% (Hare and Clark 2007).

In calculating the CEY (Constant Exploitation Yield) estimates for each area, the staff has taken a middle course, applying a 25% harvest rate in Area 2 instead of the target. This approach moves the exploitation rate closer to the target but at the same time recognizes the stock distribution implied by the eastward migration, and the historical distribution of catches.

Development of a coastwide assessment

In 2006 growing concerns about evidence of migration of legal-sized fish from the western Gulf of Alaska (Areas 3B and 4) to the east (Area 2) led the staff to question the accuracy of the customary closed-area assessments, which assume that the stock in each area is a closed population (Clark and Hare 2007). The effect of migration on the customary closed-area assessments is to produce underestimates of present abundance in the areas from which fish are emigrating (Areas 3B and 4) and overestimates in the areas into which they are immigrating (Area 2). This happens because emigration inflates the closed-area estimates of fishing mortality in the source areas and immigration shrinks them in the receiving area. Moreover, there is no assurance that the sum of the biased estimates from faulty closed-area assessments will be an accurate estimate of the total coastwide abundance, so the staff was concerned about our estimates of total abundance as well as our estimates of abundance in each regulatory area.

In order to obtain accurate estimates of abundance both coastwide and by area, the staff conducted a coastwide assessment and then estimated the proportion in each regulatory area using the survey index of exploitable biomass in each area (survey CPUE of legal-sized fish multiplied by bottom area). The coastwide assessment is not affected by migration because fish on the move contribute to the single series of commercial and survey catch rates wherever they go. The estimate of total abundance can therefore expected to be accurate, and it is also more precise than the area-specific estimates because the coastwide data series are much less noisy than the data from individual areas.

Apportionment of the estimated coastwide biomass among regulatory areas is a difficult problem. Our best estimate of relative abundance in each area is certainly the survey index, but that relies on the assumption that survey catchability is the same in all areas, which is uncertain.

It seems likely that catchability is similar in Areas 2B and 2C, and in Areas 3A and 3B, but what about Areas 2A and 4B? Some checks for differences in survey catchability are reported below.

Data compilation

The first stage of work was to assemble coastwide series of commercial and survey data. Commercial catch-at-age and CPUE data series could be compiled straightforwardly because IPHC has collected specimen and logbook data from all areas for many years. Commercial CPUE data from Areas 2A and 4C were not included in the coastwide series because of unique features of the fisheries in those areas. Like the data series used for the closed-area assessments in Areas 3B and 4, the coastwide data series goes back only to 1996 because survey data are required to estimate the sex composition of commercial landings.

Survey data were more challenging because even in recent years there have been gaps in our survey coverage in Areas 2A, 4A, and 4D, and until 2006 no surveys at all on the eastern Bering Sea shelf, which comprises about half the continental shelf in the Commission area. The gaps in recent survey data in Areas 2A, 4A, and 4D were filled by interpolation in some cases and predictive relationships in others (Clark and Hare 2007). A setline survey was done on the eastern Bering Sea shelf for the first time in 2006 (Dykstra et al. 2007). The 2006 survey CPUE (18 lb/skate) was used to scale an index of exploitable biomass calculated from the swept-area estimates of total abundance at length obtained from the annual NMFS trawl survey of the eastern Bering Sea shelf in 1982-2006.

Bycatch, sport catch, and personal use catches were similarly combined. In the end we had catch data sets including all removals, and properly weighted commercial and survey age composition and CPUE series representing the entire Commission area, including Area 4CDE. The coastwide data set is the same as any of the area-specific data sets; it just refers to the whole coast.

Model-free estimates of mortality and abundance

When a stock assessment model is fitted, total mortality is estimated from the year-to-year decline in the CPUE of individual cohorts, fishing mortality is estimated as the difference between total mortality and natural mortality, and abundance is estimated from the known removals at the estimated rate of fishing mortality. The same estimates can be approximated external to the full assessment model from plots of CPUE at age by cohort in recent years (Fig. 1). The year-to-year change in CPUE has to be adjusted for the year-to-year change in selectivity, which is taken from the full stock assessment, but those selectivity estimates are very well determined, and they hardly affect the estimates of total mortality of fish that are at least 50% selected.

The 1992-1995 year-classes were 11-14 years old in 2006, 90-100 cm long, and about 50% selected. Their average total mortality (Z) in recent years was about 0.25, so with natural mortality M = 0.15, fishing mortality (F) for them was about 0.1, implying a fully selected F of 0.2. Similarly, fishing mortality was about 0.15 for the 1989-1991 year-classes which were 80% selected, again suggesting a fully selected F around 0.2. All of the older year-classes in the plots were fully selected in 2006 and had estimated total mortality of 0.4-0.5, implying a fully selected F of .25-.35. The highest values doubtless reflect some senescent mortality among the oldest fish, so on the whole the plots suggest a fully selected F of 0.2-0.3. With F = 0.25 and M = 0.15, the exploitation rate was about 20%. Coastwide removals by all fisheries in 2006 were about 80 million pounds, so exploitable biomass was roughly 400 million pounds. The commercial fishery accounted for 80% of all removals, so commercial fishing mortality was about 0.2.

Model fits

The model fitted to the coastwide data is the one described by Clark and Hare (2006) that has been used since 2003 for the closed-area assessments. Like other stock assessment models, it estimates initial numbers, subsequent recruitments, fishing mortality, and fishery and survey catchability and selectivity parameters by predicting commercial catch at age, survey age composition, and commercial and survey CPUE. Selectivity is determined by length, and females and males are tracked separately because growth differs by sex. The likelihood that is maximized follows Fournier et al. (1990): all errors are treated as being normally distributed, and the externally estimated sampling variance of each observation is multiplied by a variance scaler to standardize the variances. During the final phase of fitting the deviations are computed with a robust formula that limits the influence of extreme deviations. In the coastwide assessment some 2150 observations are fitted and the sum of squares is similar in size, so the variance scaling is effective overall and the root mean squared errors for all data types are near one. There is some double fitting involved; for example the total catch at age is fitted as well as the catch at age of females and males. The calculated likelihood is scaled down accordingly to obtain accurate variance estimates based on the inverse Hessian and to provide appropriate deviances for calculating the Akaike Information Criterion (AIC) in the model selection table below.

The model can be fitted in various ways, the differences lying in what data types are fitted, how the errors are weighted, and how many parameters are estimated. Seven coastwide fits were done this year, summarized below. (A detailed specification of each fit is given in Table 2.) Fit 0 is the customary closed-area fit. It is parsimonious and heavily reliant on the series of total commercial and survey CPUE data. It does not attempt to fit CPUE at age. All of these features help to stabilize the closed-area fits where in some cases the data are noisy and the abundance estimates are quite sensitive to how the model is fitted. The coastwide data set is very orderly and the abundance estimates are not very sensitive to how the model is fitted, so other alternatives can be considered.

Fit 1 removes the heavy weight on total CPUE and adds CPUE at age to the fit. Fits 1-6 all calculate the same sum of squares but it is different from the one calculated by Fit 0, so no AIC value is shown for Fit 0. Fit 2 estimates separate selectivity, catchability, and natural mortality parameters for females and males; it is a major improvement on Fit 1.

Fit 3 is an attempt to allow for the variations in survey catchability that have taken place during the last ten years. These variations can be estimated by running the assessment model as a Virtual Population Analysis (VPA). This is done by fixing the value of F in 2006 and then freely estimating the catchabilities in each year. The true value of F in 2006 is unknown, but it is clear from the model-free estimates above and all the model fits that it must be near 0.2. The plotted values (Fig. 2) show that survey catchability is quite variable and that it was relatively high in 1997 and low in 2006. (There is no coastwide survey value for 1996.) This happenstance produces a spurious trend in the data. To avoid that, three survey catchability parameters are estimated in Fit 3: one for 1997, one for 1998-2005, and one for 2006. It is a slight improvement on Fit 2 but the AIC is almost the same.

Fit 4 mimics the assessments done for most Alaska stocks by the National Marine Fisheries Service: the commercial catch at age is fitted with a separable model, but commercial CPUE is not used, so the trends in estimated abundance are determined by survey CPUE. This results in a worthwhile reduction in the AIC. Despite this, we prefer to continue to use commercial CPUE in the assessment with commercial catchability allowed to drift subject to a penalty. VPA runs show that commercial catchability, while not constant, is much less variable than survey catchability (Fig. 3), and we believe this can improve the year-to-year continuity of the assessment.

Fit 5 is the opposite of Fit 4; it holds commercial catchability constant and so gives equal weight to commercial and survey CPUE in estimating trends in abundance. We do not believe that commercial catchability can be expected to remain constant for any extended period of time, but for the number of years in this assessment it might be a reasonable working assumption. The AIC is similar to Fits 2 and 3.

Fit 6 harks back to CAGEAN, the model that was used by IPHC from the mid-1980s to the mid-1990s, except that survey as well as commercial data are used and selectivity is determined by length rather than age. It is a substantially worse fit than the others.

Our choice for a reference assessment is Fit 3. It has the lowest AIC except for Fit 4, it is not affected by some of the recent ups and downs in survey catchability, and the biomass estimate is near the middle of the range of plausible fits.

Description of fit	Number of parameters	AIC	Commercial F in 2006	Biomass in 2007
0. The customary closed-area fit: same parameters for females and males, constant survey catchability, penalized drift in commercial catchability, heavy weight (10) on total commercial and survey CPUE; CPUE at age not fitted.	104	NA	0.22	377
1. Same as Fit 0 except: neutral error weighting, and fit to commercial and survey CPUE at age added to likelihood.	104	1318	0.24	345
2. Same as Fit 1 except: separate parameters estimated for females and males.	119	1142	0.22	378
3. Same as Fit 2 except: three survey catchabilities estimated: 1997, 1998-2005, and 2006.	121	1138	0.21	414
4. Same as Fit 3 except: commercial catchability estimated freely each year.	129	1128	0.20	425
5. Same as Fit 3 except: constant commercial catchability.	119	1141	0.18	469
6. Same as Fit 3 except: constant commercial and survey catchability (CAGEAN).	117	1160	0.19	445

Quality of fits

For the most part the fitted model predicts the observations quite well, even down to the sex-specific CPUE at age (Figs. 4 and 5). As in the area-specific fits, the model negotiates the change from surface ages to break-and-burn ages in 2002 smoothly, and the fit to the data in years since then is generally better than in earlier years when the surface age compositions are predicted by a misclassification matrix that smears the older ages widely. The total commercial and survey CPUE values are perforce also fitted well (Fig. 6).

Variance estimates

The coefficient of variation of the 2007 exploitable biomass estimate, calculated from the inverse Hessian, is about 7%, which is half the value found in closed-area assessments (Clark and Hare 2006). A normal approximation of the marginal distribution of the estimate is quite close to the calculated likelihood profile (Fig. 7). The spread of the distribution is similar to the spread of point estimates among plausible model fits.

Area apportionment

The estimated coastwide exploitable biomass in 2007 is 414 M lb. To estimate the biomass in each regulatory area, we used a survey index of biomass calculated as the average of the last three years' survey CPUE of legal-sized fish multiplied by the bottom area lying between zero and 300 fathoms in each regulatory area. The proportions and biomass estimates are shown in Table 1 in the section relating to the 2006 coastwide assessment.

Selectivity, target harvest rate, and CEY

In the coastwide assessment, exploitable biomass is calculated with the commercial length-specific selectivity schedule estimated in the assessment, and we have adopted that schedule as our standard commercial selectivity for use in the fishery simulations and calculations of spawning biomass per recruit that are done to choose a target harvest rate. The old standard was an average of Alaska commercial selectivities estimated in the closed-area assessments. The new coastwide schedule is a little higher, so a new harvest rate analysis produced a reduction in the target harvest rate, from 0.225 to 0.20 (Hare and Clark 2007).

The new coastwide target harvest rate of 0.20 was used to calculate total CEY in Areas 3A, 3B, and 4A. A lower rate was applied in Areas 4B and 4CDE for reasons given by Hare and Clark (2007). A higher rate—25%—was applied in Area 2. As explained below, this rate is at present midway between the coastwide target and the rate that would have to be applied to match the CEY that would be estimated by closed-area assessments in Area 2.

Comparison of the coastwide and closed-area assessments

The staff's biomass and CEY estimates are based mainly on the coastwide assessment with survey apportionment. We have also done the customary closed-area assessments for comparison, meaning we have performed Fit 0 to the data from each area (Fig. 9).

