Assessment of the Pacific halibut stock at the end of 2008

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Abstract

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

Introduction

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

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

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

Observations from the survey and commercial fishery

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

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

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

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

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

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

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

Description of the assessment model

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

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

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

Alternative model fits

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

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

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

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

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

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

Effect of the 2008 data on abundance estimates

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

Evaluation of the assessment

Quality of fits

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

Estimates of recruitment, exploitable biomass and spawning biomass

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

Estimates of uncertainty

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

Retrospective performance

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

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

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

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

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

Harvest policy, status relative to reference points and biomass projections

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

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

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

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

Apportioning the coastwide biomass among regulatory areas

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

Station depth distribution

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

Hook competition

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

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

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

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

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

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

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

Methods of apportioning biomass

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

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

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

Area-apportioned biomass, total and fishery constant exploitation yields

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

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

Area summaries

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

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

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

Area 2

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

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

Area 3

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

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

Area 4

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

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

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

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

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

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

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

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

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

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

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

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

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
Coastwide assessment [1]									
2009 exploitable biomass	3.2	27.0	27.9	140.0	68.8	18.5	15.4	24.2	325
Proportion of total	0.010	0.083	0.086	0.431	0.212	0.057	0.047	0.074	1.000
Target harvest rate	0.20	0.20	0.20	0.20	0.20	0.15	0.15	0.15	<0.20
Total CEY	0.64	5.41	5.57	28.01	13.76	2.77	2.31	3.62	62.10
Other removals [2]	0.142	0.495	3.836	7.123	0.555	0.567	0.275	1.658	14.651
2009 fishery CEY [2]	0.500	4.919	2.721	20.838	13.202	2.203	2.035	1.966	48.384

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

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

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

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

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

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

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

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

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

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

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

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

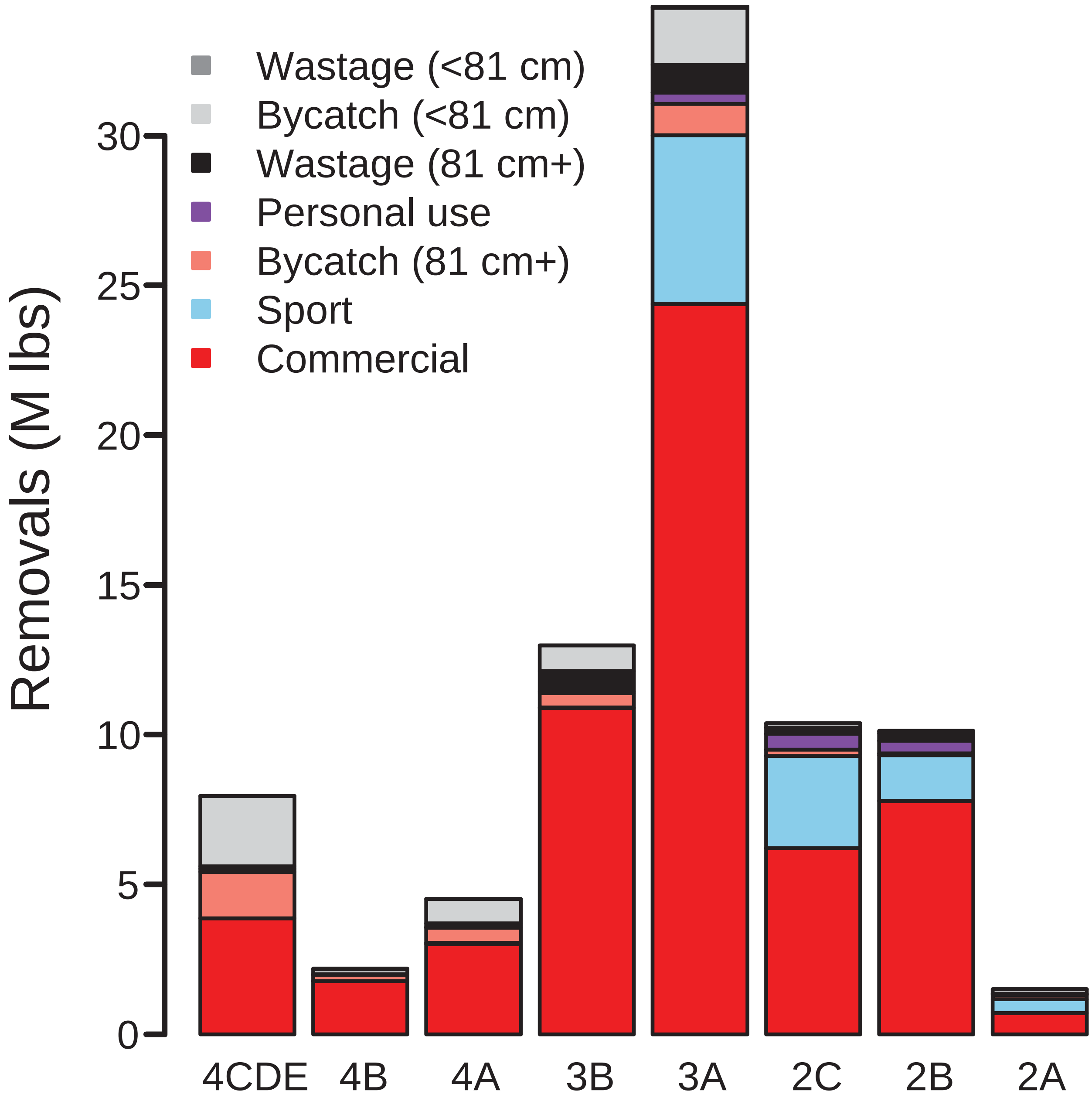


Figure 1. Total removals by type and regulatory area for 2008.

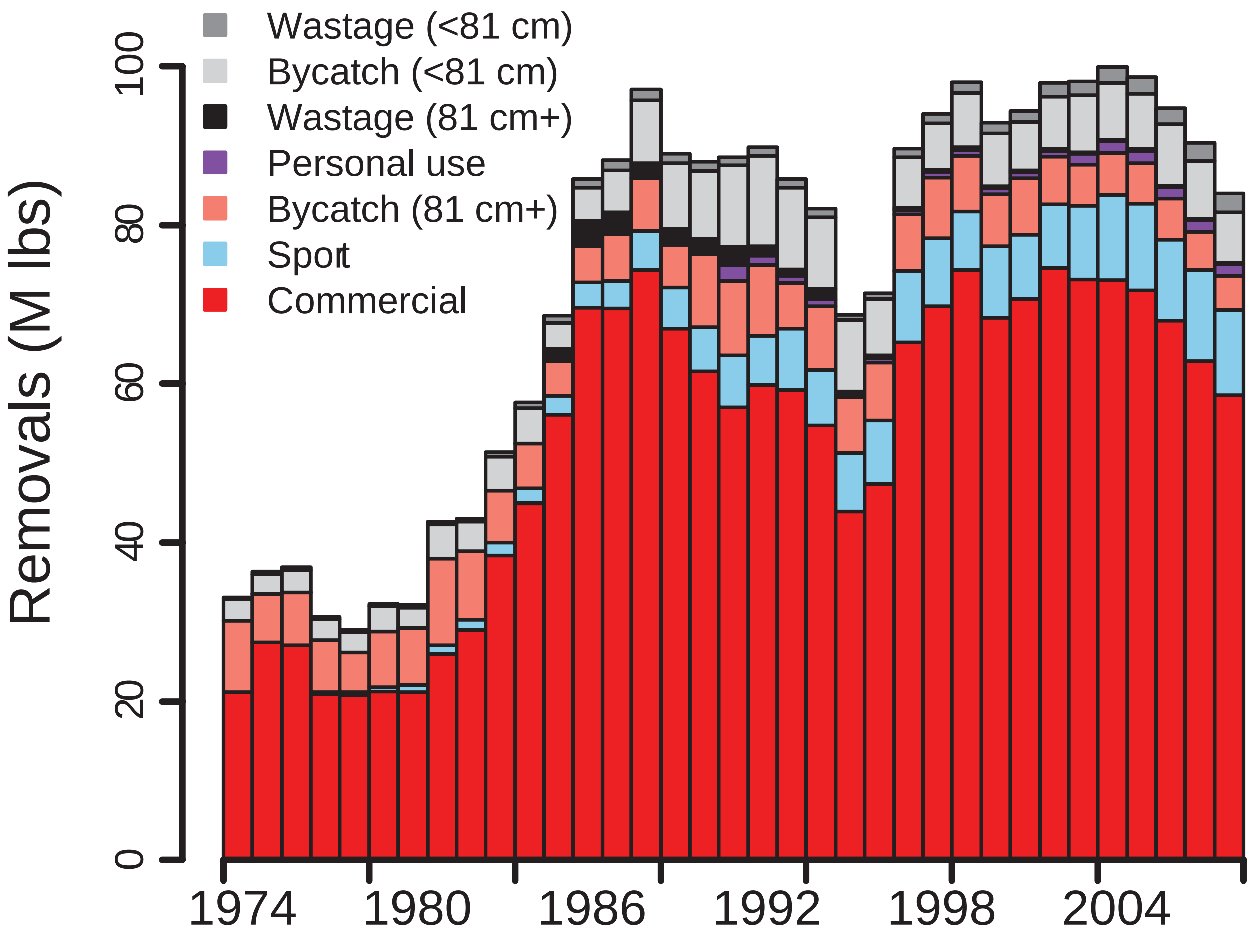


Figure 2. Total removals coastwide for the period 1974-2008.

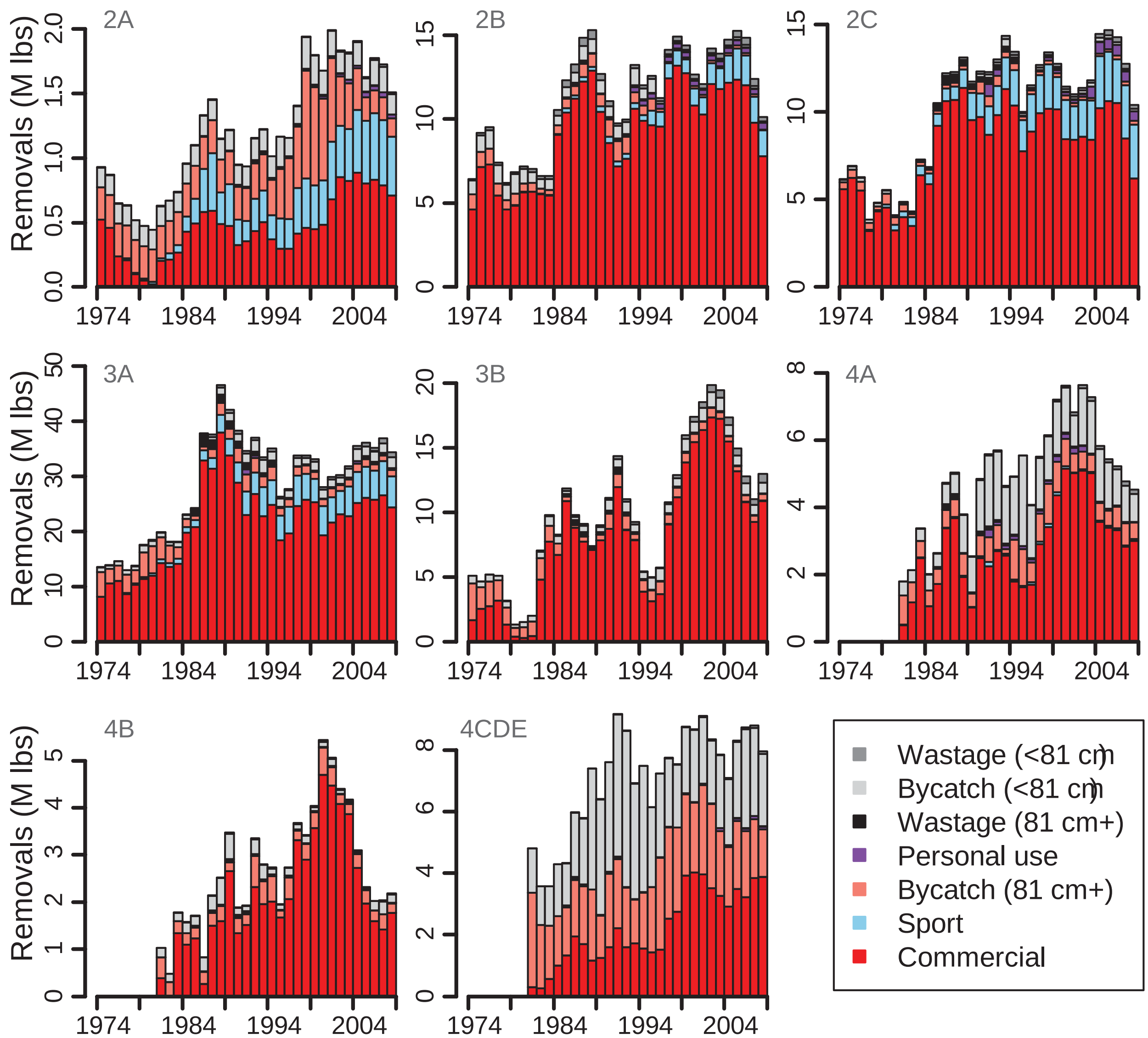


Figure 3. Total removals of halibut, by Regulatory Area, 1974-2008. The two sublegal categories (bycatch and wastage, colored in gray) and not included in the total removals listed in Table A1).

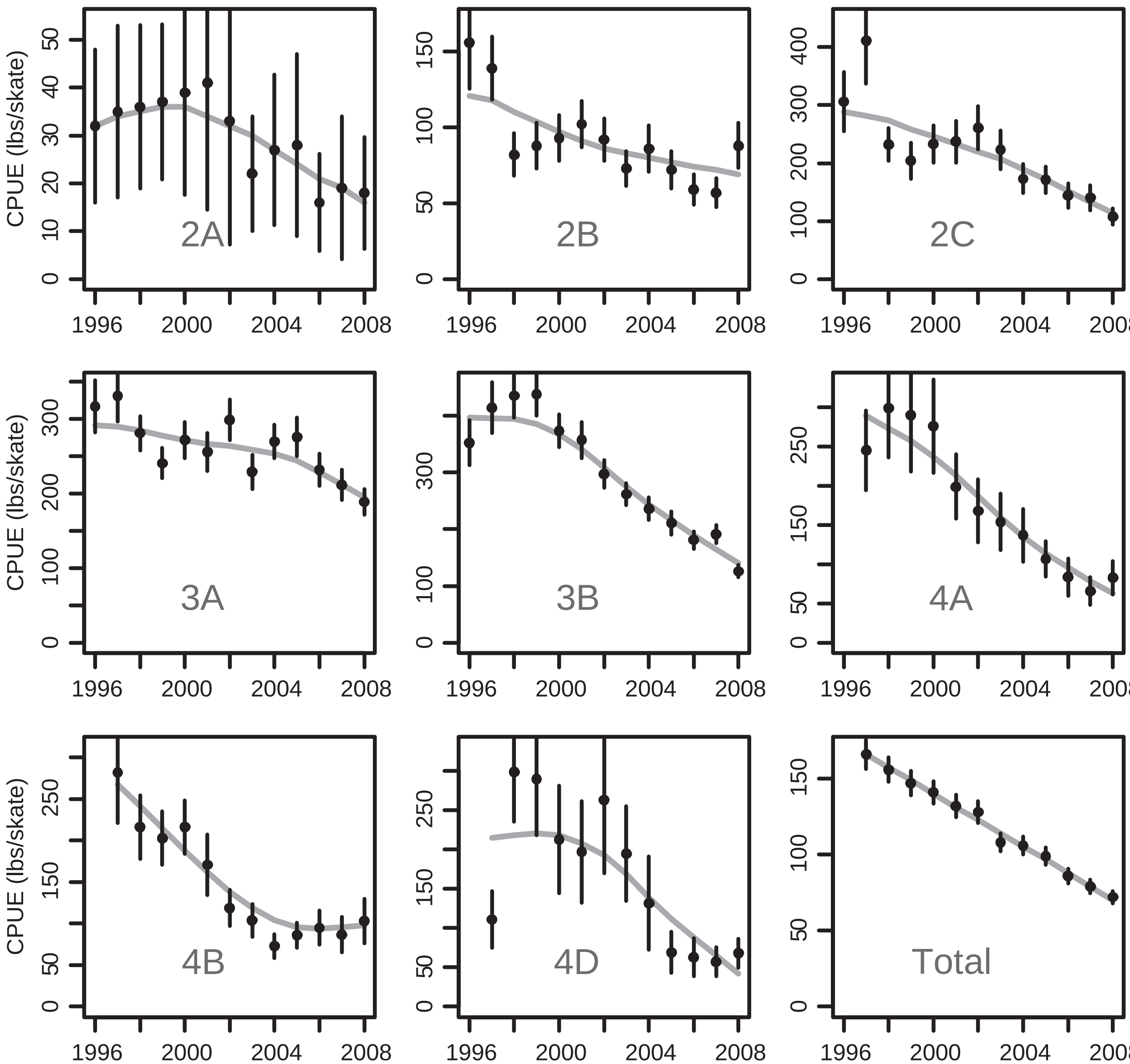


Figure 4. Survey CPUE (weight of legal-sized halibut per standardized skate of gear) by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray line is a smoother to illustrate trend; it is not an assessment model fit to the CPUE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

