# Historical Coastwide IPHC Stock Assessments: 1998 to 2005 – *Compendium of documents*

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# LIST OF DOCUMENTS FOR THE 1998 TO 2005 HISTORICAL COASTWIDE IPHC STOCK ASSESSMENTS

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# Assessment and management of Pacific halibut: data, methods, and policy

**by**

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# Assessment and management of Pacific halibut: data, methods, and policy

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## Abstract

The International Pacific Halibut Commission (IPHC) sets annual catch limits by regulatory area for the directed halibut fisheries in the northeast Pacific Ocean. Abundance in each area is estimated by fitting an age- and sex-structured population model to commercial and survey data. A biological target for total removals, called the "constant exploitation yield" (CEY), is then calculated by applying a carefully chosen target harvest rate to the estimated exploitable biomass in each area. The catch limits recommended by the staff to the Commission may be somewhat higher or lower than the CEY depending on a number of technical and policy considerations. The Commissioners make the final decision. This paper details the data and the model used in the annual stock assessment (exemplified by the 2004 assessment), summarizes our present understanding of stock dynamics, and describes the constant harvest rate policy.

# Assessment and management of Pacific halibut: data, methods, and policy

**William G. Clark and Steven R. Hare**

## Overview

The aim of this paper is to document the data and methods used by the staff of the International Pacific Halibut Commission (IPHC) in its annual assessment of the abundance and potential yield of the stocks. The focus is on how stock size and productivity are estimated rather than on a particular set of estimates. The 2004 assessment model is described in detail, but only for the purpose of showing the quality and retrospective behavior of some actual fits. There are usually a few minor changes in model parameterization or weighting every year, along with an extra year of data, and the estimates of abundance change from year to year as a result. The most recent annual stock assessment document (posted on the IPHC website) should be consulted for the exact form of the latest model and the latest estimates of stock status.

There are actually two components of the stock assessment. Present abundance is estimated by fitting a modern age- and sex-structured model to survey and commercial data from recent years covered by setline surveys, meaning back to 1974 for the eastern Gulf of Alaska (westward to Kodiak Island) and back to 1996 for areas farther west. In a second step, abundance in the eastern Gulf is estimated back to 1935 by beginning with the modern estimates for 1974 and fitting a simpler model to commercial data for earlier years. We cannot estimate historical abundance for areas west of Kodiak Island because those areas were only lightly fished until the mid-1990s.

In what follows, the first two introductory sections summarize halibut distribution and life history, and the development of the fishery and Commission management. The next two sections describe the various kinds of data used in the modern assessment and how they are compiled and preprocessed external to the assessment model. The next two sections set out the structure of the modern assessment model, how it is fitted to the data, and how well it performs in terms of goodness of fit, retrospective behavior, and variance of the abundance estimates. The next section details the historical model used to estimate abundance in years before 1974. The full series of abundance estimates (and growth data) for the eastern Gulf of Alaska from 1935 to the present are the basis of our analysis of population dynamics, summarized in the penultimate section. These dynamic relationships are used in simulations that guide our choice of a target constant harvest rate and other elements of the Commission's harvest policy, as described in the last section.

## Biological background

Pacific halibut (*Hippoglossus stenolepis*) are widely distributed in coastal waters of the northeast Pacific from central California around the Gulf of Alaska out the Aleutian Island chain and into the Bering Sea, with a center of abundance around Kodiak Island (Fig.1). About 2% of the biomass is off Oregon and Washington, about 15% off British Columbia, and the remainder off Alaska. The species also occurs on the Asian side, but this paper deals only with North American waters where halibut are studied and managed by the International Pacific Halibut Commission.

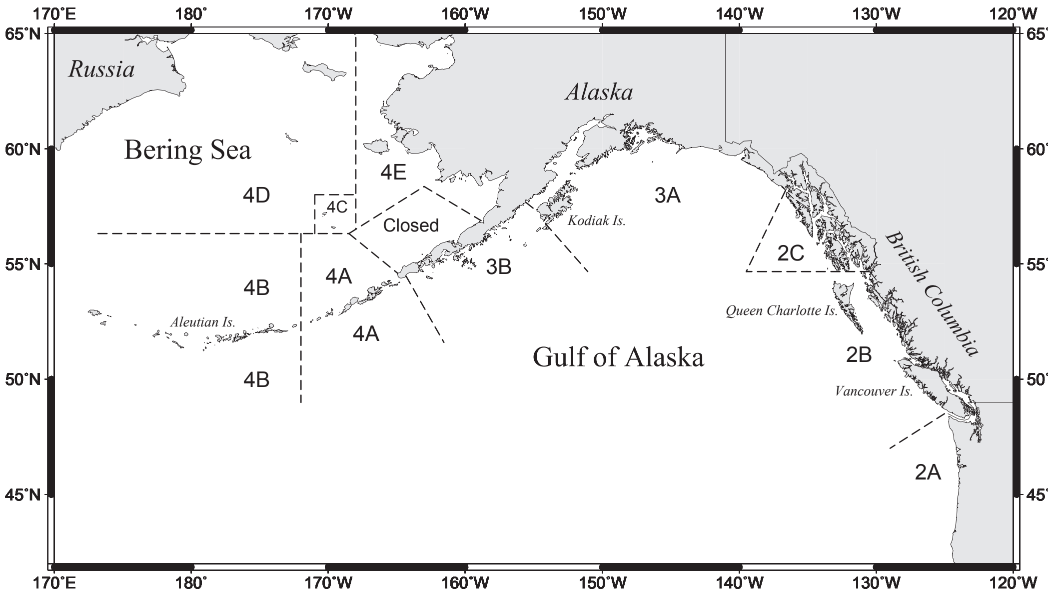


**Figure 1. IPHC regulatory areas.**

In summer halibut are distributed on the continental shelf and upper slope. In winter mature fish migrate to spawning grounds deeper on the slope (IPHC 1998). The eggs, larvae, and postlarvae drift in the currents for about six months before settling out and metamorphosing to the flatfish form. This drift generally transports fish spawned in the Gulf of Alaska westward, with the result that the major nursery grounds are in the western Gulf and Bering Sea, and few very young fish are found east of Kodiak Island. Stocks in the eastern Gulf of Alaska are replenished by juvenile fish that migrate eastward from the western nursery grounds (Skud 1977, St-Pierre 1989, Clark and Hare 1998). Recoveries of fish marked in summer at lengths over 65 cm (6-7 years old) are mostly made near the release location, indicating that by that age fish have completed the migration from the nursery grounds and thereafter occupy the same summer feeding ground year after year (Trumble et al. 1990). Recoveries of mature fish marked in winter are often made some distance away in summer, however, showing that some fish undertake a substantial spawning migration in winter. The fish off Oregon, Washington, and most of British Columbia in particular must migrate north to spawn because there are no significant spawning grounds south of the Queen Charlotte Islands (St-Pierre 1984).

Genetic studies in the past using protein electrophoresis have shown differences between halibut stocks on the eastern and western sides of the North Pacific, and also between Atlantic halibut (*Hippoglossus hippoglossus*) and Pacific halibut, but no differences within the northeast Pacific (Grant et al. 1984). Further research on this question is being conducted with modern methods (Hauser et al. 2006). For the time being we regard the halibut in the northeast Pacific as a single spawning stock. Separate catch limits are set for each of the regulatory areas shown in Figure 1, and we sometimes speak of e.g. the “Area 3A stock”, but these are management stocks rather than biological stocks. The setting of catch limits by regulatory area serves to allocate the harvest among areas (and between the United States and Canada) more or less in proportion to abundance.

Female and male halibut both grow to a length of about 60 cm at age 6. Thereafter females grow faster and reach substantially greater sizes. All really large halibut are females. The modal length in commercial landings is around 100 cm. As explained below in the section on stock dynamics, growth rates of both sexes have varied greatly over the last century (Clark and Hare 2002). Females reach sexual maturity at an average age of 11 years, males somewhat earlier. A few fish older than 40 years have been observed in samples, but over 90% of the commercial catch consists of fish 7-20 years old.

## Fishery and management background

Aboriginal peoples in North America have fished halibut for thousands of years. Commercial longline fisheries based in Seattle and Vancouver developed shortly after the completion of the first transcontinental railroads to those cities late in the nineteenth century. In the early years of the twentieth century the fishery went through the classic boom-and-bust cycle. Fishing effort and catches increased rapidly at first, then catch rates dropped, and eventually the total catch peaked and declined as well, despite the continuing increase in fishing effort (Thompson and Freeman 1930, Bell 1981). The industry in both countries petitioned the governments for relief, and in 1923 they signed a convention establishing the International Fisheries Commission (renamed the International Pacific Halibut Commission in 1953) to conduct biological studies and recommend management measures. The first Director of the Commission, W. F. Thompson, was a giant in the history of fishery science who in a few short years both collected the data and developed the methods needed to assess the stock and determine what level of catches could be sustained (Thompson and Bell 1934). He recommended to the governments that the Commission be authorized to define regulatory areas, set catch limits, and adopt other regulations. The governments gave their assent in a new convention signed in 1930, and the Commission commenced quota management in 1932.

The stock and the fishery recovered under Commission management in the 1930s and fared well until the 1960s under the operation of Thompson's principles (Fig. 2). During the 1960s distant-water trawl fleets arrived in the northeast Pacific and took a large bycatch of halibut (Williams et al. 1989). Recruitment to the halibut stock in these years was poor (very possibly because of the trawl bycatch of juveniles). The Commission was slow to reduce catch limits in the directed longline fishery because under current international agreements the coastal states were obliged to demonstrate "full utilization" of the halibut stock to ward off a directed distant-water fishery. As a result of all these developments the stock declined steeply during the 1960s and by the early 1970s had fallen back to the low level reached previously in the early 1930s. Faced with this crisis, the Commission acted resolutely. Catch limits were drastically reduced and for a decade were kept below the estimated surplus production in order to rebuild the stock.

Once again the lowered catch limits were effective. Thanks in part to a regime shift in the climate of the North Pacific in 1977 that approximately doubled recruitment (Clark and Hare 2002), the stock rebounded in the late 1970s and early 1980s. In 1984 the Commission declared the stock rebuilt and adopted a constant harvest rate policy for setting catch limits, which has continued to the present. Each year the staff estimates abundance in each regulatory area by fitting a population model to commercial and survey data going back to 1974. A biological target level for total removals in each area is calculated by applying a carefully chosen target harvest rate to the estimate of exploitable biomass. This biological target level is called the "constant exploitation yield" or CEY. Part of the total yield is set aside to provide for miscellaneous removals (e.g., bycatch in other fisheries, sport and subsistence catches in Alaska). The remainder is available for directed fisheries subject to allocation, which are the commercial longline fisheries in all areas and the sport fisheries in Areas 2A and 2B. This amount is called the "fishery CEY." Staff catch limit recommendations may be lower or higher than the calculated fishery CEY depending on the Director's assessment of the uncertainties and risks involved in each regulatory area. The Commissioners make the final decision. at the annual meeting in January after considering the recommendations of the staff, the industry and the two governments' scientific advisers.

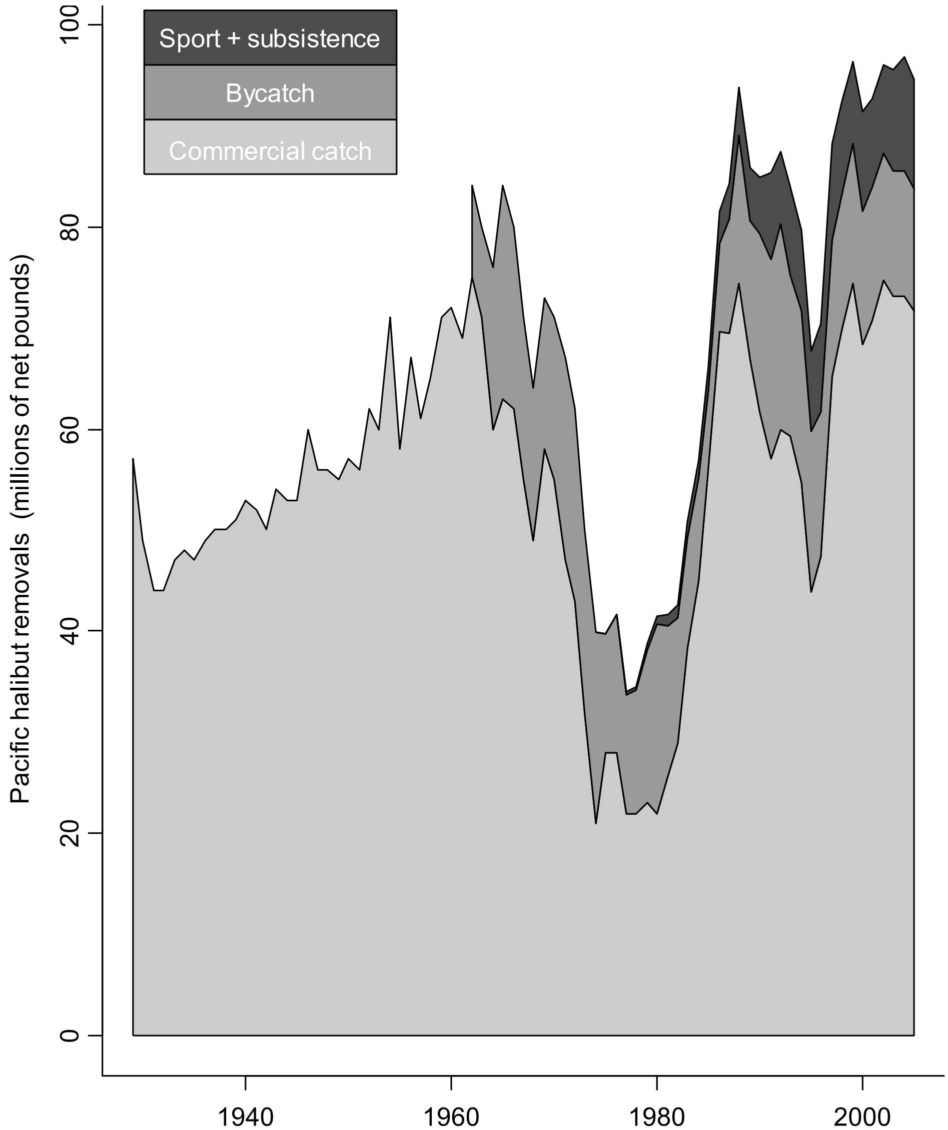


**Figure 2. Removals of Pacific halibut from all IPHC areas, 1929-2005. The bycatch figures refer to bycatch mortality and include sublegals. There are no estimates of bycatch before 1962; it was probably a few million pounds per year in the late 1950s and negligible before 1955.**

During most of the twentieth century Canadian and U.S. halibut boats fished coastwide, and about half the catch in Alaska waters was taken by Canadian vessels. When both countries extended their maritime jurisdiction in 1976, Canadian vessels were expelled from U.S. waters and vice versa. Canada carried out a buyback program to reduce its fleet to a size more appropriate for the yield available from Canadian waters, but it was still larger than needed. In Alaska a flood of new vessels entered the fishery. In both countries the fishing seasons grew shorter and shorter during the 1980s, to only a few days in most areas. These years are remembered as the "derby fishery" and not fondly. The fishery was hectic, chaotic, and dangerous, and fish quality suffered. Canada adopted an individual quota system in 1991 which eliminated the problems associated with the derby fishery and allowed vessel owners to fish more efficiently and profitably. Alaskans who had adamantly opposed individual quotas were quickly won over by the Canadian example, and an individual quota system was adopted for Alaska in 1995. Today the derby fishery survives only in Washington and Oregon.

The bycatch of halibut by distant-water fleets was brought under strict control after Canada and the United States extended jurisdiction in 1976, but bycatch has remained a contentious issue between the halibut fishery and other domestic fisheries, particularly the groundfish trawl fisheries. It has also been a contentious issue between Canada and the United States because the large trawl bycatch of juvenile halibut in Alaska (mainly in the Bering Sea) must include some fish that would otherwise migrate to Canada and recruit to the fishable stock there. Lacking detailed knowledge of juvenile distribution and migration, it is not possible to make good estimates of the area-specific impacts of the bycatch of different sizes of halibut in different parts of Alaska. Simulation studies using a range of assumptions indicate that the impact falls mostly but not entirely in the area where the bycatch is taken. At present there is a two-part process for dealing with bycatch in calculating fishery CEY. The bycatch of fish above the commercial minimum size limit (81 cm), which have presumably completed their juvenile migration, is deducted from the total CEY in the regulatory area where they are caught. The coastwide recruitment loss resulting from sublegal bycatch—estimated to be about 10%—is included in the simulations that are conducted to choose a target harvest rate. It therefore depresses the target harvest rate slightly in all areas, but the choice of an optimum harvest rate is not at all sensitive to this factor. This method of accounting for juvenile bycatch therefore finesses the uncertainty about unequal and unknown area-specific impacts of juvenile bycatch (Clark and Hare 1998).

## Assessment data

The annual stock assessment uses data from commercial landing reports, commercial logbooks, port sampling of commercial landings, IPHC setline surveys, and fishery agencies in both countries that report estimates of bycatch, sport catch, and subsistence catch. This section describes each data type.

### Commercial fishery data

The weight of every commercial landing is recorded on a sales report (fish ticket), a copy of which is sent to the IPHC. The total catch in weight in every regulatory area in every year is known from this reporting system. The weight reported is net weight, meaning headed and gutted weight which is about 75% of round weight. Curiously, this measure of weight is used throughout in halibut assessment and management, so for example estimates of biomass in the sea are stated in net weight not round weight. In 2004 commercial landings totaled 73 million (net) pounds.

IPHC port samplers collect additional information on commercial fishing trips and catch composition. They are stationed in about a dozen ports in Washington, British Columbia, and Alaska that collectively account for the majority of landings from every regulatory area. For as many trips as possible, port samplers record the areas fished, amount of gear set and hauled, and catch by copying the skipper's logbook or interviewing the skipper. These records are combined with fish ticket data to calculate commercial catch per unit effort (CPUE) in each area.

Port samplers also obtain a carefully chosen random sample of (presently) about 1500 fish from each regulatory area, from which the length and age composition of the commercial landings can be estimated (Clark 2006a, Clark et al. 2000). From 1963 through 1990, in order to save money, the lengths of fish in the sample were not actually measured but predicted from a regression of body length on otolith size (Clark 1992a), which complicates the assessment in some ways. Since 1991 samplers have measured the lengths.

## Setline survey data

Except for a hiatus in the years 1987-1992, IPHC has conducted systematic setline surveys since 1977, with both the frequency and coverage of surveys increasing over the years. Before 1996, no surveys were done in Areas 3B and 4. Since 1997, most areas have been surveyed in their entirety nearly every year. In recent years survey stations have been placed on a square 10 nautical mile (nmi) grid covering the entire continental shelf between 20 and 275 fathoms (fm). Between four and eight standard skates (100 baited hooks each) have been set at each station. Figure 3 shows the survey stations fished successfully in Area 3B in 2004. All halibut in the catch are measured, and a random sample (of target size 2000 per area) is collected for age, sex, and maturity determination.

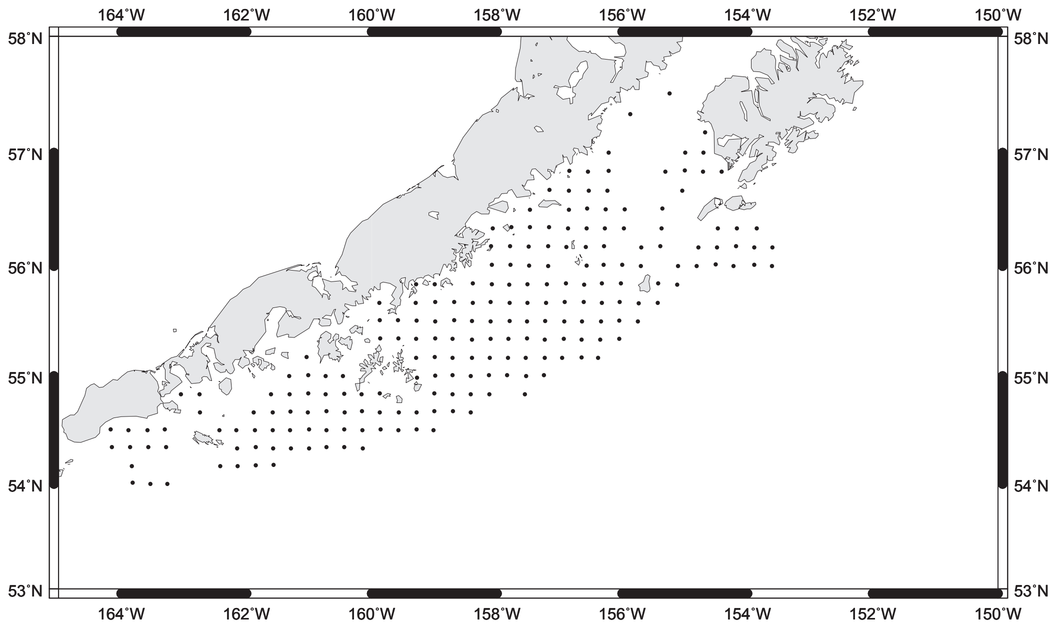


**Figure 3. IPHC setline survey stations in Area 3B in 2004. Some sets in the eastern part were ineffective due to heavy shark damage.**

## Bycatch estimates

Halibut taken as bycatch in other groundfish fisheries must be returned to the sea, and a proportion of them die in the process. Both Canada and the United States place observers aboard fishing vessels to estimate the amount and length composition of the halibut bycatch, and to assess the condition of halibut before being discarded. These condition factors are used to predict mortality. The bycatch estimates available for the assessment are therefore estimates of bycatch mortality in number by length; no age data are collected.

Bycatch varies greatly among regulatory areas in both amount and size composition (Fig. 4). In Areas 3 and 4 where there are large trawl fisheries and large numbers of juveniles, the bycatch is large and has a modal length around 50-60 cm. In Area 2 where there is less trawling and fewer juveniles, the bycatch is much smaller and has a modal length of 70-80 cm. In 2004 bycatch mortality totaled 12 million (net) pounds (Williams 2005a), about evenly divided between fish larger and smaller than the commercial minimum size limit (81 cm).

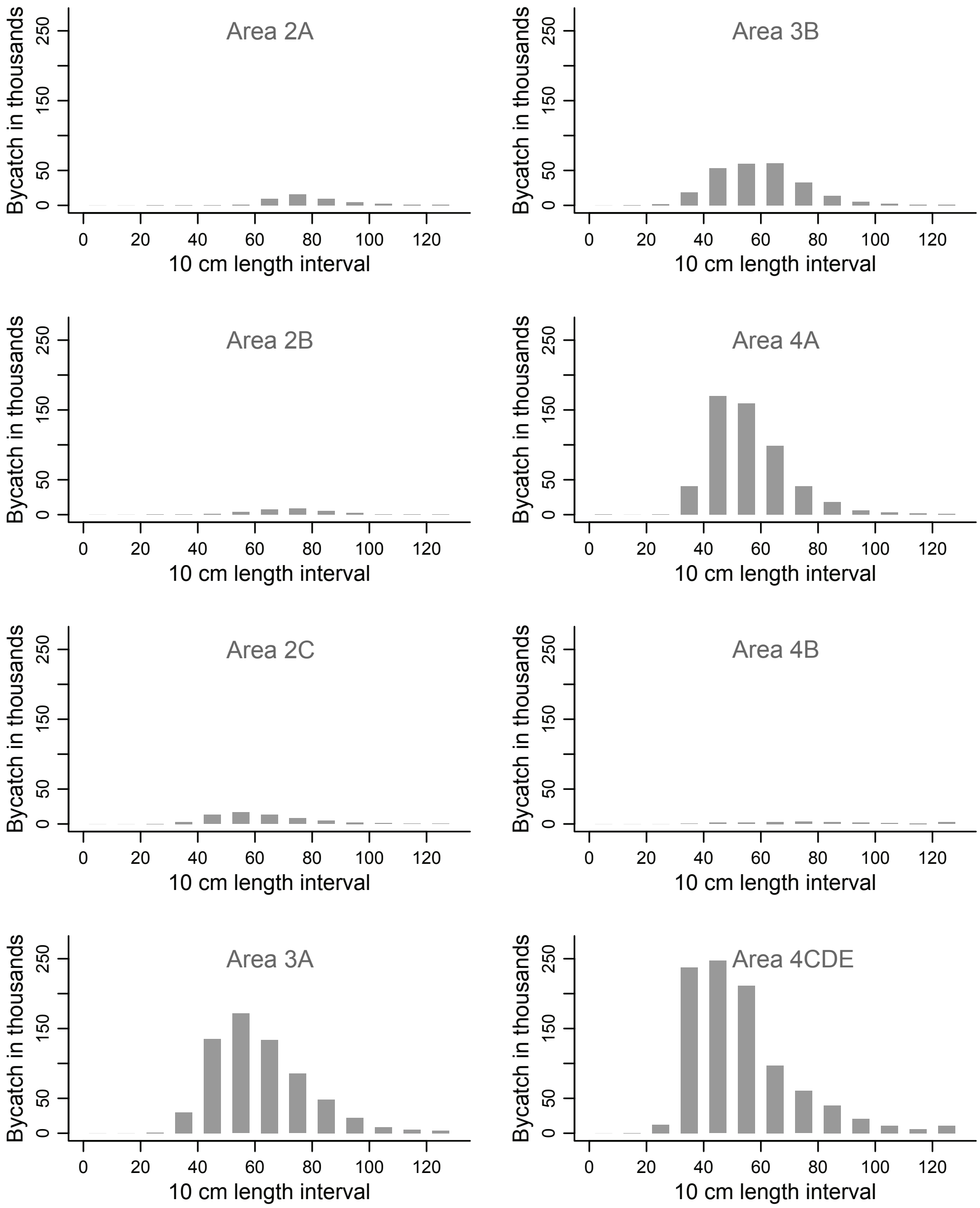


**Figure 4. Bycatch in number by 10 cm length interval by regulatory area in 2004.**

## Sport catch estimates

There are substantial sport fisheries in Areas 2 and 3A. Sport catches in U.S. waters are estimated in various ways by the states of Oregon, Washington, and Alaska. The Canadian Department of Fisheries and Oceans (DFO) estimates the British Columbia sport catch. Length frequency data are available for most but not all jurisdictions; age samples only from Alaska. The length frequencies of sport catches are very similar to the length frequencies of IPHC setline survey catches (Fig. 5). In 2004 sport catches totaled nine million (net) pounds (Blood 2005). Fish below the 81 cm commercial size limit made up about 30% of the sport catch in number but only about 10% in weight.

## Subsistence catch estimates

Both Canada and the United States authorize some fishing for subsistence or personal use apart from sport fishing. The catches in weight are reported but no length or age data are collected. Because these are all hook-and-line fisheries, they are assumed to have length frequencies similar to IPHC setline survey catches, like the sport catches. In 2004 subsistence catches totaled 1.4 million (net) pounds (Williams 2005b).

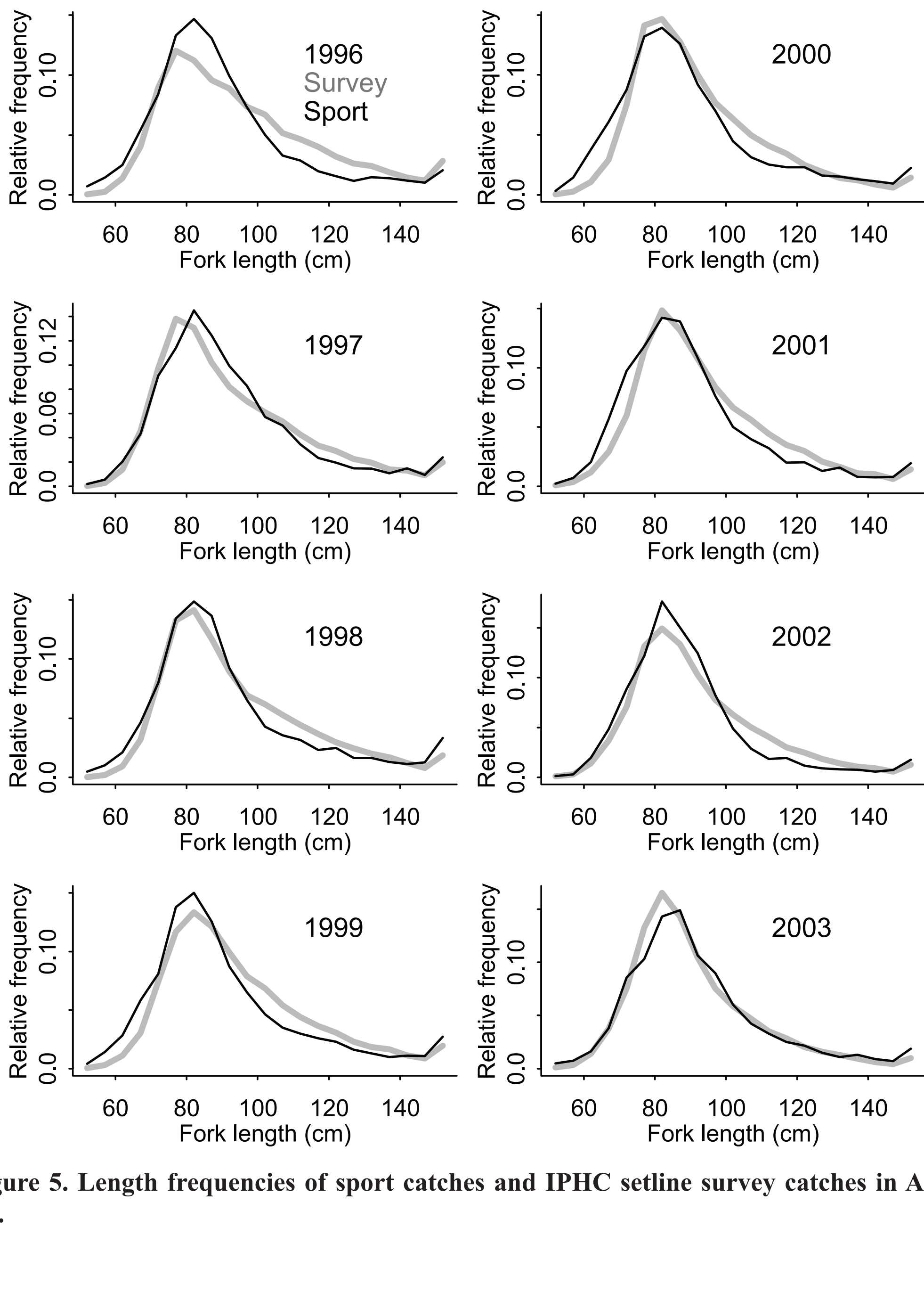


**Figure 5. Length frequencies of sport catches and IPHC setline survey catches in Area 3A.**

## Data compilation and preprocessing

### Commercial data selection

Commercial setline gear consists of a long, stout groundline with baited hooks on 1-4 ft gangions (leaders) attached at 5-20 ft intervals. The gangions can be permanently tied to beckets on the groundline, in which case the gear is called fixed-hook or just fixed; or they can be attached with snaps each time the groundline is set and removed when it is hauled back, in which case the gear is called snap-hook or just snap. In controlled experimental sets fixed and snap gear have equal catch rates (Myhre and Quinn 1984), but in the commercial fishery fixed gear generally has higher catch rates.

In almost all areas the assessment uses only fixed-hook commercial CPUE, for the following reasons:

(i) To avoid variations in commercial CPUE due to changing proportions of fixed and snap effort.

(ii) Because fixed-hook data are available back to the beginning of the fishery, whereas snap gear did not appear until the 1950s.

(iii) Because the spacing of hooks on snap gear can be quite variable, which means that the average hook spacing recorded in logbook data is imprecise. This complicates the hook spacing adjustment (explained below).

The exception to this rule is Area 2B, where at present the great bulk of the catch is taken with snap gear. Fortunately this is also the area where the relationship between fixed and snap CPUE is most consistent, with fixed CPUE being close to 135% of snap CPUE year after year (Clark 2002a). Both kinds of gear are used in the Area 2B assessment, with snap CPUE scaled up by 1.35.

### Setline survey data selection

The early survey data (before 1993) have some features that require care in compiling a time series; these are explained in Appendix A. Generally all survey data are used in the assessment, except in Area 2B where only the area north of Cape Scott (containing about 90% of the Area 2B abundance) is consistently surveyed. Where extensions of the survey within areas have changed average CPUE (Clark 2002b), that effect is estimated within the assessment model (as a change in survey catchability) rather than being estimated externally and used to adjust the raw data.

### Hook type and hook spacing adjustments

The commercial fishery switched from J-hooks to much more effective circle hooks (C-hooks) in 1983; the survey followed suit in 1984, when both hook types were fished. The 1984 survey data showed that C-hook catchability was more than twice that of J-hooks and that length-specific selectivity was also different (Sullivan et al. 1999, Appendix 1). In the IPHC database all of the J-hook effort—commercial and survey—is divided by 2.2 to make the J-hook catch rates comparable with C-hook catch rates. That adjustment is removed when the assessment data are compiled so that the assessment uses raw J-hook data and estimates the hook change effect separately for commercial and survey CPUE in each regulatory area. The reason for doing that is to allow for differences among areas and between commercial and survey CPUE in the effect of the hook change. The 1983 commercial data contain an unknown mixture of hook types and are not used in the assessment.

Setline CPUE is also affected by hook spacing, with catch per hook generally increasing with spacing (distance between hooks). Hamley and Skud (1978) conducted experiments using J-hook gear and spacings in the range 10-40 ft, and found that catch per hook at a spacing of $H$ ft was $1.52 \cdot \left(1 - \exp\left(-0.06 \cdot H\right)\right)$ times catch per hook at a spacing of 18 ft (Fig. 6). Recent


**Figure 6. The hook spacing adjustment applied to survey and commercial CPUE**.

analysis (Clark 2006b) has shown that this formula describes the effect of hook spacing in the present-day commercial fishery quite well. This adjustment is incorporated in the data stored in the IPHC database and used in the assessment without change. The adjusted catch per hook is also multiplied by 100 so that the effort data in the database all refer to a 100-hook skate with 18 ft spacing, called an effective skate.

## Estimation of the catch at age

The weights of fish in the commercial sample in each area/year are estimated from their lengths using a length-weight relationship (Clark 1992b). The mean weight of fish in the catch is estimated as the mean weight in the sample, and the number of fish in the catch as the reported weight of landings divided by the mean weight. The catch at age is estimated by applying the age composition of the sample to the total catch in number.

## Estimation of the sex composition of commercial landings

Because females are larger than males and commercial selectivity is determined by length, females and males are distinguished in the assessment model. The sex composition of the survey catches is observed and recorded, but fish in the commercial catch are eviscerated at sea, so port samplers cannot determine sex when they sample the landings. For the assessment, the sex composition of the landings at each age, and the size composition of females and males at each age in the landings, are estimated from survey catches in the same area and same year (or close to it). Details are given in Appendix B. This procedure limits the assessment in each area to those years with survey data. In Areas 2 and 3A the assessment can be extended back to 1974; in Areas 3B and 4 only to 1996.

## Estimation of age misclassification

Ages of sampled fish are determined by reading their otoliths (Forsberg 2001). Before 2002 surface readings were done, and these tended to underestimate the ages of fish older than 12 years. Since then all otoliths have been broken and burned, which gives more accurate readings.

In addition to being biased, surface readings have a large variance. The assessment model incorporates a misclassification matrix to predict the observed surface age compositions from the calculated true age compositions. This step is called "smearing" the true age compositions because the effect of age reading error is to redistribute some of the fish of each age group to neighboring ages. A second misclassification matrix is used to account for the effect of the much smaller variance of break-and-burn readings on observed age compositions beginning with 2002. Details are given in Appendix C.

## Estimation of size at age

In the assessment model, setline selectivity is treated as a function of observed mean size at age by sex in setline survey catches. This is not the true mean size at age in the stock because the gear selects for larger fish, but it can be used as an alternative size metric to predict selectivity at age. Survey data are used because the sexes are distinguished and the catches include fish below the minimum commercial size limit of 81 cm. Size at age has decreased greatly since the mid-1980s (Fig. 7).

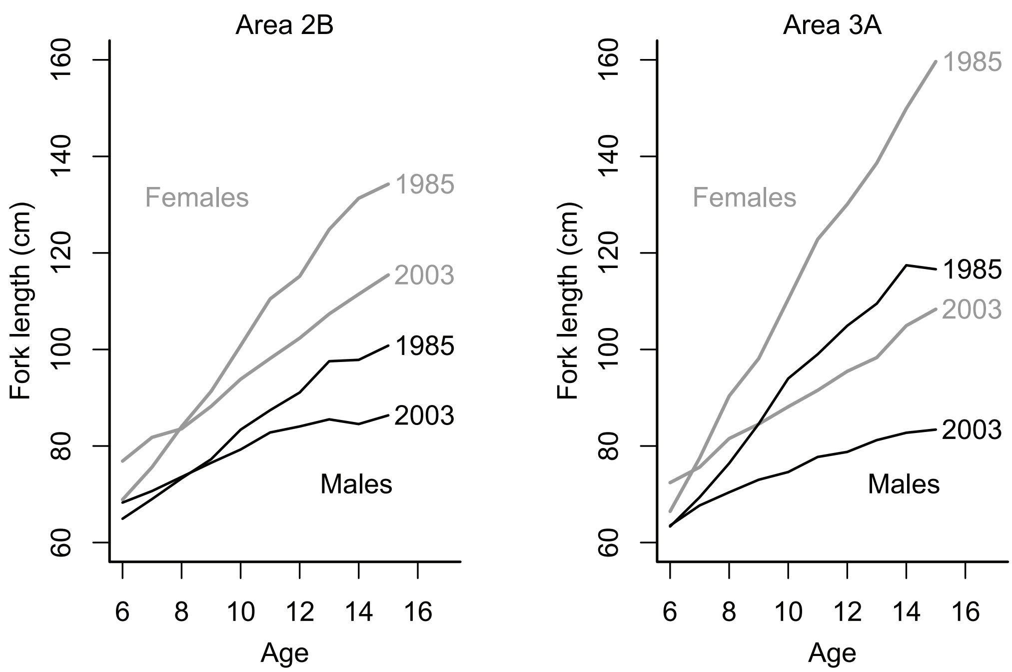


**Figure 7. Mean length at age in IPHC setline surveys, by sex, in 1985 and 2003**.

Survey data are used to estimate mean weight at age/sex in the survey and in the sport and subsistence fisheries (needed for fitting to reported catches in weight). Mean weight at age/sex in the commercial landings is estimated from the commercial data, broken down by sex as described above.

Estimates of the mean and standard deviation of size at age by sex in the bycatch are also needed for fitting the observed bycatch at length, which is mostly taken in trawl fisheries. Fish younger than age 6 are rare in setline catches, but trawl fisheries catch many younger fish. Among age groups that appear in both setline and trawl catches, mean size at age is lower in trawl than setline catches. The values of size at age/sex in the bycatch are based on NMFS trawl survey data. For ages 1 though 6, the values are the same for females and males and they are:

| | Age 1 | Age 2 | Age 3 | Age 4 | Age 5 | Age 6 |
|---|---|---|---|---|---|---|
| **Mean length (cm)** | 15 | 25 | 35 | 45 | 52 | 59 |
| **Standard deviation (cm)** | 3.0 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 |
| **Mean weight (net lb)** | 0.05 | 0.20 | 0.80 | 1.70 | 2.65 | 3.90 |

The observed trawl survey values are used in the assessment for ages 1-5. For ages 6+, the mean and standard deviation of length at age/sex in the bycatch are 90% of the age/sex-specific setline survey values, and mean weight is 80% thereof. These multipliers are based on regressions of trawl values on setline survey values in areas and years that had both kinds of survey data. They allow the distribution of size at age in the bycatch to be estimated from setline survey data in areas where there are no trawl survey data.

Because of the bias in surface readings, size at age data are inaccurate for older fish through 2001. In order to have a consistent series for predicting selectivity in the assessment, an adjusted set of size at age estimates is calculated that attempts to correct for the underestimates of age in surface readings. It is not entirely successful in that even the adjusted series show some discontinuities in size at age between 2001 and 2002, but mainly among older and larger fish that are mostly or fully selected anyway.

### Estimation of sampling variances

A non-zero sampling variance is estimated for every data point to which the assessment model is fitted, the main types being commercial catch at age/sex, commercial CPUE, survey age/sex composition, and survey CPUE. The rules used are:

(i) A multinomial variance is calculated for proportions at age: $\hat{V}(\hat{p}) = \hat{p} \cdot (1-\hat{p})/n$, where $n$ is the sample size for that area/year.

(ii) If a sample proportion is zero, a variance is calculated with $\hat{p} = 0.005$.

(iii) The setline survey stations fished in a given area/year are treated as a simple random sample, and the mean and standard deviation of catch per skate are calculated with the standard formulas. This must overestimate the variance to some extent because the stations are placed systematically.

(iv) Commercial CPUE in a given area/year is assigned a coefficient of variation (CV) of 0.05, based on the scatter of year-to-year values about a data smoother. The amount of logbook data is normally so large that sampling variance in the strict sense is practically nil.

(v) The estimated proportion female in a given area/year/age stratum (Appendix B) is also assigned a CV of 0.05, also based on the scatter of data points about the fitted logistic curves.

(vi) The estimated number of fish in a given 5 cm length interval in the bycatch $\hat{B}_l$ is assigned a CV of $10/\sqrt{\hat{B}_l}$, on the grounds that the unknown underlying sample sizes are on the order of 1% of the bycatch.

## Assessment methods

IPHC has set catch limits on the basis of quantitative stock assessments since 1932. In the early years the rules came from the pioneering work of Thompson and Bell (1934). Since 1982 the annual assessment has consisted of fitting an age-structured model to commercial (and later survey) data, a procedure developed at the Commission (Deriso et al.1985) and later adopted by most agencies in North America. Clark (2003) provides a history of the staff's modeling work.

At present a separate model fit is done for each regulatory area except Area 2A and Area 4CDE (Fig. 1), which are handled differently as explained at the end of this section. The area-specific model fits assume that the fish in each regulatory constitute a closed population; i.e., that there is no immigration or emigration among fish that have reached catchable size (60-80 cm). Historical marking data support this view (Trumble et al. 1990), but some doubts have been raised by recoveries of passive integrated transponder (PIT) tags from an experiment that is in progress at time of writing (Clark 2006c). If it turns out that there is significant net migration among areas, it may become necessary to enlarge the scope of the assessment, but that would not entail a change in the methods or model.

## Evolution of present assessment methods

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

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

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

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

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

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

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

The fit of this model to Area 3A data in 2002 showed a dramatic retrospective pattern, similar to the pattern of successive CAGEAN fits in the mid-1990s. Treating setline survey selectivity as length-specific rather than age-specific largely eliminated the pattern, just as freeing up age-specific commercial selectivity had improved the retrospective behavior of CAGEAN. Accumulated data showing very similar trends in CPUE 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.

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 is 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.