Standardization of commercial selectivities

In order to make the results of the coastwide and closed-area assessments comparable, we have calculated exploitable biomass in all areas with the new standard coastwide commercial selectivity, and we have generally used the new coastwide target harvest rate of 0.20 (0.15 in Areas 4B and 4CDE) to calculate CEY. For most areas this change has little effect, because for any given set of life history parameters, there is a tradeoff between the selectivity schedule used and the target harvest rate chosen, such that the target length-specific harvest rates come out about the same when a new selectivity and a new target harvest rate are adopted. The exception is Area 2B (and implicitly 2A), where exploitable biomass has been calculated in an irregular fashion for the last three years.

In 2003, when the present assessment model was adopted, the staff chose a standard commercial selectivity schedule that was near the middle of the schedules estimated in the closed-area assessments (Fig. 8). In fact it was very close to the average of all the locally estimated Alaska schedules, so it has been called the Alaska fixed schedule. This schedule was used in the harvest rate analysis that produced the old 0.225 target harvest rate, and it was used to calculate exploitable biomass in all areas except Area 2B (and implicitly 2A). It did not matter that it differed from the locally estimated schedules so long as the same schedule was used to do the harvest rate analysis and to calculate exploitable biomass. The locally estimated Area 2B schedule was substantially higher than the Alaska fixed schedule, and using the latter in Area 2B would have reduced the estimated exploitable biomass there by a third. The staff was unwilling to make such a drastic reduction on the strength of a new assessment and so used the locally estimated schedule for Area 2B. The same practice was followed in 2004 and 2005. This practice was irregular because we used the same target harvest rate in Area 2B as elsewhere, so in the case of Area 2B we were using one selectivity schedule for the harvest rate analysis and another for the exploitable biomass calculation. In effect we were overstating the exploitable biomass in Area 2B (and 2A) by using a different yardstick there. Stated another way, we were fishing at a rate about 25% above the target rate appropriate to the higher selectivity.

In this year's closed-area assessments we have used the same commercial selectivity schedule—the coastwide standard—to calculate exploitable biomass in all areas including 2B (and 2A), and we have generally used the new coastwide target harvest rate (0.20). Except in Area 2B (and 2A), this just means applying a lower harvest rate to a higher exploitable biomass, because the coastwide schedule is higher than the old Alaska fixed schedule. But in Area 2B (and 2A) it means applying a lower harvest rate to a substantially lower biomass, because the coastwide schedule is lower than the locally estimated one. It is not as much lower as the old Alaska fixed schedule, but it lowers the calculated biomass by about a fifth (rather than a third).

Area-specific results

Along with the coastwide assessment results apportioned to areas according to the survey biomass index, Table 1 shows the evolution of closed-area results from last year's numbers to this year's. Last year's assessment estimated abundance at the beginning of 2006. This year's assessment re-estimates abundance at the beginning of 2006 in light of the 2006 data and also estimates abundance at the beginning of 2007. The 2007 exploitable biomass estimates are shown as they would have been calculated with the old standard commercial selectivities (local in Area 2B/2A, Alaska fixed elsewhere) and with the new coastwide standard.

In Area 2B, last year's closed-area estimate of biomass at the beginning of 2006 was 61 M lb, but that is revised downward sharply to 48 M lb in this year's closed-area assessment. This year's closed-area assessment estimates biomass at the beginning of 2007 to be 50 M lb as calculated with the old (local) selectivities, but only 39 M lb when calculated with the coastwide selectivity.

Applying the coastwide target harvest rate of 20% to that gives a total CEY of 7.8 M lb, less than 60% of last year's 13.73 M lb. The main reasons for the decrease are the downward revision of estimated abundance at the start of 2006 (which also occurs in the 2C and 3B assessments) and the switch from local to coastwide selectivities. The lower harvest rate plays a small part. This year's estimate of exploitable biomass in Area 2B is 9.4% of the sum of closed-area estimates of exploitable biomass in 2007 (416 M lb, virtually the same as the 414 M lb estimated by the coastwide assessment). In contrast, last year's estimate of 61 M lb was 16% of the total. Even if we continued with the closed-area assessments, therefore, the estimated 2007 biomass in Area 2B would be much lower than last year, in both absolute and relative terms.

The survey estimate of the proportion of coastwide biomass in Area 2B is 6.5%, which applied to the coastwide estimate of 414 M lb gives 27 M lb in Area 2B. Given this biomass estimate, we would have to fish at 50% above the target rate to obtain the same CEY that would have been estimated for Area 2B if we had continued the closed-area assessments. The same is true in Areas 2A and 2C. And that is not unthinkable. It now appears that we have been fishing well above target in Area 2 for decades, and the fishery is clearly sustainable so long as total removals from the entire stock are on target. Rather than ignore this longstanding pattern of exploitation, the staff has calculated CEY in Area 2 using a harvest rate of 25% that is intermediate between the coastwide target (20%) and the historical practice (50% above 20% = 30% using this year's numbers). The estimated CEY of 6.75 M lb in Area 2B is therefore 25% of the biomass estimate of 27 M lb from the coastwide assessment.

Area 2A follows much the same course as Area 2B. The closed-area estimate of biomass in Area 2A is 12.5% of Area 2B biomass based on the survey index, and this relative value is naturally the same when abundance in both areas is estimated by distributing the coastwide total according to the survey index.

The closed-area assessment in Area 2C follows a different course. There last year's closed-area estimate of biomass at the beginning of 2006 was 61 M lb, just as in Area 2B, and this estimate was also revised down sharply (to 47 M lb) in this year's closed-area assessment. But the change to coastwide selectivity then raises the Area 2C estimate to 57 M lb, close to last year's, with a CEY of 11.4 M lb. The 57 M lb estimated in Area 2C is 13.7% of the coastwide total, but the survey sees only 8.0% of the total in Area 2C, or 33 M lb, not much more than in Area 2B. At a harvest rate of 25%, this gives a total CEY of 8.25 M lb. Unlike Area 2B, therefore, Area 2C would not be greatly affected by changes in this year's closed-area assessment with coastwide selectivity, but it is greatly affected by the change to a coastwide assessment with survey apportionment.

In Area 3A, despite some ups and downs in the closed-area estimates, the total CEY is about the same in both kinds of assessment. Area 3A is the man in the middle, where exploitation rates have probably been close to the target in recent years.

As would be expected, Area 3B gains substantially from the coastwide assessment. This year's closed area estimate of CEY (10.4 M lb) is not much different from last year's (9.0 M lb), but the survey sees 20.8% of the coastwide biomass in Area 3B, giving a total CEY (at a 20% harvest rate) of 17.2 M lb. The relative increases are similar in Areas 4A and 4B although the absolute amounts are smaller.

Area 4CDE is unlike the other areas in that exploitable biomass there was calculated last year from the NMFS trawl survey estimate of total abundance. Last year's estimate was 36 M lb, which was calculated using a trawl survey catchability of 1.3 (rather than 1.0) to allow for herding. We have since been advised that halibut are probably not herded by the trawl cables, so when we update that estimate this year we get 50 M lb. The setline survey of the eastern Bering Sea shelf in 2006 had a CPUE of 18 lb/skate, which when included in the survey index implies 10.1% share of coastwide biomass, or 41 M lb. Both of these estimates are valid, and either could be used this year. The trawl survey estimate is less variable than this year's setline survey CPUE (which a coefficient of variation of 20% vs 10% for the trawl survey), and there is no assurance that the setline survey will be repeated. In future years, therefore, it is likely that we will revert to using the trawl survey.

Checks for differences among areas in survey catchability

The area apportionments of exploitable biomass in this year's coastwide assessment rely on the survey index of abundance (survey CPUE multiplied by bottom area). Specifically, they assume that survey catchability is the same in all areas, meaning that a skate of survey gear fishing on the same density of fish on the bottom will have the same CPUE in all areas. This is not certain. It was long thought, for example, that survey catchability was lower in Area 2B because of competition with dogfish for the bait. Similarly, strong tides in some areas might be thought to reduce catchability.

In trawlable areas it is possible to check for differences in setline catchability among areas by comparing trawl and setline catch rates of fish of the same size. Figure 10 (reproduced from Clark and Hare 2007) shows the ratio of IPHC setline to NMFS trawl survey catch rates at length in Areas 3A, 3B, and 4A, where the trawl survey can be expected to provide a reliable index of abundance. Unfortunately, this is not the case in other parts of the Gulf of Alaska. At least in Areas 3A, 3B, and 4A, however, there is no indication of any large differences. The data are too noisy to rule out small or even moderate differences.

Another indication of differences among areas in survey catchability would be differences in the relative frequency of PIT tags in catches. The PIT tag release was done by tagging all fish caught on three skates of gear at every survey station in order to mark in proportion to abundance in all areas, so if survey catchability really is the same in all areas PIT tags should be recovered at the same rate (tags recovered per 10,000 fish scanned) in all areas. On the other hand, if survey catchability is low in some area, there should be fewer recoveries per 10,000 fish scanned from that area because a smaller proportion of the stock would have been marked on the survey. Table 3 shows the recovery rates of fish released coastwide in 2003 by year and area (Forsberg 2007 and references therein). In commercial catches there is no difference among Areas 2B, 3A, and 3B, but recovery rates were consistently and significantly higher in Area 2C, and there were some significant differences among ports in Area 3A. The recovery rate in Homer was consistently about half that in Kodiak and Seward.

In 2006 all fish caught on the IPHC setline survey were scanned as well, and there recovery rates were much higher than in commercial landings and consisted overwhelmingly of fish released at the station where they were caught. We thought we had achieved a very even distribution of marked fish by releasing them in proportion to abundance on the 10 nautical mile survey grid, but evidently the probability of catching a tagged fish depends on precisely where a boat fishes. There is probably some difference in the distribution of commercial fishing relative to the location of survey stations that accounts for the higher recovery rates in Area 2C and the lower rates in Homer. Whatever the reason, it reduces confidence in the finding that there is no difference in recovery rates among Areas 2B, 3A, and 3B.

The one clean comparison among areas is the recovery rates observed in the survey (last section of Table 3), which unfortunately were very few in Area 2. For what they are worth, however, they show no significant differences among areas with the exception of a marginally significant lower rate in Area 3B. In particular, like the commercial data they show no evidence of a lower recovery rate, and therefore a lower survey catchability, in Area 2.

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Table 1. Estimates of exploitable biomass and CEY from the 2006 assessment.

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
2006 total CEY	1.71	13.73	13.73	32.18	9.00	3.80	1.35	5.40	80.90
2006 catch limit [1]	1.38	13.22	10.63	25.20	10.86	3.35	1.67	3.55	69.86
2006 exploitable biomass									
2005 area assessments	7.6 [2]	61	61	143	45	19	9	36	382
2006 area assessments	6.0	48	47	163	35	16	11	50	376
2007 exploitable biomass									
2006 area assessments									
—Using old selectivities	6.3	50	48	159	40	15	10	50 [3]	378
—Using new selectivities	4.9	39	57	186	52	17	10	50	416
—Proportion of total	0.012	0.094	0.137	0.447	0.125	0.041	0.024	0.120	1.000
—Total CEY [4]	1.00	7.8	11.4	37.2	10.4	3.4	1.50	7.5	80.2
—Fishery CEY [5]	0.73	7.27	7.61	29.31	9.97	2.83	1.21	5.20	64.13
2006 coastwide assessment with survey apportionment									
—Survey proportion	0.009	0.065	0.080	0.423	0.208	0.069	0.045	0.101	1.000
—Exploitable biomass	3.7	27	33	176	86	29	19	41	414
—Total CEY [4]	0.93	6.75	8.25	35.2	17.2	5.8	2.85	6.15	83.13
—Fishery CEY [5]	0.66	6.22	4.46	27.31	16.77	5.23	2.56	3.85	67.06
Other removals									
Sport catch	0.52	2.26	3.03	6.09	0.01	0.06	---	---	11.97
Legal-sized bycatch	.23	.19	.14	1.32	0.36	0.46	0.28	2.21	5.19
Personal use	0.04	0.30	0.60	0.43	0.05	0.04	0.00	0.09	1.55
Legal-sized wastage	0.00	0.04	0.02	0.05	0.01	0.01	0.01	0.00	0.14
Total	0.79	2.79	3.79	7.89	0.43	0.57	0.29	2.30	18.85
…excluding sport catch	0.27	0.53	---	---	---	---	---	---	---

Notes on Table 1:
1. 2006 catch limit and 2007 fishery CEY include sport catch in Areas 2A and 2B.
2. Area 2A exploitable biomass estimated as 12.5% of Area 2B.
3. Increase in 4CDE results from a reduction of the working value of trawl survey catchability from 1.3 to 1.0.
4. In the area-specific assessments, total CEY is calculated as 20% of exploitable biomass in Areas 2A through 4A, and 15% in Areas 4B and 4CDE. In the coastwide assessment with survey apportionment, total CEY is calculated as 25% of exploitable biomass in Area 2, 20% in Areas 3 and 4A, and 15% in Areas 4B and 4CDE.
5. Fishery CEY is calculated as Total CEY less the other removals detailed below.

