Assessment of the Pacific halibut stock at the end of 2009

Steven R. Hare

Abstract

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

Introduction

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

For many years the staff assessed the stock in each regulatory area by fitting a model to the data from that area. This procedure relied on the assumption that the stock of fish of catchable size in each area was closed, meaning that net migration was negligible. A growing body of evidence from both the assessments (Clark and Hare 2007) and the ongoing mark-recapture experiment

(Webster and Clark 2007, Webster 2010) shows that there is a continuing and predominantly eastward migration of catchable fish from the western area (Areas 3 and 4) to the eastern side (Area 2). The effect of this unaccounted for migration on the closed-area stock assessments was to produce underestimates of abundance in the western areas and overestimates in the eastern areas. To some extent this has almost certainly been the case for some time, meaning that exploitation rates were well above the target level in Area 2 and a disproportionate share of the catches have been taken from there.

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

Changes to the assessment and apportionment in 2009

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

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

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

Observations from the survey and commercial fishery

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

Halibut removals

Total removals from the halibut populations come from seven categories: commercial catch (IPHC survey catch is included in this category), sport catch, O32 bycatch (from a variety of fisheries targeting species other than halibut), personal use, O32 wastage from the commercial fishery, U32 bycatch from non-target fisheries, and U32 wastage from the commercial fishery. Detailed descriptions of each category are contained in the Fishery Removals section of the annual Report of Assessment and Research Activities (Gilroy et al. 2010). The 2009 regulatory area total removals are illustrated in Figure 1, coastwide total removals from 1935 to 2009 are illustrated in Figure 2. On a coastwide basis, total removals are at their lowest level since 1996 and third lowest total over the past 23 years. The pattern of changes between 1996 removals and 2009 removals has been quite different among regulatory areas, however.

Changes in definition of bottom area

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

Treatment of Area 4CDE

Due to its large size and relatively low density of halibut, Area 4CDE does not have a grid of setline survey stations across its entire range. Since 2000, the IPHC setline survey has included 48 stations along the 4D Edge at depths between 75 and 275 fathoms. Since 2006, a total of 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 National Marine Fisheries Service (NMFS) annual Eastern Bering Sea (EBS) trawl survey.

In order to construct a more comprehensive and representative dataset for Area 4CDE, several changes and additions have been implemented this year. The 4D Edge, with the 48 stations, remains unchanged. The 4D Edge represents about 91,711 nmi^2. Beginning this year, the 4CDE islands surveyed as part of the survey now form an area operationally (though not officially) referred to as Area 4I and comprises about 4,019 nmi^2. Prior to this year, the habitat definition for Area 4CDE stopped at 61°N. A review of commercial landings showed that a not-insignificant amount of commercial landings were being taken north of 61°N, up to and including Norton Sound (Hare et al. 2010). To account for this area, we have expanded Area 4CDE northward to 65.5°N - though constrained on the western boundary by the U.S. Exclusive Economic Zone. This newly added region is operationally (again, not officially) referred to as Area 4N, and includes that part of Area 4E north of 61°N and Area 4D north of 62.5°N. The area represented by Area 4N is about 46,793 nmi^2. The reason for the differing southern boundaries is discussed later in the section on Bering Sea trawl surveys. South of Area 4N, that part of the shelf that is not part of the 4D Edge or Area 4I, is operationally termed Area 4S and comprises about 153,474 nmi^2. The boundaries for the four Area 4CDE areas are illustrated in Figure 3. Density estimates for the four areas all rely on surveys - Areas 4D Edge and 4I on the IPHC setline survey; Areas 4S and 4N on trawl surveys as discussed in the next section.

NMFS and ADFG Bering Sea trawl surveys

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

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

As noted above, the shelf area north of 62.5°N (in 4D) and north of 61°N (in 4E) has been added to the definition of halibut habitat this year. In adding this area, however, we were concerned as to the validity of applying the south shelf density estimate from the NMFS trawl survey to the northern part of the shelf. Fortunately, there has been an approximately triennial trawl survey, conducted in a similar manner to the 4S survey with a similar net, in the greater Norton Sound area since 1976. The survey was conducted by NMFS until 1991 and since then by the Alaska Department of Fish and Game (ADFG). In all, there have been surveys conducted in 1976, 1979, 1982, 1985, 1988, 1991, 1996, 1999, 2002, 2006, and 2008). There has been no formal analysis of the halibut data from the survey; however, ADFG provided us with the raw catch rate (WPUE) data at all stations fished each year. The survey has been conducted each time in a core area (indicated by the Norton Sound outline in Figure 3) as well as opportunistic stations often well away from Norton Sound. In order to create a consistent index for Area 4N across years, we selected just the stations within the core area and calculated a simple mean value and its standard error (Fig. 6a). This index has units of kg of halibut per km^2 area swept. As there are no sample data, we are unable to derive an O32 index similar to that derived from the NMFS trawl survey. To create a density index comparable to the other IPHC areas (i.e., O32 lbs/standard skate), we proceeded in the following manner.

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

This procedure makes several assumptions, most stringently that density trends in 4N and 4S vary synchronously. Consideration of the years with actual survey data shows this not to be that poor of an assumption and the square root transform downweights the single very large 4N data point of 1996 to achieve a closer match. The end result (Fig. 6b) is a density estimate comparable to the other IPHC areas. In general, 4N density averages 1/3rd to 1/10th of 4S density. As 4S is more than 3 times larger than 4N, the overall added biomass to 4S is relatively minor (Fig. 6c). More importantly though, all halibut are accounted for in Area 4CDE up to 65.5°N.

IPHC setline survey

The current SSA survey has been conducted since 1996 in almost all areas and in all years. The exceptions are the Eastern Bering Sea shelf which was surveyed only in 2006; Area 2A which was not surveyed in 1996, 1998, and 2000, the Area 4D edge which was not surveyed in 1996, 1998 and 1999, and Area 4A and 4B which were not surveyed in 1996. Stations are placed on a 10-nautical mile grid between depths of 20 and 275 fathoms, resulting in a total of approximately 1280 stations. The 2009 SSA survey is fully described in White et al. (2010). A key indicator of stock status in each regulatory area is the weight of O32 halibut caught per standardized skate, termed the survey WPUE (Fig. 7). Survey WPUE has declined by over 50% on a coastwide basis over the past 10 years. While the rate of decline has differed among areas, there has been a substantial decrease in WPUE in all areas, indicative of a consistent coastwide decline in exploitable biomass. As described earlier, Area 4CDE is assembled from four subareas. The derived WPUE indices from each of those areas are weighted by its respective bottom area to construct the single Area 4CDE WPUE time series shown in Figure 7. The component time series are illustrated in Figure 8, which gives a unified perspective on the relative densities of halibut in the different sub-areas of 4CDE.

The survey catch of halibut is sampled to obtain biological information about the stock including sex and age distribution and is described in Forsberg (2010a). The 2009 age distributions for males, females, and sexes combined for all regulatory areas are plotted in the Area Summary plots (Figs. 22-29). The age structure of the population is of considerable interest for a variety of reasons. These distributions indicate the relative abundance of fish available to the fishery, relative contributions to the female spawning biomass, etc. In 2009 as in 2008, there is a general tendency for an older age structure in the western areas, relative to the eastern areas. In particular, the lack of fish older than 20 years is noted for Area 2. Areas 3B and 4A present somewhat anomalous age distributions in that they more closely resemble Area 2 than Area 3A or most Area 4 distributions. The reasons for this are presently unclear although the estimated rate of fishing mortality is not excessive and there appears to be substantial recruitment into this area. The staff is recommending a reduction in the harvest rate in Area 3B in part based on the more truncated age distribution. Survey age-specific catch rates (not shown) 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. Optimistically, it appears that the 1999 and 2000 year classes are now entering the survey catch at the larger rates the assessment model has been predicting the last few years. The declining growth is likely responsible for the delay in recruiting to the survey and it may still be a few years before these two year classes enter the commercial fishery in proportion to their overall numbers in the population.

Commercial fishery

The second major component of the annual IPHC data collection is sampling the commercial catch. The port sampling program is detailed in Erikson and MacTavish (2010) and age sampling in Forsberg (2010b). From commercial fishing logs, commercial CPUE is computed for each regulatory area (Fig. 9). 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 10. 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 11a 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 11b shows this has not been the case as average age in both the survey and commercial catch has actually increased by a couple of years. Trends, by regulatory area, in average age and average weight are illustrated in Figure 16.

Description of the assessment model

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

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

Until 2006, estimates of halibut abundance were made using closed-area models for all areas except Areas 2A and 4CDE. Area 2A leveraged the Area 2B assessment and relative survey WPUE, while Area 4CDE relied upon the NMFS EBS trawl estimates of swept area abundance. The closed-area models are not considered reliable due to violation of the closed-population assumption. Beginning this year, we do not report on closed-area model fits nor biomass estimates from the models. The coastwide model has considerably 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 for the past few years, several versions of the basic assessment model were fitted. Differences among all the models concerned how survey and commercial catchability (generally termed "q") were parameterized. Two additional models were fitted that excluded commercial CPUE, and is considered similar to many of the NMFS groundfish assessment models. The models are summarized as such:

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

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

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

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

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

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

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

Effect of the 2009 data on abundance estimates

Coastwide survey WPUE declined by 3.5% and commercial WPUE declined by 6.5% from 2008 to 2009 (Figs. 7 and 9). As a result, the 2009 coastwide model fit is revised downwards, by about 10%, from the estimate of abundance at the beginning of 2009 made in the 2008 assessment (Table 2). On the other hand the 2009 fit shows an increase in abundance, of about 14%, between the beginning of 2009 and the beginning of 2010. The net result is an estimated increase of 3% between the 2009 beginning of year exploitable biomass and the 2010 beginning of year exploitable biomass.

Evaluation of the assessment

Quality of fits

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

Coastwide estimates of recruitment, exploitable biomass and spawning biomass

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

Estimates of uncertainty

There are a number of ways of estimating the uncertainty associated with a given model fit and biomass estimate. They are all unsatisfactory in that they are conditioned on the correctness of the model when in fact it is the choice of one model rather than another that is the major source of uncertainty in assessments. This is well illustrated by the difference in area-specific biomass estimates between the coastwide and closed-area fits of the IPHC model as reported in past years. One standard method of illustrating uncertainty around an estimate, for a given model, is the likelihood profile. The bottom panels in Figure 13 show the likelihood profiles for both the exploitable biomass as well as the female spawning biomass. The 95% confidence interval (C.I.) for EBio is 295 to 374 million pounds, while the 95% C.I. for the female spawning biomass is 289 to 375 million pounds. Confidence intervals for the recruitment estimates were also computed and are plotted with the recruitment estimates (Fig. 13, top panel). For comparison purposes, the 95% C.I. for the alternative model fits described above are plotted in Fig. 14. The means of both EBio and SBio for all the alternative model fits, with the exception of Alternative 4, lie within the 95% C.I. of the Base (production) model estimates. Alternative 4, due to its unconstrained survey q parameter and non-use of commercial CPUE has very wide C.I.s, indicating relatively high uncertainty in the biomass estimates.

Retrospective performance

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

Our assessment shows modest retrospective behavior for the last few years. Each year the assessment has revised downward the previous year's biomass estimates (Fig. 15a), meaning that biomass was overestimated then and may be overestimated now if the cause of the retrospective problem lies somewhere within the model. There is some precedent for that; the assessment models in use in the mid 1990s and the early 2000s showed strong retrospective patterns that turned out to be the result of misspecified selectivity (age- rather than length-based). There is also the possibility that the retrospective pattern is caused in some way by the external estimation of the sex composition of the commercial catch, or by the internal prediction of surface age compositions prior to 2002 through the application of an age misclassification matrix (Clark and Hare 2006).

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

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

Causes of retrospective behavior are notoriously difficult to diagnose. In the case of halibut, it appears to result from lower NPUE rates than expected, given the estimated mortality rate. This could be due, for example, to a trend in natural (or undocumented fishing) mortality, or a trend in catchability. The catchability explanation seems less likely, however, given that a model which allows catchability to have a trend produces assessment estimates that differ little from models with tightly constrained catchability. We consider it most likely that the retrospective behavior continues to derive, in large part from the still declining growth rates. Each year, a new set of size at age data is collected and used to smooth earlier estimates of size at age. The addition of smaller sizes at age results in a reduction of the earlier estimated weights at age thus lowering EBio for the same number of fish. More important however is that as growth slows, fewer fish of the same age are selected to the gear and their lack of appearance in expected numbers forces the model to revise recruitment estimates to match the observed survey and commercial catch rates. 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 1980s. 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 has, in simulation studies, provided a large fraction of maximum available yield while minimizing risk to the spawning biomass. Since the early 2000s, and similar to many fisheries management agencies, the harvest policy has incorporated a measure designed to avoid rapid increases or decreases in catch limits, which can arise from a variety of factors including true changes in stock level as well as perceived changes resulting from changes in the assessment model. The adjustment, termed “Slow Up Fast Down (SUFD)” is based on a target harvest rate of 20% but a realized rate usually a bit different. The SUFD approach is somewhat different from similar phased-change policies of other agencies in that it is asymmetric around the target value, i.e., the catch limit responds more strongly to estimated decreases in biomass than to estimated increases. This occurs for two reasons: first, the assessment generally has a better information base for estimating decreasing biomass compared with increasing biomass; and second, such an asymmetric policy follows the Precautionary Approach.

The unfished female spawning biomass ($B_{unfished}$) is computed by multiplying spawning biomass per recruit (SBR, from an unproductive regime) and average coastwide age-six recruitment (from an unproductive regime). The recruitment scaling uses the ratio of high to low recruitments based on long term recruitment estimates from Areas 2B, 2C and 3A and applied to the current coastwide average recruitment (Clark and Hare 2006) which we believe to represent a productive regime. The SBR value, computed from Area 2B/2C/3A size at age data from the 1960s and 1970s is 118.5

lbs per age-six recruit. Average coastwide recruitment for the 1990-2000 year classes (computed at age-six) is 23.4 million, and the estimate of unproductive regime average recruitment is 7.43 million recruits. This gives a $B_{unfished}$ of 880 million pounds, a B_{20} of 176 million, a B_{30} of 264 million pounds, and the 2010 female spawning biomass value of 331 million pounds establishes $B_{current}$ as 38% of $B_{unfished}$ (Fig. 16, top panel), up from the 2009 beginning of year estimate of $B_{current}$ of 35%. The revised trajectory of SBio suggests that the female spawning biomass did drop slightly below the B_{30} level which, had it been so estimated at the time, would have triggered a reduction in the harvest rate. On an annually estimated basis, however, the stock has not been that low; it is only retrospectively that we estimate the spawning biomass to have gone below to the reference point threshold. One problem with this method of establishing reference points is that the threshold and limit are dynamic, changing each year as the estimate of average recruitment changes. In this year's calculation the very strong 2000 year class was included among the year classes used to compute average recruitment. However, due to the downward revision of several year classes in this year's assessment, the estimate of $B_{unfished}$ changed very little from the 2008 estimates. Corresponding, B_{20} and B_{30} values also changed very little and the projected increase in the 2010 SBio results in the new determination that $B_{current}$ is around B_{38}. The estimated age composition of the coastwide spawning biomass shows a broad range of ages including 7% females age 20 and older (Fig. 16, 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. 17). The coastwide harvest rate over the past decade for halibut has generally been 0.20. Exceptions include a briefly increased rate to 0.225 and 0.25 between 2004 and 2006, and a lower rate of 0.15 in Areas 4B and 4CDE. On a coastwide basis, however, recent realized harvest rates have hovered around 0.25. A sizable portion of this above-target harvest rate comes from the retrospective revision of exploitable biomass estimates. Thus, while the intended rate has been around 0.20, with catch limits based on such a rate, a retrospective revision of exploitable biomass, when combined with unchanged estimates of total removals generates higher realized harvest rates. Another portion of the above-target performance results from the SUFD adjustment which prevents catch limits dropping fully to the target level indicated by contemporary estimates of exploitable biomass. Estimates of realized harvest rate among individual regulatory areas require use of an apportionment method to calculate the underlying exploitable biomass. This year staff favors the use of survey timing and hook competition adjustments to the bottom area-weighted survey WPUE (discussed below) for apportionment purposes. However, we use the unadjusted WPUE values for virtually all other data comparisons, e.g., WPUE trends over time, comparisons with trawl estimates of abundance, etc. We are uncertain what adjustments will stand the test of time and there is the problem of comparing values year to year when different adjustments are used. The unadjusted, bottom-weighted, survey WPUEs are therefore used to apportion biomass to estimates historical realized harvest rates (Fig. 18). Realized harvest rates tend to increase from west (below or at the target harvest rate during the last decade) to east (well 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. 19, 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 19 illustrate the strength of the celebrated 1987, and to a lesser extent 1988, year classes. As was true last year, the current assessment suggests that three large year classes – 1998, 1999, and 2000 – are poised to enter the exploitable biomass over the next few years. Presently, all three 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 than previous strong year classes (Fig. 19, bottom panel). Currently, a large fraction of males in the central Gulf of Alaska 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. 20) and indicate that the declines we have seen over the past decade are on the verge of reversing. It important to note that total removals should still remain at around 20% of the exploitable biomass and not be kept high in anticipation of future increases. As happened in the mid 1990s, when the biomass rises, higher catch limits will follow.

Comparison of assessment and trawl survey estimates of EBio

The 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 Area 2C westward to Area 4CDE. For Area 2B halibut we do not yet have length data for halibut sampled on the survey and because the survey is conducted for only about one-third of the entire area in any given year, we are still determining how these survey data might be used. 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 EBS 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: NMFS GOA regions Yakutat + Kodiak

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

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

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

Area 4CDE: EBS regions - region 50.

Estimates of commercially exploitable biomass (i.e., the usual EBio) can be derived by applying the commercial selectivity curve to the swept area estimates of numbers at length and then applying the IPHC length-weight relationship. For this comparison, the IPHC assessment estimates of EBio are partitioned among areas using the unadjusted bottom-weighted survey WPUE index. The results are illustrated in Figure 21.