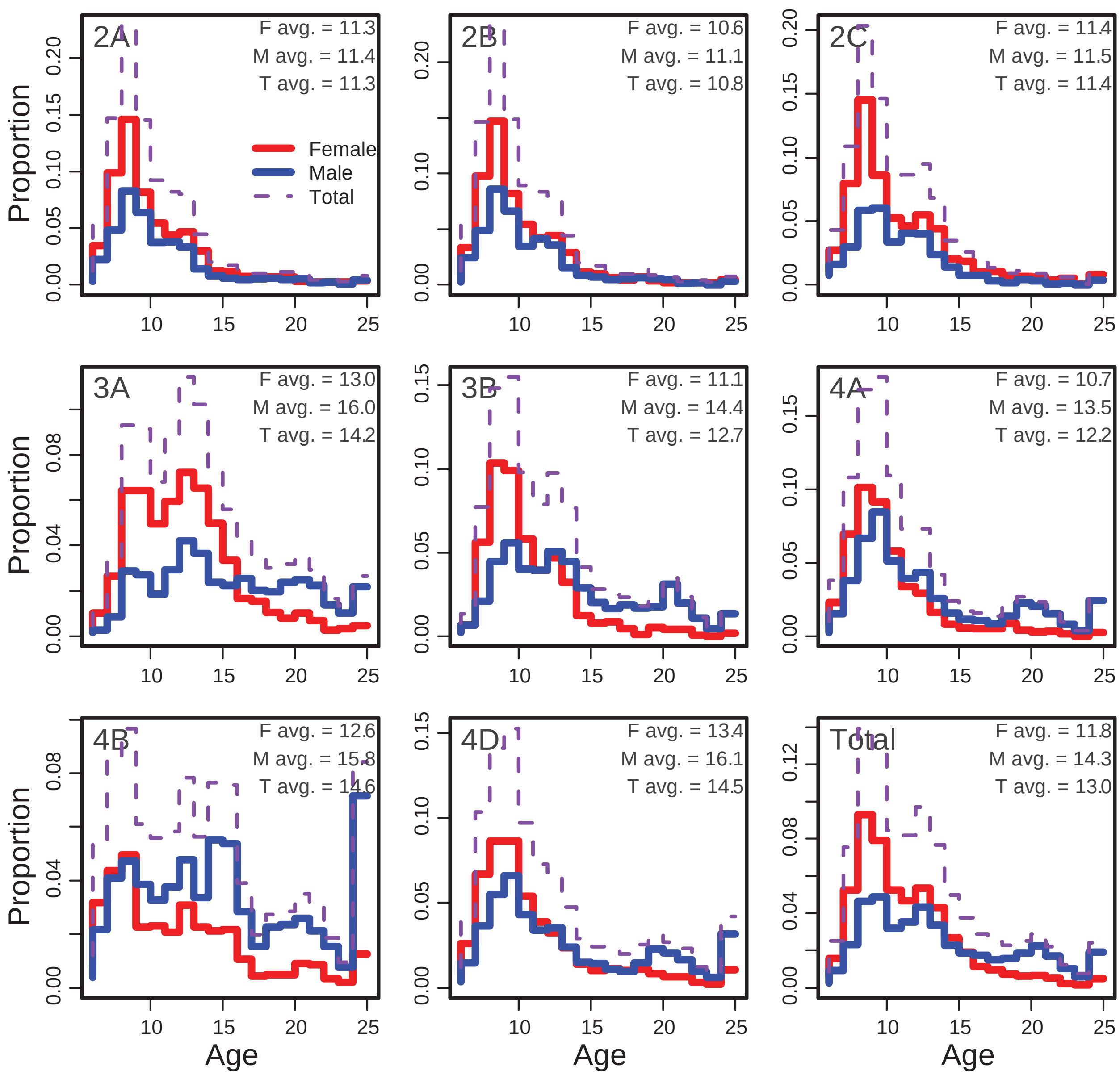


Figure 5. Regulatory area sex and age compositions from halibut taken in the 2008 IPHC stock assessment survey. Proportions are shown for females (red lines), males (blue line) and sexes combined (purple dashed line). Average age is also shown, with "T" indicating Total (sexes combined).

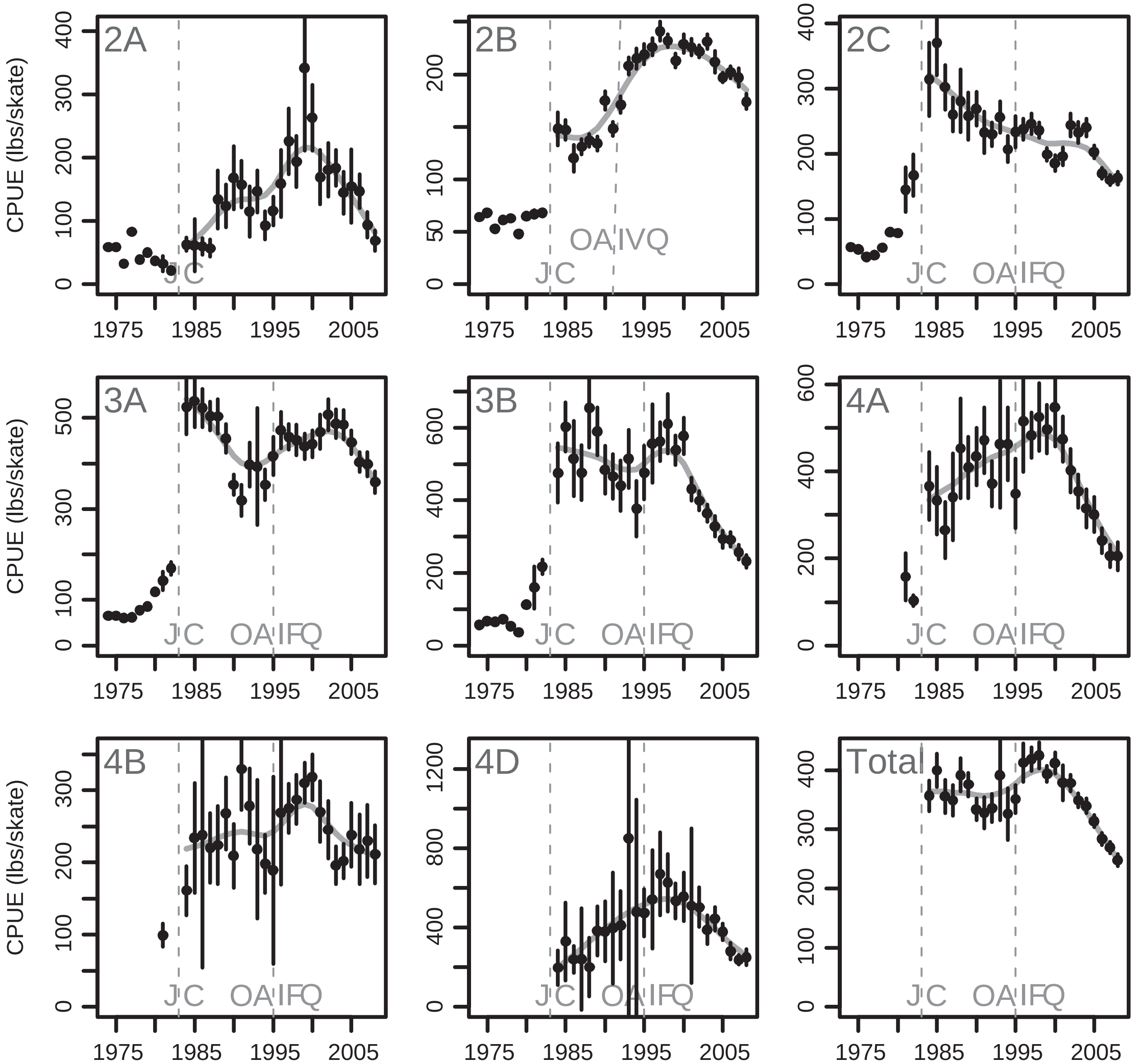


Figure 6. Commercial CPUE by regulatory area. The dots indicate the area-wide average; the vertical bars represent +/ 2 standard errors of the mean. The gray line is a smoother to illustrate trend; it is not an assessment model fit to the CPUE data. The total is computed by area-weighting the individual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

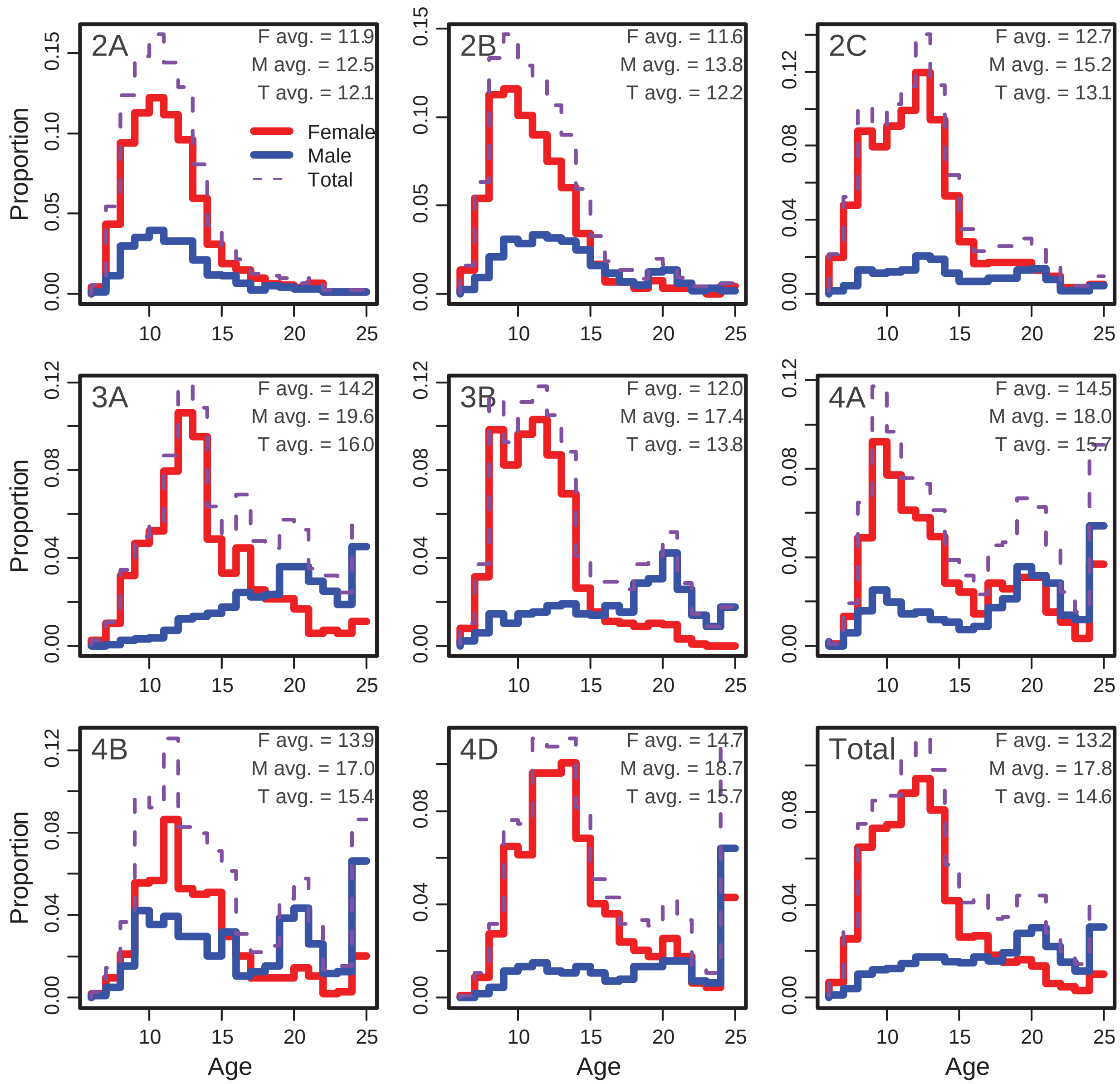


Figure 7. Regulatory area sex and age compositions from halibut sampled from commercial landings. Proportions are shown for females (red line), males (blue line) and sexes combined (purple dashed line). Average age is also shown, with "T" indicating Total (sexes combined).

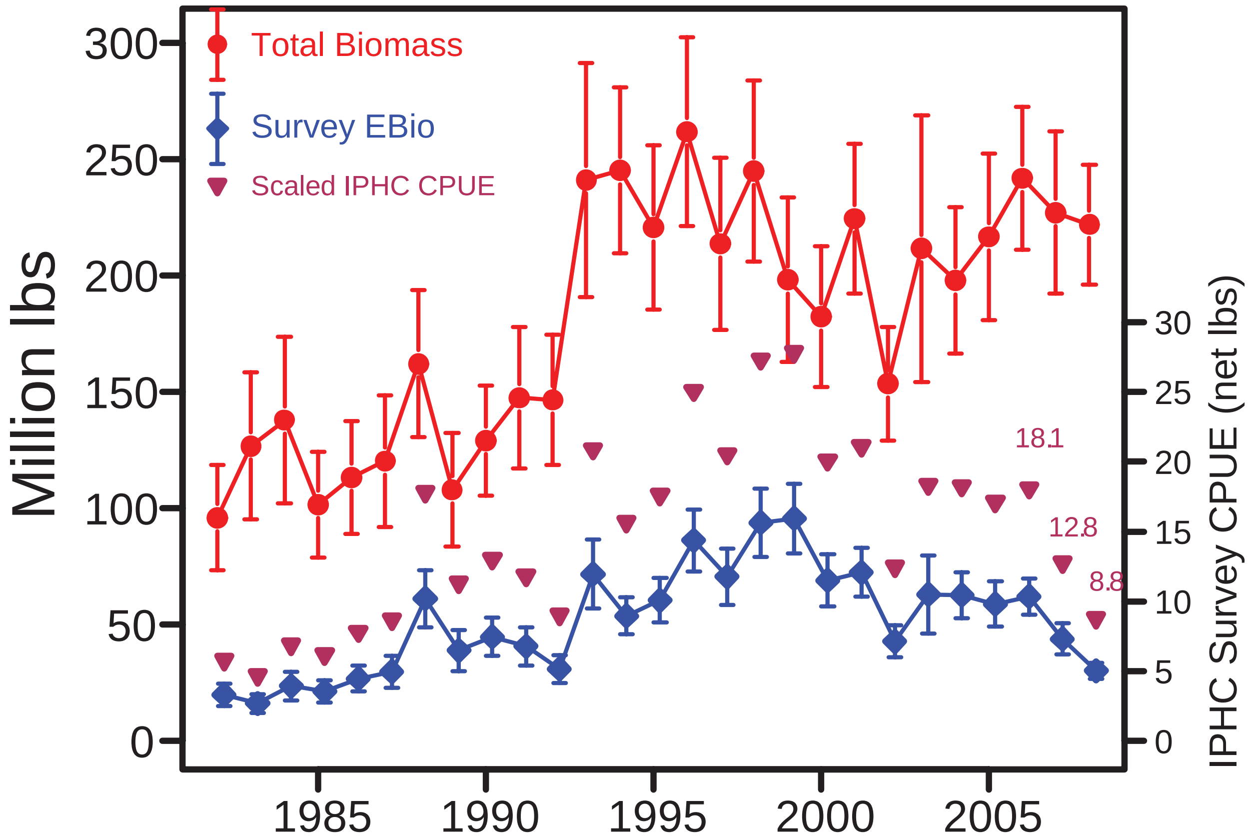


Figure 8. Swept-area estimates of halibut abundance from the NMFS EBS trawl survey. The red dots and error bars represent mean and 95% confidence interval for the total abundance; the blue diamonds are error bars represent mean and 95% confidence interval for abundance with survey selectivity applied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