Table 2. Specification of the alternative model fits reported above.

	Fit						
Feature	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Fit commercial catch at age	x	x	x	x	x	x	x
Fit total commercial CPUE	x	x	x	x	x	x	x
Fit commercial CPUE at age		x	x	x	x	x	x
Fit survey age composition	x	x	x	x	x	x	x
Fit total survey CPUE	x	x	x	x	x	x	x
Fit survey CPUE at age		x	x	x	x	x	x
Same parameters used for females and males	x	x					
Heavy weight (10) on total commercial and survey CPUE	x						
Penalized drift in commercial catchability	x	x	x	x			
Constant survey catchability	x	x	x				x
Neutral error weighting (all weights = 1)		x	x	x	x	x	x
Estimate separate parameters for females and males			x	x	x	x	x
Estimate 3 survey catchabilities: 1997, 1998-2005, and 2006				x	x	x	
Estimate commercial catchability each year (no drift penalty)					x		
Constant commercial catchability						x	x

Table 3. Relative frequency of PIT tags released in 2003 in subsequent catches.

Type and year	Area of catch	Fish scanned (thousands)	Number of recoveries	Recoveries per 10,000 scanned ± std. dev.
2004 commercial	2B	209	72	3.4±0.4
	2C	125	92	7.4±0.8
	3A	448	128	2.9±0.3
	3B	320	80	2.5±0.3
2005 commercial	2B	196	57	2.9±0.4
	2C	147	86	5.9±0.6
	3A	511	194	3.8±0.3
	3B	276	117	4.2±0.4
2006 commercial	2B	219	73	3.3±0.4
	2C	138	69	5.0±0.6
	3A	511	183	3.6±0.3
	3B	203	67	3.3±0.4
Total commercial	2B	624	202	3.2±0.3
	2C	410	247	6.0±0.4
	3A	1469	505	3.4±0.2
	3B	799	264	3.3±0.2
2006 survey	2B	2.5	10	39±12
	2C	4.0	5	12±5
	3A	23.7	45	19±3
	3B	13.1	13	10±3
	Total	30.2	60	20±3

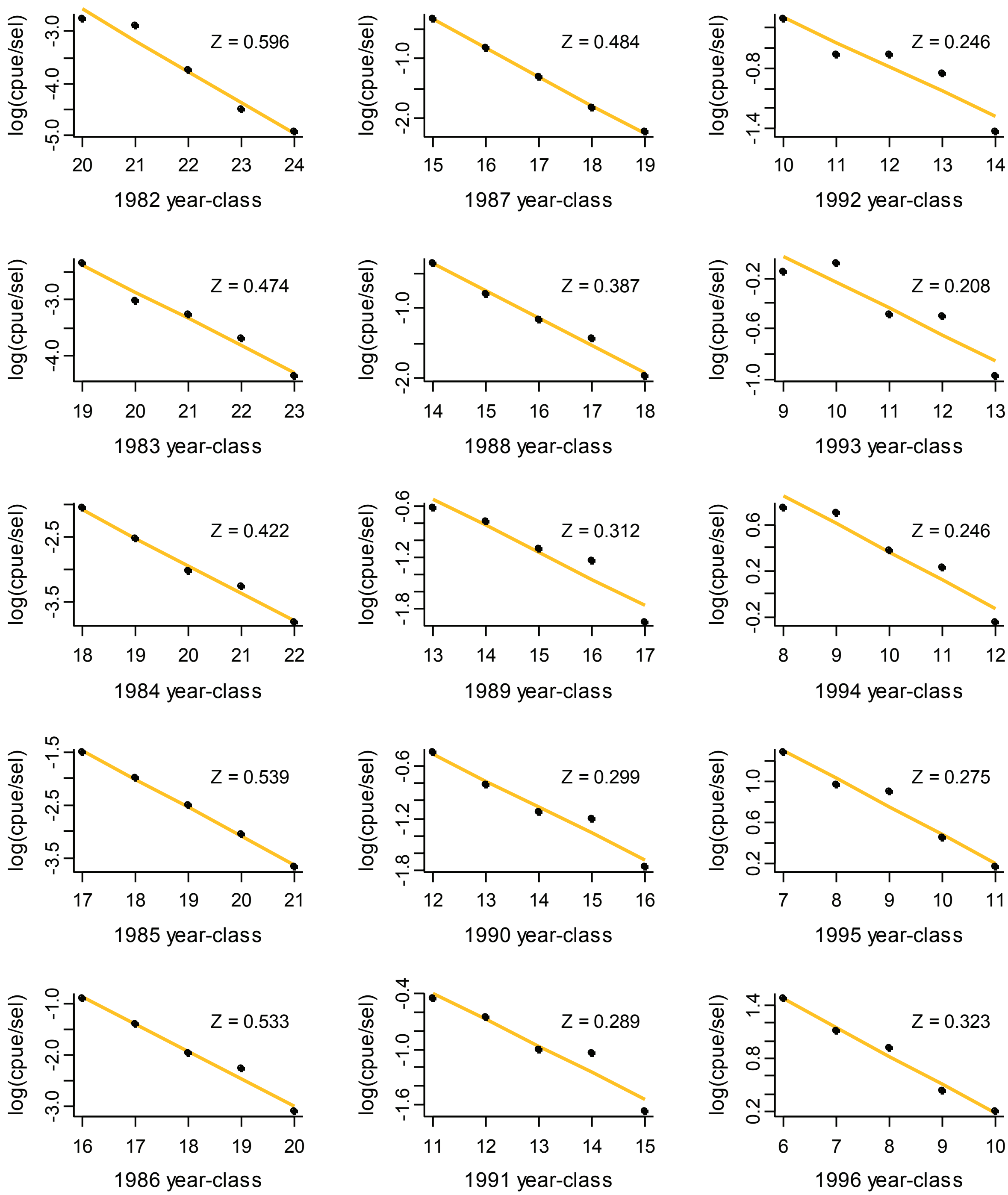

Figure 1. Instantaneous rate of total mortality (Z) estimated from the coastwide decline of survey CPUE of females of each year-class at the ages shown. The points plotted in every graph are from the years 2002-2006, for which break-and-burn ages are available. The value on the y-axis is log(CPUE) corrected for selectivity.

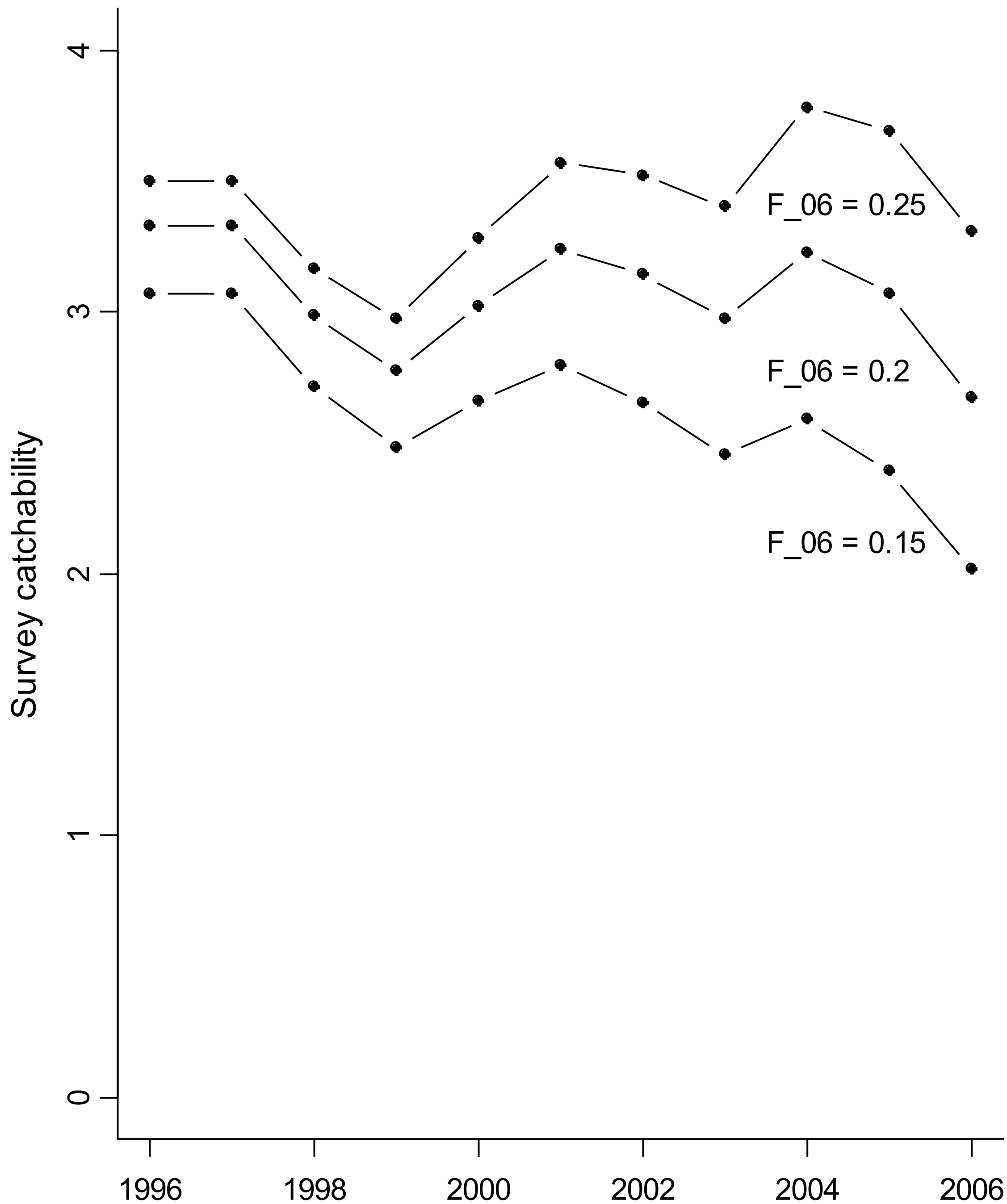

Figure 2. Values of survey catchability calculated in coastwide VPA runs with fishing mortality in 2006 (F_06) fixed at different levels.

