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 re-created 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											
Option	**WPUE adjustment**	**Time weighting**	0.20	0.20	0.20	0.20	0.15	0.15	0.15	0.15	**<0.20**
			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											
Option	**WPUE adjustment**	**Time weighting**	0.215	0.215	0.215	0.215	0.16125	0.16125	0.16125	0.16125	**<0.215**
			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											
Option	**WPUE adjustment**	**Time weighting**	0.23	0.23	0.23	0.23	0.1725	0.1725	0.1725	0.1725	**<0.23**
			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.

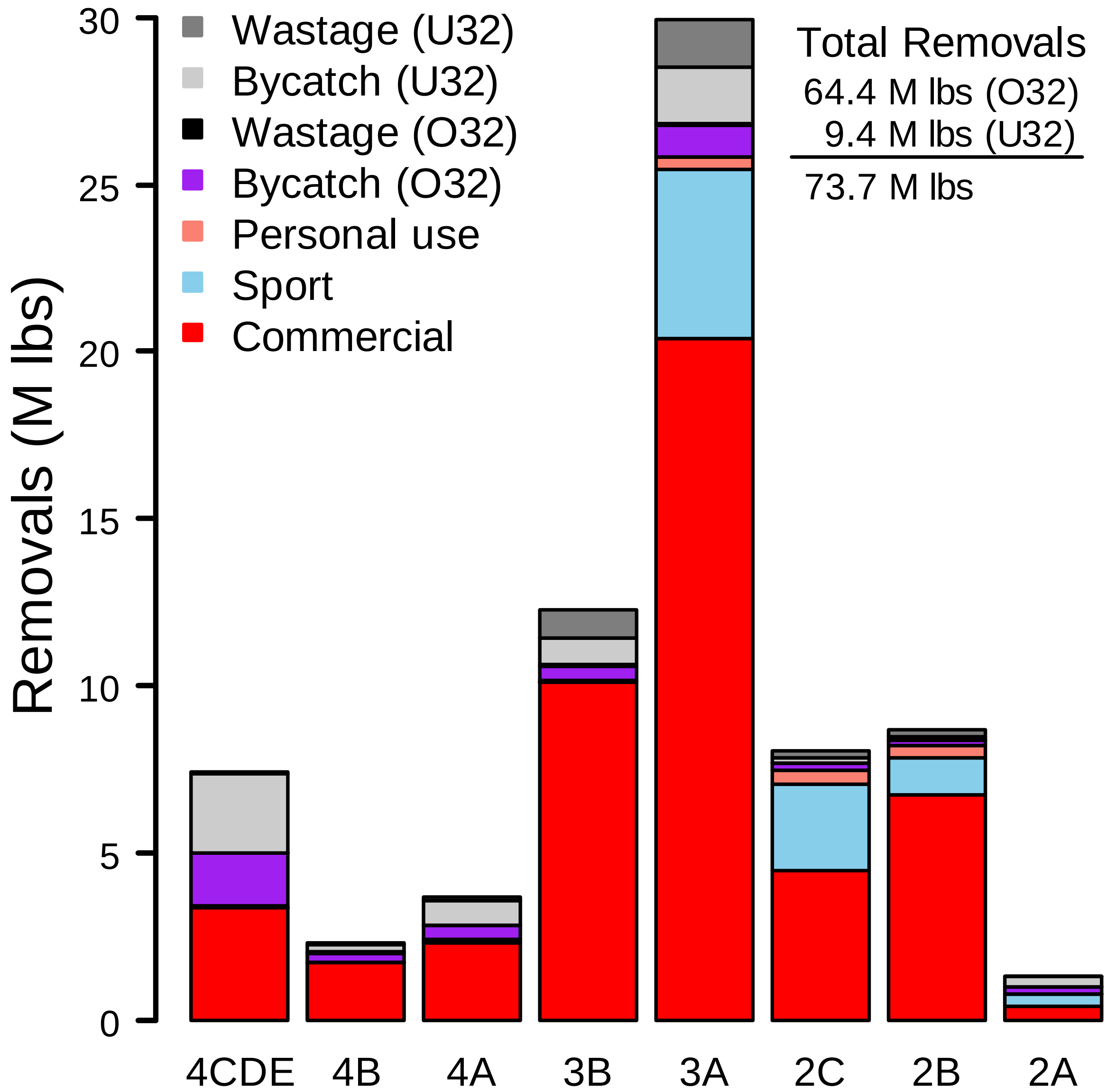


Figure 1. Total removals by type and regulatory area for 2010.

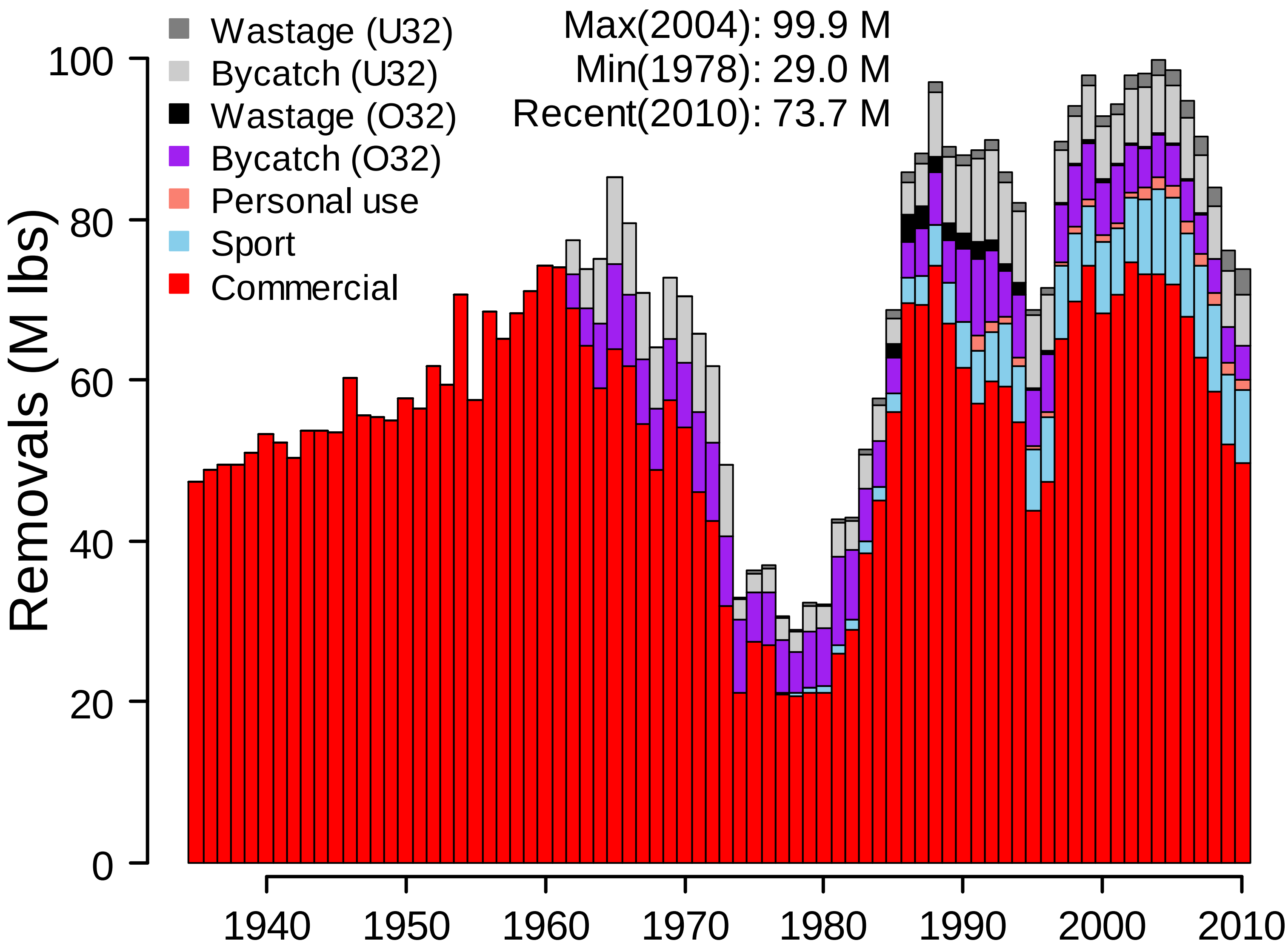


Figure 2. Total removals coastwide for the period 1935-2010. Year and amount of minimum, maximum, and most recent removals are also listed.

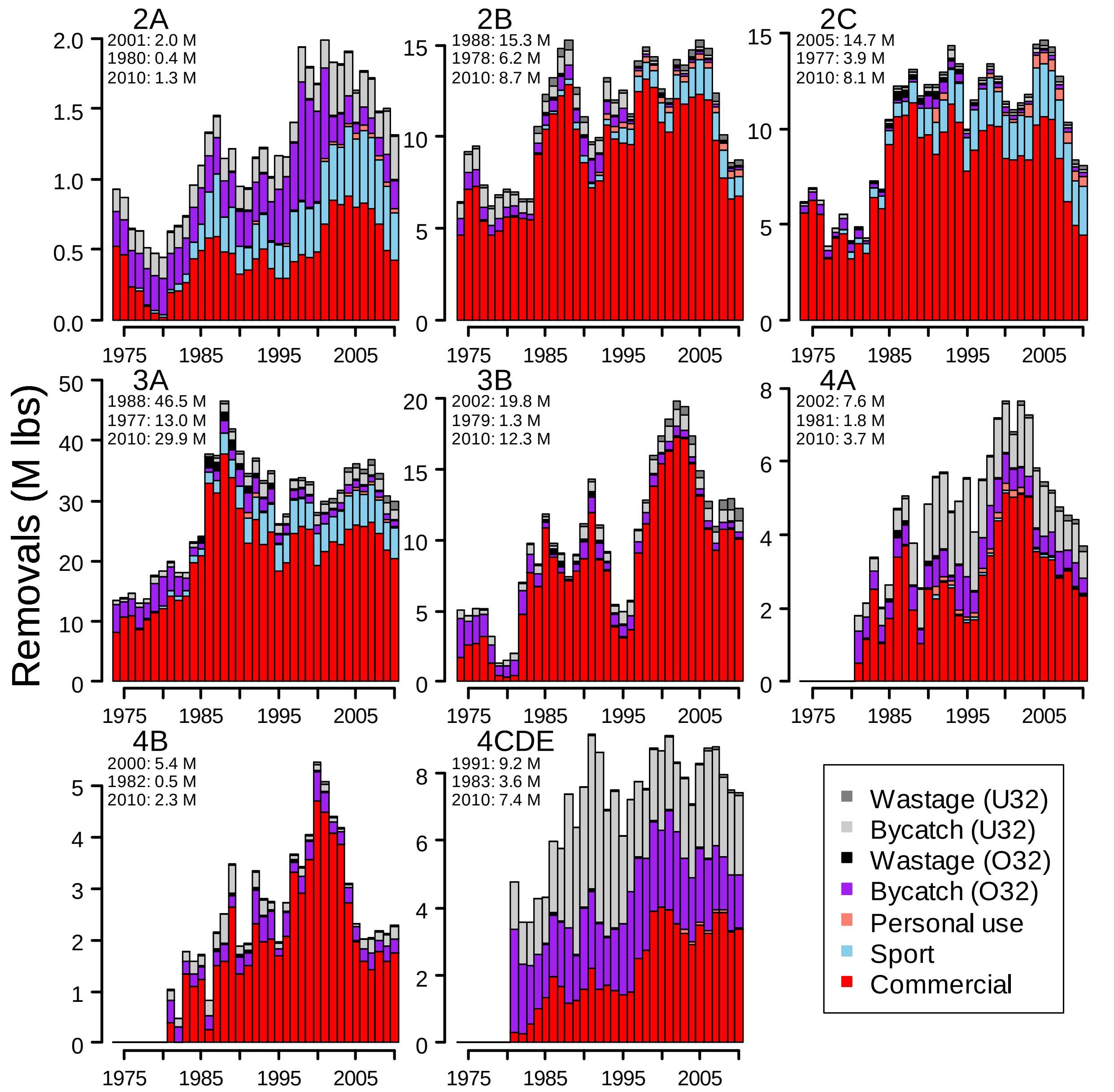


Figure 3. Total removals of halibut, by Regulatory Area, 1974-2010. The two U32 categories (bycatch and wastage, colored in gray) are not included in the total removals listed in Table A1). Year and amount of minimum, maximum, and most recent removals are listed in the upper left corner for each regulatory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

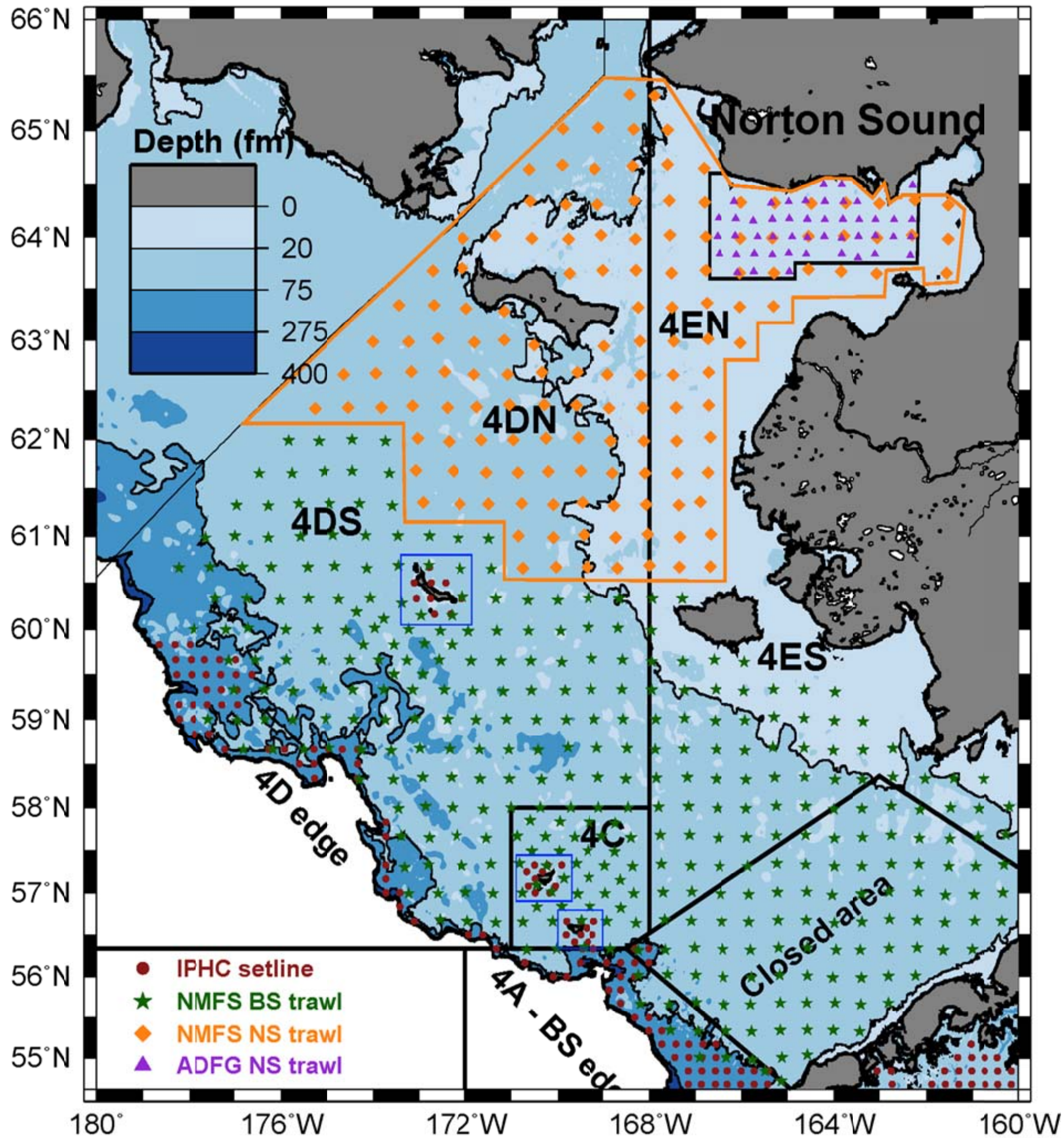


Figure 4. Summary of information sources and subareas utilized to construct a dataset for Area 4CDE. See text for details.

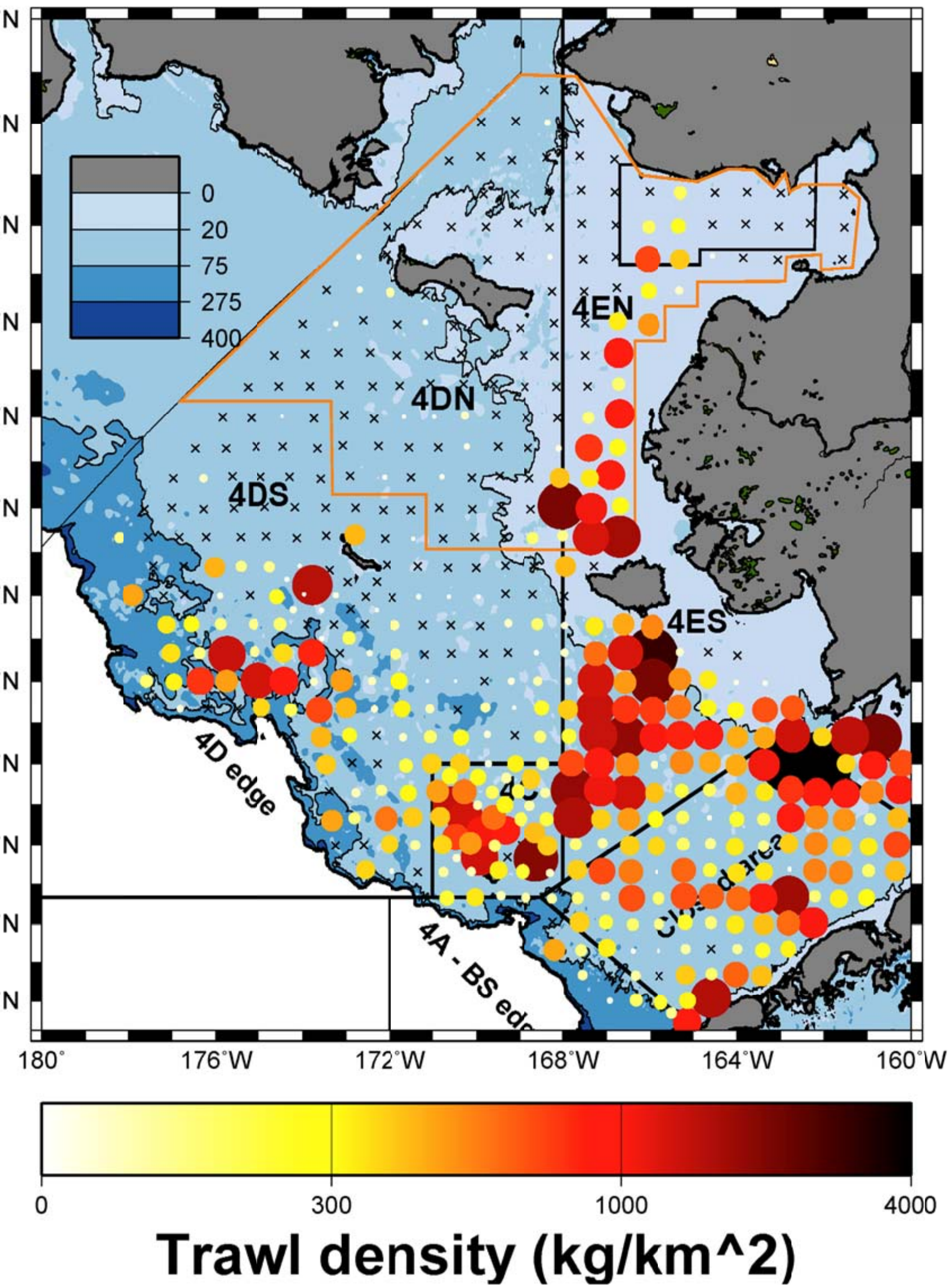


Figure 5. Catch rates of halibut (all sizes) at survey stations in the 2010 NMFS expanded Eastern Bering Sea trawl survey. The size of the circles is proportional to catch rate (kg/km^2) and conveys the same information as the coloring of the circles. Stations with zero catch are indicated by an "x".