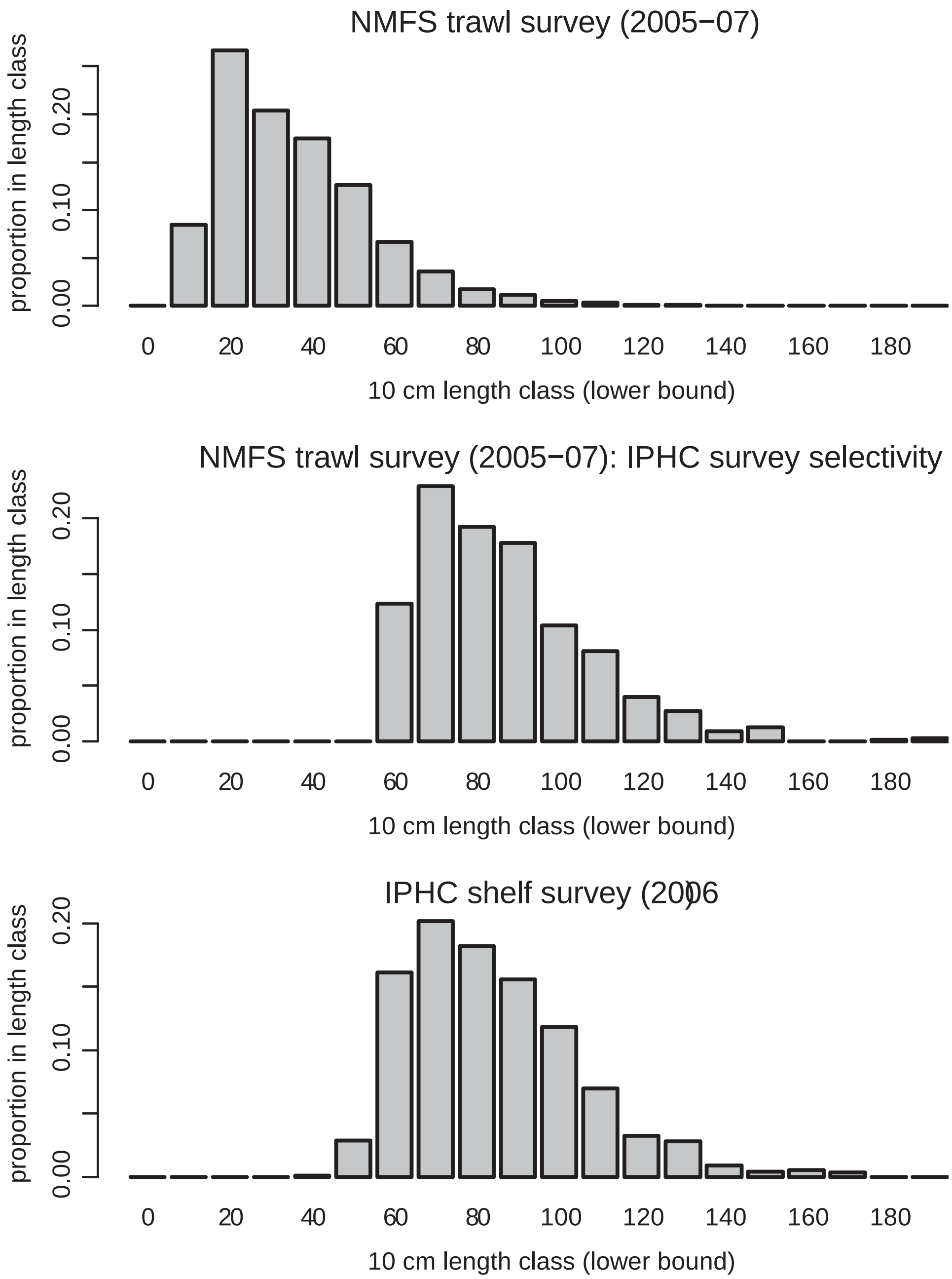


Figure 9. Comparison of NMFS trawl survey and IPHC length frequency compositions. The top panel shows the length frequency composition for all halibut caught by the NMFS trawl gear for years 2005-7. the middle panel shows the frequency distribution of lengths after the IPHC setline selectivity curve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

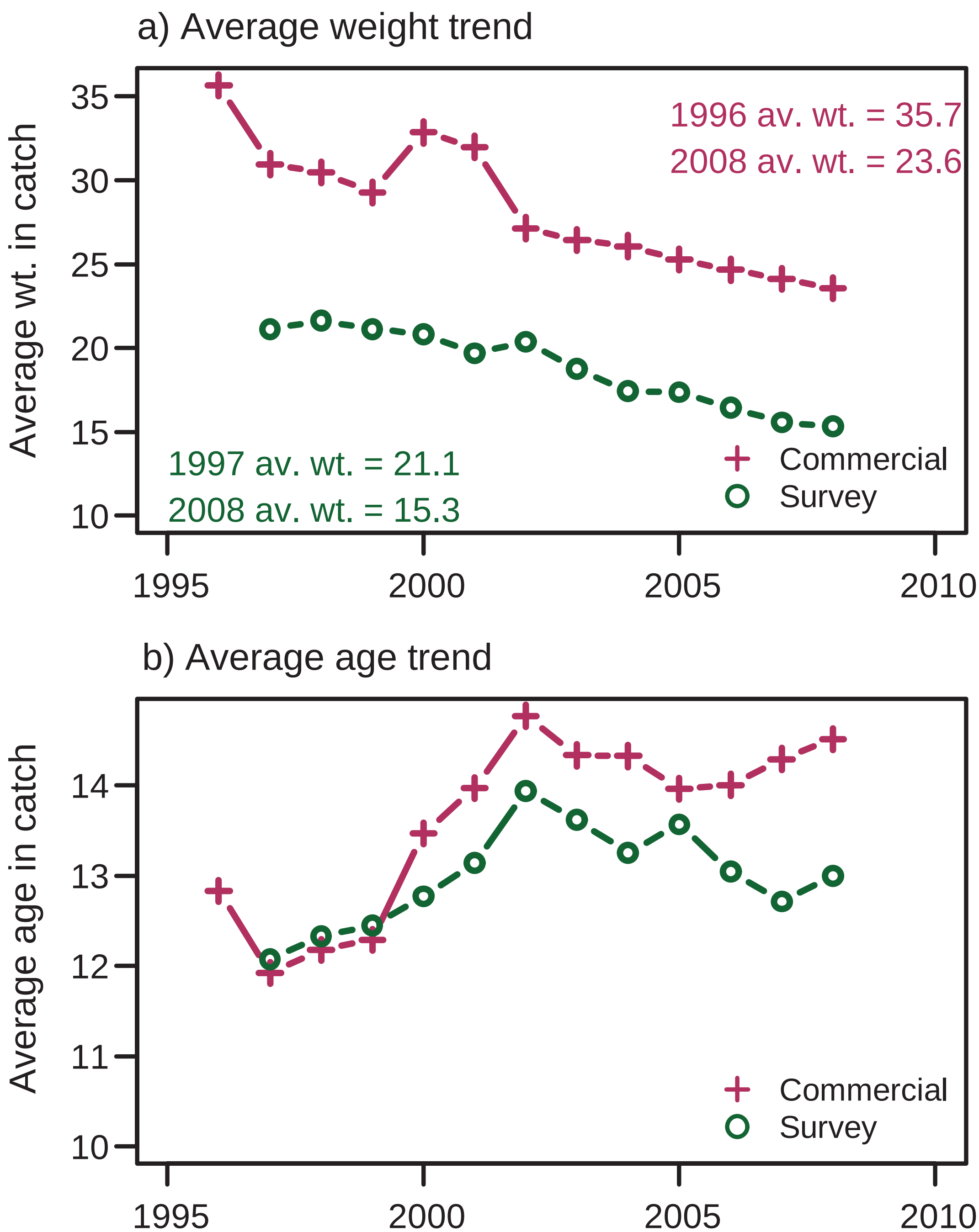


Figure 10. Average weight (panel a) and average weight (panel b) trends for the coastwide halibut stock for 1996 to 2008.

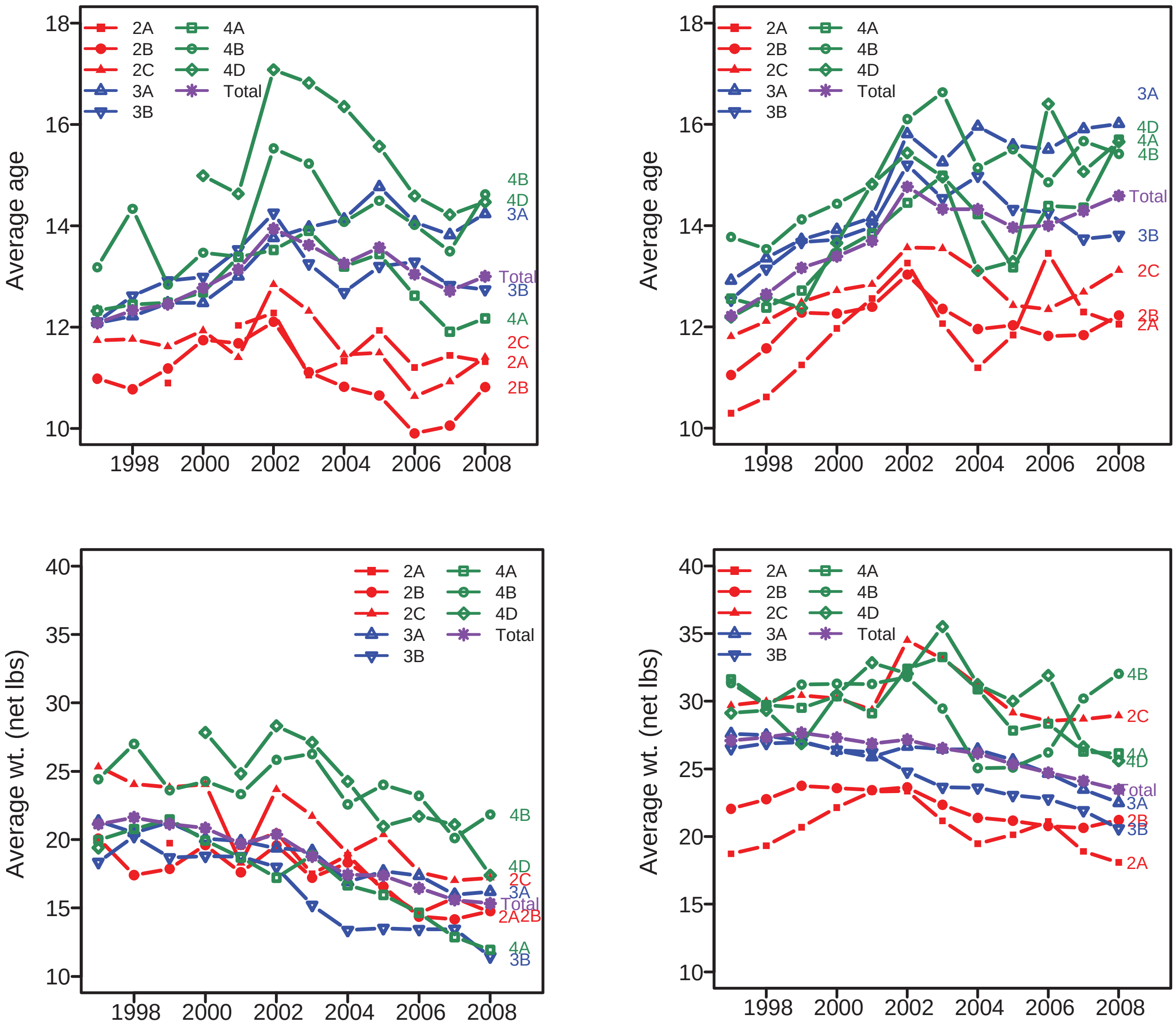


Figure 11. Trends in average age (top panels) and average weight (bottom panels) in survey catches (left panels) and commercial catches (right panels).

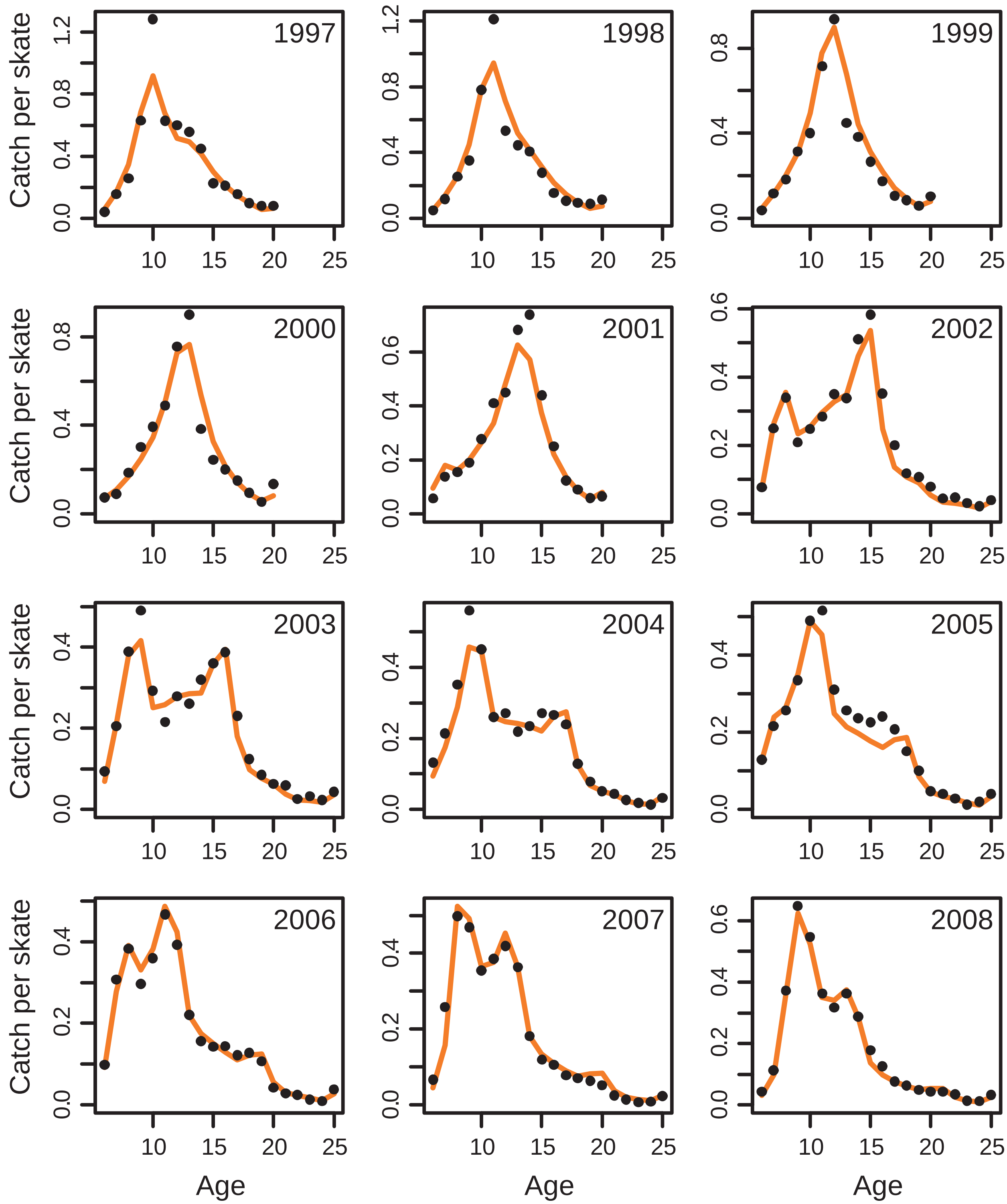


Figure 12a. Observed (points) and predicted (lines) survey CPUE at age of females in the 2008 coastwide model fit.

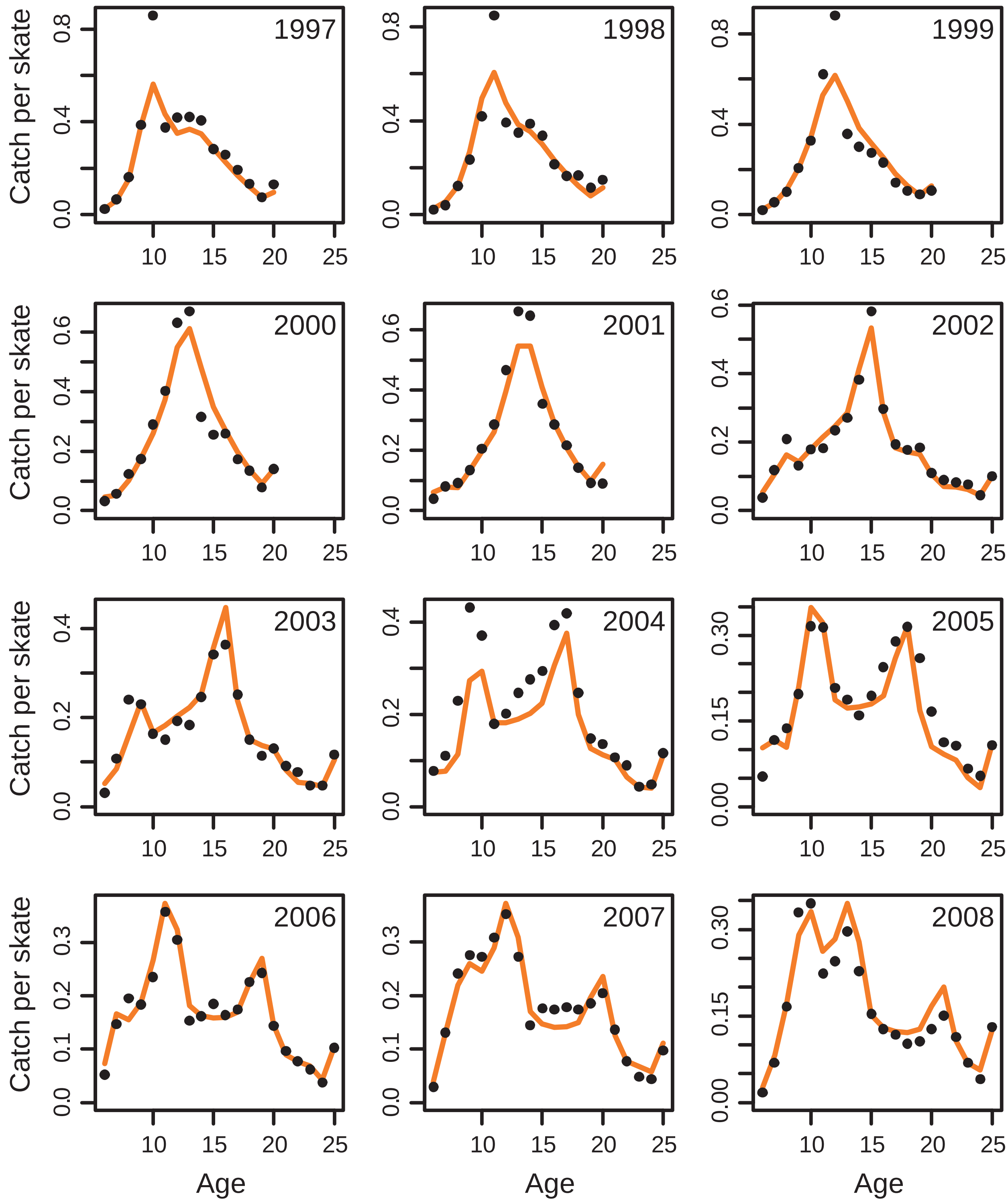


Figure 12b. Observed (points) and predicted (lines) survey CPUE at age of males in the 2008 coastwide model fit.