## Treatment of natural mortality

An age-structured assessment model estimates the size of each year-class by back-calculating the sum of all removals from it, including commercial catches, other directed catches, bycatch, and natural deaths. The natural deaths can be a large fraction of the total removals, so the natural mortality rate used in the calculations has a large effect on estimates of absolute abundance.

Natural mortality rates are notoriously difficult to estimate directly. Early halibut catch curve analyses gave estimates of the instantaneous natural mortality rate (*M*) ranging from 0.15 to 0.25 with an average around 0.20 (IPHC Staff 1960). Myhre (1967) estimated total mortality from tagging experiments and then obtained area-specific estimates of *M* by regressing total mortality on fishing effort. His estimates were around 0.30, which he considered unrealistically high. All of these estimates are questionable because they rely on equilibrium assumptions that probably did not hold. Chapman et al. (1962) stated that any value in the range 0.15-0.20 would be consistent with the available data, and Myhre (1974) accordingly opted for a value of 0.175 when doing the calculations to locate an optimum minimum size limit.

An age-structured assessment model will usually provide equally good fits for a wide range of natural mortality rates, so in practice the analyst has to pick a value outside the assessment and use that in the model calculations for better or worse. That was (and still is) the case for the halibut assessment, and during the 1980s and most of the 1990s the staff resolutely used the value 0.20.

Clark (1999) analyzed the effects of an erroneous estimate of natural mortality on yield recommendations when the same erroneous estimate is used both in the stock assessment where absolute abundance is estimated and in the dynamic fishery simulations where an optimum harvest rate is chosen. He found that the yield recommendations were quite robust to error in the estimate of natural mortality, but that the cautious policy was to select a value toward the low end of the plausible range. The working value in the assessment was therefore lowered to 0.15 in 1998, and there it has remained.

Recently Lester et al. (2004) formulated a simple energetic model of growth and reproduction and from that derived equations for the age at maturity *T* and gonadosomatic index *g* (gonad weight as a proportion of somatic weight) that maximize fitness given the rate of natural mortality *M* and the age intercept $t_1$ of a linear function $L_t = h_1 \cdot (t - t_1)$ describing length at age $L_t$ during the years before the age of maturity. These equations can be inverted to estimate the natural mortality rate of halibut from the observable parameters *T, g,* and $t_1$. Unlike other predictors of natural mortality based on life history parameters, this procedure does not depend in any way on empirical relationships between life history parameters and published estimates of natural mortality in various stocks that are themselves highly questionable. For halibut, a straight line through the origin represents juvenile growth quite well, so $t_1 \approx 0$. The age at maturity of females has remained at eleven years despite large changes in size at age (Hare and Clark 2005). The gonadosomatic index of halibut is about 0.18 (Schmitt and Skud 1978). Lester et al. (2004) found that $(T - t_1) \approx 1.95 / (e^M - 1)$, implying $M = 0.163$ for halibut. They also found that $g \approx 1.18 \cdot (1 - e^{-M})$, implying $M = 0.165$. These estimates are purely theoretical and not at all precise, but they do provide some reason for believing that the working value $M = 0.15$, while uncertain, is not so far the true value that the yield recommendations are wrong.

## Present model structure

The assessment model is a conventional age-structured model. The parameters estimated are numbers at age in the first year (1974 in Areas 2 and 3A, 1996 elsewhere), subsequent recruitments, survey catchability and selectivity, commercial catchability, and selectivity and annual fishing mortality rates for all fisheries (commercial, sport, subsistence, and bycatch). The model calculates abundance and catches for ages 1-30+, with age 30+ being the plus group where all older fish are accumulated. It predicts commercial catch at age, total commercial CPUE in number and weight, survey age composition, total survey CPUE in number and weight, bycatch in number at length, and sport and subsistence catch in weight. These predictions refer to true age compositions. They are multiplied by an age misclassification matrix (Appendix C) to predict the observed age compositions, which are influenced by bias and variance in the age readings. The predictions are calculated for ages 1-20+ for years with surface ages (through 2001) and for ages 1-25+ for recent years with break-and-burn ages because that is how the data are tabulated. Carrying the model calculations out to age 30+ assures that the effect of age misclassification is properly accounted for in predicting the observed numbers in and near the plus group in the data.

### *Modeling of catchability*

Catchability coefficients are estimated for the commercial fishery and the setline survey for the purpose of predicting the respective CPUE series. Changes in catchability over time are allowed by a flexible system of waypoints and paths that can provide a piecewise linear approximation of any trajectory. For each CPUE series, a catchability coefficient can be estimated for each of a specified set of years—the waypoints. In an Area 3A assessment, for example, separate commercial catchabilities could be estimated for 1974 (the first year in the data, when the fishery used J-hooks exclusively), 1984 (the first year of pure C-hook fishing), and every four years thereafter (1988, 1992, …). During the years between waypoints, the path of the catchability coefficient can be either flat or interpolated. If flat, the catchability stays at the value of the initial waypoint until the next waypoint and then changes abruptly. This would be appropriate for the 1974-1982 period of J-hook fishing before the abrupt change in hook type in 1983. If the path is interpolated, the catchability is interpolated between the waypoint values. This would be appropriate to describe the gradual, continuous changes in commercial selectivity beginning in 1984 as a result of technological changes, derby fishing, individual quotas, etc. The chosen waypoints and path types determine a catchability coefficient for every year in the data series. The actual estimates (Fig. 8) show the large increase in catchability that resulted from the change to C-hooks in 1984, the gradual decline in catchability during the derby fishery of the later 1980s and early 1990s, and the increase in catchability after the adoption of individual quotas in 1995. Because the survey follows a standard protocol, survey catchability is assumed to be constant apart from the effect of changing to C-hooks in 1984.

### *Modeling of selectivity*

The setline selectivity of an age/sex group in a given fishery in a given area/year is modeled as a function of its observed mean length in setline survey catches (or trawl catches for bycatch). Instead of a parametric function, the model fits a piecewise linear approximation by estimating selectivity at 10 cm intervals from 60 to 130 cm and interpolating between them (Fig. 9). The value at 60 cm is used below there, and the value at 130 cm is used above there. This sort of function can assume a variety of forms, and it can be constructed so as to have a prescribed form. The options available in the model are:

(i) Asymptotic, with selectivity simply set to one at and after a specified length (i.e., selectivity is fixed not estimated at those lengths). Commercial setline selectivity is modeled this way.

(ii) Domed, with selectivity set to one at a specified length and required to decrease monotonically on either side of it.

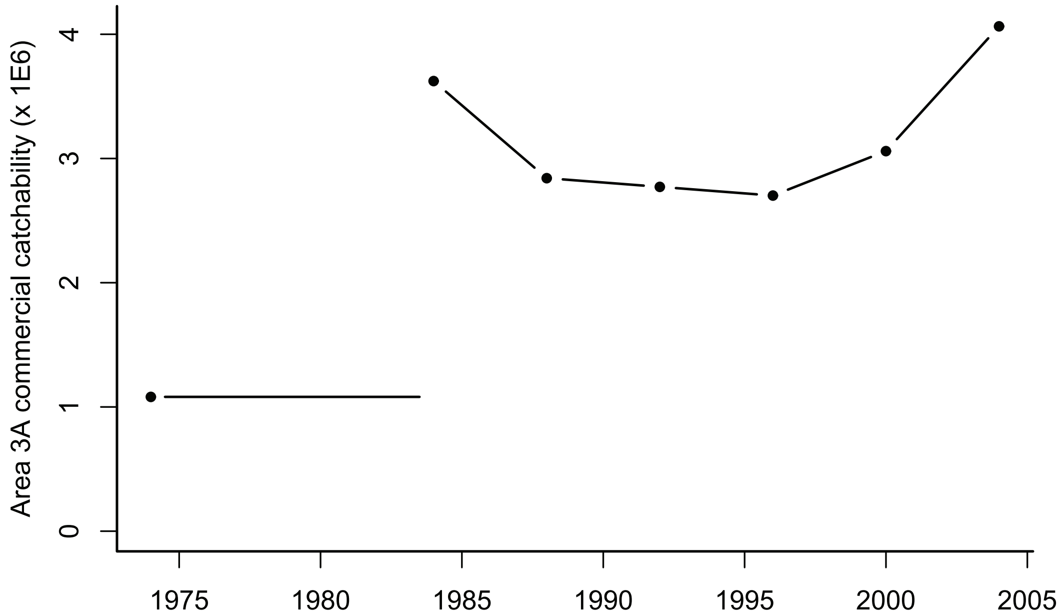


**Figure 8. Estimated path of commercial catchability in Area 3A. A constant value is estimated for the J-hook period (1974-1982) and gradual changes from 1984 on, with catchability estimated at waypoints every 4 years and interpolated between.**

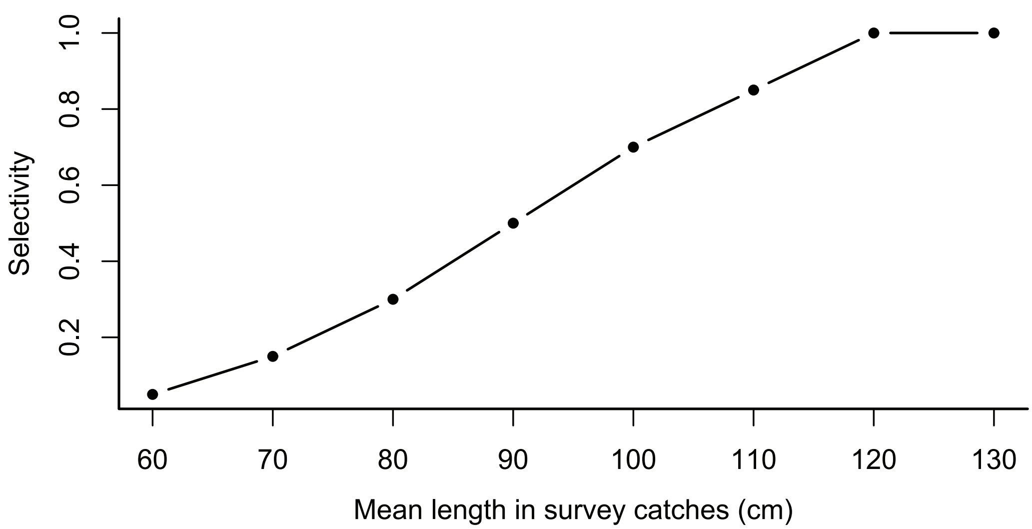


**Figure 9. Setline selectivity at age/sex is modeled as a piecewise linear function of observed mean length in survey catches. The parameters estimated are the selectivities at the points spaced every 10 cm. Selectivity at intervening lengths is interpolated.**

(iii) Free-form, with selectivity set to one at a specified length and allowed to have any value (including values greater than one) elsewhere. Setline survey selectivity is modeled this way, with selectivity set to one at 120 cm. So is bycatch selectivity, with selectivity set to one at 60 cm and estimated elsewhere every 10 cm from 0 cm to 120 cm.

Changes in selectivity parameters over time are modeled by the same system of waypoints and paths described above for catchability. Commercial selectivity is lower than survey selectivity for young fish because of the effect of the commercial minimum size limit of 81 cm, but it is not necessarily zero for age/sex groups whose mean length is less than 81 cm because some fraction will be legal-sized. The sport and subsistence fisheries are assumed to have the same selectivity as the setline survey.

## *Catch equations and survivorship*

All sources of mortality are modeled as competing exponential rates, and predicted catches are calculated with the Baranov catch equation. Specifically, let the subscript *c* denote the commercial fishery, *r* the sport fishery, *p* the subsistence fishery, and *b* the bycatch fisheries. The selectivities of a given age/sex group *g* ($Sel_{cg}$, $Sel_{rg}$ etc.) in a given area/year are determined by its mean length in setline (or trawl) survey catches as explained above. Instantaneous fishing mortality rates are then just the product of the selectivity and the corresponding full-recruitment fishing mortality in that area/year ($F_c$, $F_r$ etc.), or $F_{cg} = Sel_{cg} \cdot F_c$ and so on. The total instantaneous mortality rate is $Z_g = F_{cg} + F_{rg} + F_{pg} + F_{bg} + M$ . If the number of survivors at the beginning of the year is $N_g$, the average number during the year is $\bar{N}_g = N_g \cdot \left(1 - \exp\left(-Z_g\right)\right) / Z_g$ and the predicted catches in number are $C_{cg} = F_{cg} \cdot \bar{N}_g$ and so on. The number of survivors at the beginning of the next year is $N'_g = N_g \cdot \exp\left(-Z_g\right)$. If commercial catchability in that area/year is $q_c$, predicted commercial CPUE in number for that group is $CPUE_g = q_c \cdot Sel_{cg} \cdot \bar{N}_g$ and predicted commercial CPUE in weight is just $CPUE_g \cdot \bar{w}_{cg}$ where $\bar{w}_{cg}$ is observed mean weight for that group in the commercial landings. Predicted setline survey CPUE in total number and in weight of legal-sized fish are calculated the same way.

Using the Baranov catch equation (rather than treating the commercial fishery as a point removal as in some earlier models) permits the model code to be highly modular. Most of it consists of fishery-specific routines that determine catchabilities, selectivities, and fishing mortality rates from the specified waypoints and paths. Once that has been done, the core catch and survivorship calculations take only a few lines, so the really critical section of the code is very robust.

## *Summary of parameters estimated and data predicted*

The table below lists the model parameters estimated along with the data predicted for each area. The subscript *y* denotes year, *a* age, *s* sex, *f* fishery type, and *k* length interval.

| Parameter | Description | Data predicted |
|---|---|---|
| $InitN_{as}, a = 2,...,30$ | Number at age/sex in the first year. | All. |
| $R_y$ | Recruitment at age 1 in each year (except for the last six or so). | All. |

| Parameter | Description | Data predicted |
|---|---|---|
| $F_{fy}$ | Full-recruitment fishing mortality for each fishery in each year. | Catch at age/sex in all fisheries (commercial, sport, subsistence, bycatch). |
| $CSel_{ky}, k = 60, 70, ...120;$ $y = \text{(e.g.) } 1974, 1984, 1988, ...$ | Commercial selectivity at 10-cm waypoints in chosen waypoint years. | Commercial catch at age/sex, total commercial CPUE in number and weight. |
| $CQ_y, y = \text{(e.g.) } 1974, 1982, 1984, 1988, ...$ | Commercial catchability at chosen waypoint years. | Total commercial CPUE in number and weight. |
| $SSel_{ky}, k = 60, 70, ..., 130;$ $y = \text{(e.g.) } 1974, 1984$ | Survey selectivity at 10-cm waypoints in chosen waypoint years, normally one schedule for J-hooks and one for C-hooks. | Survey age/sex composition, total survey CPUE in number and weight, sport and subsistence catch at age/sex. |
| $SQ_y, y = \text{(e.g.) } 1974, 1984$ | Survey catchability, normally one for all J-hook years and one for all C-hook years. | Total survey CPUE in number and weight. |
| $BSel_{ky}, k = 0, 10, 20, ...120;$ $y = \text{(e.g.) } 1974,\ 1979,\ 1984, ...$ | Bycatch selectivity at 10-cm waypoints in chosen waypoint years. | Bycatch at age/sex. |

## Error structure and log likelihood

The error structure and likelihood are based on Fournier et al. (1990). In summary, the model is fitted by minimizing the sum of scaled, squared deviations between the model predictions and the observations, meaning that all the observations are treated as independent normal random variables. In addition, the squared deviations are calculated in a way that makes the estimates robust to the few outliers by reducing their influence.

### *Variance scalers*

Let $Y_i$ denote an observation in the data, which might be a commercial catch in number at age/sex or a proportion at age/sex in the survey or an annual commercial CPUE, and let $s_i^2$ denote the estimated sampling variance of $Y_i$, and $\hat{Y}_i$ the model prediction of it. The usual procedure is to weight each squared deviation by the inverse of its variance, or:

$$D_i^2 = \frac{\left(\hat{Y}_i - Y_i\right)^2}{s_i^2}$$

If the model were correctly specified and the observations contained only sampling error, the $\langle D_i \rangle$ would be standard normal random variables, so the mean error of the predictions would be zero and the root mean squared error would be one. This is far from true; the mean error is near zero but the root mean squared errors are 2 to 3 depending on the data type (Table 1). What this means is that sampling variance accounts for a quarter or less of the total error variance.

To stabilize and standardize the variances of the deviations, each of the sampling variances of the observations is multiplied by a variance scaler $\tau_i^2$ and a scaled squared deviation $d_i^2$ is computed with that weight:

$$d_i^2 = \frac{\left(\hat{Y}_i - Y_i\right)^2}{\tau_i^2 \cdot s_i^2}$$

The $\langle \tau_i \rangle$ can be modeled in various ways, and they can be estimated internally as parameters (Fournier et al. 1990) or set externally (Maunder and Watters 2003). In the halibut assessment the working values of the $\langle \tau_i \rangle$ are set to the average values of the root mean squared errors for each data type in unscaled fits; they are shown in the last column of Table 1.

Apart from outliers, the scaled deviations $d_i = \left(\hat{Y}_i - Y_i\right) / \left(\tau \cdot s_i\right)$ should have approximately a standard normal distribution, and they do. In Area 3A (Fig. 10b), the commercial and survey catch at age deviations match a standard normal distribution quite well, and there is only one deviation greater than 5. Outliers are more numerous among the Area 2B commercial catch at age deviations (Fig. 10a), with 17 (out of 475) deviations greater than 5 or less than -5. In both areas the commercial and survey CPUE deviations depart from a standard normal distribution, but this is mainly the result of the small sample sizes (only 25-30 points).

**Table 1. Root mean squared errors of various model predictions in unweighted fits using unscaled sampling variances. The working value of τ in the last column is used to scale the sampling variances when fitting the model normally.**

| Data type | Area 2B | Area 2C | Area 3A | Central value and working value of τ |
|---|---|---|---|---|
| Catch at age | | | | |
| Total | 2.6 | 2.3 | 2.4 | 2.5 |
| Female | 1.9 | 2.1 | 2.0 | 2.0 |
| Male | 1.8 | 2.3 | 1.7 | 2.0 |
| Commercial CPUE | | | | |
| Number | 2.2 | 2.4 | 2.1 | 2.2 |
| Weight | 2.2 | 2.9 | 2.3 | 2.5 |
| Survey proportion at age | | | | |
| Total | 2.6 | 2.7 | 2.6 | 2.5 |
| Female | 2.6 | 3.1 | 2.6 | 2.5 |
| Male | 2.9 | 2.3 | 2.3 | 2.5 |
| Survey CPUE | | | | |
| Total number | 2.7 | 2.4 | 4.3 | 3.0 |
| Legal-sized weight | 2.8 | 2.4 | 5.3 | 3.0 |
| Bycatch at length | 2.6 | 2.0 | 4.3 | 3.0 |

It is somewhat inconsistent to treat the catch at age data as having a normal distribution when the sampling distribution is multinomial and the sampling variance is estimated using the multinomial formula. Fournier et al. (1990) give some practical and statistical reasons for doing so as a general practice. In the case of the halibut assessment the compelling reason is that the scaled deviations really do follow a normal distribution. This is not surprising. The individual sample proportions are binomial, and the normal distribution approximates the binomial well. Moreover, when the sampling variance accounts for only a small fraction of the total variance, one should not expect the shape of the distribution to be determined by the shape of the sampling distribution. The variance of observed proportions about the model predictions doubtless results from a combination of various kinds of process error and model misspecification, the sum of which could be expected to produce a normal distribution of deviations.

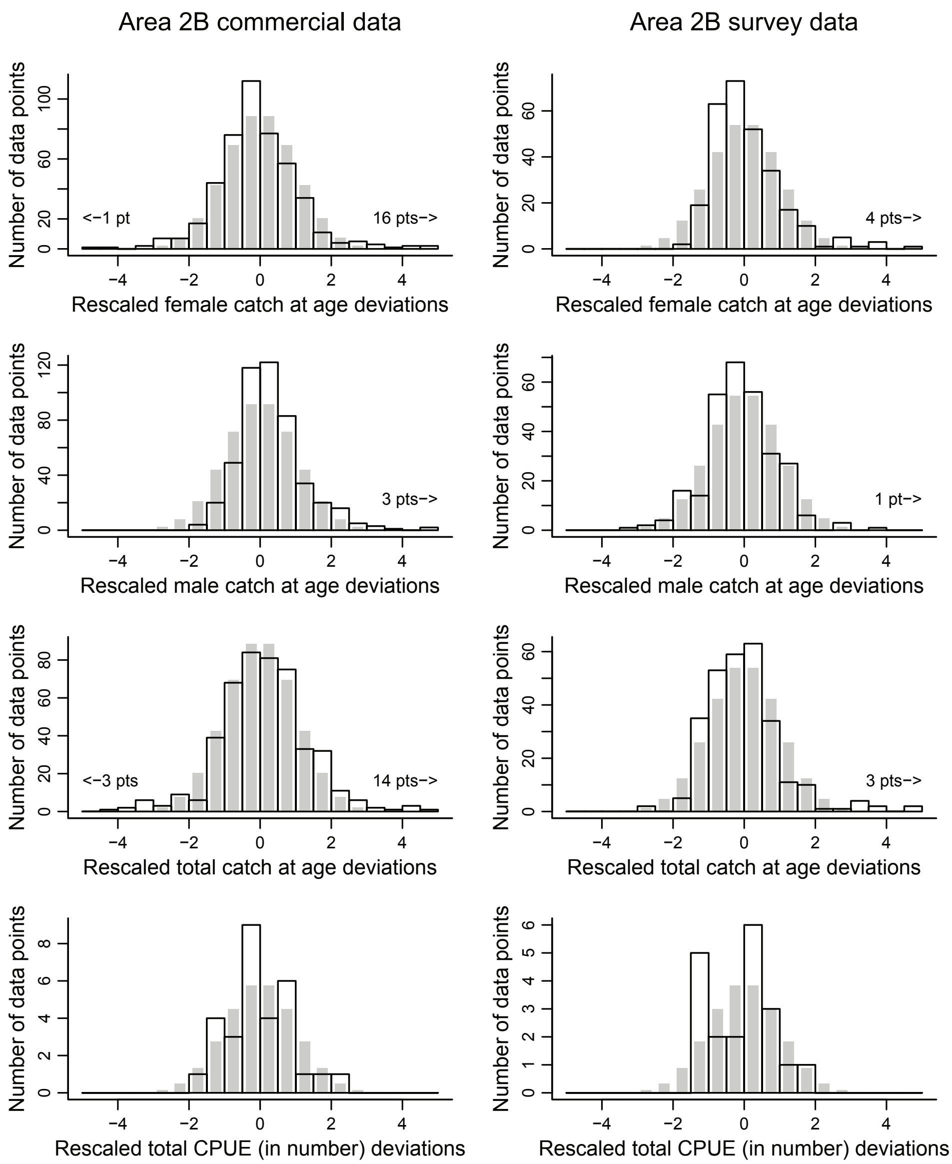


**Figure 10a. Distribution of scaled deviations of model predictions from observations in the 2004 assessment of Area 2B. The white bars outlined in black show the actual distribution of deviations; the gray bars show a standard normal distribution for comparison. The notation "14 pts →" means there were 14 deviations larger than 5 that are not plotted.**

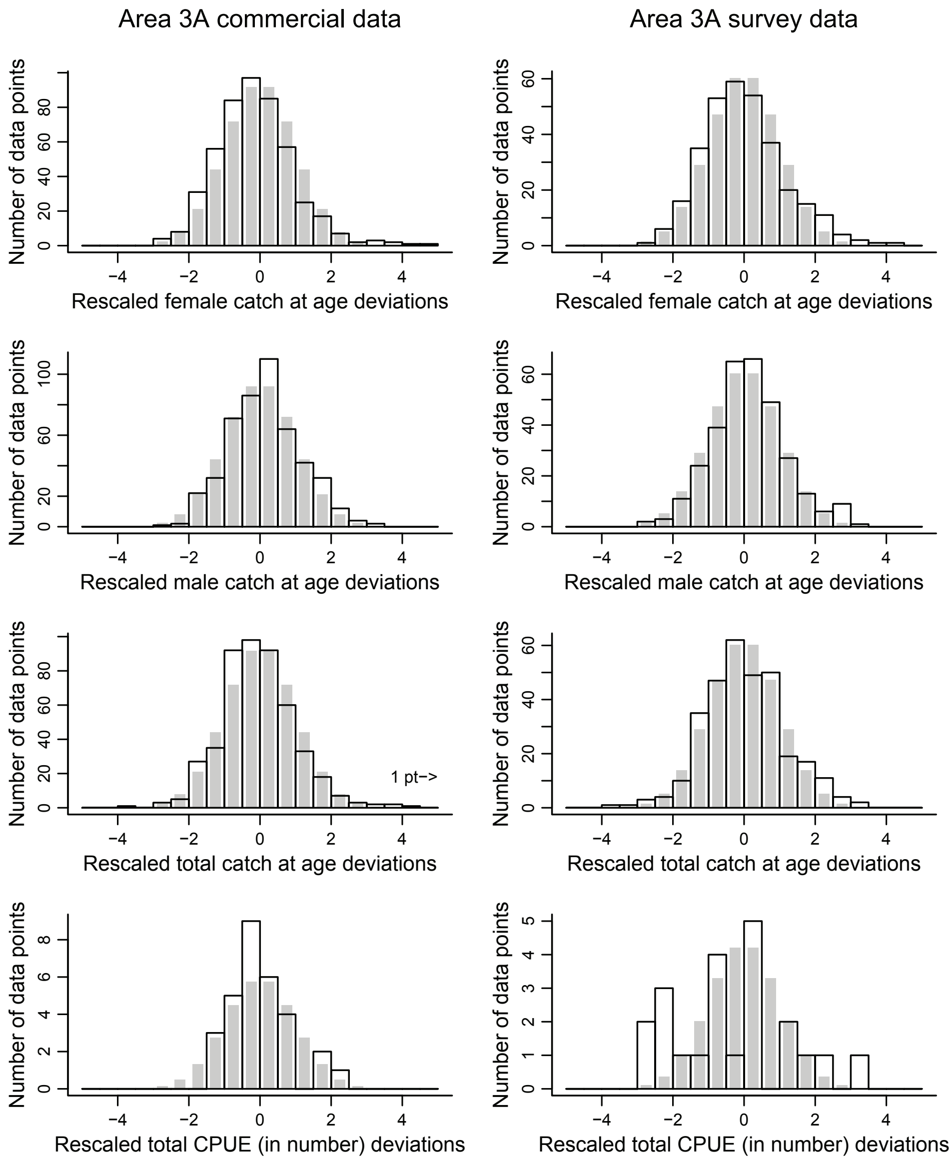


**Figure 10b. Distribution of scaled deviations of model predictions from observations in the 2004 assessment of Area 3A. The white bars outlined in black show the actual distribution of deviations; the gray bars show a standard normal distribution for comparison. The notation "1 pt→" means there was 1 deviation large than 5 that is not plotted.**

*Robust estimation*

While not numerous, the very large values among the scaled deviations when squared can make a large contribution to the sum of squares and have an inordinate influence on the estimates. To avoid giving that much weight to points that may just be outliers, the scaled deviations are run through a smooth function (Fig. 11) that is the identity function up to $|d| = 2.5$ and thereafter increases at a decreasing rate toward an asymptote at $|d| = 3$:

$$\text{for } |d| \le 2.5: \quad f(d) = d$$

$$\text{for } |d| > 2.5: \quad f(d) = \text{sign}(d) \cdot \left(2.5 + 0.5 \cdot \left(1 - \exp\left(-\left(|d| - 2.5\right)/0.5\right)\right)\right)$$

The first derivatives of both portions of this function are $f'(d) = 1$ at $d = 2.5$, so it has a continuous first derivative, which is important for numerical minimization.

Application of this function has the effect of mapping all deviations greater than 2.5 onto the interval (2.5, 3), so they are still treated as improbably large deviations but not as impossibly large deviations. Fournier et al. (1990) accomplish the same thing by adding a small constant to the normal density function.

To obtain the robust estimates, the model is first fitted with the raw scaled deviations, including outliers, from an arbitrary starting point. (If robustified deviations were calculated at this point, all of the data would look like outliers.) The model is then refitted with robustified deviations using the first fit as the starting point. The parameter estimates are almost the same, but the extra step assures that outliers are not affecting them.

## *Log likelihood*

The scaled and robustified deviations $\langle d_i \rangle$ are all treated as standard normal random variables, so the likelihood is:

$$L = \prod_i \frac{1}{\sigma\sqrt{2\pi}} \cdot \exp\left(\frac{-d_i^2}{2\sigma^2}\right) = \prod_i \frac{1}{\sqrt{2\pi}} \cdot \exp\left(\frac{-d_i^2}{2}\right) \text{ because } \square = 1$$

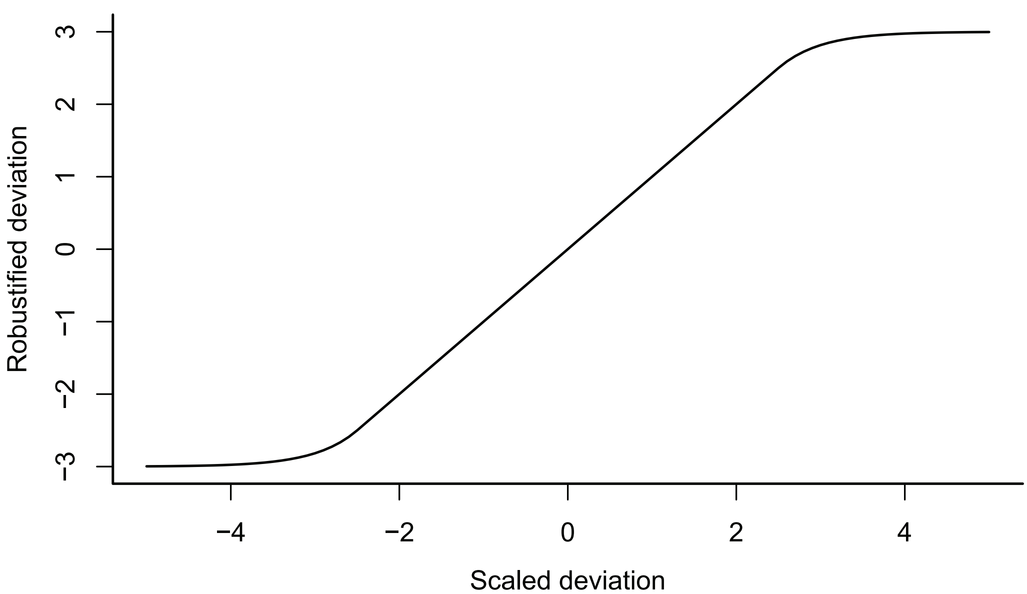


**Figure 11. The robustification function. The robust deviation is equal to the scaled deviation up to 2.5 in absolute value. Thereafter the robust deviation increases slowly in absolute value toward an asymptote at 3.**

$\sigma_{Sel}$



and the log likelihood is $\log L = \text{constant} + \sum_i -d_i^2/2$. The estimates are located by minimizing $-\log L = \sum_i d_i^2/2$ which is just half the sum of scaled, squared deviations. Taking half the sum rather than just minimizing the sum of squared deviations assures that the log likelihood is scaled properly for estimating the variance-covariance matrix of the parameter estimates from the inverse Hessian matrix.

## Penalties

In addition to the sum of squared deviations for the data, the objective function includes some penalty sums of squares for the parameter estimates that serve to control certain features of the estimates. The most important of these is a penalty on the second differences of the selectivity parameters that in effect requires length-specific selectivity to vary smoothly with length or, in other words, prevents the selectivity function from making large changes in direction at any point. Specifically, if $Sel_k,\ k = 1,\ldots,K$ are the estimated selectivities at the *K* waypoint lengths of a schedule where selectivity is estimated (or possibly fixed), the penalty is calculated as $\sum_{k=3}^{K}\left(Sel_k - 2\cdot Sel_{k-1} + Sel_{k-2}\right)^2 \big/ \left(2\cdot\sigma_{Sel}^2\right)$, where $\sigma_{Sel}$ is an assigned tolerance. In practice a value of 0.025 is sufficient to produce acceptably smooth selectivity schedules. This penalty is typically about 5% of the total sum of squares.

Another penalty is calculated on year-to-year relative changes in commercial catchability. If the estimated catchabilities for the *Y* years of data are $\langle CQ_y \rangle$, the penalty is calculated as $\sum_{y=2}^{Y}\left(\log CQ_y - \log CQ_{y-1}\right)^2 \big/ \left(2\cdot\sigma_{CQ}^2\right)$ where $\sigma_{CQ}$ is an assigned tolerance, presently 0.03, which was found sufficient to prevent wide swings in the estimates. The penalty is not calculated at waypoints where there is a break in commercial catchability, such as at the time of the changeover from J-hooks to C-hooks. This penalty discourages rapid changes in estimated commercial catchability but allows for large cumulative changes over the course of several years, which doubtless occur (Fig. 8). This device makes the commercial CPUE data useful for tracking relative abundance without having to assume that commercial catchability is constant. This penalty is typically about 1% of the total sum of squares.

Two other penalties are calculated to prevent wild estimates of year-class strength or sex ratio among the cohorts present in the stock in the first data year. Wild values of year-class strength can occur because of age smearing, and they are prevented by penalizing large differences in abundance at successive ages in the initial numbers. Wild sex ratios can occur because the initial numbers of females and males at each age in the first year are estimated independently. (Year-classes that recruit in subsequent years are assumed to have an equal sex ratio at age one.) Wild sex ratios are prevented by penalizing deviations from an equal sex ratio through age 8, and large differences in sex ratio at successive ages thereafter. These penalties have no effect on the estimates of present abundance in Areas 2 and 3A where the first data year is 1974, and little effect in Areas 3B and 4. These two penalties together are typically about 5% of the total sum of squares.

## Weights

The catch at age data points far outnumber the CPUE data points (survey and commercial) because every year there are 15 or 20 of the former and only one of the latter. As a result the best model fit may be one that does not agree very well with the abundance trends indicated by the CPUE series, especially the survey CPUE series where catchability is held constant. The staff regards the survey CPUE as the most reliable index of long-term changes in relative abundance, and the commercial CPUE as a reliable index of short-term changes in abundance, so we normally weight the CPUE deviations much more heavily than the catch at age deviations in order to obtain fits that agree well enough with the CPUE trends. At present a weight of 10 is used, which gives the catch at age and CPUE deviations roughly equal shares of the total sum of squares. It also provides model predictions that fit both the catch at age data and the CPUE trends reasonably well.

## Assessment results

When the annual assessment is done, several candidate models may be considered that differ in how commercial and survey catchability and selectivity are parameterized and how the CPUE data are weighted. Putting in more catchability and selectivity waypoints will generally improve the fit but reduce the precision of the parameter estimates by reducing the number of data points per parameter estimated. The staff catch limit recommendations are normally based on the most parsimonious model that provides acceptable fits in all areas and performs well in retrospective runs. Once such a model has been adopted, the staff attempts to use it in the following year so as to avoid changes in biomass estimates due to changes in model structure or parameterization. But as explained above, there have been frequent changes over the course of the last ten years or so.

### Parameterization and weighting of the 2004 assessment model

The 2004 production assessment model had the following features:

(i) The commercial catchability waypoints in Areas 2 and 3A were 1974, 1982, 1984 and every four years thereafter, with interpolation between all waypoints except for 1984 when the C-hook data begin. In Areas 3B and 4 the waypoints were 1996, 2000, and 2004.

(ii) A single length-specific commercial selectivity schedule was estimated for all years in the data series, J-hook as well as C-hook. This was decided after fitting the model with a number of selectivity waypoints and seeing that the commercial selectivity schedules for different periods were all very similar.

(iii) The survey catchability waypoints were only 1974 and 1984, with no interpolation, because we assume that survey catchability has been constant apart from the effect of the change from J-hooks to C-hooks in 1984.

(iv) A single length-specific survey selectivity schedule was estimated for all years, because here too separate schedules estimated for the J-hook and C-hook years were almost the same.

(v) Length-specific bycatch selectivity waypoints in Areas 2 and 3A were 1974 and every five years thereafter; in Areas 3B and 4, 1996 and 2001. Bycatch selectivity was not interpolated between waypoints, so a single schedule applied throughout each five-year period. The five-year periods were chosen because that was the most parsimonious parameterization of bycatch selectivity that still provided satisfactory predictions of bycatch length compositions (Fig. 12). Bycatch selectivities are estimated solely for the purpose of accurately accounting for the removals, so it would be natural to estimate a schedule for each year. The drawback is the large increase in the number of model parameters.

(vi) Commercial and survey CPUE data were given a weight of 10.

### Quality of fits

The model predictions of commercial catch at age of females and males are very good (Fig. 13). This is remarkable because all of the predictions are based on a single length-specific commercial selectivity schedule that is used for both sexes in all years, when female length at age was always larger than male length at age and both declined dramatically in the 1990s (Fig. 7). The predictions also navigate the change from surface to break-and-burn age readings in 2002 successfully, and they correctly predict the growing preponderance of females in the catches (Fig. 14). The fits to survey age compositions are not as good but they are quite satisfactory for years since the systematic surveys resumed in 1993 (Fig. 15).