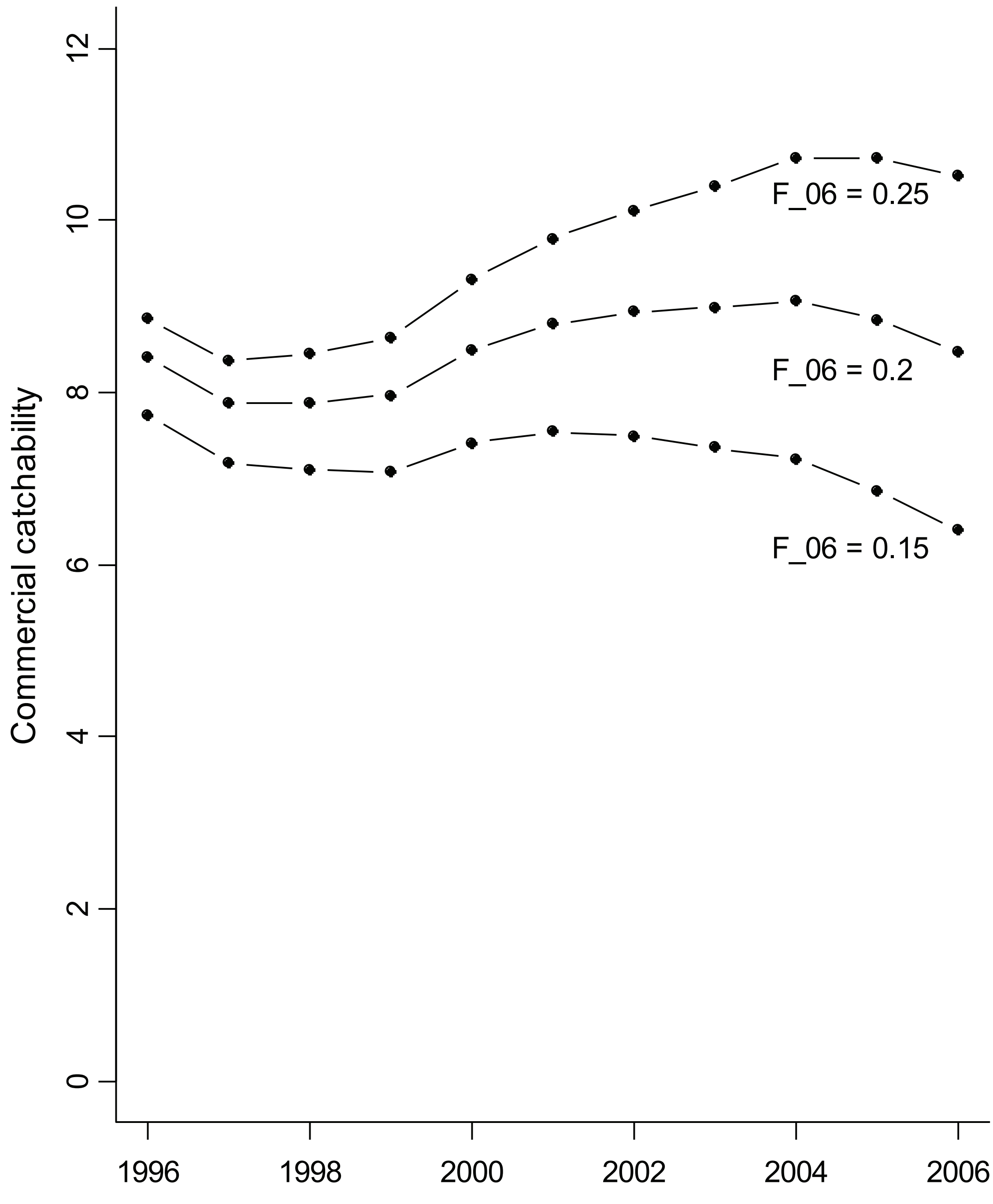

Figure 3. Values of commercial catchability calculated in coastwide VPA runs with fishing mortality in 2006 (F_06) fixed at different levels.

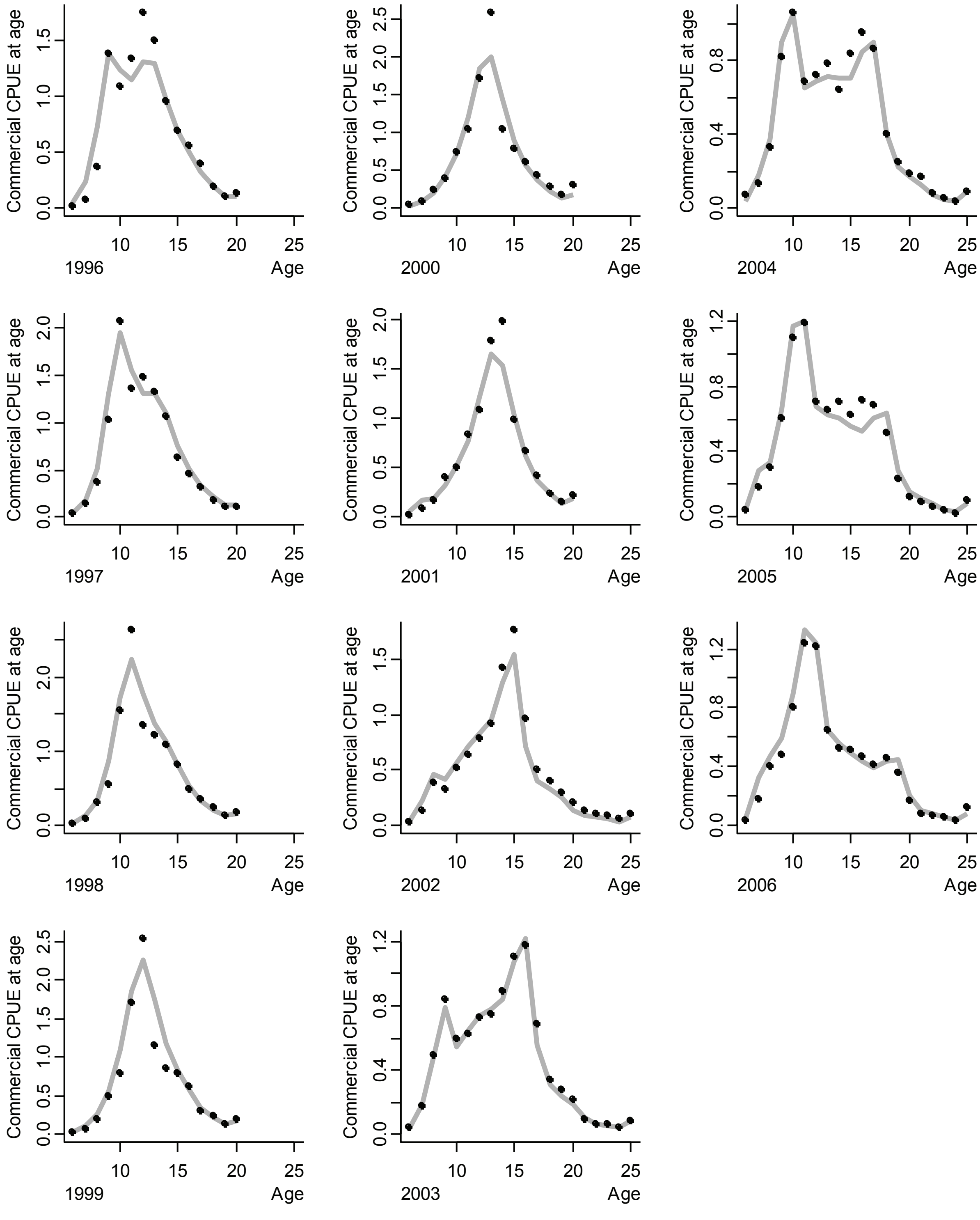

Figure 4a. Observed (points) and predicted (lines) commercial CPUE at age (fish/skate) of females from the coastwide assessment.

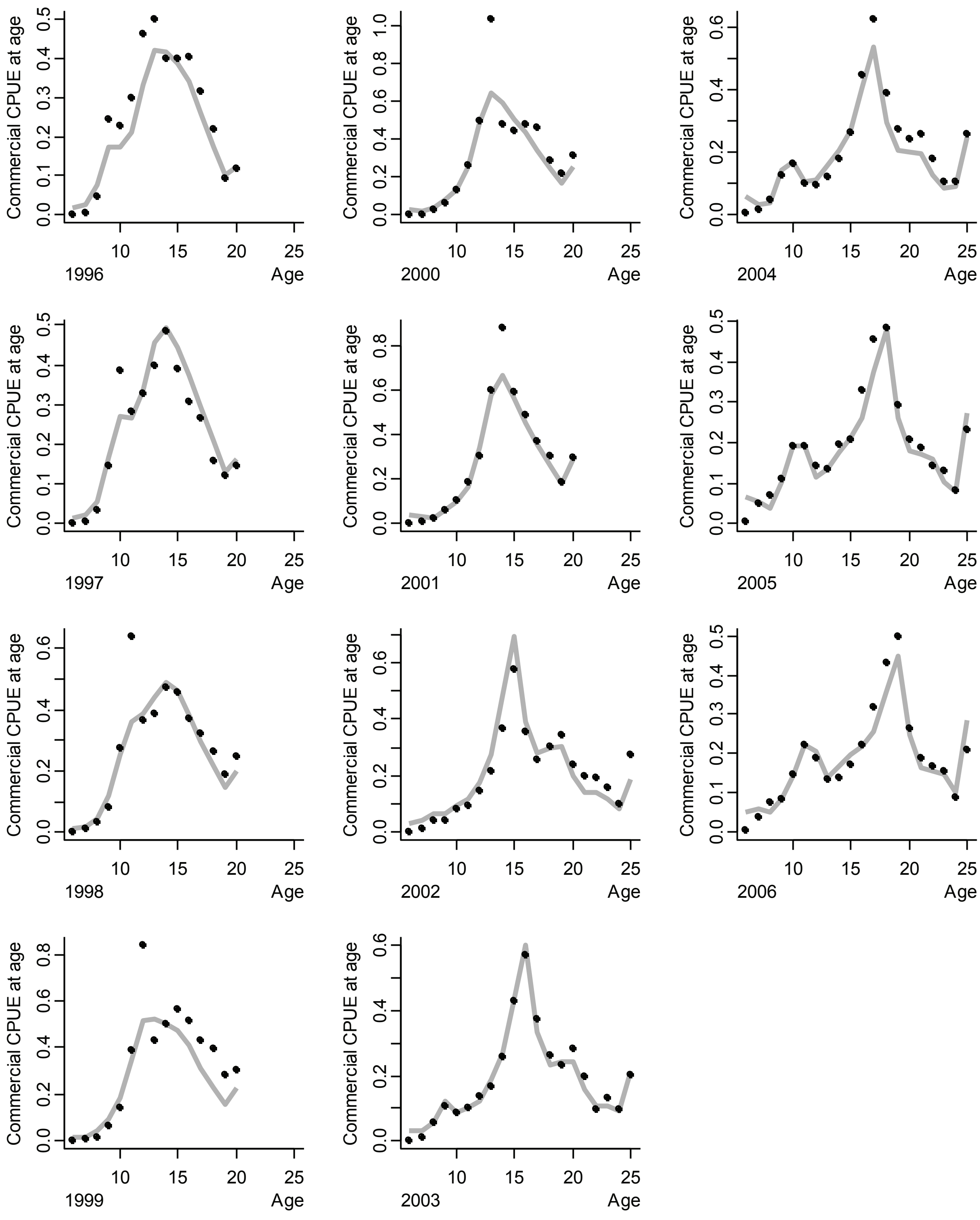

Figure 4b. Observed (points) and predicted (lines) commercial CPUE at age (fish/skate) of males from the coastwide assessment.

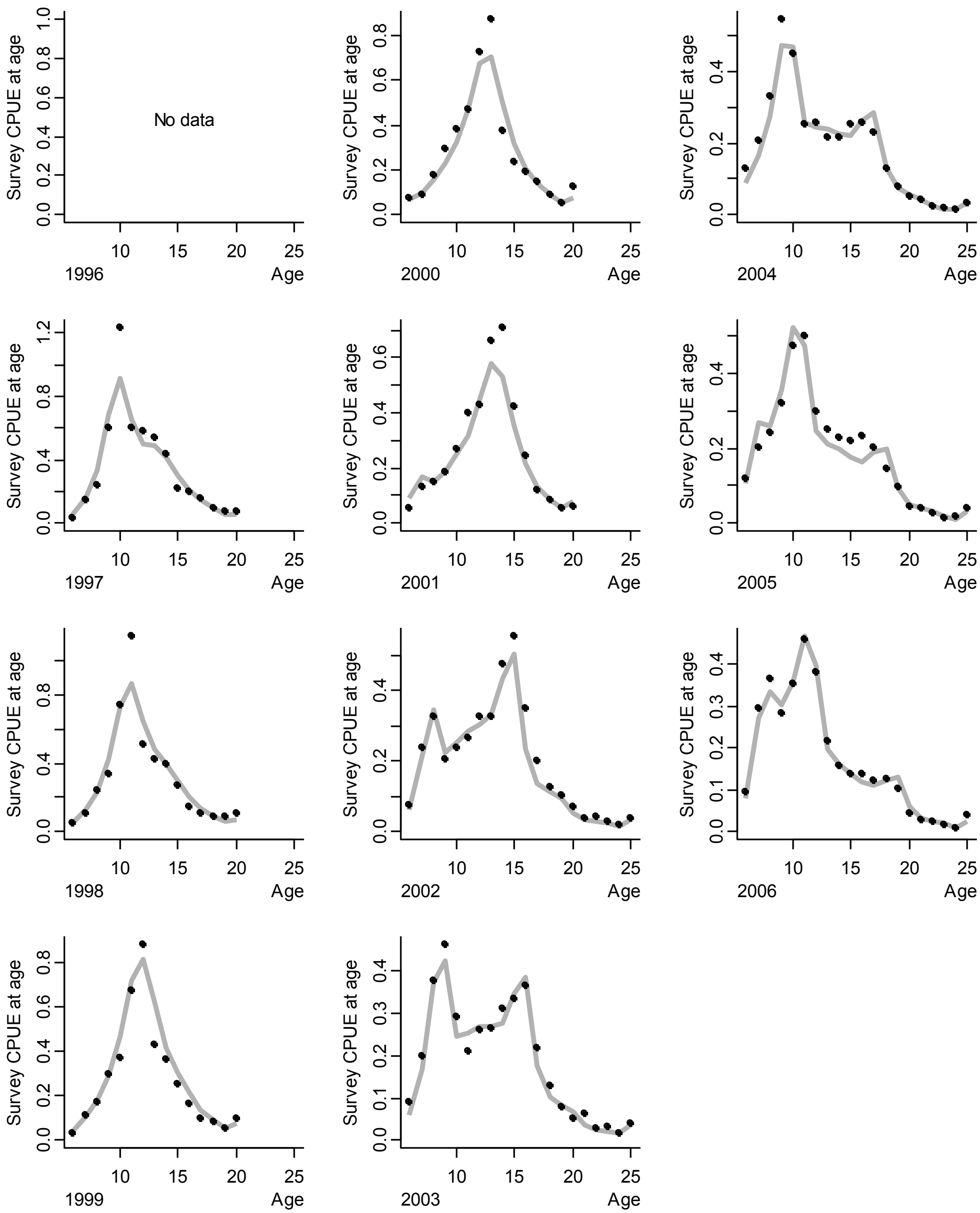

Figure 5a. Observed (points) and predicted (lines) survey CPUE at age (fish/skate) of females from the coastwide assessment.