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 discussed earlier. There is also an unprecedented number of halibut in the 50-70 cm range in the Gulf of Alaska. 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 (or at least the female component), we should see the steady increase in EBio predicted by the coastwide assessment.

Apportioning the coastwide biomass among regulatory areas

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

Adjustment factors

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

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

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

Time-averaging methods of (possibly adjusted) survey WPUE

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

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

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

Historical shares weight

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

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

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

Methods of apportioning biomass

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

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

For this year, the staff recommends the following

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

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

Area-apportioned biomass, total and fishery constant exploitation yields

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

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

Area summaries

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

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

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

Area 2

Areas 2A, 2B, and 2C indices are illustrated in Figures 22, 23, and 24, respectively. Between 1997 and 2006, total removals were stable in all three areas, averaging 1.6 million pounds in Area 2A, 13.5 million pounds in Area 2B, and 12.4 million pounds in Area 2C. Removals declined sharply between 2007 and 2009, in response to the change from closed-area to coastwide assessment and the resultant revised view of relative halibut abundance in Area 2. Bycatch of U32 fish, and subsequent lost yield to Constant Exploitation Yield (CEY), is estimated to be rather low, though O32 bycatch in Area 2A still represents a sizable portion of total removals. Surplus production estimates suggest that removals have exceeded surplus production in Area 2 for most of the past decade. Commercial effort has steadily increased in Area 2A for almost a decade but dropped sharply in 2009. In Areas 2B and 2C commercial WPUE has declined for the past three to four years. The main indices of abundance all suggest a steady decline in biomass from the mid 1990s to the late 2000s. Area 2A saw in 2009 a drop to the lowest survey WPUE on record, and a drop of 50% from 2008, to an average survey catch of 8 pounds of O32 halibut per standard skate. Area 2B had seen an increase in survey WPUE of 50% between 2007 and 2008; the 2009 value was nearly as strong as the 2008 value, suggesting a change in the declining trend in that area. For Area 2C, the increase in survey WPUE, while relatively minor, was the first in nearly a decade. Survey partitioning of the coastwide biomass suggests that the beginning of year 2010 EBio is down in 2A, up strongly in 2B, and up slightly in 2C from 2009 values. What is still a strong concern to staff is the generally much younger age structure of fish caught in Area 2. Mean age is around 11 years of age, with little difference between males and females. In particular, the catch of females is concentrated on ages where maturity at age is low thus removing females from the population before many have the opportunity to contribute to the spawning biomass.

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

Area 3

Areas 3A and 3B indices are illustrated in Figures 25 and 26, respectively. While these two areas occupy the current central area of distribution of the halibut stock, they have substantially different exploitation and biomass histories over the past 10-20 years. Area 3A removals, both the total as well as the individual components (commercial, sport, bycatch) have been very stable over the past 10 years. Commercial effort has also seen relatively little variation. During the past decade when WPUE indices were falling sharply coastwide, Area 3A generally showed the most stability. That pattern has now changed as in 2009 Area 3A had the second largest decline from 2008 (after Area 2A). The WPUE indices are at about 71% (commercial) and 52% (survey) of their average values between 1997 and 1999. Biomass declined steadily in 3A between the late 1990's and early 2000's but then appeared to stabilize as surplus production basically matched removals. Area 3B saw a large increase in removals beginning in 1996 which peaked in 2002 and has dropped sharply since. Commercial fishing effort more than tripled in the seven years after 1996 and then declined modestly over the past four years before increasing again beginning in 2008. We estimate that removals greatly exceeded surplus production between 1998 and at least 2007. Commercial and survey WPUE are at 37% and 26%, respectively, of their average level between 1997 and 1999. Area 3A has a much broader spectrum of ages in the population than is seen in Area 2. Average age for females in survey catches is 13 and for males is 16 years of age. Area 3B, however, is more similar to Area 2 in age distribution than to Area 3A.

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

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

Area 4

Areas 4A, 4B, and 4CDE indices are illustrated in Figures 27, 28, and 29, 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 mid-1990s and mid-2000s. All three areas have shown increases in recent years, with the turnarounds occurring immediately after the cut in the harvest rate in each area. The recent increases in WPUE, which reflect slow increases in EBio as estimated by the coastwide assessment, are evidence that the western portion of the stock, which is a net exporter of halibut, is best served by a lower harvest rate than that in the eastern areas. As the stock builds up, removals will also increase. There is evidence in both the assessment and the trawl surveys that extremely large numbers of halibut, in the 50-80 cm size range, are found in Area 4 and should continue to add substantially to the exploitable biomass over the next several years.

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

Acknowledgements

We wish to acknowledge the many samplers, age readers, data entry personnel, and other IPHC staff who are responsible for collecting and quality control checking the data upon which the halibut assessment depends so strongly. A great deal of effort is expended both on the setline survey as well as in the port sampling programs and the assessment staff appreciates the time constraints involved in having the data available days after the fishery ends, in time for the annual stock assessment.

References

Clark, W.G. 2004. A method of estimating the sex composition of commercial landings from setline survey data. Int. Pac. Halibut Com. Report of Assessment and Research Activities 2003: 111-162.

Clark, W.G. 2008a. Effect of station depth distribution on survey CPUE. Int. Pac. Halibut Comm. Report of Research and Assessment Activities 2007: 205-210

Clark, W.G. 2008b. Effect of hook competition on survey CPUE. Int. Pac. Halibut Comm. Report of Research and Assessment Activities 2007: 211-215.

Clark, W.G. 2008c. Comparison of setline and trawl survey catch rates in different areas. Int. Pac. Halibut Comm. Report of Research and Assessment Activities 2007: 221-228.

Clark, W.G., and Hare, S.R. 2006. Assessment and management of Pacific halibut: data, methods, and policy. Int. Pac. Halibut Comm. Sci. Rep. 83.

Clark, W.G., and Hare, S.R. 2007. Motivation and plan for a coastwide stock assessment. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2006: 83-96.

Clark, W.G., and Hare, S.R. 2008. Assessment of the Pacific halibut stock at the end of 2007. Int. Pac. Halibut Comm. Report of Research and Assessment Activities 2007: 177-203.

Forsberg, J.E. 2010a. Age distribution of Pacific halibut in the 2009 IPHC stock assessment setline survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2009 (this volume).

Forsberg, J.E. 2010b. Age distribution of the commercial halibut for 2009. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2009 (this volume).

Gilroy, H.L., Erikson, L.M., and MacTavish, K.A. 2010. Commercial fishery and regulation changes. Int. Pac. Halibut Comm. Report of Assessmnent and Research Activities 2009: 39-52.

Hare, S.R., Webster, R.A., and Kong, T.M. 2010. Updated and expanded estimates of bottom area in IPHC regulatory areas . Int. Pac. Halibut Comm. Report of Assessmnent and Research Activities 2009: 347-362.

Hare, S.R. 2010. Estimates of halibut total annual surplus production, and yield and egg production losses due to under-32 inch bycatch and wastage. Int. Pac. Halibut Comm. Report of Assessmnent and Research Activities: 323-346.

Hare, S.R. and Clark, W.G. 2007 IPHC harvest policy analysis: past, present, and future considerations. Int. Pac. Halibut Comm. Report of Assessmnent and Research Activities 2007: 275-295.

Hare, S.R. and Clark, W.G. 2009. Assessment of the Pacific halibut stock at the end of 2008. Int. Pac. Halibut Comm. Report of Assessmnent and Research Activities 2009: 137-201.

Erikson, L.M. and MacTavish, K.A. 2010. Commercial catch sampling. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2009: 75-82.

Sadorus, L.L. and Lauth, R. 2010. Cruise report for the 2009 NMFS Bering Sea trawl survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2009: 611-616.

Soderlund, E., Dykstra, C.L. , Geernaert, T, and Ranta, A.M and Anderson, E. 2007. 2006 standardized stock assessment survey. Int. Pac. Halibut Comm. Report of Assessmnent and Research Activities 2007: 335-365.

Valero, J.L. and Hare, S.R. 2010. Effect of migration on lost yield due to U32 bycatch and U32 wastage of Pacific halibut . Int. Pac. Halibut Comm. Report of Assessmnent and Research Activities 2009: 307-322.

White, E., Dykstra, C.L. , Geernaert, T. Soderlund, E., and Ranta, A.M. 2010. 2009 standardized stock assessment survey. Int. Pac. Halibut Comm. Report of Assessmnent and Research Activities 2009: 553-580.

Webster, R. 2009. Further examination of fisheries-survey interactions. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2008: 203-211.

Webster, R. 2010. Analysis of PIT tag recoveries through 2009. Int. Pac. Halibut Comm. Report of Assessmnent and Research Activities 2009: 177-186.

Webster, R., and Clark, W.G. 2007. Analysis of PIT tag recoveries through 2006. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2006:129-138.

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

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

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

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

Table 3. Other removals in detail. Sport catch figures for Areas 2C and 3A are actual catches not GHL levels as in Table 4[1].

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Sport catch	0.401	1.095	2.546	4.531	0.025	0.039	0.000	0.000	8.637
O32 bycatch	0.245	0.105	0.128	1.918	0.862	1.063	0.218	1.550	6.089
Personal use	0.029	0.405	0.458	0.337	0.042	0.020	0.005	0.046	1.342
O32 wastage	0.001	0.012	0.012	0.042	0.021	0.009	0.006	0.014	0.117
Total	0.676	1.617	3.144	6.828	0.950	1.131	0.229	2.400	16.185
Total excl.sport catch in Areas 2A and 2B	0.275	0.522	3.144	6.828	0.950	1.131	0.229	2.400	14.660
U32 discard mortality (shown for information; not taken off total CEY)	0.015	0.231	0.262	1.118	0.773	0.139	0.012	0.074	2.624
U32 bycatch mortality (shown for information; Not taken off total CEY)	0.138	0.105	0.128	1.918	0.862	1.063	0.218	2.340	6.772

[1] - Subsequent to the printing of the RARA, errors were discovered in this table. This table contains the corrected values (highlighted in yellow) and therefore differs from the printed version (Hare, S.R. 2010 Assessment of the Pacific halibut stock at the end of 2009. Int. Pac. Halibut Comm. Bluebook 2010: 73-129). Tables 4 and 9, which rely on values in this table, have also been updated.

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

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

Notes:

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

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

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

[4] See footnote 1 in Table 3. Highlighted values differ (i.e., are updated) from printed version in Bluebook.

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

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

Notes:

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

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

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

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

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

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

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

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

Table 9. Fishery CEY by area according to various apportionment methods. Values for Area 4CDE and the Total column differ from the printed version of the Bluebook (i.e., are updated). See footnote 1 in Table 3.

3 year averages	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.342	5.796	2.261	17.035	7.866	2.094	3.828	4.833	44.055
Hook AF	0.434	5.482	2.374	18.051	8.972	2.264	2.745	3.961	44.282
Depth AF	0.245	5.923	2.282	16.093	7.894	2.291	4.520	4.585	43.832
Timing AF	0.468	5.880	2.268	17.241	7.808	1.969	3.833	4.693	44.161
Hook + Depth AFs	0.327	5.608	2.417	17.170	9.043	2.468	3.277	3.767	44.077
Timing + Hook AFs	0.573	5.554	2.390	18.279	8.909	2.120	2.750	3.821	44.396
Timing + Depth AFs	0.361	6.006	2.290	16.294	7.835	2.169	4.534	4.444	43.935
Timing + Hook + Depth AFs	0.460	5.679	2.433	17.390	8.979	2.331	3.290	3.625	44.187
Reverse weighted	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.320	6.244	2.192	16.679	7.428	2.253	4.001	4.938	44.056
Hook AF	0.434	5.769	2.297	17.351	8.897	2.505	2.832	4.075	44.159
Depth AF	0.234	6.421	2.182	15.738	7.468	2.442	4.662	4.694	43.840
Timing AF	0.434	6.323	2.188	16.940	7.369	2.109	3.998	4.806	44.168
Hook + Depth AFs	0.335	5.939	2.306	16.476	8.981	2.707	3.334	3.882	43.961
Timing + Hook AFs	0.562	5.837	2.303	17.638	8.836	2.340	2.827	3.940	44.282
Timing + Depth AFs	0.348	6.500	2.177	15.988	7.407	2.303	4.669	4.559	43.950
Timing + Hook + Depth AFs	0.468	6.008	2.311	16.749	8.916	2.549	3.337	3.742	44.081
Historical shares									
15 year (1993-2007) average	1.7%	15.8%	15.1%	37.1%	14.5%	5.3%	3.9%	6.5%	100.0%
3 year averages (2:1)	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.530	7.219	3.846	16.988	7.356	1.907	3.126	3.764	44.735
Hook AF	0.592	7.009	3.922	17.665	8.093	2.020	2.404	3.183	44.886
Depth AF	0.465	7.303	3.860	16.360	7.374	2.038	3.588	3.599	44.587
Timing AF	0.614	7.274	3.851	17.126	7.317	1.824	3.129	3.671	44.806
Hook + Depth AFs	0.521	7.093	3.950	17.078	8.140	2.156	2.759	3.053	44.750
Timing + Hook AFs	0.684	7.057	3.932	17.818	8.051	1.924	2.407	3.089	44.962
Timing + Depth AFs	0.543	7.359	3.865	16.494	7.335	1.957	3.597	3.505	44.655
Timing + Hook + Depth AFs	0.609	7.140	3.960	17.225	8.097	2.065	2.768	2.959	44.823
Reverse weighted (2:1)	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Survey only	0.516	7.517	3.800	16.751	7.063	2.013	3.241	3.834	44.735
Hook AF	0.591	7.200	3.870	17.199	8.043	2.181	2.462	3.259	44.805
Depth AF	0.458	7.635	3.793	16.123	7.090	2.139	3.682	3.671	44.592
Timing AF	0.592	7.570	3.797	16.925	7.024	1.917	3.240	3.746	44.810
Hook + Depth AFs	0.526	7.314	3.876	16.616	8.099	2.315	2.797	3.130	44.672
Timing + Hook AFs	0.677	7.246	3.874	17.390	8.002	2.070	2.459	3.169	44.886
Timing + Depth AFs	0.534	7.688	3.790	16.290	7.049	2.046	3.686	3.581	44.665
Timing + Hook + Depth AFs	0.614	7.359	3.880	16.797	8.056	2.210	2.799	3.037	44.752

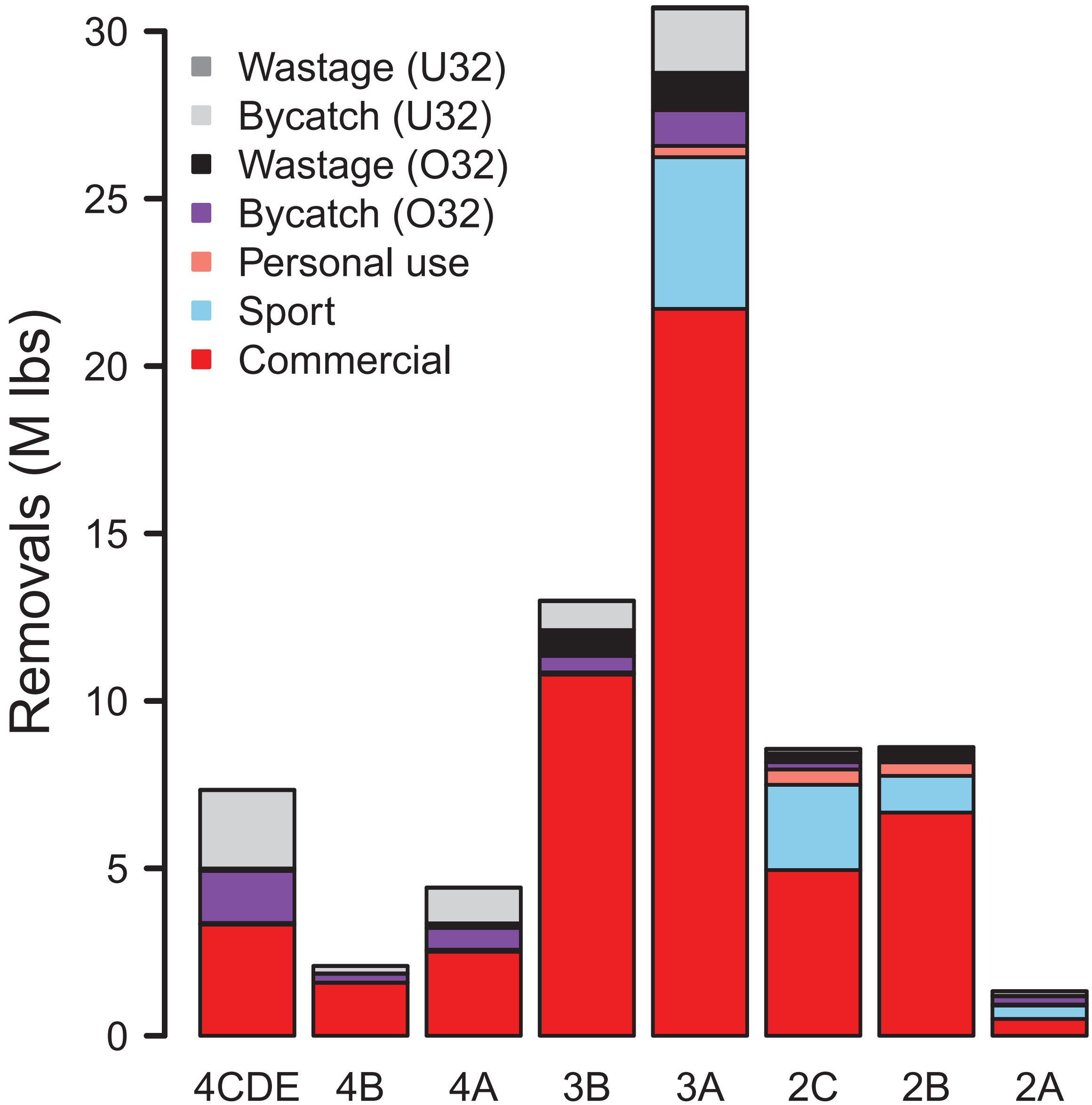


Figure 1. Total removals by type and regulatory area for 2009.