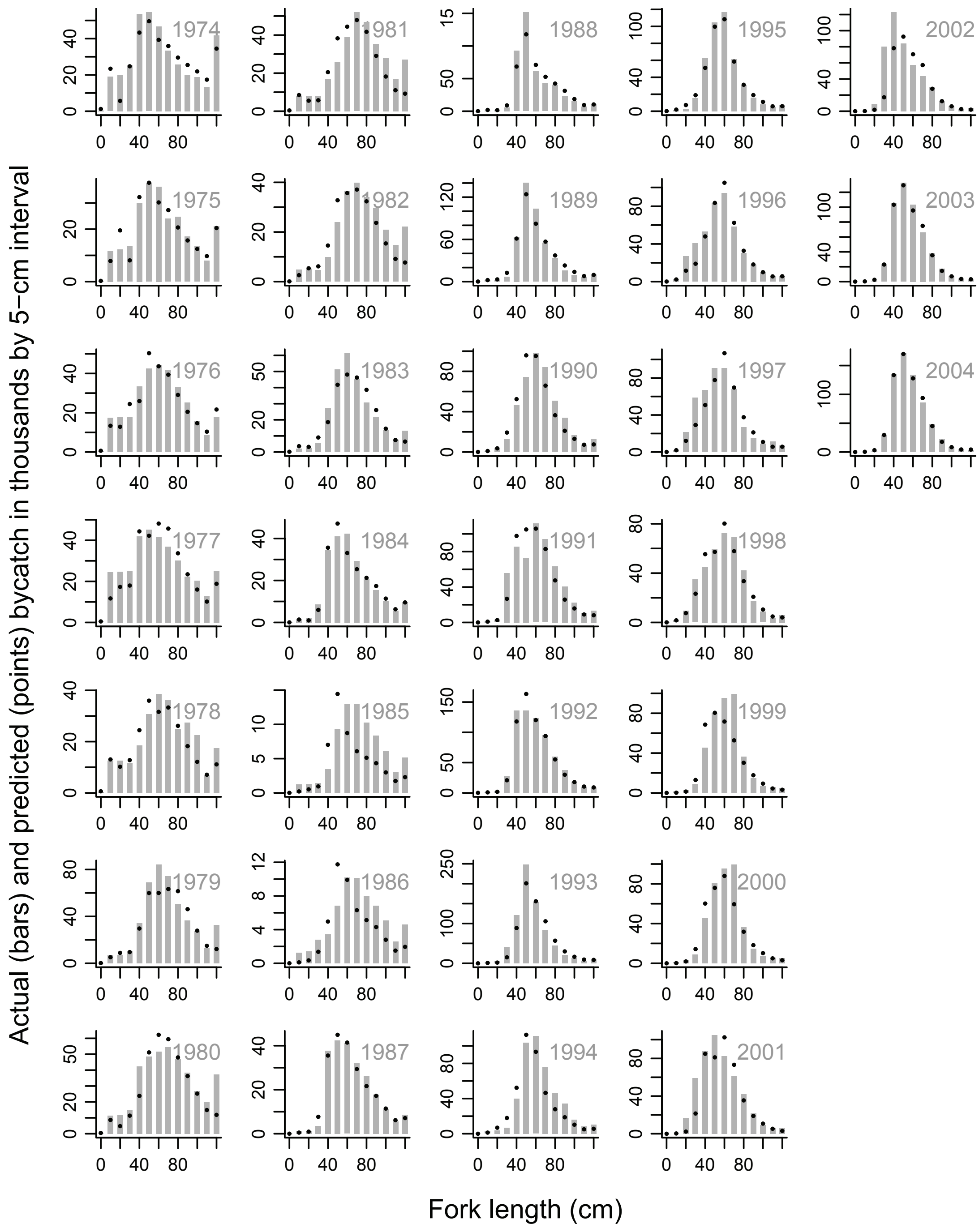


**Figure 12. Actual (bars) and predicted (points) bycatch at length in the 2004 Area 3A assessment. An average bycatch selectivity was estimated for each five-year period.**

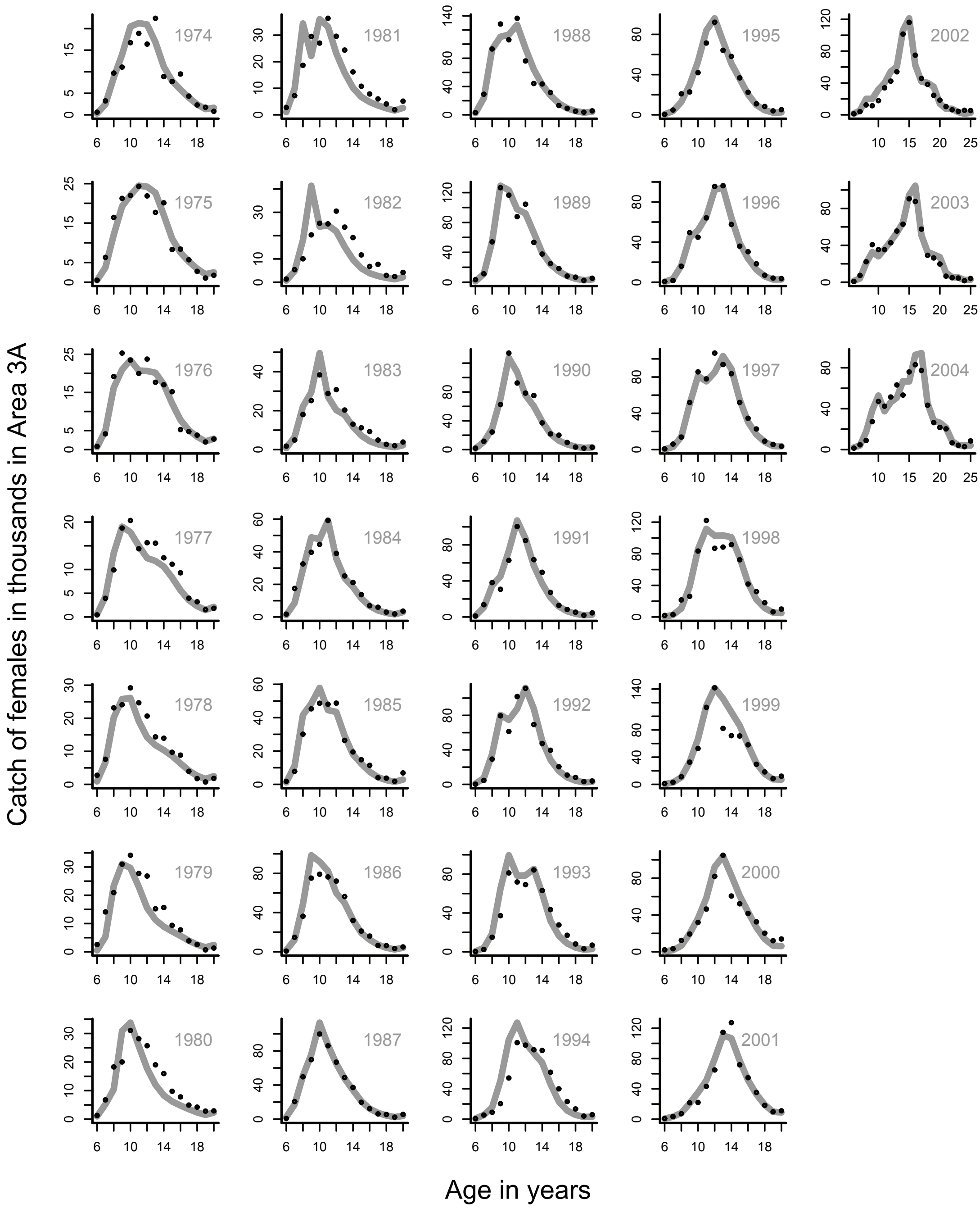


**Figure 13a. Observed (points) and predicted (gray lines) commercial catch at age of females in the 2004 assessment in Area 3A.**

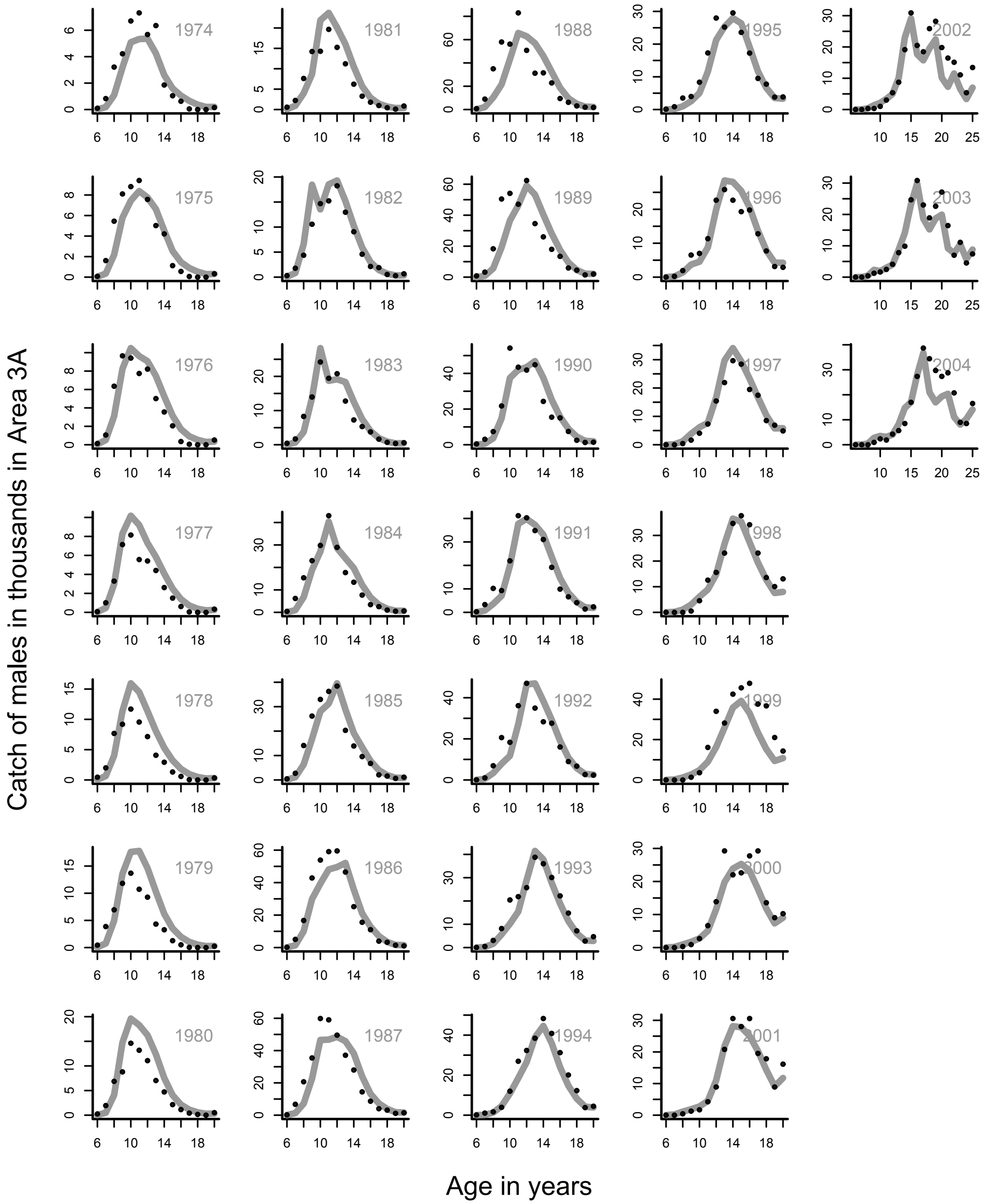


**Figure 13b. Observed (points) and predicted (gray lines) commercial catch at age of males in the 2004 assessment in Area 3A.**

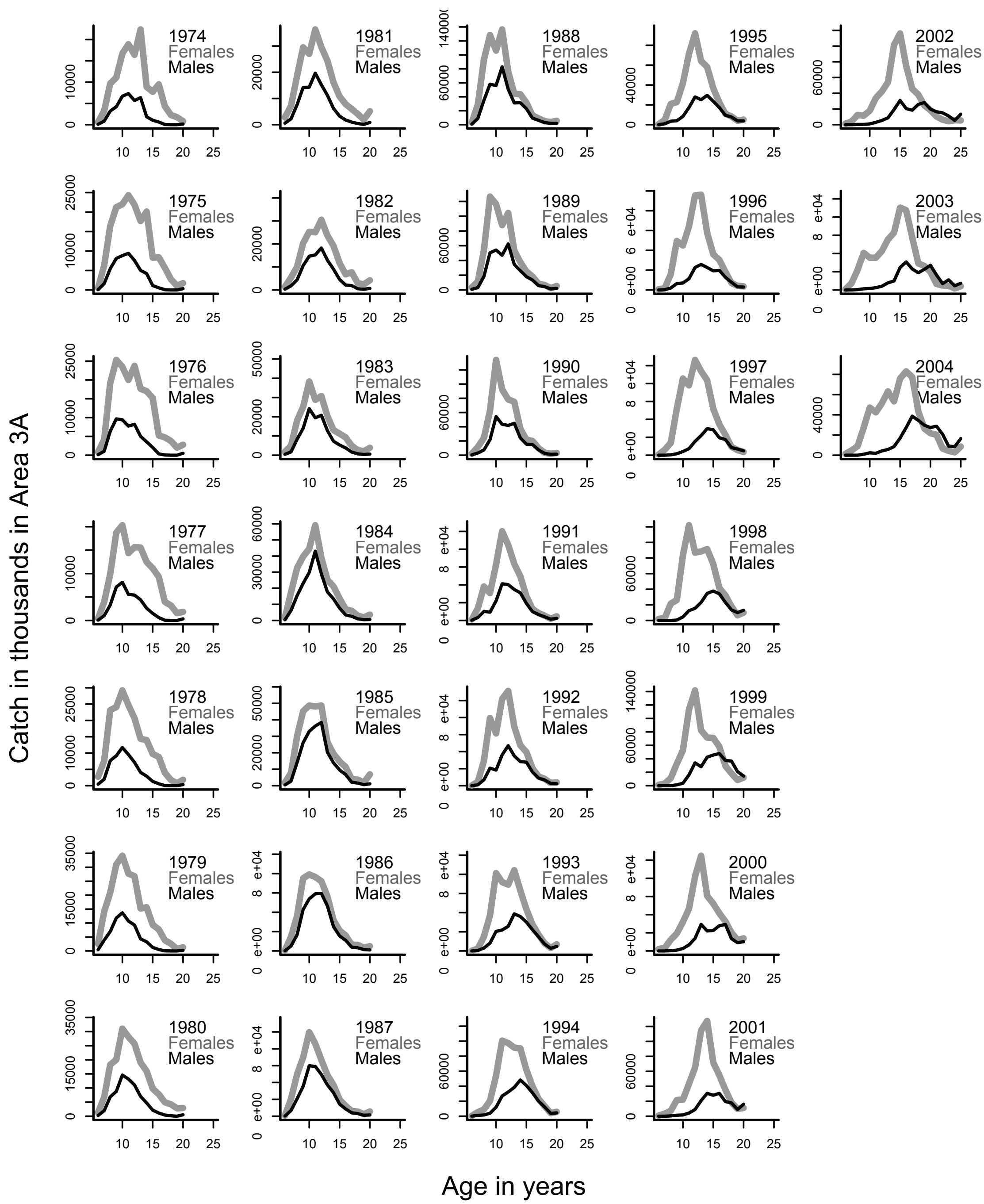


**Figure 14. Catch at age of females and males in Area 3A. The values plotted are the data values not the predictions, which track the data very well as shown above.**

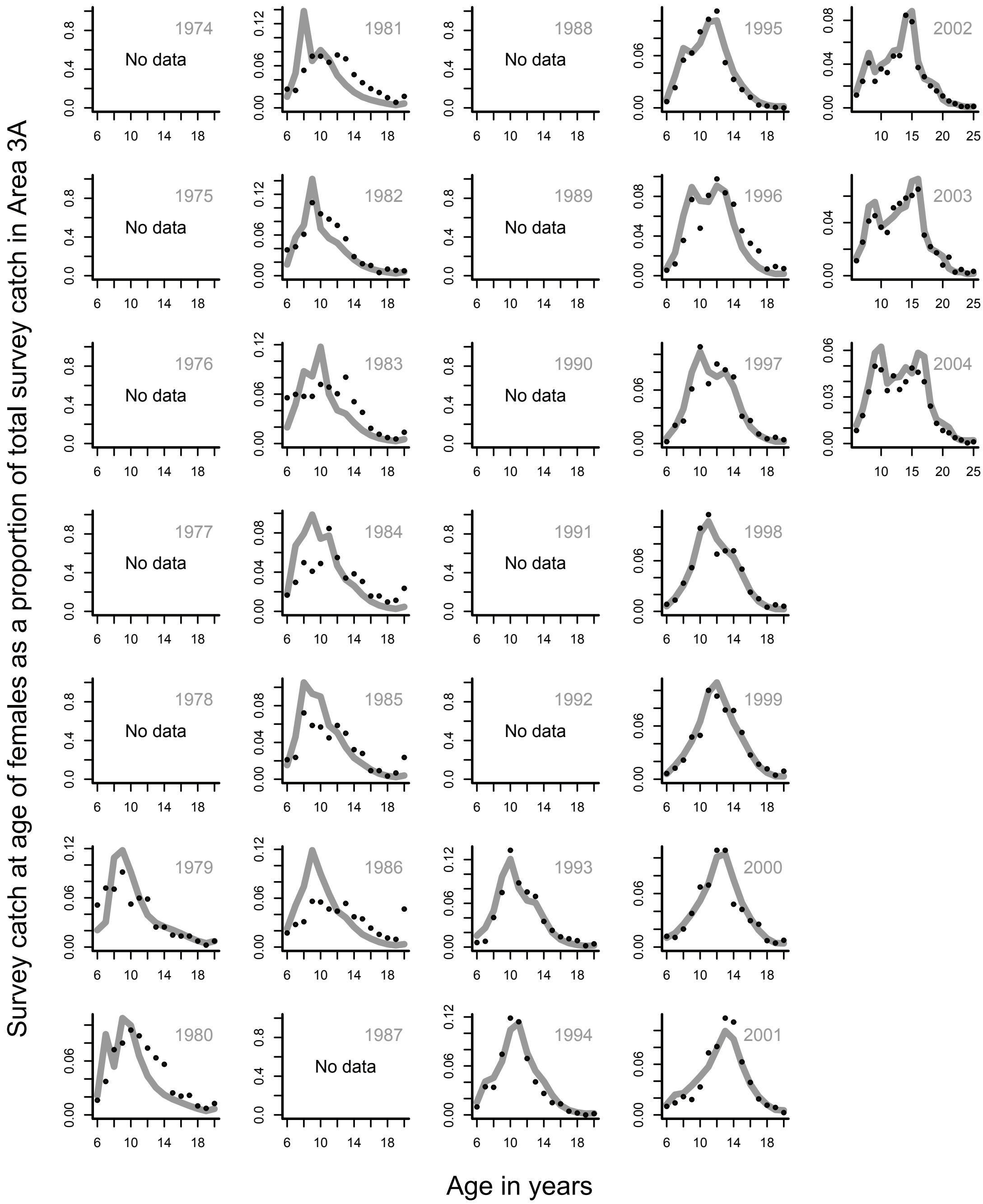


**Figure 15a. Observed (points) and predicted (lines) survey catch at age of females as a proportion of total survey catch (including males), in Area 3A. The proportions sum to the proportion female in each year, not to one.**

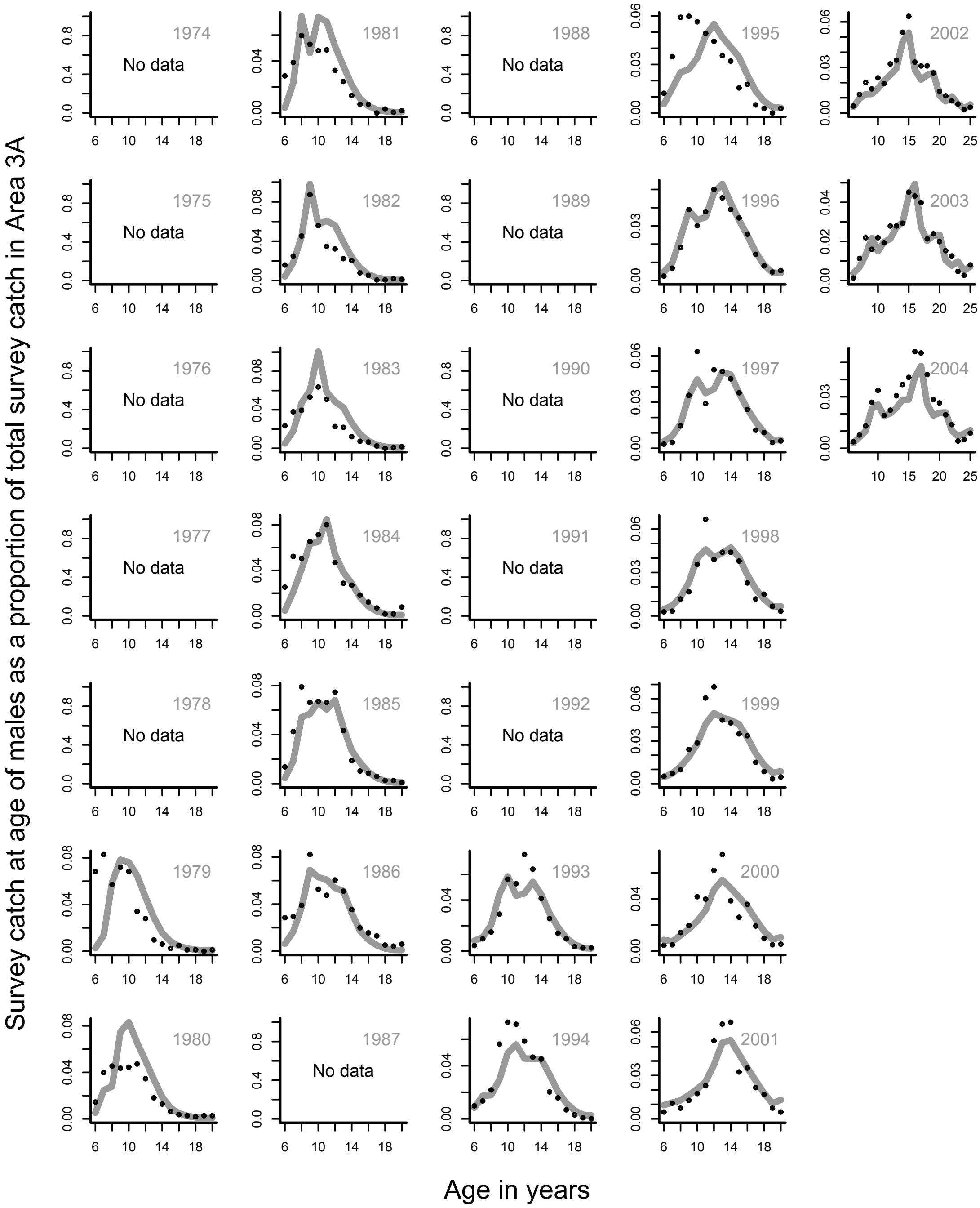


**Figure 15b. Observed (points) and predicted (lines) survey catch at age of males as a proportion of total survey catch (including females), in Area 3A. The proportions sum to the proportion male in each year, not to one.**

The model CPUE predictions, shown in the upper right panels of Figures 16a-f, also track the observations quite well. (The large jump in all series in 1984 is the result of the change from J-hooks to C-hooks, not a sudden increase in abundance.) That is to be expected in the case of the commercial CPUE because commercial catchability is allowed to vary somewhat over time, but survey catchability is held constant. Because of the heavy weighting of the CPUE series, the model fits are effectively required to match the long-term trend in survey CPUE, and they do, but except for a few years in Areas 2B and 2C the fits also follow the year-to-year trajectory of survey CPUE reasonably well.

Overall the good model fits inspire some confidence that the model is correctly specified and that the procedures used to estimate the commercial catch at age by sex and to allow for the bias and variance of surface age readings, are working properly. Stock trends are therefore probably estimated correctly. The estimates of absolute abundance are conditional on the working value of the natural mortality rate, and are almost certainly high or low by some proportion. (And if the natural mortality has changed over time, the estimated trends are also in error to some extent.)

## Retrospective performance

Every year the assessment model is fitted to data going back to 1974 (1996 in Areas 3B, 4A and 4B), so the historical biomass series is re-estimated along with the present biomass. If the model were correctly specified, each year's assessment would reproduce the previous year's estimate of the trajectory of historical biomass with only minor, random differences. The success or failure of a model in this respect is called retrospective performance. Poor retrospective performance is a systematic movement of the estimated biomass trajectory from one year to the next. It can result from trends in model parameters that are not allowed for in the model specification, or from features of the data.

Figure 17a shows the poor retrospective performance of the 2004 model in Area 2B when data are added one year at a time and the same model is fitted to the successive series. An assessment based on data through 1997 shows a large increase in biomass from 1985 to 1997, but subsequent assessments steadily reduce their estimate of the 1997 biomass. According to the 2004 assessment, the 1997 assessment overestimated current biomass by close to 50%. This is poor retrospective performance, but in this case the problem lies in the data. It is now clear that in the mid-1990s there were three anomalously high survey CPUE values in succession in Area 2B (Fig. 16a). At the time, however, those were the current data, and they consistently indicated a greatly increased abundance, which the assessment estimated. As later years' data with lower CPUE values accumulated, the assessment's estimate of abundance at that time was steadily revised downward; hence the retrospective pattern.

Figure 17b shows the retrospective performance of the assessment in Area 3A, where there were no rogue survey CPUE values, and it is acceptable. The estimated biomass trajectory does drop a ways from the 1997 to 2002 assessments but then come back up. There is not a sustained movement either way, and the estimate of biomass in 1997 is quite close in the 1997 and 2004 assessments.

## Variance estimates

If the model and the error structure are correctly specified, the inverse Hessian matrix evaluated at the maximum likelihood estimate is a good estimate of the variance-covariance matrix of the parameter estimates. In fisheries assessments the model is always a gross simplification of the stock and fishery, and thus misspecified to some extent, and the data are always over-dispersed (meaning that there are more extreme values in the data than would be expected from the assumed sampling distribution). For both reasons the usual Hessian-based estimates of variance are always too low, as are alternative methods of variance estimation like bootstrapping and Markov chain Monte Carlo sampling (Punt and Butterworth 1993). For lack of anything better, such estimates are often reported anyway.

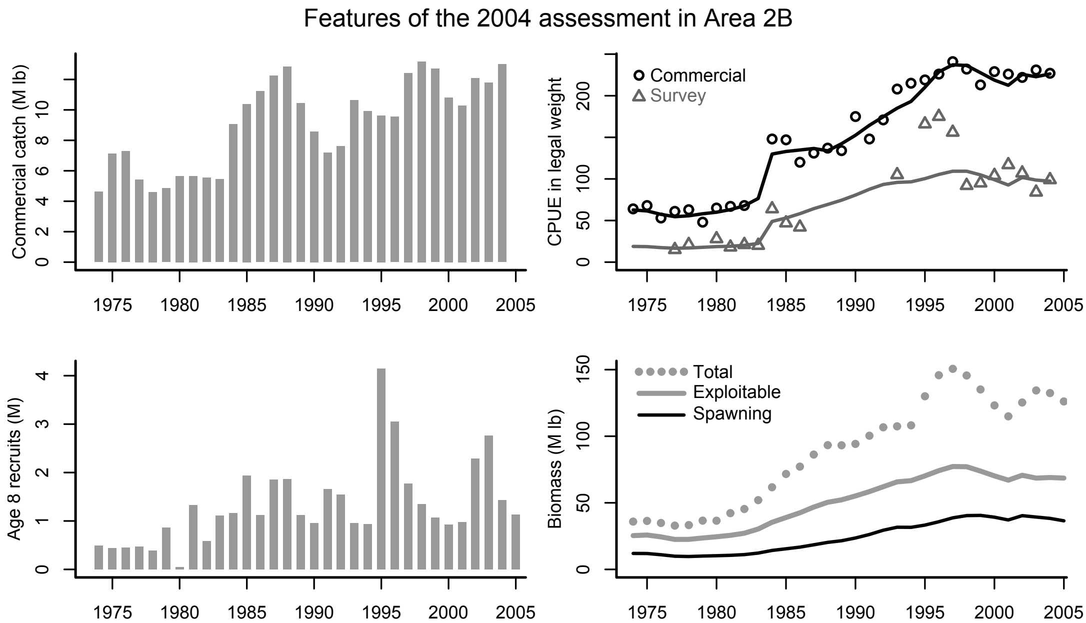


**Figure 16a. Area 2B stock trends as shown by the 2004 assessment. In the figure at upper right, the points are observed CPUE values and the lines are model predictions. The recruitment and biomass series are model estimates.**

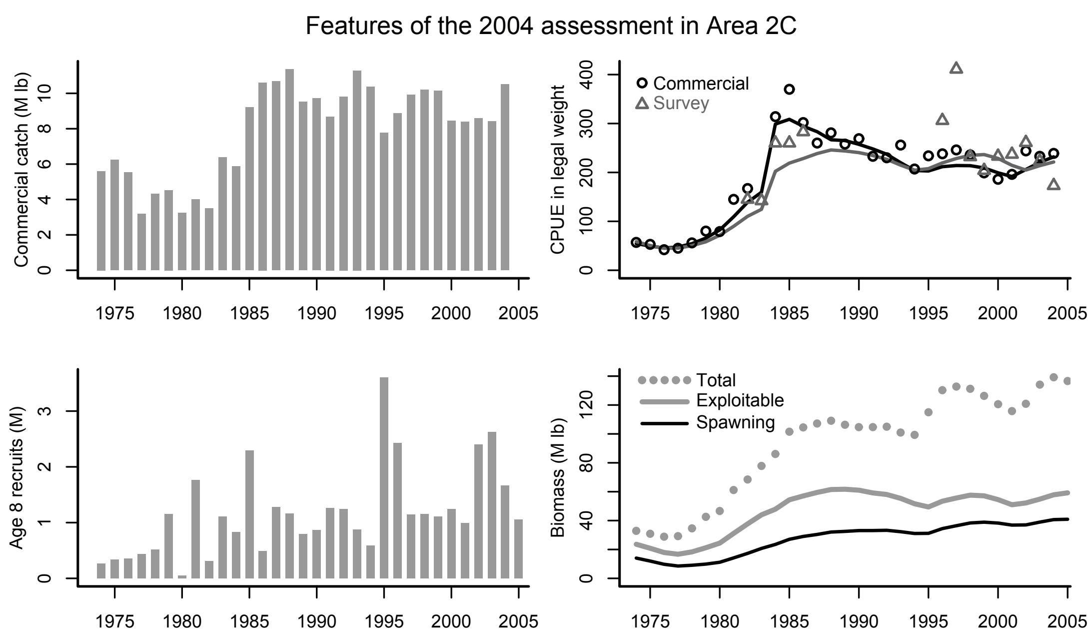


**Figure 16b. Area 2C stock trends.**

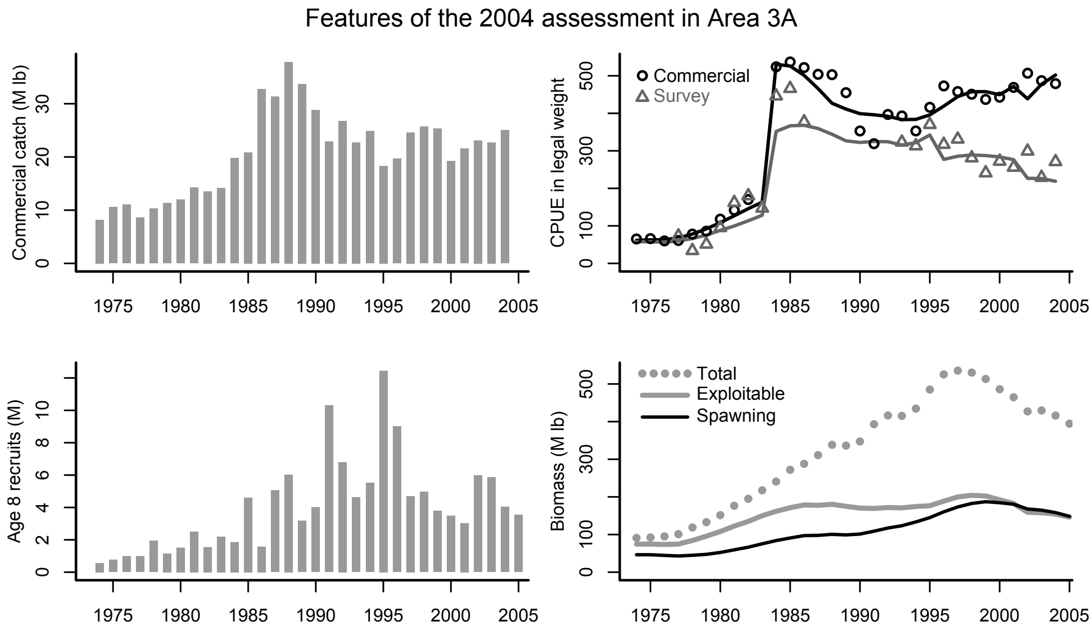


**Figure 16c. Area 3A stock trends**.

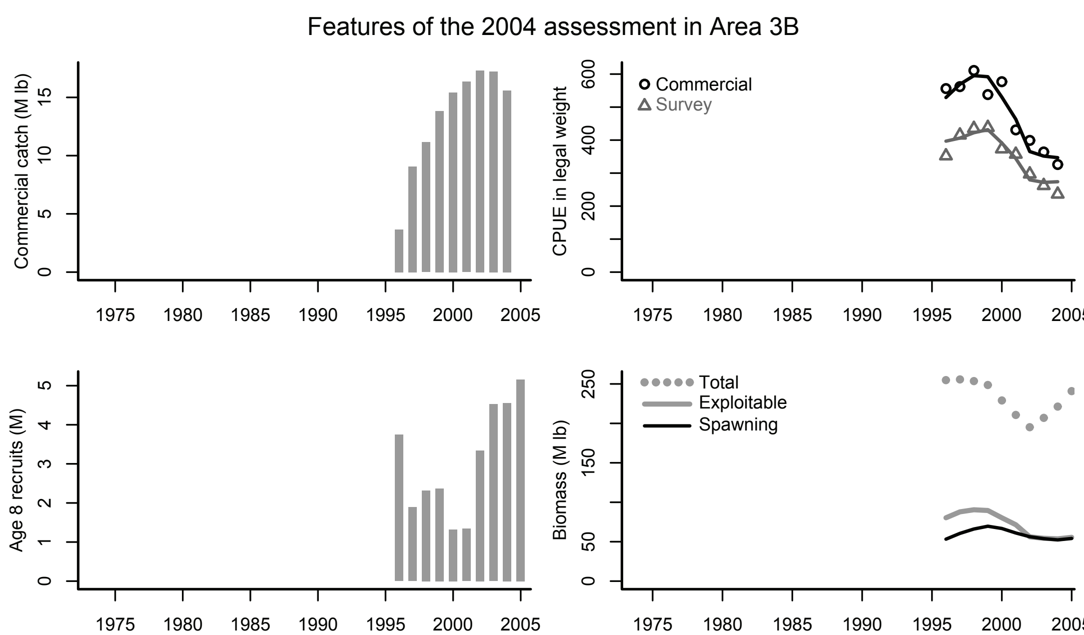


**Figure 16d. Area 3B stock trends**.

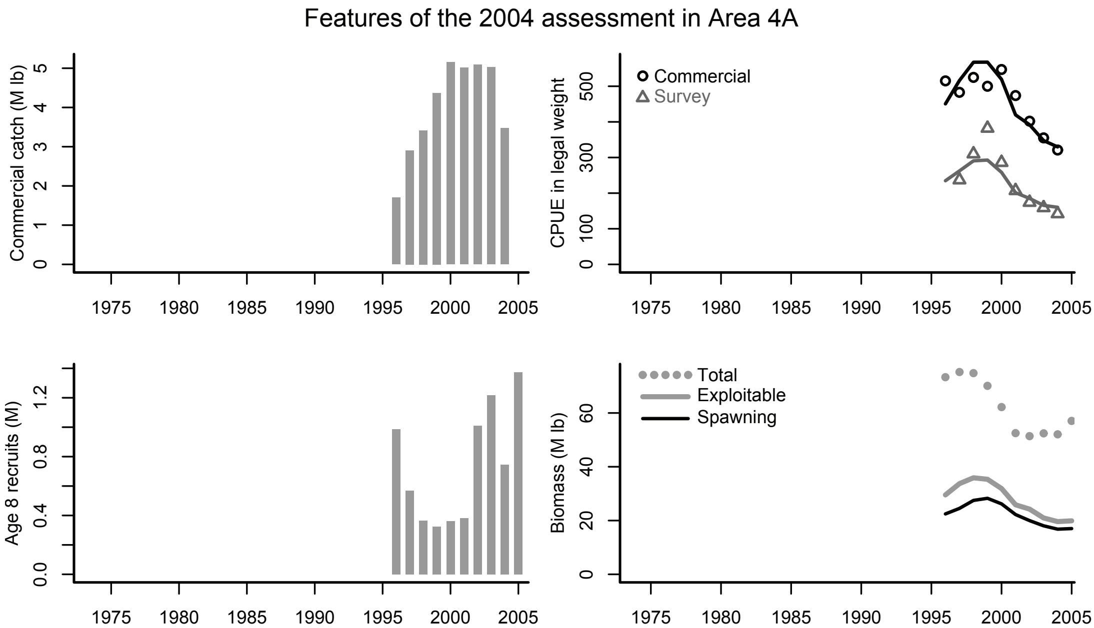


**Figure 16e. Area 4A stock trends.**

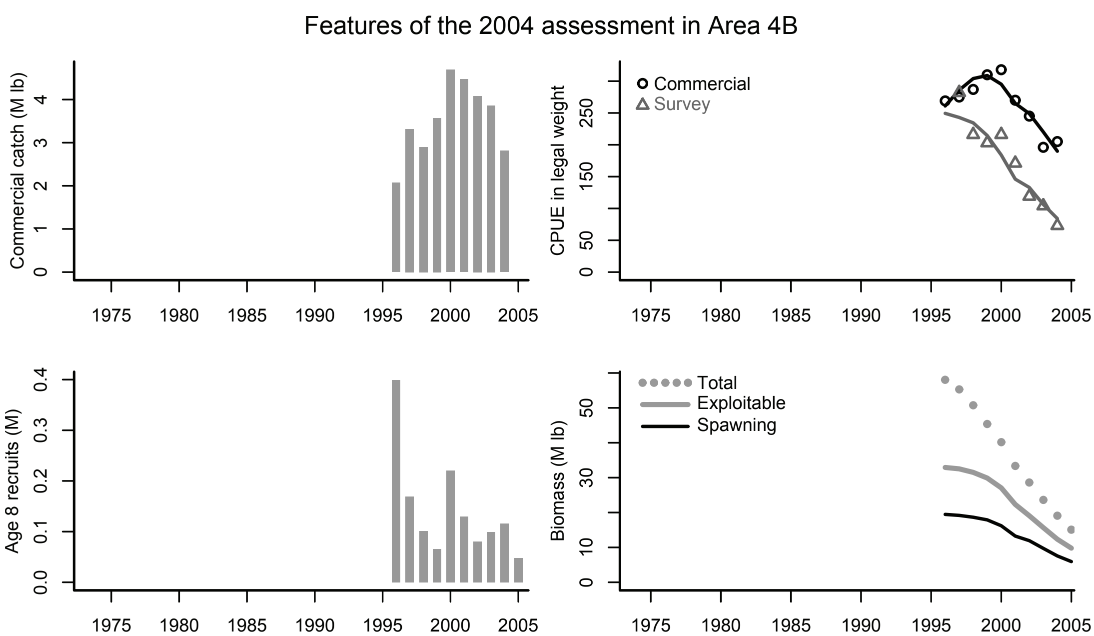


**Figure 16f. Area 4B stock trends.**

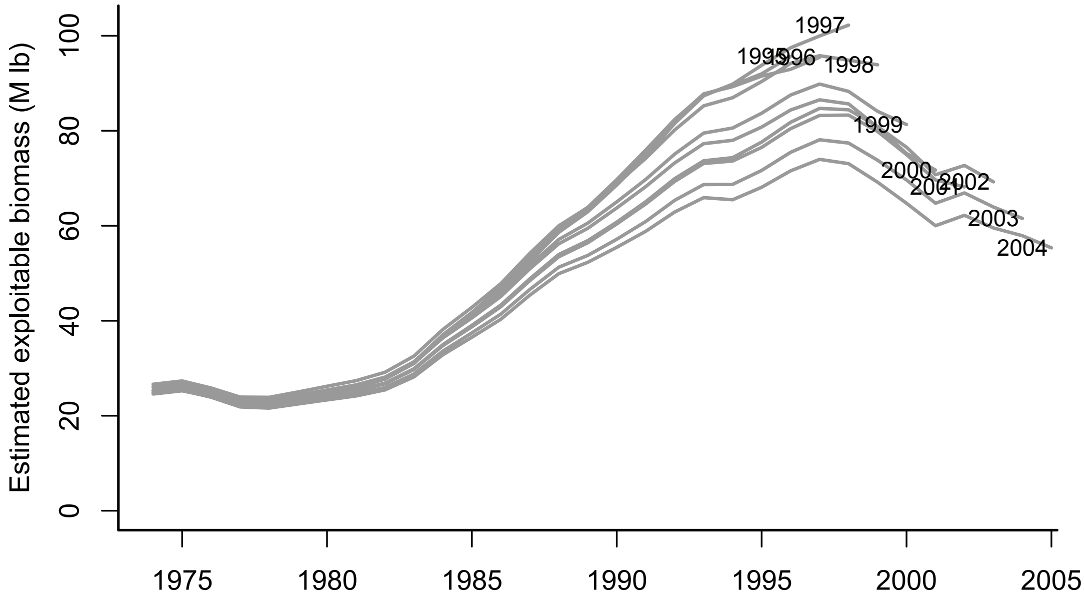


**Figure 17a. Retrospective performance of the 2004 assessment in Area 2B. Each plotted line shows the biomass trajectory**

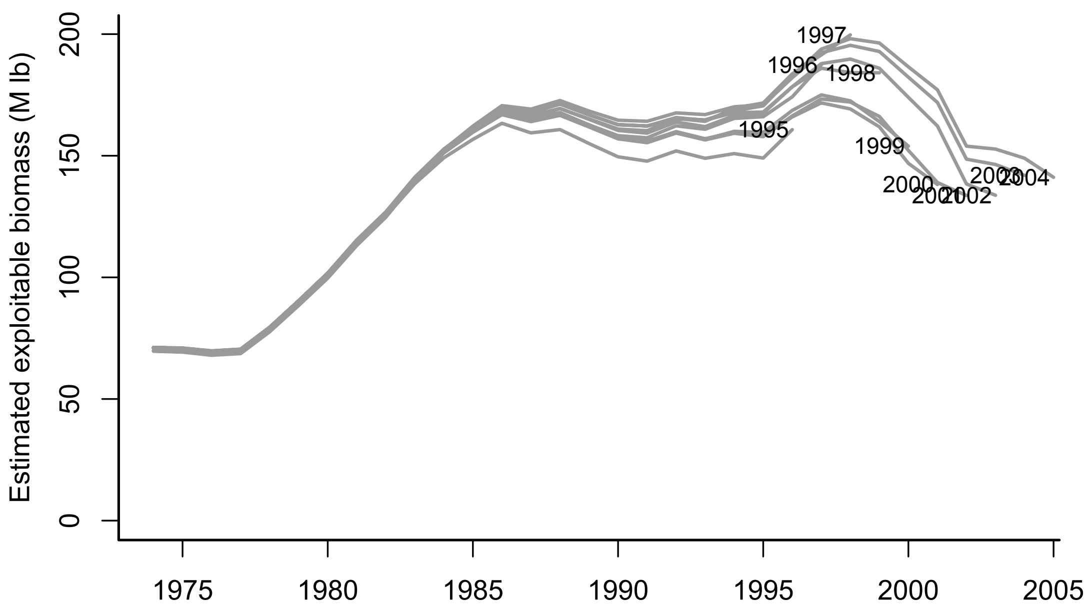


**Figure 17b. Retrospective performance of the 2004 assessment in Area 3A.**

In the case of the halibut assessment, the standard Hessian-based estimate of the coefficient of variation (CV) of the present biomass is less than 5%, because the heavy weighting of the CPUE series inflates the log likelihood. From a statistical viewpoint, the weighting amounts to saying that we have a lot of CPUE data, whereas in fact we have a small amount that we choose to rely on heavily. In unweighted fits of the model, the CV of the present biomass estimate is about 10%, and even that is low because the log likelihood includes some double counting. For example, the sum of squares includes the total catch at age as well as the female catch at age and the male catch at age; likewise the CPUE values in both number and weight. If we allow for that by dividing the sum of squares by 4 instead 2 when computing the log likelihood, the CV of the present biomass estimate in unweighted fits increases to 15%.

An alternative estimate can be made from the retrospective performance of the fit. In particular, the observed variance of the estimate of present biomass must overstate the variance of the estimate itself because it also includes any variance in the true biomass. Specifically, if $B_y$ is the true biomass in year *y* and $\hat{B}_y$ is the estimate of it in that year's assessment, then the variance of $\hat{B}_y$ among years is $V\left(\hat{B}_y\right)=V\left(B_y\right)+V\left(\hat{B}_y \mid B_y\right)$. Over the last ten years, the CV of the present biomass estimate has been about 15% in Areas 2C and 3A, and about 20% in Area 2B (owing to the rogue survey CPUE values).

Considering both ways of estimating variance, we believe that a CV of 10-15% is a reasonable value for the present biomass estimate, but as the Area 2B example shows the fits are capable of much larger excursions which can persist for years.

## Estimates of present female spawning biomass in Areas 2B, 2C, and 3A relative to 1974

The Commission's paramount management objective is to maintain a healthy level of spawning biomass, meaning a level above the historical minimum that last occurred in the mid-1970s. Although low, this spawning stock nevertheless produced average or better year-classes. One of the main reasons for implementing a sex-specific assessment was to obtain direct estimates of female mortality rates and female spawning biomass. We now have those estimates, and fortunately they show that female spawning biomass is 3-4 times what it was in the mid-1970s (Figs. 16a-c). So on that score the stock is in good shape.

The numbers of fish aged 8 and older are now 5-10 times what they were in 1974, but their total biomass is only 3-5 times the 1974 level, and exploitable biomass (computed with length-specific commercial selectivities as explained below) only 2-3 times. The difference between the large increase in numbers and the more modest increase in biomass results from the dramatic decline in size at age and therefore commercial selectivity that has occurred over the last fifteen years. A significant part of the age 8+ biomass now consists of males that never get large enough to be caught in any numbers, as shown by their near disappearance from commercial catches in Area 3A (Fig. 6b). Looked at another way, in 1974 a large fraction of the total age 8+ biomass was exploitable; now that fraction is much smaller.

## Length-specific and age-specific commercial selectivities

As in previous length-specific model fits (in the 1990s), commercial selectivity is estimated to be higher in Area 2B than in Area 3A, with Area 2C intermediate (Fig. 18). The estimates for Areas 3B, 4A, and 4B are similar to the Area 2C estimates.

Because length-specific commercial selectivity appears to have been the same for the last thirty years while mean length at age has declined greatly over the last fifteen years, age-specific commercial selectivity has also declined greatly over the last fifteen years (Fig. 19). And because males in the modal age range (10-15) were less vulnerable to begin with, the relative decline in age-specific selectivity of males has been greater than that of females. In Area 3A, males reached full vulnerability by age 15 in the 1970s and 1980s; now even the oldest males are only about 50% vulnerable, while the oldest females are still fully vulnerable. The same sort of change has occurred elsewhere. Females always sustained higher fishing mortality rates than males because they were larger, but twenty years ago females and males both reached the size of full vulnerability at some point. Males no longer reach that point, so an even larger share of fishing mortality is falling on the females.