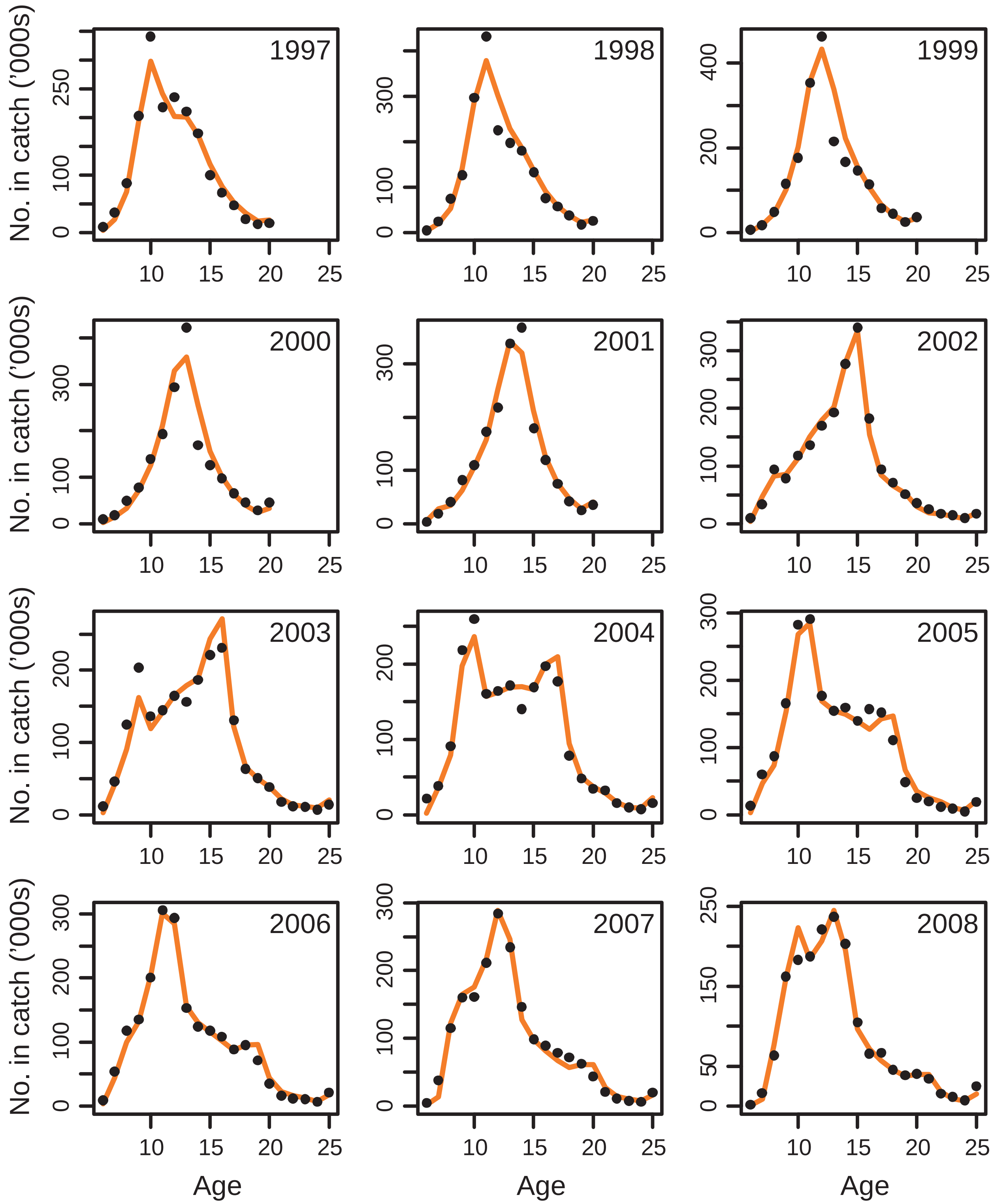


Figure 13a. Observed (points) and predicted (lines) commercial catch at age of females in the 2008 coastwide model fit.

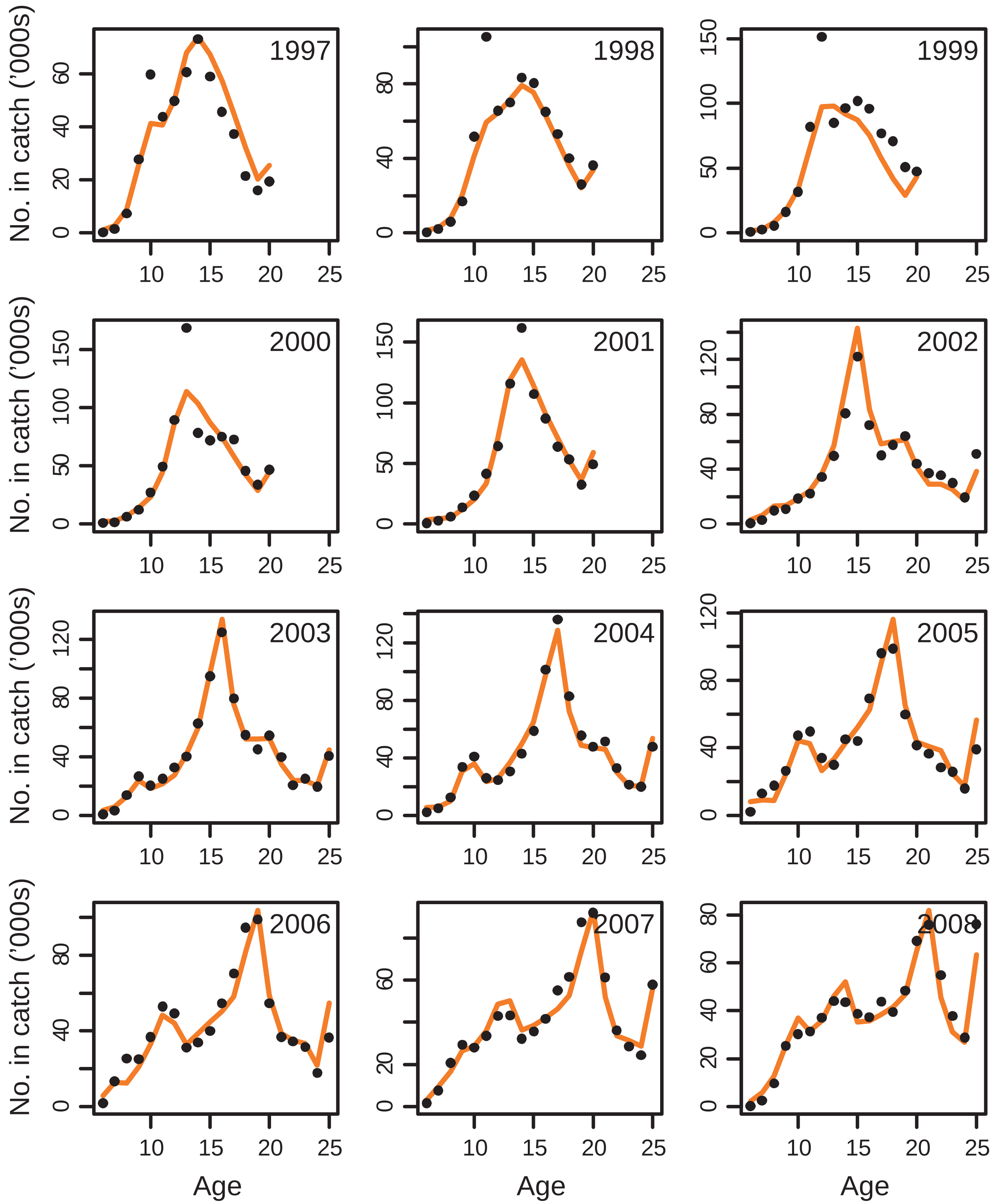


Figure 13b. Observed (points) and predicted (lines) commercial catch at age of males in the 2008 coastwide model fit.

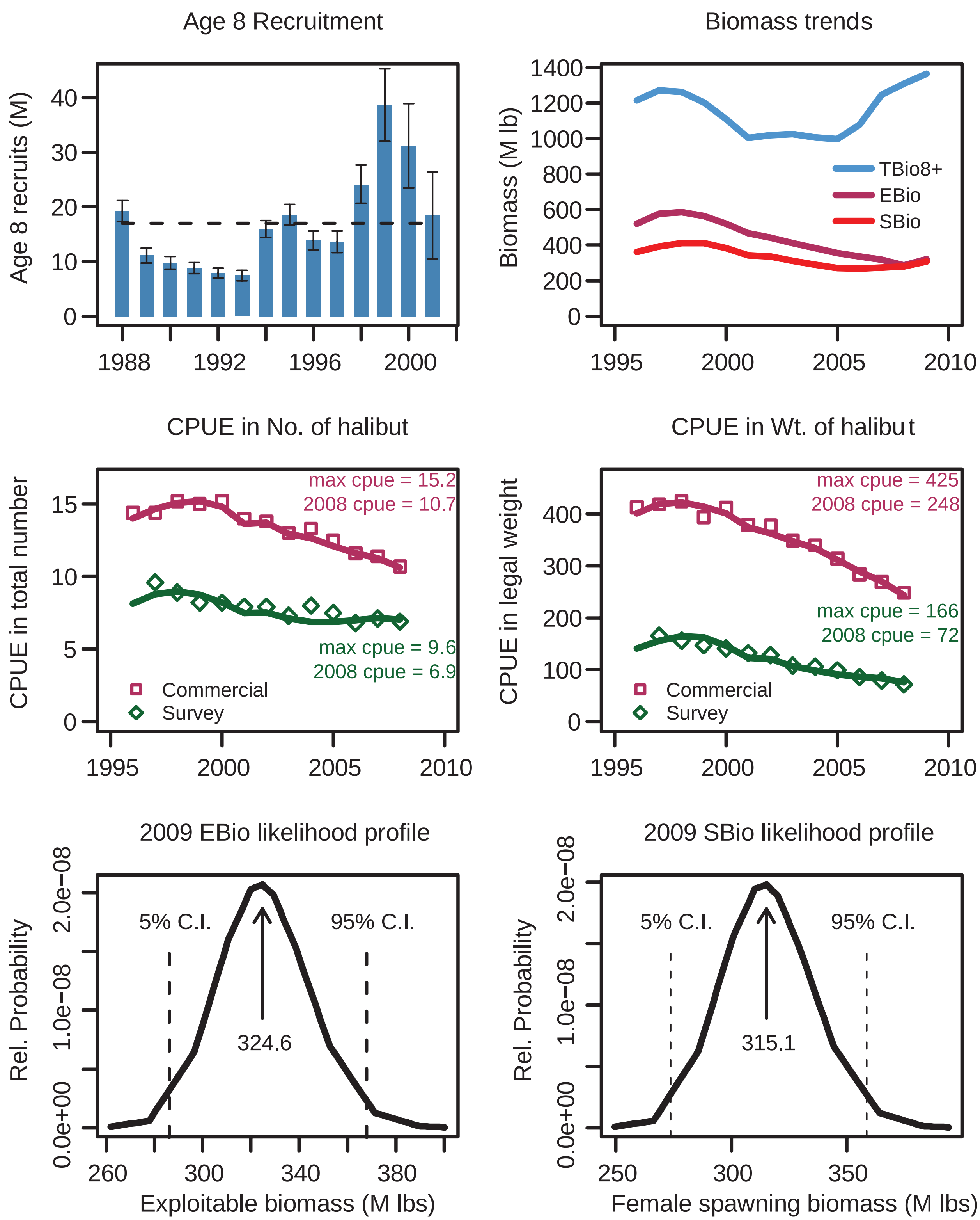
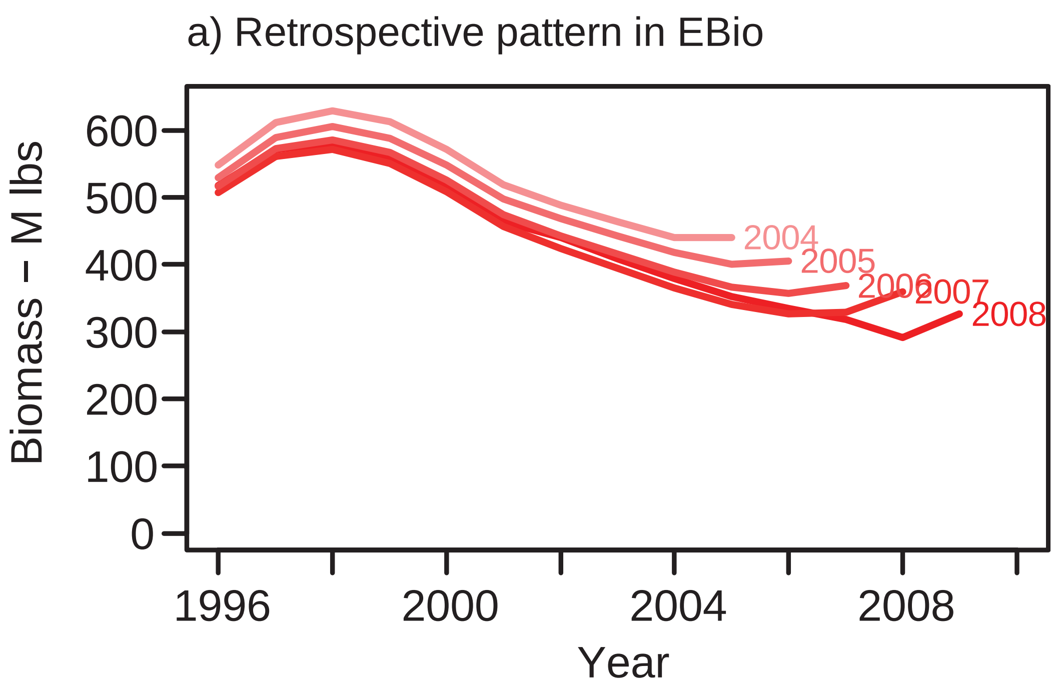


Figure 14. Features of the 2008 halibut coastwide assessment.