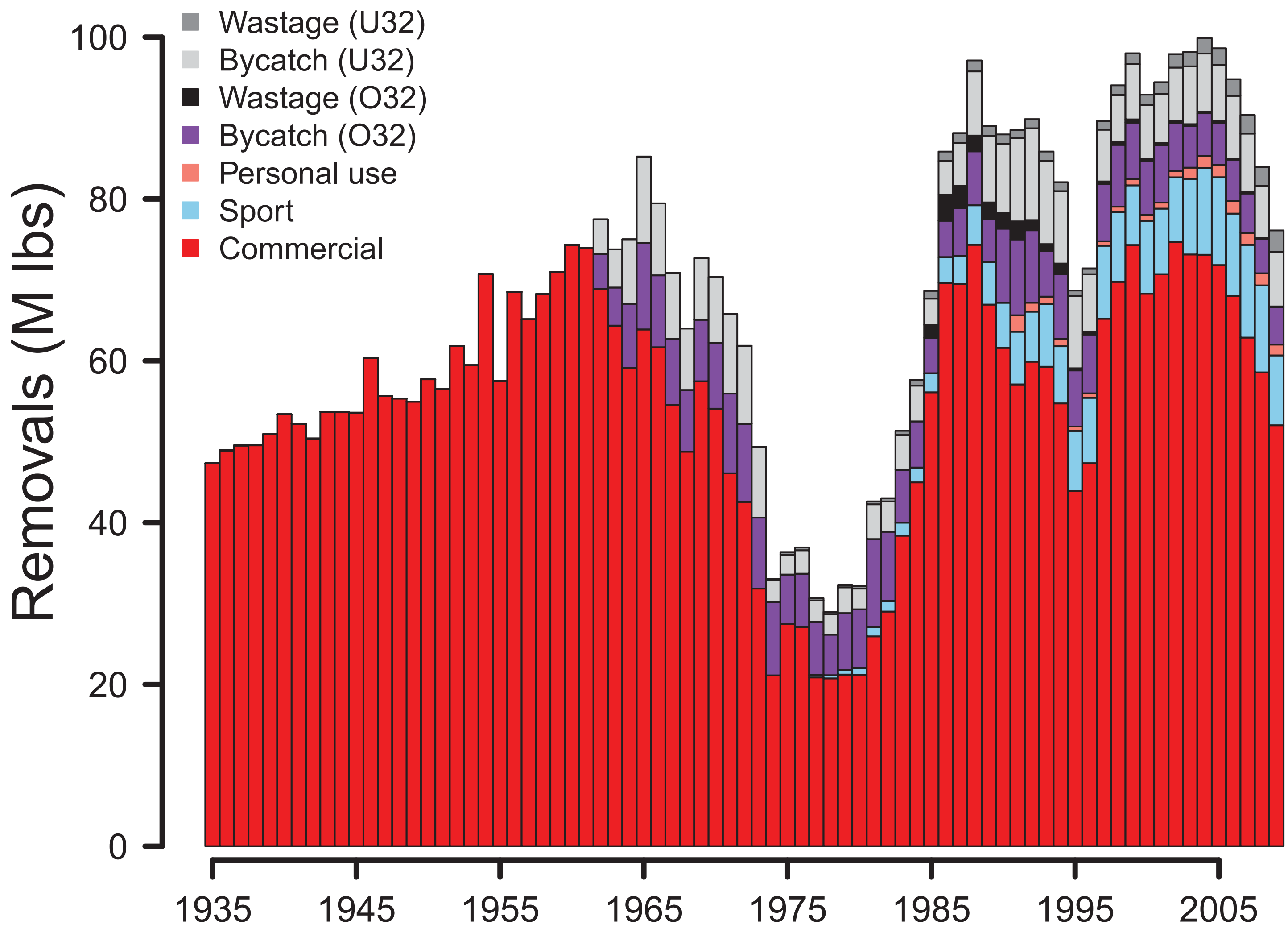


Figure 2. Total removals coastwide for the period 1935-2009.

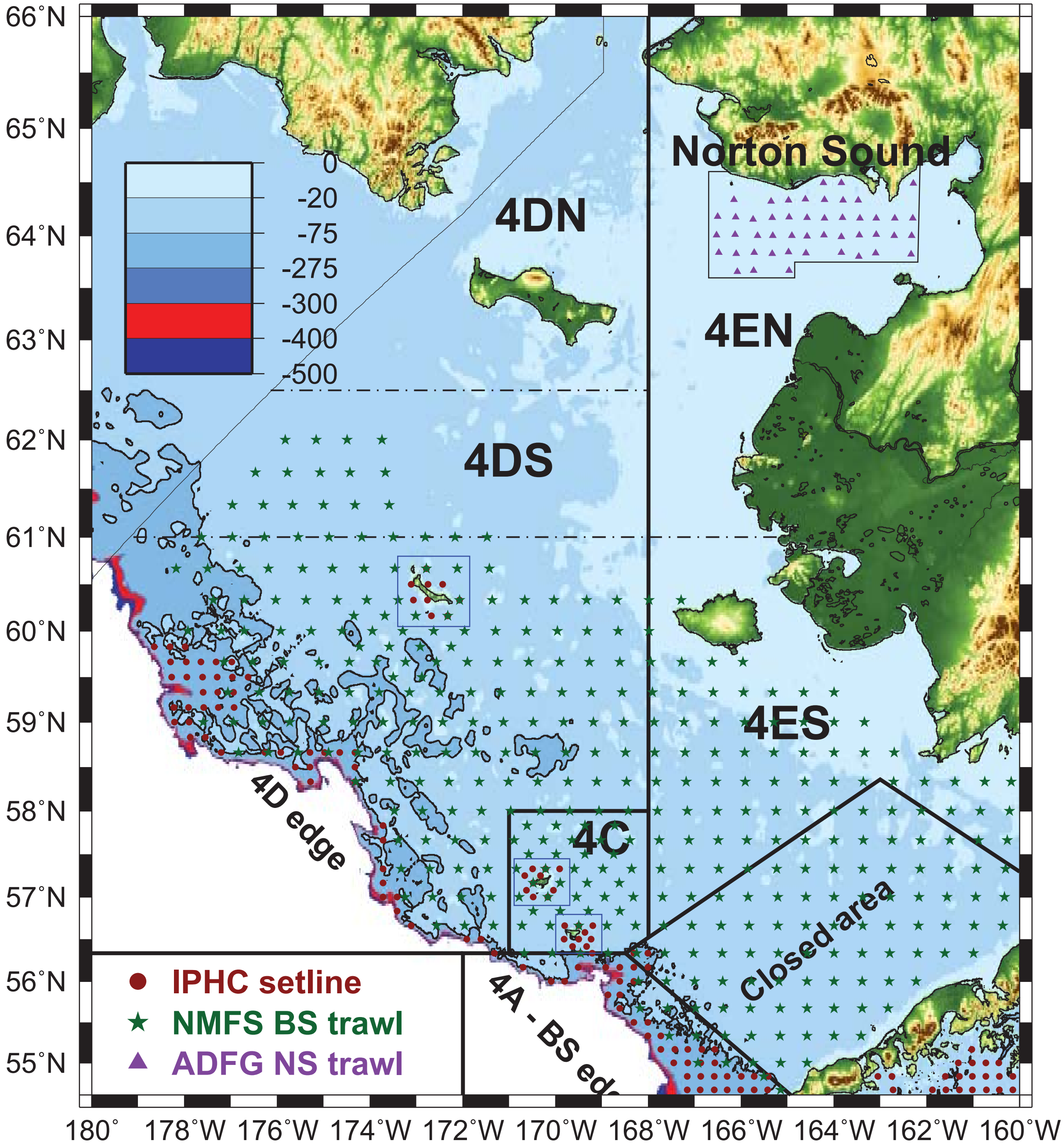


Figure 3. Summary of information sources and subareas utilized to construct a dataset for Area 4CDE. See text for details

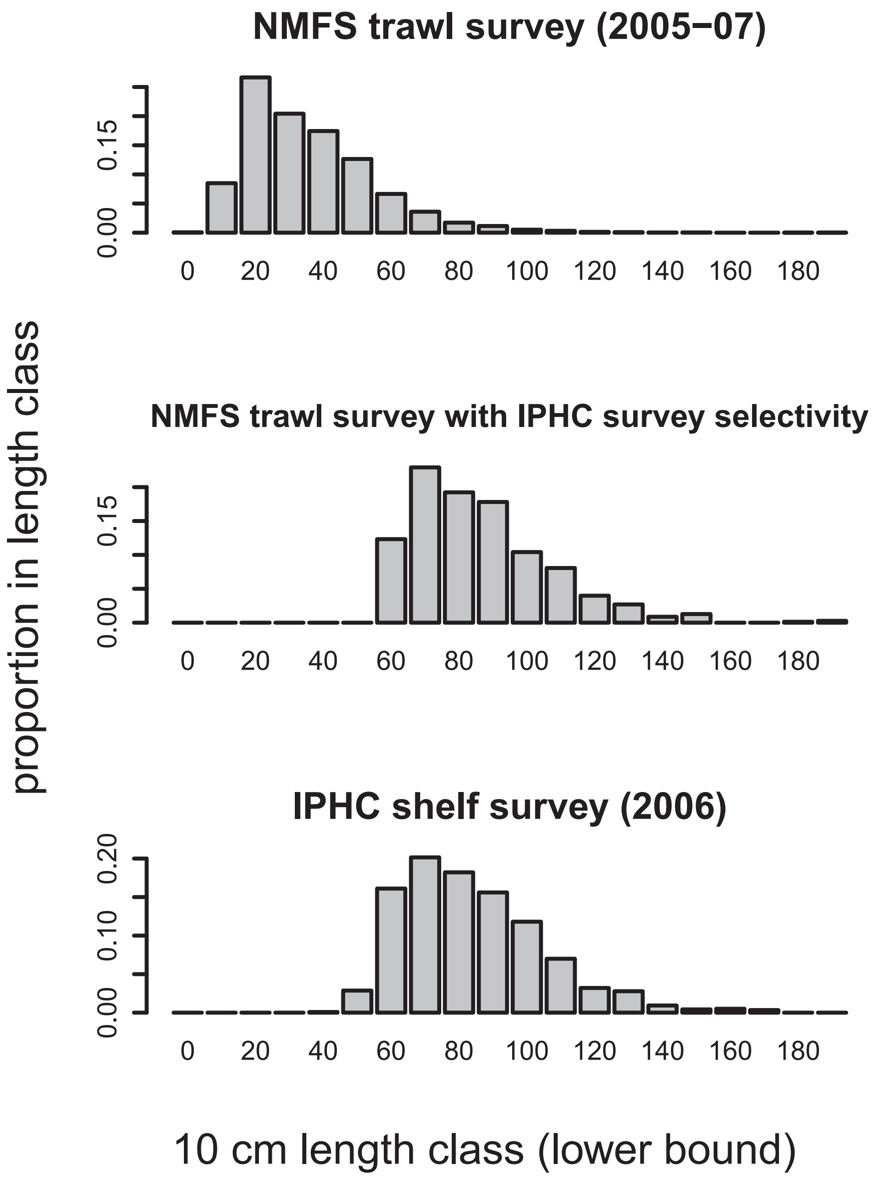


Figure 4. Comparison of NMFS trawl survey and IPHC length frequency compositions. The top panel shows the length frequency composition for all halibut caught by the NMFS trawl gear for years 2005-7. the middle panel shows the frequency distribution of lengths after the IPHC setline selectivity curve is applied to raw counts. The bottom panel illustrates the length composition of halibut in the 2006 IPHC shelf survey.

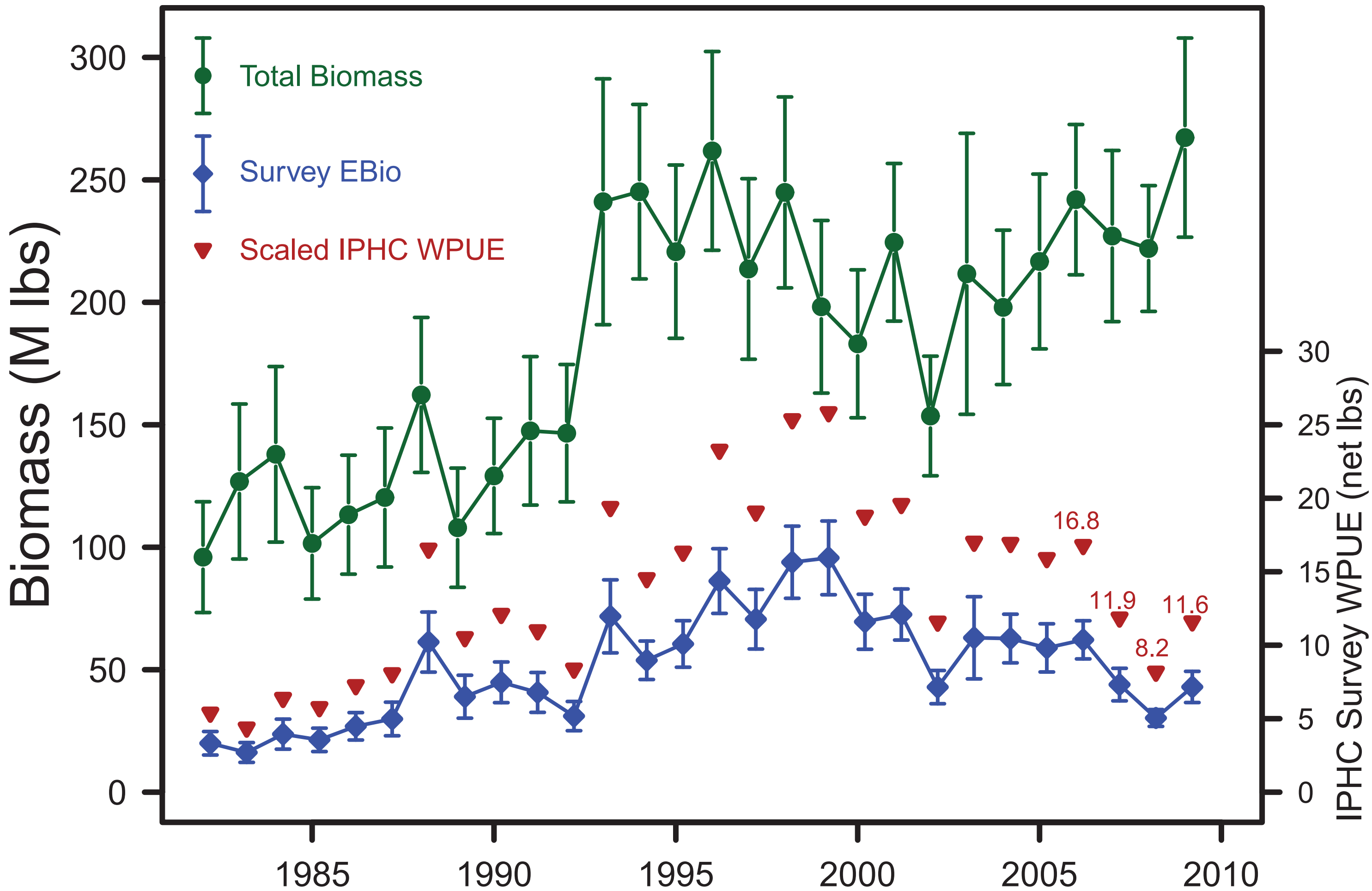


Figure 5. Swept-area estimates of halibut abundance from the NMFS EBS trawl survey. The red dots and error bars represent mean and 95% confidence interval for the total abundance; the blue diamonds are error bars represent mean and 95% confidence interval for abundance with survey selectivity applied to the total biomass (termed survey EBio). The inverted purple triangles represent the estimated density of O32 halibut (per standardized skate of gear) across the shelf; this index is scaled to the survey EBio trend (see text for full details).