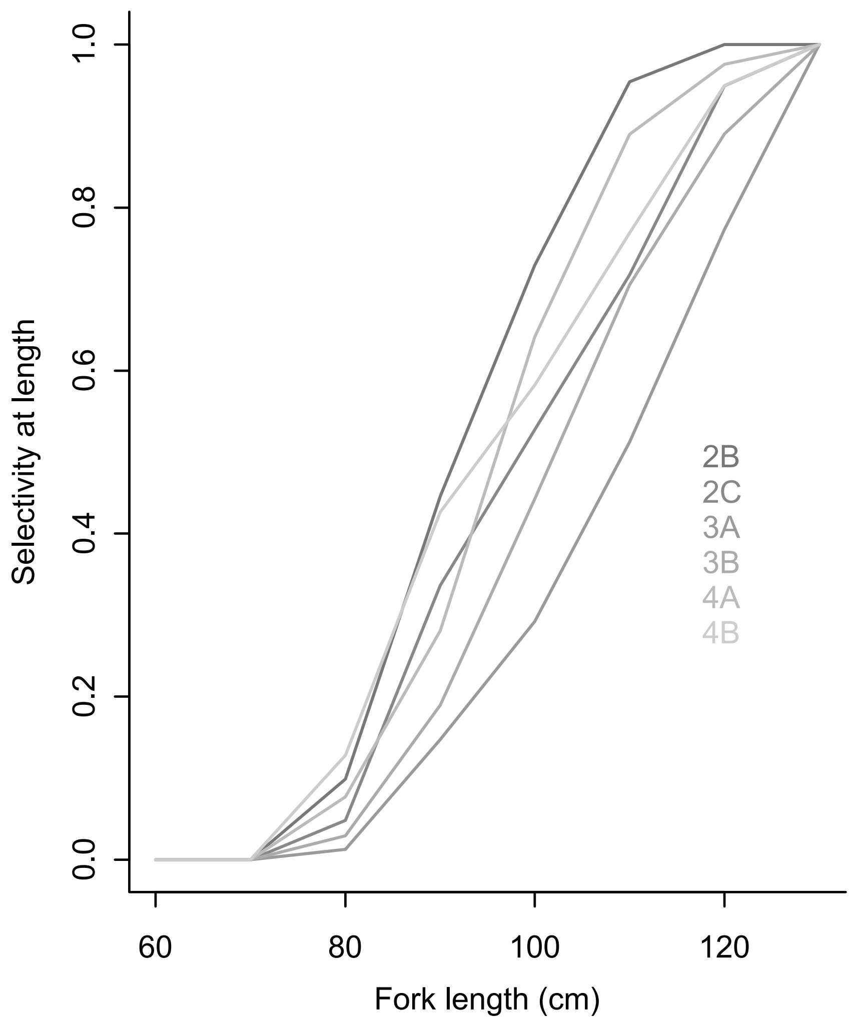


**Figure 18. Estimated length-specific commercial selectivity. The topmost line is Area 2B. The bottom line is Area 3A, and the other Alaska areas are clustered in the middle.**

## Calculation of exploitable biomass

The exploitable biomass of an age/sex group is the product of surviving number, commercial selectivity of the group, and mean weight of the group in commercial landings. The staff has always tried to use the same commercial selectivity schedule in all areas so as to report a single measure of biomass. A common schedule is used for all Alaska areas (approximately the Area 2C estimate), but in Area 2B the local estimate is used because it is substantially higher than all of the Alaska schedules.

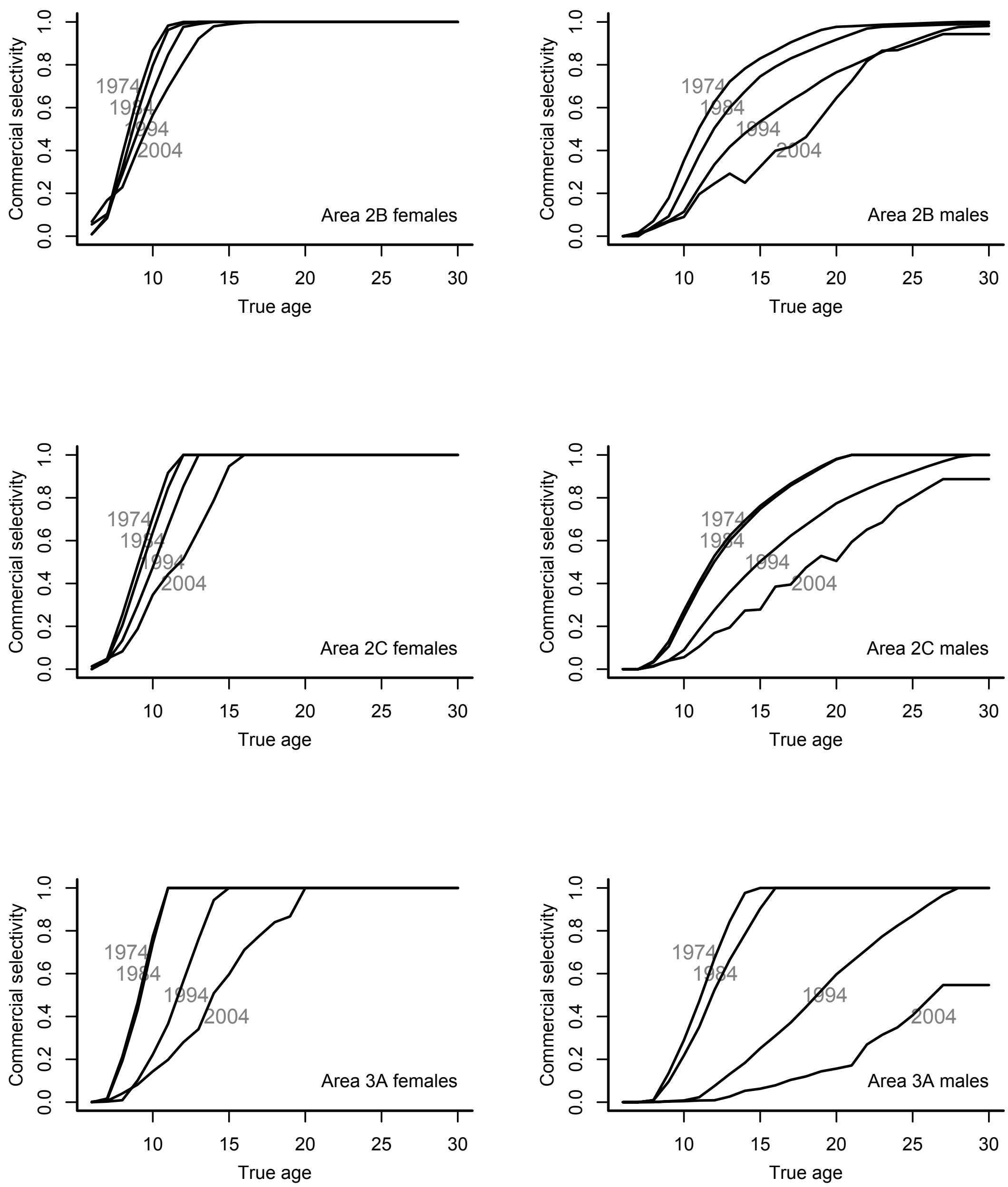


**Figure 19. The downward drift of age-specific commercial selectivities over time due to constant length-specific selectivity and declining size at age, plotted by area and sex.**

## Estimation of exploitable biomass in Areas 2A and 4CDE

Areas 2A and 4CDE present special problems. In Area 2A there are gaps in the commercial data, a history of changes in the commercial and treaty fisheries, sparse survey data, and a large bycatch removal for which we have no length data. Also in Area 4CDE setline survey data are scanty and, like the fishery, limited to the shelf edge. In both areas we lack the data series used in the standard assessment in other areas and so have resorted to an ad hoc procedure to estimate present biomass.

Exploitable biomass in Area 2A is calculated as a proportion of the Area 2B analytical estimate. The proportion used is the ratio of setline survey CPUE's (three-year running mean) weighted by bottom areas:

$$\frac{(\text{2A biomass})}{(\text{2B biomass})} = \frac{(\text{2A CPUE}) \times (\text{2A bottom area})}{(\text{2B CPUE}) \times (\text{2B bottom area})}$$

The idea here is that survey CPUE is an index of density and multiplying it by the total bottom area gives an index of total biomass. The value of the scaling proportion in 2004 was 12%. In the same way, exploitable biomass in Area 4CDE is calculated as a proportion (160% in 2004) of the Area 4A analytical biomass estimate.

The bottom areas used for these calculations (Table 2) are 0-300 fathoms, the upper limit chosen because very few halibut are caught below 300 fathoms in summer.

## Estimated abundance 1935-1973

The modern Pacific halibut stock assessment model produces abundance estimates for the years 1974-present (1996-present in Areas 3B, 4A, and 4B). The modern assessment begins in 1974 because stock biomass reached the historical minimum at that time, and it is of interest to see the comparison between the estimates of present biomass and that reference point. It would not be possible to start the modern assessment any earlier because the survey data only go back to the late 1970s.

The Pacific halibut fishery dates to the late 1890s, and estimates of abundance before 1974 are of interest for a variety of reasons, including evaluating stock-recruitment and environment-recruitment relationships, determining productivity of the stock, detecting evidence of density-dependence and establishing minimum and maximum biomass levels. Catch and effort data from the halibut fishery have been collected since at least the mid-1920s, but the size and age data required for catch at age modeling were first collected in 1935. Data adequate for fitting an age-structured assessment model are available for IPHC regulatory areas 2B, 2C, and 3A. In the western part of the Commission area fishing was light and spotty before the mid-1990s, and there are some large gaps in the data series.

**Table 2. Bottom areas of IPHC regulatory areas (0-300 fm), in square nautical miles.**

| Area | Bottom area |
|---|---:|
| Area 2A in total | 12100 |
| North of Pt. Chehalis at 46º53´ N (“2A-1”) | 4077 |
| Remainder (“2A-2”) | 8023 |
| Area 2B in total | 28100 |
| North of Vacouver Island (50º45´N) | 22074 |
| Remainder (W. coast Vancouver Island) | 6026 |
| Area 2C | 15000 |
| Area 3A | 49500 |
| Area 3B | 30200 |
| Area 4A | 18500 |
| Area 4B | 16200 |
| Area 4CDE (to about 60º N) | 120000 |
| Area 4C | 9600 |
| Area 4D edge (75-300 fm) | 5000 |

The model that is fitted to estimate historical abundance for the period 1935-1973 is simpler than that used for the modern assessment. Absent survey data, the sexes are not distinguished. Only commercial CPUE is available as an abundance index. The historical assessment is joined to the modern assessment by forcing the numbers at age (for sexes combined) to match the "smeared" numbers at age in 1974 in the modern assessment. Because commercial catchability is allowed to drift, the model fit to the early years' data is essentially a VPA (Virtual Population Analysis) with the terminal values fixed, so the historical estimates are entirely determined by the catch at age data; they have no variance to speak of. The historical and modern assessments together provide a seamless time series of recruitment and biomass estimates over the entire time period 1935-2005 for Areas 2B, 2C, and 3A.

## Input data

The basic input data for the historical assessment model are removals at age, weight at age, and effort data. Removal data consist of commercial catch, bycatch, sport catch, personal use, and wastage. The following input data can be found in tables in Hare (2001). A brief description of the data sources follows.

### *Catch at age*

The commercial catch at age data were taken from a recent documentation of IPHC sampling protocols (Clark et al. 2000). These data are for ages 6 to 19 with a plus group for ages 20 and older. (Fish younger than age six are rare in the catch except for Area 2B. The number of such fish that would have survived to age 6 if not caught is added to the assessment estimate of abundance at age 6 when calculating estimates of recruitment.) Catch numbers at age are decremented using an annual natural mortality rate of 0.15 to estimate number of absent six year olds. Strictly speaking, recruitment losses should be distributed among downstream areas using a migration schedule as is done for juvenile bycatch losses (Clark and Hare 1998). That is not done here because only in Area 2B is juvenile catch of any significance and those fish would almost all recruit to Area 2B. Lost recruitment is simply added to estimated numbers at age in the area where the juveniles were captured.

The effects of bycatch are dealt with in a direct and comprehensive manner. Estimates of halibut bycatch mortality (i.e., mortality of halibut in fisheries other than the directed setline fishery) begin in 1962 (Williams et al. 1989); historical length-frequency distributions of bycatch have been assembled recently (Hare et al. 2004). Using a length-age key, the bycatch mortality can be divided into adult (age 8+) and sublegal mortality (see Clark 2000 for details).

Adult and juvenile bycatch mortality are incorporated differently. Adult bycatch mortality is added to the commercial removals and effort data are expanded for the increased removals (see below for methodology). Juvenile bycatch is added to the estimate of age-six recruits in the manner described for commercial catch of juvenile fish. Because the sublegal halibut are in the process of migrating, they are often captured in areas "upstream" from where they would have recruited. The migration model of Clark and Hare (1998) is used to assign recruitment loss by area (using the "Intermediate" model); i.e., lost recruitment is added to the number of six-year- old fish in the area they would have recruited to rather than the area where they were captured (though they are to a large measure the same area).

Three other forms of removal from the halibut population—sport catch, personal use and wastage—are assumed to be negligible prior to 1974.

*Weight at age*

Weight at age has been estimated in a variety of ways over time. The preferred method is to collect fork length samples and estimate weight using a length-weight relationship that has held up well over time (Clark 1992a). However, between 1963 and 1990, fork length was not measured in the field but estimated from otolith measurements (radius from 1963-1967, length from 1968-1977, and weight from 1978-1990). The weight at age data used here for this period were taken from Clark et al. (2000).

*Effort*

The effort data used here were taken from IPHC Technical Report No. 14 (Myhre et al. 1977) which was re-keyed specifically for this purpose. To be consistent with the effort data used in the modern stock assessment, the values from that report have all been divided by a factor of 2.2, reflecting the difference in fishing power between "J" hooks used before 1983 and "C" hooks used since.

## Assessment model

A modified version of the CAGEAN model (Deriso et al. 1985) was used to produce historical estimates of abundance. Prior to fitting, commercial catch at age in number and effort data for each year were expanded to account for bycatch as follows (the temporal subscript is eliminated here for clarity purposes only):

$$C_1 = \sum_{6}^{20+} C_a$$

$$\bar{w} = \frac{\sum_{6}^{20+} \left(C_a \cdot w_a\right)}{C_1}$$

$$C_2 = C_1 + \frac{B}{\bar{w}}$$

$$C'_a = C_a \cdot \frac{C_2}{C_1}$$

$$E' = E \cdot \frac{C_2}{C_1}$$

where $C_a$ is commercial catch at age in numbers, $C'_a$ is expanded catch numbers, $B$ is weight of adult bycatch mortality and $E$ and $E'$ and original and expanded effort numbers, respectively. The operational equations are:

$$C'_{t,a} = N_{t,a} \frac{F_t \cdot Sel_{t,a}}{F_t \cdot Sel_{t,a} + M} \left(1 - \exp\left(-\left(F_t \cdot Sel_{t,a} + M\right)\right)\right)$$

$$N_{t+1,a+1} = N_{t,a} \exp\left(-\left(F_t \cdot Sel_{a,t} + M\right)\right) \qquad a=7, ..., 19$$

$$N_{t+1,20} = N_{t,19} \exp\left(-\left(F_t \cdot Sel_{19,t} + M\right)\right) + N_{t,20} \exp\left(-\left(F_t \cdot Sel_{20,t} + M\right)\right) \qquad a=20+$$

$$SpBio_t = \sum_{a=1}^{20+} N_{t,a} \cdot w_{t,a} \cdot Mat_a$$

$$R_t = N_{t,6} + BycatchLosses$$

where $C$ is catch, $N$ is numbers, $F$ is full recruitment fishing mortality, *Sel* is selectivity, $SpBio$ is spawning biomass, $w$ is weight, $Mat$ is maturity, $M$ is natural mortality and $R$ is age-six recruits. The subscript $t$ indexes time and $a$ indexes age. Recruitments are freely estimated within the model.

### *Catchability and selectivity*

Selectivity is assumed to be a length-specific process. Selectivity was assumed to be 0.0 for lengths less than 60 cm and 1.0 at lengths greater than or equal to 120. Intermediate (monotonically increasing) values $Sel_l$ were estimated at 10 cm intervals with interpolation used to complete the selectivity schedule. Catchability was allowed to drift over time and was implemented as a constrained random walk:

$$\ln(q_{t+1}) = \ln(q_t) + {}_q\varepsilon_t$$

The constraint was implemented in the form of a lambda (inverse variance) in the minimization function.

### *Parameters*

For each area, a total of 137 parameters was estimated:

| Parameter | | Years | Ages | Number |
|---|---|---|---|---|
| Initial abundance | $N_{1935,a}$ | 1935 | 7-20+ | 14 |
| Recruitment | $N_{6,t}$ | 1935-1973 | 6 | 39 |
| Full recruitment fishing mortality | $F_t$ | 1935-1973 | 16+ | 39 |
| Catchability | $q_{1935}$ and ${}_q\varepsilon_t$ | 1935-1973 | | 39 |
| Selectivity | $Sel_l$ | 1935-1973 | | 6 |

### *Objective function*

Parameter estimates were obtained by fitting the model to observations of catch and effort. The variance associated with effort was taken to be half that associated with catch at age (Deriso and Quinn 1985). The objective function is the sum of the weighted residual sum of square (RSS) terms:

$$RSS(C) = \lambda_C \sum_a \sum_t \left(\ln C_{t,a}^{obs} - \ln C_{t,a}\right)^2 \qquad \lambda_C = 1.0$$

$$RSS(E) = \lambda_E \sum_t \left[\ln F_t - \left(\ln q_t + \ln E_t^{obs}\right)\right]^2 \qquad \lambda_E = 0.5$$

The negative log likelihood –ln $L$, ignoring constant terms, is

$$-\ln L = 0.5 n_{obs} \ln\left(RSS(C) + RSS(E)\right)$$

where $n_{obs}$ is the total number of observations. For each regulatory area there are 15 age groups and 39 years of catch at age data and 39 observations of fishing effort, for a total of 624 observations.

The objective function also includes three penalty terms: one to constrain the amount of drift allowed in catchability ( $q_t$ ), another to penalize abrupt changes in selectivity ( $Sel$ ) and a third on differences between the projected numbers at age ( $N_a$ ) in 1974 and the corresponding stock assessment estimates $(N'_a)$. The catchability and selectivity standard deviations were set at 0.05 (similar to values used in the modern assessment) while the numbers at age standard deviation was set much lower at a value of 0.01 to insure the final numbers at age match those generated by the modern assessment for the 1974-present period

$$PSS(Q) = \sum_t {}_q\varepsilon_t^{\,2} \Big/ \left(2 \cdot \sigma_q^2\right)$$

$$PSS(S) = \sum_{k=3}^{K} \left(Sel_k - 2 \cdot Sel_{k-1} + Sel_{k-2}\right)^2 \Big/ \left(2 \cdot \sigma_{Sel}^2\right)$$

$$PSS(N_a) = \sum_{a=7}^{20+} \left(N_a - N'_a\right)^2 \Big/ \left(2 \cdot \sigma_{N_a}^2\right)$$

$$penalties = PSS(Q) + PSS(S) + PSS(N_a)$$

The objective function that was minimized is:

$$OF = -\ln L + penalties = 0.5 n_{obs} \ln\big(RSS(C) + RSS(E)\big) + PSS(Q) + PSS(S) + PSS(N_a)$$

## Model output

For the purposes of the harvest rate analysis, the assessment provides two outputs of interest: long term estimates of recruitment and biomass. The recruitment estimates are straightforward and are illustrated in Figure 20. (All of these estimates of recruitment at age 6 are adjusted for bycatch mortality before age 6.) As detailed in Clark et al. (1999) and Clark and Hare (2002), the most notable aspect of the recruitment time series is the appearance of alternating recruitment "regimes" of 15-30 years duration. A productive regime occurred from at least 1935 until around the mid 1940s, followed by a relatively unproductive regime that lasted until the mid 1970s. Recruitment from spawning in the late 1970s to the present has been at a very high level. The dynamics of recruitment are discussed more fully below in the "Population dynamics" section.

Establishing a long term, consistent estimate of biomass is more problematic. As noted, the early period assessment is not sex specific and there are no fishery-independent estimates of weight at age. Without the sex data, no long-term estimate of female spawning biomass can be made. The change in size limit that occurred in 1974 also precludes estimation of a consistent exploitable biomass time series. The most consistent time series is a measure of total biomass for halibut age 10 and over. Total biomass is the product of numbers at age and weight at age. For the period prior to 1974, there is only the commercial weight at age data. For 1974 and afterwards, estimated survey weight at age is used to compute total biomass. However, the estimated weight at age for ages 6-9 are very different between the two time series, likely due to differences in selectivity. By limiting the total biomass summation to ages 10 and older the time series show a very smooth transition between the two time periods (Fig. 21).

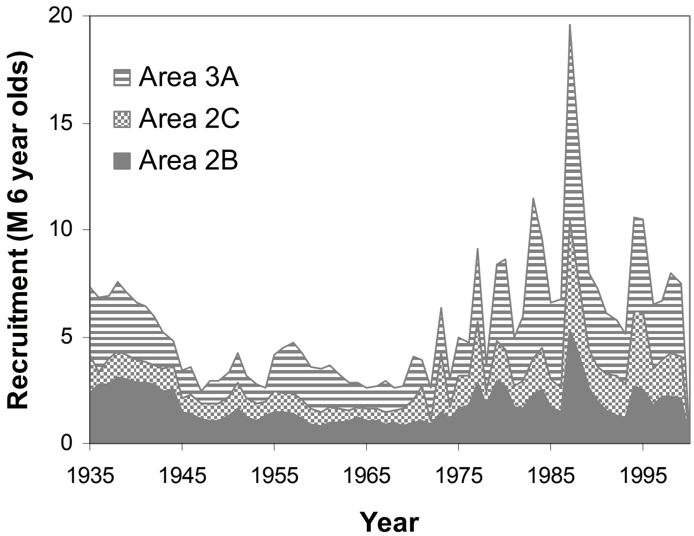


**Figure 20. Trend in recruitment of age-six halibut for IPHC Regulatory Areas 2B, 2C, and 3A. The year plotted is the year of spawning.**

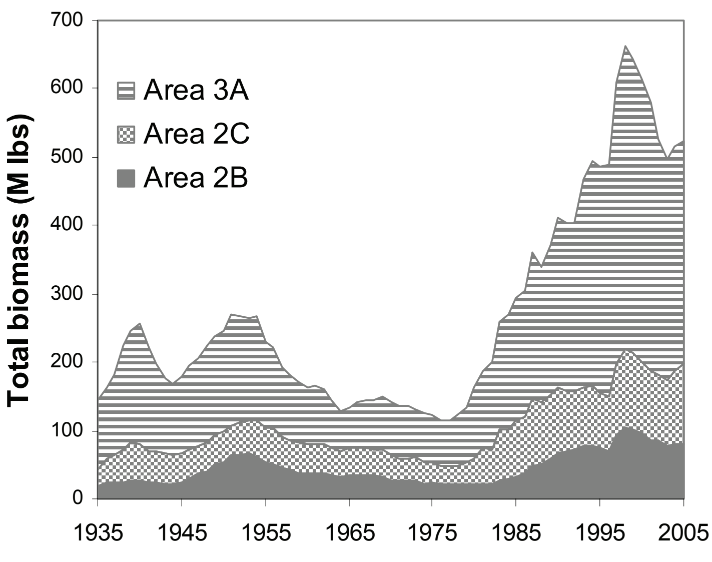


**Figure 21. Trend in total biomass (age 10+) of halibut for IPHC Regulatory areas 2B, 2C and 3A.**

## Population dynamics

The most important aspects of halibut life history as they apply to determining an appropriate harvest strategy are the dynamics of recruitment, growth and maturity. The productivity of halibut depends on its rates of recruitment and growth, both of which have varied greatly over the last 70 years. The pronounced change in size at age also has the potential to affect the maturity and egg production of female halibut. In their analysis of recruitment and growth dynamics, conducted external to the assessment, Clark and Hare (2002) concluded that recruitment was likely environmentally driven (at least within the range of observed spawning stock sizes) while growth was a density dependent process, most closely linked to the number of adult (age 10+) halibut in the population. At the time of their analysis, the halibut assessment was not yet differentiated by sex. The new population assessment model has produced estimates of population and growth rates that, in some cases, differ substantially from the earlier estimates. The basic models for both growth and recruitment have remained unchanged however. In the sections below, the growth and recruitment models are updated from Clark and Hare (2002). For a more complete treatment the source publication should be consulted. The section on maturity is an update of a similar analysis by Parma (1998).

## Recruitment

Although IPHC estimates biomass and sets catch limits for each regulatory area separately, we regard the halibut of the northeast Pacific as a single biological stock because there is no evidence of genetic differences and variations in year-class strength are highly correlated among areas. For those reasons we calculate estimates of total spawning biomass and total recruitment to investigate recruitment dynamics. As explained above, our historical abundance estimates are limited to Areas 2B, 2C, and 3A, so the analysis is perforce limited to these areas.

Halibut recruitment has alternated between high and low "regimes" of productivity over at least the past 70 years. Transitions between regimes most recently occurred in 1947 (from high to low) and 1977 (from low to high). Recent research has linked these productivity regimes to an interdecadal mode of pan-Pacific climate variability termed the Pacific Decadal Oscillation (PDO, Mantua et al. 1997).

A plot of age-six recruits (on a log scale, combining the three core areas) and the annual PDO index is shown in Figure 22. A plot of total (age 10+) biomass and age-six recruitment shows little relationship between the two (Fig. 23) and a simple Ricker stock recruitment (S-R)

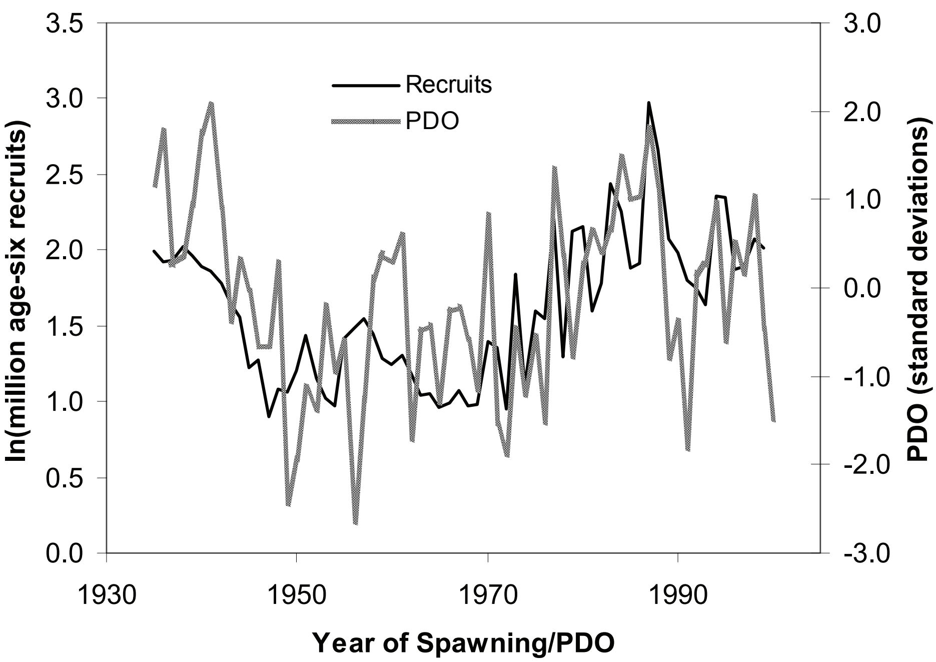


**Figure 22. Trend in the annual index of the Pacific Decadal Oscillation (PDO) and the logarithm of age-six recruits for IPHC areas 2B, 2C, and 3A combined.**

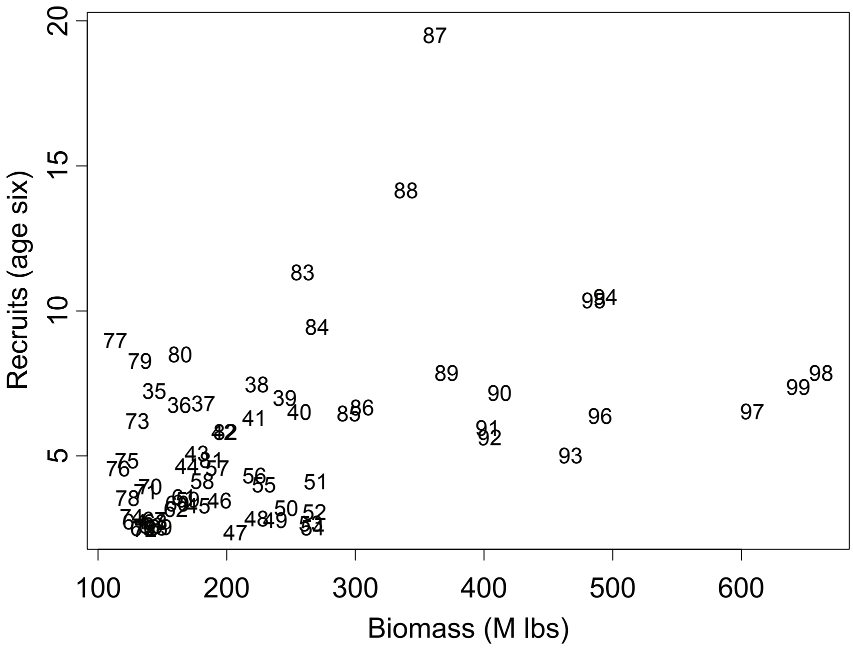


**Figure 23. A biomass-recruit plot for halibut for Areas 2B, 2C and 3A combined. The digit numbers refer to the year class during the 20th century.**

model fits the data very poorly. Clark and Hare (2002) fitted a series of both density-dependent and density-independent models to halibut recruitment data from different periods. The two basic models were as follows, with *i* indexing period:

$$(1) \qquad \ln(R) = \ln(\alpha_i) - \beta \cdot S + \gamma \cdot PDO$$

$$(2) \qquad \ln(R) = \delta_i + \rho \cdot PDO$$

Model 1 is the usual Ricker S-R model but incorporates regime-specific intercepts and includes the annual PDO index in the year of spawning as a covariate. (Leading and lagging PDO values were found to be not significant.) In this update, the measure of biomass that is used is the total biomass of age 10+ halibut. Model 2 predicts recruitment solely on the basis of regime levels and the annual PDO index with no information on biomass.

Both model fits are greatly improved by allowing regime-specific intercept parameters. In addition to the regime shifts in 1947 and 1977, additional intercept parameters for both models were allowed in 1958 and 1970. The reasoning is that this was a period of unreliable bycatch estimates and it is quite possible that our corrections for bycatch (which are added to the number of age-six recruits) do not capture the full effect. The fit of the two models is very similar (Fig. 24). Model fitting statistics—lower values of the Akaike Information Criterion (AIC) and Schwarz' Bayesian Criterion (SBC)—favor Model 2:

| Model 1 | | | | Model 2 | | | |
|---|---|---|---|---|---|---|---|
| Term | Years | Value | SD | Term | Years | Value | SD |
| $\ln(\alpha_1)$ | 1935-1946 | -3.01 | 0.13 | $\delta_1$ | 1935-1946 | 1.67 | 0.08 |
| $\ln(\alpha_2)$ | 1947-1958 | -3.38 | 0.16 | $\delta_2$ | 1947-1958 | 1.37 | 0.07 |
| $\ln(\alpha_3)$ | 1959-1970 | -3.38 | 0.13 | $\delta_3$ | 1959-1970 | 1.17 | 0.06 |
| $\ln(\alpha_4)$ | 1971-1976 | -2.91 | 0.13 | $\delta_4$ | 1971-1976 | 1.55 | 0.10 |
| $\ln(\alpha_5)$ | 1977-1998 | -2.69 | 0.18 | $\delta_5$ | 1977-1998 | 2.00 | 0.05 |
| $\beta$ | 1935-1998 | 0.003 | 0.0004 | No $\beta$ | | | |
| $\gamma$ | 1935-1998 | 0.127 | 0.03 | $\rho$ | 1935-1998 | 0.128 | 0.04 |
| AIC | | -70.7 | | AIC | | -72.2 | |
| SBC | | -55.7 | | SBC | | -59.3 | |

Recruitment for halibut is clearly driven by environmental conditions. The best fit to the recruitment data uses no information on spawning stock size. The best fit for a model using spawning stock as a predictor has regime specific parameter values further verifying the importance of the PDO to halibut recruitment. For the population dynamics simulations described later, recruitment is modeled as a purely environmentally driven process.

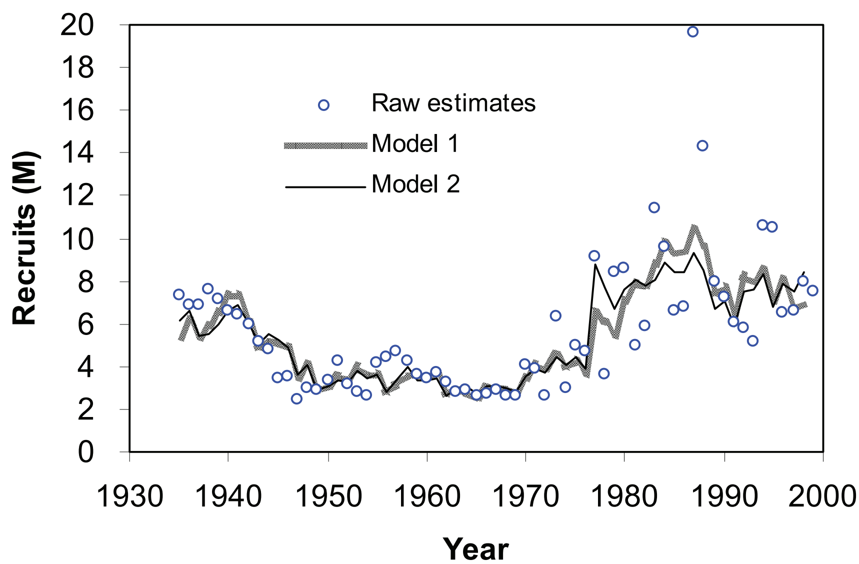


**Figure 24. Raw halibut recruitment estimates and values predicted by fits of model 1 and model 2. See text for details.**

## Growth

Long-term changes in size at age have long been noted for halibut. Halibut of both sexes and all ages 8 and older are substantially smaller than halibut of the same sex and age 30 years ago. However, halibut of the same size at age were seen in the 1920s and 1930s. Clark and Hare (2002) estimated trends in growth using a simple linear model of growth with time varying parameters. Separate models were fitted for IPHC Areas 2B and 3A. The models were of the form:

$$w_a = w8_y + \sum_{9}^{a} GI_y$$

in which weight at age $w_a$ is modeled as the sum of mean weight at age 8 ($w8_y$) and annual growth increments ($GI_y$) thereafter. Mean weight at age 8 and growth increments were estimated every 10 years between 1920 and 2000 and annual values were then interpolated. The resulting time series for both growth parameters were then plotted against environmental and stock indices. Both growth parameters showed the strongest linear relationship with total numbers of adult halibut (age 10+) with little evidence for an environmental influence. Figure 25 illustrates growth trends for males and females in IPHC Areas 2B and 3A and the contemporary trajectories of total adult numbers. A slightly modified form of this relationship between population size and growth increment is used to model growth dynamics in the simulation modeling described below.

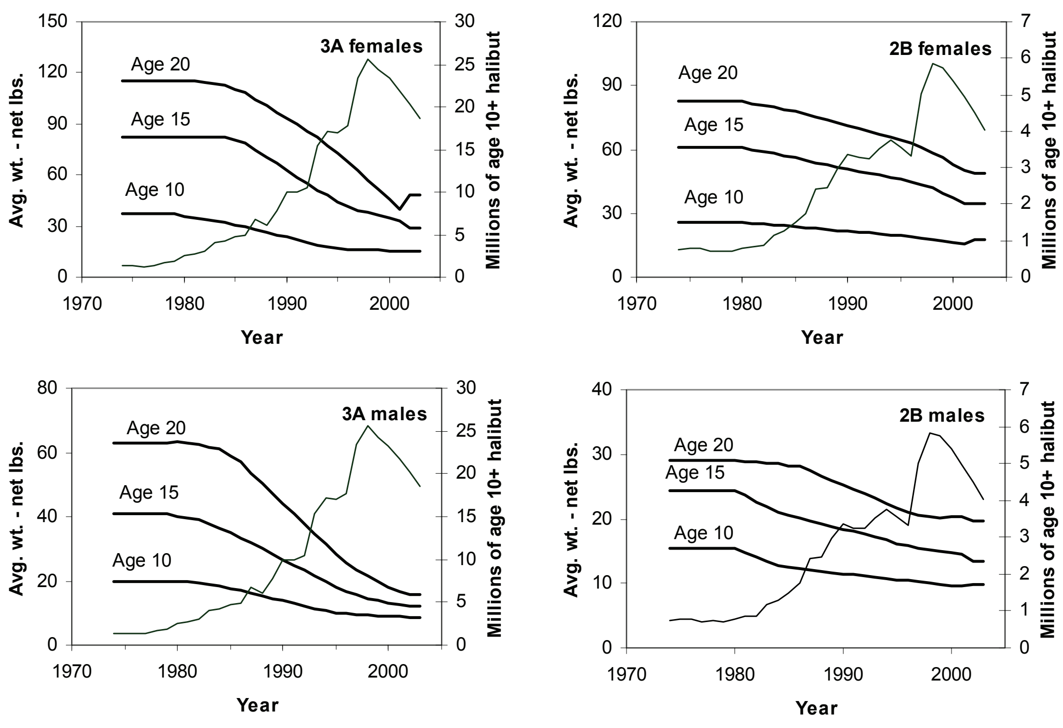


**Figure 25. Halibut weight at age from 1974 to 2004. Trend lines are shown for three ages and both sexes for IPHC areas 2B and 3A. The contemporary trajectory of total numbers of adult halibut (ages 10+) is shown as a thin line.**

## Maturity

Halibut maturity at age has been examined several times, most recently by Parma (1998). All previous analyses were conducted using halibut ages determined by surface readings. We re-examined maturity at age in Areas 2B and 3A during several time periods to look for time trends. For comparison we also examined maturity at length. The available maturity data were grouped as follows: 1963-1966, 1976-1983, 1992-1996, 1997-2001, 2002-2003. To estimate proportion mature *p* at age/length, logistic functions were fitted to the data for each period and region. The form of the function was as follows:

$$p = \frac{1}{1+\exp\left(-k\cdot\left(A-A_{50}\right)\right)} \quad \text{or} \quad p = \frac{1}{1+\exp\left(-k\cdot\left(L-L_{50}\right)\right)}$$

where $k$ is a slope parameter and $A_{50}$ is the age, and $L_{50}$ is the length, at which 50% of the females are mature. To avoid mixing ages from different reading techniques, only surface ages were used for the periods prior to 2001 and only break and burn ages were used for 2002-2003.

The results are illustrated in Figure 26 and maturity function parameter estimates are given in Table 3. Despite the differences in time periods and aging techniques, female maturity at age has been remarkably consistent over time and between Areas 2B and 3A. These time periods capture the extreme in changing growth rates over time and show that maturity is likely determined mainly by age and not by size. The age at which 50% of females attain maturity varies from a low of 10.47 in 2B in the early 90's to a high of 12.27 in 2B in 2002-2003. In Area 2B, the higher age at 50% maturity might be attributed to the new aging technique but a similar increase in $A_{50}$ was not found in Area 3A. The difference in assigned ages is not appreciable until after approximately age 15 and this accounts for why there is no systematic difference between the different aging types. For the harvest rate simulations, we use a single maturity schedule with the parameter estimates from the logistic model fitted to all 2002-2003 data for both areas ( $A_{50}$ = 11.59, $k$ = 0.563).

**Table 3. Time periods, sample sizes, and parameter estimates for logistic function fits to Pacific halibut maturity data at age (A) and length (L).**

| Area | Years | n | $A_{50}$ | k | $L_{50}$ | k |
|---|---|---|---|---|---|---|
| 2B | 1963-1966 | 647 | 11.96 | 0.515 | 119.71 | .111 |
| 2B | 1976-1983 | 753 | 10.99 | 0.772 | 111.14 | .100 |
| 2B | 1992-1996 | 3581 | 10.47 | 0.674 | 97.60 | .093 |
| 2B | 1997-2001 | 5419 | 10.78 | 0.583 | 93.65 | .099 |
| 2B | 2002-2003 | 2124 | 12.27 | 0.555 | 101.36 | .107 |
| 2B | All years | 12528 | 10.97 | 0.592 | 98.15 | .089 |
| | | | | | | |
| 3A | 1963-1966 | 2538 | 10.45 | 1.043 | 119.59 | .169 |
| 3A | 1976-1983 | 3514 | 11.62 | 0.887 | 125.98 | .129 |
| 3A | 1992-1996 | 4389 | 10.91 | 1.002 | 92.09 | .122 |
| 3A | 1997-2001 | 5508 | 10.66 | 0.789 | 85.44 | .095 |
| 3A | 2002-2003 | 2222 | 10.83 | 0.527 | 85.25 | .091 |
| 3A | All years | 18175 | 10.93 | 0.822 | 96.53 | .060 |
| | | | | | | . |
| All areas | 2002-2003 | 4347 | 11.59 | 0.563 | 97.63 | .070 |
| All areas | All years | 30704 | 10.91 | 0.711 | 93.37 | .093 |

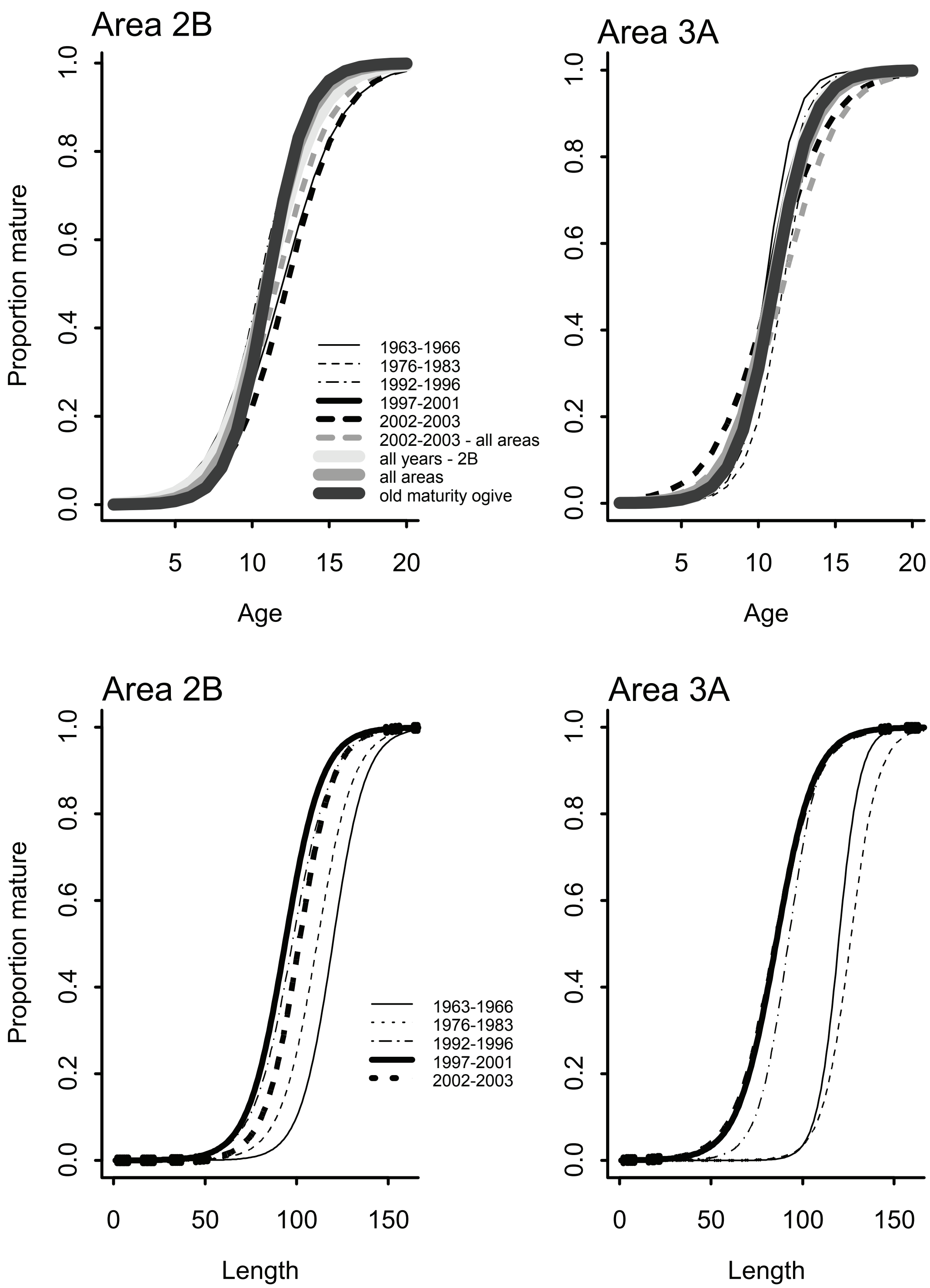


**Figure 26. Maturity at age and maturity at length ogives for Pacific halibut in Areas 2B and 3A for a variety of time periods.**

There has been a highly significant change in maturity at length. Length at 50% maturity ranged from a high of 120 cm in the 1960s to a low of 94 cm in the late 1990s in Area 2B and from a high of 126 cm in the 1970s to a low of 85 cm in the late 1990s in Area 3A. As shown by the 2002-2003 break and burn data, the declining trend in maturity at length has stopped and even rebounded slightly in Area 2B. Based on these results, maturity is modeled as an age-dependent process in the simulation modeling conducted for the harvest policy analysis.