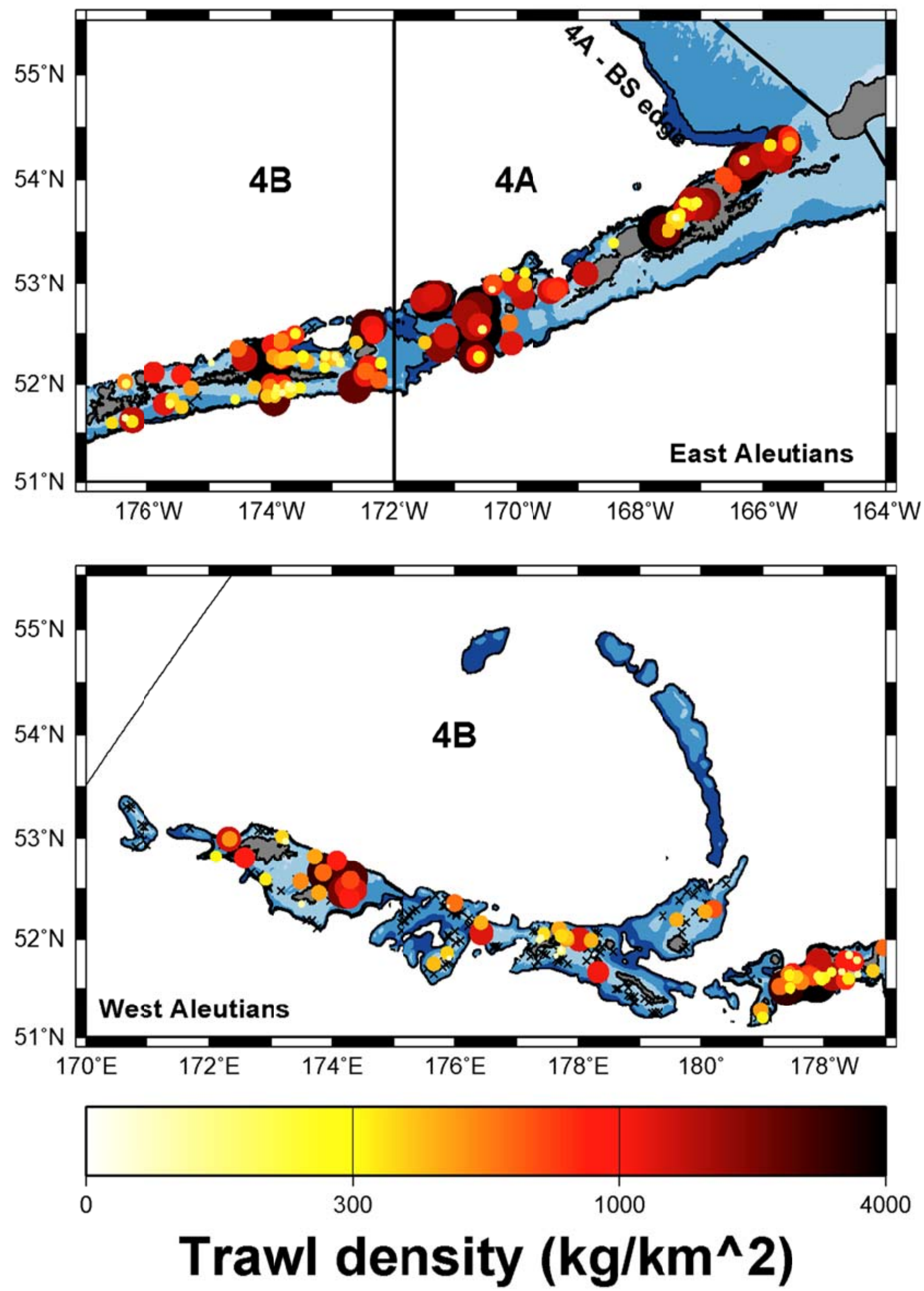


Figure 6. Catch rates of halibut (all sizes) at survey stations in the 2010 NMFS triennial Aleutian Islands trawl survey. The size of the circles is proportional to catch rate (kg/km^2) and conveys the same information as the coloring of the circles. Stations with zero catch are indicated by an "x".

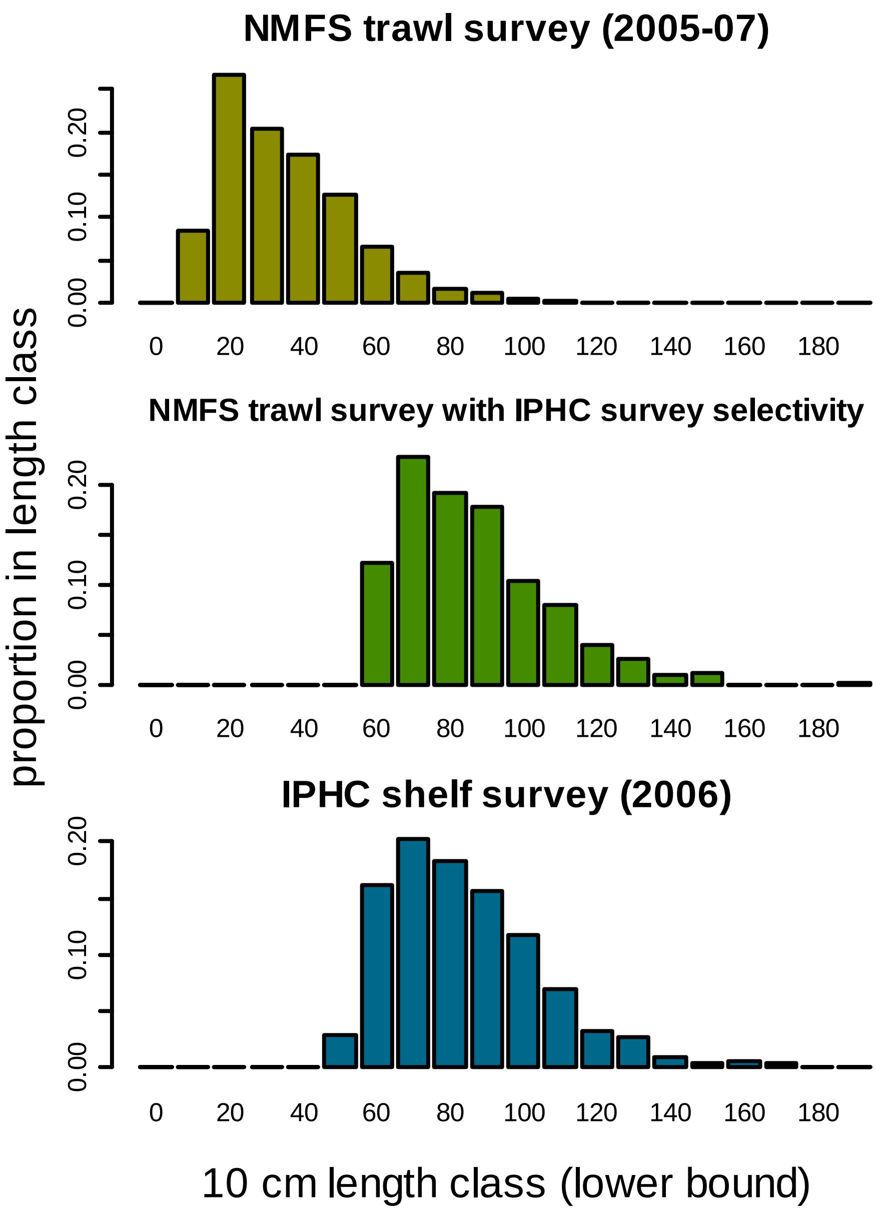


Figure 7. Comparison of NMFS trawl survey and IPHC length frequency compositions. The top panel shows the length frequency composition for all halibut caught by the NMFS trawl gear for years 2005-7. the middle panel shows the frequency distribution of lengths after the IPHC setline selectivity curve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

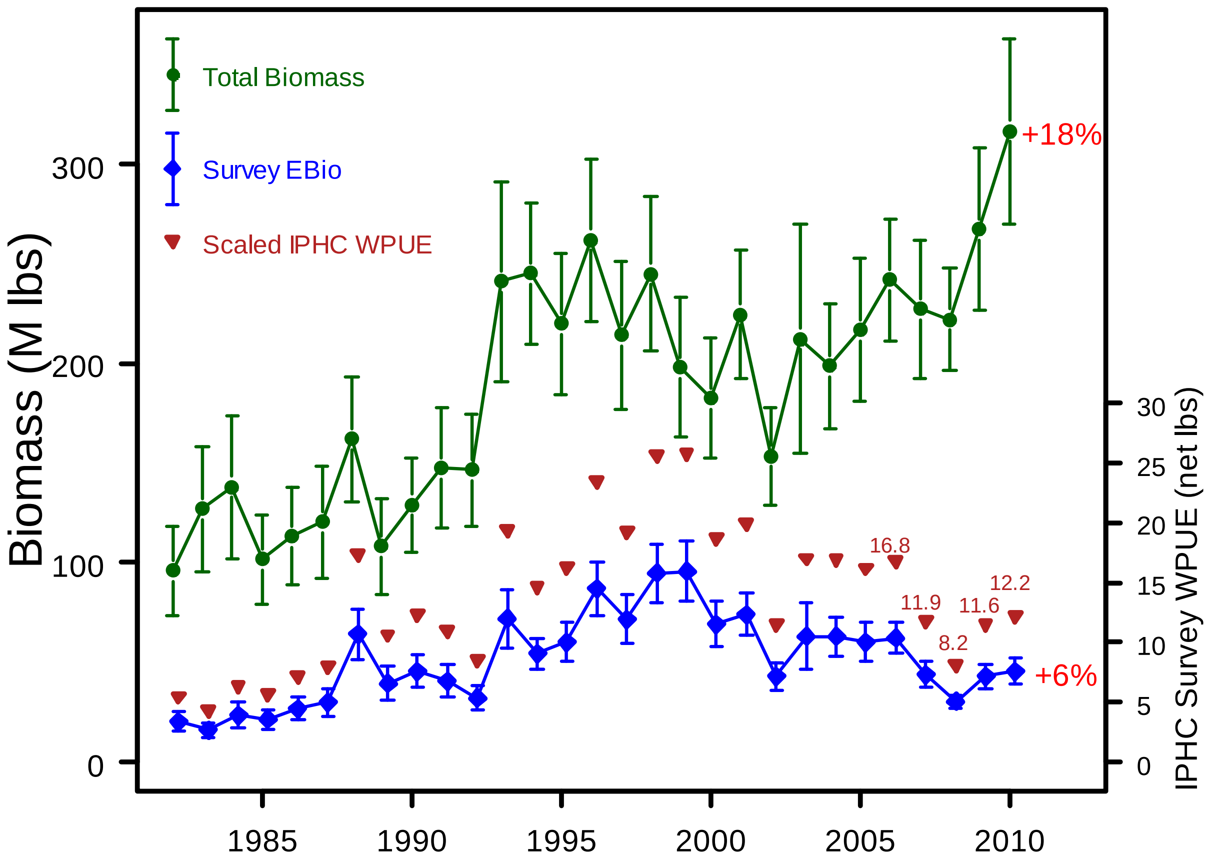


Figure 8. Swept-area estimates of halibut abundance from the NMFS EBS trawl survey. The red dots and error bars represent mean and 95% confidence interval for the total abundance; the blue diamonds are error bars represent mean and 95% confidence interval for abundance with survey selectivity applied 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.

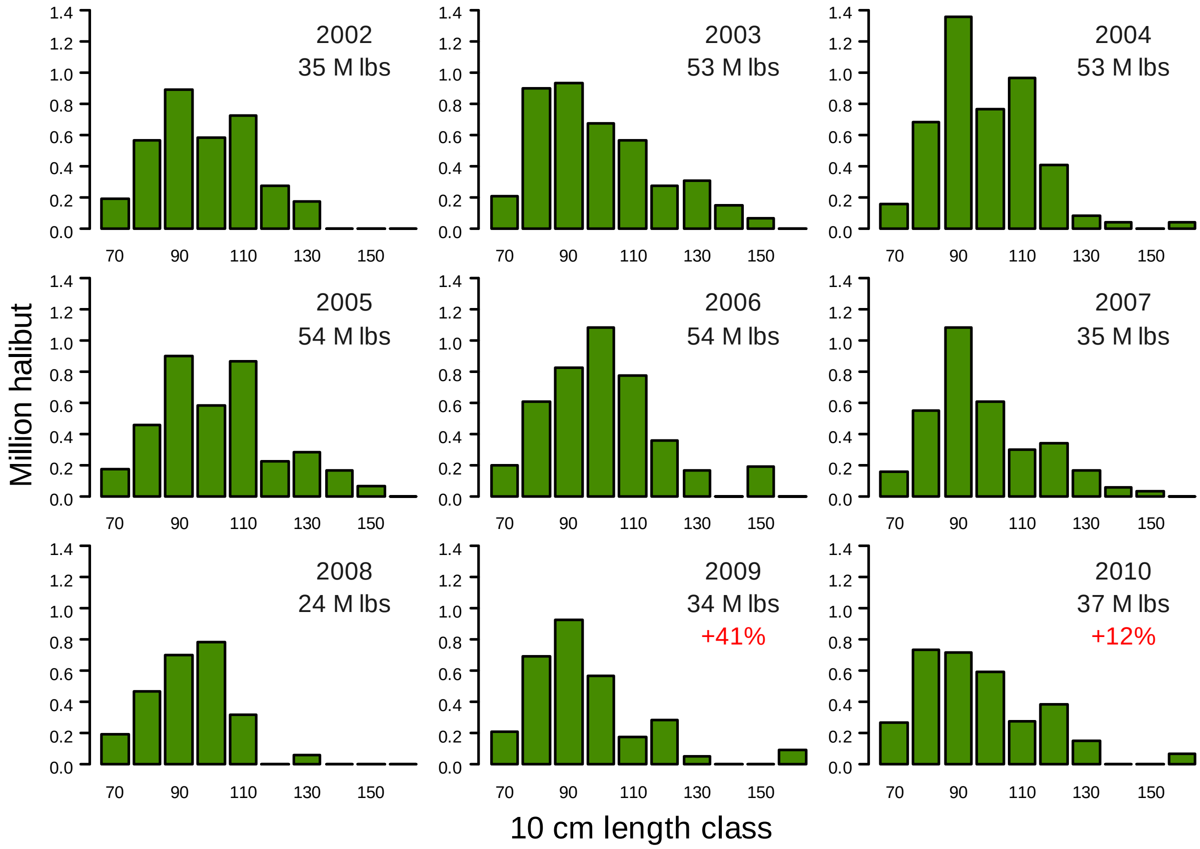


Figure 9. Swept area estimates of halibut EBio, by 10-cm length interval, in the NMFS EBS trawl survey for the years 2002 to 2010. Increases in estimated EBio over the previous year are indicated in the 2009 and 2001 plots. Exploitable numbers of halibut are illustrated by the darker bars. The percentages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

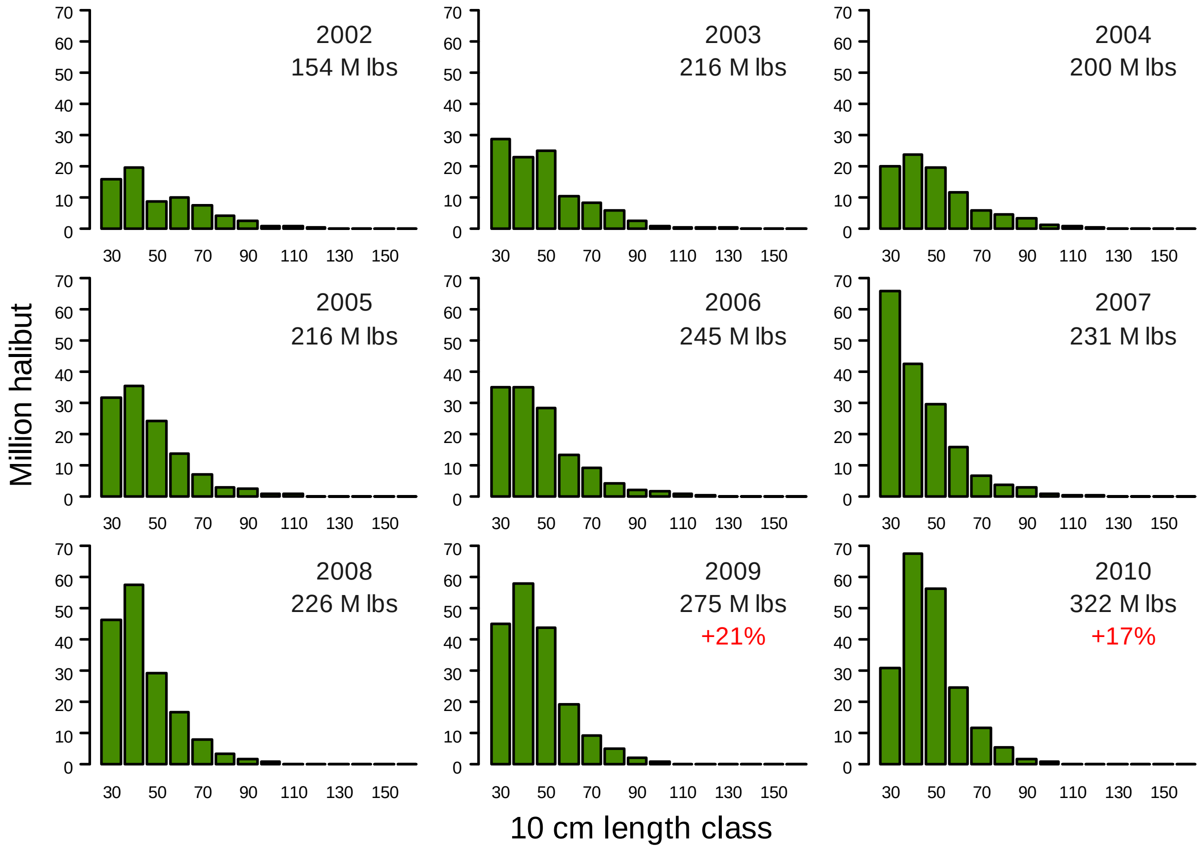


Figure 10. Swept area estimates of halibut TBio, by 10-cm length interval, in the NMFS EBS trawl survey for the years 2002 to 2010. Increases in estimated EBio over the previous year are indicated in the 2009 and 2001 plots. Exploitable numbers of halibut are illustrated by the darker bars. The percentages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

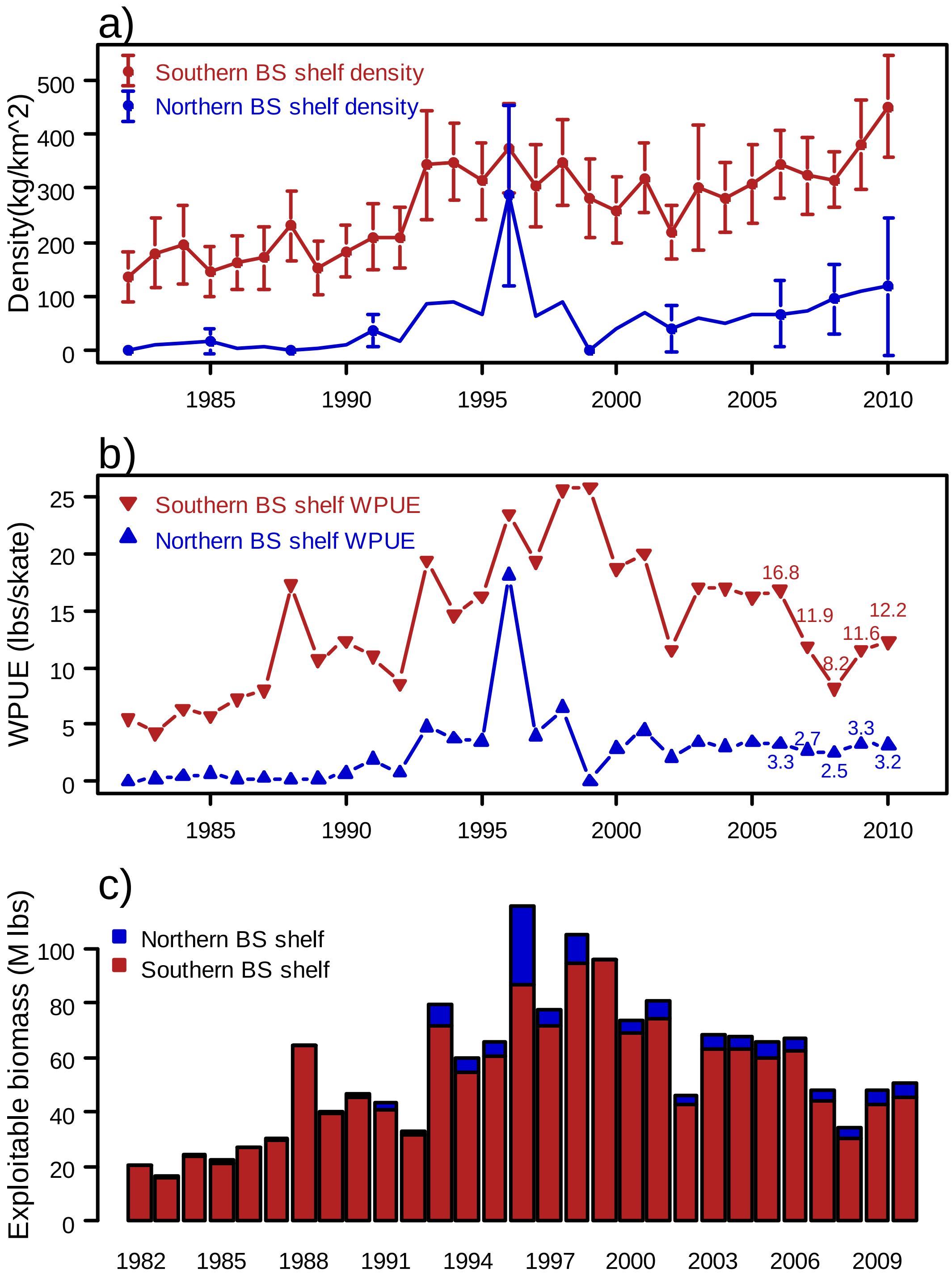


Figure 11. Time series used to construct an estimate of halibut biomass in the northern shelf region of Area 4CDE, termed Area 4N. See text for details.