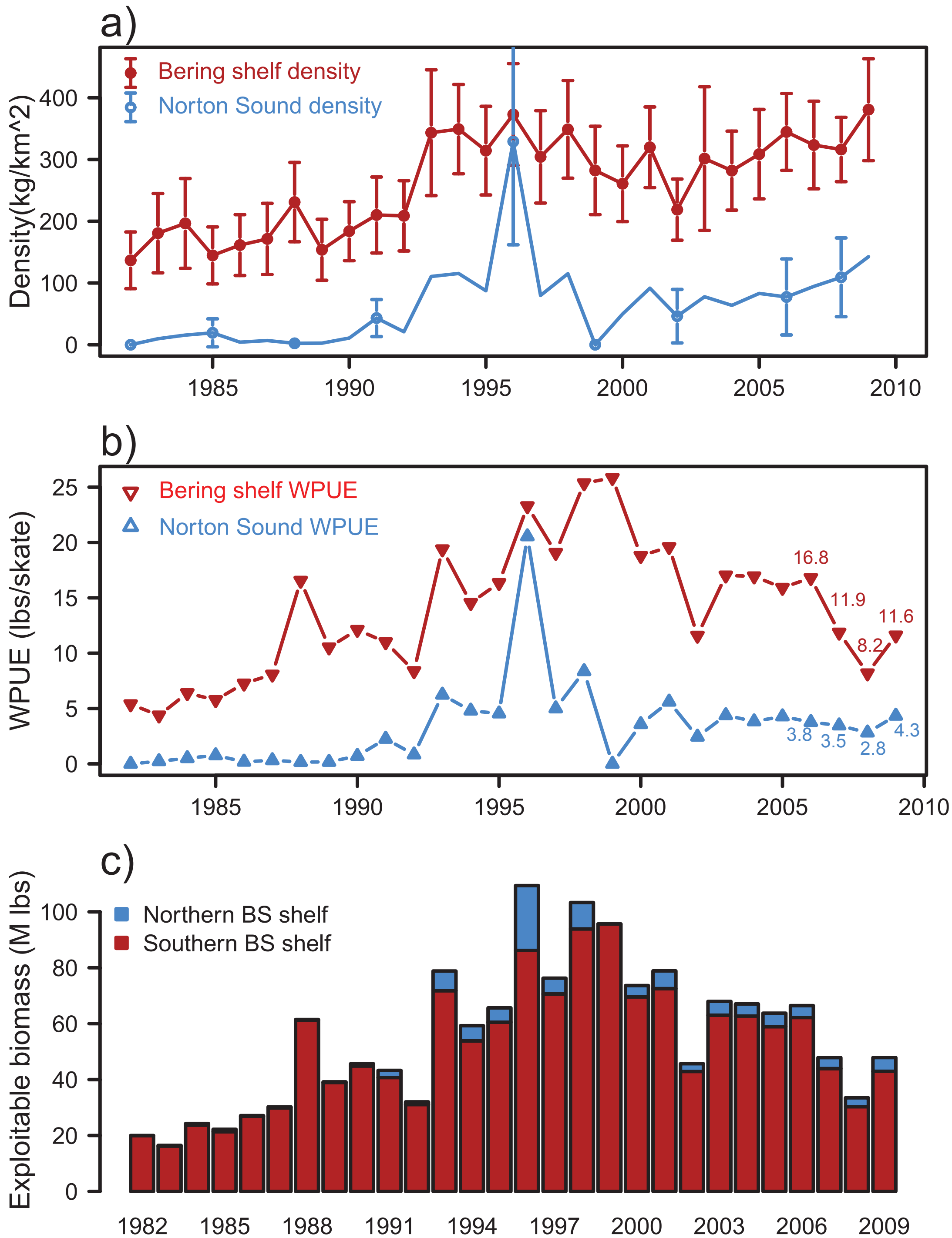


Figure 6. Time series used to construct an estimate of halibut biomass in the region north of 62.5°N in 4D and 61°N in Area 4E, together termed Area 4N. See text for details.

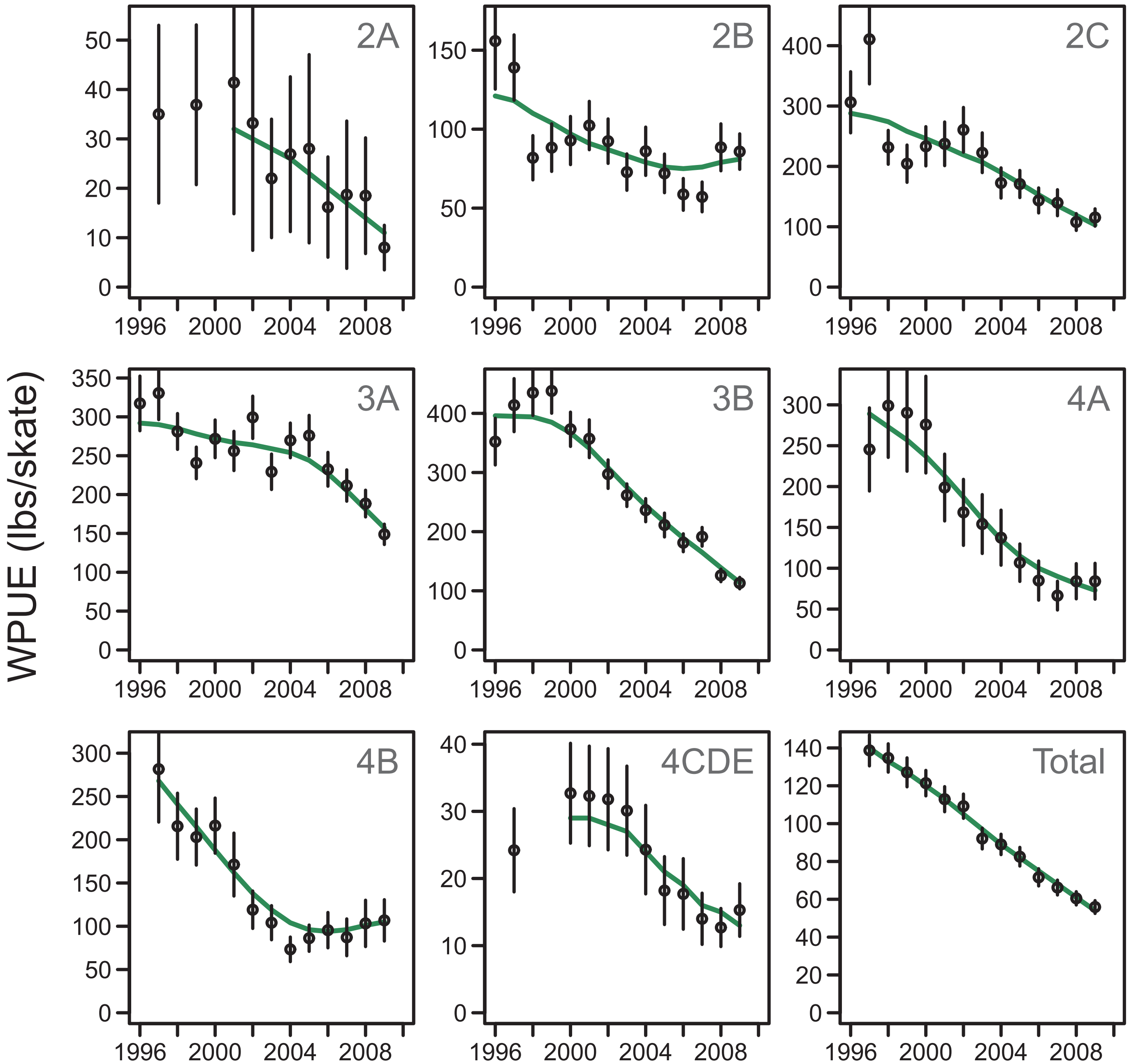


Figure 7. Survey WPUE (weight of O32 halibut per standardized skate of gear) by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray line is a smoother to illustrate trend; it is not an assessment model fitted to the WPUE data. The total is computed by area-weighting the individual area WPUE time series.

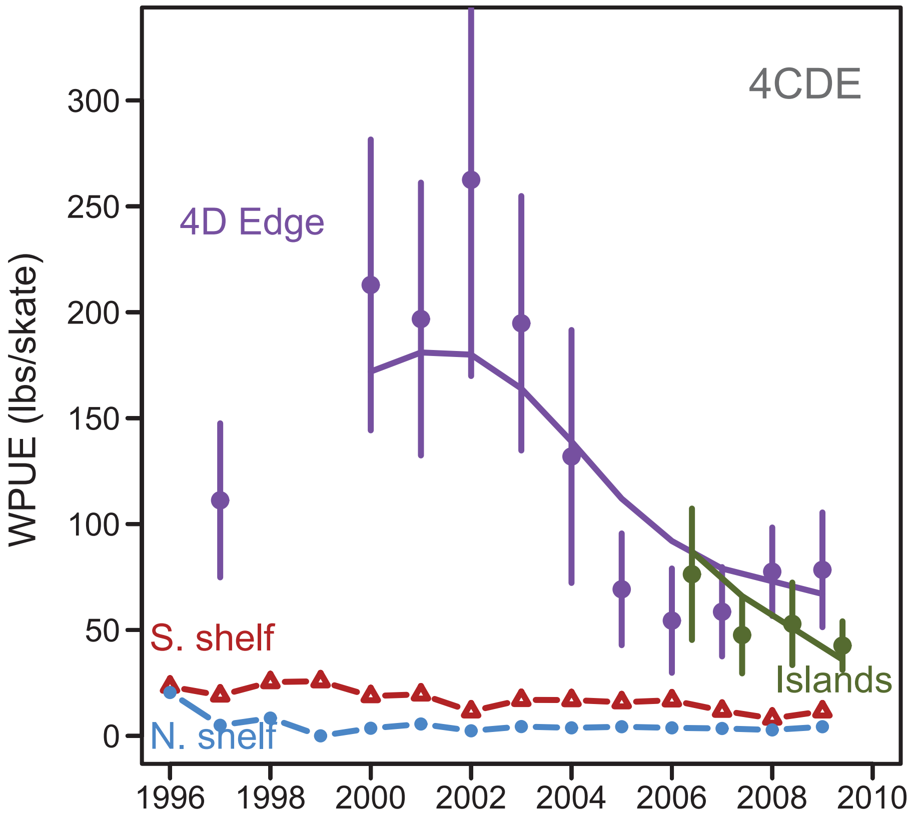


Figure 8. The four subarea components used to construct the WPUE survey index for Area 4CDE.

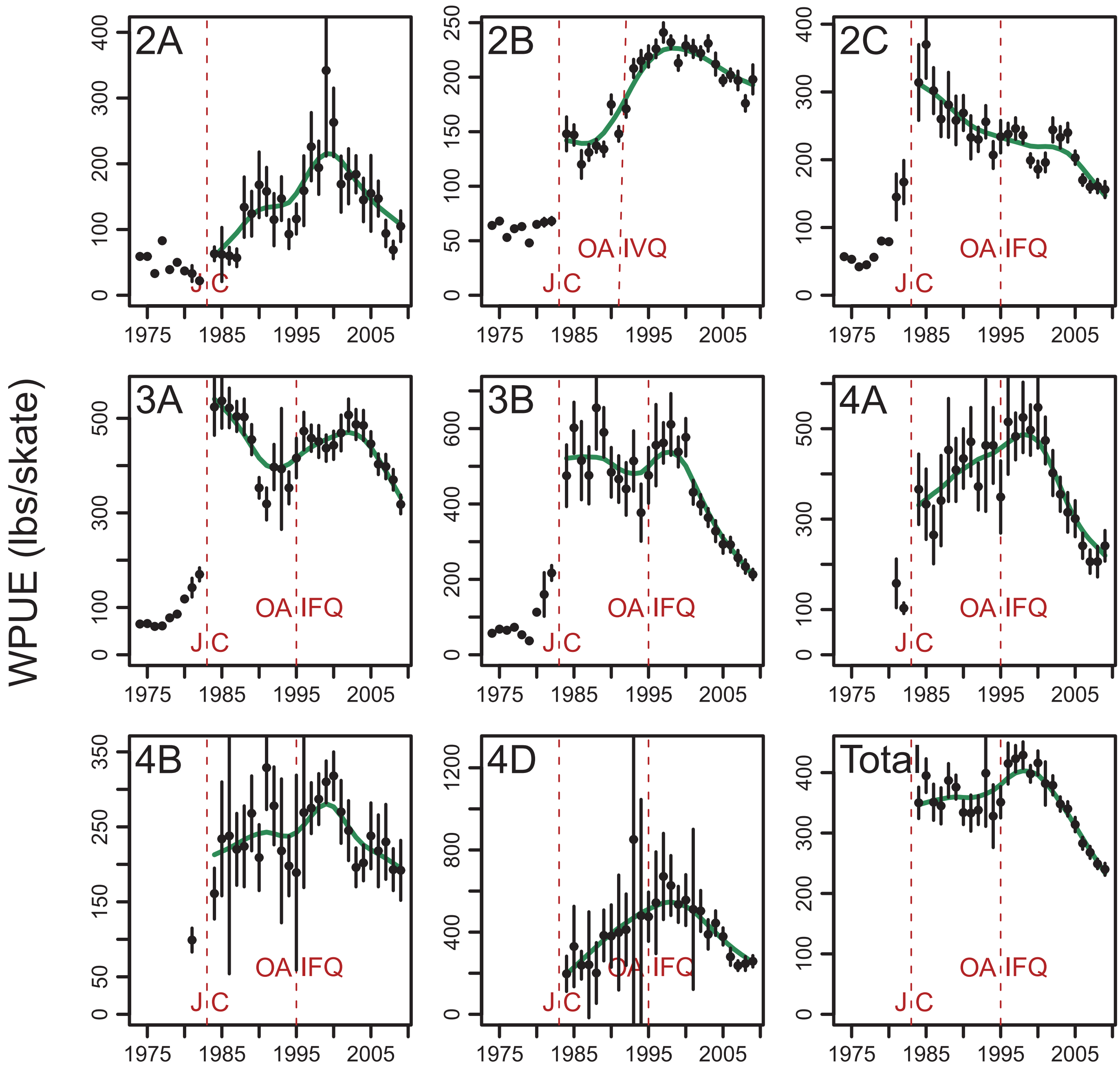


Figure 9. Commercial WPUE by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray line is a smoother to illustrate trend; it is not an assessment model fit to the CPUE data. The total is computed by area-weighting the individual area WPUE time series. The dashed vertical lines indicate transitions between J and C hook, between open access (OA) and Individual Vessel Quotas in Area 2B, and between open access and Individual Fishing Quotas in Areas 2C, 3 and 4.

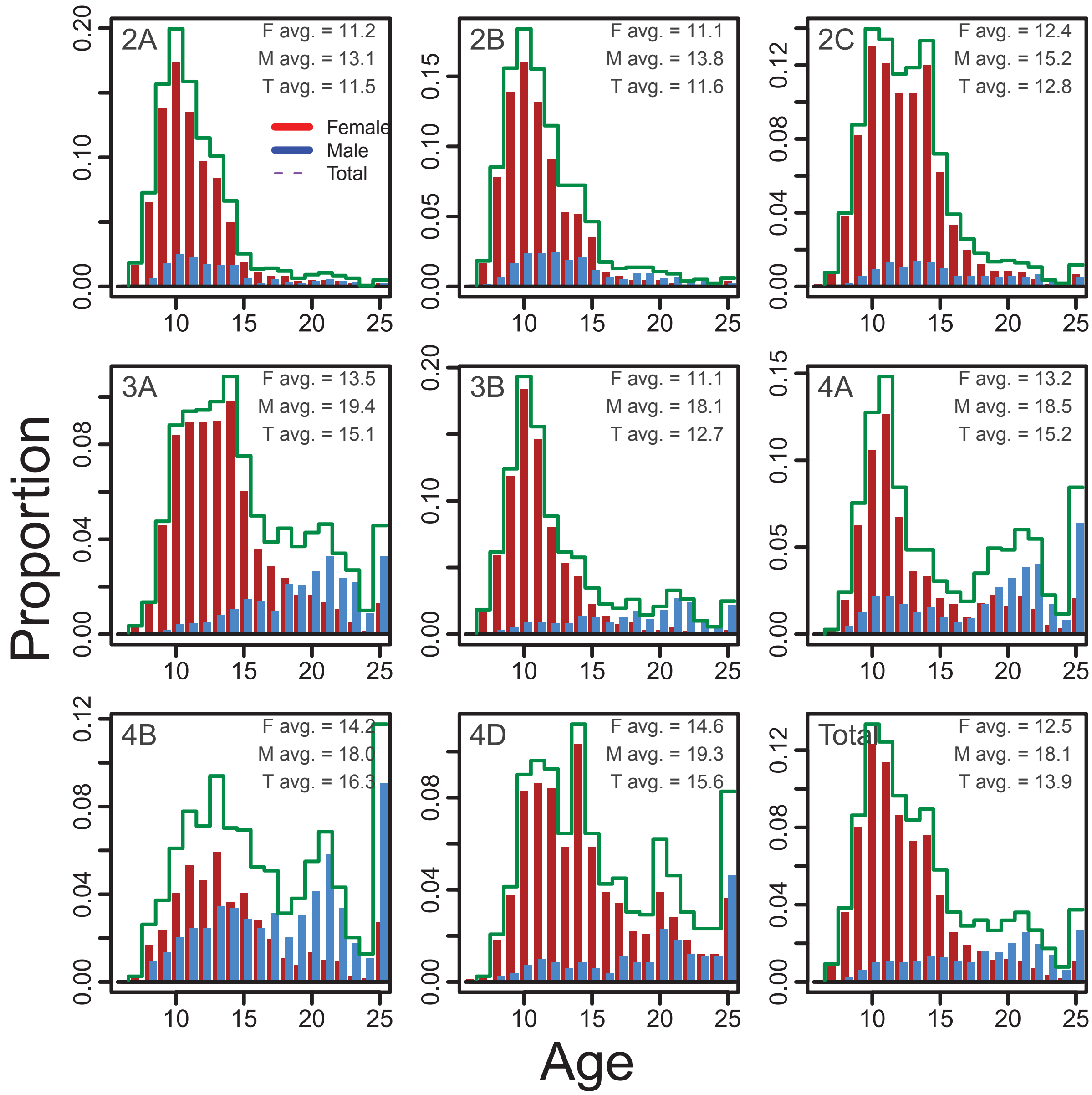


Figure 10. Regulatory area sex and age compositions from halibut sampled from commercial landings. Proportions are shown for females (red bars), males (blue bars) and sexes combined (green line). Average age is also shown, with "T" indicating Total (sexes combined).