## Harvest policy

Since 1985, the IPHC has followed a constant harvest rate (CHR) policy to determine annual available yield, termed the Constant Exploitation Yield (CEY). The harvest rate, which is the fraction of the exploitable biomass allowed to be harvested annually, has changed over time, from 0.35 in 1985 to 0.30 in 1993 to 0.20 in 1996 to a provisional rate of 0.25 in 2003 to the current value of 0.225 set in 2004. Prior to the CHR policy, harvests were set as a percentage of the estimated annual surplus production (ASP). The ASP policy was implemented at a time of historically low biomasses (Deriso and Quinn 1985). The change to a CHR policy occurred once the stocks were considered to have been rebuilt.

A constant harvest rate policy has a number of attractive features. The CEY rises and falls smoothly with the biomass; catches are automatically scaled down at lower biomasses and increased during periods of high biomass levels. Yields near the theoretical maximum sustainable yield can be taken across a broad range of harvest rates. In a number of simulation studies, a CHR policy has been shown to be quite robust to climate induced variability in productivity of the stock (Walters and Parma 1996, Hilborn and Walters 1992). A CHR policy has also been well received by the industry – it is relatively simple to understand and the halibut fishery has enjoyed a sustained period of high yields.

Between 2002 and 2004, the IPHC staff developed a modified CHR policy, termed the Conditional Constant Catch (CCC) harvest policy (Clark and Hare 2004). The CCC harvest policy was developed to provide more stable catch quotas than the CHR policy used by the IPHC for the past 20 years. The defining features of the CCC policy were an upper cap on quotas at high biomass levels and minimum biomass limits and thresholds at low biomass levels (Hare and Clark 2003). Ultimately, the policy was rejected for use in the halibut fishery. Much of the simulation work done during analyses of the CCC policy is relevant to the current CHR policy and is summarized in this report.

In the years since a CHR policy was adopted, numerous changes have taken place in the halibut stock assessment, and in our understanding of the population dynamics of the stock. With each change, the harvest policy is re-evaluated and an appropriate harvest rate determined. Factors such as density dependent growth and recruitment regimes present novel challenges in modeling halibut population dynamics. The harvest policy builds upon an understanding of the long term dynamics of the stock, and is investigated using a simulation model that incorporates time varying stock dynamics. For this reason, the harvest policy is developed based on the productivity of the IPHC "core" areas, i.e., Areas 2B, 2C and 3A.

### Implementation of a minimum biomass threshold and limit

The IPHC considers first and foremost the impact of the harvest policy on female spawning biomass. The approach taken is one of avoidance of dropping below the minimum observed historical level. This is different from the philosophy where harvest control rules are based on a more theoretical construct: spawning biomass per recruit. Within the three areas being analyzed, halibut populations rebounded from the minimum spawning biomasses of the early 1970s to the high levels observed for the past 15-20 years. We can have some confidence therefore of stock dynamics at those spawning biomass levels, but not at lower levels. There is no compelling reason to allow spawning biomass to drop below the minimum limit.

In keeping with the global movement towards precautionary management, an additional biomass safeguard was investigated and adopted. The terms "threshold" and "limit" have come into use in fisheries management to define levels at which extra conservation measures are implemented. There is no universally accepted definition for the terms and they are often used interchangeably. For the purposes of the Pacific halibut harvest policy, we define threshold as a level at which more conservative harvest rates begin to apply, and limit as a biomass level at which all fishing on the stock ceases.

There are at least two rationales for establishing reasonable minimum biomass safeguards. A fairly common threshold is $B_{MSY}$, i.e., the equilibrium biomass when fishing at the MSY rate. A common limit associated with this threshold is 0.5 $B_{MSY}$. This is somewhat problematic for halibut due to its alternating productivity regimes as well as density dependent growth. A second rationale for selecting a limit and threshold has to do with what has historically been observed for the stock. If a stock has been monitored long enough to observe a descent to, and recovery from, a low point then that low point may be a "safe" minimum limit. We followed this second rationale in establishing a minimum biomass threshold and limit for Pacific halibut.

The minimum observed spawning biomasses for the three IPHC core areas all occurred in the mid 1970s, approximately 9 million pounds in 2B, 13 million pounds in 2C and 42 million pounds in 3A. By definition, these become the spawning biomass limits. These are common sense limits. In the IPHC harvest policy, the target harvest rate is linearly scaled downwards once spawning biomass reaches the threshold. In simulations, this was found to be very effective in returning the spawning biomass to at least the threshold in a short time without greatly affecting yield. We tested several thresholds, ranging from 1.25 to 2.00 times the limit. A threshold equal to 1.5 times the limit performed well in simulations, producing lower variability in yield than higher or lower values (Hare and Clark 2003). The IPHC modified CHR policy is illustrated in Figure 27.

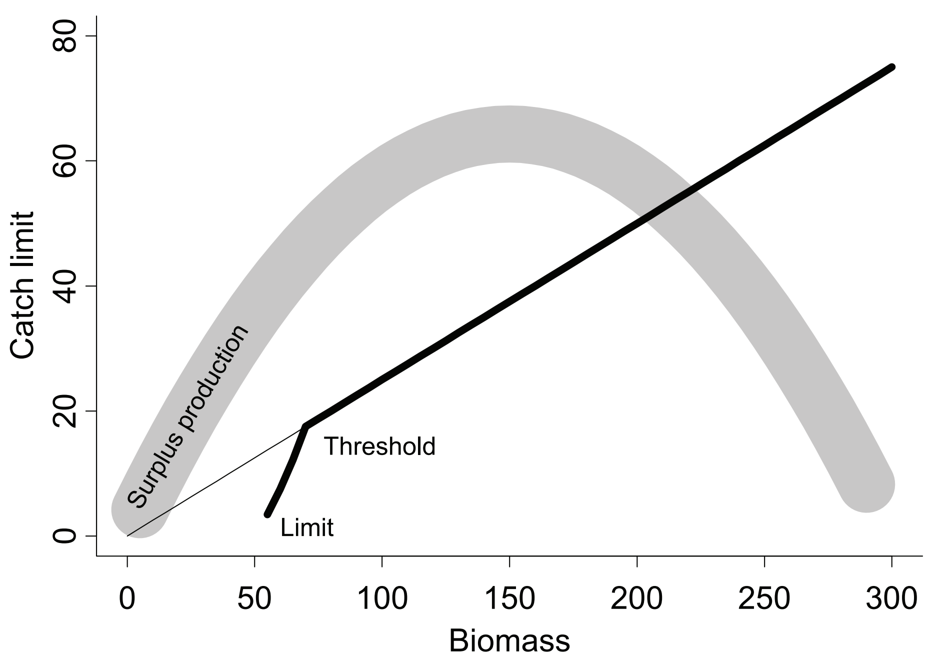


**Figure 27. Illustration of how a modified constant harvest rate policy would operate. Above the threshold the harvest rate is equal to the slope of the angled line. The harvest rate scales down to a rate of 0.0 as the biomass drops below the threshold and approaches the limit. Theoretical relaionship between biomass and surplsus production is illustrated in the background. All units are arbitrary.**

## Performance of harvest policy

The goal of the halibut harvest policy is to achieve a high level of yield while at all times maintaining a healthy female spawning biomass (all subsequent references to spawning biomass imply female spawning biomass). Over the past few years there have been several advances in our understanding of halibut population dynamics. Several substantive changes have also occurred in the stock assessment model used to estimate population. Among the most important changes since the last published analysis of the harvest policy (Sullivan et al. 1997) are: a lower natural mortality rate, independent accounting of sexes, quantification of aging error, length-specific selectivity, and the new views about factors affecting growth and recruitment. A constant harvest rate policy has served the halibut population well but needs to be re-examined in light of these changes.

### *Simulation model*

The harvest policy is investigated via standard population dynamics simulation. The simulation model has separate accounting of males and females and sex-specific growth rates. Stock dynamics are modeled as described above, with recruitment controlled by environmental conditions and growth varying in a density-dependent manner. Separate simulation models are run for each area.

Under the modern assessment model, average recruitment (in millions of age-6 recruits) for the periods before and after the regime shift of 1977 are as listed in the following table. Recruitment estimates have been adjusted for bycatch losses to the commercial groundfish fisheries.

| Area | 1968-1976 | 1977-1998 | All years |
|---|---|---|---|
| **2B** | 1.18 | 2.35 | 2.02 |
| **2C** | 1.17 | 2.16 | 1.89 |
| **3A** | 2.80 | 7.39 | 6.06 |
| **Combined** | 5.14 | 11.84 | 9.98 |

Area 3A accounts for approximately 60% of total recruitment to the three regions while Areas 2B and 2C each account for about 20%; annually simulated recruitment was divided among the three areas in these proportions. We simulated the duration of a PDO-associated climate regime by drawing from a uniform (15, 30) distribution. For the harvest rate simulations, we modeled recruitment as alternating regimes of high and low productivity. During productive regimes average recruitment into the three regions was 11.84 million age-6 halibut (50% male and 50% female), and during unproductive regimes average recruitment was 5.14 million age-6 halibut. Variability within regimes was generated using the following relationships:

$$R_6 = \exp(\ln(\mu_i)) + \varepsilon_t$$
$$\varepsilon_t = \rho\varepsilon_{t-1} + e_t$$

where $\mu$ is average recruitment, *i* indexes regime, lag-1 autocorrelation $\rho$ = 0.1 (estimated from the observed recruitments), $\varepsilon_t$ is autocorrelated error, $e_t$ is normal process error with $\sigma_\varepsilon$ =0.4 ( $\rho$ and $\sigma_\varepsilon$ obtained from residuals of recruitment Model 2 described above).

The method devised by Clark and Hare (2002) to estimate density dependent effects on growth was altered slightly to account for changes in size at age since that analysis. The growth model developed for this analysis contains three growth parameters: mean size at age 6, an annual growth increment between ages 6 and 20, and an annual growth increment between ages 21 and 30. Growth in weight is therefore linear from age 6 to 20 at one rate and then linear at a different (and lower) rate from ages 21 to 30. There are separate parameter estimates for each area (Area 2B, 2C, 3A and all three regions combined), sex and fishery (survey and commercial). For each area, sex and fishery type, there are high and low values for the two annual growth increments and these are related to the number of adult animals in the stock. Size at age 6 varies by sex, region and fishery but is constant across population size. The parameter estimates, along with minimum and maximum mean weight at age for ages 20 and 30 are given in Table 4. Weight at age from the survey is used to represent the weight of halibut in the population (e.g., for computing spawning biomass and total biomass), weight at age from the commercial fishery is used to represent the weight of halibut in the catch (e.g., for computing exploitable biomass and numbers of fish caught).

Selectivity is assumed to be a fixed function of length. Commercial selectivity assumes the current 81 cm size limit and approximates the selectivities estimated in the modern stock assessment. For areas 2C and 3A the selectivity schedule is as follows:

$$Sel = 0 \qquad L \le 80$$

$$Sel = \frac{(L - 80)}{40} \qquad 81 \le L < 120$$

$$Sel = 1 \qquad L \ge 120$$

Area 2B has consistently shown higher selectivity at length than Areas 2C and 3A. The schedule used in Area 2B is:

$$Sel = 0 \qquad L \le 75$$

$$Sel = \frac{(L - 75)}{35} \qquad 76 \le L < 110$$

$$Sel = 1 \qquad L \ge 110$$

A survey selectivity schedule was also used to evaluate the effect of dropping the minimum size limit (and making the assumption that commercial selectivity would then be comparable to survey selectivity). The survey selectivity schedule is similar to the commercial selectivity schedule for Areas 2C and 3A but the lengths at which selectivity equals zero and one are 70 cm and 130 cm, respectively. The same survey selectivity schedule was used for all three areas.

Selectivity at age is computed by combining the fixed selectivity at length schedules with estimated length at age. Length at age ($L_a$) is computed from mean weight at age ($w_a$) by inverting the length-weight relationship (Clark 1992a):

$$L_a = \sqrt[\frac{1}{3.24}]{\frac{w_a}{0.00000692}}$$

In general, this method underestimates mean length compared to the usual method of integrating across length using the observed mean length at age and standard deviation. An analysis of survey data showed that the underestimate of mean length computed in this manner is at most 2%; this difference is quite minor and allows us to use our growth model point estimates of mean length.

**Table 4. Growth parameters used to establish current and past weight at age by area, sex, fishery and age. See text for details on model.**

| Area | Sex | Min-Max | Age 10+ fish in population | Age 6 weight (net lbs) | 7-20 growth increment (net lbs) | 21-30 growth increment (net lbs) | Age 20 wt (net lbs) | Age 30 wt (net lbs) |
|---|---|---|---|---|---|---|---|---|
| **Setline survey parameters** | | | | | | | | |
| 2B | F | Min | 1 | 9.0 | 3.0 | 2.0 | 51.0 | 71.0 |
| | F | Max | 6 | 9.0 | 5.2 | 2.5 | 81.8 | 106.8 |
| | M | Min | 1 | 6.0 | 1.0 | 0.5 | 20.0 | 25.0 |
| | M | Max | 6 | 6.0 | 1.7 | 1.0 | 29.8 | 39.8 |
| 2C | F | Min | 1 | 7.0 | 4.0 | 1.5 | 63.0 | 78.0 |
| | F | Max | 6 | 7.0 | 6.5 | 2.5 | 98.0 | 123.0 |
| | M | Min | 1 | 5.5 | 1.3 | 1.0 | 23.7 | 33.7 |
| | M | Max | 6 | 5.5 | 2.5 | 1.0 | 40.5 | 50.5 |
| 3A | F | Min | 2 | 7.0 | 2.5 | 2.0 | 42.0 | 62.0 |
| | F | Max | 25 | 7.0 | 8.0 | 2.0 | 119.0 | 139.0 |
| | M | Min | 2 | 7.0 | 1.0 | 0.5 | 19.0 | 24.0 |
| | M | Max | 25 | 7.0 | 4.0 | 2.0 | 61.0 | 81.0 |
| All | F | Min | 4 | 8.0 | 3.0 | 2.5 | 50.0 | 75.0 |
| | F | Max | 37 | 8.0 | 6.5 | 2.5 | 99.0 | 124.0 |
| | M | Min | 4 | 5.5 | 1.0 | 1.0 | 19.5 | 29.5 |
| | M | Max | 37 | 5.5 | 3.0 | 1.0 | 47.5 | 57.5 |
| **Commercial fishery parameters** | | | | | | | | |
| 2B | F | Min | 1 | 15.0 | 2.3 | 2.0 | 47.2 | 67.2 |
| | F | Max | 6 | 15.0 | 4.8 | 2.5 | 82.2 | 107.2 |
| | M | Min | 1 | 13.0 | 0.5 | 0.6 | 20.0 | 26.0 |
| | M | Max | 6 | 13.0 | 1.2 | 0.9 | 29.8 | 38.8 |
| 2C | F | Min | 1 | 13.0 | 3.0 | 2.4 | 55.0 | 79.0 |
| | F | Max | 6 | 13.0 | 6.3 | 2.4 | 101.2 | 125.2 |
| | M | Min | 1 | 14.0 | 0.7 | 1.0 | 23.8 | 33.8 |
| | M | Max | 6 | 14.0 | 2.0 | 1.0 | 42.0 | 52.0 |
| 3A | F | Min | 2 | 13.0 | 2.0 | 1.0 | 41.0 | 51.0 |
| | F | Max | 25 | 13.0 | 7.5 | 4.0 | 118.0 | 158.0 |
| | M | Min | 2 | 13.0 | 0.5 | 0.5 | 20.0 | 25.0 |
| | M | Max | 25 | 13.0 | 3.5 | 2.0 | 62.0 | 82.0 |
| All | F | Min | 4 | 13.0 | 2.5 | 1.5 | 48.0 | 63.0 |
| | F | Max | 37 | 13.0 | 6.3 | 3.0 | 101.2 | 131.2 |
| | M | Min | 4 | 13.0 | 0.5 | 0.6 | 20.0 | 26.0 |
| | M | Max | 37 | 13.0 | 2.0 | 1.3 | 43.8 | 56.8 |

### *Simulation results*

The combination of alternating recruitment regimes and density dependent growth response results in complex population dynamics. To some extent, halibut are cushioned against a rapid decline in population biomass by the higher growth rates achieved at low population sizes. The prime age classes in the catches — ages 11 to 17 — can weigh more than twice as much at a given age at low population numbers than when the population is at a high level. We did not extrapolate beyond the data to estimate growth rates at population numbers smaller than we have observed.

In Clark and Hare (2004), harvest rates up to a maximum of 0.40 were investigated; values higher than 0.40 sometimes drove spawning biomass below the limit, but values equal to or less did not. Thus, a harvest rate of 0.40 functions in the same manner as the "maximum fishing mortality threshold" that is defined under National Standard 1 for NMFS' managed groundfish stocks. By that definition, harvest rates above the reference value of 0.40 would constitute "overfishing". By restricting allowable harvest rates to the range of 0.00 to 0.30, allowance is made for observation error in estimates of exploitable biomass. Analysis of retrospective patterns in halibut assessments indicate initial stock biomass estimates have a coefficient of variation of 10-15% (Clark and Hare 2005). Thus, even with a persistent underestimate of the true stock biomass, restriction of harvest rates to a maximum of 0.30 would ensure that the maximum rate of 0.40 would not be reached.

For each harvest rate and area, simulations run forward (from currently estimated numbers and weight at age) for 150 years to establish equilibrium conditions, and performance statistics are tabulated for the next 100 years. Two hundred Monte Carlo replicates are run and results are averaged across replicates. Many population and catch indices are tracked in the simulations; for purposes of selecting a harvest rate, four sets of indicators are used: average catch, frequency of spawning biomass reaching the threshold, realized average harvest rate, and long term average spawning biomass relative to unfished level. Other indicators of interest but not reported here include, e.g., female proportion in the catch, numbers of age 20+ fish remaining in the population, average weight of fish in the catch, etc.

A reference set of simulations and results are developed for the "Most Likely" scenario, i.e., one incorporating all dynamics as outlined above. In addition to reporting results for the "Most Likely" scenario, a second set of results are shown for an alternative scenario—the "Low Growth" scenario. This scenario is utilized to test the robustness of the harvest policy to what is likely the most critical of the dynamic life history traits: density dependent growth. Under this scenario, it is assumed that the current low growth rates—attributed to large numbers of fish in the population—are instead the result of some fundamental ecosystem change. Alternatively, a low growth rate might occur if the halibut population had been "culled" of fish with a genetic disposition towards rapid growth. This alternative scenario is believed to be the most realistic alternative scenario. In previous analysis, other scenarios were examined, including redistributed recruitment among areas and continuous low recruitment levels (Hare and Clark 2003).

The dynamics of the modeled population and effect of the harvest policy are illustrated in Figure 28. The figure shows a single 100-year run for Area 3A at a harvest rate of 0.25. The top panel shows alternating regimes of productivity. The second panel shows how recruitment varies within and between regimes. The third panel illustrates how the mean weight at age for 14 year old halibut change over time in response to varying population numbers. The fourth panel shows yield varying between a low of approximately 25 million pounds to a maximum of nearly 70 millions pounds. Due to their larger size, females form a larger fraction of the yield. The trajectory of spawning biomass is illustrated in the fifth panel. Two lines are shown here – the thin line shows what the biomass trajectory would have been absent the minimum spawning biomass threshold and limit. The thick line show the trajectory when the threshold and limit are imposed and the harvest rate is reduced once spawning biomass reaches the threshold. It is clear that the imposition of the reduced harvest rate acts to limit the downward tendency of the spawning biomass. The bottom panel shows the realized harvest rate, i.e., any excursions below 0.25 represent years that the spawning biomass reached the threshold and triggered a harvest rate reduction.

Performance statistics for both the Most Likely and Low Growth scenarios are summarized in Table 5. Differences between growth scenarios are greatest in Area 3A because the density

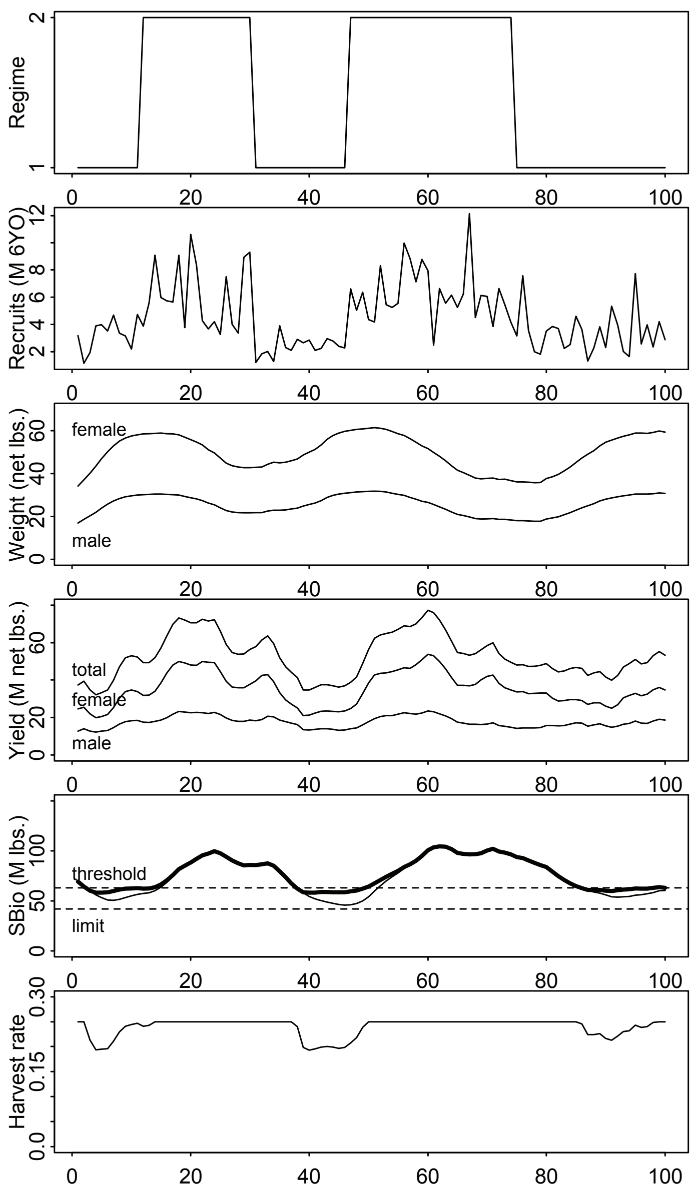


**Figure 28. An illustration of the simulations conducted to test the harvest rate policy. The x axis in all plots is years. The top panel plot shows the duration of alternating regimes. Below that is shown total age 6 recruits, next is average weight of a 14 year old fish (male and female), next is yield (male, female and total), next is Spawning Biomass (SBio, females only, threshold and limit biomass reference levels shown as horizontal lines), and bottom panel shows actual harvest rate. These simulations are for Area 3A at a target harvest rate of 0.25.**

**Table 5. Performance statistics for a range of harvest rates under the Most Likely (Density Dependent (DD) Growth) and Low Growth scenarios.**

| DD Growth | | | | Low Growth | | | |
|---|---|---|---|---|---|---|---|
| | Average annual yield (million pounds) | | | | Average annual yield (million pounds) | | |
| HR | 2B | 2C | 3A | HR | 2B | 2C | 3A |
| 0.000 | 0 | 0 | 0 | 0.000 | 0 | 0 | 0 |
| 0.200 | 15.3 | 16.2 | 45.0 | 0.200 | 11.5 | 11.5 | 23.5 |
| 0.225 | 16.0 | 17.1 | 49.2 | 0.225 | 11.9 | 11.9 | 24.4 |
| 0.250 | 16.6 | 17.8 | 52.9 | 0.250 | 12.2 | 12.2 | 25.2 |
| 0.275 | 17.1 | 18.3 | 56.1 | 0.275 | 12.5 | 12.4 | 25.8 |
| 0.300 | 17.5 | 18.8 | 58.9 | 0.300 | 12.7 | 12.6 | 26.4 |

| | Average spawning biomass (fraction of HR=0.00 biomass) | | | | Average spawning biomass (fraction of HR=0.00 biomass) | | |
|---|---|---|---|---|---|---|---|
| HR | 2B | 2C | 3A | HR | 2B | 2C | 3A |
| 0.000 | 105.0 | 122.6 | 268.0 | 0.000 | 100.4 | 117.3 | 250.7 |
| 0.200 | 0.24 | 0.27 | .036 | 0.200 | 0.22 | 0.27 | 0.36 |
| 0.225 | 0.20 | 0.24 | 0.32 | 0.225 | 0.20 | 0.24 | 0.34 |
| 0.250 | 0.18 | 0.22 | 0.30 | 0.250 | 0.18 | 0.22 | 0.32 |
| 0.275 | 0.16 | 0.20 | 0.28 | 0.275 | 0.17 | 0.21 | 0.30 |
| 0.300 | 0.15 | 0.18 | 0.26 | 0.300 | 0.15 | 0.19 | 0.29 |

| | Average actual harvest rate | | | | Average actual harvest rate | | |
|---|---|---|---|---|---|---|---|
| HR | 2B | 2C | 3A | HR | 2B | 2C | 3A |
| 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.200 | 0.200 | 0.200 | 0.199 | 0.200 | 0.199 | 0.198 | 0.193 |
| 0.225 | 0.224 | 0.222 | 0.222 | 0.225 | 0.220 | 0.218 | 0.211 |
| 0.250 | .0244 | 0.242 | 0.240 | 0.250 | 0.238 | 0.236 | 0.228 |
| 0.275 | 0.261 | 0.258 | 0.256 | 0.275 | 0.253 | 0.252 | 0.244 |
| 0.300 | 0.276 | 0.273 | 0.270 | 0.300 | 0.268 | 0.267 | 0.258 |

dependent variation in growth is greatest there. The results show the expected pattern of increasing catch and decreasing spawning biomass. Average annual yield increases rapidly from a harvest rate of 0.00 to 0.20 and then increases only moderately up a harvest rate of 0.30. Average spawning biomass declines sharply in response to fishing. At a harvest of 0.20, average spawning biomass declines to 24-36% of the unfished average. At a harvest rate of 0.30, average spawning biomass drops as low as 15% of the unfished value in Area 2B. The realized harvest rate begins to drop below the target harvest rate at a target harvest rate of 0.20 and accelerates rapidly thereafter. This is illustrated in Figure 29, which depicts the percentage of time that spawning biomass drops below the minimum biomass threshold. Every time the threshold is reached, the realized harvest rate is less than the target harvest rate. Under the Most Likely scenario, at a target harvest rate of 0.25 the minimum biomass threshold is reached 21-29% of the time in the three IPHC areas. At a harvest rate of 0.30, the threshold is reached approximately twice as often as at a rate of 0.25. However, at a slightly reduced harvest rate of 0.225, the frequency of reaching the threshold is less than half the frequency at 0.25.

## Discussion

A CHR strategy has been used to establish catch limits at the IPHC for 20 years. The harvest rate has ranged from a low of 0.20 to a high of 0.35. The latter value, based on old estimates of recruitment and growth, appears now to be clearly too large. The optimal value thus appears to be within a range of 0.20-0.30. On the basis of the relative infrequency of reaching the minimum biomass threshold and the relatively minor difference in average yield between a harvest rate

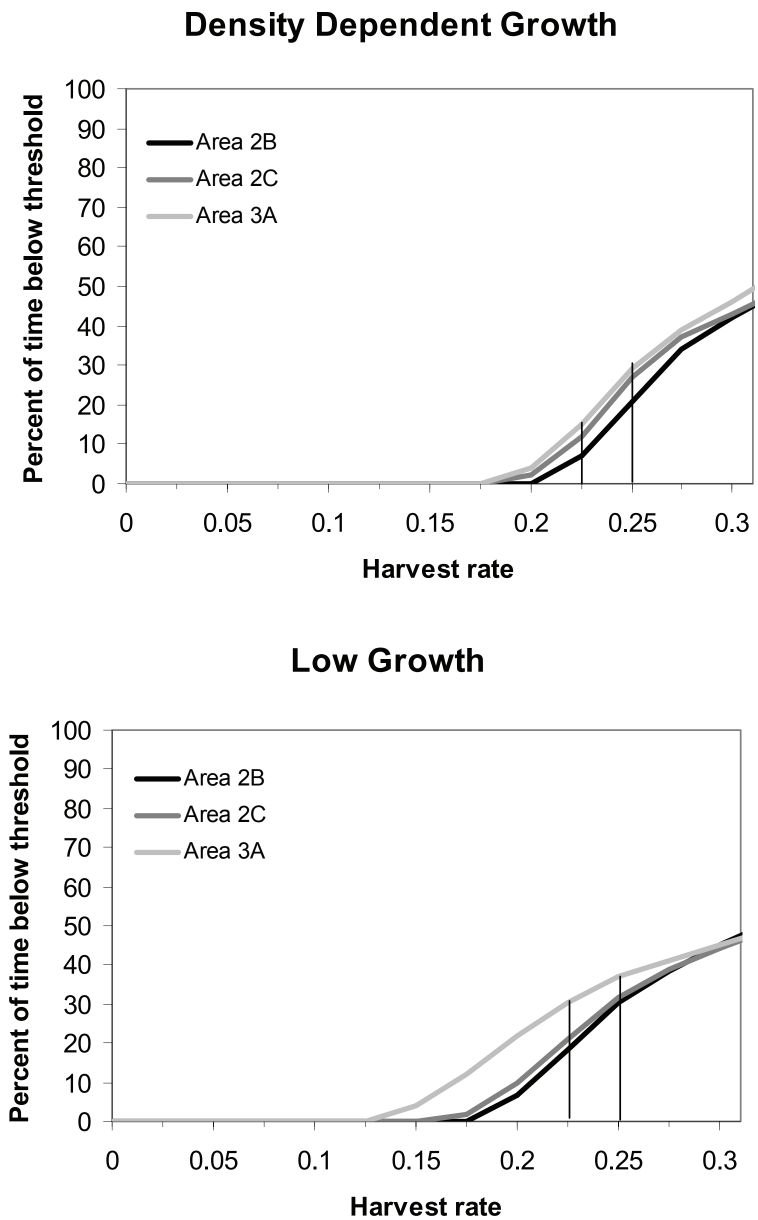


**Figure 29. In the harvest rate simulations, the percent of years in which spawning biomass dropped below the minimum spawning biomass across a range of harvest rates. The upper panel illustrates the Most Likely (Density Dependent Growth) scenario, the bottom panel shows the Low Growth scenario.**

of 0.225 and 0.25, a target harvest rate of 0.225 appears appropriate for the halibut stock in the core areas. Under the Low Growth scenario, there is an increased frequency of reaching the minimum biomass threshold, particularly in area 3A. However the expected occurrence is no greater than 30% of the time. Given the precautionary application of the reduced harvest rate triggered when the threshold is reached, this appears to be a tolerable level of risk.

Support for a harvest closer to the lower end of the range is provided from a couple of other perspectives. At harvest rates over 0.225, the average spawning biomass in Areas 2B and 2C drops below 20% of the unfished level. A number of published studies have suggested that for groundfish, average spawning biomass should remain in the range of 20-60% (e.g., Clark 1991). Secondly, yield per recruit and spawning biomass per recruit analyses were conducted using different sets of growth rates (Hare and Clark 2005b). Based on those analyses, a harvest rate in the range of 0.15-0.20 would be recommended as spawning biomass per recruit was reduced to 35-40% of the unfished level.

The target harvest rate of 0.225 applies to the IPHC core areas of 2B, 2C and 3A. In Area 2A, where biomass is leveraged off the 2B estimate, the target harvest rate is also set 0.225. For Areas 3B and 4, a lower target harvest rate of 0.200 is currently used. Under the precautionary principle, a more conservative fishing rate should be applied since far less is known about the productivity potential of those areas. There is not currently enough historical data to conduct a dynamic harvest policy analysis for areas 3B and 4. In the absence of a dynamic analysis, a reasonable fallback is the spawning biomass per recruit equilibrium analysis using weight at age data from the appropriate regions. Since size at age in Areas 3B and 4 is not greatly different from Area 3A the same basic results would apply – a harvest rate between 0.15 and 0.20 is appropriate.

In this harvest rate analysis, we have attempted to capture the dynamics of the halibut stock in establishing an appropriate harvest rate. Numerous sources of uncertainty in addition to the "Most Likely" scenario were explored and reported upon here and elsewhere (Hare and Clark 2001, 2003). These included uncertainties in density dependent growth response, future levels of recruitment as well as distribution of recruitment among areas, stock- and environment-recruitment relationships, selectivity curves, etc. There are other forms of uncertainty that could be considered. These include both biological and operational factors. The biological uncertainty is likely to have been mostly captured in the simulations. However, uncertainty in the annual stock assessment—other than putting observation error on biomass estimates—is not incorporated. Neither is management uncertainty, e.g., not faithfully setting catch limits at the computed levels. Testing the robustness of the harvest policy to these types of uncertainty is the goal of the developing paradigm of "management strategy evaluation" (Punt and Smith 1999, Cooke 1999). Exploring the IPHC harvest policy in such a framework is a logical next step.

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# Appendix A. Catalogue of IPHC setline survey data through 1999

## Abstract

This paper identifies all sets in the IPHC survey database that were part of systematic (grid) surveys through 1999. It also describes some of the query parameters that often enter into retrievals of grid survey data.

## List of early survey stations (1963-1986)

IPHC has conducted a number of systematic setline surveys in various parts of the Commission area in the years 1963-66, 1976-86, and 1993-present. Before 1993 stations were laid out on transects. Since then they have been laid out on a grid, first in triangular clusters and since 1998 as single stations on a regular 10 nmi square pattern. Surveys through 1979 are described by Hoag et al. (1980); evolution of survey design up to the present by Randolph (1998).

The data from survey trips reside in a setline database that contains data from all charters, so retrieving the survey data requires a properly qualified query. Since 1993 all standard survey data have been assigned a code of "SG" (Standard Grid) in the "purpose" field of each station record. For earlier years it is necessary to retrieve the data by vessel, year, and in some cases station number (where a vessel did some survey stations and some other work on the same trip).

Before 1993, offshore survey stations were spaced along parallel transects that ran east-west in Area 2 and north-south in Area 3. Transects were numbered from 1 to 95 in a counterclockwise direction. Stations along a transect were labeled by letter A, B, C, … from inshore to the edge of the shelf. For these stations the "station number" (called "stnno") that appears in the database is actually the transect number. The "station position" (called "stnpos") in the database is the letter label.

Stations in the inside waters of Southeast Alaska (Area 2C) were not laid out according to a geometrical pattern but were distributed purposively over several of the major inside grounds. These stations were assigned individual station numbers in the range 401 through 824, and no letter label.

Table A1 lists all of the stations that constitute the IPHC grid survey data, plus the inside stations in Area 2C, for the years 1963-1986. Note that stations with missing and zero station numbers have to be excluded when the data are retrieved.

## Other selection criteria

### Station type

Users interested in truly systematic stations only may want to exclude the stations in the inside waters of Area 2C in the early data (1963-1986), because they were placed arbitrarily. That can be done on the basis of station number. In the recent data (the 2C series resumes with 1996), the inside stations with a purpose code of "SG" are in fact regular grid stations. The survey vessels sometimes fished additional stations for operational reasons, but those stations have a purpose code of "ES".

In 1993, offshore stations were placed in groups of four, of which three were the vertices of triangles laid out systematically on a grid. The skipper of the survey vessel was free to choose the location of the fourth station anywhere within the triangle, so those stations are not truly

**Table A1. List of all IPHC grid survey stations through 1986. Some stations fished by the listed vessels have no station numbers at all; these are not survey stations and must be excluded.**

### Surveys in Canada

| Year | Vessels | Stations |
|---|---|---|
| 1965 | CHR | Stations with numbers > 0 |
| 1966 | CHE | Stations with numbers > 0 |
| 1976 | SEY | Stations with numbers > 0 |
| 1977 | CHE, EVE | Stations with numbers > 0 |
| 1978 | CHE | Stations with numbers > 0 |
| 1980 | ELL | Stations with numbers > 0 |
| 1981 | PRC | Stations with numbers > 0 |
| 1982 | PRC | Stations with numbers > 0 |
| 1983 | EVE, WIN | Stations with numbers > 0 |
| 1984 | STW, WIN | Stations with numbers > 0 |
| 1985 | STW | Stations with numbers > 0 and < 900 |
| | CFL | Stations with numbers > 0 |
| 1986 | SNO, WIN | Stations with numbers > 0 |

### Surveys in Alaska

| Year | Vessels | Stations |
|---|---|---|
| 1963 | ECL | Stations with numbers > 0 |
| 1964 | ECL | Stations with numbers > 0 |
| 1965 | CHE | Stations with numbers > 0 |
| 1976 | POL | Stations with numbers > 0 |
| 1977 | POL, RES | Stations with numbers > 0 |
| 1978 | VAN | Stations with numbers > 0 |
| 1979 | CHE | Stations with numbers > 0 |
| 1980 | SEY | Stations with numbers > 0 |
| 1981 | EVE | Stations with numbers > 0 |
| 1982 | KRI, THR | Stations with numbers > 0 (fixed gear) |
| | DLY, VAL | Stations with numbers > 0 (snap gear) |
| 1983 | POL, MAS | Stations with numbers > 0 (fixed gear) |
| | VAL | Stations with numbers > 0 (snap gear) |
| 1984 | CHE, SEY | Stations with numbers > 0 |
| 1985 | CHE | Stations with numbers > 0 and < 900 |
| | CFL | Stations with numbers > 0 |
| 1986 | CFL | Stations with numbers > 0 |

systematic, either. They are distinguished in the 1993 data by a two-letter rather than a one-letter station label ("station position" in the database), formed by appending "C" to one of the regular one-letter labels. As a practical matter the catches at the skipper stations were substantially higher than at the other stations in 2B (9.8 vs. 5.5 fish/skate, P=0.001) but slightly lower in 3A. In 1994 and 1995 the same station pattern and coding scheme were used, but the interior station was always placed at the centroid of the triangle.

## Gear type

The standard gear for surveys has always been fixed (stuck) gear (gear code "FH"), but in three cases—noted in Table 1—vessels fished snap gear (code "SN") for comparative purposes. In all cases the vessel using snap gear fished a subset of the stations fished by another vessel using fixed gear in the same area and year, so the snap gear sets can all be excluded without loss of coverage, and should be excluded to avoid giving extra weight to the subset of stations fished twice. At the 139 stations fished with both gears in 1982 and 1983, fixed gear catches were significantly higher than snap gear catches, but not by a large amount (10.3 vs. 8.7 fish/skate, P=0.0001).

## Hook type

Surveys were done with J-hooks (hook type code "J") through 1984. In 1984 and thereafter C-hooks (code "C") were used. In 1984 all of the stations in Areas 2B and 3A were fished with both J- and C-hooks for comparative purposes. Five survey stations in 1984 and 1985 were fished with a mixture of J- and C-hooks; they have a code of "M" and should normally be excluded.

## Effectiveness of set

Beginning in 1993, each set was assigned an "effectiveness" code, either "Y" for a normal, successful set or "N" for an unsuccessful one (e.g., lost most of the gear, set in the wrong place etc.) . Most users of the data will want to exclude unsuccessful sets.

For years before 1993 the effectiveness code is empty, but there are a few sets where the number of *effective* skates hauled ("effskt") is given as zero even though it is clear that some gear was hauled (e.g., in very rough weather when many fish are lost during hauling). These sets should also be regarded as ineffective.

## Number of skates hauled

The number of skates set at each station has varied over the years, the minimum being the equivalent of four 100-hook skates. Part of a string is often lost, so the number of skates hauled can be less. It makes sense to set some minimum number of skates hauled in a data retrieval to avoid catch rates based on a small number of hooks. Setting the minimum at two 100-hook skates is reasonable and eliminates only a small proportion of sets.

In the database, the field called "number of skates" ("noskt") is the number of skates actually hauled, but this does not refer to standard 100-hook skates with 18-foot spacing. Skate length and hook spacing both vary among trips. Surveys in the 1960s and 1990s were all done with 18-foot gear; almost all surveys in the 1970s and 1980s with 21-25-foot gear. Other things being equal, catch per hook is higher if hook spacing is larger. The relationship has been studied (Skud 1972), so the effect of non-standard hook spacing can be removed by calculating an adjustment.