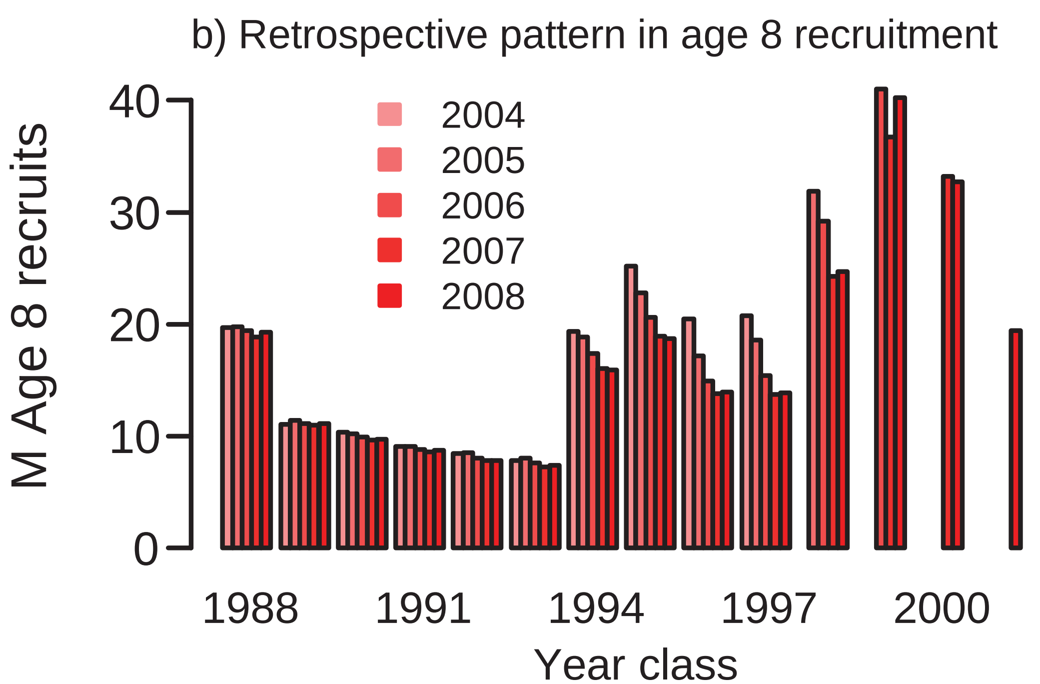


Figure 15. Retrospective behavior of 2008 halibut assessment model. The top panel illustrates the effect on estimates of EBio by sequentially removing years of data. The bottom panel illustrates the efect on estimation of age eight recruitment. Note that the most recent year class (2001) is only estimated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

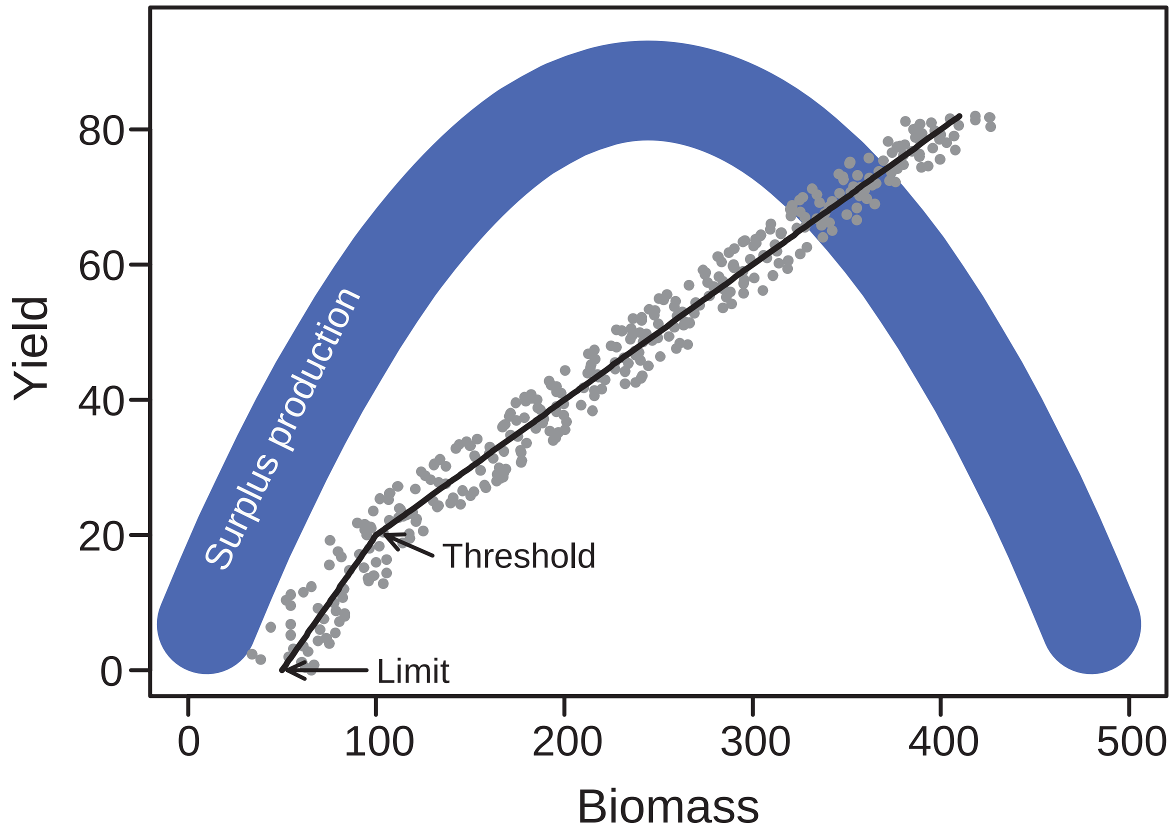


Figure 16. Representation of the IPHC harvest policy. The background curve illustrates theoretical relationship between biomass and surplus production, taken as yield. The slope of the straight line is a 20% harvest rate (Yield/Exploitable biomass), and the harvest rate deceases linearly to zero as the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

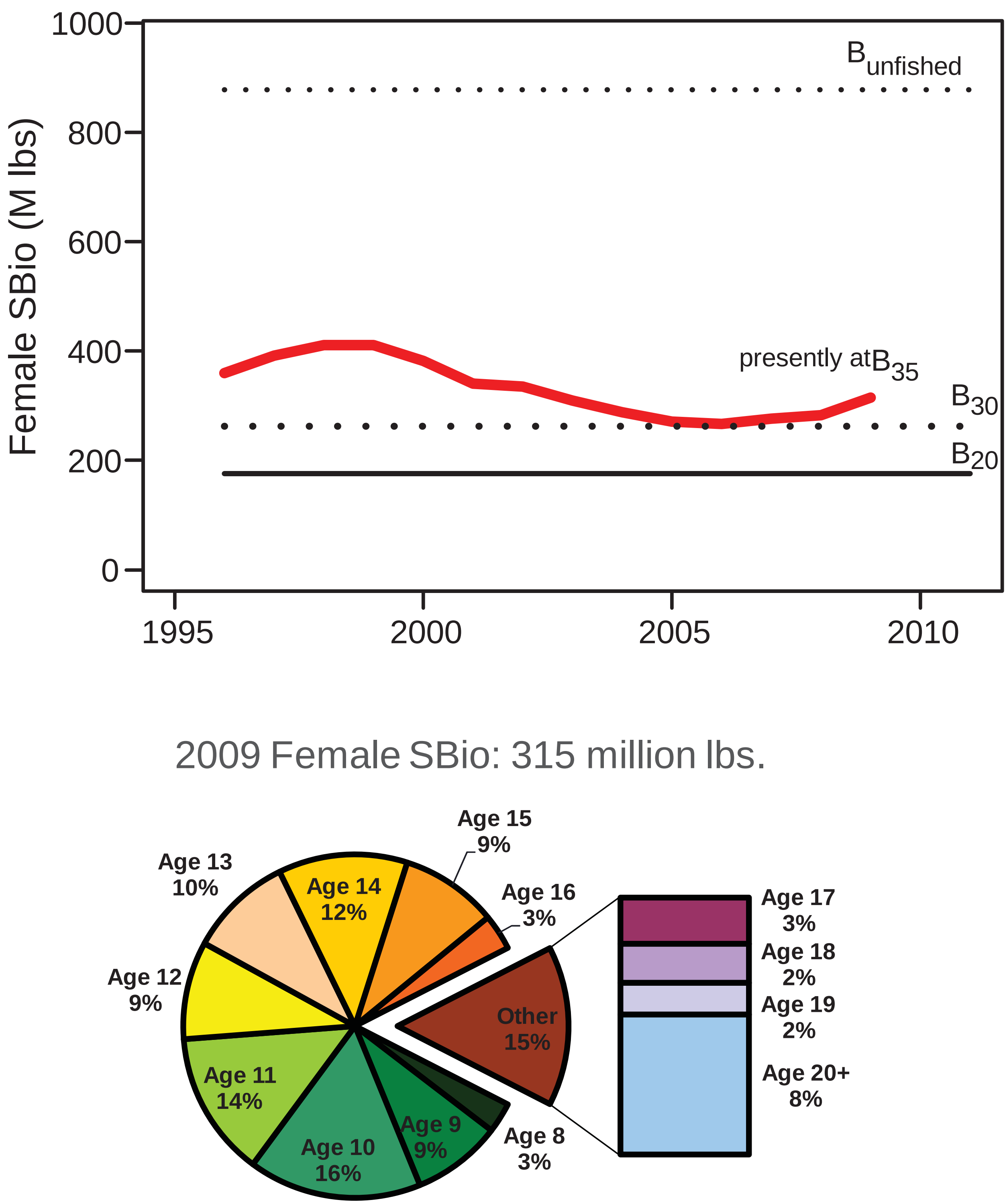


Figure 17. Status (top panel) and current age composition (bottom panel) of female spawning biomass. See text for details.

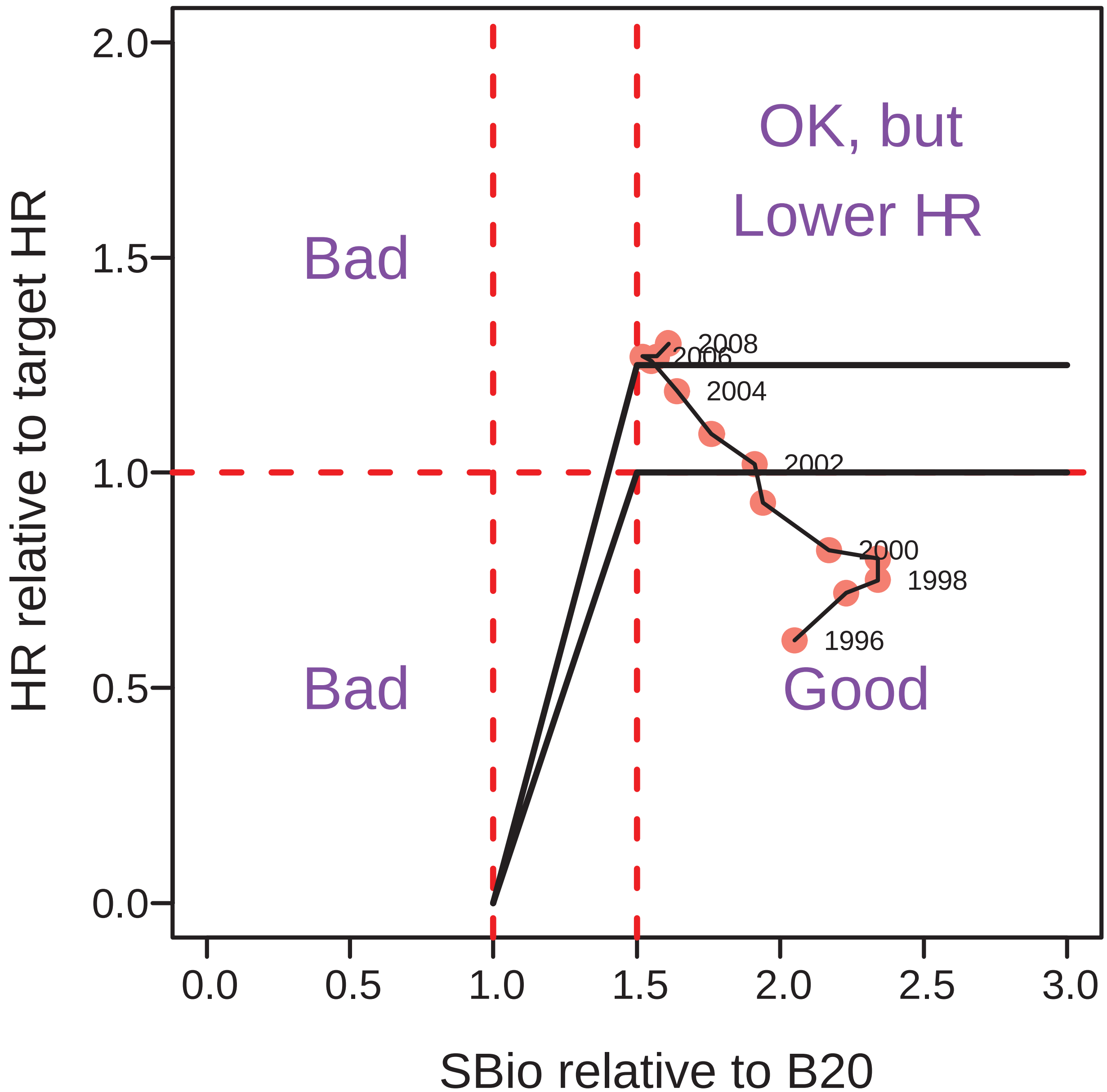


Figure 18. Trend and status of halibut management relative to reference points. Horizontal axis indicates female spawning biomass (SBio) relative to B_{20} (value of 1.0) and B_{30} (value of 1.5). Vertical axis illustrates realized harvest rate relative to a target harvest rate of 0.20 (value of 1.0)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

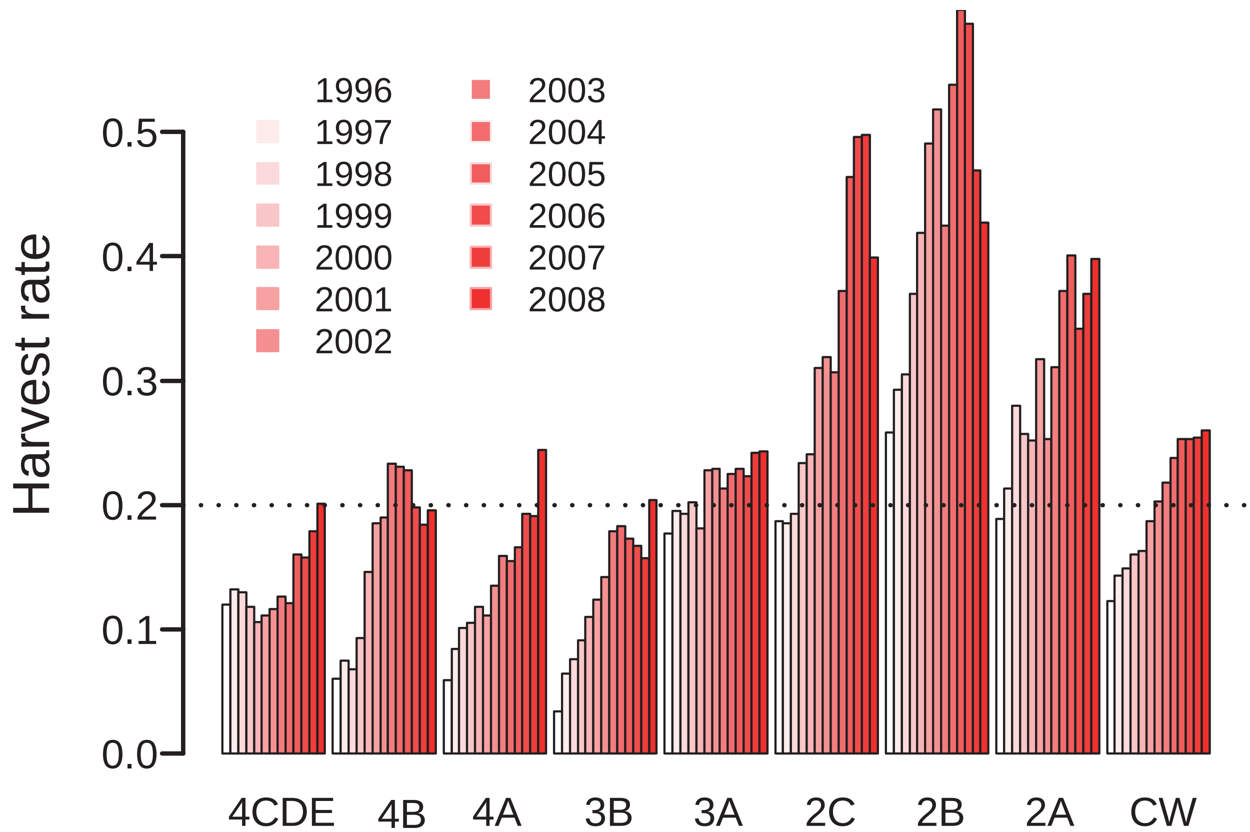


Figure 19. Summary of realized harvest rates from the coastwide assessment, using survey CPUE weighted by hook competition to partition biomass among areas.

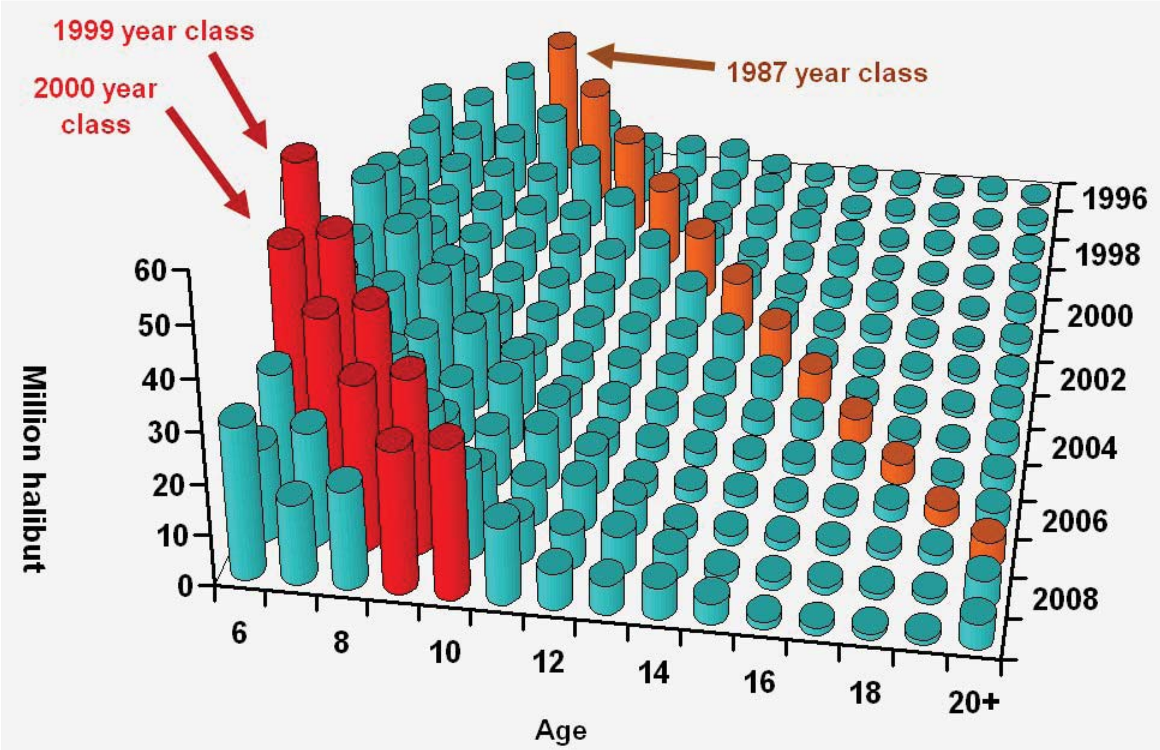


Figure 20. Coast population estimates of halibut. Several large year classes are highlighted.