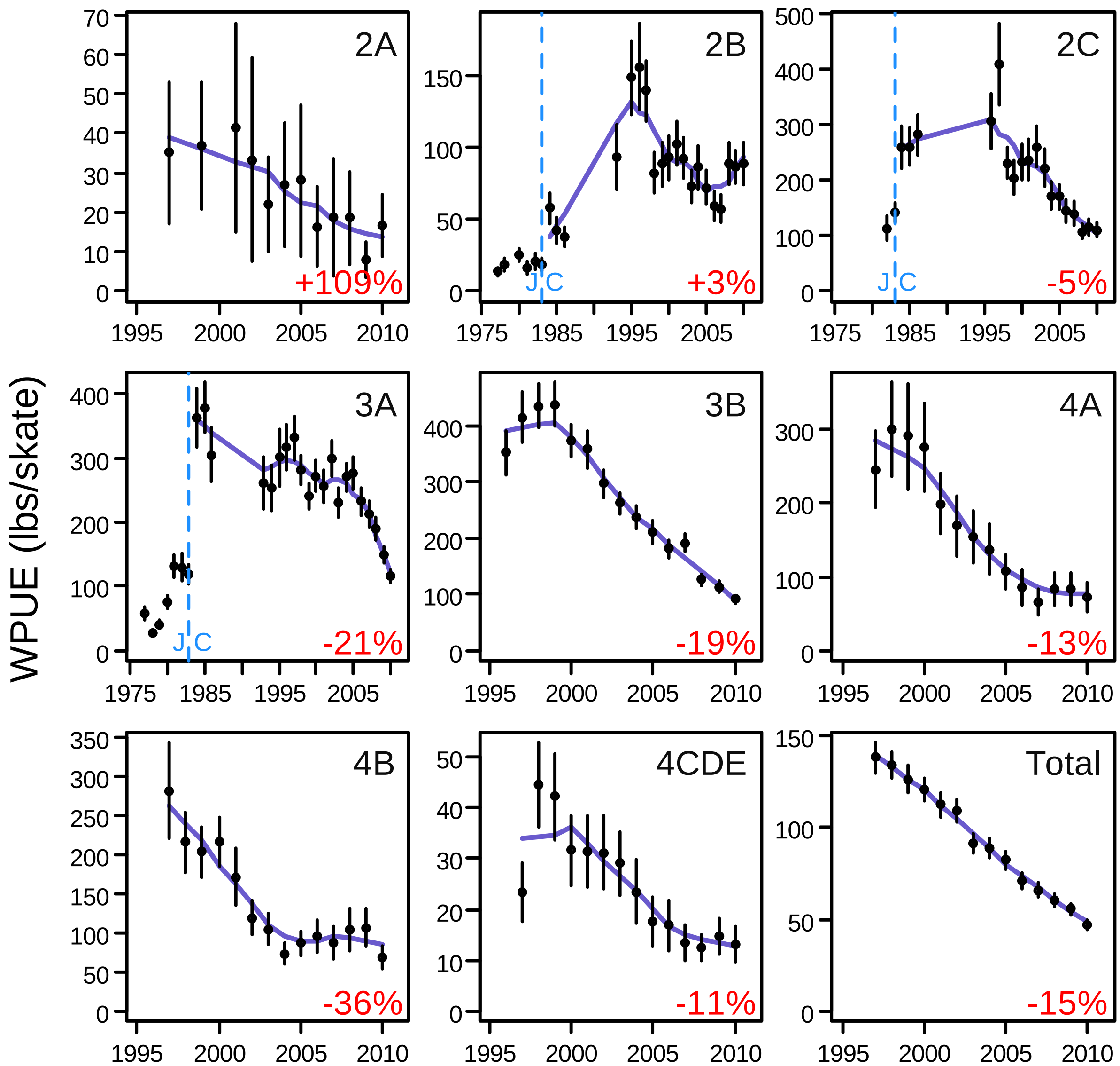


Figure 12. Survey WPUE (weight of O32 halibut per standardized skate of gear) by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The thick line is a smoother to illustrate trend; it is not an assessment model fitted to the WPUE data. 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.

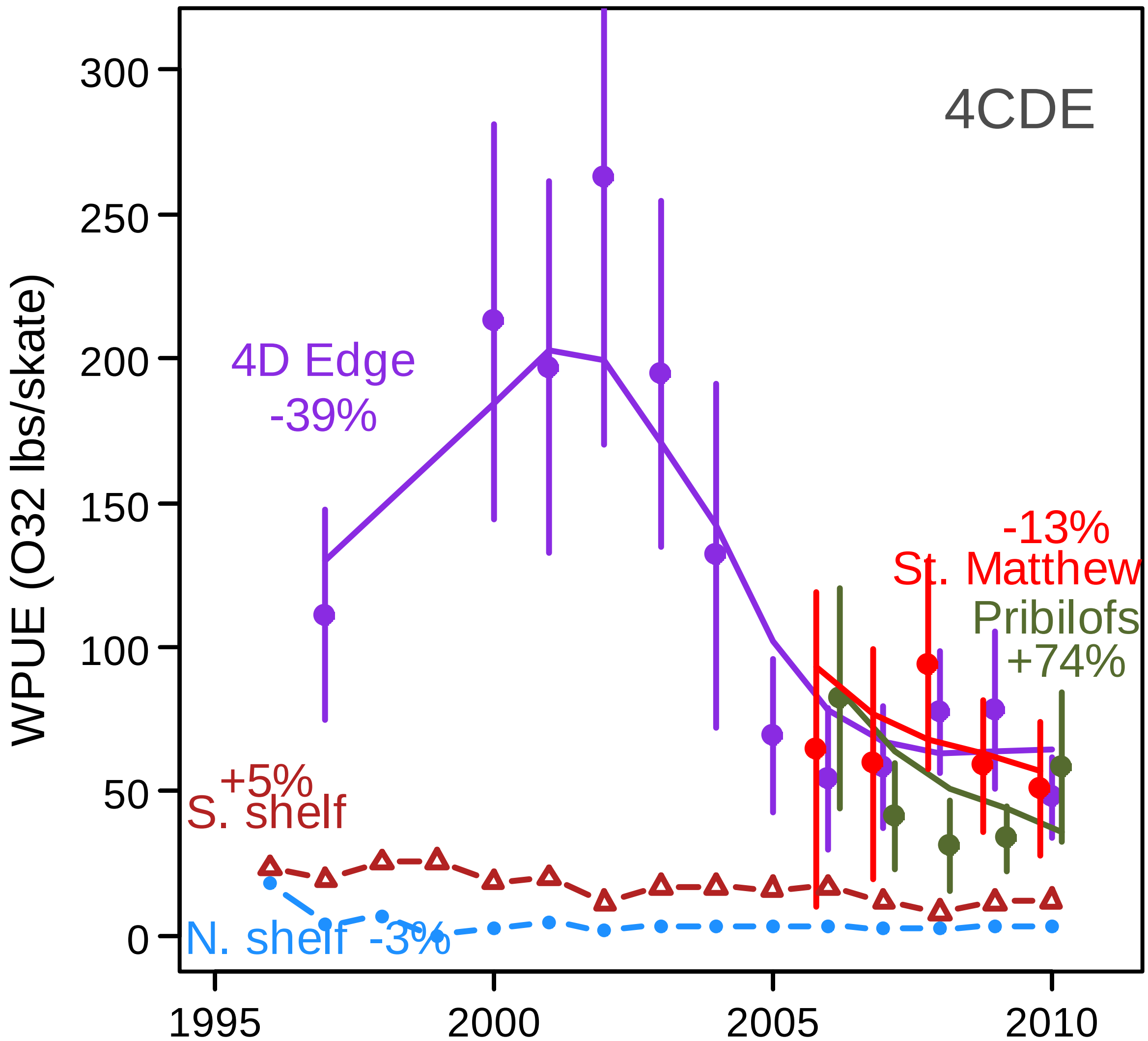


Figure 13. The five subarea components used to construct the WPUE survey index for Area 4CDE. The percentages show the change in the index values from 2009 to 2010.

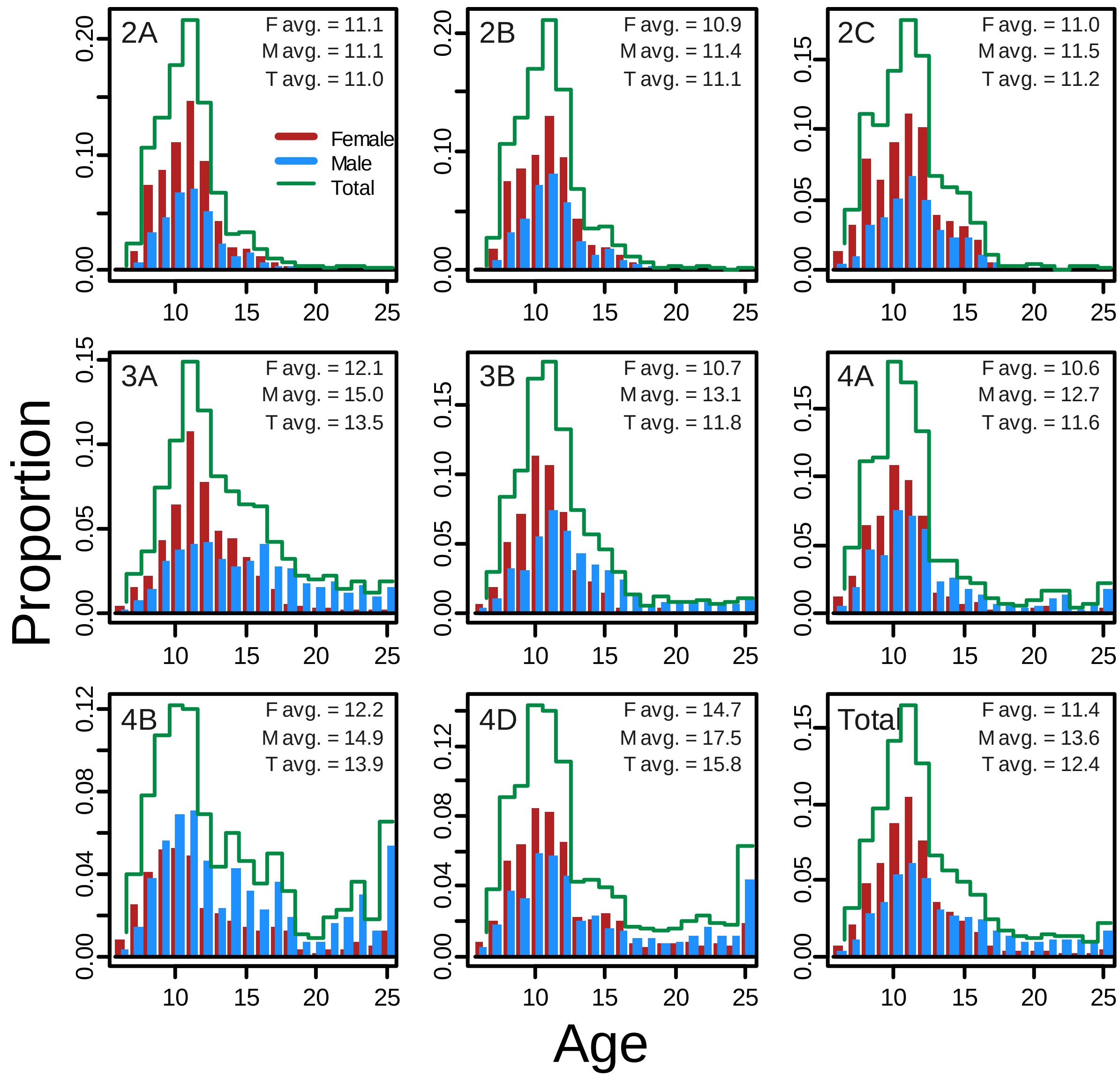


Figure 14. Regulatory area sex and age compositions from halibut taken in the 2010 IPHC stock assessment survey. Proportions are shown for females (red bars), males (blue bars) and sexes combined (green line). Average age is also shown, with "T" indicating Total (sexes combined).

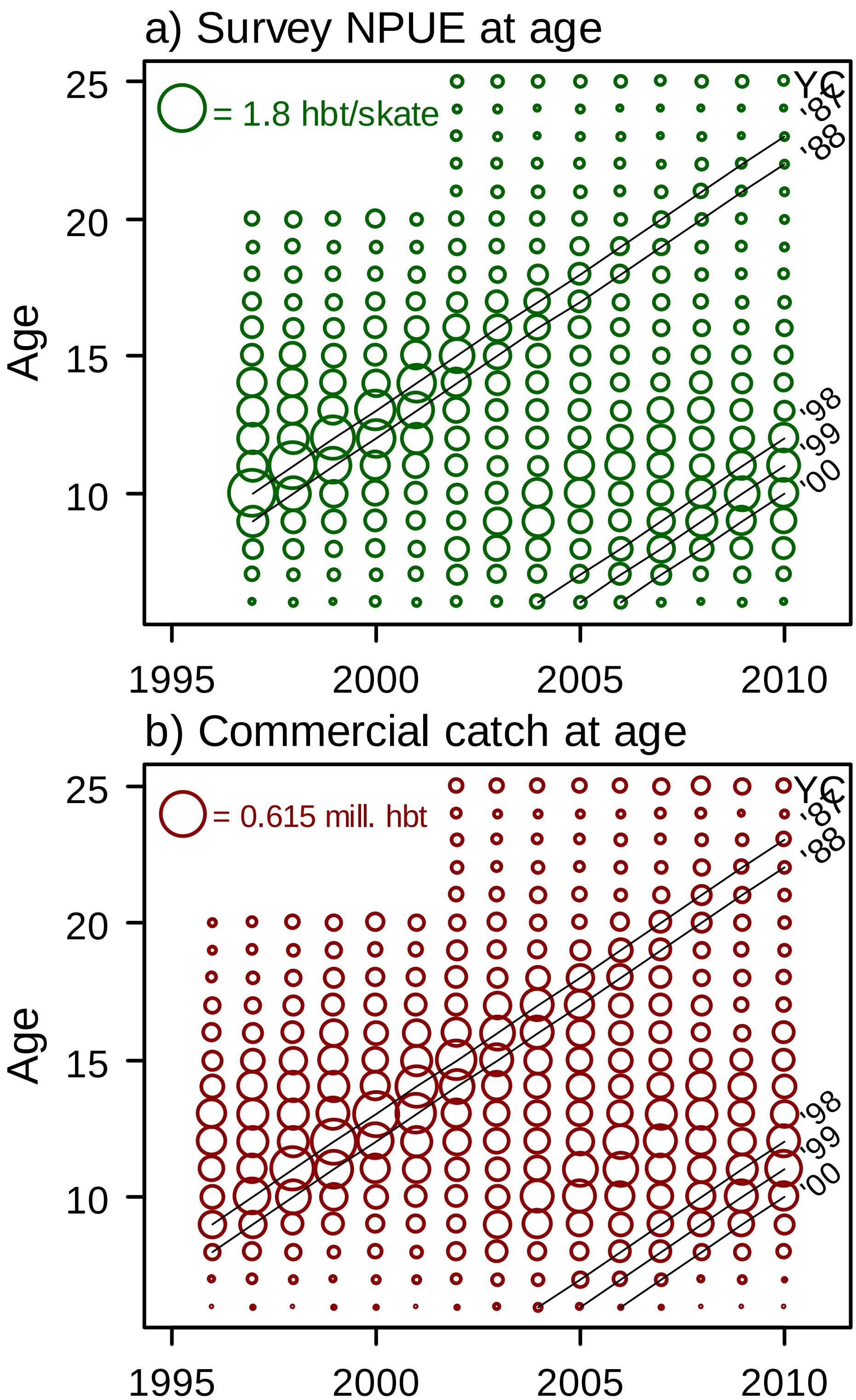


Figure 15. Bubble plots showing age-specific survey catch rate of halibut (both sexes combined, panel a), and catch at age (both sexes combined) in the commercial fishery (panel b).

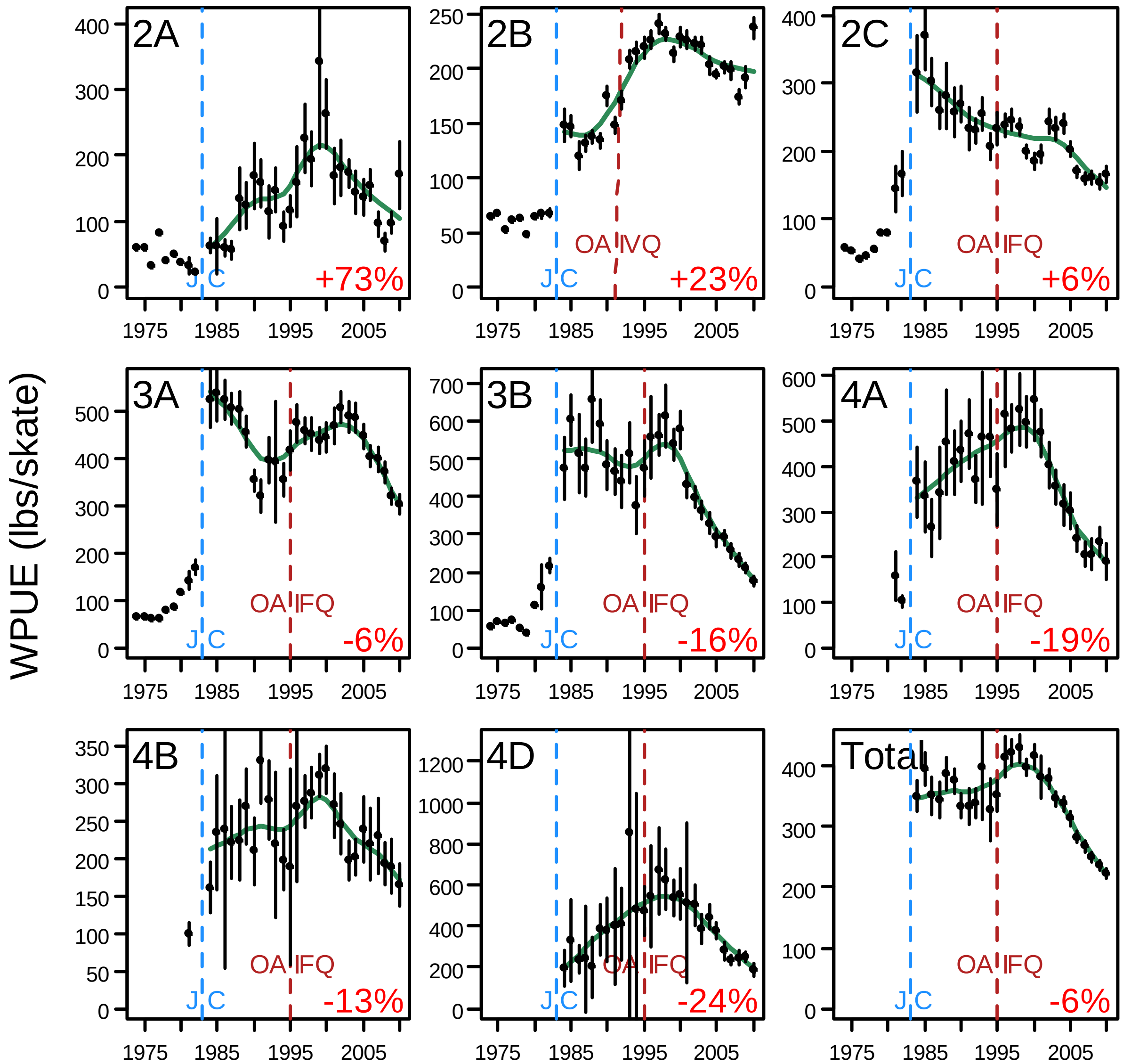


Figure 16. Commercial WPUE by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray/green line is a smoother to illustrate trend; it is not an assessment model fit to the CPUE data. The total is computed by area-weighting the 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.