A field in the database called "effective skates" ("effskt") is the number of skates hauled, adjusted for hook type, hook spacing, and skate length to the equivalent number of standard skates of 100 C-hooks at 18-foot spacing. The number of C-hook skates is not adjusted for hook type, but the number of J-hook skates is divided by 2.2 because C-hook catches of legal-sized

**Table A2. Extent of survey coverage by year. The core survey area in 2B is the part north of Vancouver Island (Fig. 2); the core area in 3A is the western part of the outer shelf (Fig. 3). A grid survey was first conducted in 2A in 1999.**

| Year | Area 2B | Area 2C | Area 3A | Area 3B | Area 4 |
|---|---|---|---|---|---|
| **1963** | --- | --- | Core | --- | --- |
| **1964** | --- | --- | Shelikof Strait only | Eastern half only | --- |
| **1965** | Southern part of core | --- | --- | Western half only | Eastern 4A only |
| **1966** | Northern part of core | 4 stray stations | --- | --- | --- |
| | | | | | |
| **1976** | Northern part of core | --- | Only 2 transects | --- | --- |
| **1977** | Core | --- | Core | --- | --- |
| **1978** | Core | --- | Core | --- | --- |
| **1979** | --- | --- | Core | --- | --- |
| **1980** | Core (fewer stations) | --- | Core (fewer stations) | --- | --- |
| **1981** | Core | --- | Core | --- | --- |
| **1982** | Core | All [1] | Core | Western half only | --- |
| **1983** | Core | All [1] | Core | --- | --- |
| **1984** | Core (twice, C&J) | All [1] | Core (twice, C&J) | --- | --- |
| **1985** | Core | All [1] | Core | --- | --- |
| **1986** | Core | All [1] | Core | --- | --- |
| | | | | | |
| **1993** | Core | --- | Core | --- | --- |
| **1994** | --- | --- | Core | Eastern half only | --- |
| **1995** | Core | --- | Core | 3 stray stations | --- |
| **1996** | Core | All | All outside waters | All | --- |
| **1997** | Core | All | All outside waters | All | 4A, 4B, 4C, 4D edge |
| **1998** | Core | All | Outside + inside waters | All | 4A, 4B |
| **1999** | All | All | Outside + inside waters | All | 4A, 4B |

[1] Stations in inside waters chosen purposively.

fish in weight were 2.2 times J-hook catches in paired sets in 1984. The relative fishing power of the two hook types actually depends strongly on the size of the fish (Sullivan et al. 1999), so the adjustment is not really reliable.

The number of standard 100-hook skates actually hauled, adjusted for hook spacing and skate length but not hook type, can be obtained by taking the "effskt" value for C-hooks, and multiplying that value by 2.2 for J-hooks.

As explained above, sets where "effskt" is zero should be regarded as ineffective regardless of the value of "noskt".

### Survey area

Before 1999, grid surveys in Area 2B were confined to the waters north of Vancouver Island (Fig. 2), and in some years did not cover all of those waters. In 1999 all of 2B was surveyed, and for the first time 2A as well. (Random stratified surveys, with high sampling densities on commercial grounds, were carried out in 2A and southern 2B in 1995 and 1997.) Likewise in Area 3A, only the western part of the shelf (west of 148ºW, excluding Cook Inlet and Shelikof Strait; Fig. 3) was normally surveyed before 1996, and in some years not all of that. In 1996 the eastern half of 3A was added, and in 1998 stations in Prince William Sound, Shelikof Strait, and lower Cook Inlet were added. Area 2C was always surveyed entirely if at all, but only in recent years (1996-) have regular grid stations been fished in the inside as well as the outside waters. For Area 3B and Area 4 there are only spotty data before comprehensive surveys began in 1996 (3B) and 1997 (4). The evolution of survey coverage over time is summarized in Table A2.

Assembling a consistent series of survey data for 2B requires filtering out the years with only partial coverage of the core survey area. It also requires setting some northern boundary for Area 2B, which is controversial because Canada and the U.S. both claim a large part of the northern side of Dixon Entrance. The operational boundary used in designing the surveys has usually been 54º30'N. Beginning with 1999 it is also necessary to filter out stations off Vancouver Island (south of, say, 50º30'N). Assembling a consistent series of grid-only data for Area 2C requires filtering out all of the inside stations. That can be done on the basis of station number for years through 1986, but thereafter only on the basis of latitude and longitude. Assembling a consistent series for 3A requires filtering out years with partial coverage of the core area before 1996.

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Sullivan, P. J., Parma, A. M., and Clark, W. G. 1999. The Pacific halibut stock assessment of 1997. Int. Pac. Halibut Comm. Sci. Rep. 79.

## Checklist

Here is a checklist of selection criteria that should be considered when retrieving grid survey data:

| Feature | Criteria |
|---|---|
| Station number | Valid number: not missing or zero |
| Vessel, year, station number | Table 1 for years 1963-1986.<br>Purpose code = "SG" for years 1993 on. |
| Station type | Exclude 2C inside stations before 1993?<br>Exclude skipper stations in 1993? |
| Gear type | Exclude snap gear (gear code = "SN")? |
| Hook type | Exclude sets with mixed hooks (hook code = "M")?<br>Select only J-hook (code "J") or C-hook ("C") data? |
| Effectiveness of set | Exclude sets with zero effective skates.<br>Exclude ineffective sets (code = "N")?<br>(Effectiveness field is empty for years before 1993.) |
| Number of skates hauled | Exclude sets with too few skates hauled? |
| Area coverage | Exclude years with partial coverage (Table 2)?<br>Exclude stations outside core areas in 2B and 3A? |

# Appendix B. A method of estimating the sex composition of commercial landings from setline survey data

This is a condensed version of:

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

The whole text of the paper is reproduced here. The original paper has many more figures showing the data and fits to support statements made in the text.

## Abstract

The sex ratio of fish of a given age and length in survey catches does not vary appreciably with depth or with location within a regulatory area in any given year, so it seems safe to assume that commercial landings of fish in the same category have the same sex ratio as survey catches. The relationship between length and sex ratio (proportion female) for fish of a given age does vary among regulatory areas and years, but in all cases it is well described by a simple logistic function. For recent years, the commercial age/length samples can therefore be keyed out to sex by estimating the two logistic parameters for each area/year/age category from the survey data. For earlier years when the actual lengths of fish in the commercial landings were not measured, the age-specific sex and size compositions of legal-sized fish in the survey catches appear to be reasonable estimates of the commercial values.

## Introduction

Setline gear is selective for larger fish, and the commercial fishery has an 81 cm minimum size limit. Female halibut are larger at each age than males, so they presumably sustain a higher fishing mortality. The dramatic reduction in halibut growth rates over the last fifteen years, especially in Alaska, has likely increased the difference in fishing mortality between the sexes.

Because halibut are eviscerated at sea, we have no sample data on the sex composition of commercial landings, so the annual stock assessment has never distinguished the sexes. Instead a single catchability coefficient and selectivity schedule have been calculated for the combined sexes, and both exploitable and spawning biomass have been computed from estimates of combined abundance.

Concern about the actual fishing mortality rate of females and the actual level of female spawning biomass relative to earlier levels led to a decision to attempt an age- and sex-structured assessment in 2003; i.e. to use a model that does the usual population calculations for females and males separately. Sex-specific catchability and selectivity parameters can be estimated for the survey because we have a sexed sample, but the commercial data are a problem.

One approach is to continue estimating a single commercial catchability coefficient and age-specific selectivity schedule. Because those parameters are modeled as random walks, they could in principle track changes in the age-specific averages due to changes in age-specific sex composition. But that would mean applying the same fishing mortality rate to females and males at each age in the population accounting, which is almost certainly wrong.

Another possibility is to estimate a single commercial catchability coefficient and length-specific selectivity schedule (both random walks) and then use sex-specific mean length at age in the survey to predict fishing mortality and therefore catches at age by sex. This approach requires the strong assumption that the same length-specific values apply to both sexes, and even if that is true, it is doubtful that the parameters would be estimable in the absence of observations of catch at age by sex. The resulting estimated commercial sex compositions could also turn out to be quite different from the observed survey sex compositions, which would be problematic.

The simplest solution is to somehow estimate commercial sex compositions from the survey sex compositions external to the assessment and then do straightforward, mostly parallel age-structured assessments of each sex. Sex-specific commercial parameters would then be readily estimable, and the working estimates of commercial sex composition would agree with the survey data. This paper reports a method of estimating the sex composition of the commercial catch at age using a survey-based estimate of the age-specific relationship between length and sex ratio.

## Mean length at age in survey catches and commercial landings

Because females are larger than males at each age, the mean length at age in commercial landings is an indicator of sex composition. In particular, if the mean length at age in commercial landings closely matched the mean length at age of legal-sized fish in survey catches, that would be strong evidence that commercial and survey sex ratios at age (and sex-specific length distributions at age) are the same. This appears to be the case in Area 2B (Fig. B1a), and until the last few years in Areas 2C and 3A. But in Areas 3B (Fig. B1b) and 4 the mean length at age has always been much larger in commercial landings than in survey catches, and the same pattern has appeared in Areas 2C and 3A recently.

There are a number of possible reasons why the commercial fishery could select larger fish at each age than the survey, including ground selection, gear differences, and highgrading. Whatever the reason, selecting larger fish must result in a higher proportion of females in commercial landings, at least in some areas and years.

## Length frequencies at age in survey catches and commercial landings

For all survey years back to 1993, when surveys resumed after a 6-year hiatus, it is possible to compare age-specific commercial and survey length frequencies to see what causes the differences in mean age at length. In the survey data the female and male components of each length interval can also be distinguished so as to show what sort of differences between survey and commercial sex composition might result from the differences in length composition.

Direct comparisons of length frequencies cannot be made for earlier years because the fork lengths of fish in commercial samples were not measured between 1963 and 1990. Instead one or another measurement of the otoliths was made and fork lengths were calculated from a predictive relationship. At best this sort of prediction would provide the expected fork length of each fish, but the distribution of expected fork lengths would not be the same as the distribution of true fork lengths. To further complicate matters, the relationship between otolith size and fork length changed over time. The staff has reworked the predictions to improve the estimates of mean size at age in commercial landings (Clark 1992), but there is still some doubt even about the means, and there is no satisfactory way to recover the entire length frequency distributions.

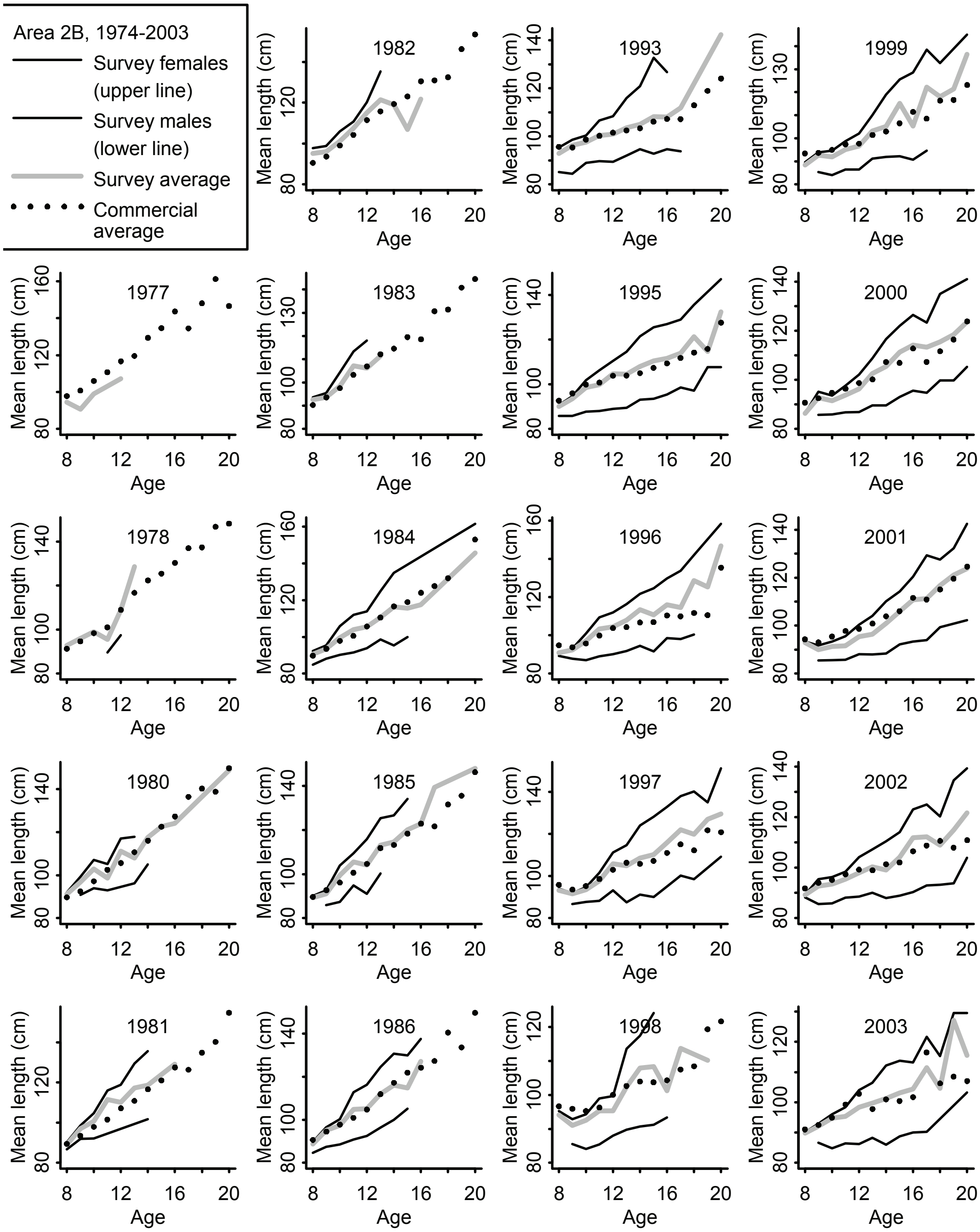



**Figure B1a. Mean length at age of legal-sized fish in commercial landings and survey catches in Area 2B.**

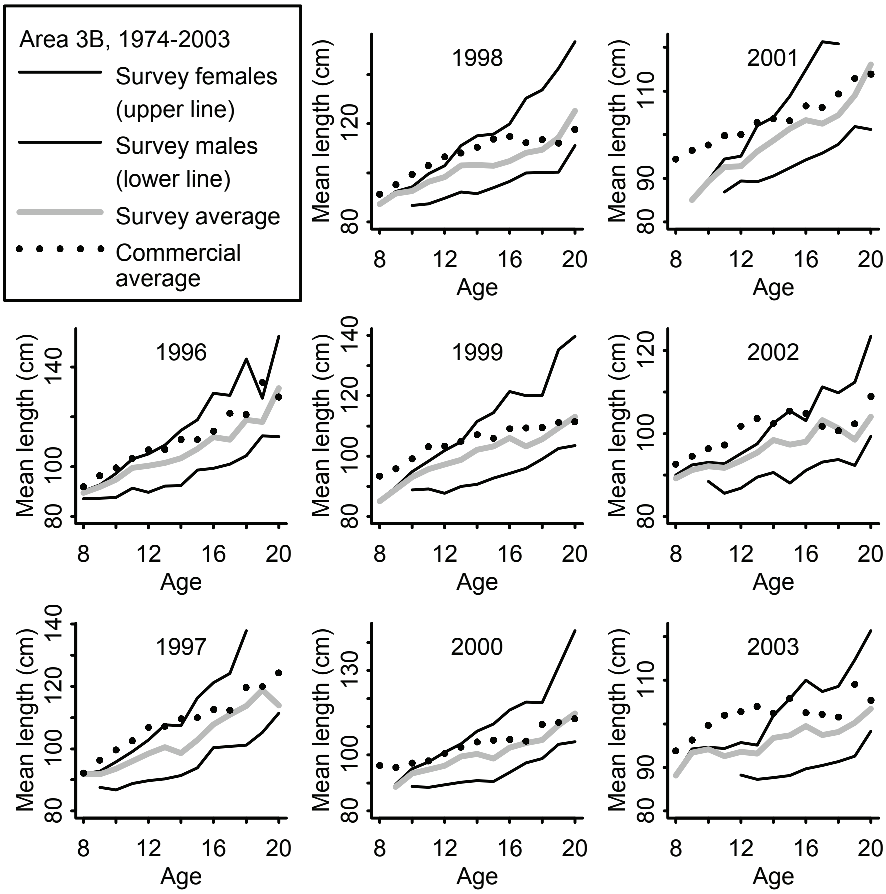



**Figure B1b. Mean length at age of legal-sized fish in commercial landings and survey catches in Area 3B.**

The available data are further complicated by a change in age reading practices at IPHC. All of the age data in the database through 2001 are surface readings, which on average underestimate the ages of fish older than 12 or so. Beginning with 2002 all of the data are break-and-burn readings, which are accurate. For that reason the analysis is this paper will generally treat the age data types separately, meaning that most comparisons show data from the more numerous years of surface age readings, ending in 2001. The methods eventually developed apply equally well to 2002 and later data, as is shown, and are applied to those data separately to obtain working formulas.

In recent years where direct comparisons between survey and commercial data can be made (i.e., surface reading years when surveys were done and commercial lengths were measured), the data show that relative to the survey length frequencies, the commercial landings contain substantially fewer fish under 90 cm and slightly more fish across a wide range of greater lengths, where apart from that slight difference the distributions are usually similar. This is true even in those cases where survey and commercial mean lengths at age agree closely, namely in Area 2B (Fig. B2a) and until 2000 in Areas 2C and 3A. The pattern is simply more pronounced in Areas 3B and 4 where the commercial mean lengths are consistently higher (Fig. B2b). Interestingly, limiting the survey length frequencies to data from stations deeper than 100 fm largely eliminates the pattern in Area 3A and to a lesser extent in other areas, suggesting that it results at least in part simply from the difference in grounds fished by the survey and the commercial fishery.

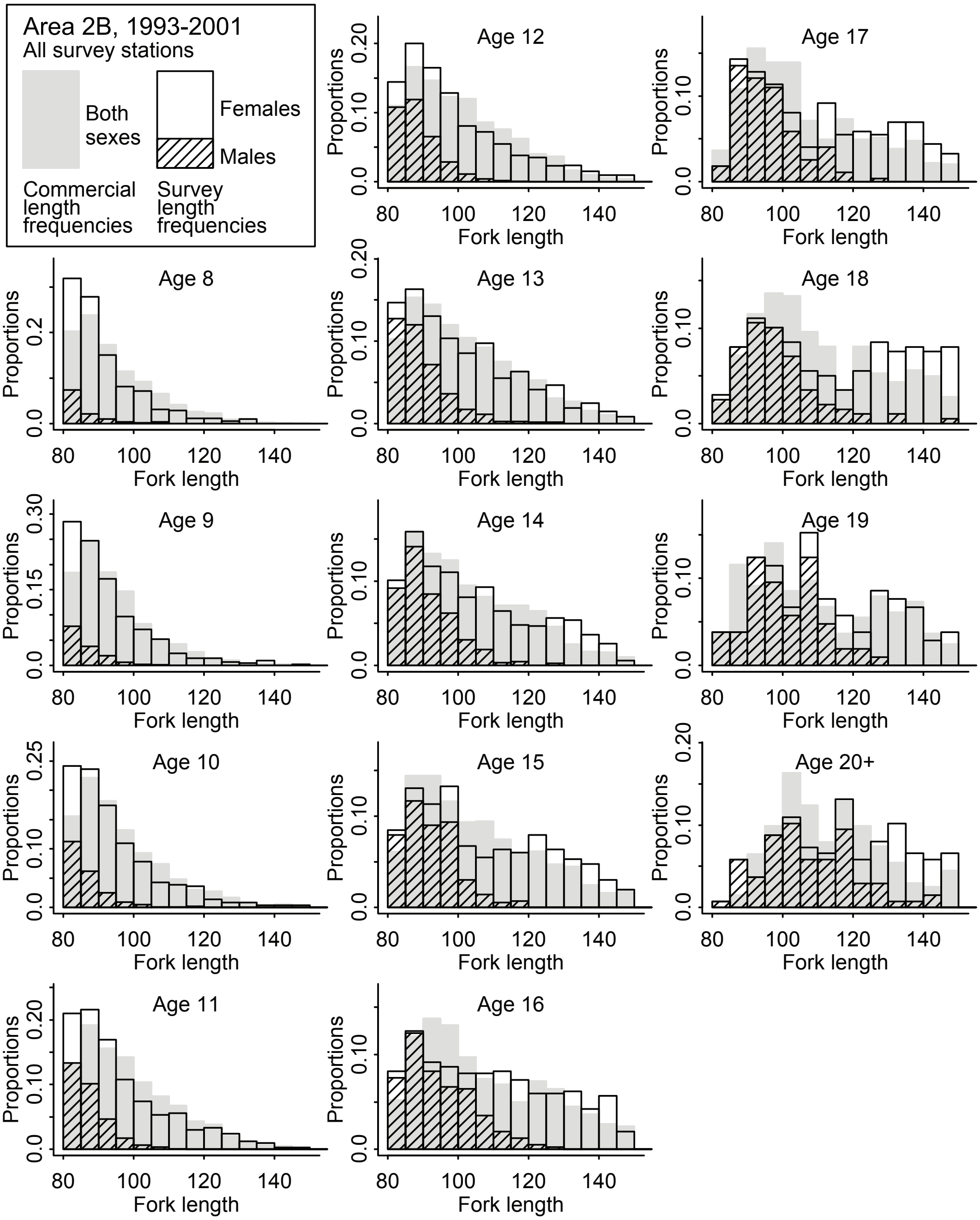



**Figure B2a. Survey and commercial length frequencies at age in Area 2B, 1993-2001 data pooled. Survey and commercial mean length at age agreed well in all these years.**

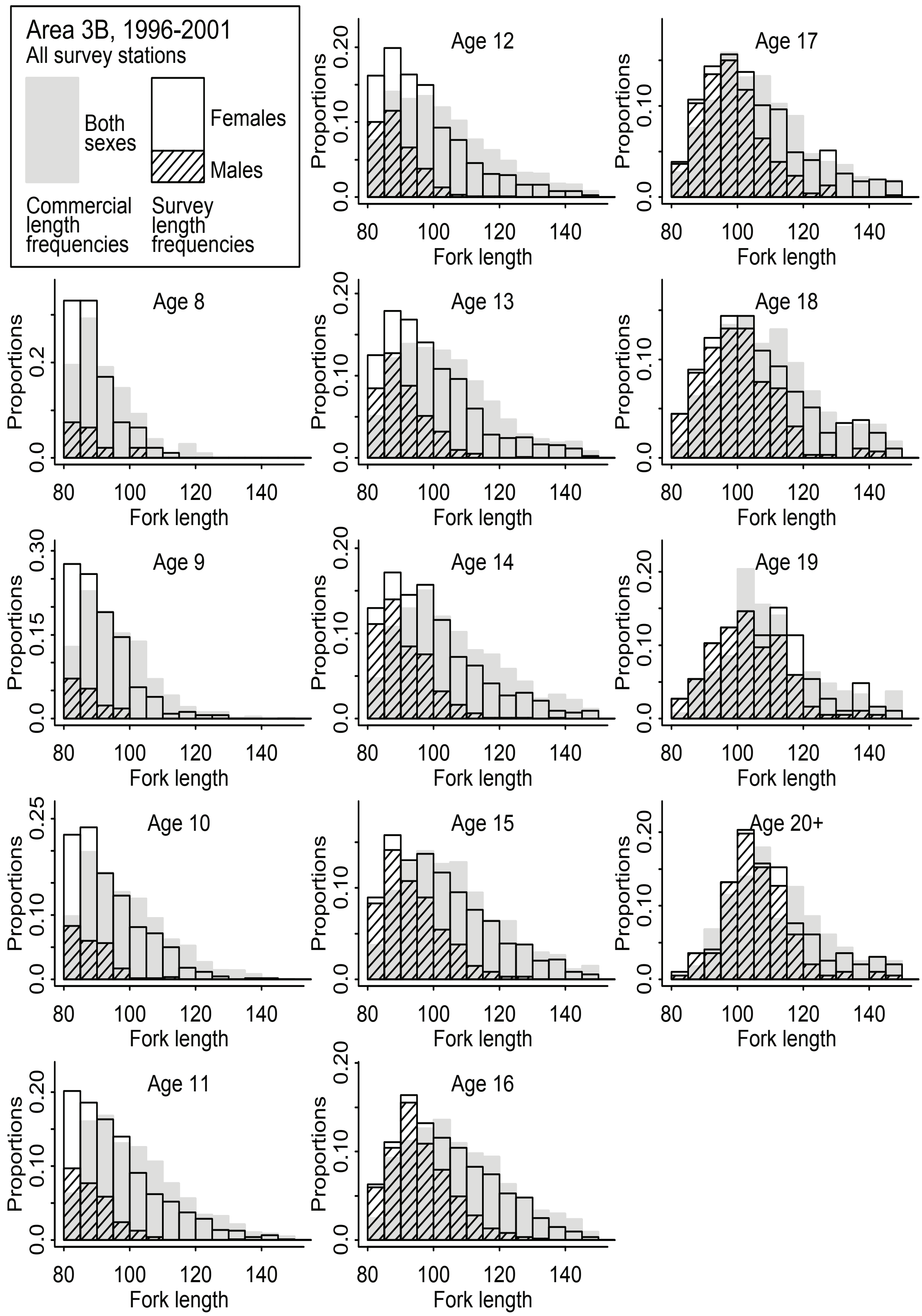



**Figure B2b. Survey and commercial length frequencies at age in Area 3B, 1996-2001 data pooled. Commercial mean lengths at age exceeded survey means in these years.**

At every age the 80-90 cm length group contains a substantially higher proportion of males than the age group as a whole. The commercial landings have relatively fewer fish of this size than the survey catches, so they presumably contain a higher proportion of females than the survey catches. The commercial sex ratio can be estimated by applying the survey sex ratio to the commercial frequencies in each length interval, but only if the sex ratio in an age/length category does not vary among grounds within a regulatory area.

It is shown below that this is the case, which is somewhat surprising given the difference in size between females and males, and the difference in length compositions between shallow and deep survey stations. But the data do in fact show little difference in sex ratio at a given age and size between deep stations and all stations in any area, and plots of the depth distributions of females and males of the same age are quite similar at all ages in all areas with the exception of teenaged fish in Area 2B, where the males tend to be shallower (Figs. B3a and B3b). Younger fish do have a more inshore distribution in all areas, but it appears that both males and females move deeper with age. Another confirmatory piece of evidence is that the sex ratio at a given length is the same in trawl and setline survey catches in Area 3A (Clark 2001) despite large differences in overall length composition and mean length at age.

## Direct estimates of the sex composition of commercial catches

This section of the paper reports estimates of the sex composition of commercial landings computed by applying the raw survey values of proportion female in each age/length category to the age/length frequencies of the commercial data, with enough years of data pooled to avoid small-sample problems. This is the natural way of computing the estimates, and it will show in a simple and direct way the size of the differences between survey and commercial sex composition in the various regulatory areas in recent years. The following sections of the paper will use fitted curves to represent the relationship between length and sex ratio within an age group so as to simplify comparisons and eventually working calculations.

Applying the survey sex ratio (proportion female) in each length interval to the commercial length frequencies for a given age group provides estimates of the commercial sex ratio at that age and the size distributions of females and males of that age in the landings, all quantities of interest for purposes of stock assessment and harvest policy evaluation. These estimates show that for Area 2B (Fig. B4a), and until recently Areas 2C and 3A, the overall sex compositions of commercial landings were very similar to the sex compositions of legal-sized fish in survey catches, despite the relative paucity of 80-90 cm fish in the landings. In these cases the estimated proportion female and mean size at age by sex are very slightly higher in the commercial estimates, but all of the differences are small compared with the year-to-year variability of survey values and, for years before 1991, the uncertainty concerning the true mean size at age in commercial landings. In view of this finding, and the generally good agreement between survey and commercial mean size at age going back to 1974, it appears to be practical to use the observed sex composition of legal-sized fish in the survey catch as estimates of the commercial values in Areas 2B, 2C, and 3A from the 1970s through the late 1990s.

The commercial estimates of proportion female at age in recent years are consistently and substantially higher than the survey values in Areas 3B (Fig. B4b) and 4A, and for most ages in Area 4B. It will therefore be necessary to key out the commercial length frequencies to estimate the commercial sex composition, effectively limiting the stock assessment in those areas to the beginning of systematic surveys in 1996-97.

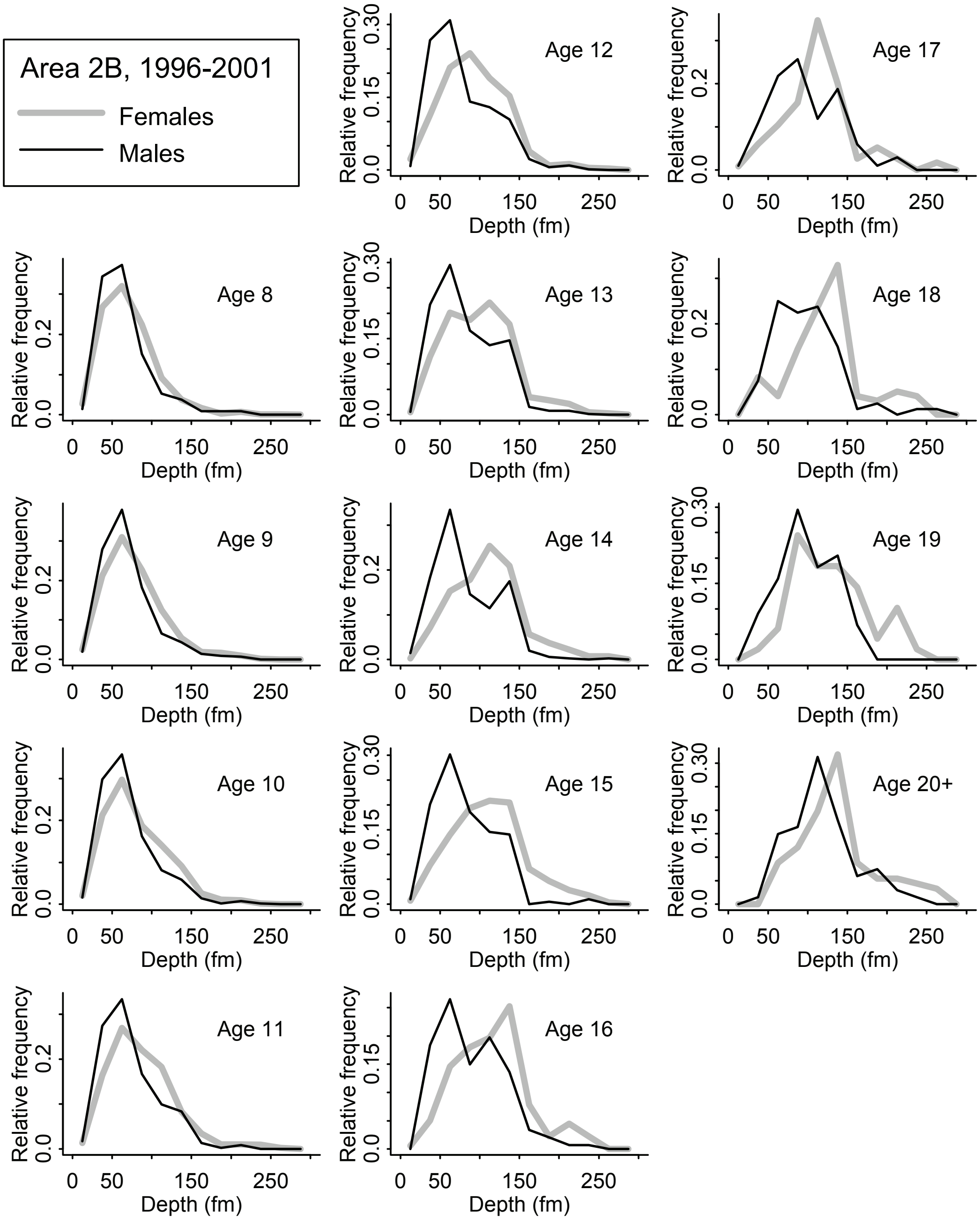



**Figure B3a. Depth distributions of survey catches of females and males of the same age in Area 2B.**

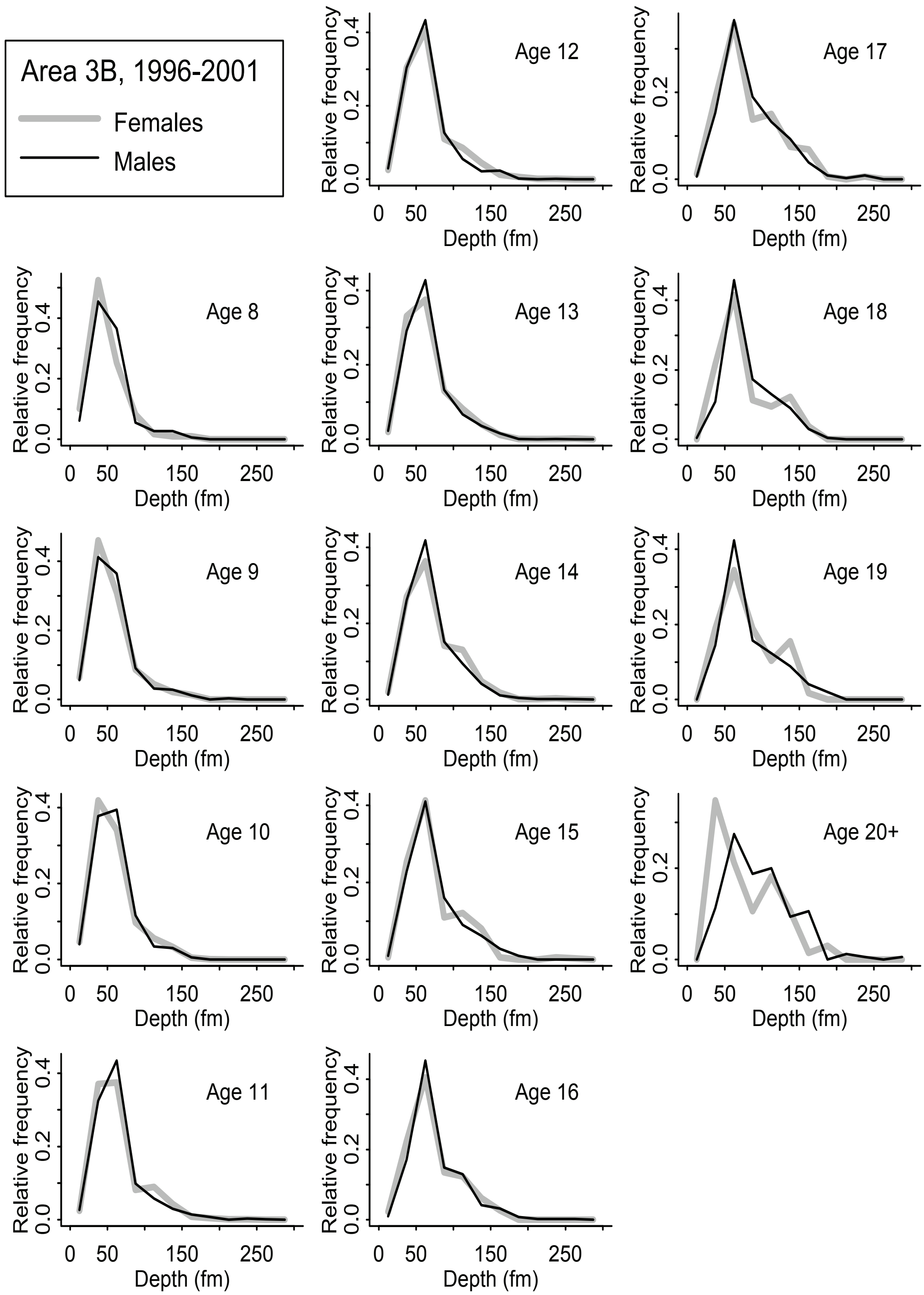



**Figure B3b. Depth distributions of survey catches of females and males of the same age in Area 3B.**

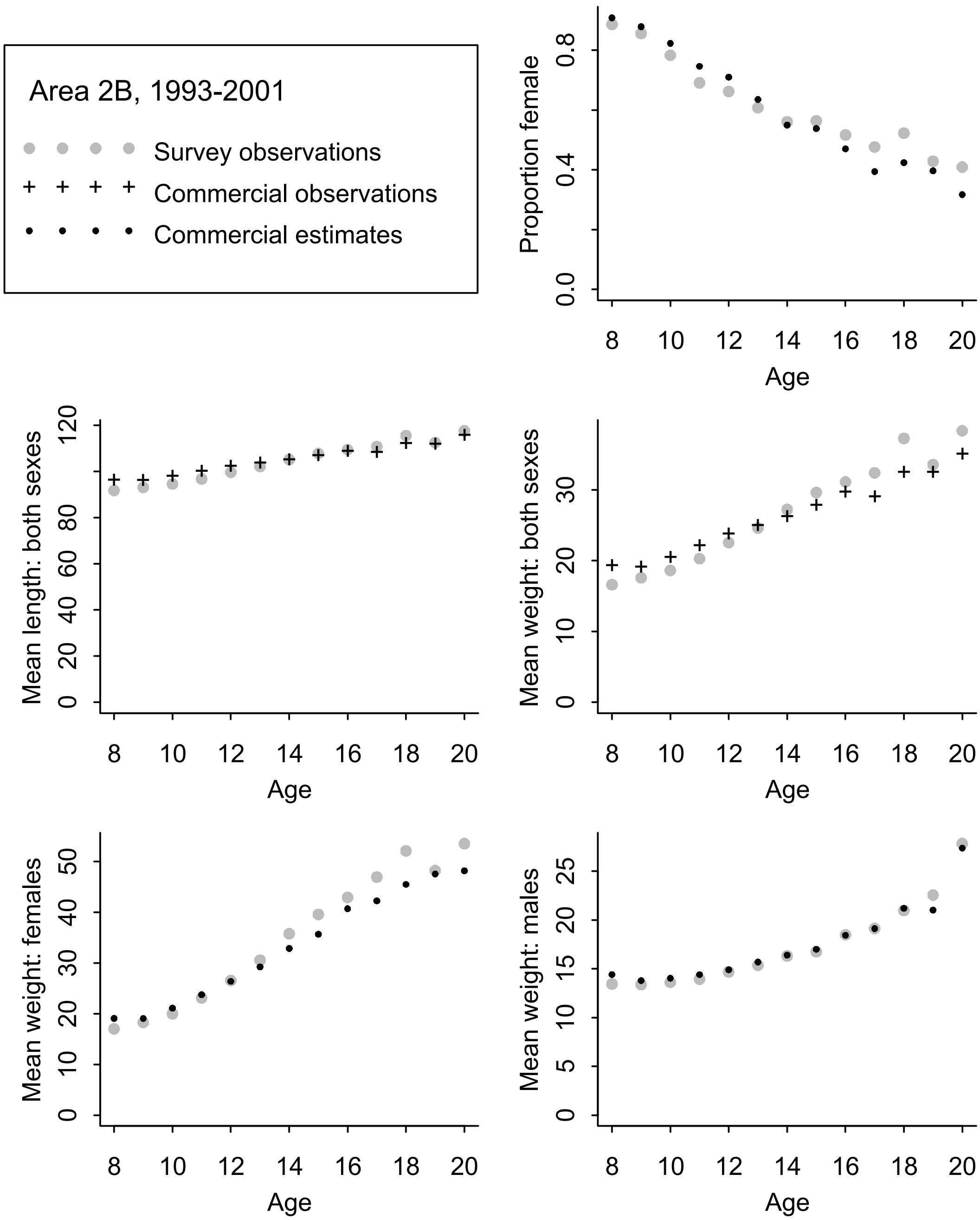



**Figure B4a. Estimates of proportion female and mean size by sex in commercial landings in Area 2B, 1993-2001 combined, computed for each age by applying the sex ratio at length in survey catches to the length frequencies of commercial landings.**

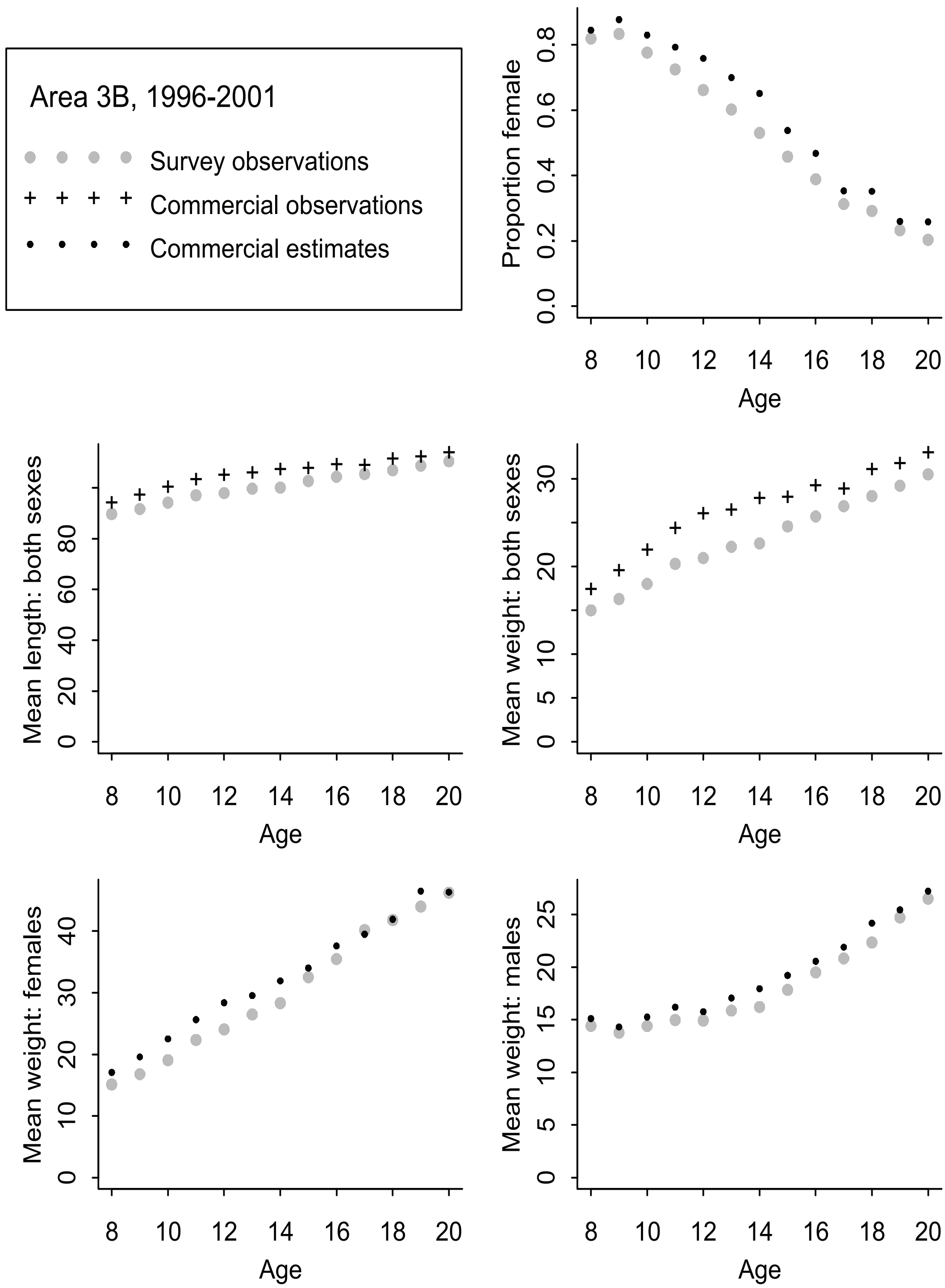



**Figure B4b. Estimates of proportion female and mean size by sex in commercial landings in Area 3B, 1996-2001 combined, computed for each age by applying the sex ratio at length in survey catches to the length frequencies of commercial landings.**

## Form of the relationship between sex ratio and length at a given age

It remains to be shown that the sex ratio at a given age and length is the same throughout a regulatory area in any given year. Comparisons between subareas and depth zones can be simplified by fitting a curve for each case of interest and then comparing the fitted curves. The relationship between proportion female $p$ and fork length $L$ for fish of a given age in a given area in a given year (all fish, not just legal-sized ones) is very well described in all cases by a simple logistic function:

$$p = 1 \Big/ \Big(1 + \exp\big(-k \cdot (L - L_{50})\big)\Big)$$

where $k$ is a slope parameter and $L_{50}$ is the length at which 50% of the fish are female (Fig. B5). The location and steepness of this curve must depend in a very complicated way on the growth and exploitation histories of the females and males in the age group, so there is no question that the parameter values will vary among areas and years. But the form is remarkably consistent.