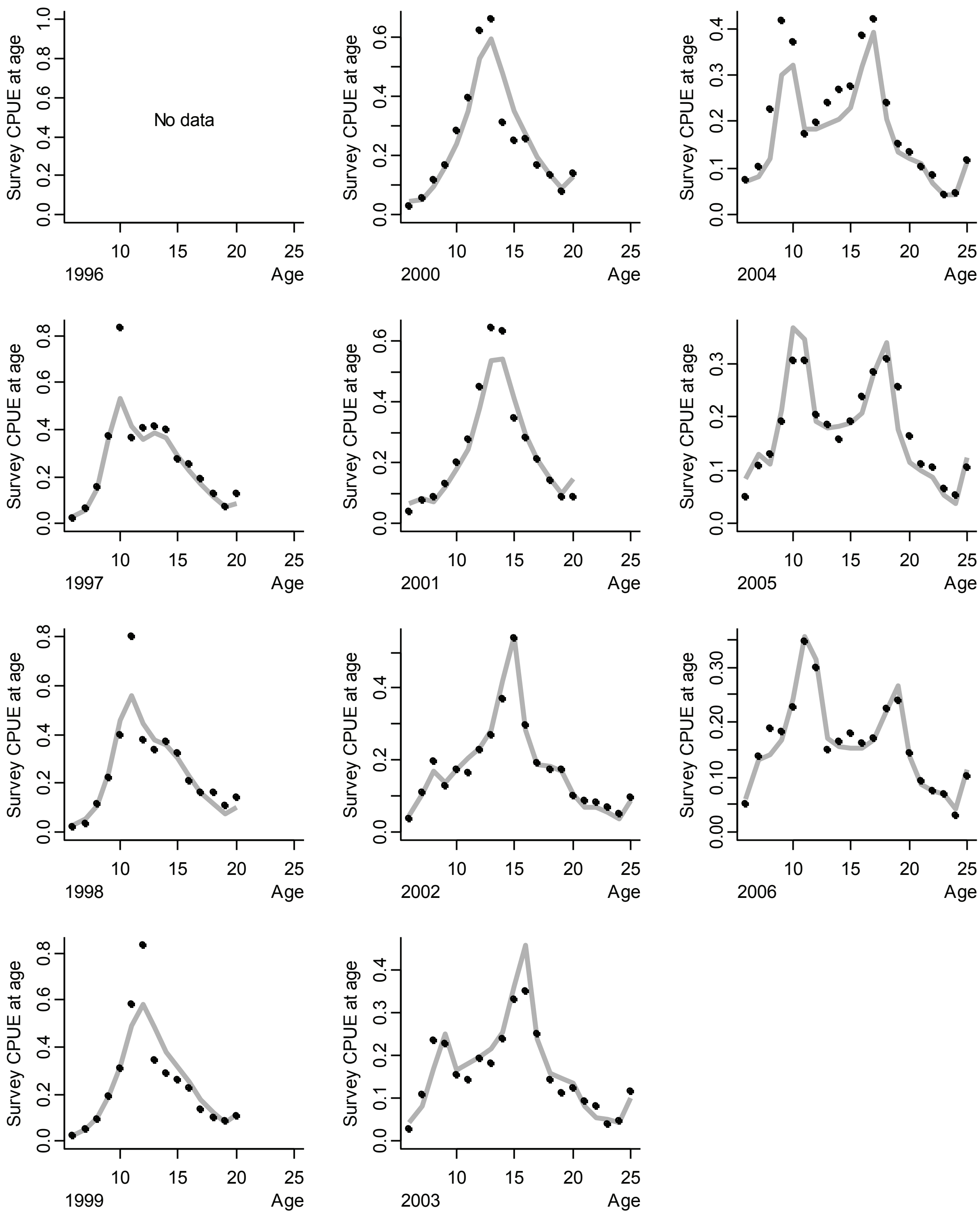

Figure 5b. Observed (points) and predicted (lines) survey CPUE at age (fish/skate) of males from the coastwide assessment.

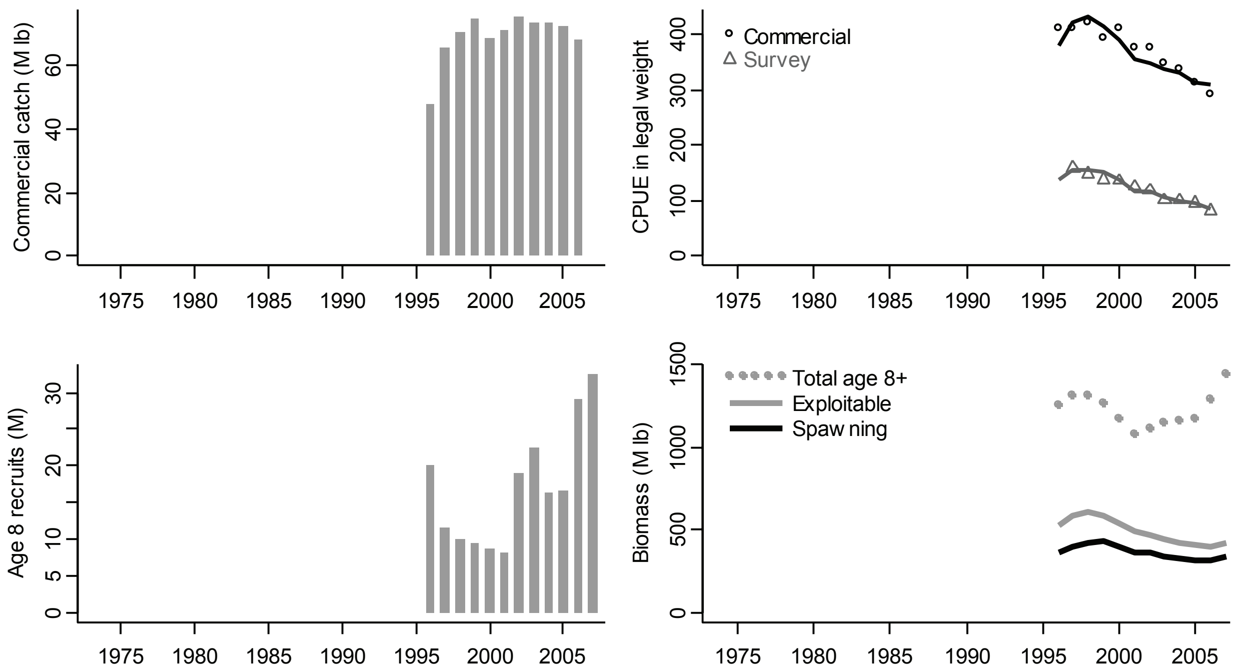

Figure 6. Features of the 2006 coastwide assessment. In the upper right panel, the points are observed CPUE (lb/skate) and the lines are model predictions.

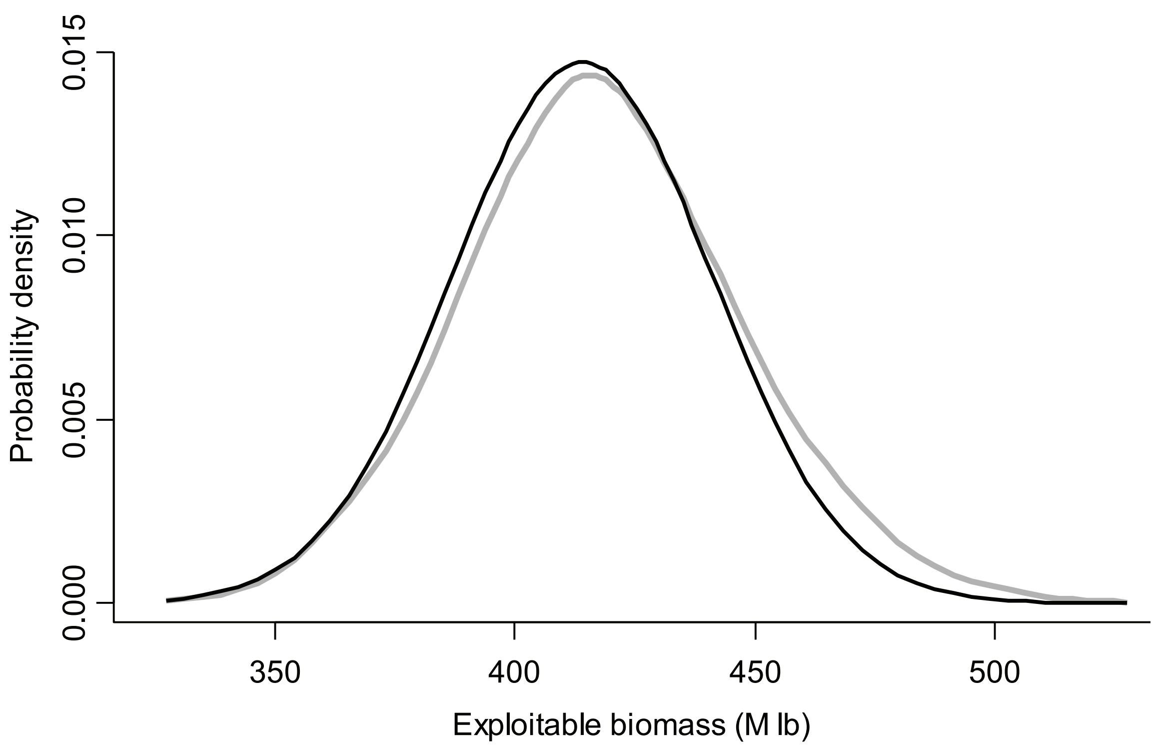

Figure 7. Normal approximation of the marginal distribution of the estimate of 2007 coastwide exploitable biomass (black line) and likelihood profile (gray line).