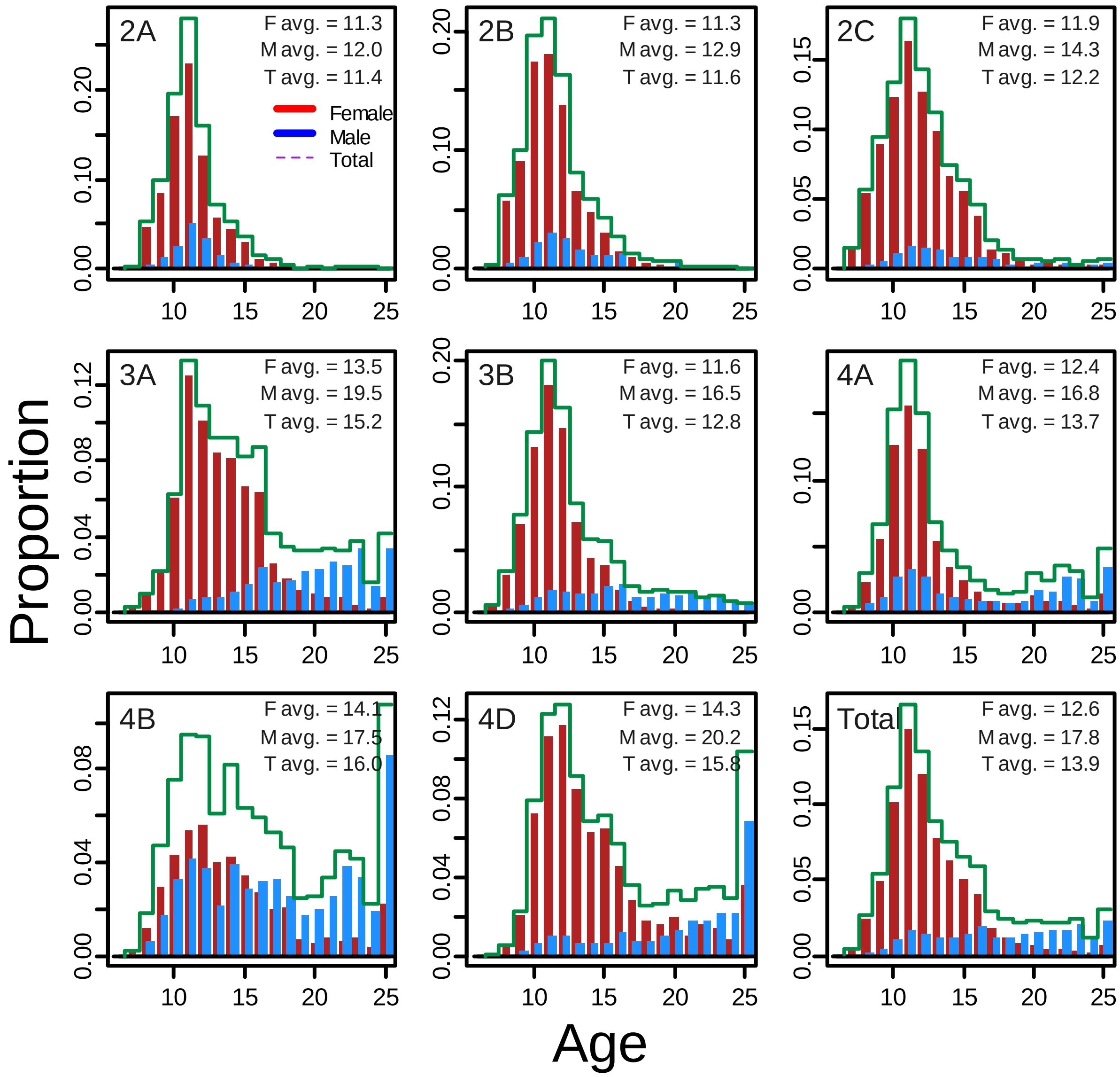


Figure 17. Regulatory area sex and age compositions from halibut sampled from commercial landings. Proportions are shown for females (red bars), males (blue bars) and sexes combined (green line). Average age is also shown, with "T" indicating Total (sexes combined).

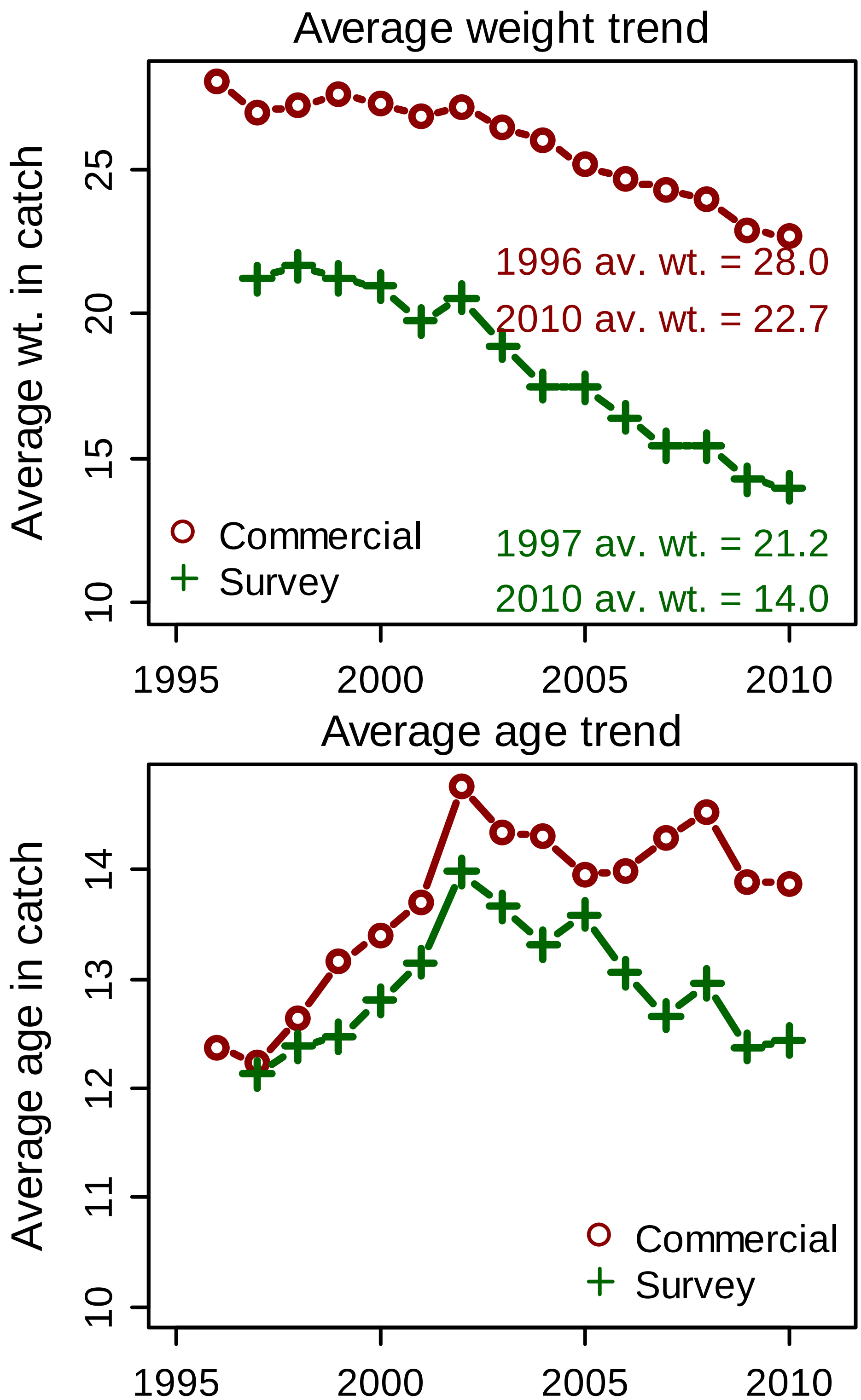


Figure 18. Average weight (panel a) and average weight (panel b) trends for the coastwide halibut stock for 1996 to 2010.

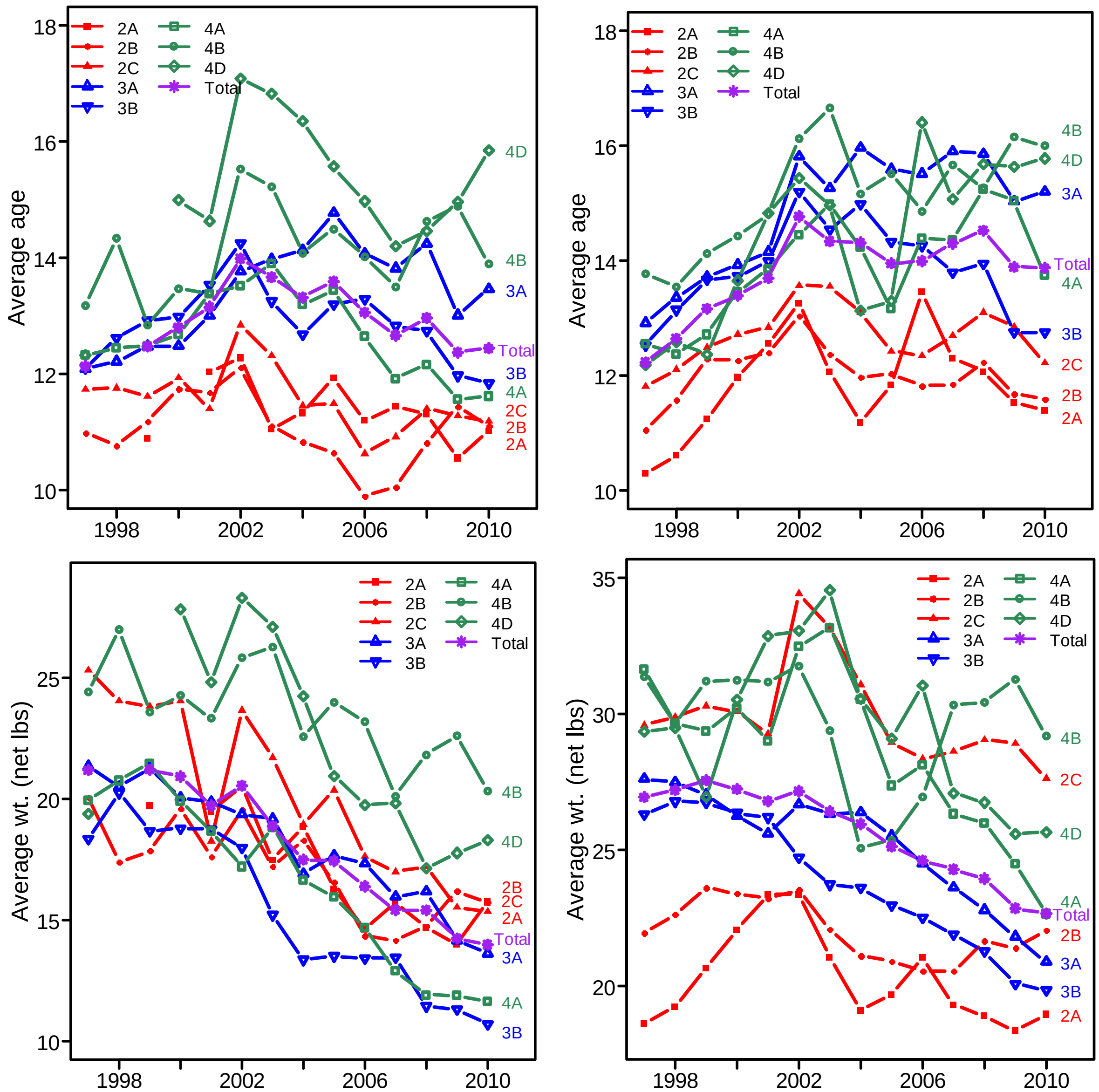


Figure 19. Trends in average age (top panels) and average weight (bottom panels) in survey catches (left panels) and commercial catches (right panels).

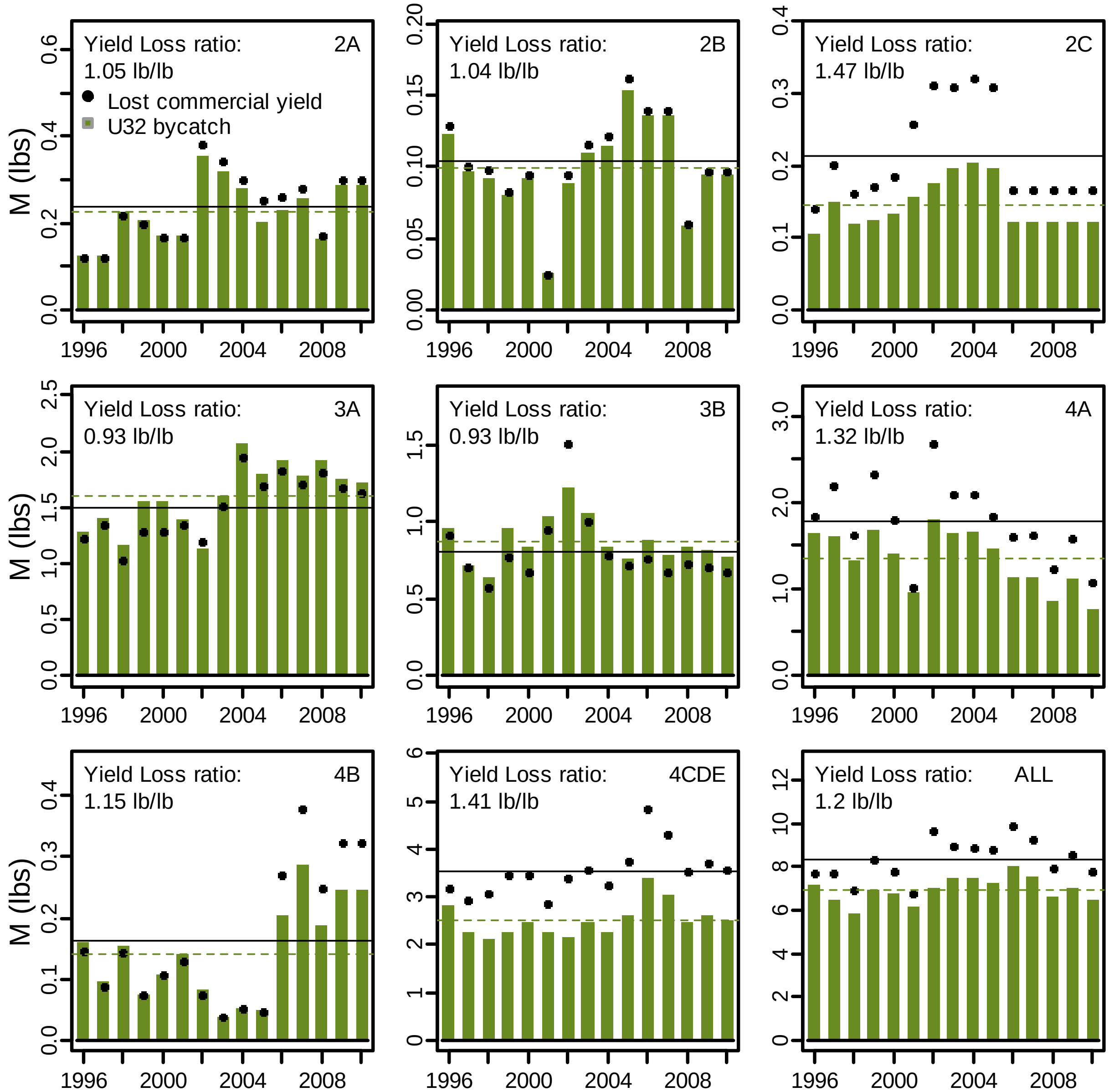
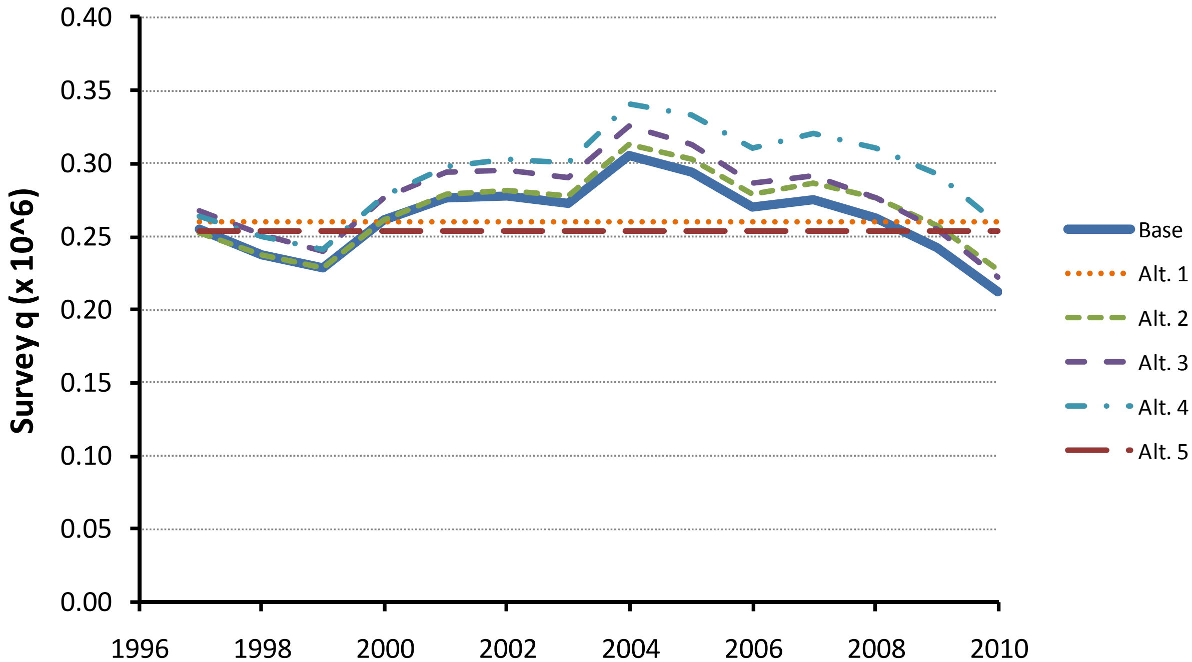


Figure 20. Illustration of impact of under-32 inch bycatch on future yield by regulatory area, without accounting for migration. The bars show estimated annual bycatch mortality, dots show estimated lost yield. Lost yield is estimated using growth models developed individually for each regulatory area. 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.



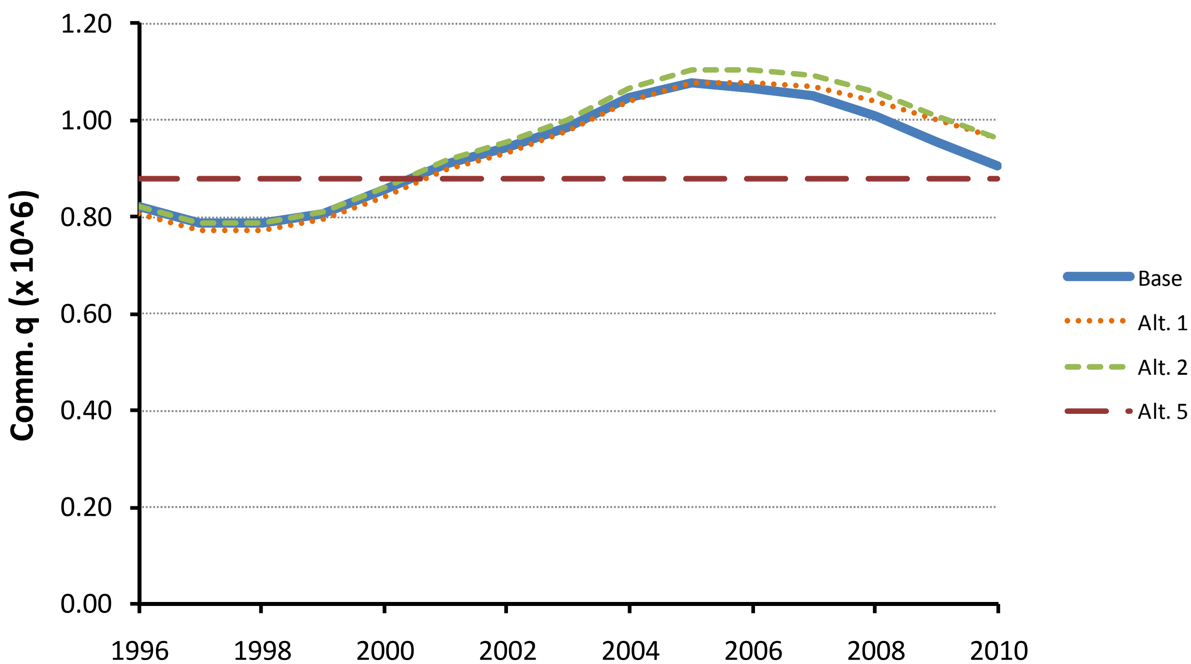


Figure 21. Illustration of time trends in survey and commercial "q" (catchability) among the Base and five Alternative assessment models. See text for details.

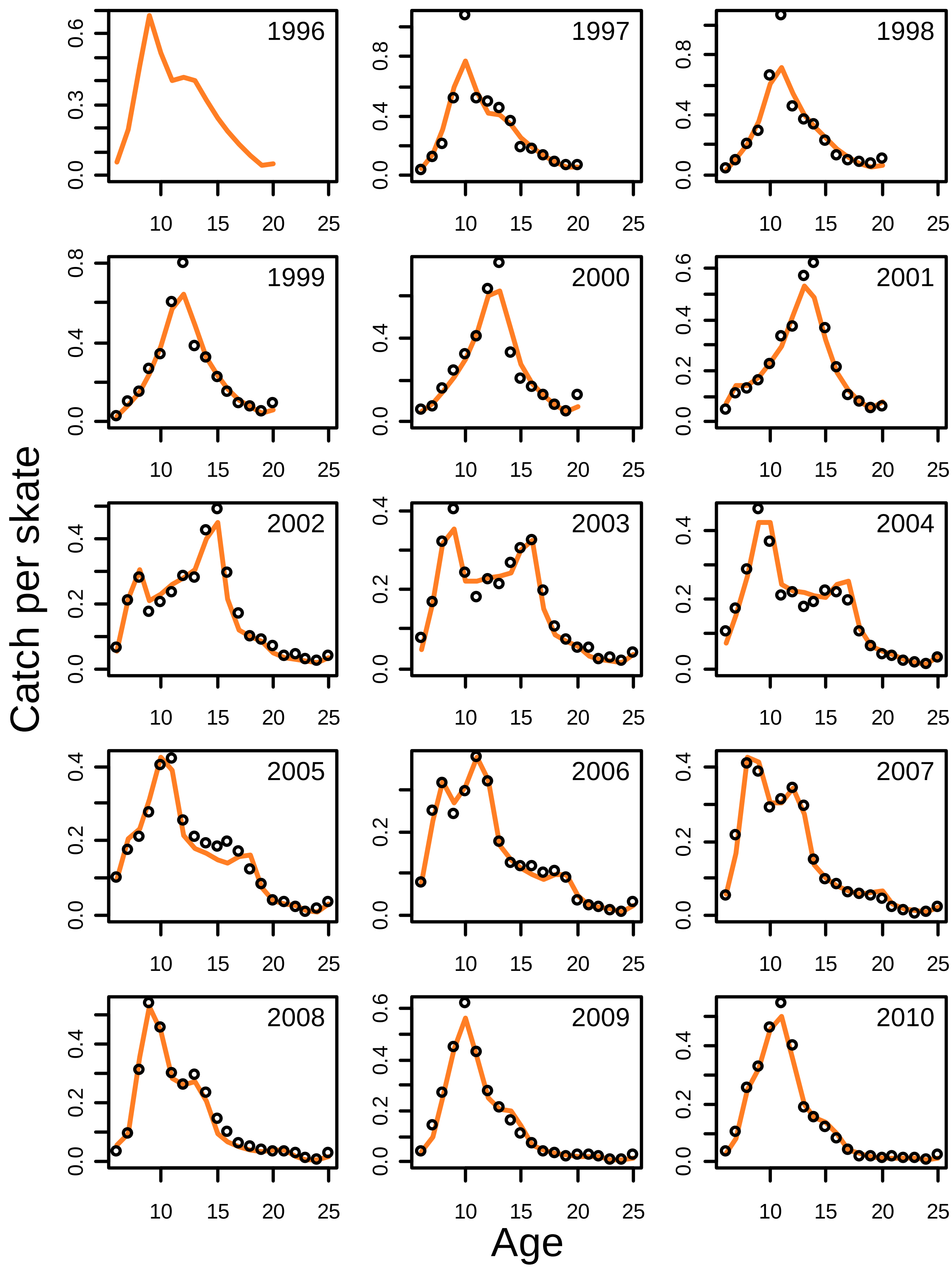


Figure 22a. Observed (points) and predicted (lines) survey NPUE at age of females in the 2010 coastwide model fit.