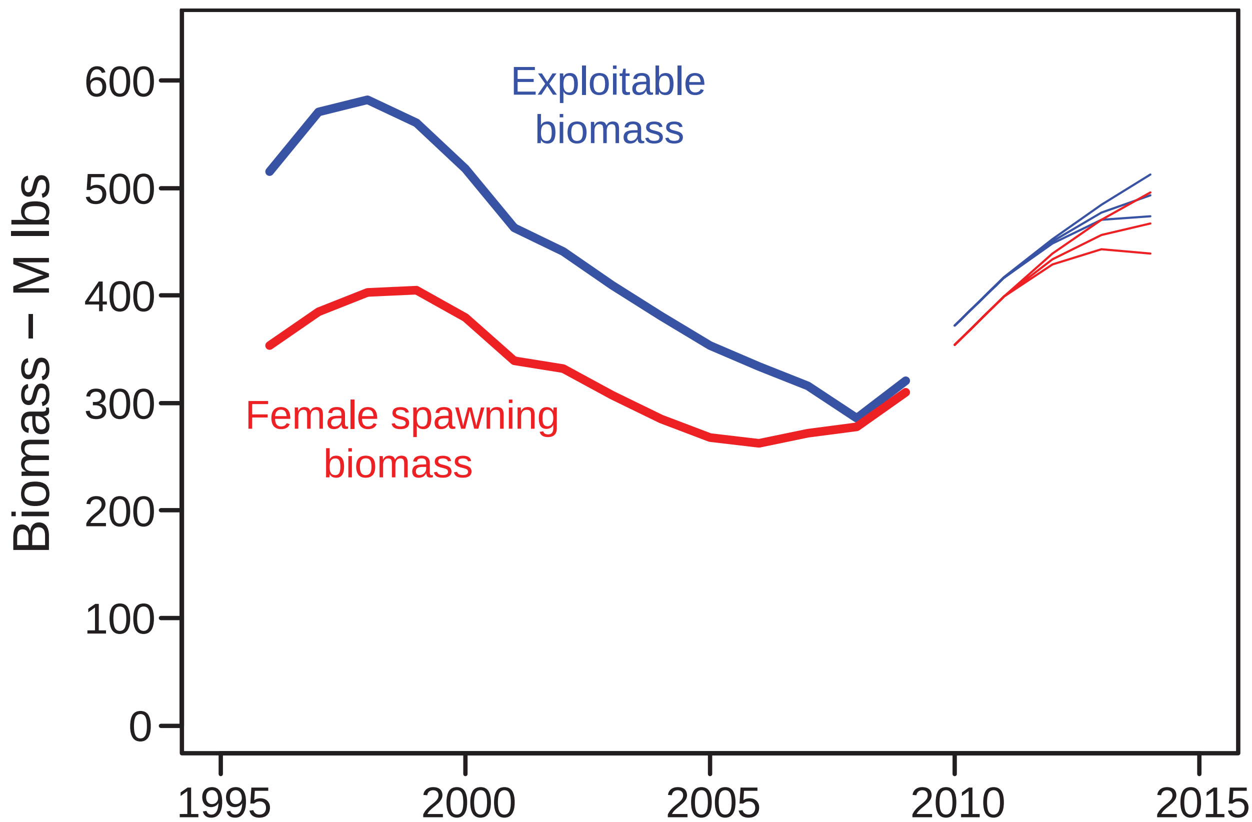


Figure 21. Projected exploitable and spawning biomasses for the coastwide population of halibut.

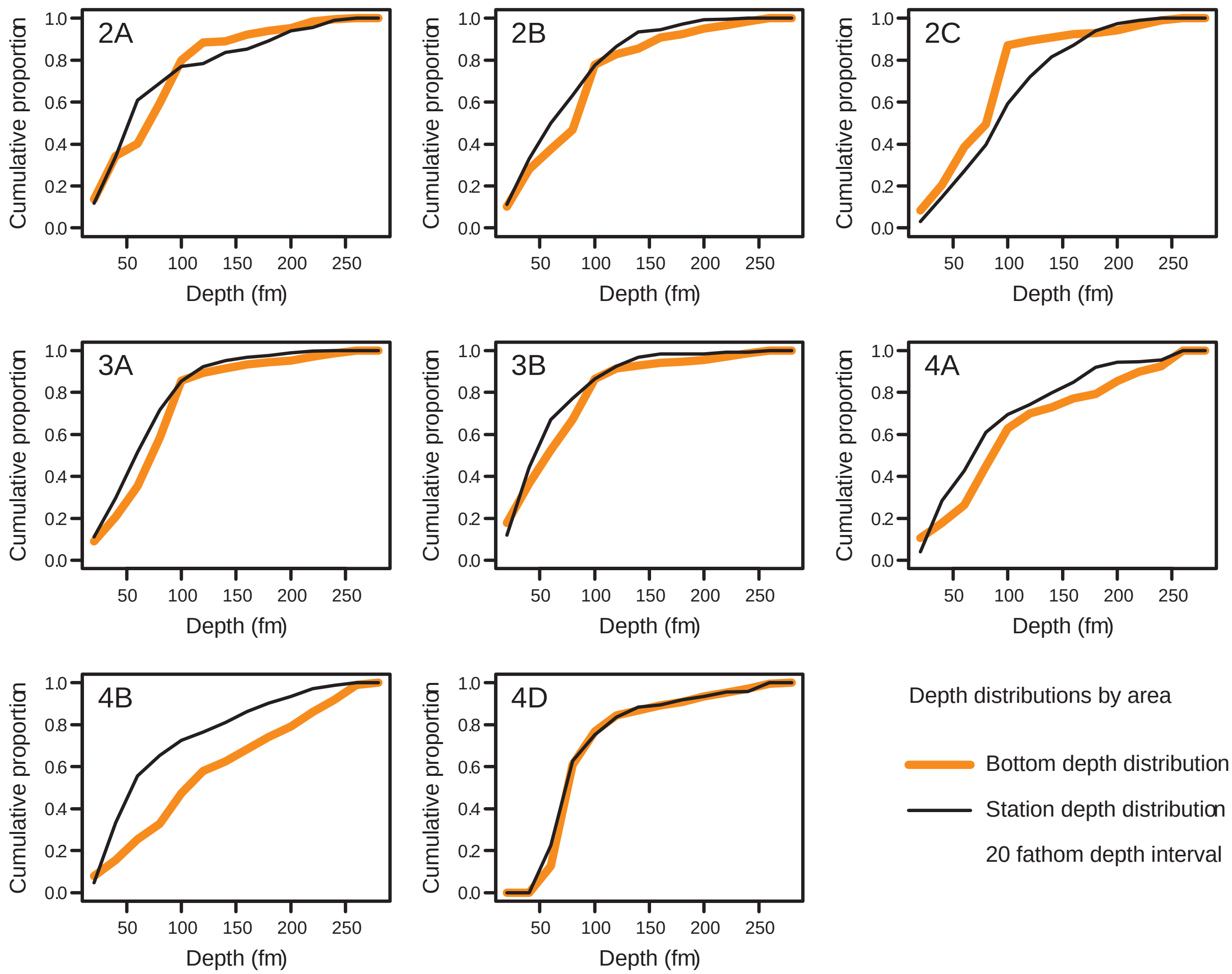


Figure 22. Cumulative distribution of bottom depth and survey station depth by regulatory area.

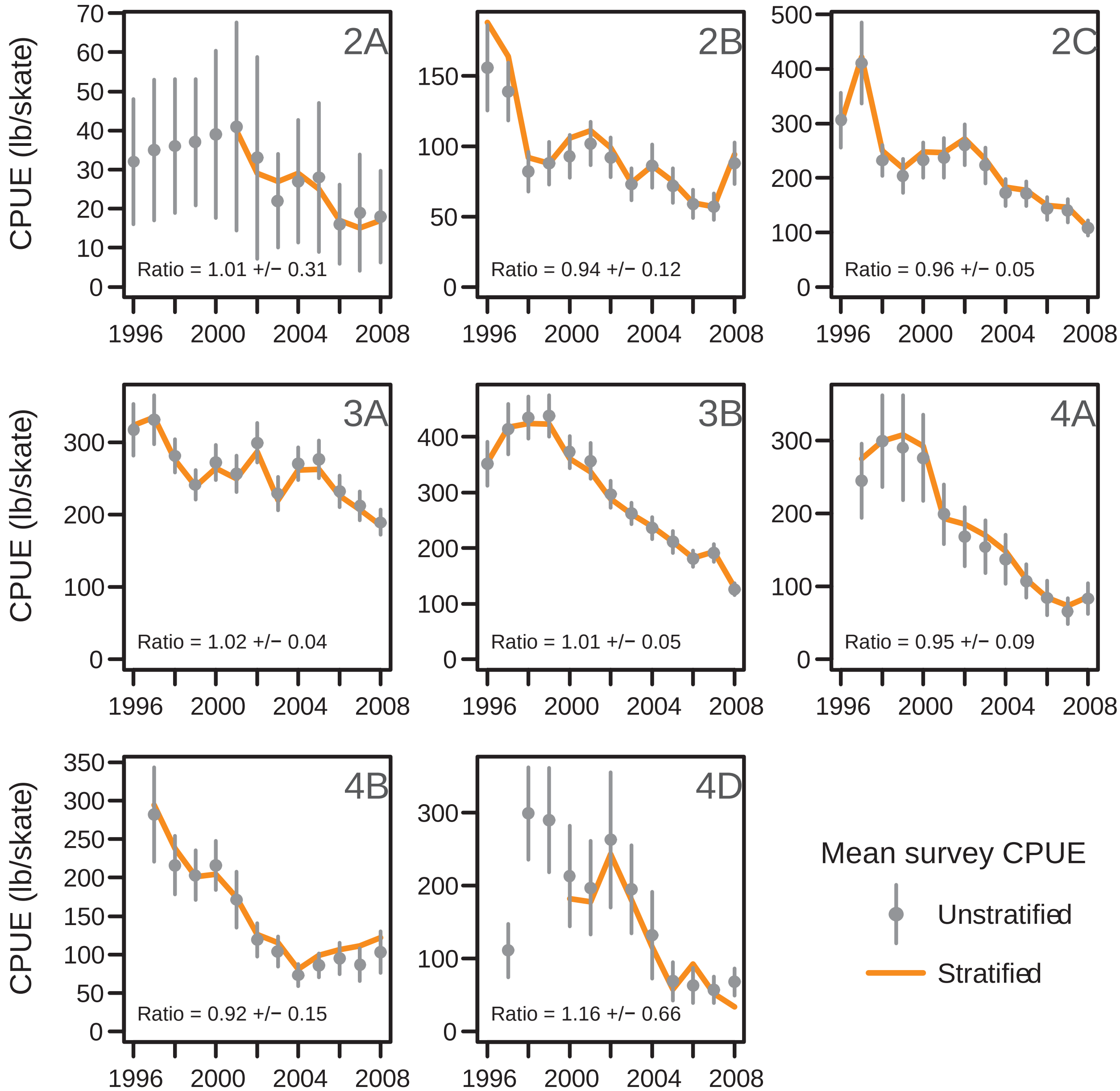


Figure 23. Survey CPUE plotted as simple mean (unstratified, gray dots) and depth-stratified CPUE (yellow line). The errors bars are +/- two standard errors of the mean for the unstratfied mean

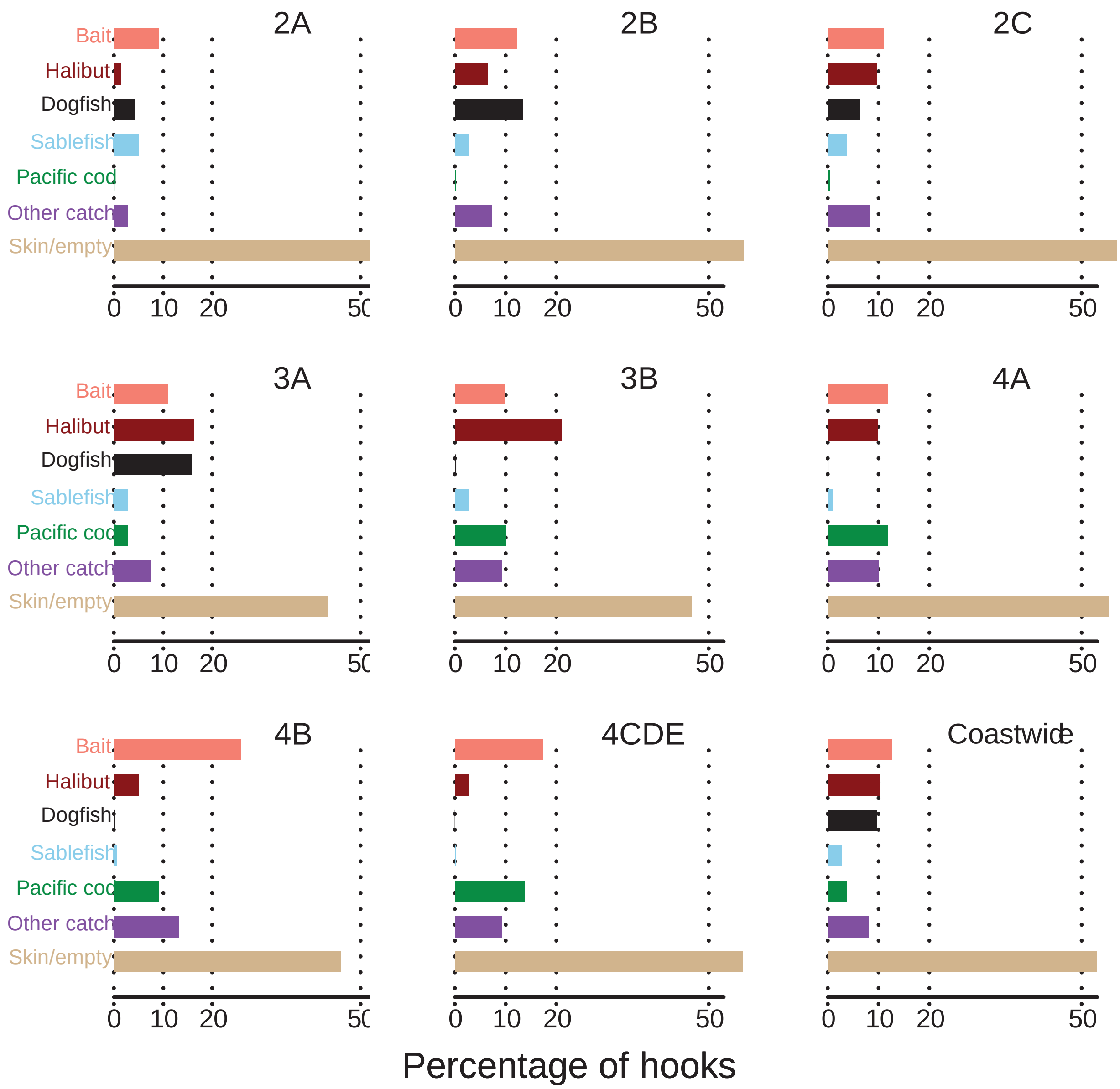


Figure 24. Hook occupancy by regulatory area, 2006-2008 data combined.