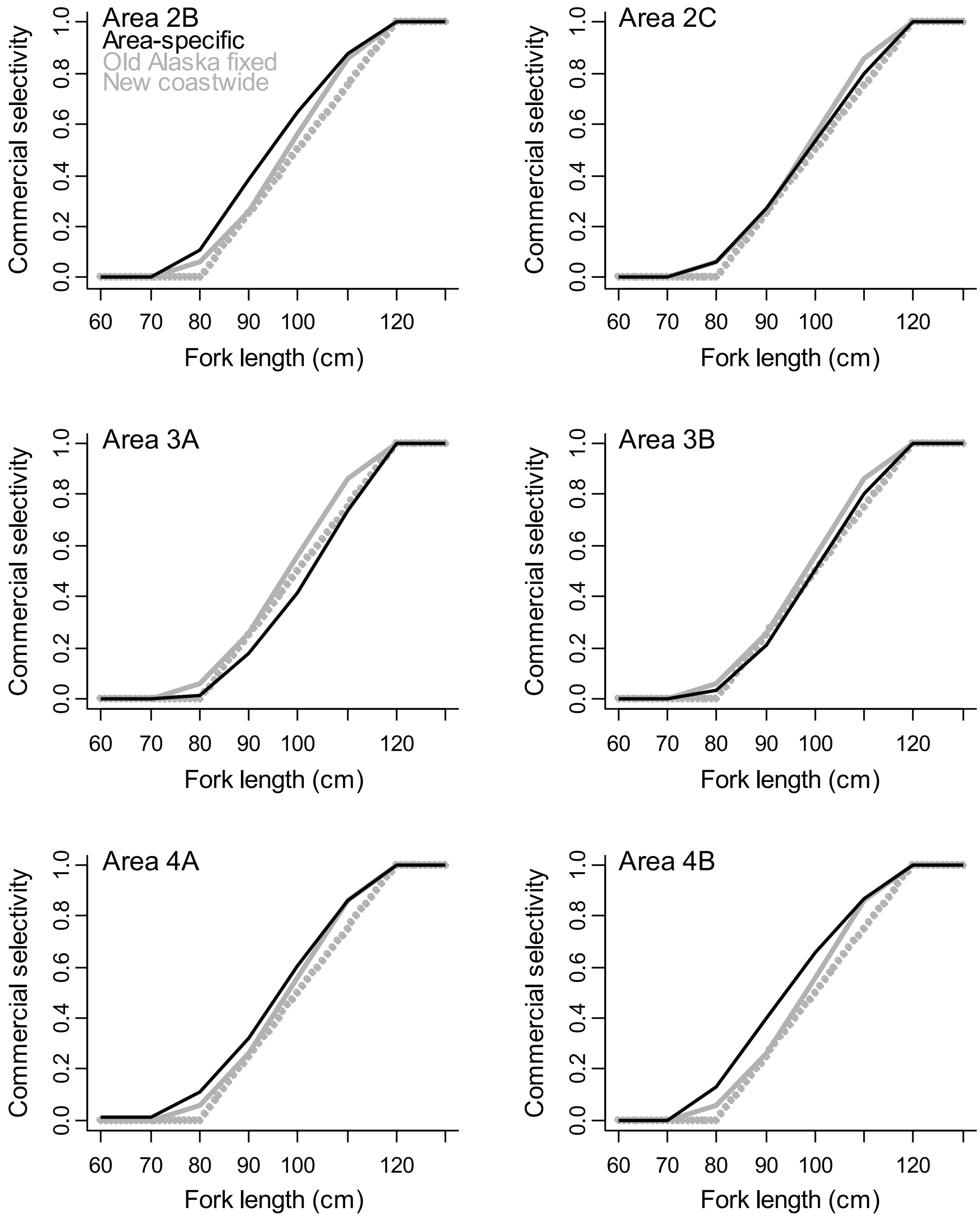

Figure 8. Commercial selectivity schedules. In each graph the broken gray line is the old standard (Alaska fixed) schedule, the solid gray line is the new coastwide standard schedule, and the black line is area-specific schedule estimated in the closed-area assessment for that area.

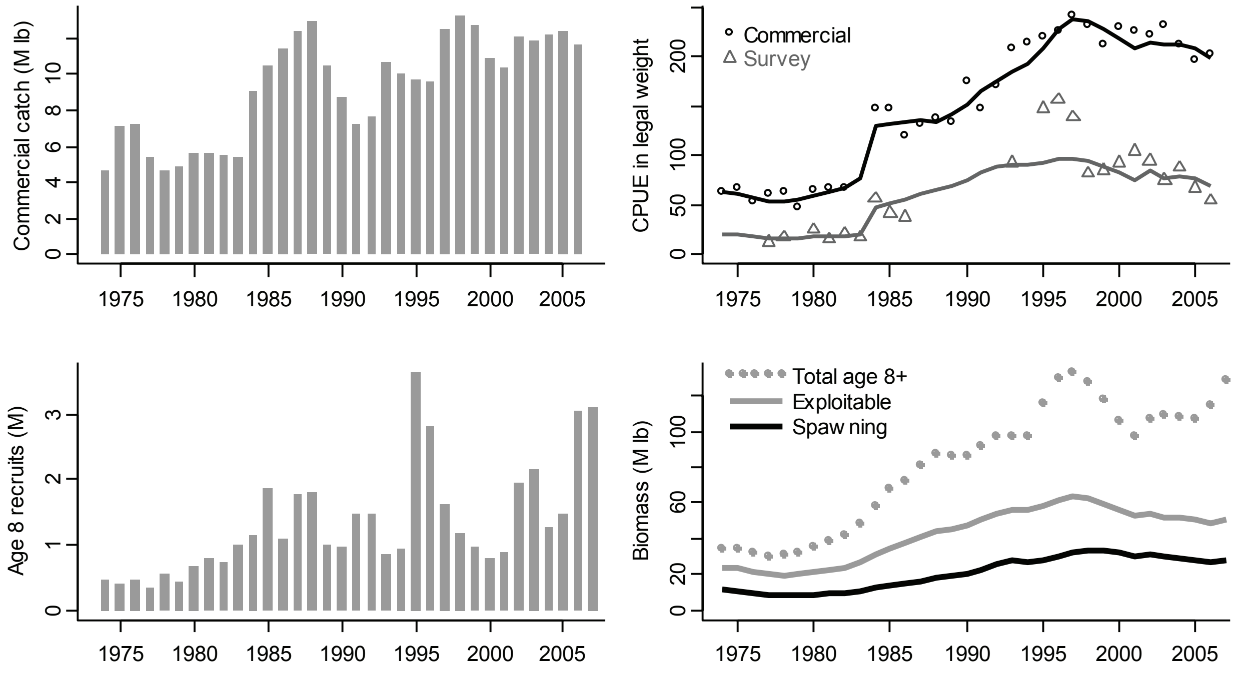

Fig. 9a. Features of the 2006 closed-area assessment in Area 2B.

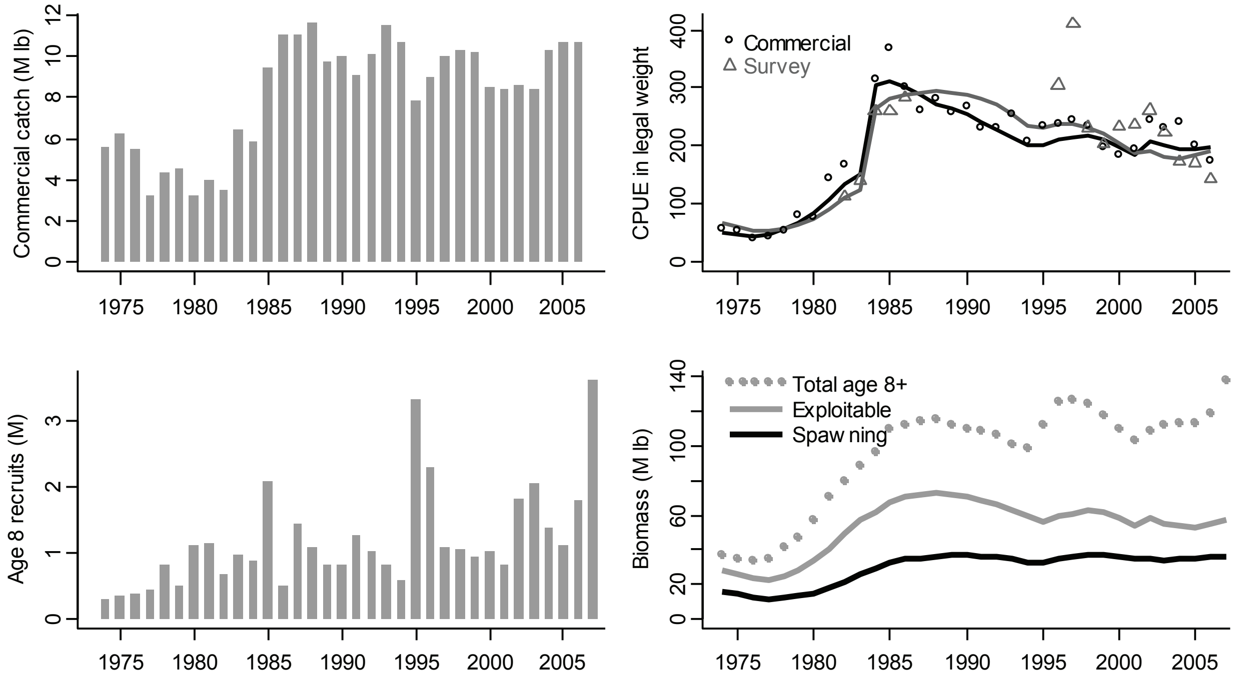

Fig. 9b. Features of the 2006 closed-area assessment in Area 2C.

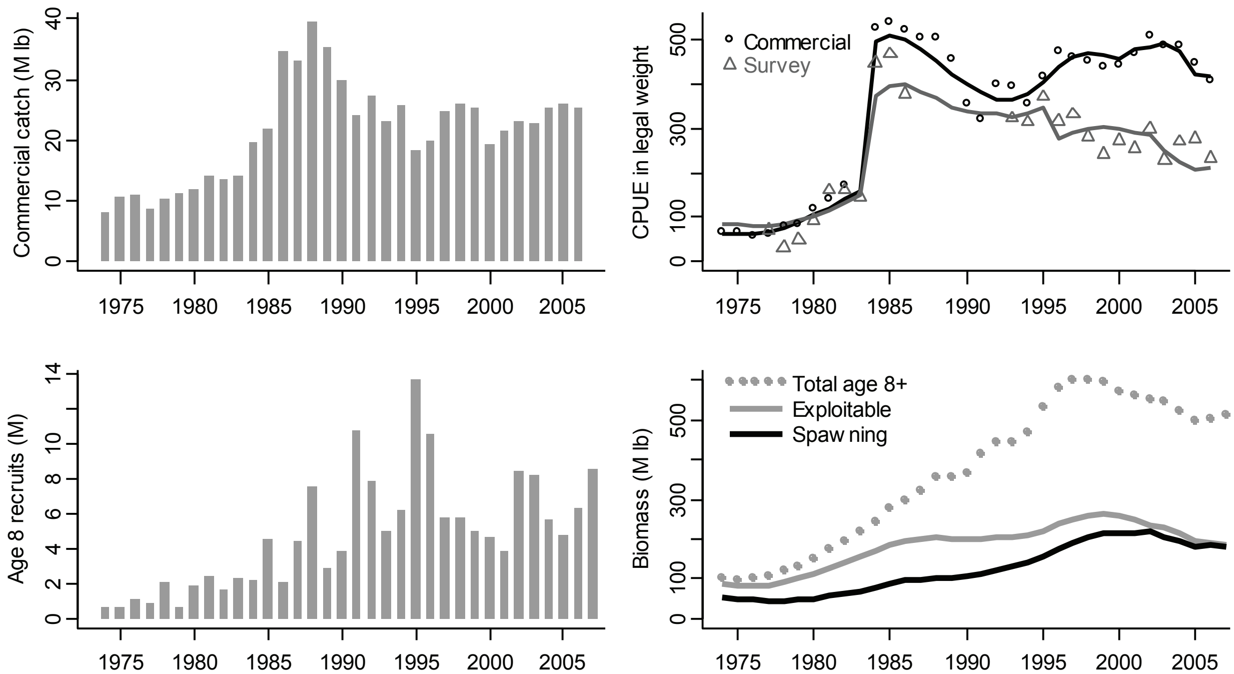

Figure 9c. Features of the 2006 closed-area assessment in Area 3A.

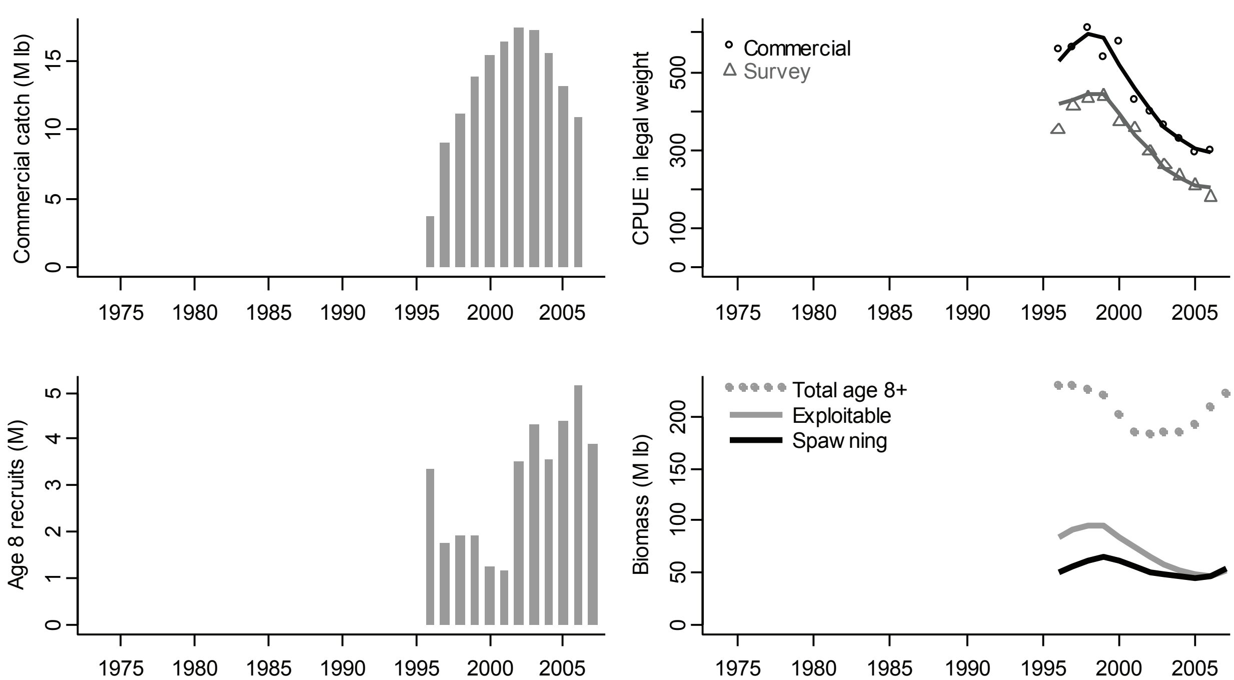

Figure 9d. Features of the 2006 closed-area assessment in Area 3B.