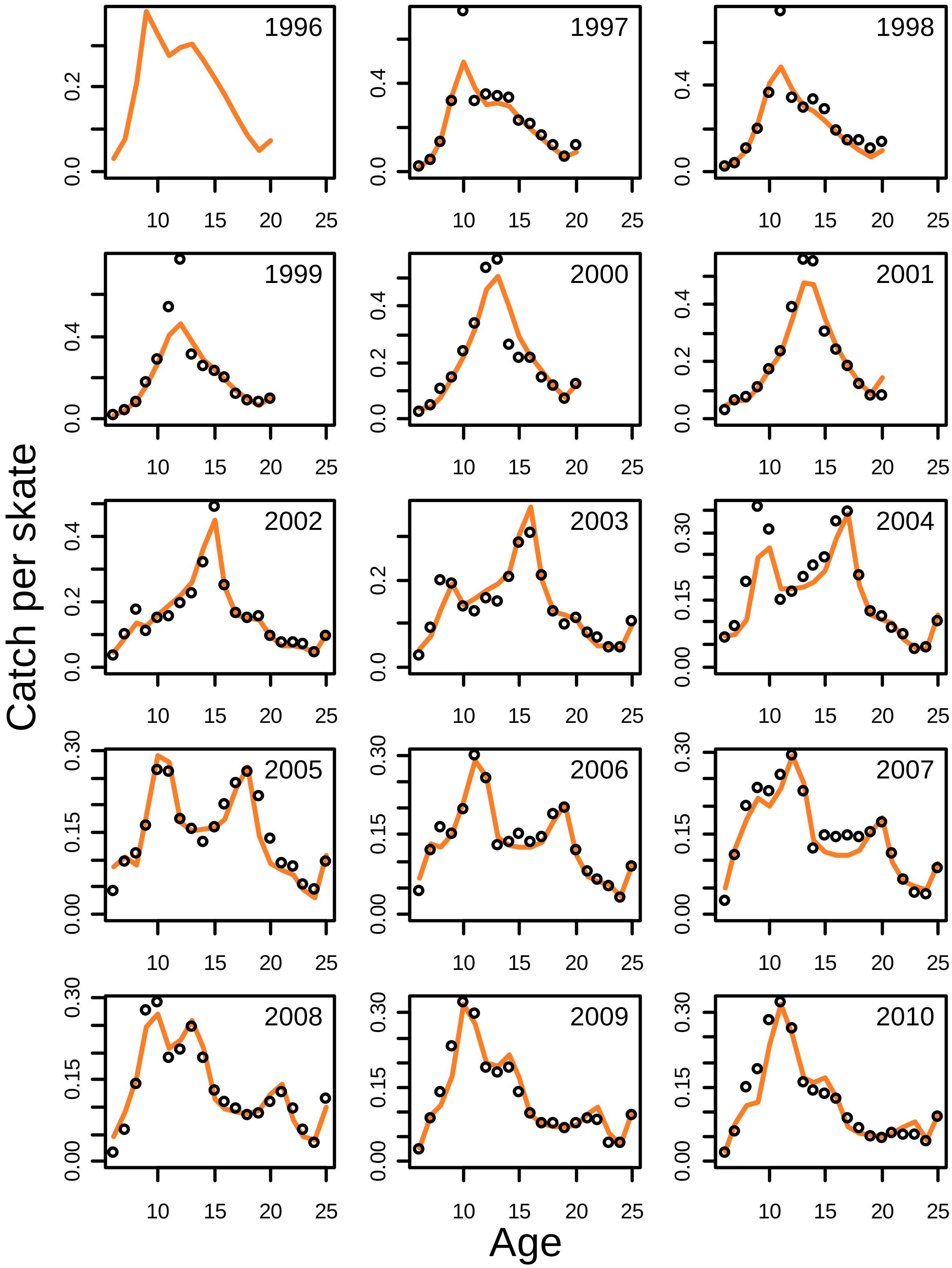


Figure 22b. Observed (points) and predicted (lines) survey NPUE at age of males in the 2010 coastwide model fit.

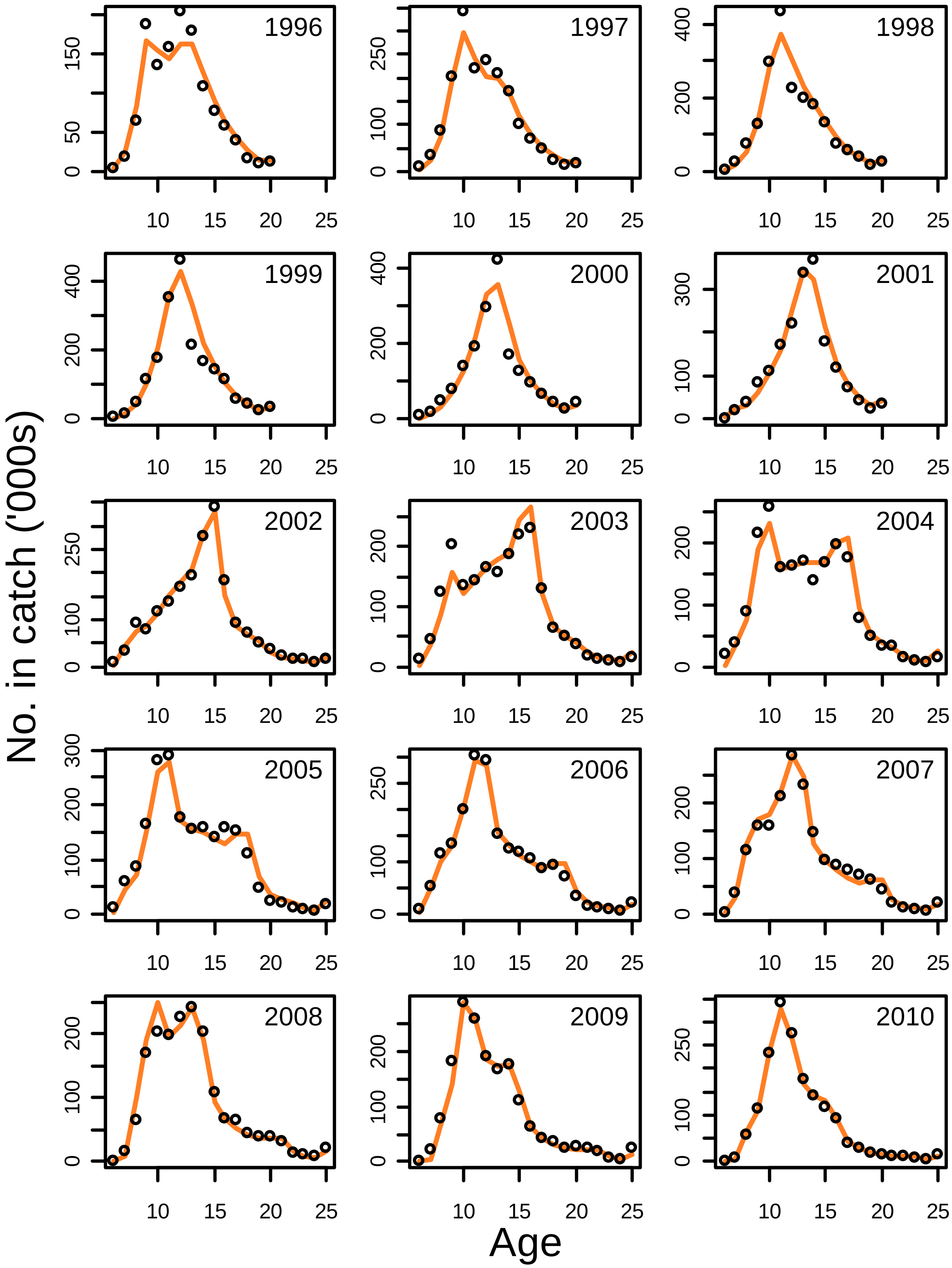


Figure 23a. Observed (points) and predicted (lines) commercial catch at age of females in the 2010 coastwide model fit.

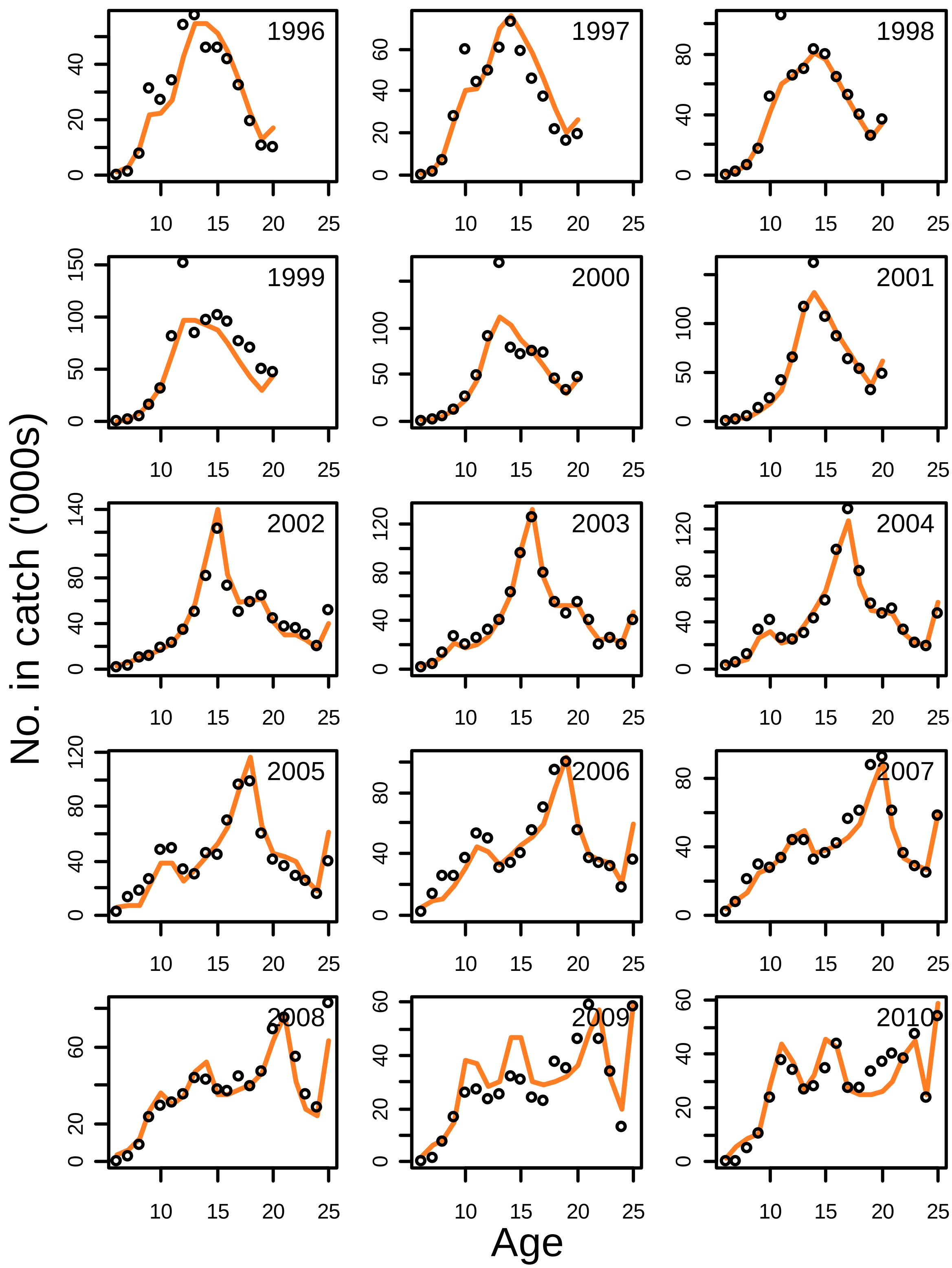


Figure 23b. Observed (points) and predicted (lines) commercial catch at age of males in the 2010 coastwide model fit.

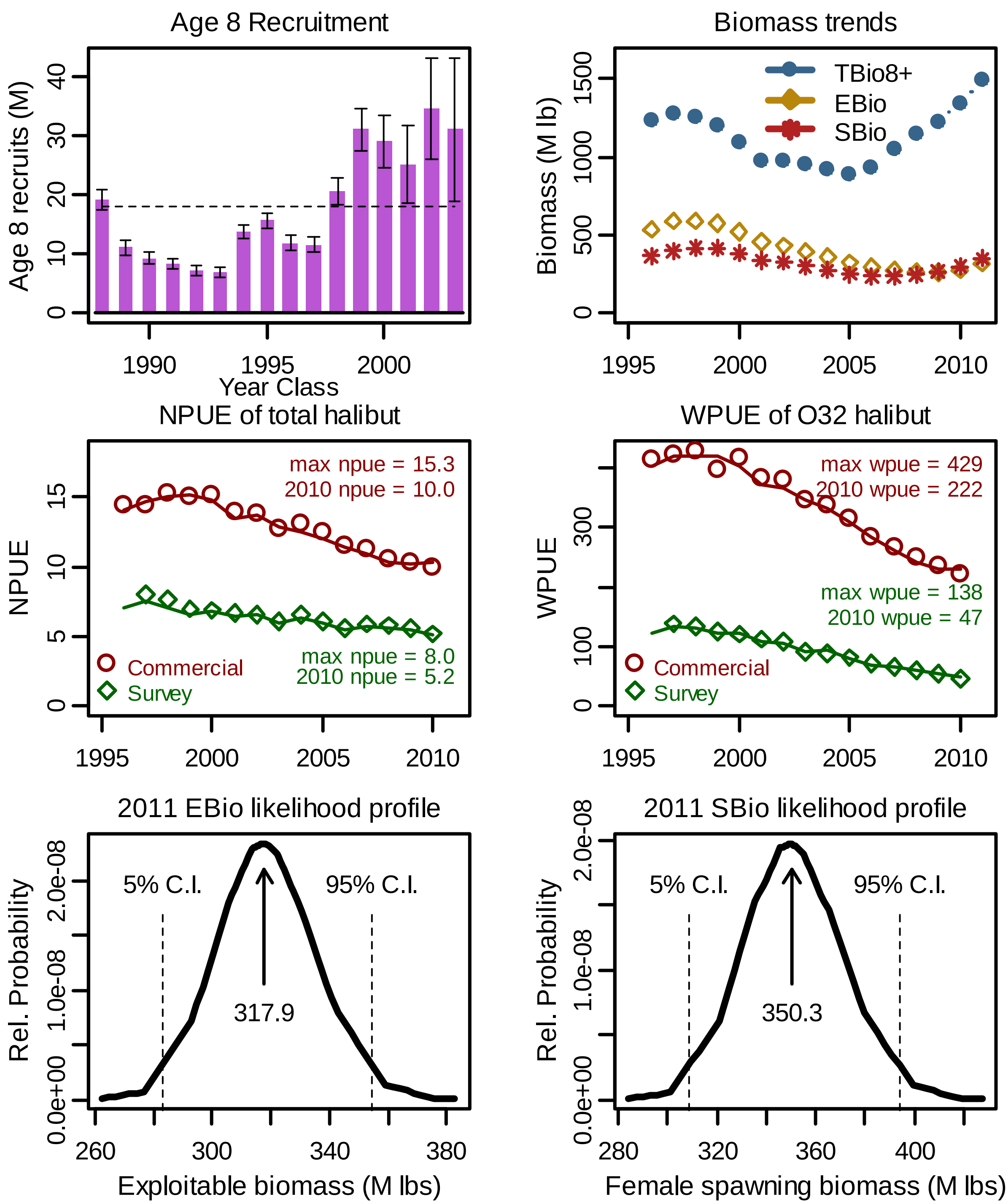


Figure 24. Features of the 2010 halibut coastwide assessment.

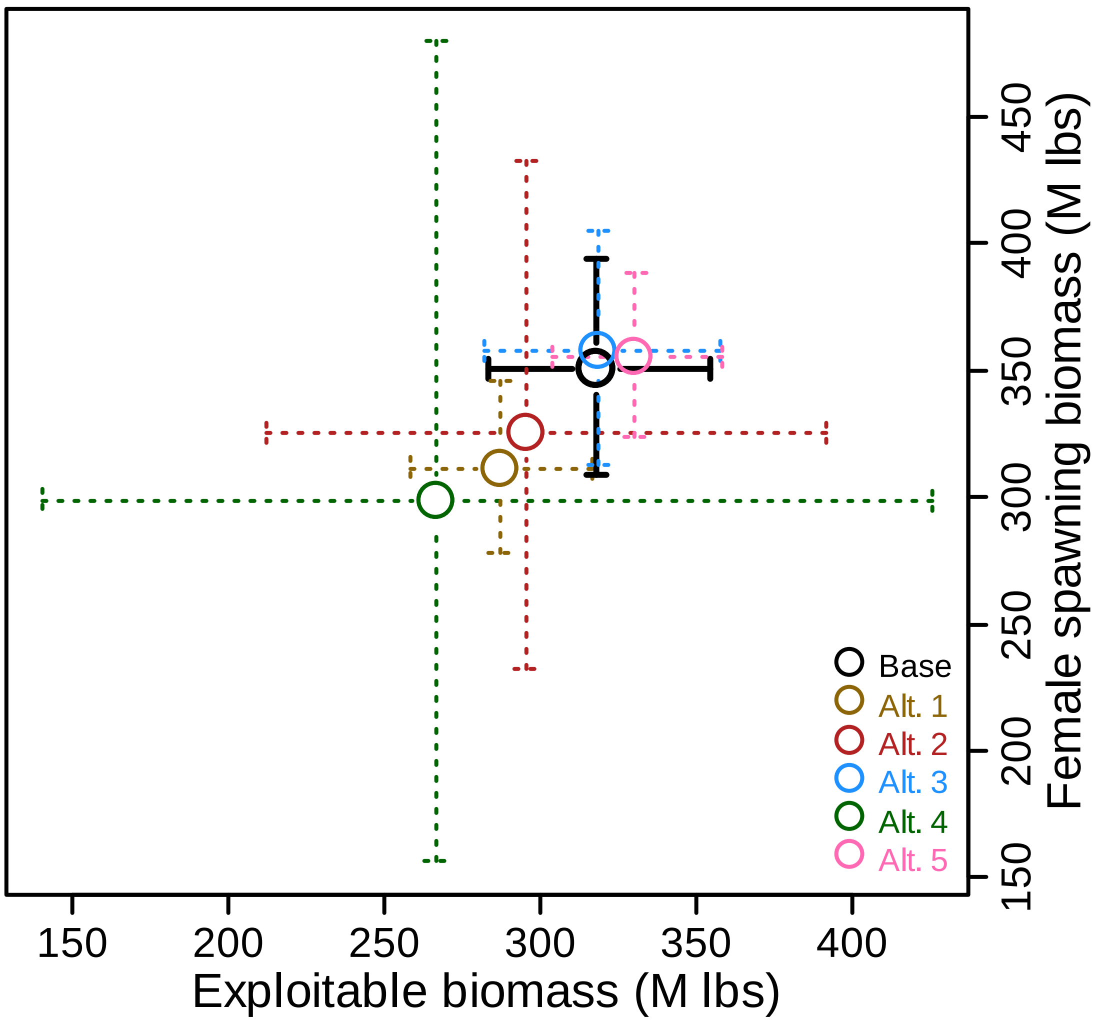


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Figure 25. Illustration of maximum likelihood estimates (circles) for EBio and SBio for various model fits. The 95% percent asymptotic confidence intervals for the likelihood profiles are shown by the end caps of the horizontal and vertical bars extending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