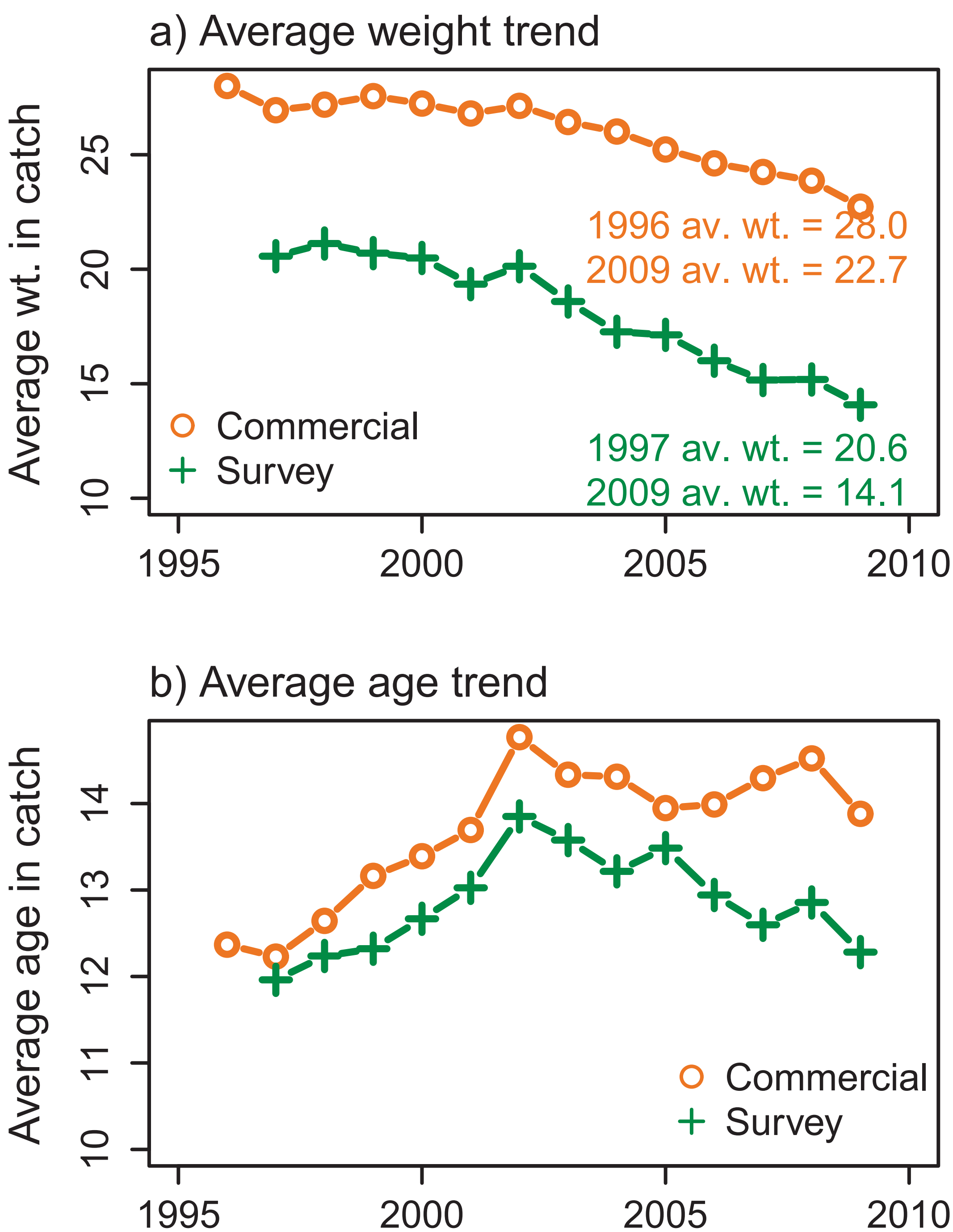


Figure 11. Average weight (panel a) and average weight (panel b) trends for the coastwide halibut stock for 1996 to 2009.

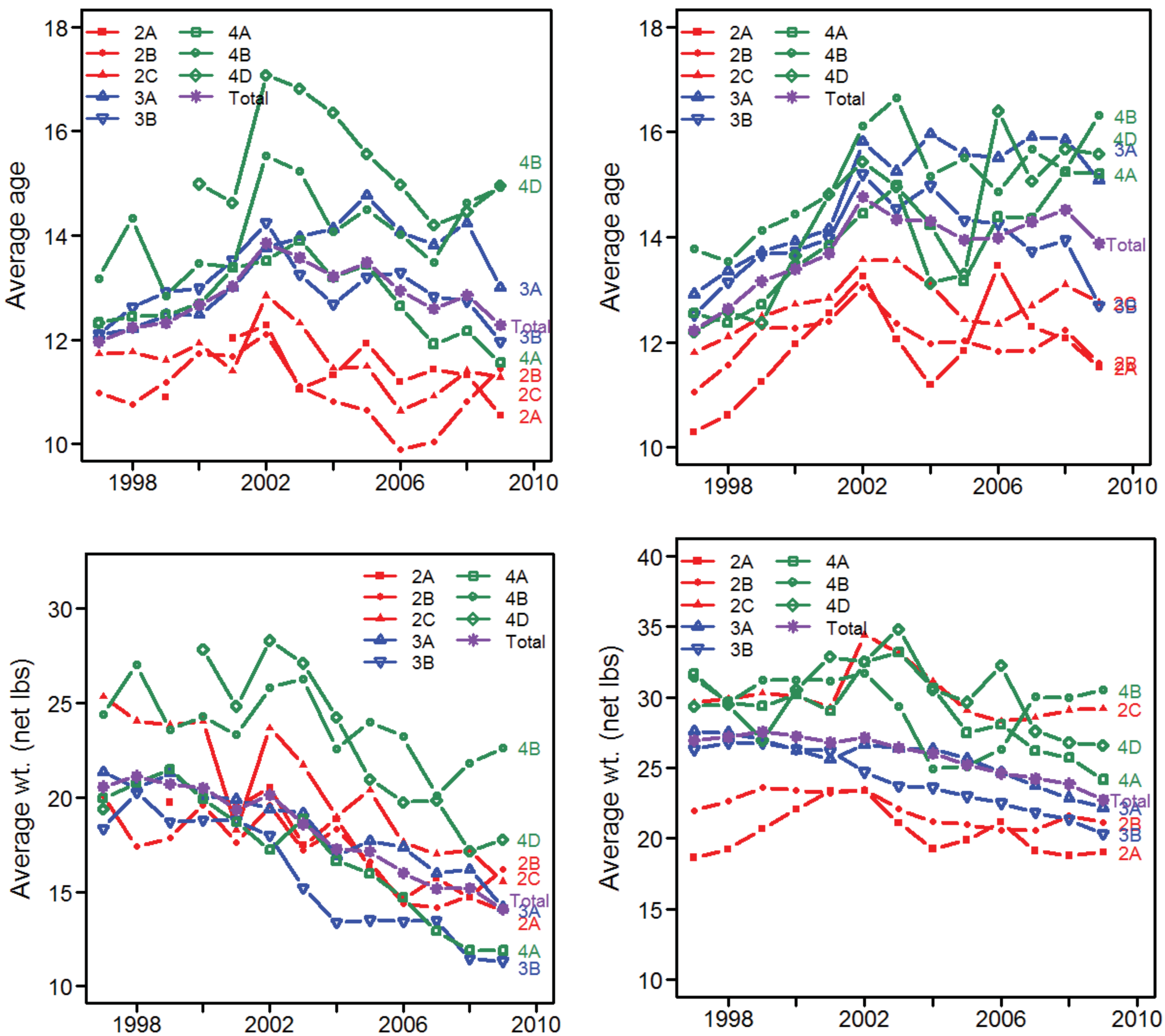


Figure 12. Trends in average age (top panels) and average weight (bottom panels) in survey catches (left panels) and commercial catches (right panels).

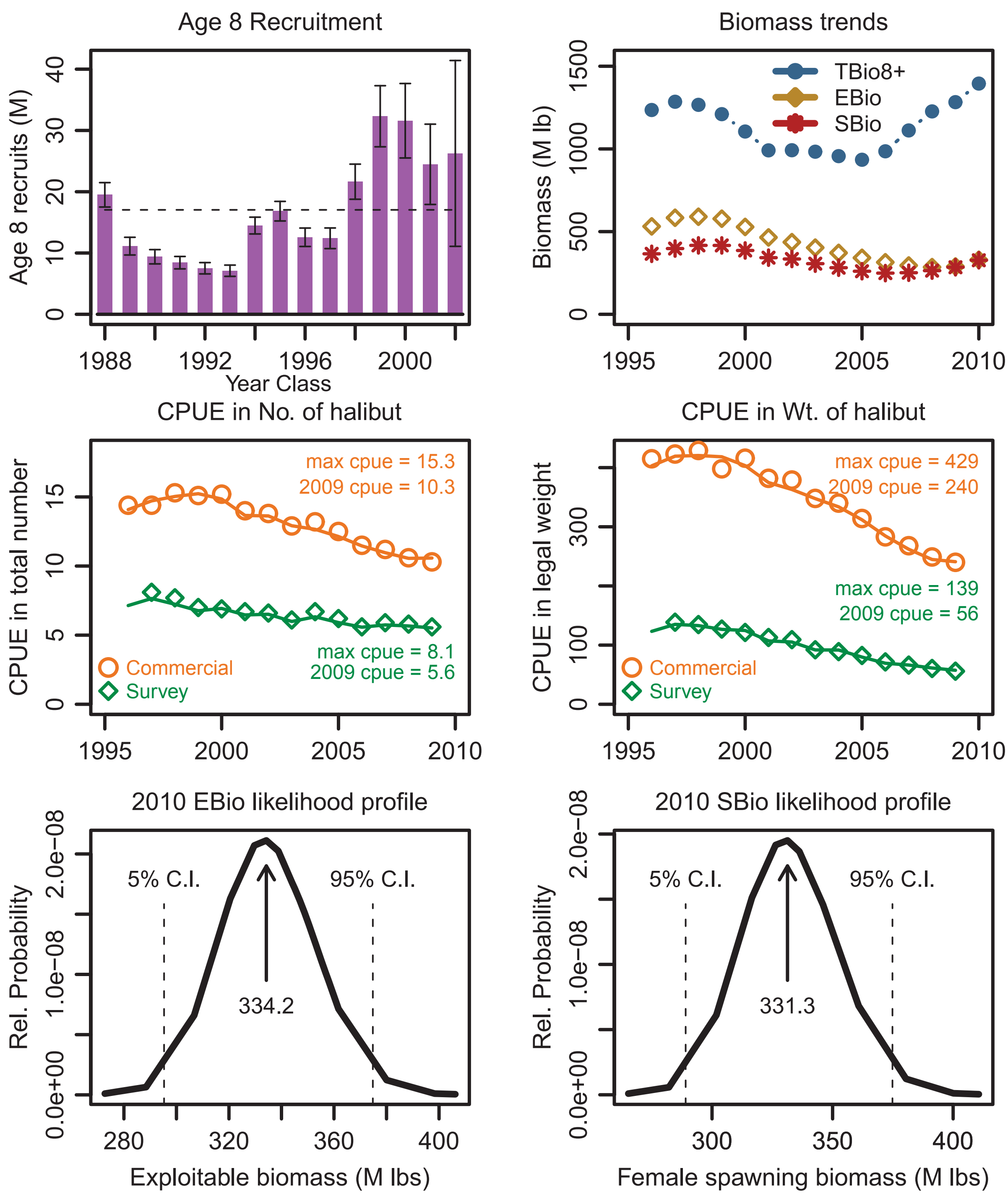


Figure 13. Features of the 2009 halibut coastwide assessment.

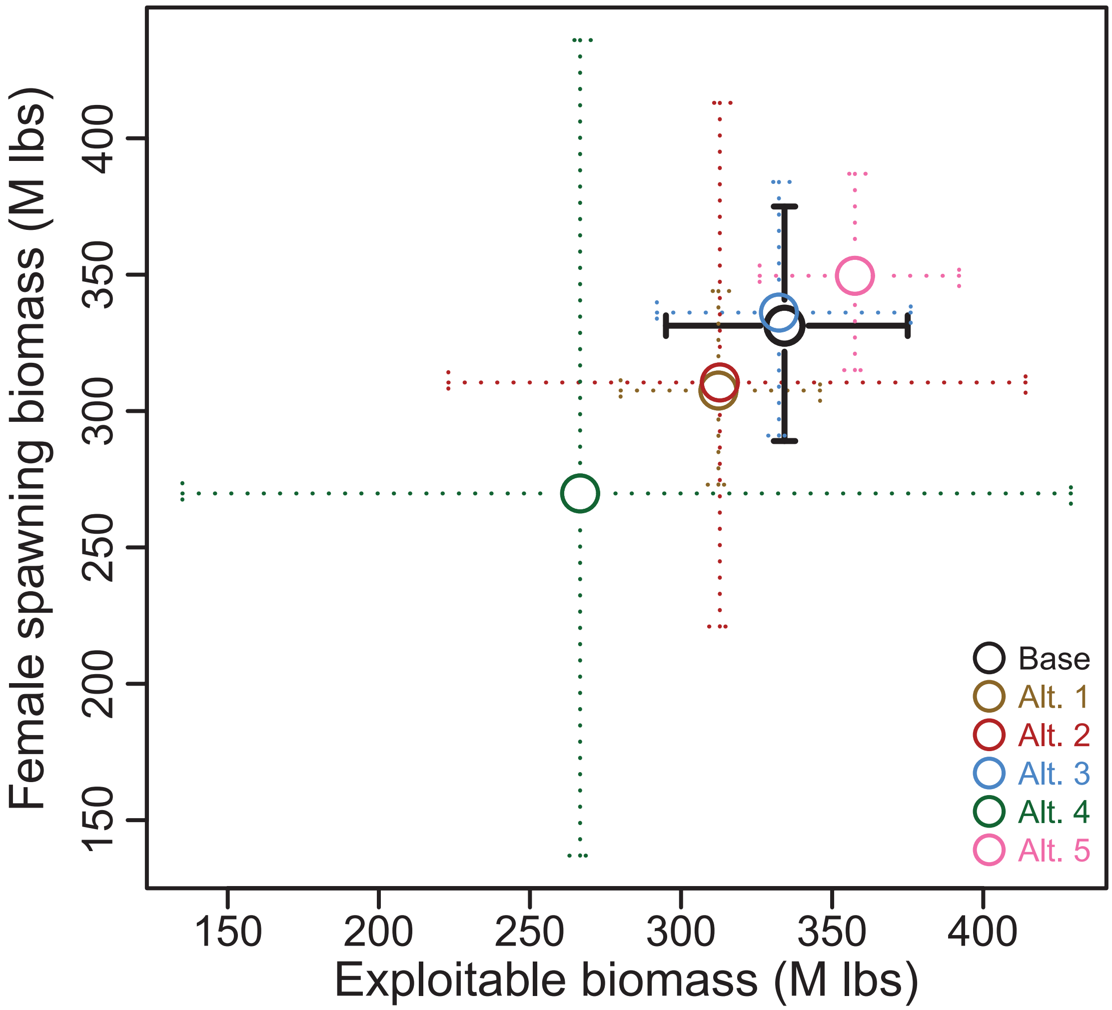


Figure 14. Illustration of maximum likelihood estimates (circles) for EBio and SBio for various model fits. The 95% percent confidence intervals for the likelihood profiles are shown by the end caps of the horizontal and vertical bars extending from the circles.

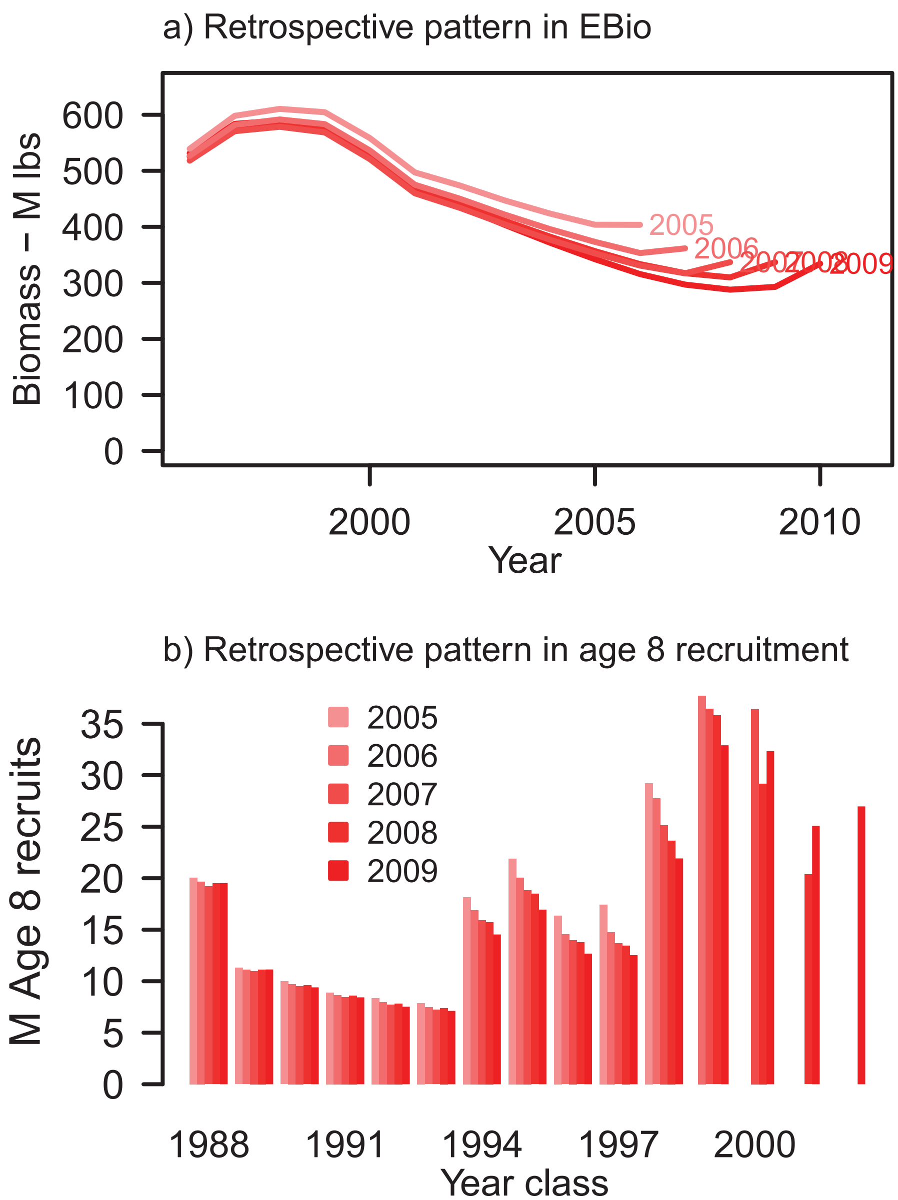


Figure 15. Retrospective behavior of the 2009 halibut assessment model. The top panel illustrates the effect on estimates of EBio by sequentially removing years of data. The bottom panel illustrates the efect on estimation of age eight recruitment. Note that the most recent year class (2002) is only estimated in the 2009 assessment, the 2001 year class in the 2008 and 2009 assessments, and so on.