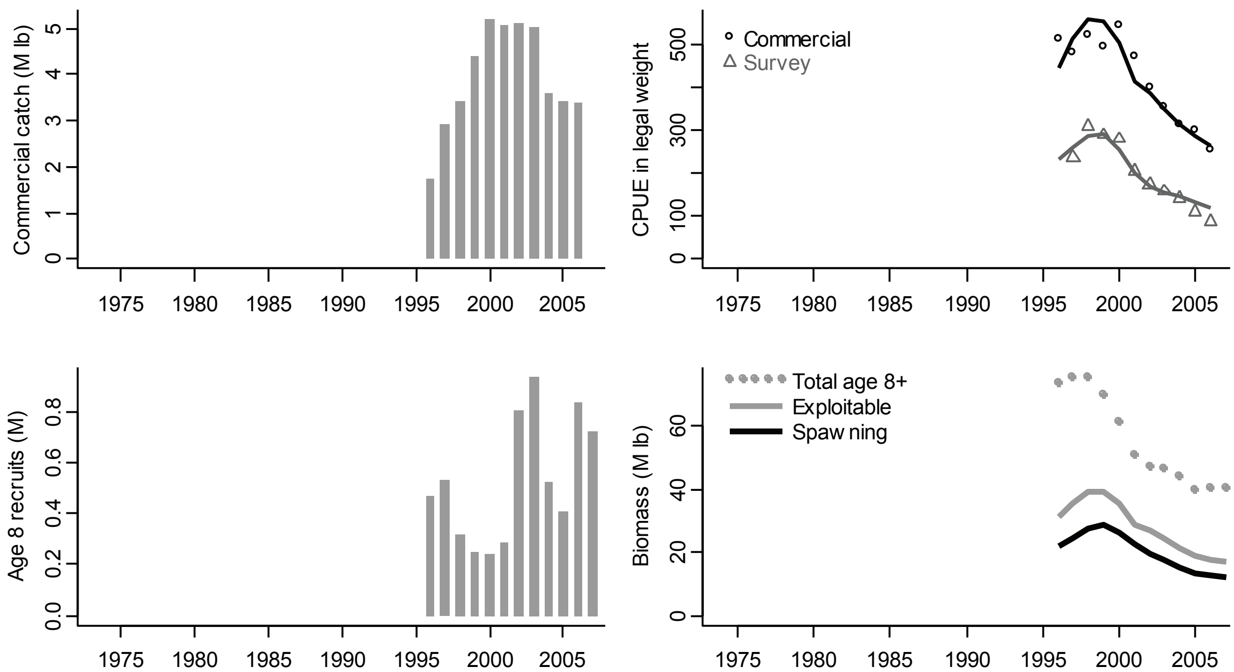

Figure 9e. Features of the 2006 closed-area assessment in Area 4A.

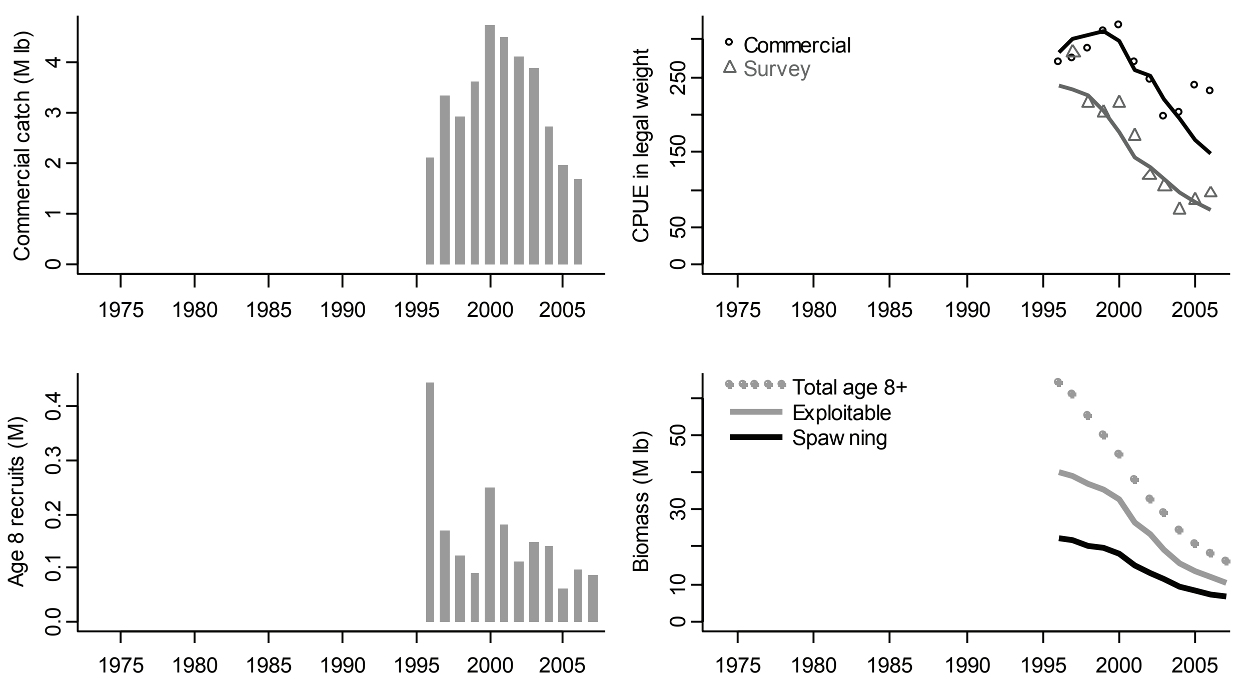

Figure 9f. Features of the 2006 closed-area assessment in Area 4B.

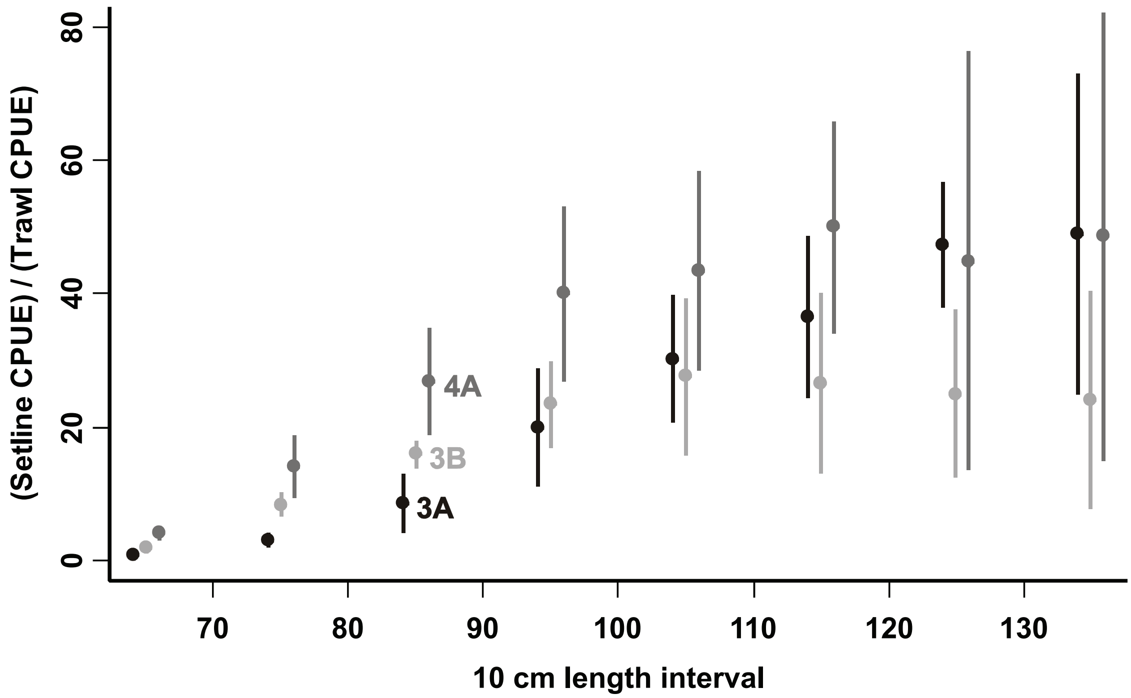

Figure 10. Ratio of setline survey catch rates at length (fish/skate) to trawl survey catch rates at length (fish/ha swept).

Appendix A. Selected fishery and survey data summaries.

Table A1. Commercial catch (million pounds, net weight). Figures include IPHC research catches. Sport catch in Areas 2A and 2B is *not* included in this table.

	2A	2B	2C	3A	3B	4	4A	4B	4C	4D	4E	Total
1974	0.52	4.62	5.60	8.19	1.67	0.71	---	---	---	---	---	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	---	---	---	---	---	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	---	---	---	---	---	27.54
1977	0.21	5.43	3.19	8.64	3.19	1.22	---	---	---	---	---	21.88
1978	0.10	4.61	4.32	10.30	1.32	1.35	---	---	---	---	---	22.00
1979	0.05	4.86	4.53	11.34	0.39	1.37	---	---	---	---	---	22.54
1980	0.02	5.65	3.24	11.97	0.28	0.71	---	---	---	---	---	21.87
1981	0.20	5.66	4.01	14.23	0.45	---	0.49	0.39	0.30	0.01	0.00	25.74
1982	0.21	5.54	3.50	13.52	4.80	---	1.17	0.01	0.24	0.00	0.01	29.01
1983	0.26	5.44	6.38	14.14	7.75	---	2.50	1.34	0.42	0.15	0.01	38.39
1984	0.43	9.05	5.87	19.77	6.69	---	1.05	1.10	0.58	0.39	0.04	44.97
1985	0.49	10.39	9.21	20.84	10.89	---	1.72	1.24	0.62	0.67	0.04	56.10
1986	0.58	11.22	10.61	32.80	8.82	---	3.38	0.26	0.69	1.22	0.04	69.63
1987	0.59	12.25	10.68	31.31	7.76	---	3.69	1.50	0.88	0.70	0.11	69.47
1988	0.49	12.86	11.36	37.86	7.08	---	1.93	1.59	0.71	0.45	0.01	74.34
1989	0.47	10.43	9.53	33.74	7.84	---	1.02	2.65	0.57	0.67	0.01	66.95
1990	0.32	8.57	9.73	28.85	8.69	---	2.50	1.33	0.53	1.00	0.06	61.60
1991	0.36	7.19	8.69	22.93	11.93	---	2.26	1.51	0.68	1.44	0.10	57.08
1992	0.44	7.63	9.82	26.78	8.62	---	2.70	2.32	0.79	0.73	0.07	59.89
1993	0.50	10.63	11.29	22.74	7.86	---	2.56	1.96	0.83	0.84	0.06	59.27
1994	0.37	9.91	10.38	24.84	3.86	---	1.80	2.02	0.72	0.71	0.12	54.73
1995	0.30	9.62	7.77	18.34	3.12	---	1.62	1.68	0.67	0.64	0.13	43.88
1996	0.30	9.54	8.87	19.69	3.66	---	1.70	2.07	0.68	0.71	0.12	47.34
1997	0.41	12.42	9.92	24.63	9.07	---	2.91	3.32	1.12	1.15	0.25	65.20
1998	0.46	13.17	10.20	25.70	11.16	---	3.42	2.90	1.26	1.31	0.19	69.76
1999	0.45	12.70	10.14	25.32	13.84	---	4.37	3.57	1.76	1.89	0.26	74.31
2000	0.48	10.81	8.44	19.27	15.41	---	5.16	4.69	1.74	1.93	0.35	68.29
2001	0.68	10.29	8.40	21.54	16.34	---	5.01	4.47	1.65	1.84	0.48	70.70
2002	0.85	12.07	8.60	23.13	17.31	---	5.09	4.08	1.21	1.75	0.56	74.66
2003	0.82	11.79	8.41	22.75	17.23	---	5.02	3.86	0.89	1.96	0.42	73.19
2004	0.88	12.16	10.23	25.17	15.46	---	3.56	2.72	0.95	1.66	0.31	73.11
2005	0.80	12.33	10.63	26.03	13.17		3.40	1.98	0.53	2.58	0.37	71.82
2006	0.82	11.78	10.47	25.38	11.03		3.31	1.60	0.50	2.40	0.36	67.64

Table A2. Commercial CPUE (net pounds per skate).