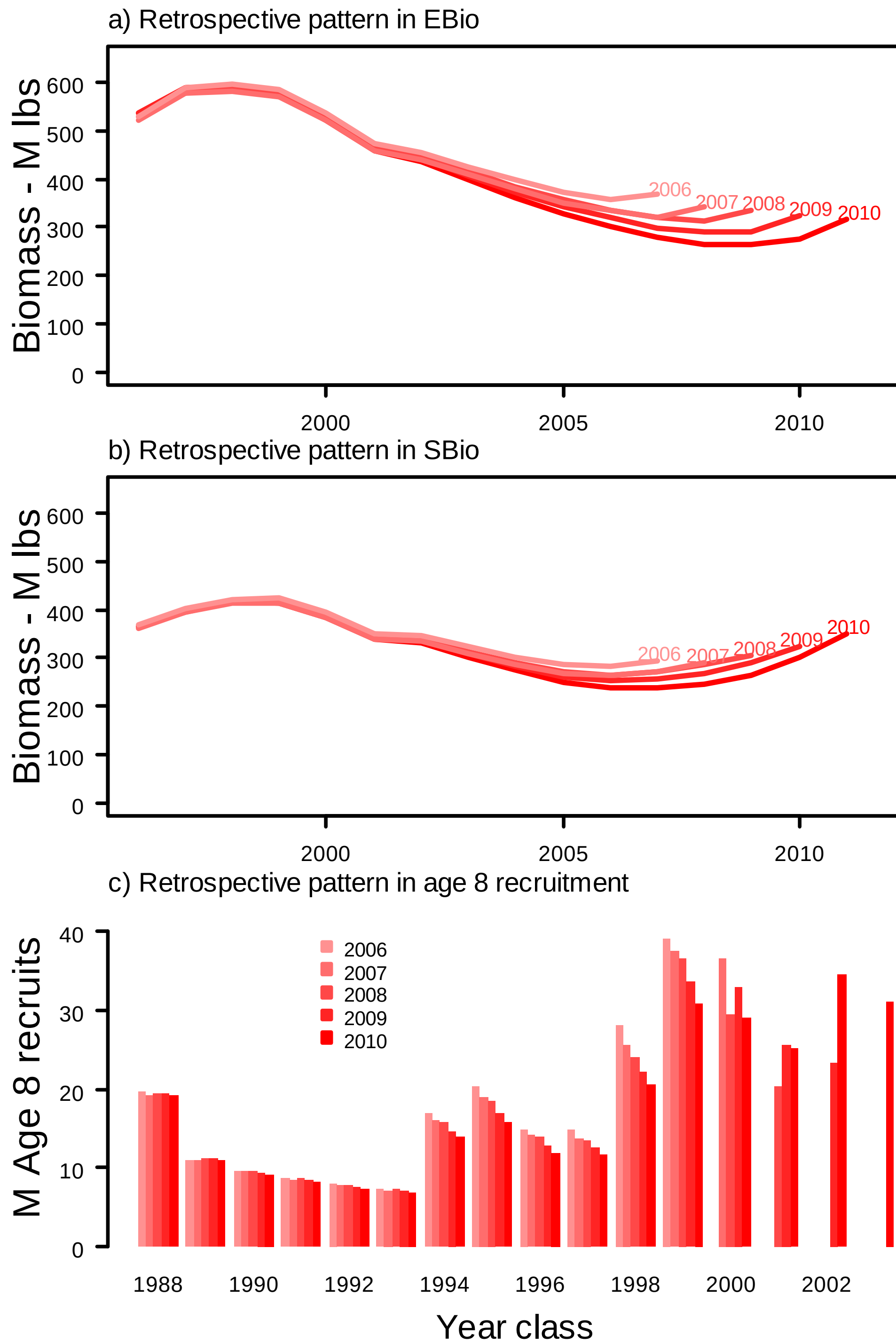


Figure 26. Retrospective behavior of the 2010 halibut assessment model. The top panel illustrates the effect on estimates of EBio by sequentially removing years of data. The middle panel illustrates the effect on estimation of female spawning biomass and the bottom panel illustrates the effect on age 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.

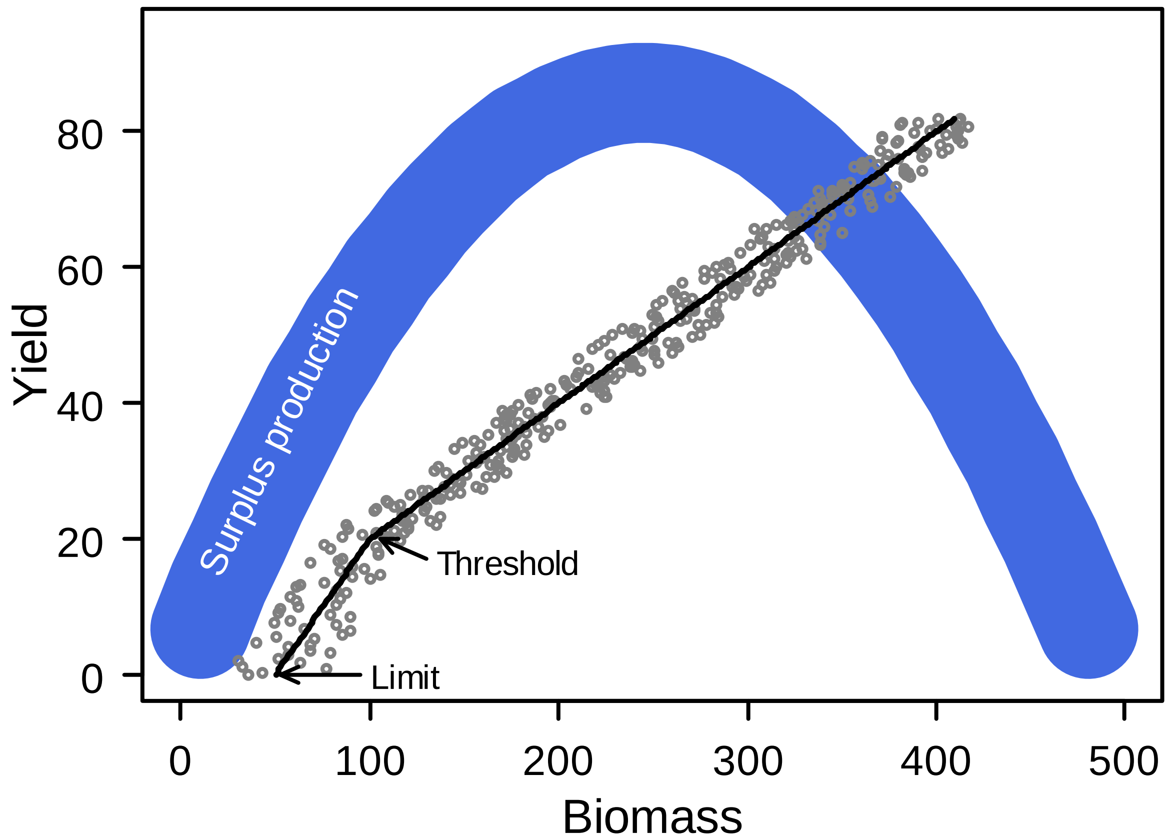
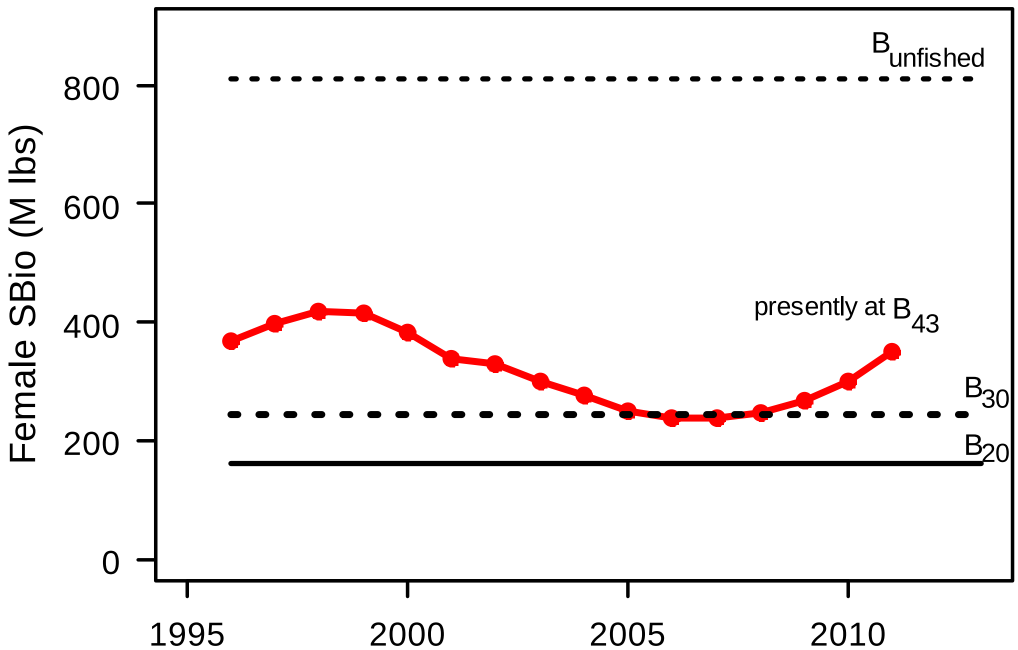


Figure 27. Representation of the IPHC harvest policy. The background curve illustrates theoretical relationship between biomass and surplus production, taken as yield. The slope of the straight line is a 20% harvest rate (Yield/Exploitable biomass), and the harvest rate deceases linearly to zero as the 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.



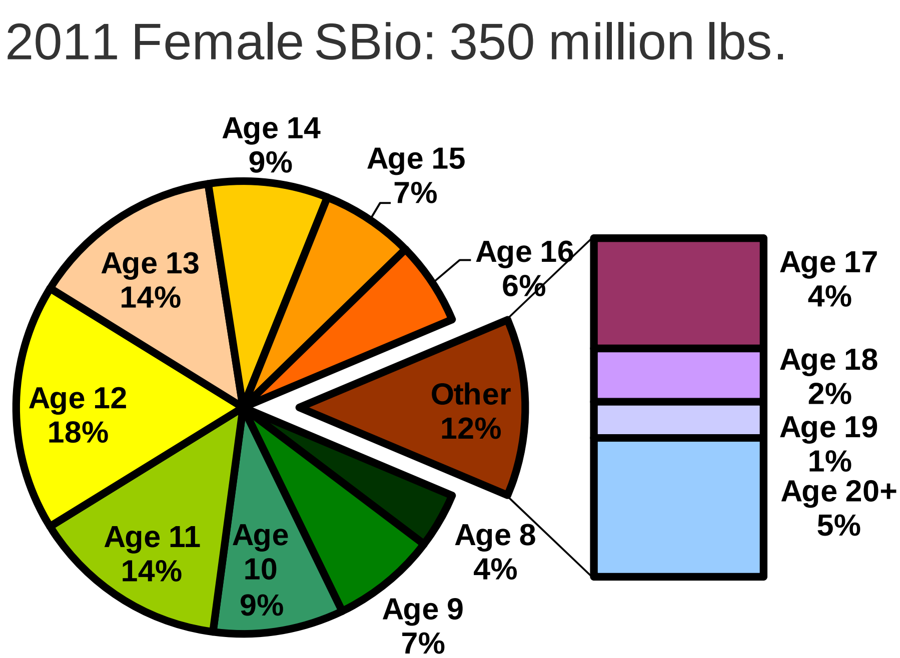


Figure 28. Status (top panel) and current age composition (bottom panel) of female spawning biomass. See text for details.

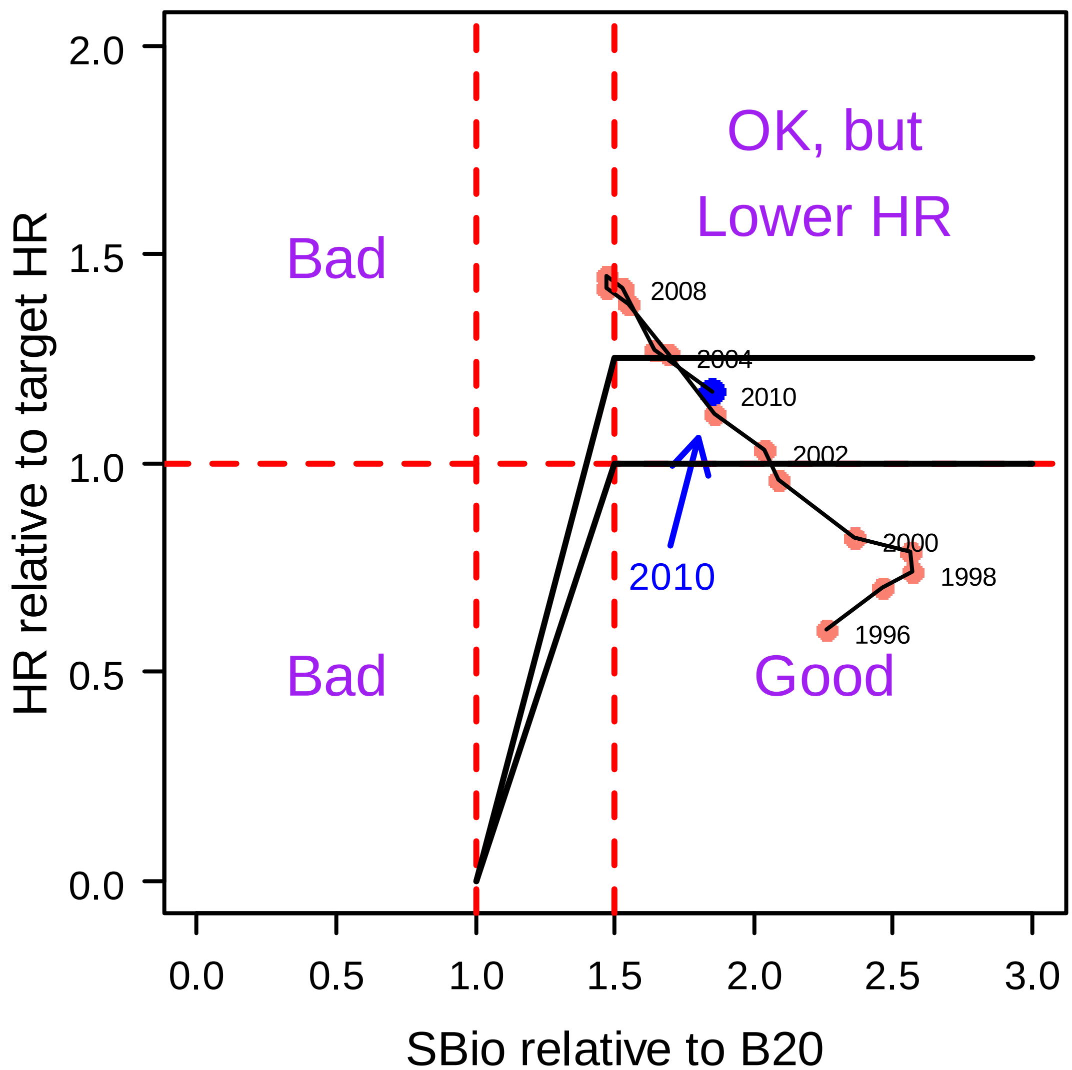


Figure 29. Trend and status of halibut management relative to reference points. Horizontal axis indicates female spawning biomass (SBio) relative to B_{20} (value of 1.0) and B_{30} (value of 1.5). Vertical axis illustrates realized harvest rate relative to a target harvest rate of 0.20 (value of 1.0)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

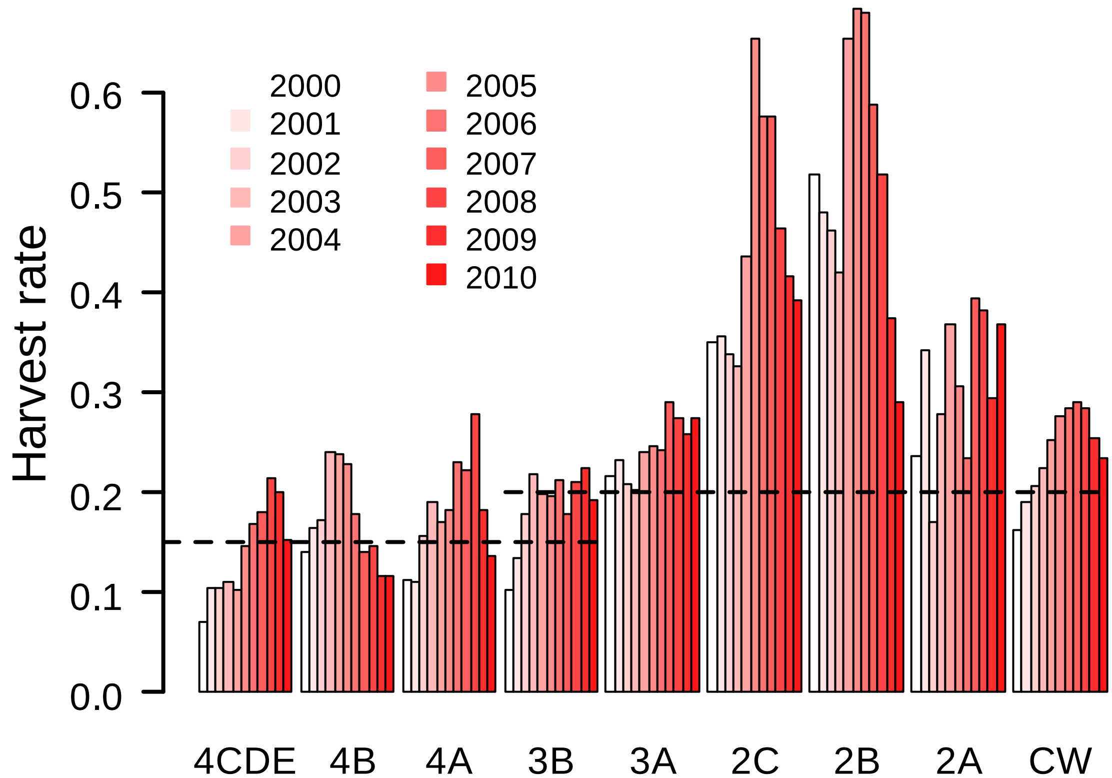
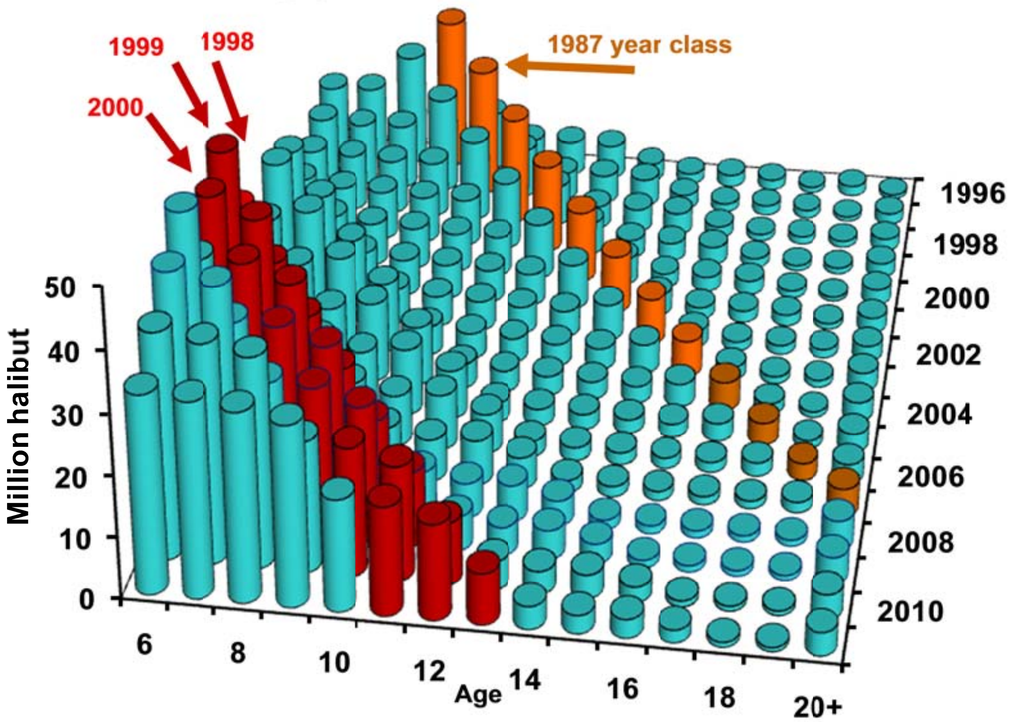


Figure 30. Summary of realized harvest rates from the coastwide assessment, using adjusted and weighted survey WPUE to partition biomass among areas.

a) Total numbers in the population



b) Exploitable biomass in the population

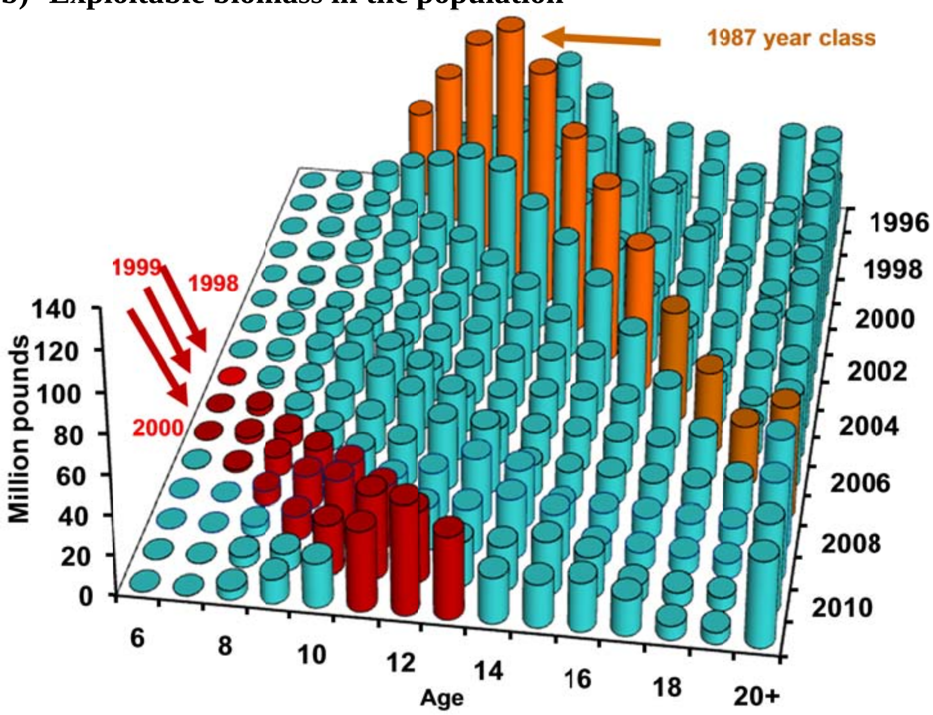


Figure 31. Coastwide population estimates in numbers of halibut (panel a) and as EBio (panel b). Several large year classes are highlighted.