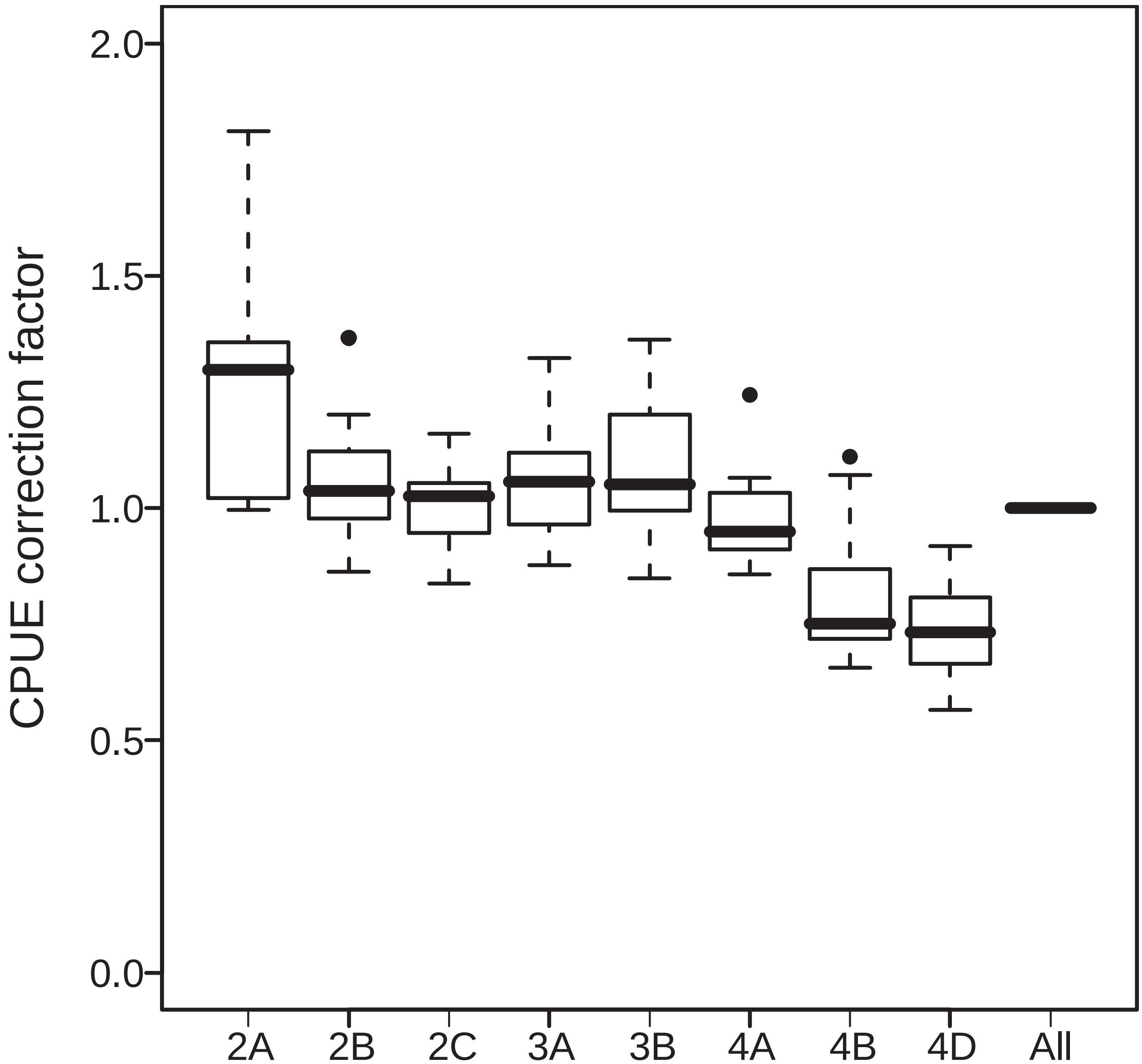


Figure 25. Boxplot of hook competition correction factors for the period 1996-2008. Correction factors were computed for each year of survey data for a maximum of 13 values for any regulatory area.

Area 2A summary

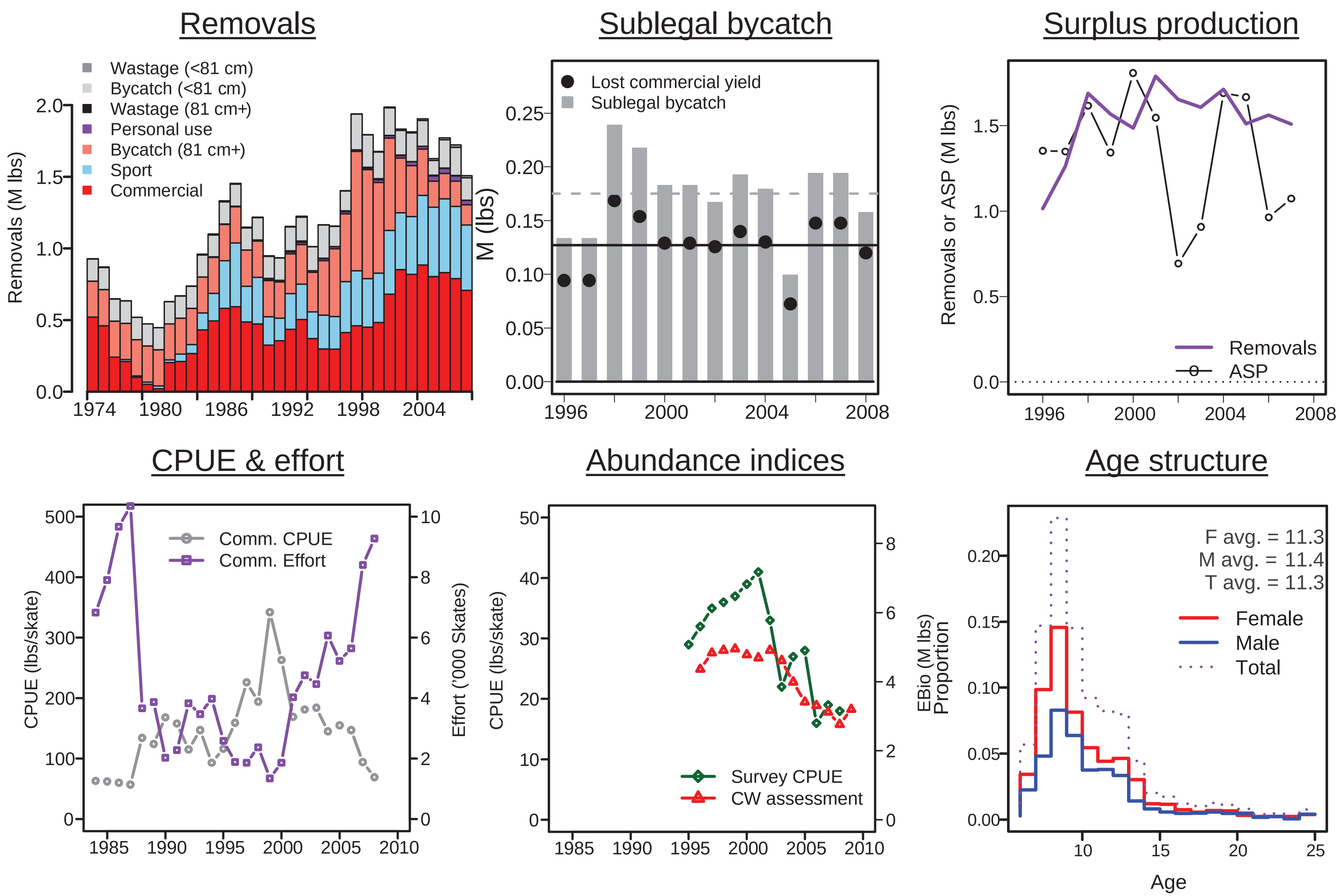


Figure 26. Summary of removals, production, effort, abundance indices and age structure for Area 2A.

Area 2B summary

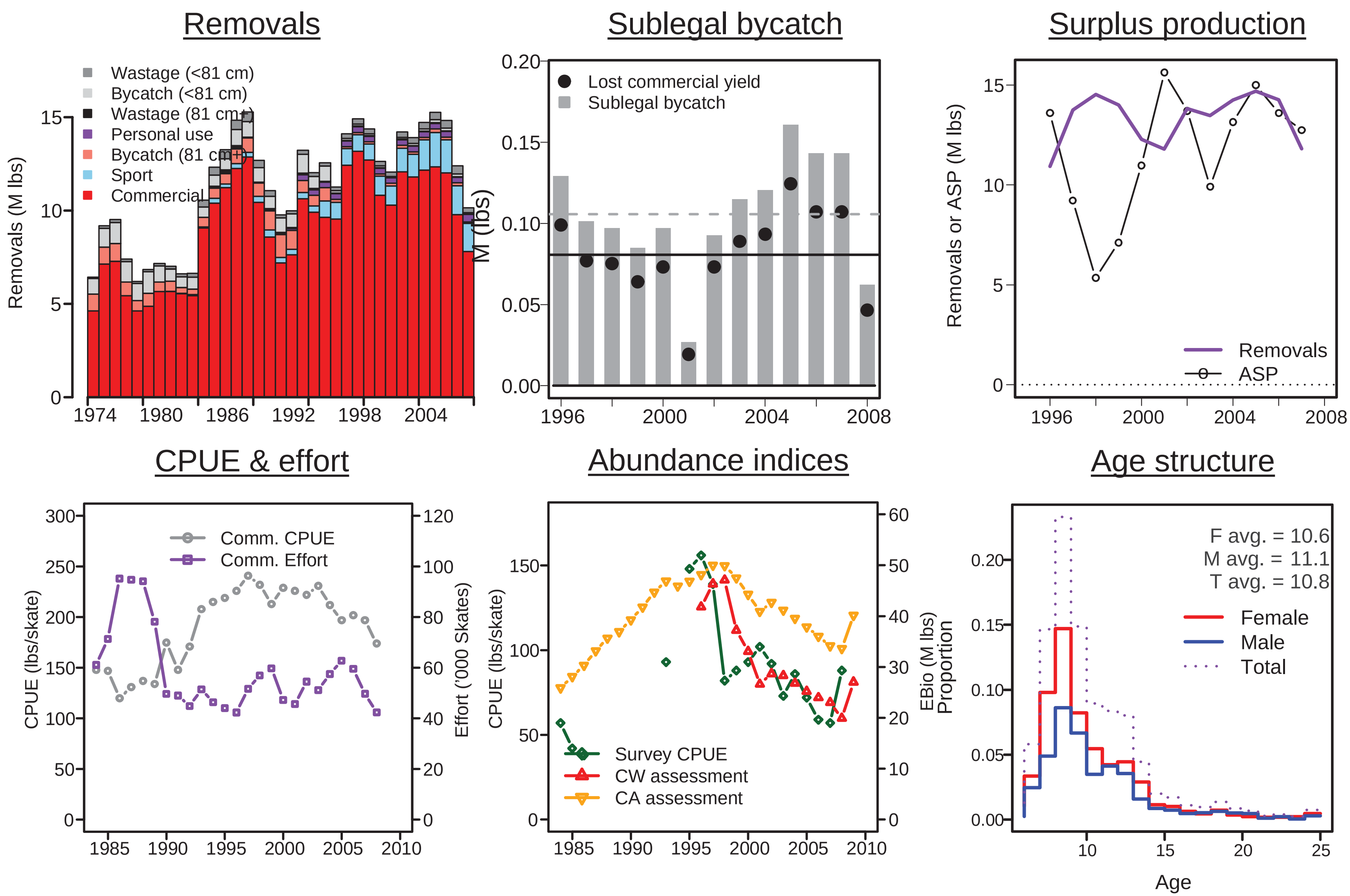


Figure 27. Summary of removals, production, effort, abundance indices and age structure for Area 2B.

Area 2C summary

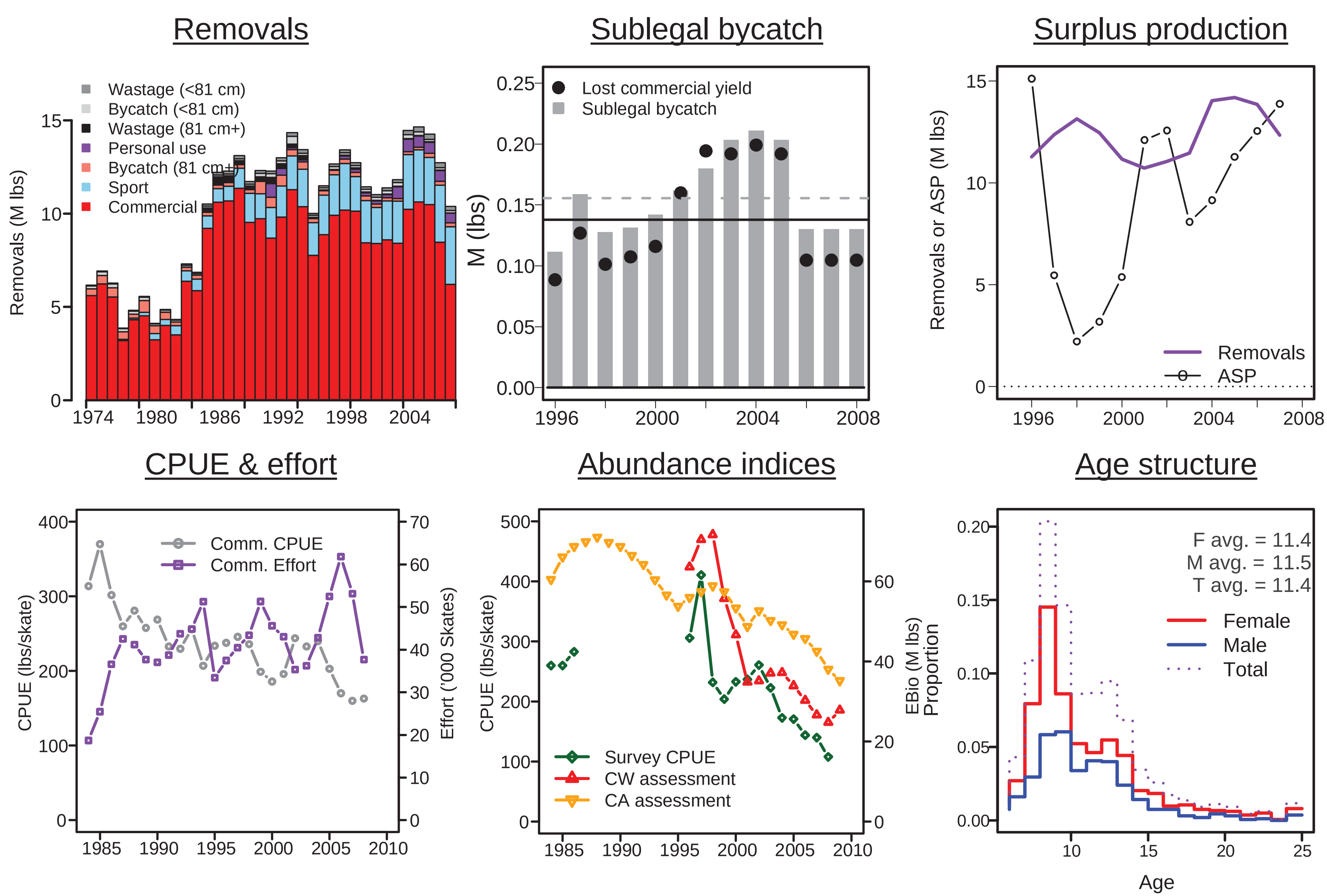


Figure 28. Summary of removals, production, effort, abundance indices and age structure for Area 2C.

Area 3A summary

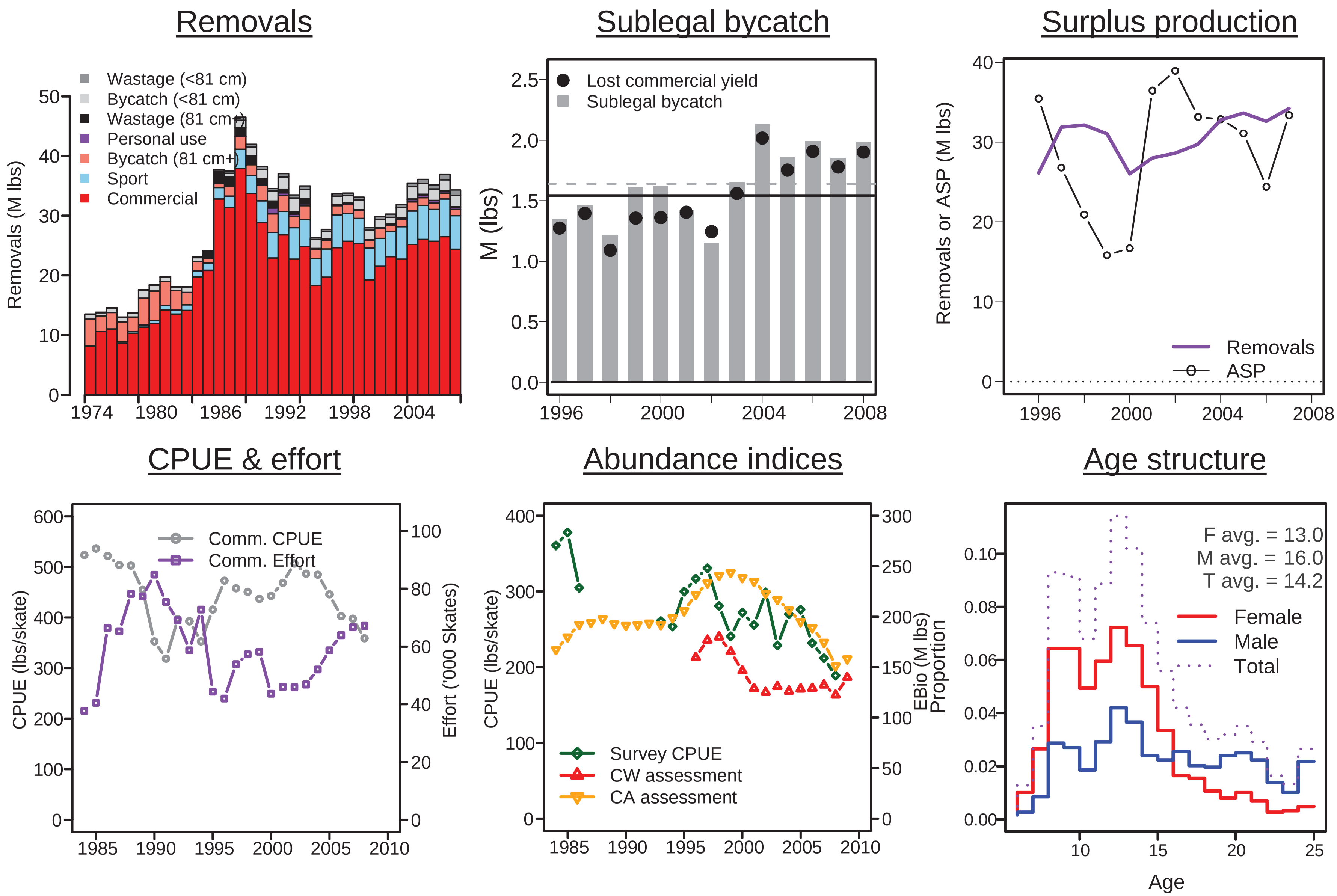


Figure 29. Summary of removals, production, effort, abundance indices and age structure for Area 3A.