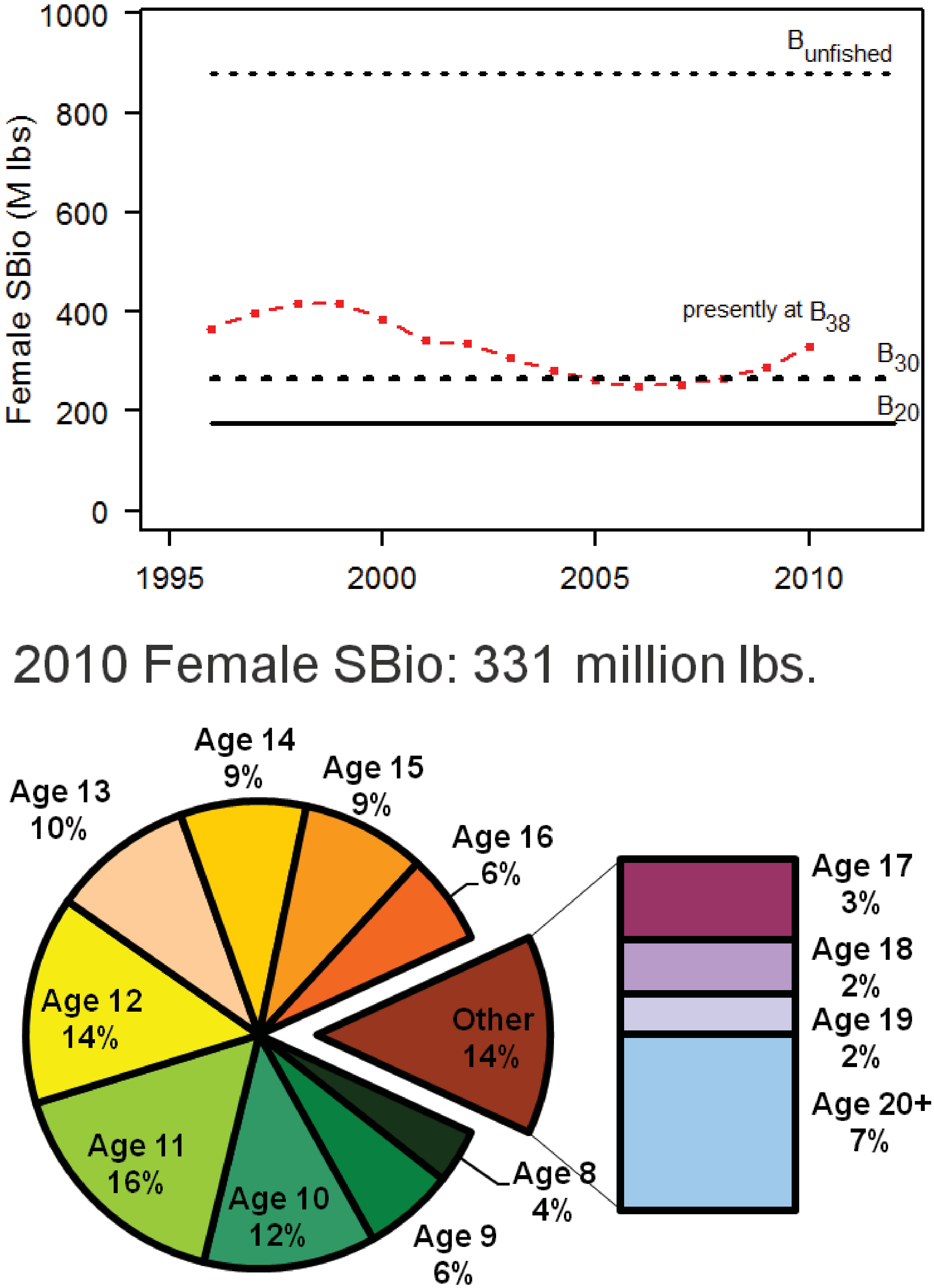


Figure 16. Status (top panel) and current age composition (bottom panel) of female spawning biomass. See text for details.

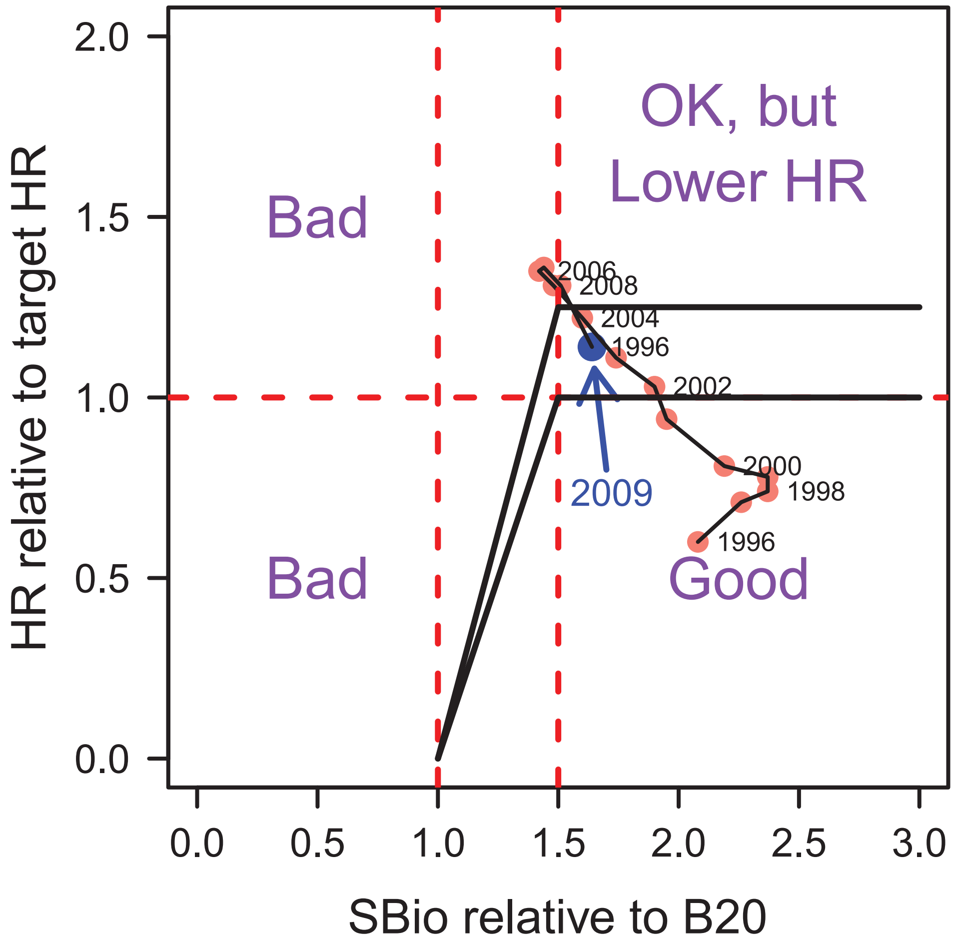


Figure 17. Trend and status of halibut management relative to reference points. Horizontal axis indicates female spawning biomass (SBio) relative to B_{20} (value of 1.0) and B_{30} (value of 1.5). Vertical axis illustrates realized harvest rate relative to a target harvest rate of 0.20 (value of 1.0) and the previous target harvest rate of 0.25 (value of 1.25).

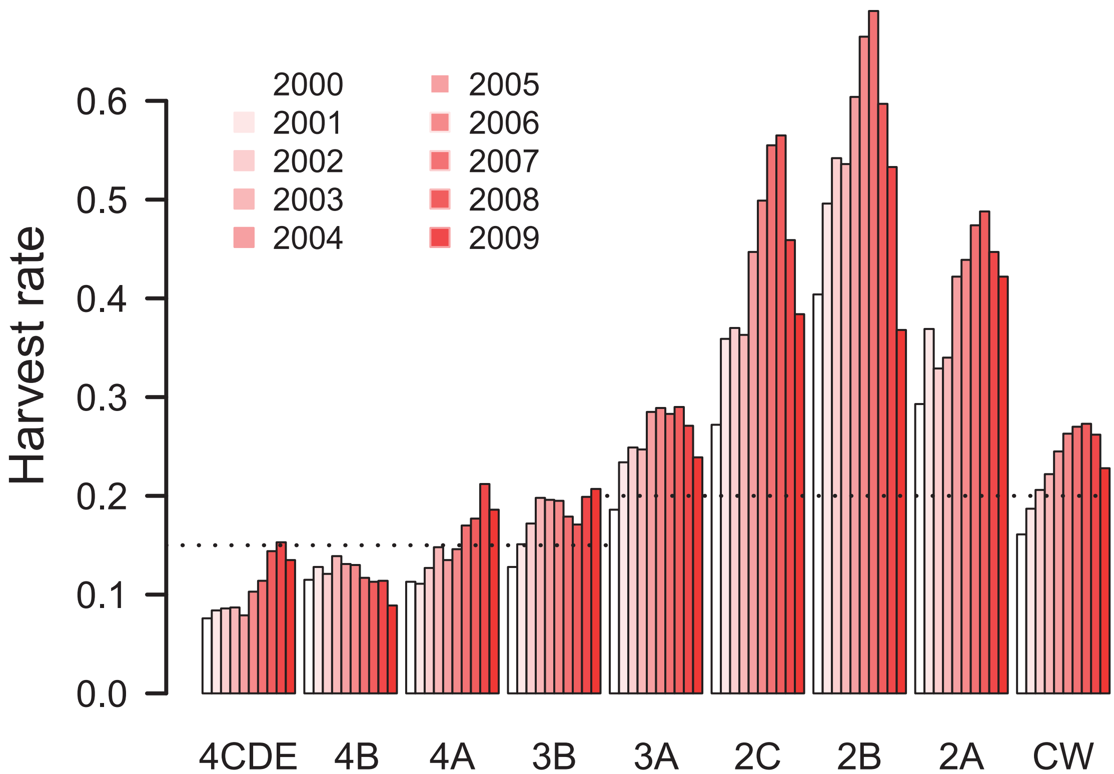
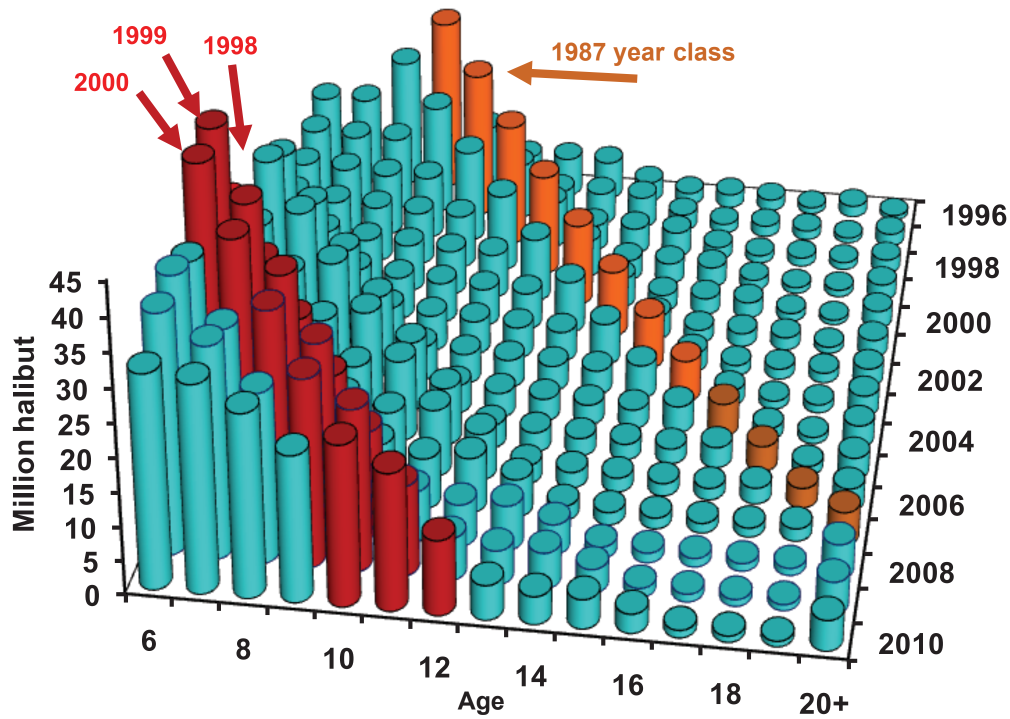


Figure 18. Summary of realized harvest rates from the coastwide assessment, using unadjusted survey WPUE to partition biomass among areas.

a) Total numbers in the population



b) Exploitable biomass in the population

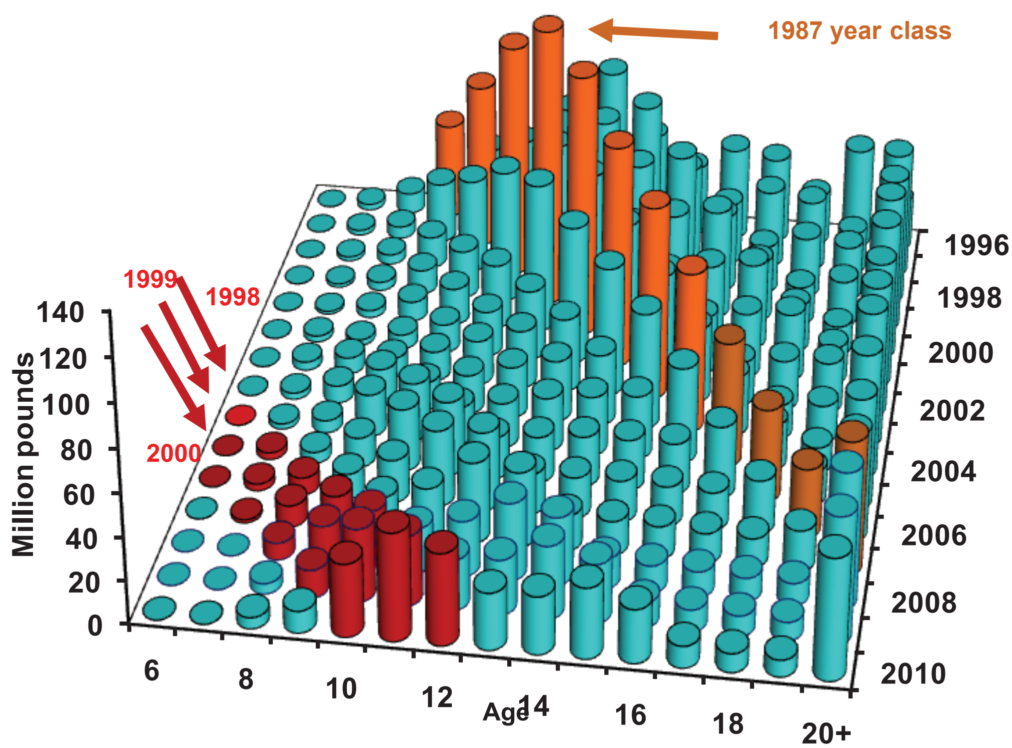


Figure 19. Coastwide population estimates in numbers of halibut (panel a) and as EBio (panel b). Several large year classes are highlighted.

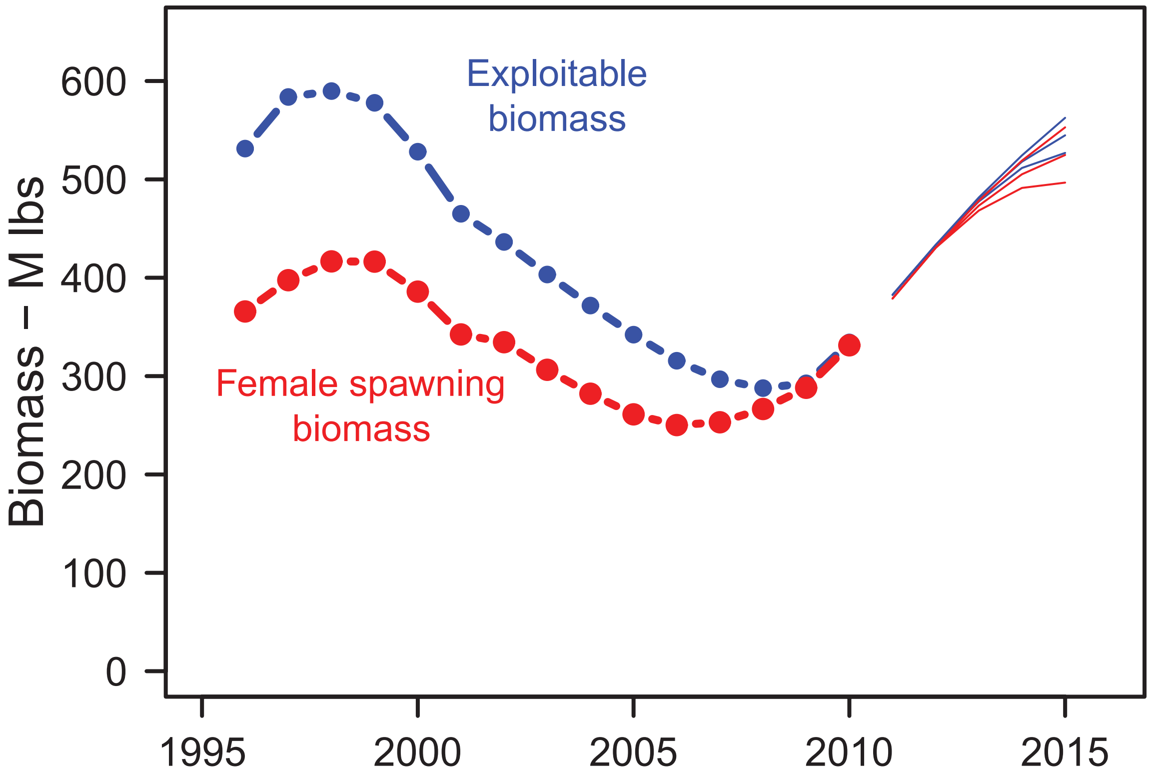


Figure 20. Projected exploitable and spawning biomasses for the coastwide population of halibut.