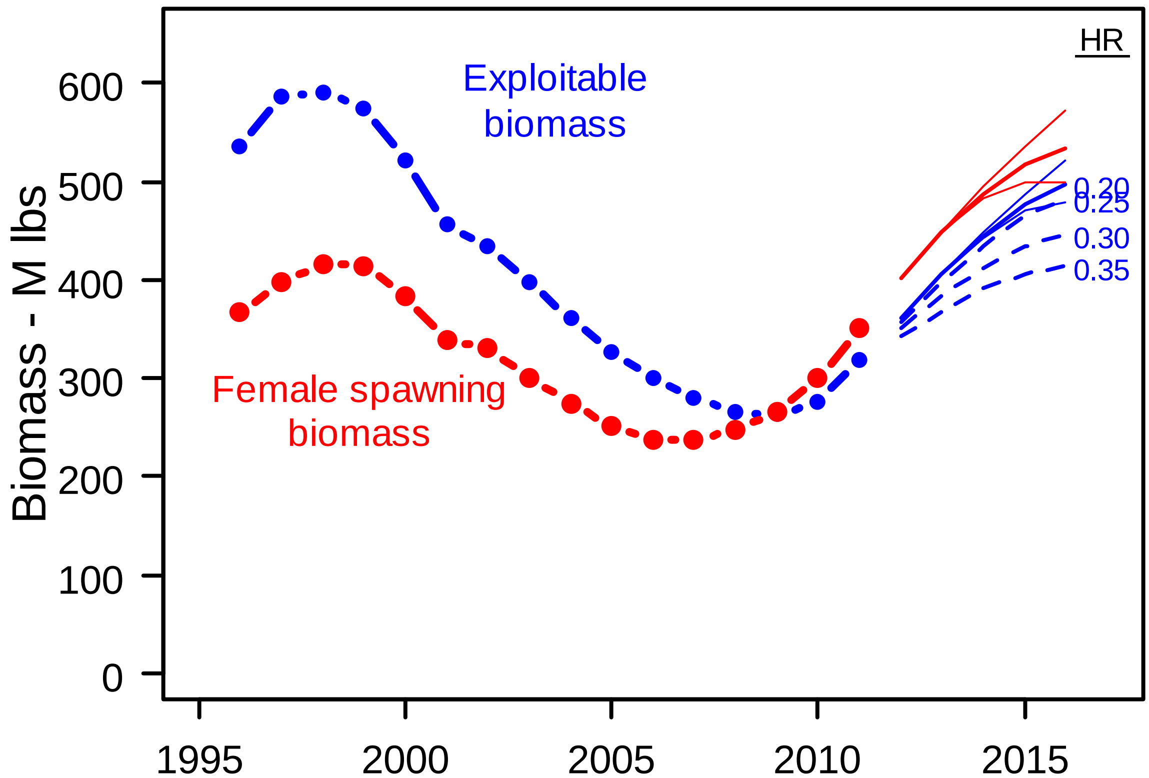


Figure 32. Projected exploitable and spawning biomasses for the coastwide population of halibut.

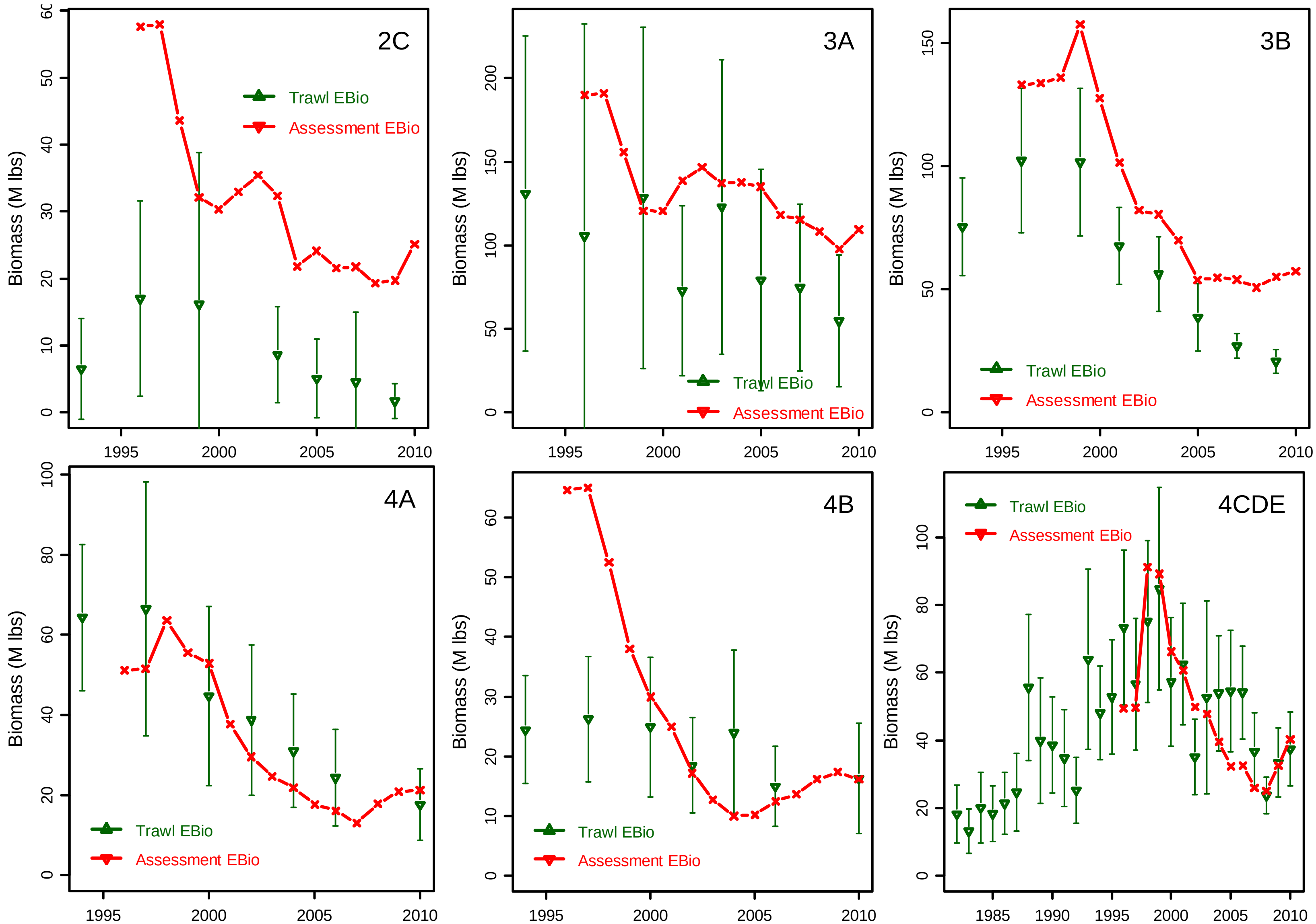


Figure 33. Comparison of IPHC assessment estimates (using adjusted survey WPUE) and NMFS swept area estimates of EBio.

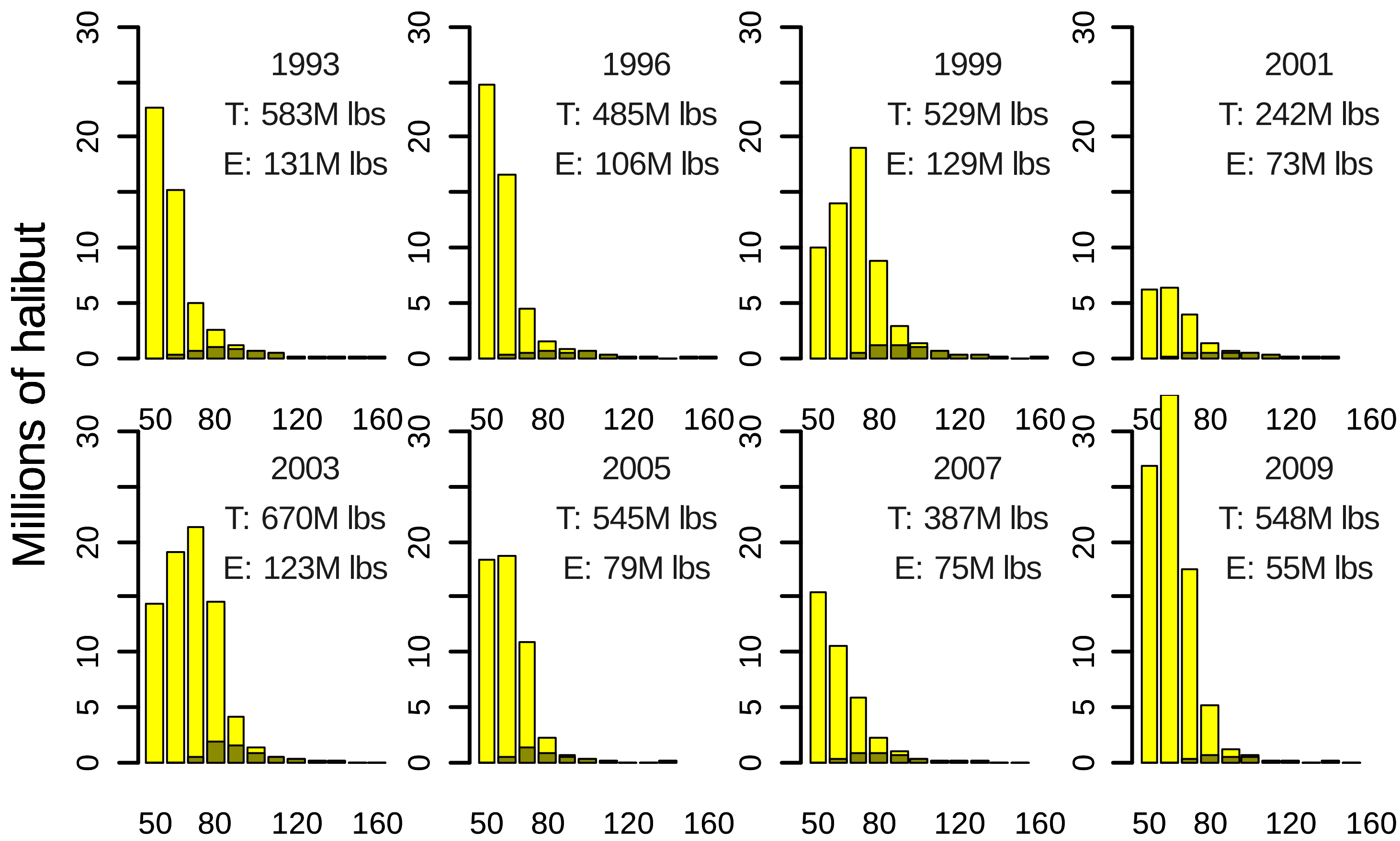


Figure 34. Swept area estimates of halibut in IPHC regulatory Area 3A, by 10-cm length interval, in the NMFS EBS trawl survey for the years 1993 to 2009. Values for total (T) and Exploitable (E) biomass estimated by the survey are also listed. Exploitable numbers of halibut are illustrated by the darker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

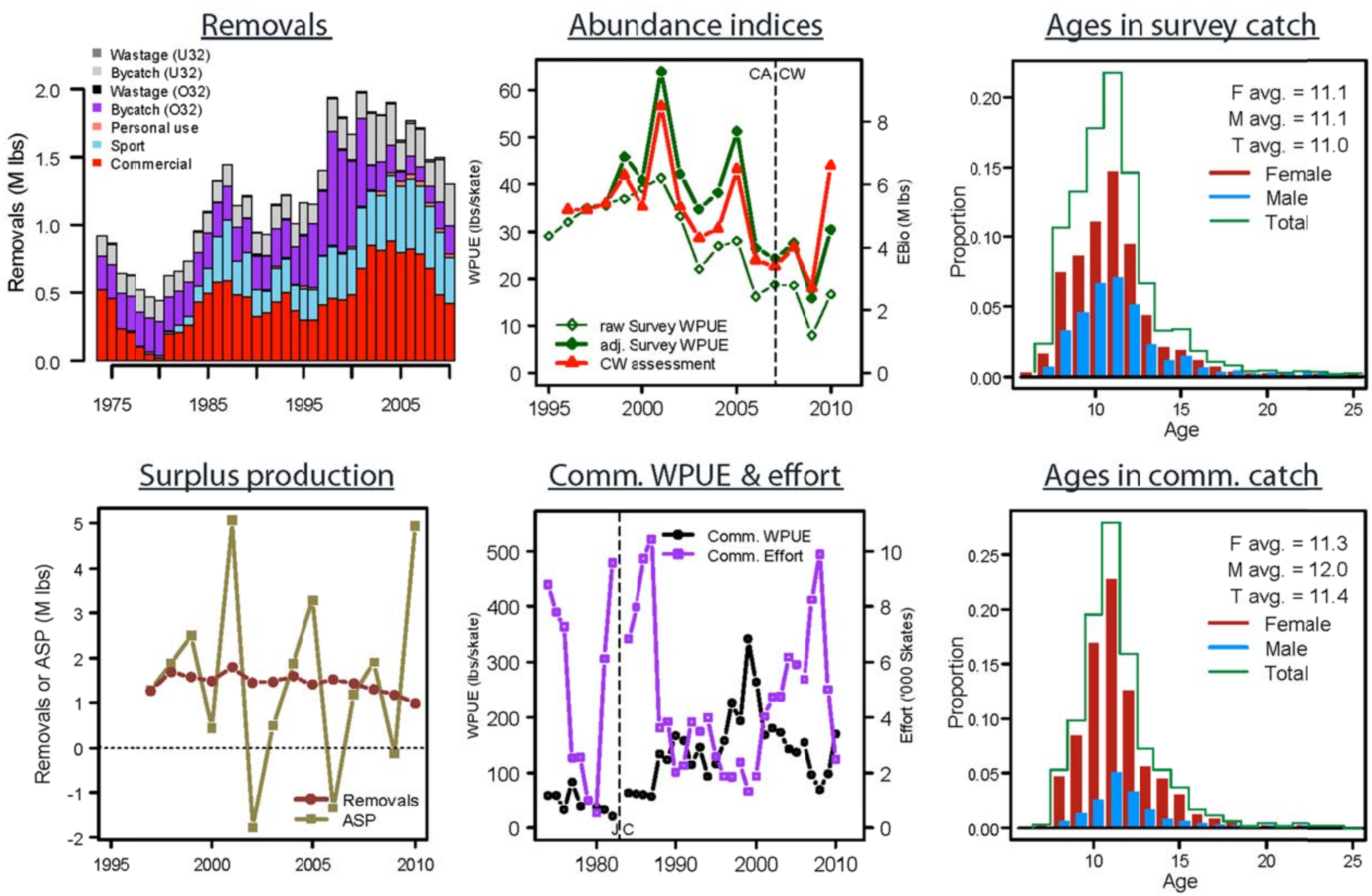


Figure 35. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 2A.

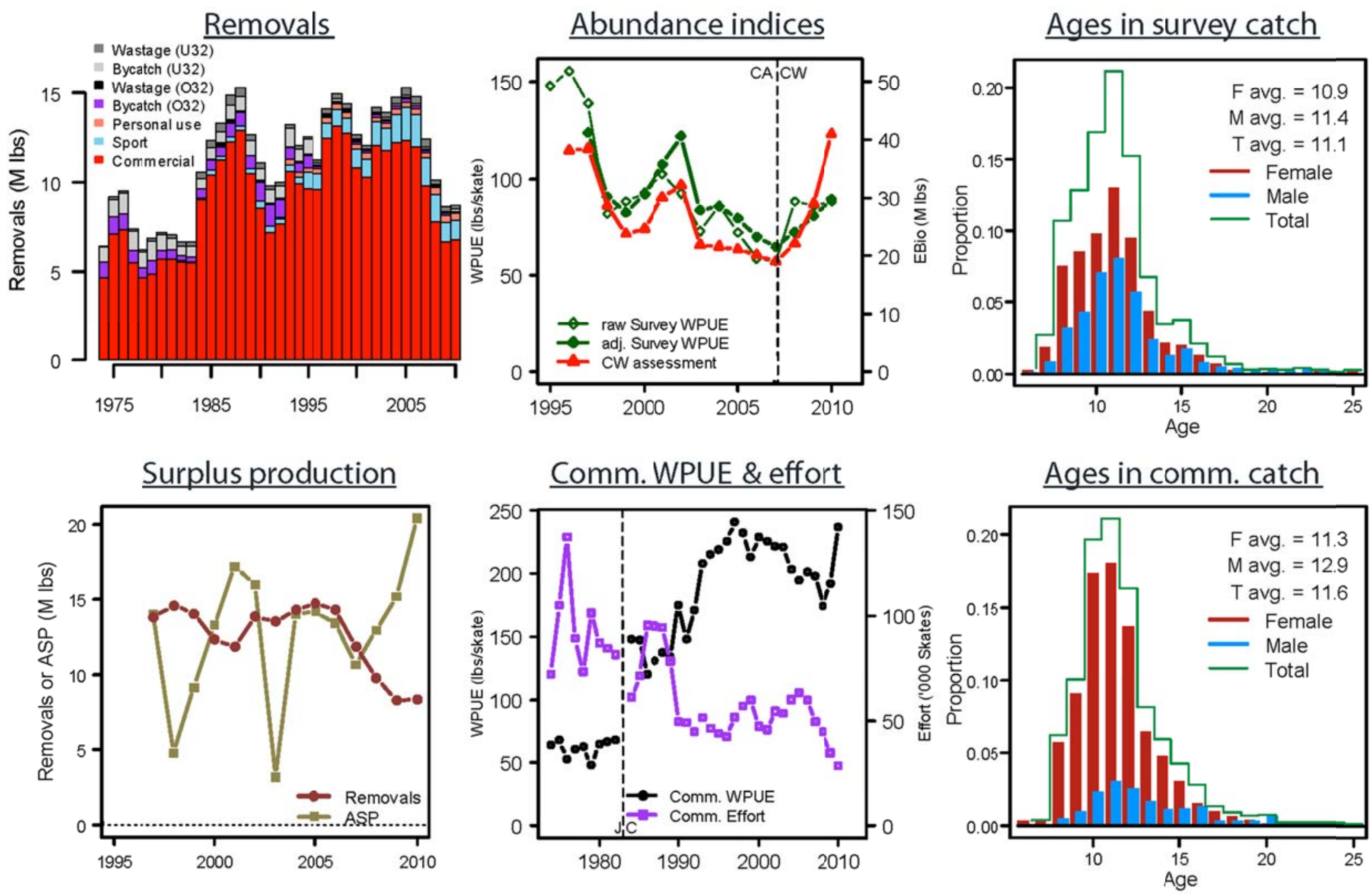


Figure 36. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 2B.