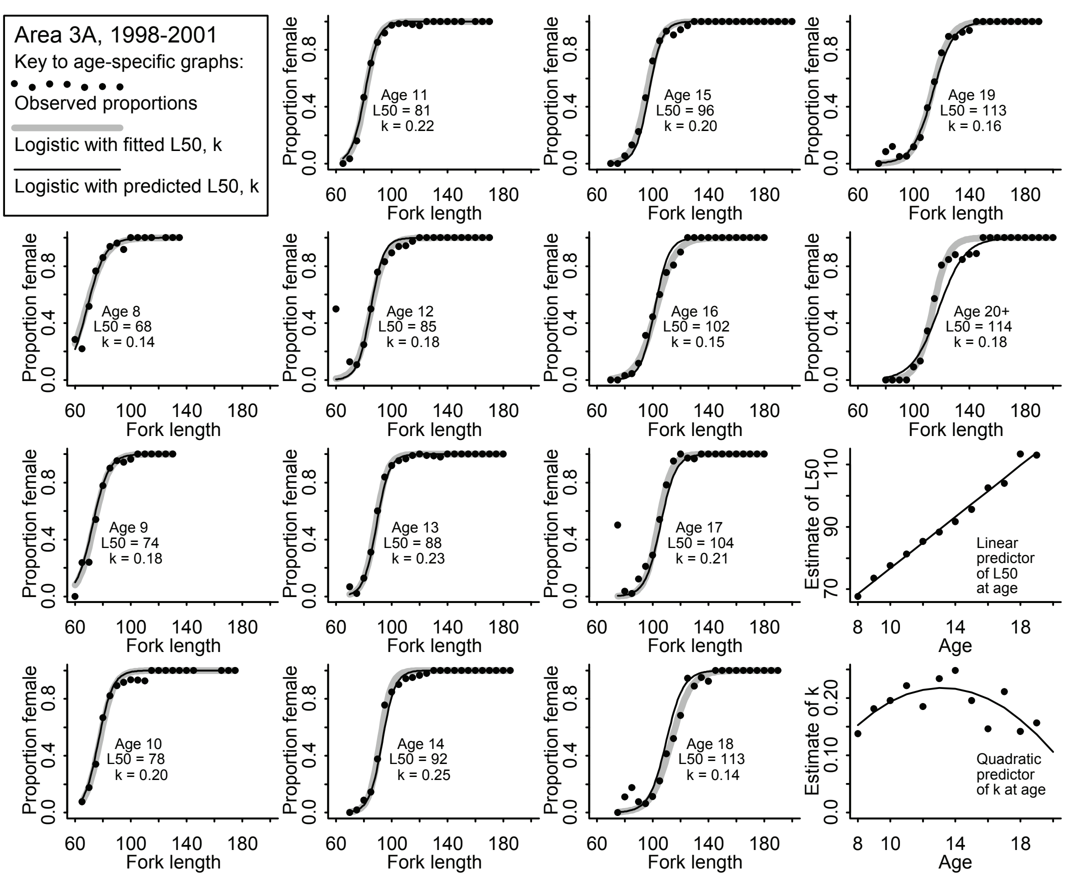



**Figure B5. Logistic fits to the proportion female at length, by age, in C-hook survey catches in Area 3A, 1998-2001.**

Another consistent feature of the relationship is a very tight linear trend with age in the estimate of $L_{50}$ for the fish in a given area and year (second to last panel in Fig. B5). The estimates of *k* are more variable from one age to the next and sometimes exhibit a modest curvature (last panel in Fig. 5). The variation of $L_{50}$ with age can be represented very well by a fitted straight line:

$$L_{50} = b_0 + b_1 \cdot age$$

and the variation of *k* with age can be represented well enough (the fits are not very sensitive to the precise value of *k*) by a fitted quadratic:

$$k = c_0 + c_1 \cdot age + c_2 \cdot age^2$$

Logistic functions with parameters predicted in this way closely match the age-specific fitted logistics for all ages except the plus group (e.g., 20+ for surface ages), which consists of a mixture of older age groups and therefore tends to have a higher $L_{50}$ and lower *k* than predicted by the trends among the younger age groups. To specify the proportion female as a function of length for all ages in a given area and year therefore requires seven meta-parameters: the coefficients $b_0, b_1, c_0, c_1, c_2$ shown above and estimated from the trends in $L_{50}$ and *k* among all ages except the plus group, and the values of $L_{50}$ and *k* for the plus group.

The comparisons in the next sections show separate logistics fitted to the data for each age group. Meta-parameter values are computed later in the paper for use in working calculations.

## Consistency of the relationship between depth zones and subareas

Because survey and commercial effort are distributed differently, a single survey-based schedule of sex ratio at length for a given area/year/age will be correct only if the schedule is the same throughout the area, i.e. in all depths and all subareas.

When the survey data are divided in two by depth, the separate logistics fitted to the shallow and deep components are very close in all cases. The largest differences occur in Area 2B, which as noted above appears to be the only area where there is any difference in the depth distribution of females and males of the same age. But even in Area 2B, the relationship between length and sex ratio at a given age is almost the same for shallow and deep stations, at least through age 16. Beyond that there are not enough old fish at shallow stations to make the comparison using only 2B data, but using data from all of Area 2 shows reasonably close agreement among the older fish as well. This is true both for the years with surface age data (through 2001), and for 2002-2003 when all the age data are break-and-burn readings. In other regulatory areas the agreement between shallow and deep fits is as good as or better than in Area 2.

In similar comparisons, there is no difference in the fits between the southern and northern halves of 2B or 2C, or between the eastern and western halves of 3A, 3B, 4A, or 4B. This is not to say that there are no differences at all within regulatory areas, but only that they are small enough to be disregarded.

There are some large differences between regulatory areas. In recent years there has been little difference between Areas 2B and 2C, or between Areas 2A and 2B, but some noticeable and consistent differences between Areas 2C and 3A; also between Areas 3A and 3B. Areas 3B and 4A are almost identical, but there are again large differences between Areas 4A and 4B. So while a single fit is sufficient for an entire regulatory area, it is desirable to treat regulatory areas separately, and there is no reason not to.

## Changes in the relationship over time

Because of the large changes in growth schedules that have occurred in the last twenty years, the schedule of sex ratio at length has shifted toward smaller sizes, modestly in Area 2B where the growth changes were less (Fig. B6a) and dramatically in Area 3A (Fig. B6b). In the mid-1980s, the length at which the proportion female reached 50% among the modal age groups (ages 10-14) in Area 3A was 120-140 cm; now it is 80-90 cm. The bulk of this shift occurred between the mid-1980s and the mid-1990s; during the latter 1990s there was some small further movement, particularly in the 20+ age group, but not a great deal.

## Working formulas

In 1996 setline surveys were begun in Area 3B, extended eastward in Area 3A to cover nearly the whole area, and resumed in Area 2C. It is therefore a convenient starting year for estimating the sex composition of the commercial landings using the procedure developed above. Surveys in Areas 4A and 4B did not begin until 1997, but because the sex ratio at length (within age) does not appear to have been changing rapidly in the latter 1990s, it should be possible to key out the 1996 commercial data in those areas reasonably well using the 1997-1998 survey data. Commercial landings in Area 2A can be keyed out with Area 2B survey data at need.

For each area and each year beginning with 1996, the seven meta-parameters of age-specific logistic functions described above have been computed. This was done using a moving three-year data window to calculate the estimates for the central year, except at the beginning and end where only two years of data were used. Where fewer than 100 observations were available at a given age, data were added from neighboring ages (to a maximum of ±2 years) to reach a minimum sample size of 100 for each age-specific estimate. Extreme outliers from a fitted logistic were removed and the curve refitted to improve the parameter estimates. The data series were broken between 2001 and 2002 at the time of the change from surface to break-and burn readings because that did affect the shape of the fitted logistics. The plus age is 20 for the surface years and 25 for the break-and-burn years. Only in Area 4 did fish over age 25 represent more than 1% of the landings—2% in Area 4A, 7% in 4B, and 5% in 4D.

For years before 1996, smoothed survey values (for legal-sized fish) were used to estimate the age- and sex-specific commercial values in Areas 2B, 2C, and 3A. This involved a long interpolation between 1986 and 1993 when surveys were suspended, but in fact this was a period of more or less steady decline in estimated commercial mean length at age, so the linear interpolation should be reasonably accurate.

## Results

Application of the estimation procedure described above to commercial length frequencies produces estimates of sex and size frequencies that are very consistent with the observed characteristics of legal-sized fish in the survey in the mid-1990s. Mean size at age by sex and sex ratio at age show good continuity from the period where raw smoothed survey observations are used (1974-1995) to the period where the sex and size compositions are estimated from the commercial length frequencies at age (1996-2003). This is not surprising, since the logistic predictors were estimated from the survey data. What the good agreement shows is that the use of meta-parameters to summarize the logistics does not degrade the estimates.

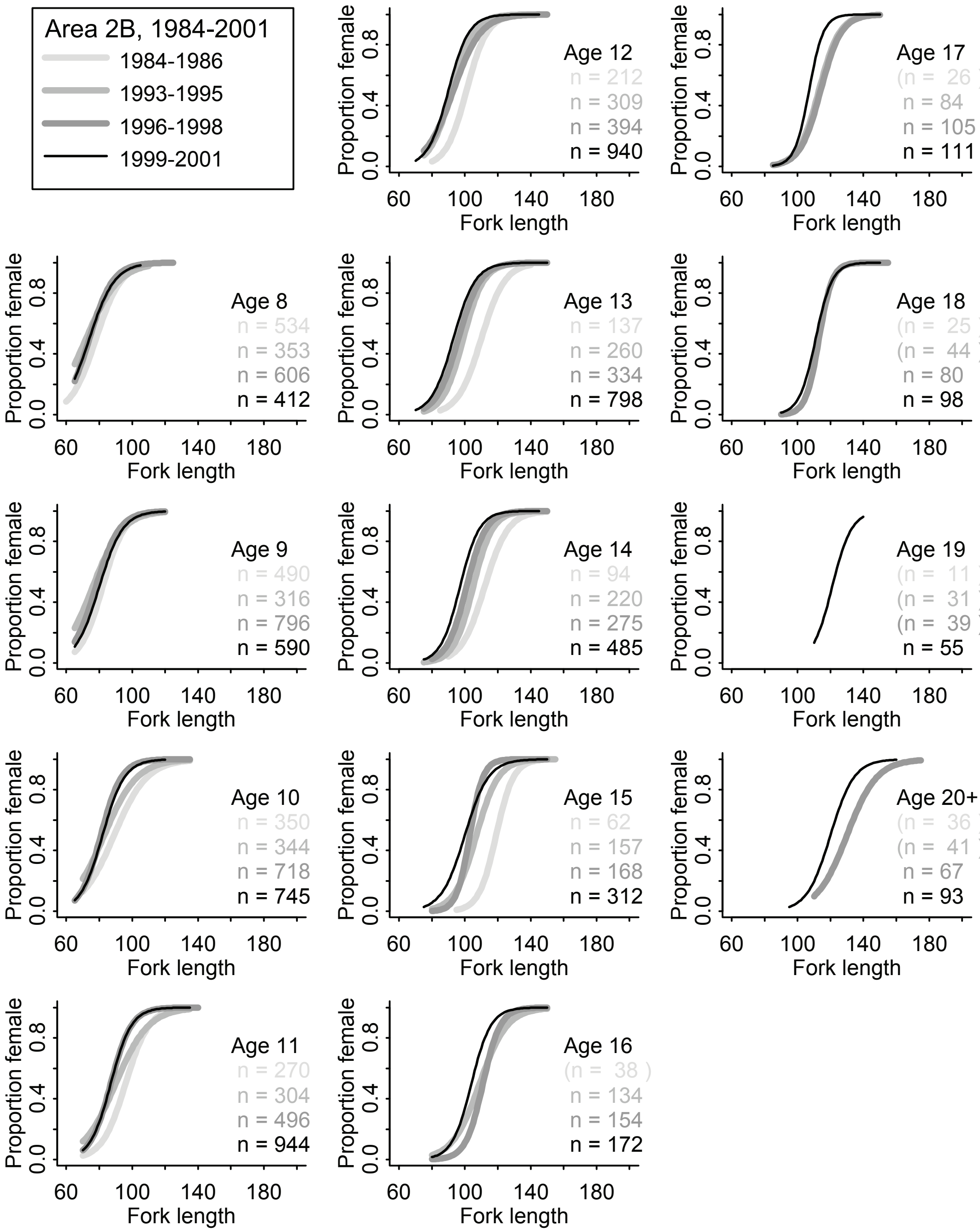



**Figure B6a. Logistics fitted to proportion female at length in Area 2B by three-year periods.**

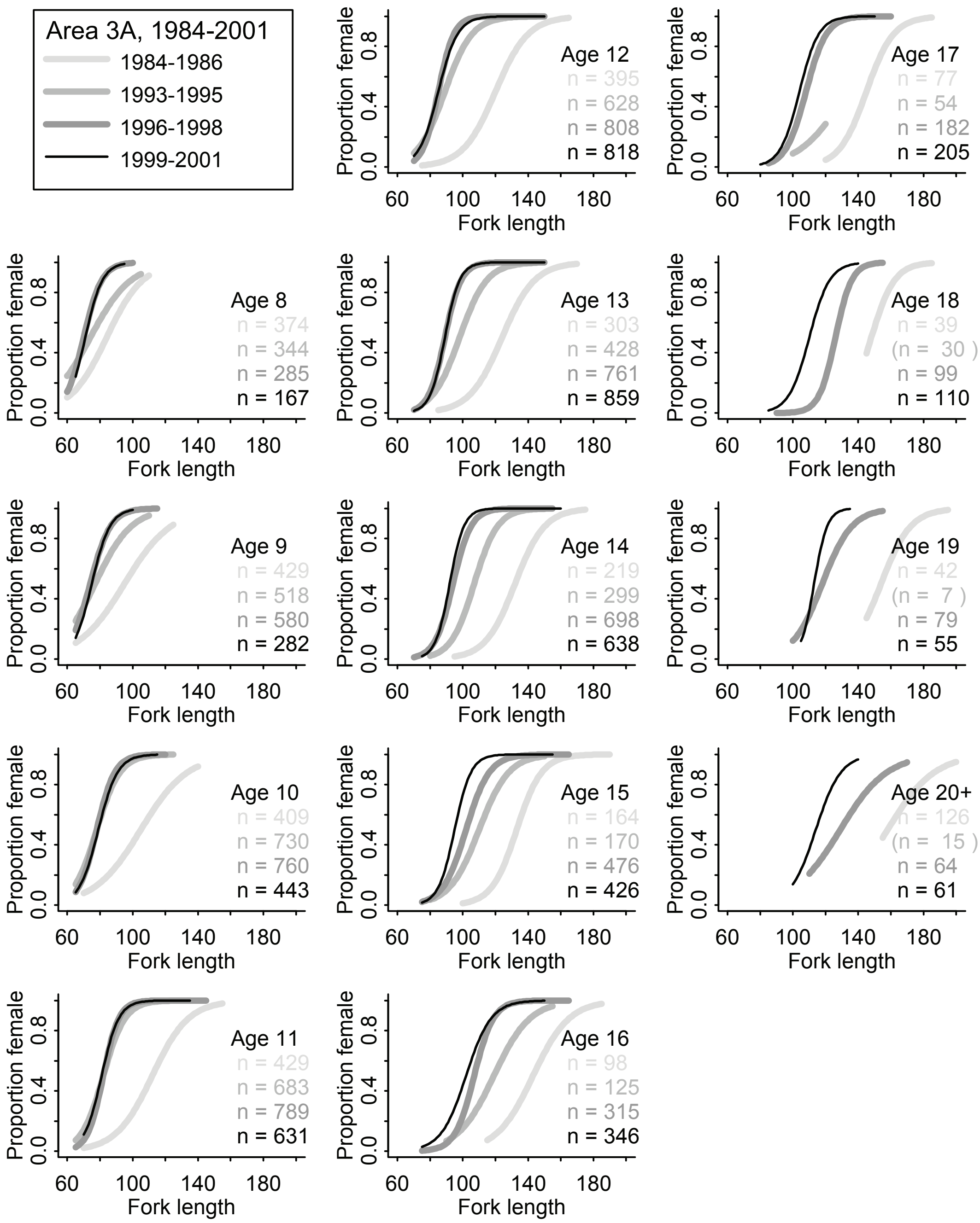



**Figure B6b. Logistics fitted to proportion female at length in Area 3A by three-year periods.**

There is a good deal of year-to-year variation in the sex ratio at a given age, in both the survey observations and the commercial estimates. It is doubtful that the sex ratio at age in the commercial landings really varies much from year to year, so it seems sensible to smooth the commercial sex ratio estimates at each age over years to compute the catch at age by sex in each year. Doing so makes very little practical difference because the year-to-year variability of estimated catch at age by sex is due almost entirely to the year-to-year variability of estimated catch at age rather than estimated sex ratio.

## Discussion

The procedure developed above seems to be quite reliable because the sex ratio at length within age has a very simple form that appears to be nearly uniform throughout a regulatory area in any given year. But that is only known to be true for the summer survey period. If there is a seasonal variation outside that period, the commercial landings could have a different sex composition. And even if the commercial fishery encounters the same sex ratio as the survey at a given age and length, the sex composition of the catch could be different if the ratio of female to male catchability is not the same as in the survey, e.g. because of a strong effect of bait type on sex-specific catchability. Differences of this sort are somewhat far-fetched but not impossible. While it seems reasonable and worthwhile for the time being to estimate commercial sex compositions as proposed, it remains desirable to devise a method of determining the sex of fish in the commercial samples.

## References

Clark, W. G. 1992. Estimation of halibut body size from otolith size. Int. Pac. Halibut Comm. Sci. Rep. No. 75.

Clark, W. G. 2001. Age and size composition and recent trawl and setline catches in Area 3A. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2000:345-352.

# Appendix C. Statistical distribution of IPHC age readings

This paper appeared first as:
Clark, W. G. 2004. Statistical distribution of IPHC age readings. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2003: 99-110.

## Abstract

This paper reports estimates of the statistical distributions of surface and break-and-burn readings about the true age of a fish. The variance of single readings of a given otolith is low for both types. Surface readings are increasingly biased downward after age 12, and among older fish they have a large variance due to variation among otoliths of a given age in the number of annuli countable by the surface method. A recipe section at the end contains detailed instructions for smearing age distributions.

## Introduction

Age readers strive to follow consistent rules when counting annuli on an otolith, but there is still some judgment involved and consequently some variability both within and among readers in the age assigned to a given otolith. A single age reading can therefore be regarded as a draw from a probability distribution. An estimate of the distribution can be incorporated into the stock assessment model to predict the observed distribution of age readings that would result from an underlying true age composition, and thereby sharpen estimates of abundance and especially year-class strengths.

In concept, the distribution of readings of a single otolith is what would be observed if the same otolith were read many times by experienced readers following the same protocol. The mode of this distribution is by definition the correct age to assign to the otolith according to that protocol, whether or not it is the true age of the fish. For clarity this modal age will be called the “canonical age” of an otolith.

At the International Pacific Halibut Commission (IPHC), otoliths were aged by surface reading until the early 1990s. During the 1990s an increasing number of difficult and older otoliths were broken and burned for reading because it was known that surface readings tended to be too low in those cases, but surface readings were continued for a majority of fish until 2002, when surface reading was discontinued altogether in favor of breaking and burning.

Break-and-burn readings have recently been validated by comparing them with a reference chronology of $^{14}C$ uptake resulting from nuclear tests in the mid-20$^{th}$ century (Piner and Wischniowski in review), so we now know that the break-and-burn protocol is accurate; i.e. that the canonical break-and-burn age of an otolith is the true age of the fish, and that the canonical surface age is too low, at least for older fish. The problem is therefore to estimate the distribution of both surface and break-and-burn readings at each canonical break-and-burn age.

## Distribution of break-and-burn readings about the canonical age

Given a sufficiently large sample of paired readings, the distribution of deviations of single readings from the canonical age can be estimated by fitting the sample distribution of differences between paired readings (Clark 2004). This procedure shows that the unsigned deviations of break-and-burn readings follow a geometric distribution. To be specific, let the random variable *b* denote a single reading of an otolith of canonical age *B*, and let $v = b - B$ be the signed deviation, so *v* has the same distribution as *b* except that it is shifted so as to have a mode at zero. Then the probability of observing a given unsigned deviation $|v| = 0,1,2,\ldots$ is $f(|v|) = p \cdot q^{|v|}$ where $q = 1 - p$. The distribution is assumed to be symmetric, so the probability of observing a given *signed* deviation *v* is $f(v = 0) = p$ and $f(v \neq 0) = p \cdot q^{|v|}/2$. The single parameter $p = f(0)$ decreases with increasing age as the variance of readings increases, and it can be computed from the sample variance $\sigma_v^2$ of the readings at each age with the formula

$$p = \frac{-3 + \sqrt{1 + 8 \cdot \sigma_v^2}}{2 \cdot (\sigma_v^2 - 1)}$$

Otoliths can and must be grouped by mean assigned age for this purpose because the canonical age of an otolith is unknown. The variance of the signed deviations $\sigma_v^2$ can be estimated conveniently as half the variance of the signed difference between paired readings.

The standard deviation of break-and-burn readings increases with canonical age in a non-linear fashion (Fig. C1), apparently leveling off at some point. The shape of this curve at ages beyond 25 or so is not well determined by the amount of data presently available; it should be re-estimated in the future. For the time being, the trend is well-described by the fitted curve, which is:

$$\sigma_v(B) = 1.28 \cdot \left(1 - \exp\left(-0.100 \cdot (B - 2.93)\right)\right)$$

where *B* is the canonical break-and-burn age (and the true age).

Parenthetically, the unsigned deviations of surface ages also follow a geometric distribution, and the standard deviation of surface age readings increases linearly with canonical *surface* age:

$$\sigma_v(A) = -0.112 + 0.0668 \cdot A$$

where *A* is canonical *surface* age, which for fish older than 12 or so is less than the canonical break-and-burn age. When corrected for the low bias of surface ages among older fish, this equation produces values similar to the standard deviations of break-and-burn readings for fish of the same true age: around 0.5 y at age 10 increasing to about 1 y at age 20 and continuing to increase thereafter. So for both kinds of reading the variance about the respective canonical age is modest.

## Mean of surface readings at a given break-and-burn age

Through about age 12 there is little difference on average between surface and break-and-burn readings. (In fact surface ages are on average slightly higher for younger fish, but the difference is negligible.) Beyond a break-and-burn age of 12, however, surface readings are lower on average, by a growing margin (Fig. C2). The relationship between assigned break-and-burn age *b* and mean surface age $\mu_a$ is well described by the curve shown in the figure, which is:

$$\mu_a(b) = b \qquad \text{b} \leq 12$$

$$\mu_a(b) = 26.58 \cdot \left(1\text{-}\exp\left(\text{-}0.0614 \cdot (\text{b-}2.17)\right)\right) \qquad \text{b} > 12$$

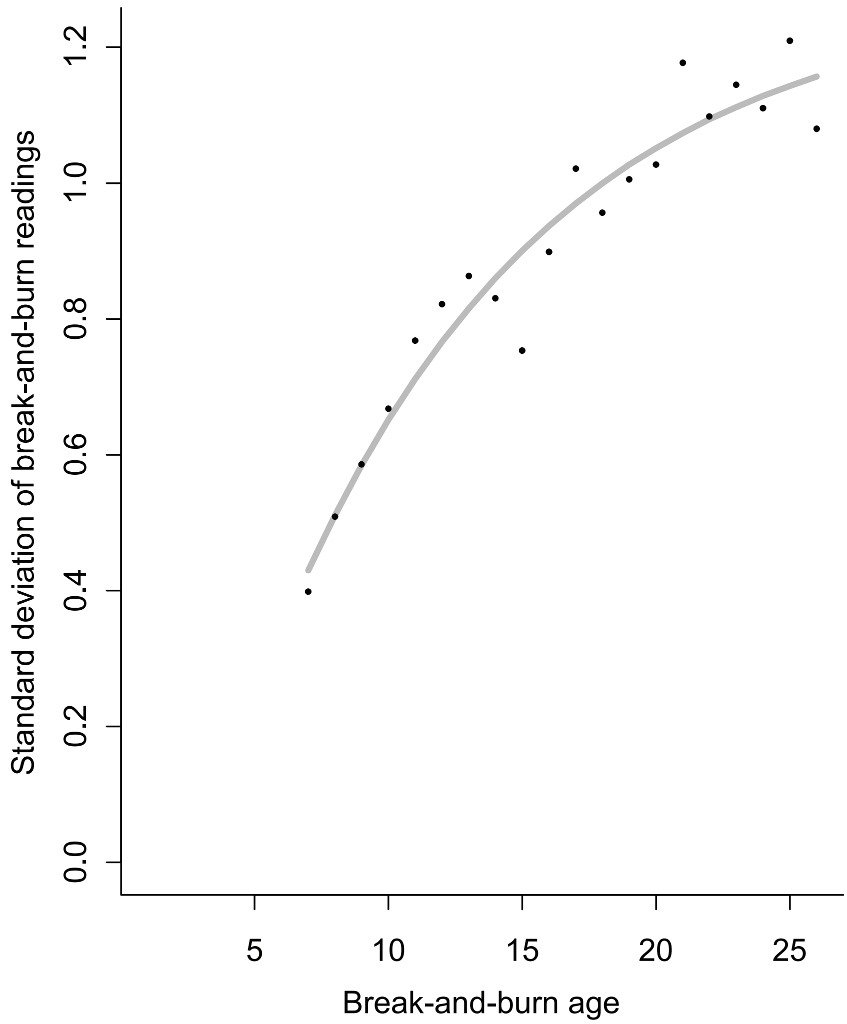



**Figure C1. Standard deviation of break-and-burn readings as function of age. The abscissa is the mean assigned age in paired readings. The ordinate is the root of half the variance of the signed difference of paired readings. The gray line is the fitted curve; see text.**

This is not precisely what we want, which is the relationship between *canonical* break-and–burn age *B* and mean surface age. The fitted curve is actually an errors-in-variables regression, but simulations show that the estimates are very close to the correct values, mainly because of the low variance of the break-and burn readings.

The data plotted in Figure C2 consist of all paired readings from 1992 through 2002, representing all regulatory areas and both sexes, some read both ways not according to any experimental design but because of difficulty in assigning a surface age. So while large, it is a mixed and not entirely random sample. But the relationship between break-and-burn and surface ages is very similar for subsets of the data grouped by area or sex or reading type, so all of the data were pooled to compute a single working formula.

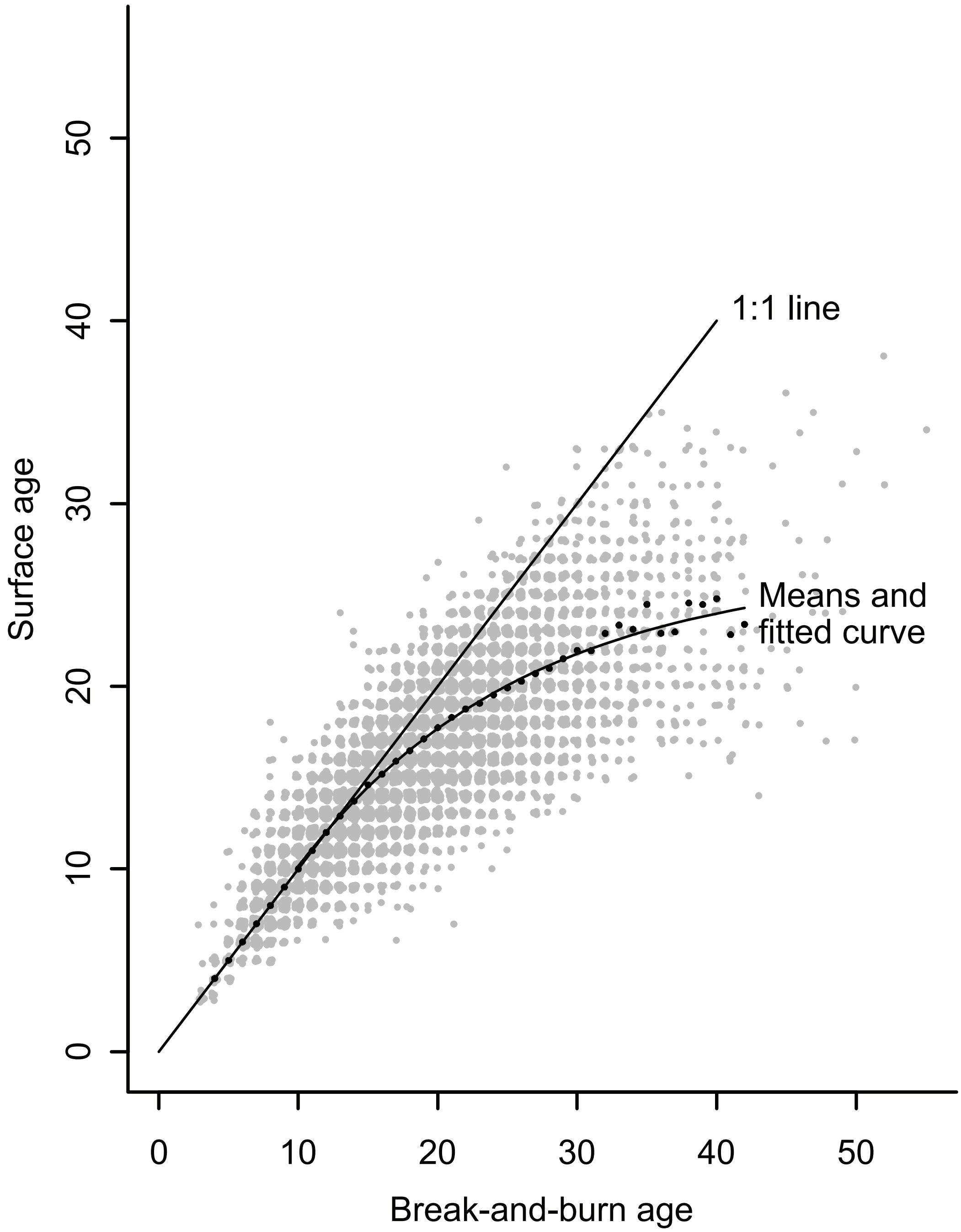



**Figure C2. Surface age reading plotted against break-and-burn age reading of the same 60,000 otoliths. The gray masses are the raw data points (jittered). The black points are the mean surface age at each break-and-burn age.**

## Variance of surface readings at a given break-and-burn age

The relationship between break-and-burn reading and the standard deviation of surface readings and is well described by the fitted logistic shown in Figure C3, which is:

$$\sigma_a(b) = 0.78 + 3.98 \Big/ \left(1 + \exp\left(-0.189 \cdot (b - 24.79)\right)\right)$$

This variance is inflated because the otoliths having a break-and-burn reading of, say, $b'$ in fact consist of a mixture of canonical break-and-burn ages. Let $B'$ denote that mixture, and let *a* and *A* denote assigned and canonical surface ages. The variance of *a* for a given $b'$ can be represented as the sum of contributions from the component ages $B \in B'$ by employing the rule that an unconditional variance is equal to the expectation of the conditional variance (over the component ages) plus the variance of the conditional expectation (over the component ages). Thus:

$$\sigma_a^2(b') = V(a|b') = \underset{B'}{E}\left[V(a|b',B)\right] + \underset{B'}{V}\left[E(a|b',B)\right]$$

For a given otolith the surface and break-and-burn readings are statistically independent, so in the first term in the sum $V(a|b',B) = V(a|B) = V(A|B) + V(a|A)$ and in the second term $E(a|b',B) = E(a|B) = E(A|B)$. Let $m(B) = E(A|B) \approx \mu_a(b')$ represent the relationship described above between canonical break-and-burn age *B* and mean canonical surface age *A*. With these substitutions:

$$\begin{aligned} V(a|b') &= \underset{B'}{E}\left[V(A|B) + V(a|A)\right] + \underset{B'}{V}\left[m(B)\right] \\ &\approx V(A|B=b') + V\left(a \,|\, A = m(b')\right) + m'(b')^2 \cdot V(b|B=b') \end{aligned}$$

The form of the third term above relies on the fact that the distributions $f(B|b)$ and $f(b|B)$ are approximately equal, so $V(B|b) \approx V(b|B)$. This is just the variance of the break-and-burn readings about the canonical break-and-burn age. Here it is multiplied by the square of the slope of $m(B)$ at $b'$ because locally $m(B) \approx m(b') + m'(b') \cdot (B - b')$ so $V(m(B)) \approx m'(b')^2 \cdot V(B|b')$. Among older fish this slope is low because surface age changes slowly with true age, so the third term contributes little to $V(a|b')$ at those ages.

The second and third terms can be computed from the known variances of surface and break-and-burn readings about their respective canonical ages. The first term is the variance of canonical surface age at a given canonical break-and-burn age. If all otoliths of a given canonical break-and-burn age belonged to a single canonical surface age, or a very narrow range, this term would be small. It is not. Through about age 15, it accounts for half or slightly less of the total variance, and beyond age 15 it increases steeply, by age 25 dwarfing the other variance components (Fig. C4).

## Form of the distribution of surface ages at a given break-and-burn age

From about age 20 onward, where the variance and therefore the form of the distribution of surface ages $f(a|b')$ is dominated by $V(A|B)$, the distribution is very well approximated (Fig. C5) by a discrete version of the normal density:

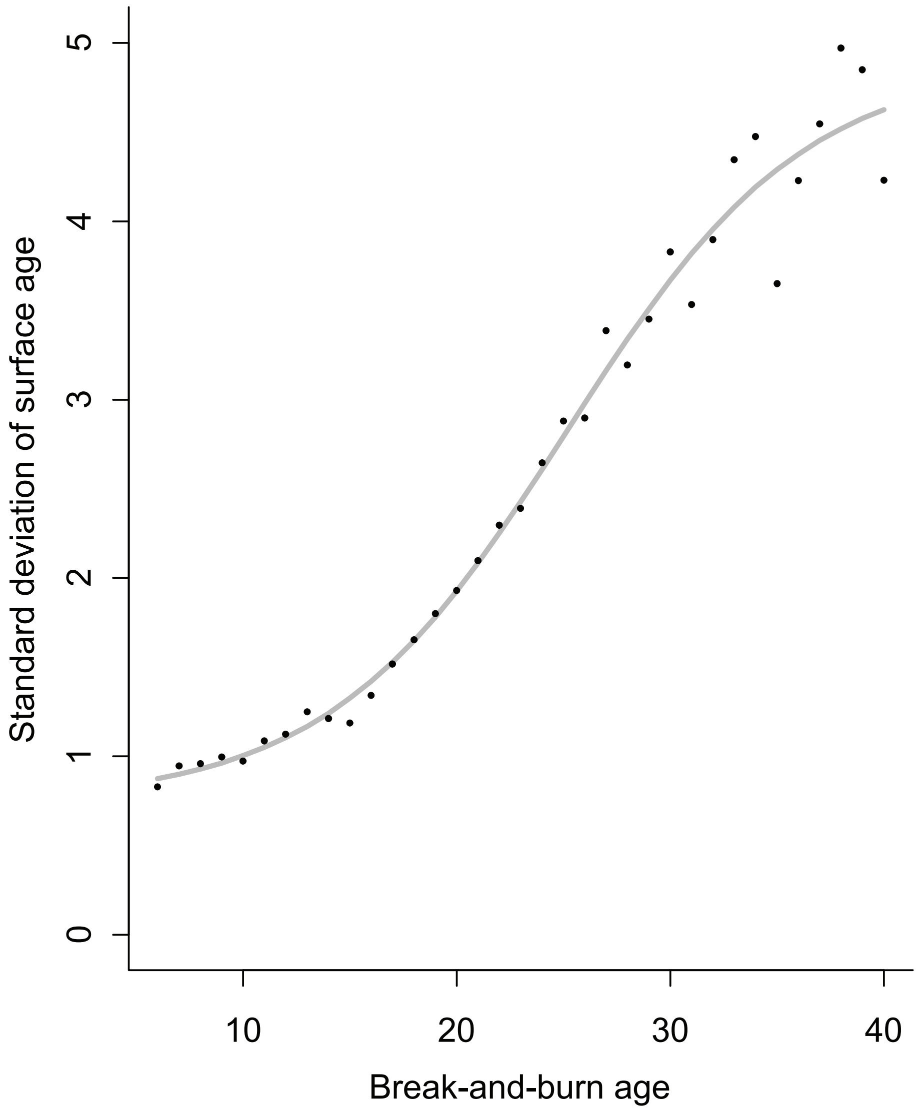



**Figure C3. Standard deviation of surface readings plotted against break-and-burn readings (points), and a fitted logistic.**

$$f\left(a\middle|b'\right) \propto \exp\left(-\left(a-\mu_a\left(b'\right)^2\right)\Big/\left(2\cdot\sigma_a^2\left(b'\right)\right)\right)$$

The standard deviation of this density is equal to the parameter $\sigma_a$ for $\sigma_a \geq 0.6$; it is less than $s_a$ for smaller values.

Among younger fish, where other variance components are significant, the distributions are leptokurtic, having more data points at the mean and in the tails (and fewer in between) than a normal distribution with the same variance. This is clear in Fig. C5, where at low ages the normal distributions with parameters equal to the sample moments (thick gray lines) fail to reach the high observed frequencies of the modal (and true) ages. This shortfall can be prevented by using an ad hoc scaler to reduce the working value of $\sigma_a$ to something less than the sample standard deviation. Specifically, if the sample standard deviation is multiplied by a scaler that increases linearly from 0.5 at age 5 to 1.0 at age 20, the normal approximation is adequate for the younger ages as well. The black lines in Figure 4 are predicted frequencies based on the discrete normal distributions with means and standard deviations taken from the fitted curves reported above, except that at younger ages $\sigma_a$ is calculated by scaling down the fitted standard deviation.