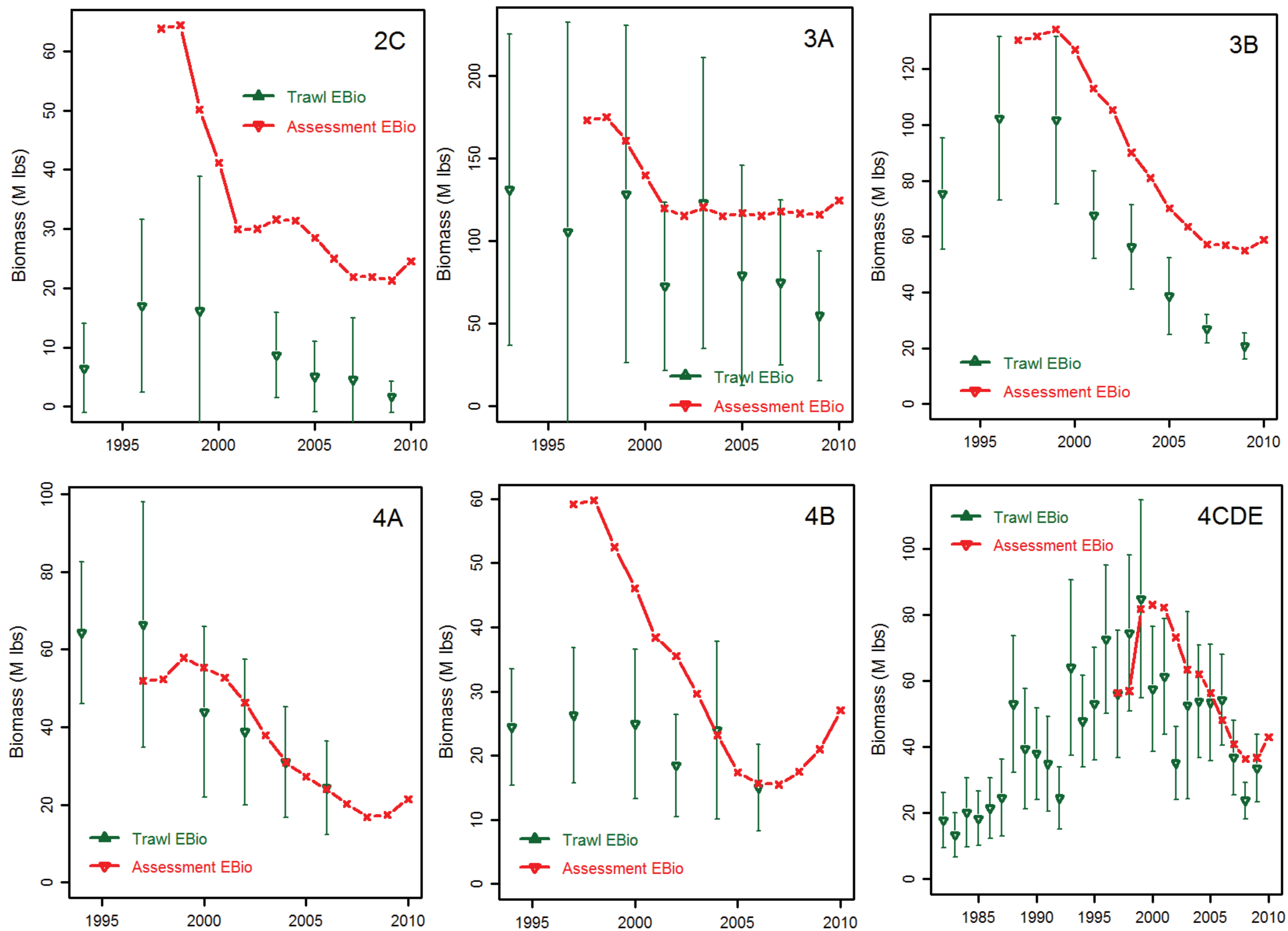


Figure 21. Comparison of IPHC assessment estimates (using unadjsuted survey WPUE) and NMFS swept area estimates of EBio.

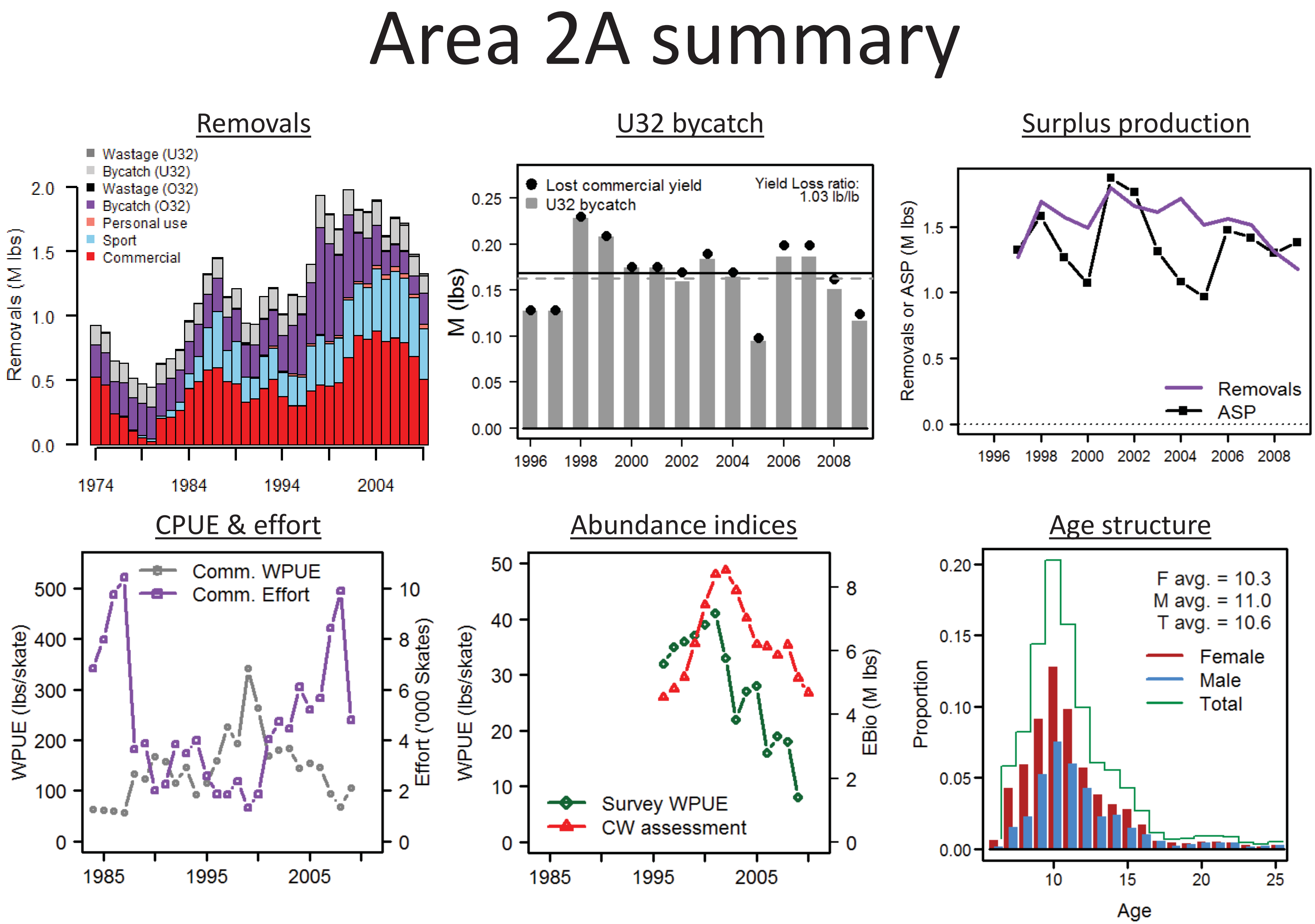


Figure 22. Summary of removals, production, effort, abundance indices and age structure for Area 2A.

Area 2B summary

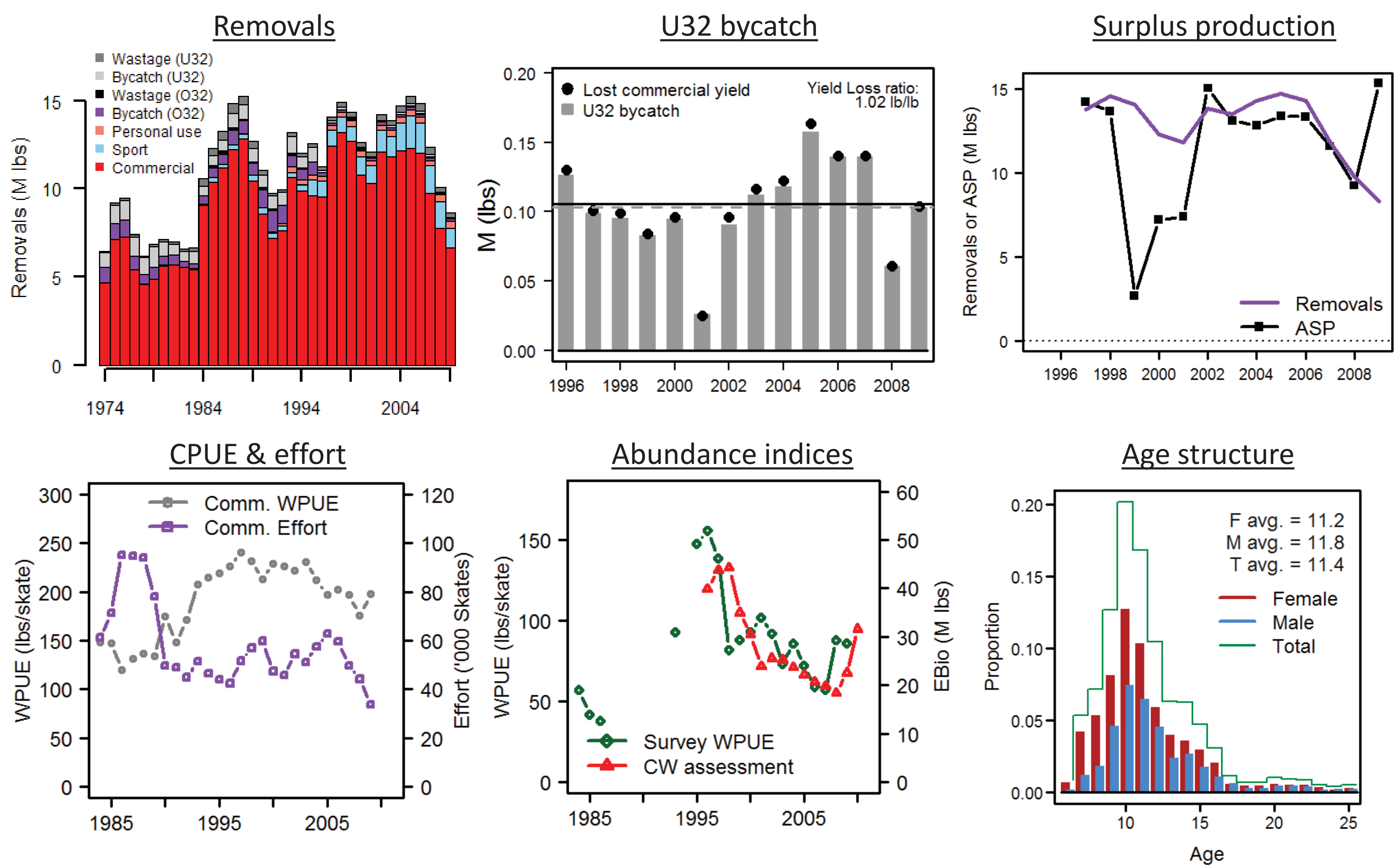


Figure 23. Summary of removals, production, effort, abundance indices and age structure for Area 2B.

Area 2C summary

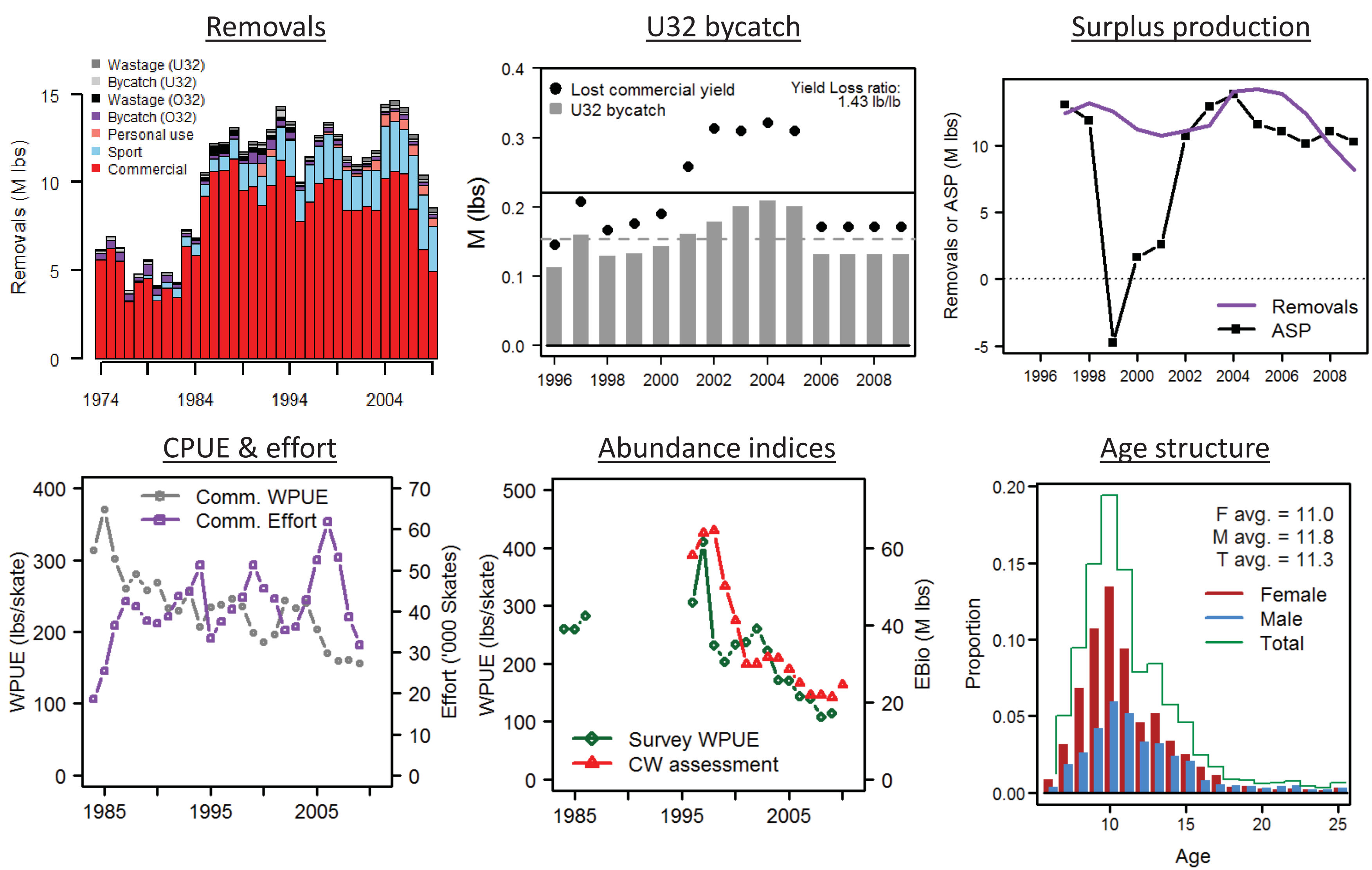


Figure 24. Summary of removals, production, effort, abundance indices and age structure for Area 2C.