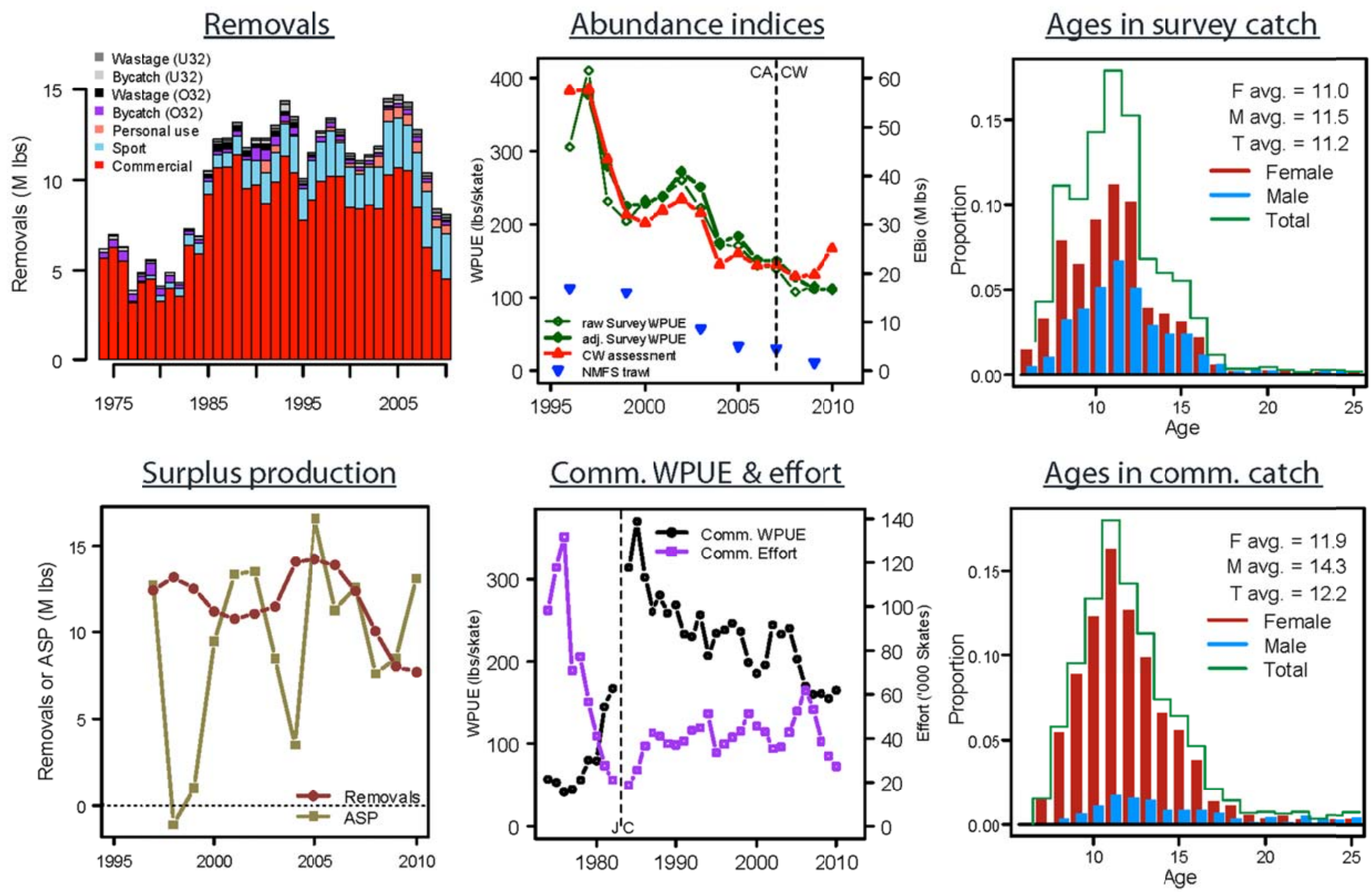


Figure 37. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 2C.

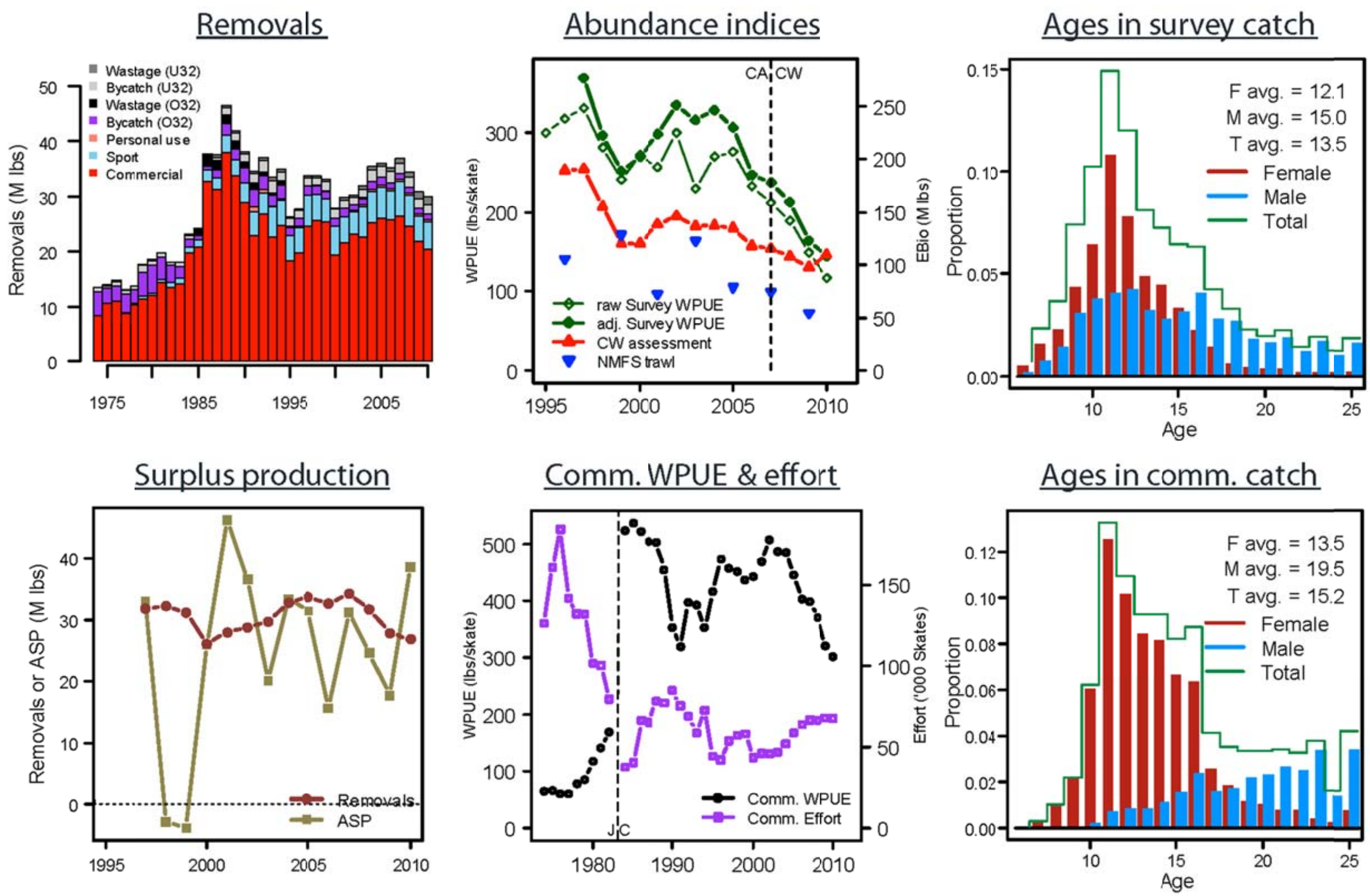


Figure 38. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 3A.

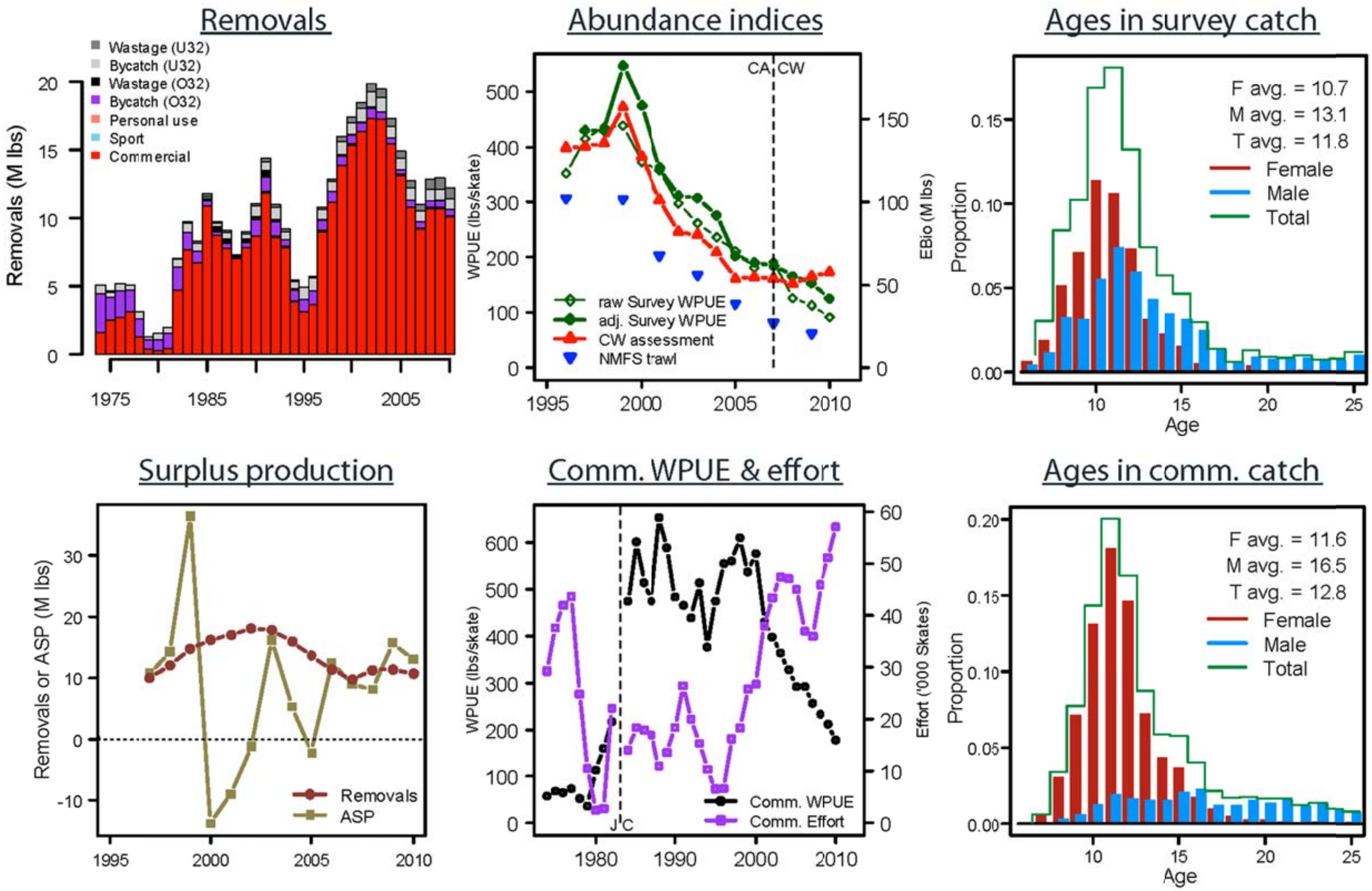


Figure 39. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 3B.

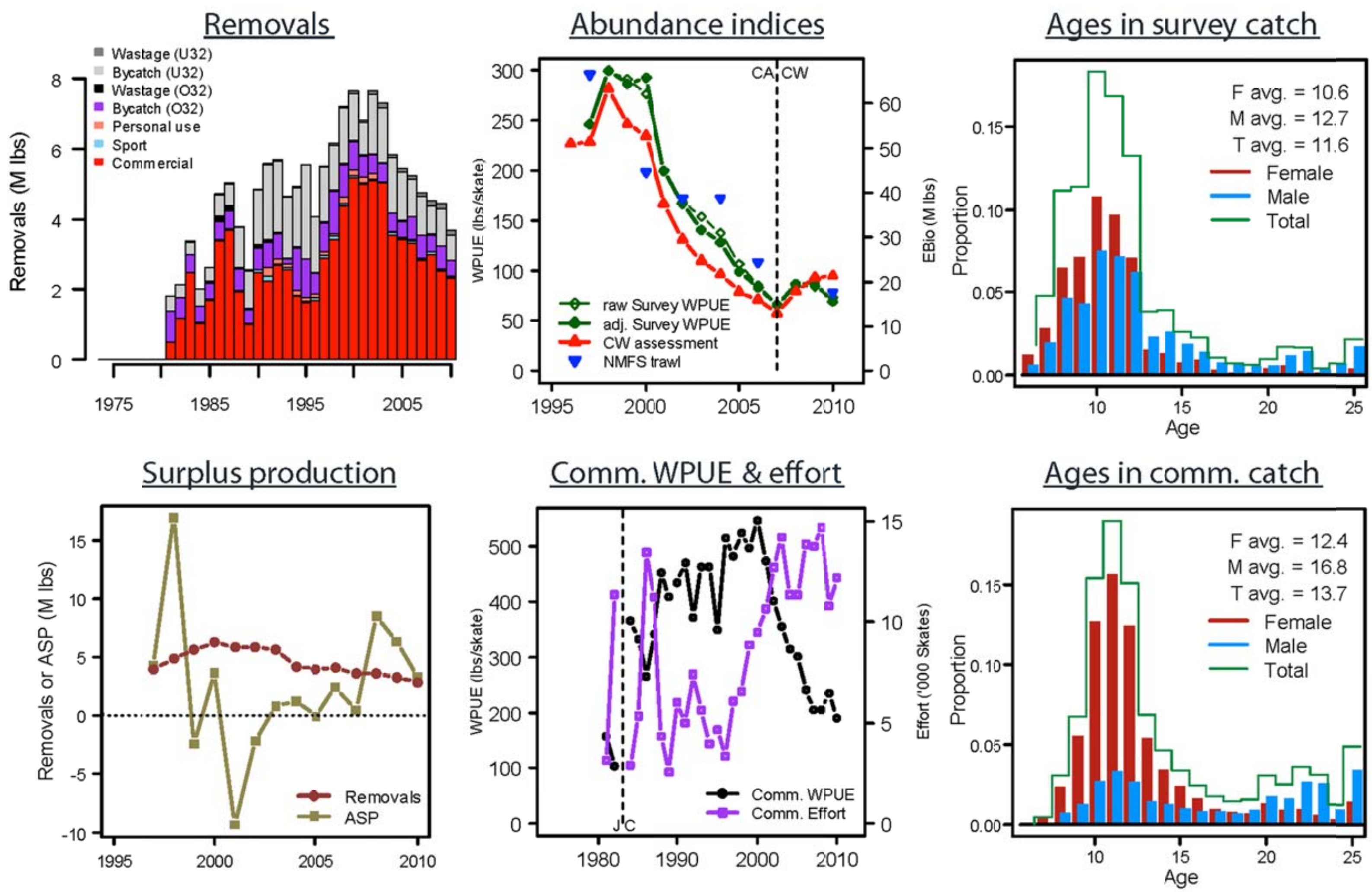


Figure 40. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 4A.

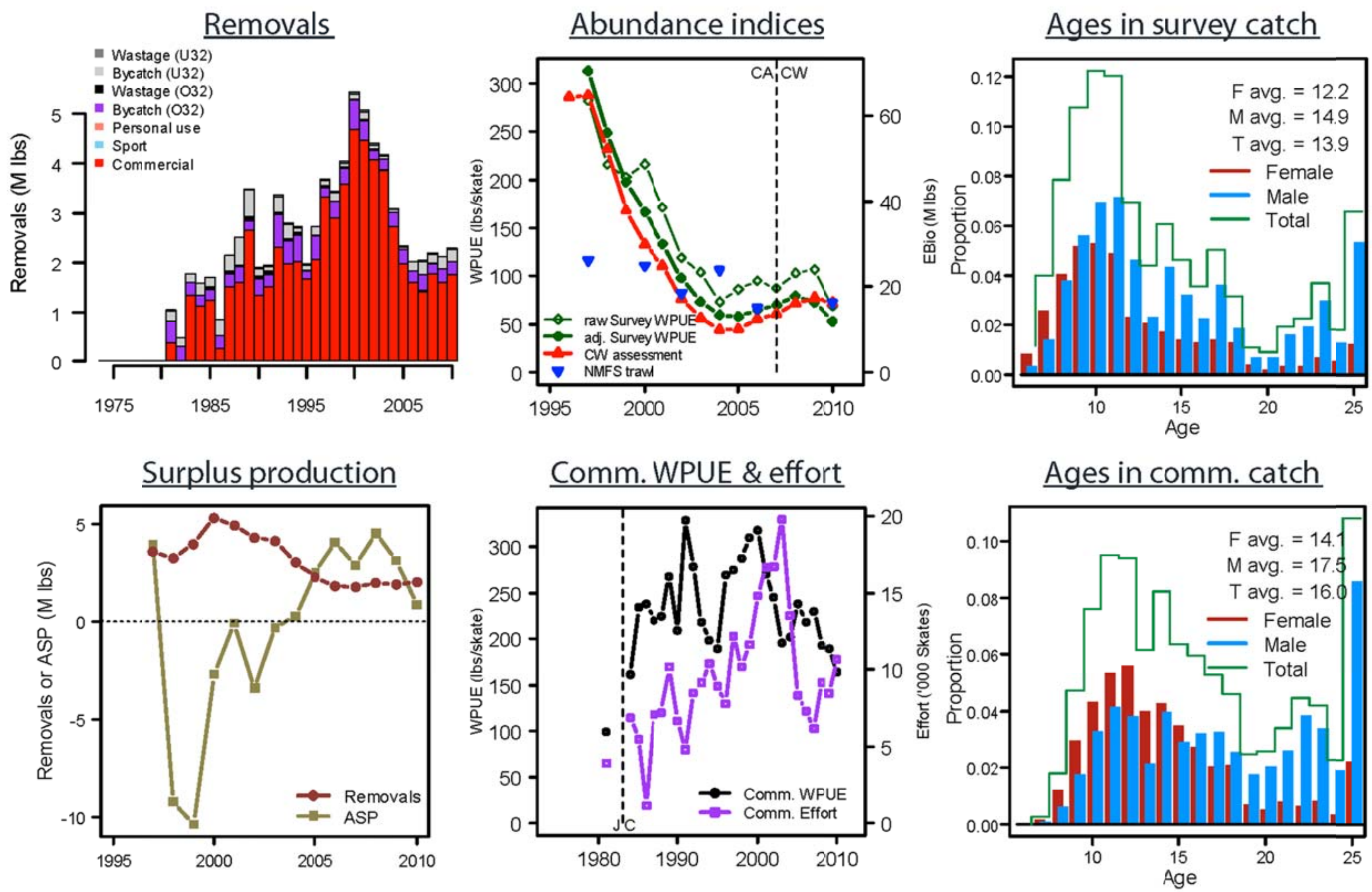


Figure 41. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 4B.

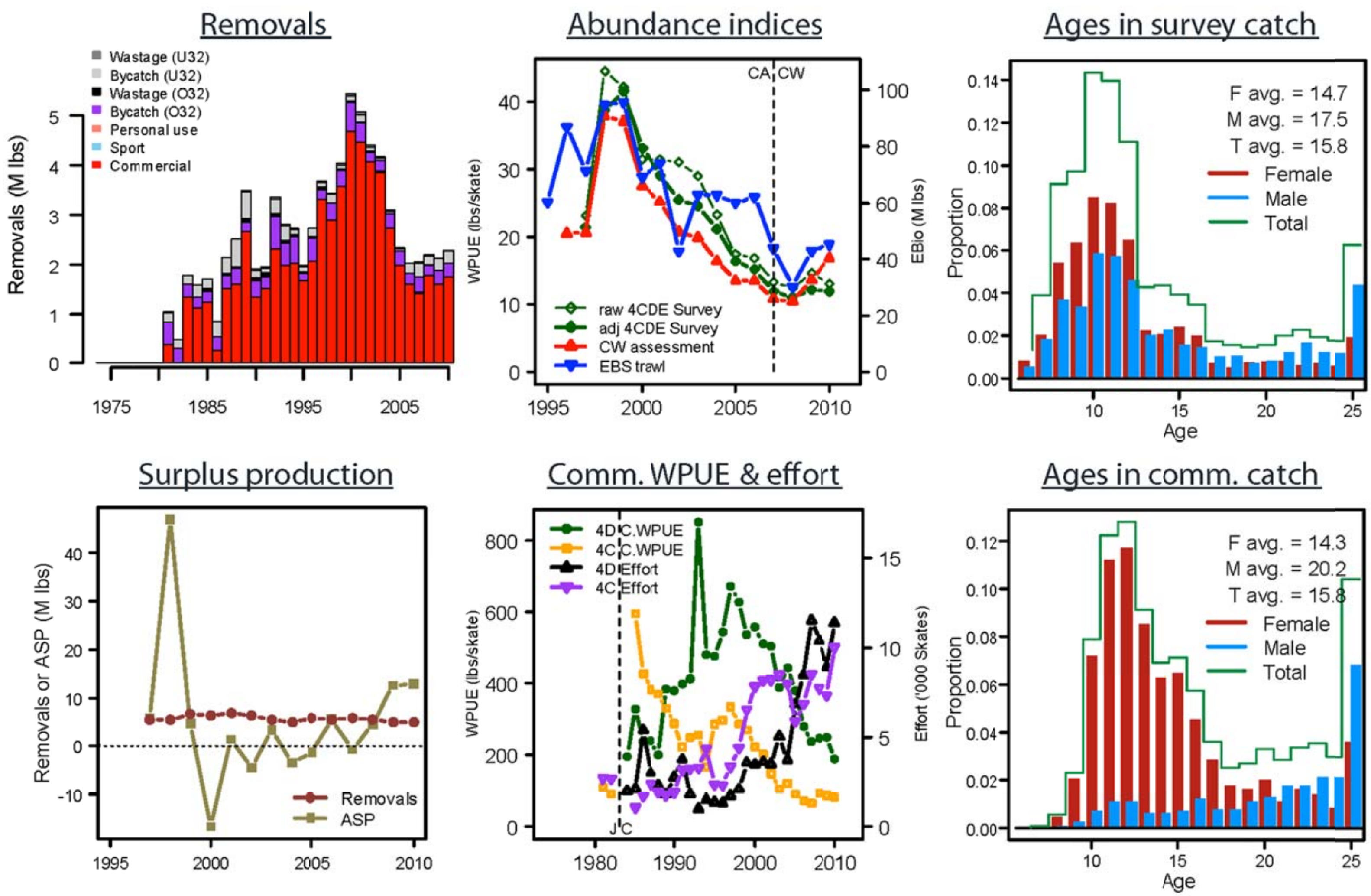


Figure 42. Summary of removals, abundance indices, age structures, surplus production, and commercial effort for Area 4CDE.

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 14.132	2B 29.601	2C 14.580	3A 49.178	3B 29.584	4A 19.888	4B 19.711	4D 15.313	4IC 2.094	4ID 1.925	4S 141.103	4N 59.499	4CDE 219.934	Total 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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