Area 3B summary

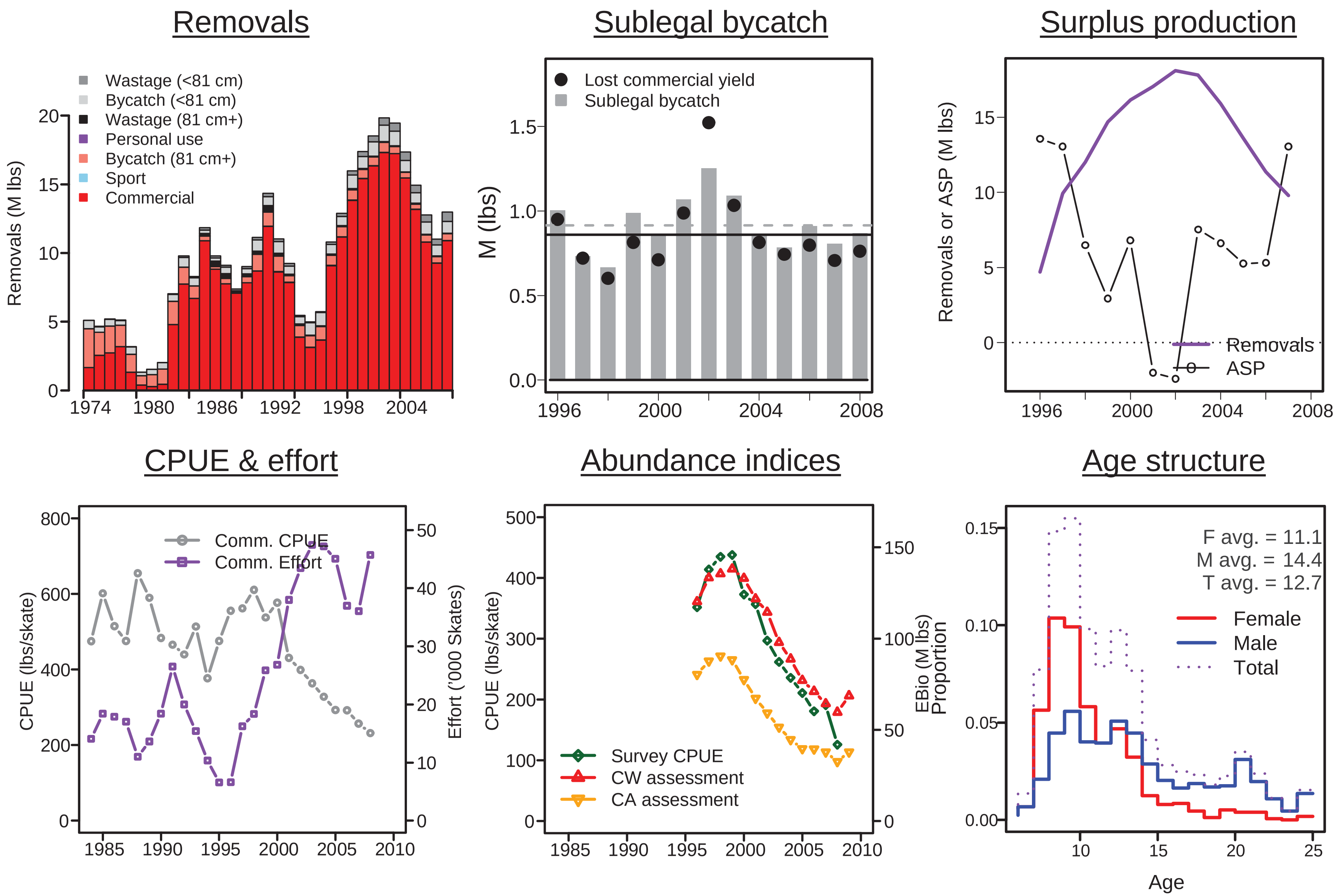


Figure 30. Summary of removals, production, effort, abundance indices and age structure for Area 3B.

Area 4A summary

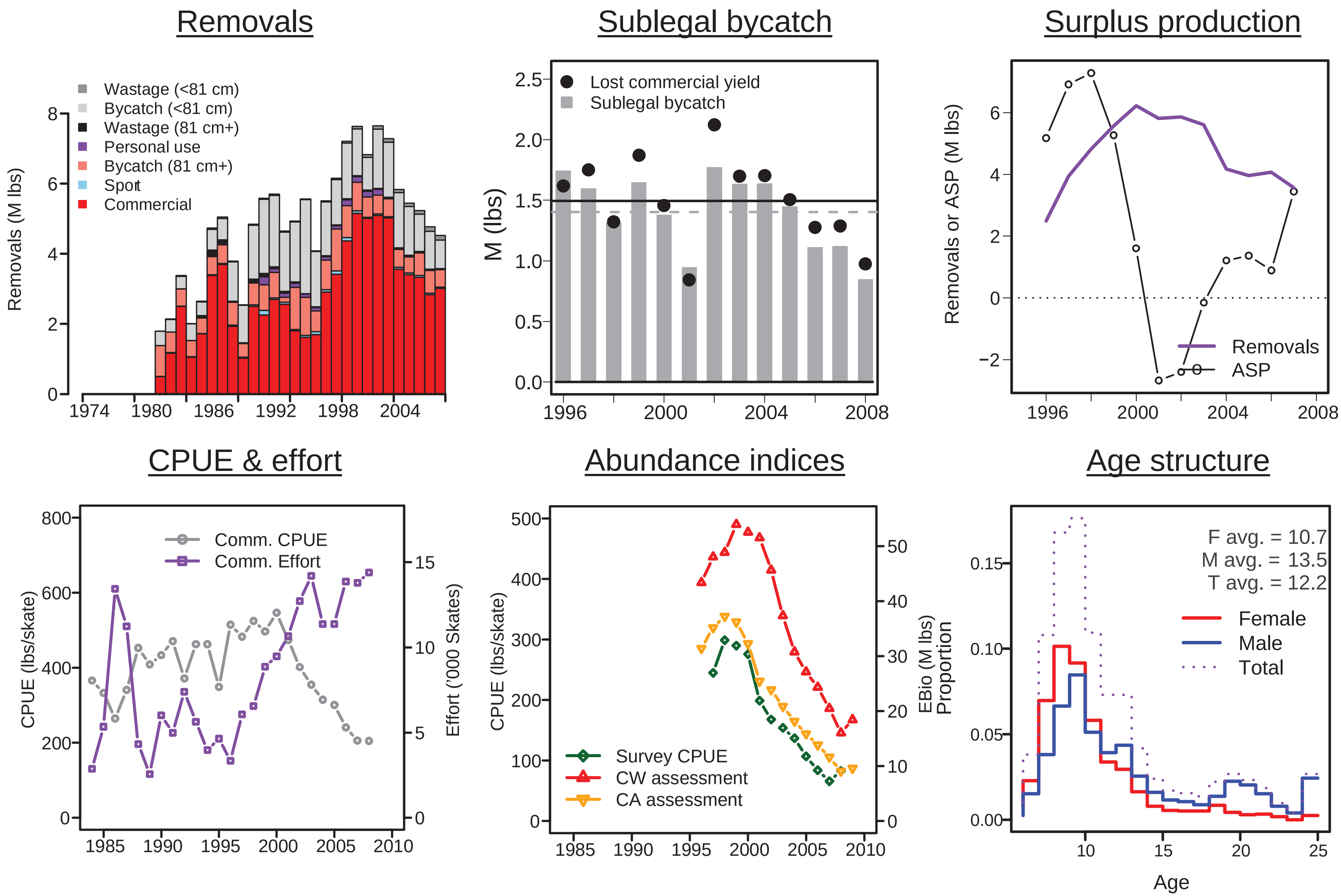


Figure 31. Summary of removals, production, effort, abundance indices and age structure for Area 4A

Area 4B summary

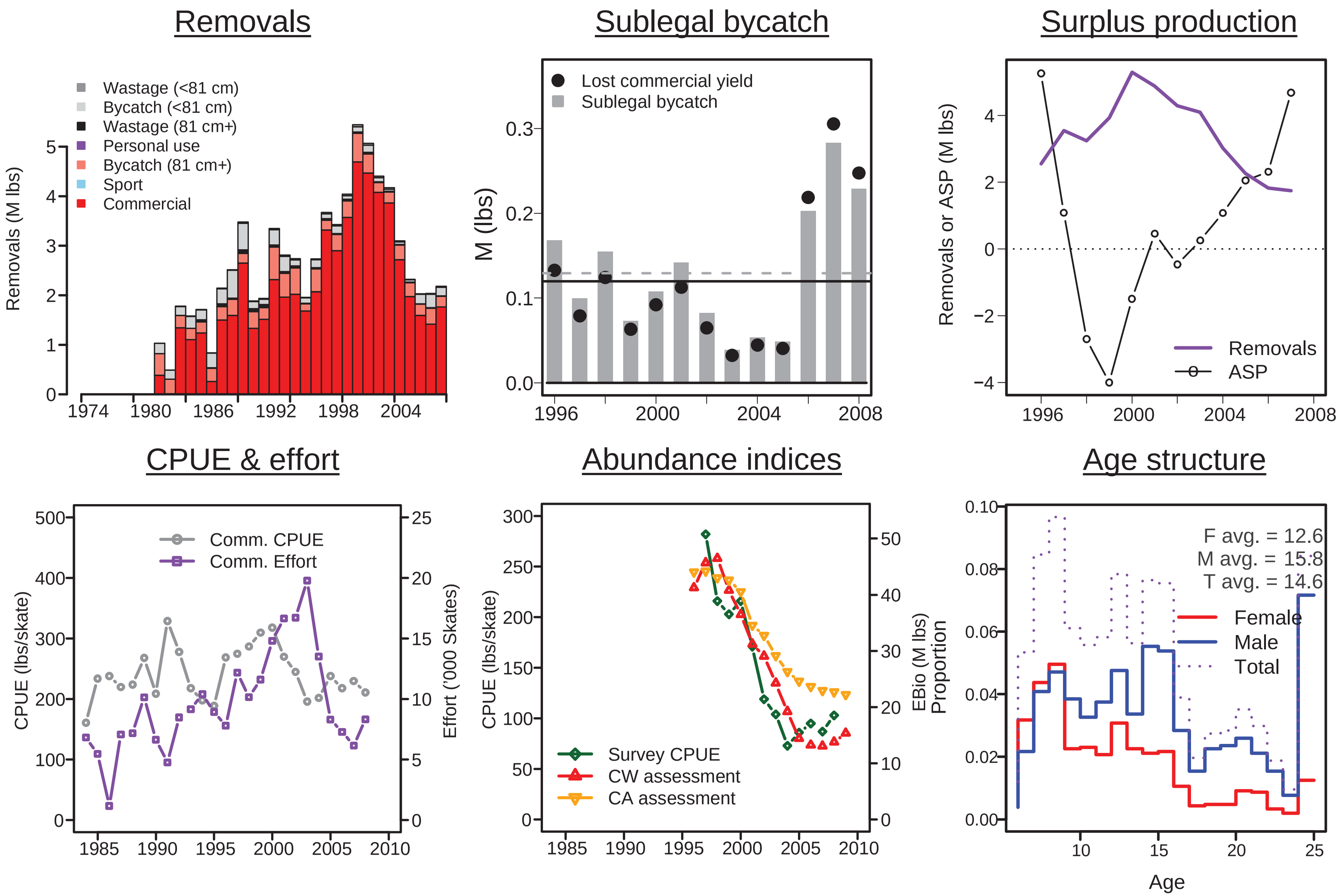


Figure 32. Summary of removals, production, effort, abundance indices and age structure for Area 4B.

Area 4CDE summary

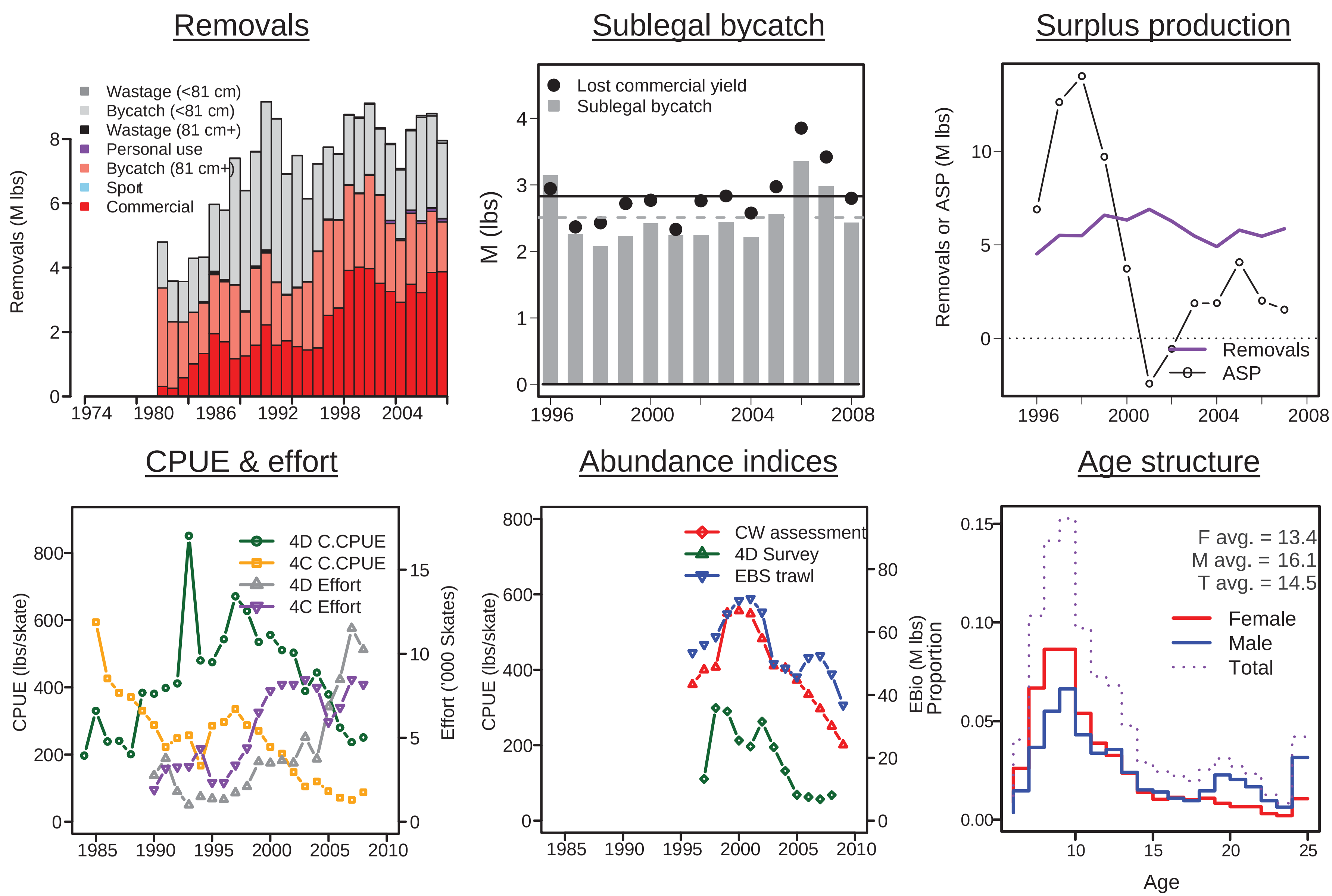


Figure 33. Summary of removals, production, effort, abundance indices and age structure for Area 4CDE.

Appendix A. Selected fishery and survey data summaries.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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