Values before 1984 are raw J-hook catch rates, with no hook correction. 1983 is excluded because it consists of a mixture of J- and C-hook data. No value is shown for area/years after 1980 with fewer than 500 skates of reported catch/effort data.

	2A	2B	2C	3A	3B	4A	4B	4C	4D	4E	Total
J-hook CPUE:											
1974	59	64	57	65	57	---	---	---	---	---	---
1975	59	68	53	66	68	---	---	---	---	---	---
1976	33	53	42	60	65	---	---	---	---	---	---
1977	83	61	45	61	73	---	---	---	---	---	---
1978	39	63	56	78	53	---	---	---	---	---	---
1979	50	48	80	86	37	---	---	---	---	---	---
1980	37	65	79	118	113	---	---	---	---	---	---
1981	33	67	145	142	160	158	99	110	---	---	---
1982	22	68	167	170	217	103	---	91	---	---	---
1983	---	---	---	---	---	---	---	---	---	---	---
C-hook CPUE:											
1984	63	148	314	524	475	366	161	---	197	---	367
1985	62	147	370	537	602	333	234	---	330	---	407
1986	60	120	302	522	515	265	---	427	239	---	365
1987	57	131	260	504	476	341	220	384	---	---	357
1988	134	137	281	503	655	453	224	---	201	---	405
1989	124	134	258	455	590	409	268	331	384	---	381
1990	168	175	269	353	484	434	209	288	381	---	335
1991	158	148	233	319	466	471	329	223	398	---	330
1992	115	171	230	397	440	372	278	249	412	---	337
1993	147	208	256	393	514	463	218	257	851	---	376
1994	93	215	207	353	377	463	198	167	480	---	321
1995	116	219	234	416	476	349	189	---	475	---	348
1996	159	226	238	473	556	515	269	---	---	---	411
1997	226	241	246	458	562	483	275	335	671	---	412
1998	194	232	236	451	611	525	287	287	627	---	421
1999	---	213	199	437	538	500	310	270	535	---	393
2000	263	229	186	443	577	547	318	223	556	---	411
2001	169	226	196	469	431	474	270	203	511	---	377
2002	181	222	244	507	399	402	245	148	503	---	376
2003	184	231	233	487	364	355	196	105	389	---	350
2004	145	212	240	485	328	315	202	120	444	---	338
2005	155	197	203	446	293	301	238	91	379	---	313
2006	131	202	174	407	299	257	231	71	294	NA	292

Table A3. IPHC setline survey CPUE of legal sized fish in weight (net pounds per skate).

Figures refer to all stations fished. For years when only the northern portion of Area 2B was fished, the CPUE is multiplied by 0.89 to reflect the relationship between overall CPUE and northern CPUE in years when the whole area was fished. The eastward expansion of the 3A survey in 1996 lowered average CPUE by around 25%; the raw values in the table should not be taken at face value. *No hook corrections* are applied; J-hook values are raw J-hook catch rates. Area 4EBS is the eastern Bering Sea shelf, first surveyed in 2006. The Total column is affected by a constructed series of eastern Bering Sea values (not shown).

	2A	2B	2C	3A	3B	4A	4B	4C	4D	4EBS	Total
J-hook surveys:											
1974	---	---	---	---	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---	---	---	---	---
1976	---	---	---	---	---	---	---	---	---	---	---
1977	---	13	---	73	---	---	---	---	---	---	---
1978	---	18	---	34	---	---	---	---	---	---	---
1979	---	NA	---	51	---	---	---	---	---	---	---
1980	---	25	---	95	---	---	---	---	---	---	---
1981	---	16	---	162	---	---	---	---	---	---	---
1982	---	21	145	180	---	---	---	---	---	---	---
1983	---	18	142	147	---	---	---	---	---	---	---
1984	---	25	---	217	---	---	---	---	---	---	---
C-hook surveys:											
1984	---	57	260	446	---	---	---	---	---	---	---
1985	---	42	260	466	---	---	---	---	---	---	---
1986	---	38	283	377	---	---	---	---	---	---	---
1987	---	NA	---	---	---	---	---	---	---	---	---
1988	---	NA	---	---	---	---	---	---	---	---	---
1989	---	NA	---	---	---	---	---	---	---	---	---
1990	---	NA	---	---	---	---	---	---	---	---	---
1991	---	NA	---	---	---	---	---	---	---	---	---
1992	---	NA	---	---	---	---	---	---	---	---	---
1993	---	93	---	323	---	---	---	---	---	---	---
1994	---	NA	---	313	---	---	---	---	---	---	---
1995	29	148	---	370	---	---	---	---	---	---	---
1996	---	156	306	317	352	---	---	---	---	---	---
1997	35	139	411	331	415	237	282	71	111	---	160
1998	---	82	232	281	435	310	216	---	---	---	149
1999	37	85	204	241	438	382	203	---	---	---	139
2000	---	93	233	272	373	286	216	---	213	---	136
2001	41	105	237	256	357	207	171	---	197	---	126
2002	33	95	261	299	297	174	119	---	257	---	120
2003	22	75	223	229	262	159	104	---	195	---	102
2004	27	88	173	270	236	142	73	---	132	---	102
2005	28	67	171	276	211	111	86	---	69	---	96
2006	16	55	144	232	181	88	95	---	63	18	83

Appendix B. Evolution of IPHC assessment methods, 1982-2005

From 1982 through 1994, the halibut stock assessment relied on CAGEAN, a simple age-structured model fitted to commercial catch-at-age and catch-per-effort data. The constant age-specific commercial selectivities used in the model were fundamental model parameters, estimated directly.

Beginning in the late 1980s, halibut growth rates in Alaska declined dramatically. As a result, age-specific selectivity decreased. CAGEAN did not allow for that, and by the mid-1990s was seriously underestimating abundance. In effect, it interpreted lower catches as an indication of lower abundance, whereas the real cause was lower selectivity. Incoming year classes were initially estimated to be small, but in subsequent years' assessments those estimates would increase when unexpectedly large numbers of fish from those year classes appeared in the catches. The year-to-year changes in the stock trajectory shown by the assessment therefore developed a strong retrospective pattern. Each year's fit showed a steep decline toward the end, but each year the whole trajectory shifted upward.

The staff sought to remedy that problem by making selectivity a function of length in a successor model developed in 1995. It accounted not only for the age structure of the population, but also for the size distribution of each age group and the variations in growth schedule that had been observed. The fundamental selectivity parameters in this model were the two parameters of a function (the left limb of a normal density) by which the selectivity of an individual fish was determined from its length. The age-specific selectivity of an entire age group was calculated by integrating length-specific selectivity over the estimated length distribution of the age group, and that age-specific selectivity was used to calculate predicted catches. The new model was fitted to both commercial data and IPHC setline survey data, with separate length-specific selectivity functions. Commercial catchability and selectivity were allowed to drift slowly over time, while survey catchability and selectivity were held constant (Sullivan et al. 1999).

When this model was fitted to data from Area 2B and Area 3A, quite different length-specific selectivities were estimated, which suggested that fishery selectivity was not wholly determined by the properties of the gear and the size of the fish but also depended on fish behavior (e.g., migration). These behavioral elements are likely to be more related to age than size. The age of sexual maturity, for example, remained virtually the same in Alaska despite the tremendous decrease in growth, so the size at maturity is now much smaller than it was. While size must affect selectivity, it was thought that age was also influential.

To allow for that, the model was fitted in two ways. The original form was called the "length-specific" fit, because a single set of estimates of the two parameters of the length-based survey selectivity function was used in all years. In a second form, called the "age-specific" fit, the parameters were allowed to drift over time (like the commercial selectivity parameters), but they were required (by a heavy penalty) to vary in such a way that the integrated age-specific selectivities calculated in each year remained constant over time.

The usual diagnostics gave little reason to prefer one fit over the other. Goodness of fit was similar: good for both in 2B, not so good for either in 3A. The retrospective behavior of both fits was dramatically better than that of CAGEAN and quite satisfactory in all cases, although the length-specific fit was more consistent from year to year in 3A and the age-specific fit was more consistent in 2B (Clark and Parma 1999). The two fits produced very similar estimates of abundance in Areas 2B and 2C, but in 3A the length-specific estimates were substantially higher,

so out of caution the staff catch limit recommendations were based on the age-specific fit through 1999.

The assessment model was simplified and recoded as a purely age-structured model in 2000 to eliminate some problems associated with the modeling of growth and the distribution of length at age. It retained the option of modeling survey selectivity as a function of mean length at age (observed not predicted), but the production fits continued to be based on constant age-specific survey selectivity, estimated directly as a vector of age-specific values rather than as a parametric function of age.

The fit of this model to Area 3A data in 2002 showed a dramatic retrospective pattern, similar to the pattern of successive CAGEAN fits in the mid-1990s. Treating setline survey selectivity as length-specific rather than age-specific largely eliminated the pattern. Accumulated data showing very similar trends in catch at length in IHPC setline surveys and NMFS trawl surveys provided further evidence that setline selectivity is, after all, determined mainly by size rather than by age (Clark and Hare 2003).

Another anomaly of the 3A model fit in 2002 was the unexpectedly large number of old fish (age 20+) in the last few years' catches. This was found to be the result of an increase in the proportion of otoliths read by the break-and-burn rather than surface method. Surface readings tend to understate the age of older fish, and IPHC age readers had been gradually doing more and more break-and-burn readings as the number of older fish in the catches increased. The poor model fit at these ages indicated a need to deal explicitly with the bias and variance of both kinds of age readings.

An entirely new model was written for the 2003 assessment (Clark and Hare 2004). Both commercial and survey selectivity were parameterized as piecewise linear functions of mean length at age in survey catches, and were required to reach an asymptote of one at or before a length of 130 cm. Because females are larger than males, all of the population accounting and predictions were done separately for each sex. (The age/sex/size composition of the commercial landings was estimated external to the assessment for this purpose.) The observed age compositions (surface or break-and-burn) were predicted by applying estimated misclassification matrices to the age distributions. Even in its most parsimonious form—with just one survey and one commercial selectivity schedule for both sexes in all years—this model achieved very good fits to the sex-specific observations and good retrospective performance. It also produced somewhat higher estimates of average recruitment and recruitment variability. With this simple model it was feasible do standalone analytical assessments of abundance in Areas 3B, 4A, and 4B for the first time, using data from 1996-2003.

Only two minor changes were made for the 2004 assessment, and neither had a significant effect on the estimates of abundance. First, both the 2004 PIT tag recoveries (Clark and Chen 2005) and a reanalysis of earlier wire tag data (Clark 2005) indicated that commercial selectivity is not always asymptotic; it appeared to be more dome-shaped in Area 2B and more ramp-shaped in Area 3A. Fitting the assessment model with free-form selectivity schedules showed much the same thing for commercial selectivity, namely an assortment of shapes beyond 120 cm. Nevertheless a schedule that reaches an asymptote of one at 120 cm is a good approximation to and compromise among the free estimates, and using an asymptotic commercial schedule is desirable for computing exploitable biomass and reporting harvest rates, so that it what was used in the assessment. All of the freely estimated survey selectivities either level out or increase after 120 cm. Freely estimated survey

selectivities present no practical difficulties, so they were estimated that way in the assessment, and most of the estimates were ramp-shaped.

Apart from a few minor and inconsequential corrections and alterations, the 2005 analytical assessment was the same as the 2004 assessment. The only important change in procedure was the use of the NMFS trawl survey to estimate biomass in Area 4CDE where an analytical assessment was not done.

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