Area 3A summary

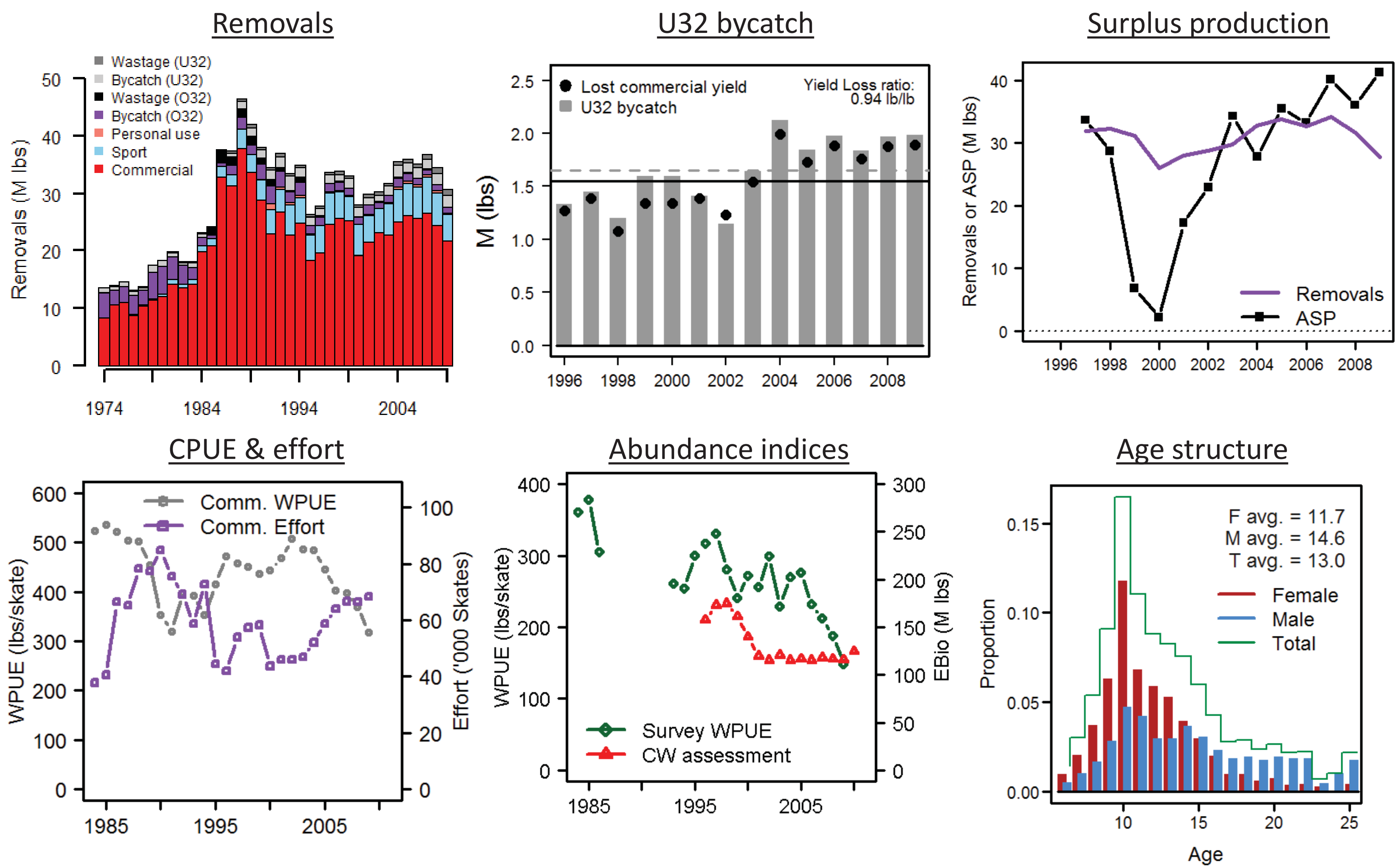


Figure 25. Summary of removals, production, effort, abundance indices and age structure for Area 3A.

Area 3B summary

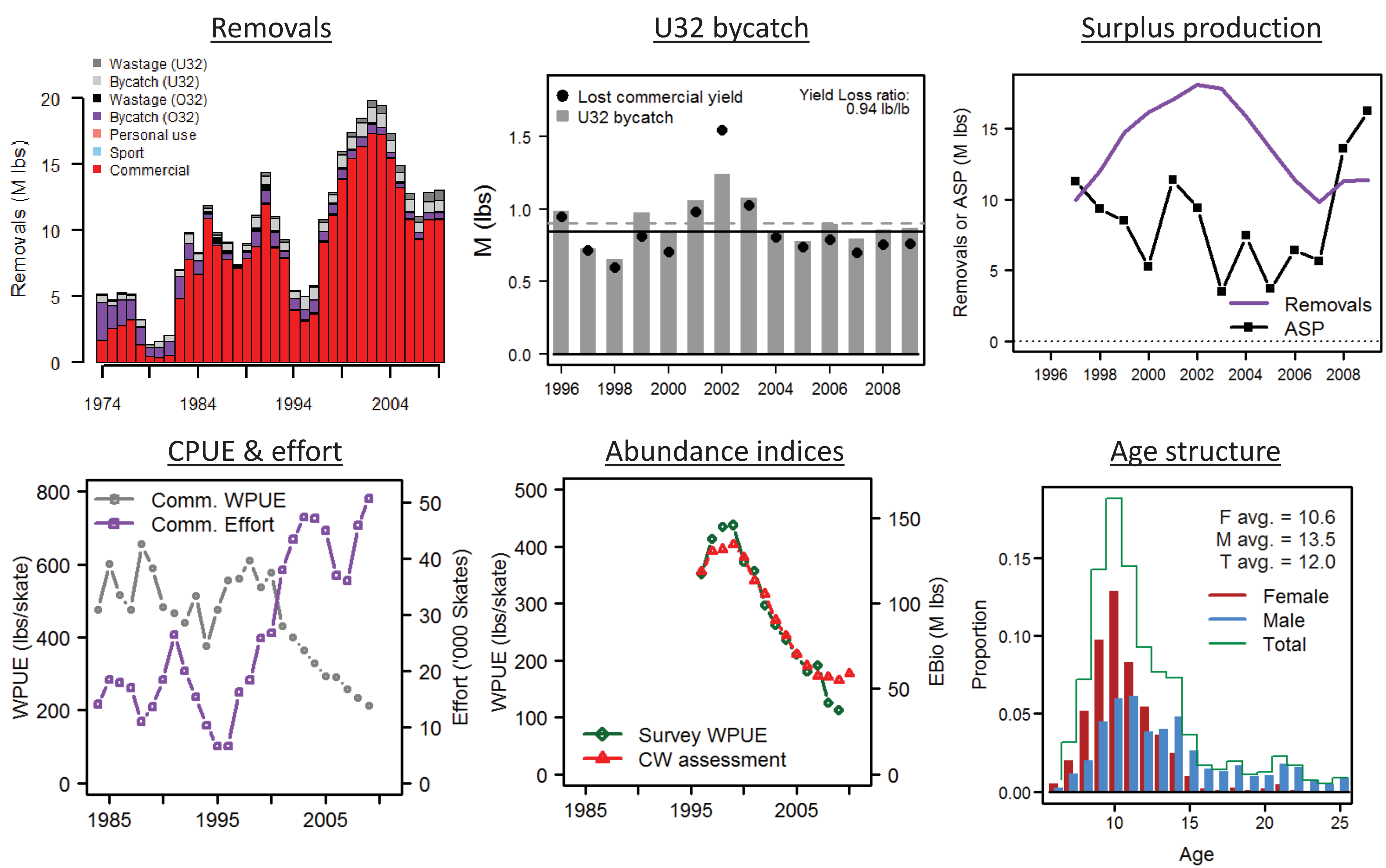


Figure 26. Summary of removals, production, effort, abundance indices and age structure for Area 3B.

Area 4A summary

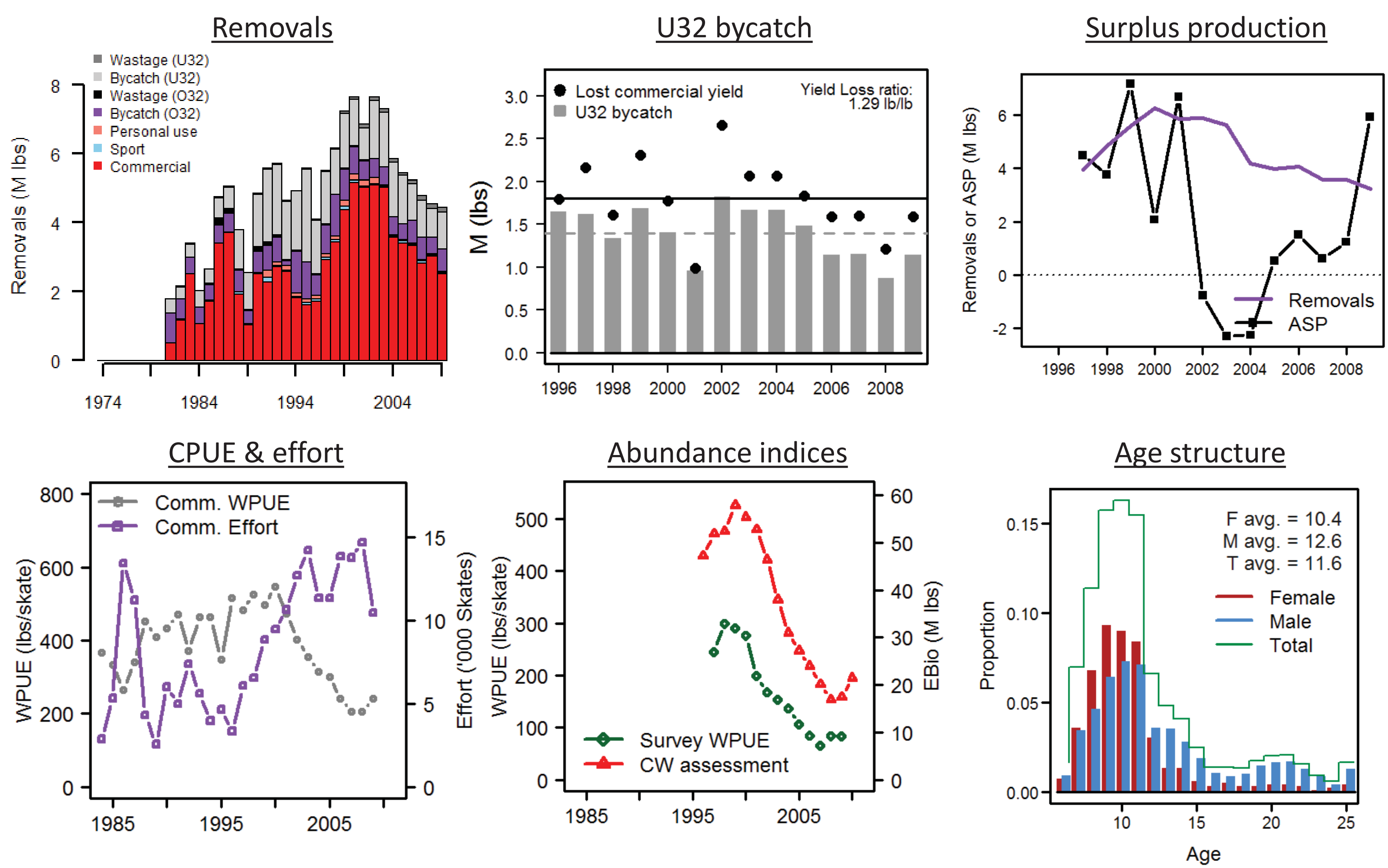


Figure 27. Summary of removals, production, effort, abundance indices and age structure for Area 4A

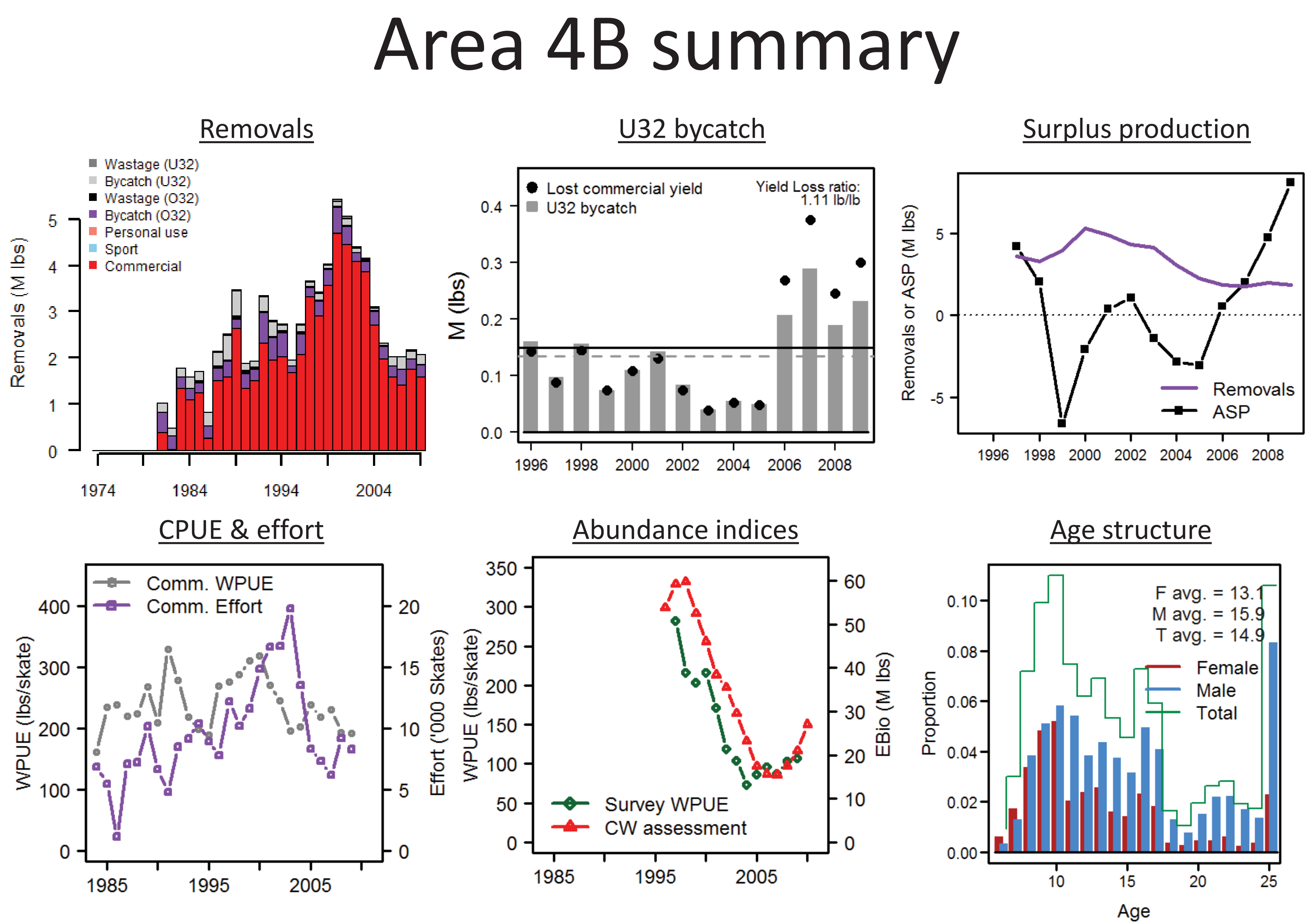


Figure 28. Summary of removals, production, effort, abundance indices and age structure for Area 4B.

Area 4CDE summary

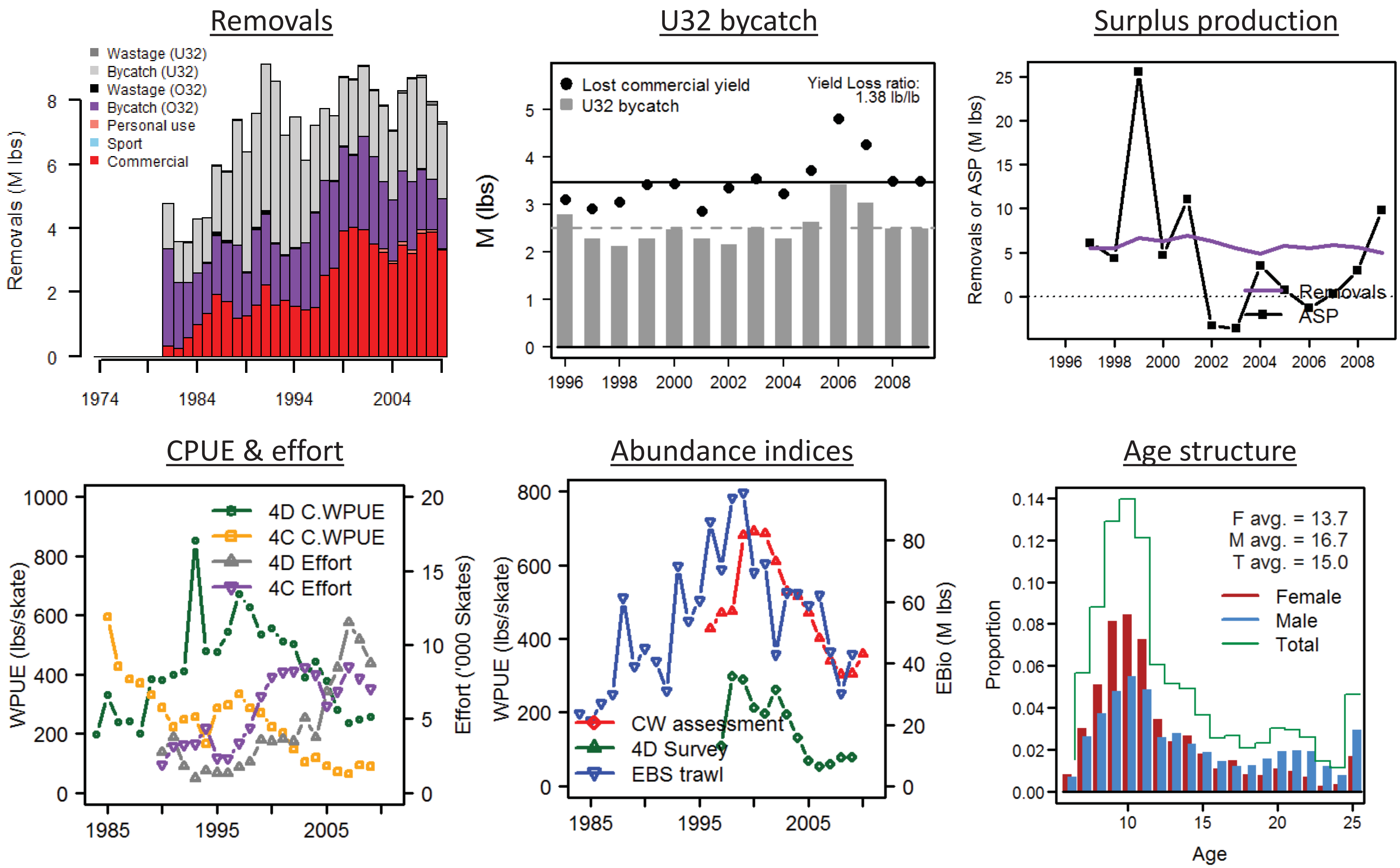


Figure 29. Summary of removals, production, effort, abundance indices and age structure for Area 4CDE.