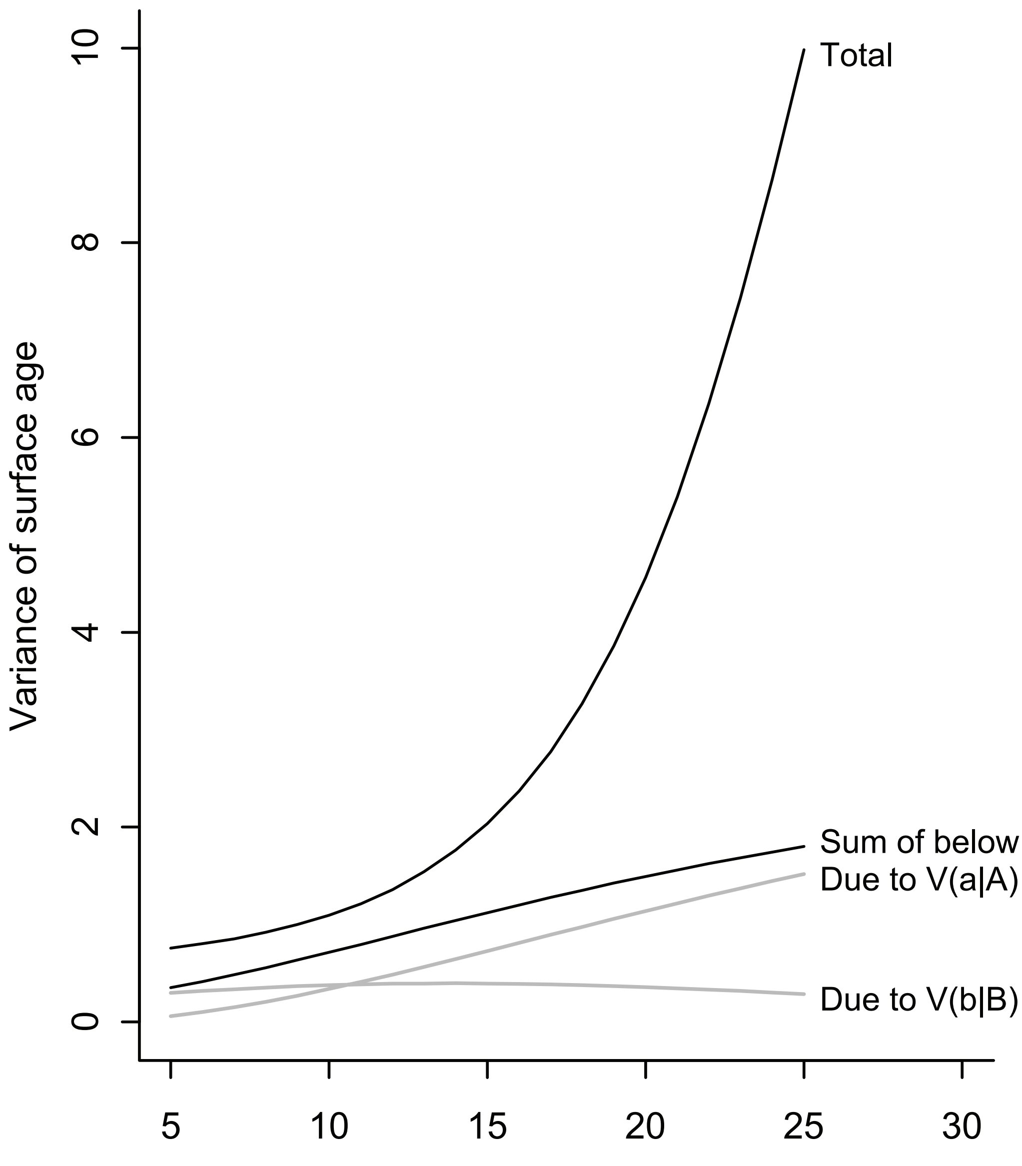



**Figure C4. Components of the variance of surface readings at a given break-and-burn reading. V(a|A) is the variance of surface readings about the canonical surface age. V(b|B) is the same for break-and-burn readings, but only a fraction enters the total variance; see text. The difference between the two upper lines is due to V(A|B), the variance of canonical surface age at a given canonical break-and-burn age.**

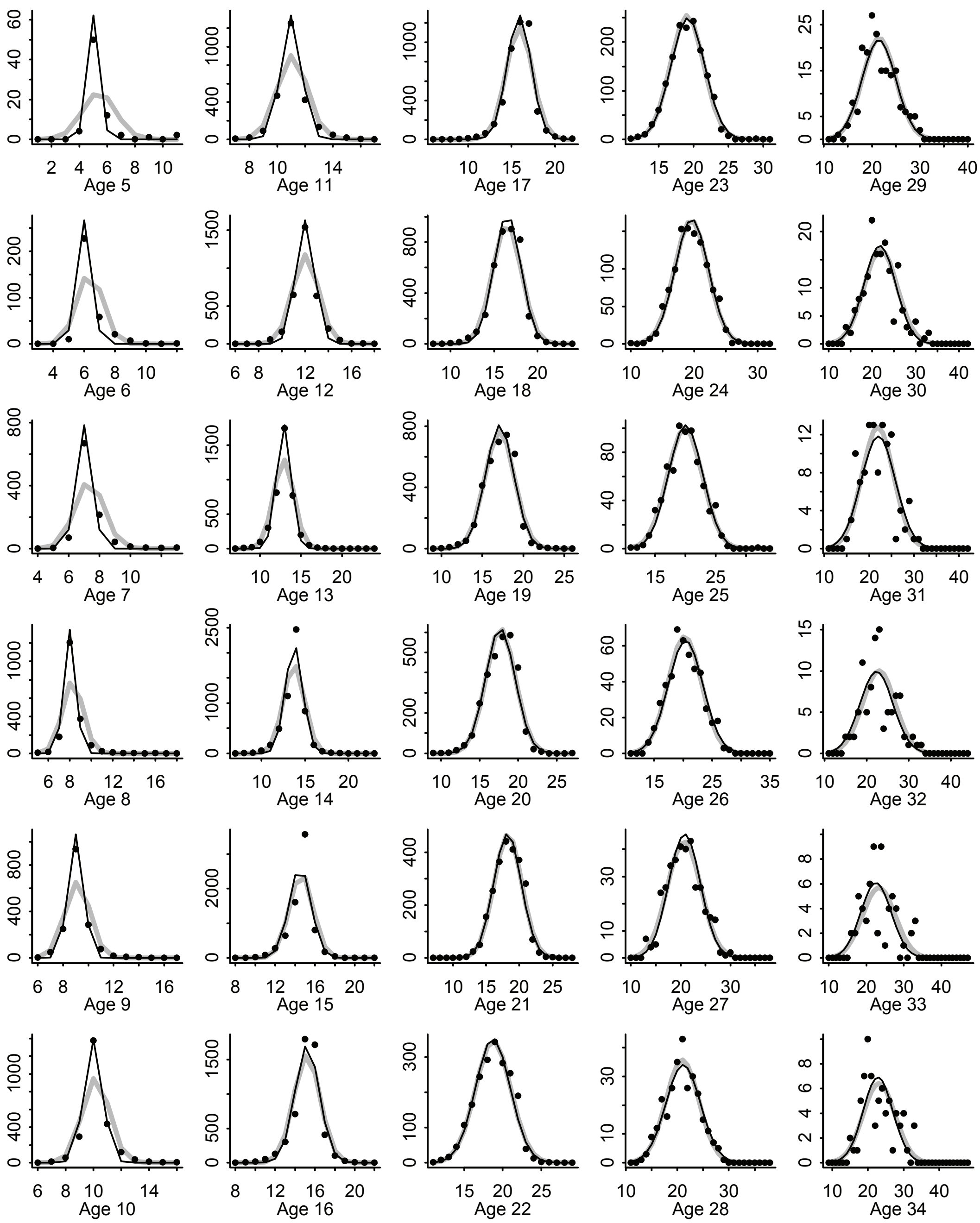


**Figure C5. Observed and predicted frequencies (number of otoliths) of surface ages grouped by assigned break-and-burn age. The gray line in each plot is a discrete version of the normal density with parameters equal to the sample moments. The black line is a normal density with parameters calculated from the fitted curves reported in the text.**

## Discussion and conclusions

Predicting the distribution of break-and-burn readings of fish of a given true age *B* is straightforward because that is also the canonical break-and-burn age, so the readings can be expected to follow the simple geometric distribution described above and detailed in the recipe section at the end.

Surface age readings are more complicated because their distribution depends on both the distribution of individual surface readings about the canonical surface age, $f(a|A)$, and the distribution of canonical surface age at a given true age or, equivalently, canonical break-and-burn age, $f(A|B)$. Beyond age 15 or 20, this source of variation is quite large. The canonical surface age of an otolith is the number of surface-countable annuli as defined in the protocol, and age readers can make that determination with a high degree of consistency. But among older otoliths of the same canonical break-and-burn age there is obviously a great deal of variation in the number of surface-countable annuli, which is not surprising.

The distribution $f(A|B)$ could be estimated by modeling, and surface readings of fish of each true age *B* could then be predicted in two steps by predicting the canonical surface age distribution and then the surface age reading distribution. A simpler alternative is to predict the distribution of break-and-burn readings $f(b|B)$ for all ages to obtain the overall marginal distribution of predicted break-and-burn readings and then use the simple model of $f(a|b)$ developed above to predict the corresponding distributions of surface readings. This approach has the attraction that both $f(b|B)$ and $f(a|b)$ can be (and have been) estimated directly from the available data. The smearing procedure is spelled out below.

## References

Clark, W. G. 2004. Nonparametric estimates of age misclassification from paired readings. Can. J. Fish. Aquat. Sci. 61:1881-1889.

Piner, K. R., and S. Wischniowski. 2004. Description of a Pacific halibut chronology of bomb radiocarbon from 1944-1981 and a validation of ageing methods. J. Fish. Biol. 64:1060-1071.

## Recipes

This section is intended as a working reference for predicting the distribution of break-and-burn and surface readings of otoliths of a given true age *B*; it contains no new material.

### Distribution of break-and-burn readings

Let $v = b - B$, the signed deviation of a single reading from the true age. The distribution of $v$ is $f(0) = p$ and $f(v \neq 0) = p \cdot q^{|v|}/2$ where $q = 1 - p$ and the parameter $p = f(0)$ is a function of the variance of break-and-burn readings at age *B*:

$$p = \frac{-3 + \sqrt{1 + 8 \cdot \sigma_v^2}}{2 \cdot (\sigma_v^2 - 1)} \text{ if } \sigma_v^2 \neq 1 \text{ else } 2/3$$

$$\sigma_v^2(B) = \left(1.28 \cdot \left(1 - \exp\left(-0.100 \cdot (B - 2.93)\right)\right)\right)^2$$

## Distribution of surface readings

The first step is to generate the distribution of predicted break-and-burn readings (assigned ages) *b* for fish of all true ages, including *B*, as described above. For each assigned age $b'$, the mean $\mu_a$ of predicted surface readings is:

$$\mu_a(b') = b' \qquad \text{b}' \le 12$$

$$\mu_a(b') = 26.58 \cdot \left(1\text{-exp}\left(\text{-}0.0614 \cdot (\text{b}'\text{-}2.17)\right)\right) \qquad \text{b}' > 12$$

The actual standard deviation of surface readings is:

$$\sigma_a(b') = 0.78 + 3.98 \Big/ \left(1 + \exp\left(-0.189 \cdot (b' - 24.79)\right)\right)$$

but the computations use a working value $\delta_a = c \cdot \sigma_a$ that is scaled down at the lower ages. The value of the scaler *c* is:

$$c = 0.5 \qquad \text{b}' < 5$$

$$c = 0.5 + 0.5 \cdot (b' - 5)/15 \qquad 5 \le \text{b}' \le 20$$

$$c = 1 \qquad \text{b}' > 20$$

Let $d(a) = \exp\left(-(a - \mu_a)^2 \Big/ \left(2 \cdot \delta_a^2\right)\right)$, a discrete form of part of the normal density function. Note the last term is $\delta_a^2$ not just $\delta_a$. Normalizing the values of $d(a)$ finally gives the density of surface readings at break-and-burn age $b'$:

$$f(a) = d(a) \Big/ \sum_a d(a).$$

## Calculation of observed age composition from true age composition

Let $\mathbf{N}_b$ be a row vector of numbers at true age *b* (*b=1,…,B*) and let $\mathbf{MM}_{ba}$ be a misclassification matrix in which each element $mm_{ba}$ is $p(a \mid b)$, the probability of assigning (observing) age *a* $(a = 1, \ldots, A)$ given that true age is *b*. So row *b* of $\mathbf{MM}_{ba}$ is the distribution of observed ages *a* at true age *b*. Then the row vector of expected numbers at observed age $\mathbf{N}_a$ is:

$$\mathbf{N}_a = \mathbf{N}_b \cdot \mathbf{MM}_{ba}$$

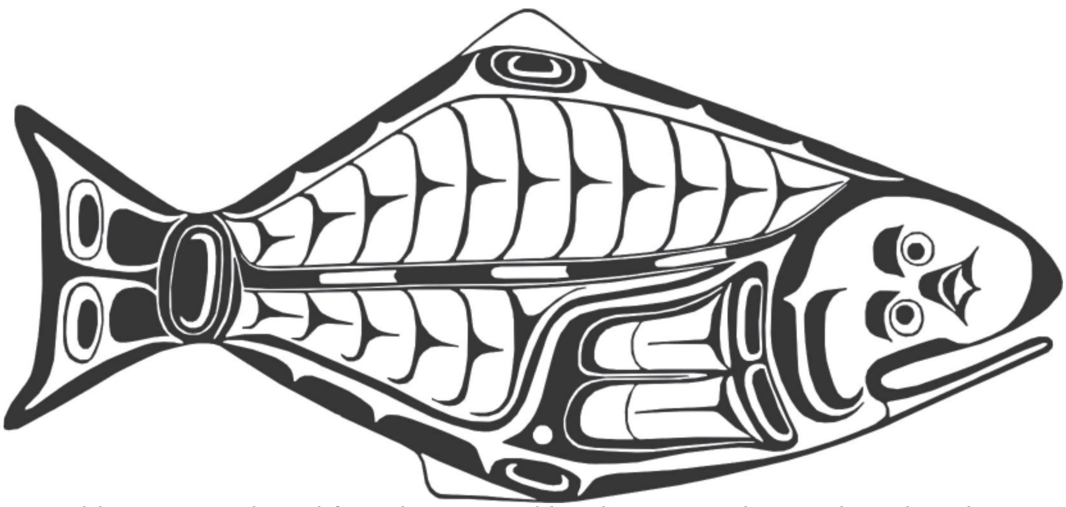
If $\mathbf{N}_{yb}$ is a matrix in which row *y* is a vector of numbers at true age *b* in year *y*, the corresponding matrix of expected numbers at observed age *a* is:

$$\mathbf{N}_{ya} = \mathbf{N}_{yb} \cdot \mathbf{MM}_{ba}$$

Alternatively if the misclassification matrix is set up columnwise, so that column *b* is the distribution of observed ages *a* at true age *b*, then $p(a \mid b) = mm_{ab}$ and the calculation is:

$$\mathbf{N}_{ya} = \left(\mathbf{MM}_{ab} \cdot \mathbf{N}_{yb}^{\mathbf{T}}\right)^{\mathbf{T}}$$

where $\mathbf{T}$ denotes transpose.



*Halibut Crest - adapted from designs used by Tlingit, Tsimshian and Haida Indians*

# Assessment of the Pacific halibut stock at the end of 2005

**William G. Clark and Steven R. Hare**


## Abstract

This year's assessment uses the same methods as last year's to estimate exploitable biomass in all areas except Area 4CDE, where an estimate based on the NMFS trawl survey is reported for the first time. The new estimate is the same as what the old estimation method would have produced. Coastwide exploitable biomass is little changed. Fishery CEY in Areas 4B and 4CDE is lower because of the adoption of a lower harvest rate in those areas.


## Introduction

Each year the IPHC staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). Exploitable biomass in each of IPHC regulatory areas 2B, 2C, 3A, 3B, 4A, and 4B is estimated by fitting a detailed population model to the data from that area, going back to 1974 in the eastern areas and to 1996 in Areas 3B and 4. Exploitable biomass in Area 2A is estimated by applying a survey-based estimate of relative abundance to the analytical estimate of biomass in Area 2B. In Area 4CDE the estimate of exploitable biomass is based on the NMFS trawl survey of the eastern Bering Sea shelf.

A biological target level for total removals is calculated by applying a fixed harvest rate to the estimate of exploitable biomass. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for catches in directed fisheries subject to allocation is called the fishery CEY. It comprises the commercial setline catch in all areas plus the sport catch in Areas 2A and 2B. It is calculated by subtracting from the total CEY an estimate of all unallocated removals—bycatch of legal-sized fish, wastage of legal-sized fish in the halibut fishery, fish taken for personal use, and sport catch except in Areas 2A and 2B.

Staff recommendations for catch limits in each area are based on the estimates of fishery CEY but may be higher or lower depending on a number of statistical, biological, and policy considerations. Similarly, the Commission's final quota decisions are based on the staff's recommendations but may be higher or lower.

## Evolution of assessment methods through 2004

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

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

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

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

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

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

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

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

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

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

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

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

## Estimates of exploitable biomass and CEY

Like last year, the model fits in Areas 2B-4B are quite satisfactory (Fig. 1), and the estimates of abundance are little changed in most areas (text table below). The Area 2C estimate is down by about 10% because of a lower commercial CPUE in 2005 and another low survey CPUE in 2005 following last year's 20% drop. The continued decline of both commercial and survey CPUE in Area 3B in 2005 resulted in a substantial downward revision of estimated biomass at the beginning of 2005, from 56 million pounds in last year's assessment to 40 million in this year's. Estimated biomass at the beginning of 2006 in this year's assessment is higher (45 million) because of strong estimated incoming recruitment.

| | 2005 biomass 2004 assessment | 2005 biomass 2005 assessment | 2006 biomass 2005 assessment |
|---|---|---|---|
| **Area 2A** | 7.0 | 7.5 | 7.6 |
| **Area 2B** | 58 | 60 | 61 |
| **Area 2C** | 66 | 60 | 61 |
| **Area 3A** | 146 | 150 | 143 |
| **Area 3B** | 56 | 40 | 45 |
| **Area 4A** | 20 | 20 | 19 |
| **Area 4B** | 10 | 11 | 9 |
| **Area 4CDE** | | | |
| Analytical | 32 | --- | --- |
| Trawl survey | --- | 36 | 36 |
| **Total** | 395 | 385 | 382 |

Exploitable biomass in Area 2A is calculated as a proportion of the Area 2B analytical estimate. The proportion used is the ratio of survey CPUE's (three-year running mean) weighted by bottom areas:

$$\text{proportion} = \frac{(\text{2A CPUE})\times(\text{2A bottom area})}{(\text{2B CPUE})\times(\text{2B bottom area})}$$

The idea here is that survey CPUE is an index of density and multiplying it by the total bottom area gives an index of total biomass. The calculated value of the scaling proportion has been 12% or 13% for the last three years, with the alternation between the two adding to the variability of the Area 2A estimate. A working value of 12.5% was adopted this year, with the aim of sticking with it unless and until the calculated value moves very far in either direction.

In last year's assessment, the estimate of biomass in Area 4CDE was calculated by scaling the Area 4A analytical estimate by the same procedure. But lacking setline survey data from the large eastern Bering Sea shelf, the calculation used an assumed setline survey CPUE of 40 lb/skate in all of Area 4CDE, based NMFS trawl survey catch rates and a comparison of trawl and setline survey catch rates at a limited number of stations in Areas 4A and 4C in the mid-1990s. Using this procedure, the estimated biomass in Area 4CDE in last year's assessment was 160% of the Area 4A estimate or 32 million pounds. Because survey CPUE in Area 4A continued to decline in 2005, this year's scaling factor would be 190% and the Area 4CDE estimate would be 36 million pounds. The value shown in the table above is the same, but it is based directly on the most recent NMFS trawl survey results as explained below.

Total CEY (Table 1) is calculated by applying a harvest rate of 22.5% in Areas 2A, 2B, 2C, and 3A, 20% in Areas 3B and 4A, and 15% in Areas 4B and 4CDE. These are the same rates used last year except in Areas 4B and 4CDE, where the rate has been reduced from 20% to 15% (Hare 2006).

## Estimates of Area 4CDE biomass from the NMFS trawl survey

The National Marine Fisheries Service has conducted an annual trawl survey on the eastern Bering Sea shelf (20-200 m) using the same gear and station pattern since 1982. The survey trawl has no rollers, so it fishes hard on bottom. The vertical opening is 3.5 m. Standard survey stations are placed on a 20 nautical mile grid, and the standard survey area extends northward to about 61º N (Fig. 2). NMFS also carries out trawl surveys in the Gulf of Alaska and Aleutian Islands using a high-rise (7 m) trawl equipped with rollers for fishing rougher bottom. In areas where both the NMFS trawl survey and the IPHC setline survey are conducted, the trends in survey catch rates at length agree quite well (Fig. 3). The trawl survey catch rates are somewhat more variable from year to year, but there is no reason to doubt that they provide a reliable index of halibut abundance in trawlable areas.

In NMFS flatfish assessments, the absolute density of fish is estimated from the survey catches and the area swept by the trawl (measured as the distance between the trawl wings multiplied by the distance towed), and this density is multiplied by the entire survey area to estimate absolute biomass. Swept-area estimates of absolute abundance are accurate if the survey trawl catches all of the fish in the path of the trawl. They can be low if fish avoid capture by outswimming the trawl or by passing over the headrope or under the footrope. On the other hand, they can be high if the trawl bridles herd fish into the path of the net, or if fish are actually attracted to the vessel.

Albert et al. (2003) observed the behavior of Greenland turbot in the path of a trawl with a video camera. They suspected that some larger fish escaped ahead of the trawl, but they did not observe any do so, and all of the fish that they did sight were overtaken by the trawl within seconds. None swam over the headrope. Handegaard and Tjostheim (2005) tracked the movements of cod in the path of an approaching trawl with a split-beam sonar, beginning at a range of 2-4 km. Fish were seen to dive slowly as the ship approached, and were seen to be herded to both sides by the trawl warps, but movement along the line of the ship's travel was slight, indicating that in this case fish did not escape in front of the trawl. Some fish did appear to be attracted by the ship, moving toward the ship's path. The authors speculate that the fish were attracted to the lower levels of propeller noise forward and aft of the ship. Krieger and Sigler (1996) visually determined the density of rockfish in the path of a trawl from a submersible. Even though the vertical distribution of the rockfish extended well above the headrope, the trawl estimate of density exceeded the visual estimate. The authors believed that both diving and herding played some role.

Somerton and Munro (2001) carried out a careful study of the degree of herding by the bridles of the NMFS Bering Sea survey trawl on seven species of flatfish, not including halibut. They found that because of herding, the trawl caught 120-140% of the fish in the path of the net, depending on species. For five of the seven species, herding was independent of fish length. For two it decreased with length. Munro and Somerton (2002) studied escapement under the footrope of the survey trawl and found it to be negligible for all flatfish studied (not including halibut) except for yellowfin sole. In a similar study of escapement under the footrope of the roller trawl used by NMFS for other surveys, no halibut were observed to escape under the footrope (Weinberg et al. 2002).

In nearly all NMFS flatfish assessments, survey trawl selectivity is assumed to be asymptotic, with the lower catchability of smaller fish due mainly to their distribution in shallow water outside the survey area rather than to lower vulnerability to capture by the trawl (which has a small-mesh liner). For the same sizes of fish, halibut selectivity should be the same, increasing with length and then not decreasing up to the largest sizes observed among other flatfish species, say 100 cm. But it may decrease among the largest fish. Clark (1993) estimated the selectivity of the roller trawl used in other surveys and found that for halibut it peaked at 65 cm and then declined gradually, reaching 50% at 120 cm. But that study assumed asymptotic selectivity in the IPHC setline survey, whereas more recently it has been found that setline survey selectivity continues to increase beyond 120 cm.

Commercial setline selectivity is well determined in the assessment, and we can use that to estimate the true length composition in any area by scaling up the commercial length composition. The survey trawl selectivity can then be calculated from the trawl survey length composition. There is not enough overlap between the commercial fishery and the trawl survey to do that in Area 4CDE, but we can do the calculations for Area 3A, 3B, and 4A which are surveyed by the roller trawl. That yields the trawl selectivity estimates below.

| Length | Area 3A | Area 3B | Area 4A | Median |
|---|---|---|---|---|
| **85** | 0.28 | 0.89 | 1.00 | 0.89 |
| **95** | 0.70 | 1.00 | 0.94 | 0.94 |
| **105** | 0.84 | 0.90 | 0.74 | 0.84 |
| **115** | 1.00 | 0.74 | 0.89 | 0.89 |
| **125** | 0.89 | 0.47 | 0.89 | 0.89 |
| **135+** | 0.56 | 0.59 | 1.00 | 0.59 |

The numbers are not very consistent among areas but on the whole they suggest little change in selectivity with length up to at least 125 cm, which covers the bulk of fish in the stock nowadays. These numbers do refer to the roller trawl, which has a larger vertical opening, but that should not be an issue because flatfish generally stay near bottom throughout the process of being captured by a trawl (King et al. 2004).

For estimating halibut biomass in Area 4CDE, we assume no decrease in selectivity with length, and we assume that because of herding the trawl catches 130% of the fish in the path of the net, the midpoint of the NMFS estimates for other flatfish. Both assumptions are conservative. With these estimates of total abundance at length, we can calculate exploitable biomass by applying the fixed length-specific commercial setline selectivity schedule used in all Alaska areas.

The estimates for each of the trawl survey strata vary substantially from year to year, but the total for the shelf survey has been quite stable at an average of 40 million pounds over the last five years. Of that total, about 10% is in stratum 5, which is mostly in Area 4A, so the Area 4CDE estimate is 36 million pounds, which by happenstance is exactly the number that we would have calculated with the old estimation procedure. Of the entire shelf biomass, about 50% is in Area 4D, about 30% in Area 4E and the Closed Area, 10% in Area 4C, and 10% in Area 4A.

NMFS also conducts a trawl survey of the eastern Bering Sea slope (Hoff and Britt 2005), but the exploitable biomass estimate for 2004 was less than 5 million pounds, and almost half was in the Area 4A sector. We have chosen to treat this component as negligible, mainly for simplicity.

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**Table 1. Estimates of exploitable biomass and CEY.**

| | Area 2A | Area 2B | Area 2C | Area 3A | Area 3B | Area 4A | Area 4B | Area 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **2005 catch limit** [1] | 1.33 | 13.25 | 10.93 | 25.47 | 13.15 | 3.44 | 2.26 | 3.99 | 73.82 |
| | | | | | | | | | |
| **2005 exploitable biomass** (2004 assessment) | 7.0 | 58 | 66 | 146 | 56 | 20 | 10 | 32 | 395 |
| **2006 exploitable biomass** (2005 assessment) | 7.6 [2] | 61 | 61 | 143 | 45 | 19 | 9 | 36 [3] | 382 |
| | | | | | | | | | |
| **Other removals** | | | | | | | | | |
| Sport catch | 0.49 | 1.46 | 2.54 | 5.44 | 0.01 | 0.04 | 0.00 | 0.00 | 9.98 |
| Legal-sized bycatch | 0.17 | 0.19 | 0.14 | 1.32 | 0.36 | 0.46 | 0.28 | 2.21 | 5.13 |
| Personal use | 0.04 | 0.30 | 0.68 | 0.40 | 0.03 | 0.03 | 0.00 | 0.07 | 1.55 |
| Legal-sized wastage | 0.01 | 0.04 | 0.04 | 0.08 | 0.03 | 0.02 | 0.00 | 0.01 | 0.23 |
| **Total** | 0.71 | 1.99 | 3.40 | 7.24 | 0.43 | 0.55 | 0.28 | 2.29 | 16.89 |
| …excluding sport catch | 0.22 | 0.53 | --- | --- | --- | --- | --- | --- | |
| | | | | | | | | | |
| **Total CEY** [4] | 1.71 | 13.73 | 13.73 | 32.18 | 9.00 | 3.80 | 1.35 | 5.40 | 80.90 |
| **Fishery CEY** [1] | 1.49 | 13.20 | 10.33 | 24.94 | 8.57 | 3.25 | 1.07 | 3.11 | 65.96 |

Notes:

1. 2005 catch limit and 2006 fishery CEY include sport catch in Areas 2A and 2B.
2. Area 2A exploitable biomass estimated as 12.5% of Area 2B (12% last year).
3. Area 4CDE exploitable biomass estimate based on NMFS trawl survey for the first time.
4. Total CEY is 22.5% of exploitable biomass in Areas 2A, 2B, 2C, and 3A; 20% in Areas 3B and 4A; 15% in Areas 4B and 4CDE.

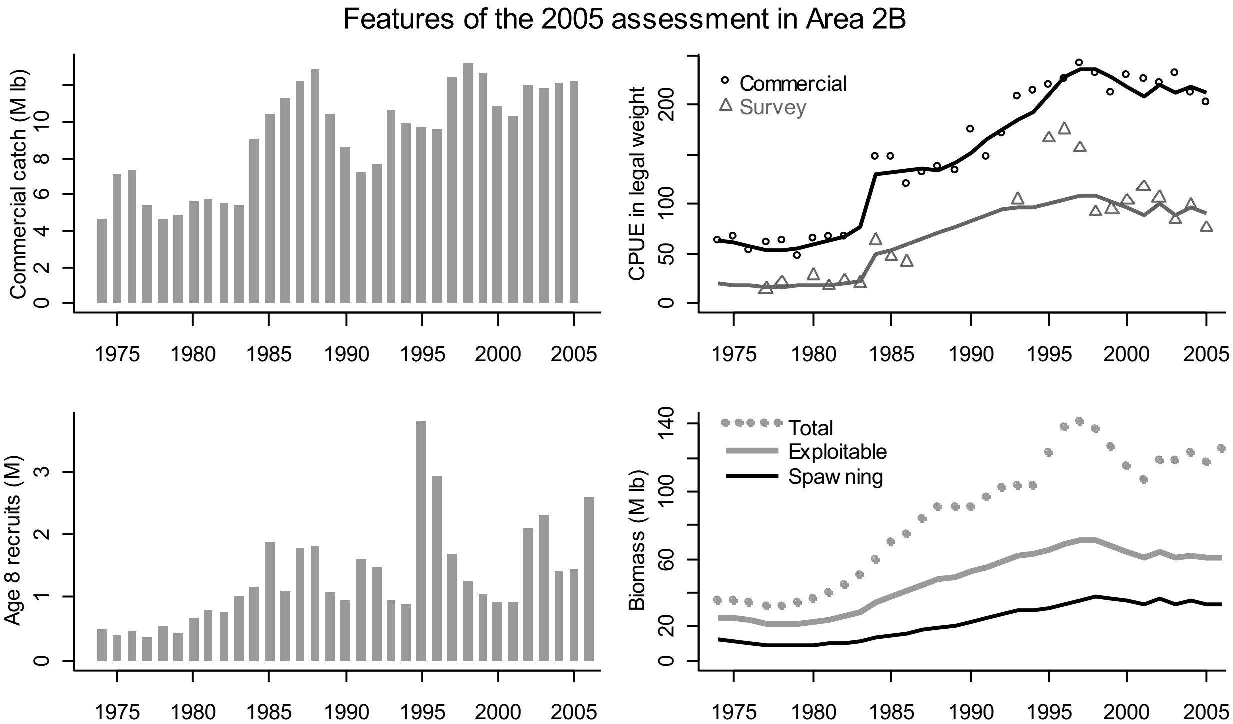


**Figure 1a. Features of the 2005 assessment in Area 2B.**

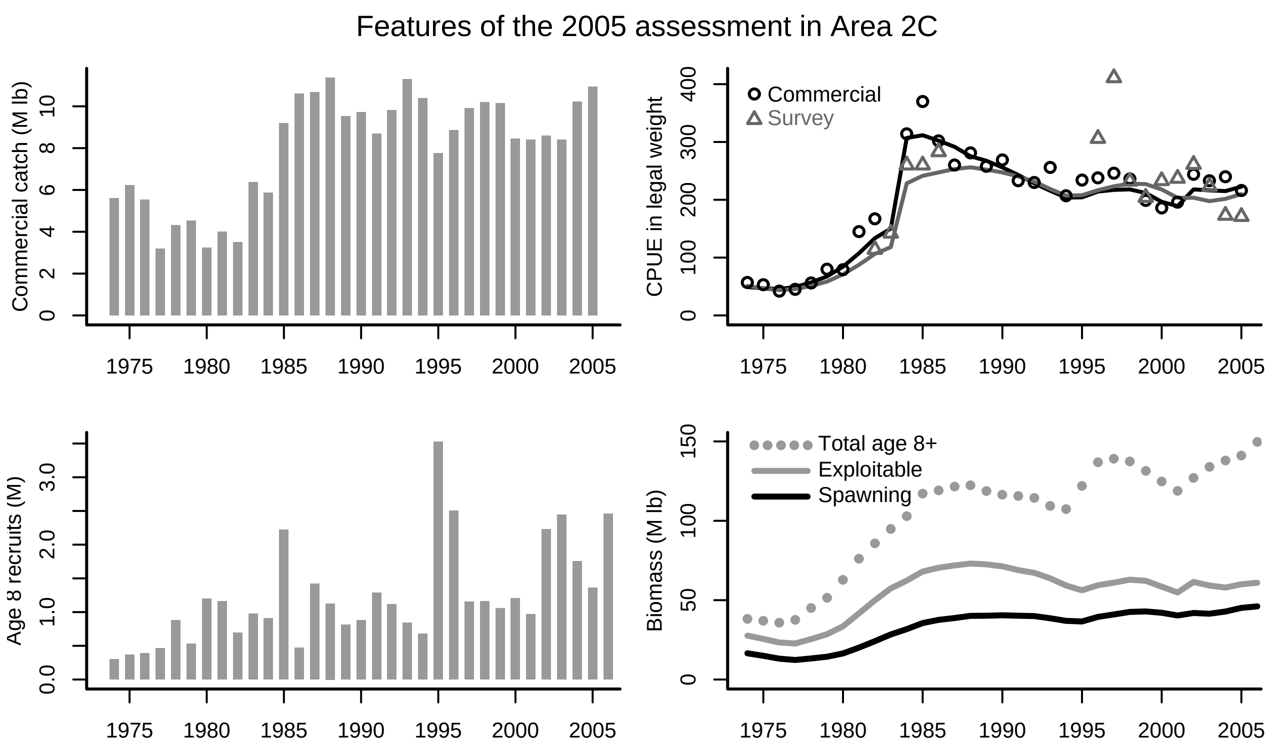


**Figure 1b. Features of the 2005 assessment in Area 2C.**

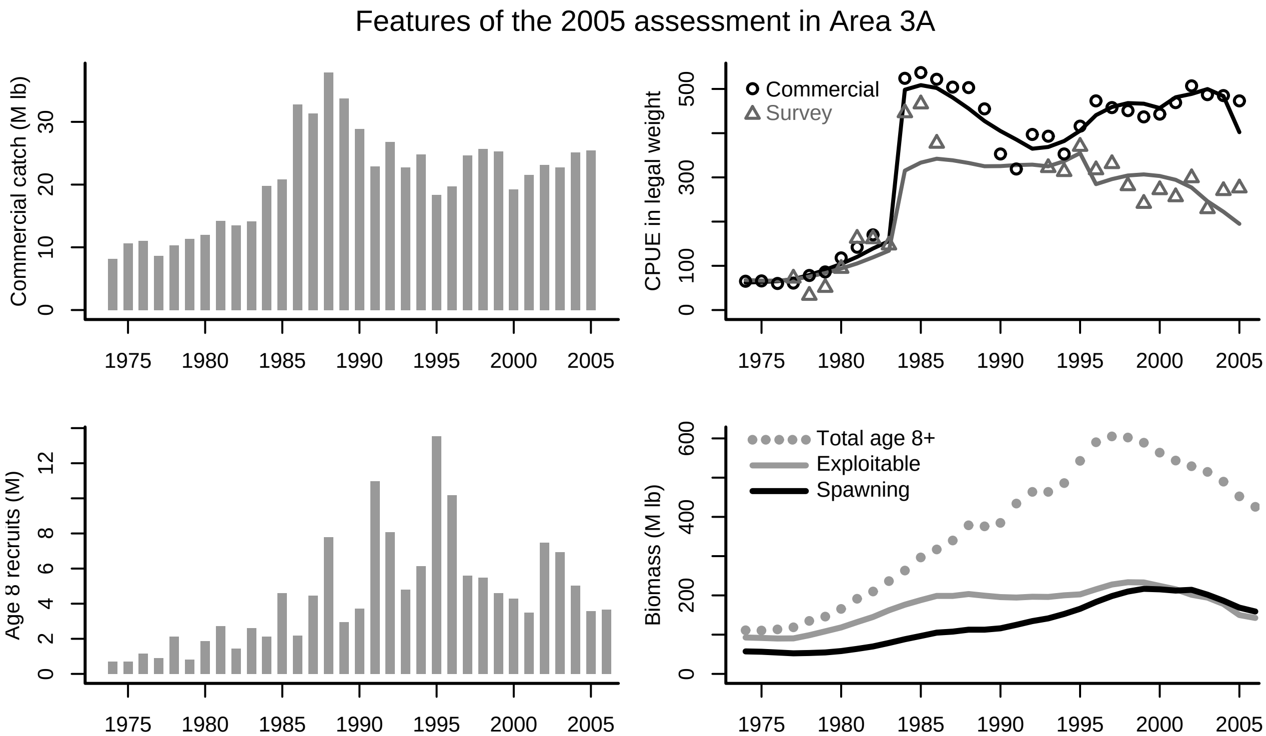


**Figure 1c. Features of the 2005 assessment in Area 3A.**

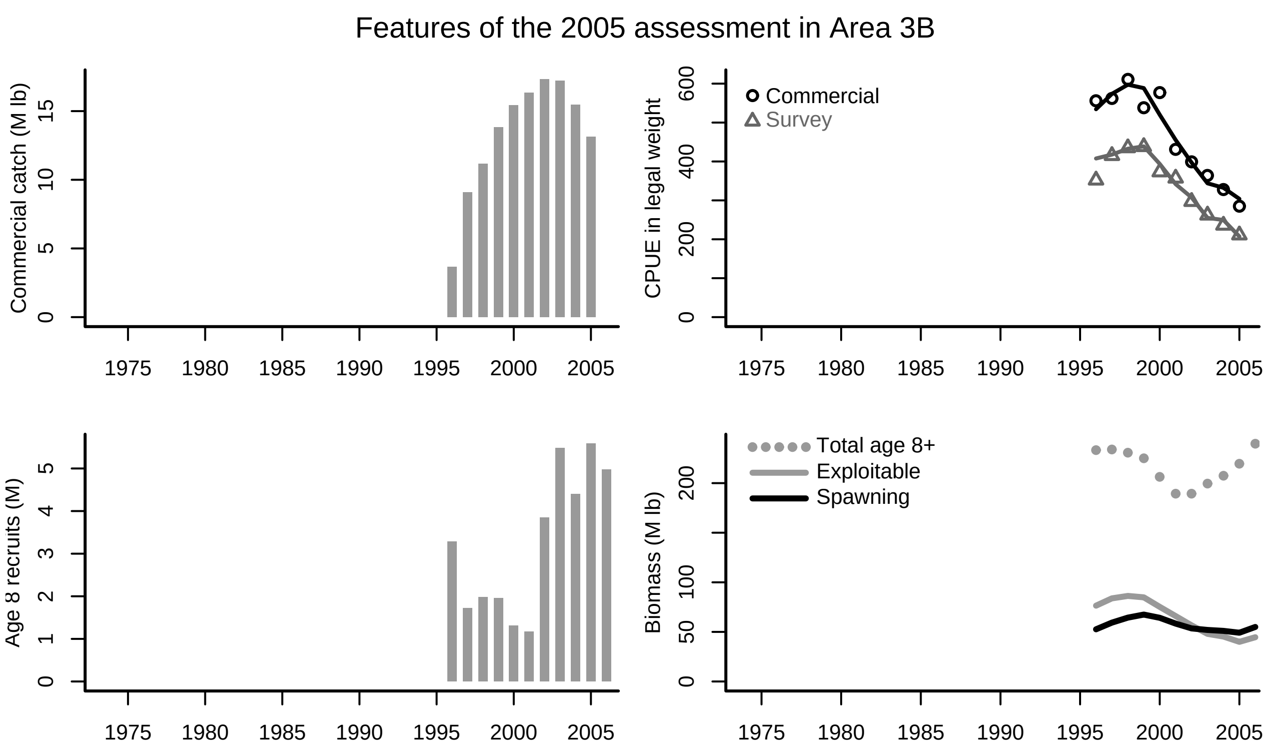


**Figure 1d. Features of the 2005 assessment in Area 3B.**

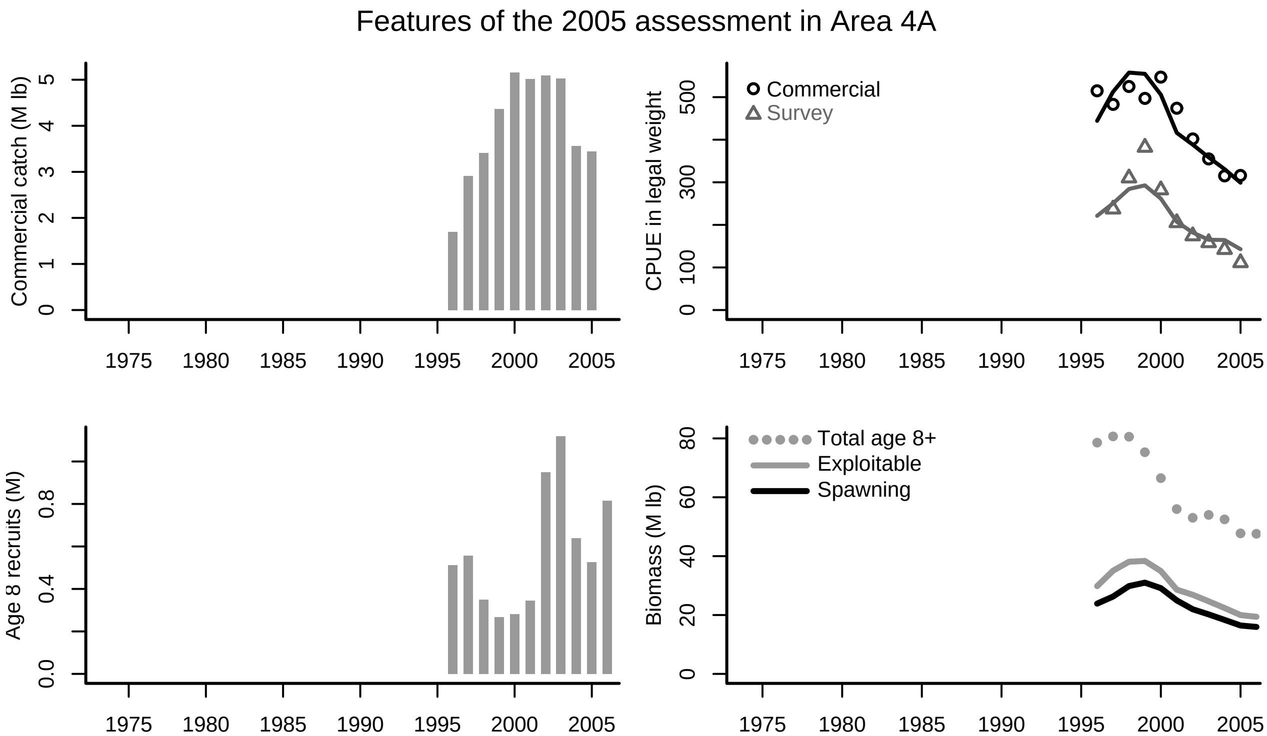


**Figure 1e. Features of the 2005 assessment in Area 4A.**

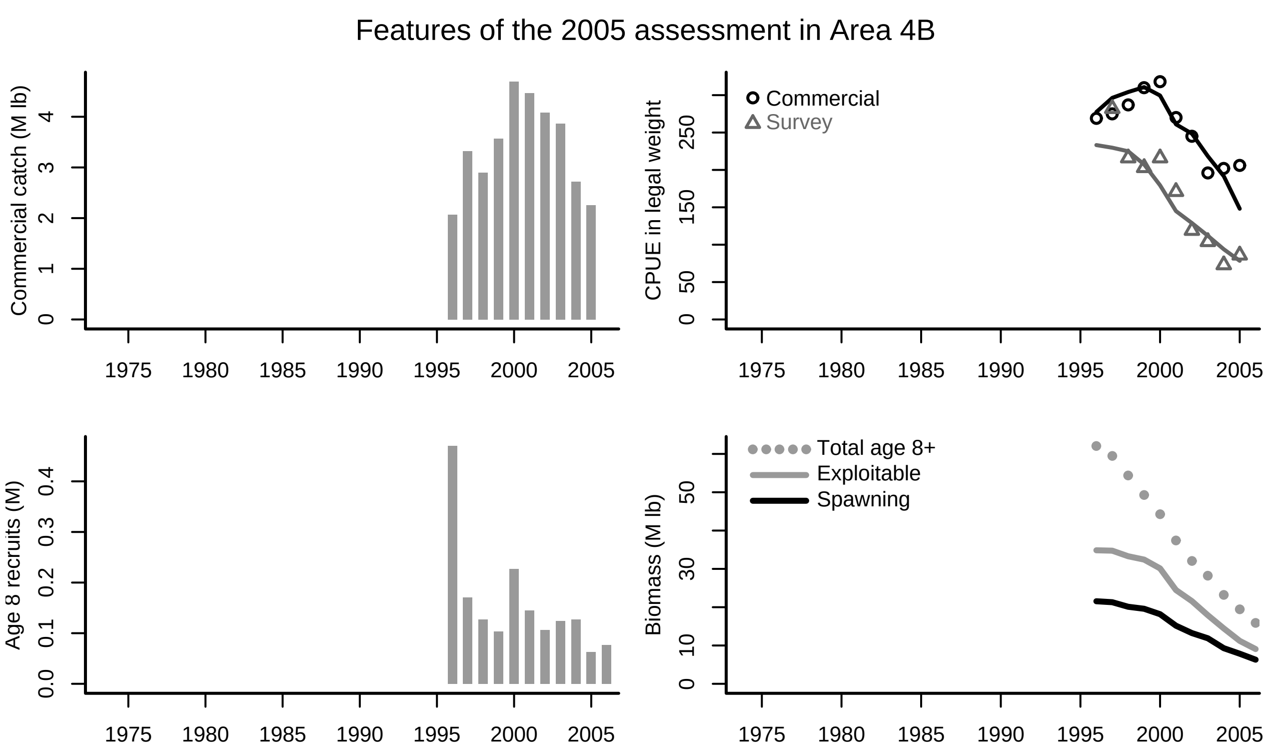


**Figure 1f. Features of the 2005 assessment in Area 4B.**

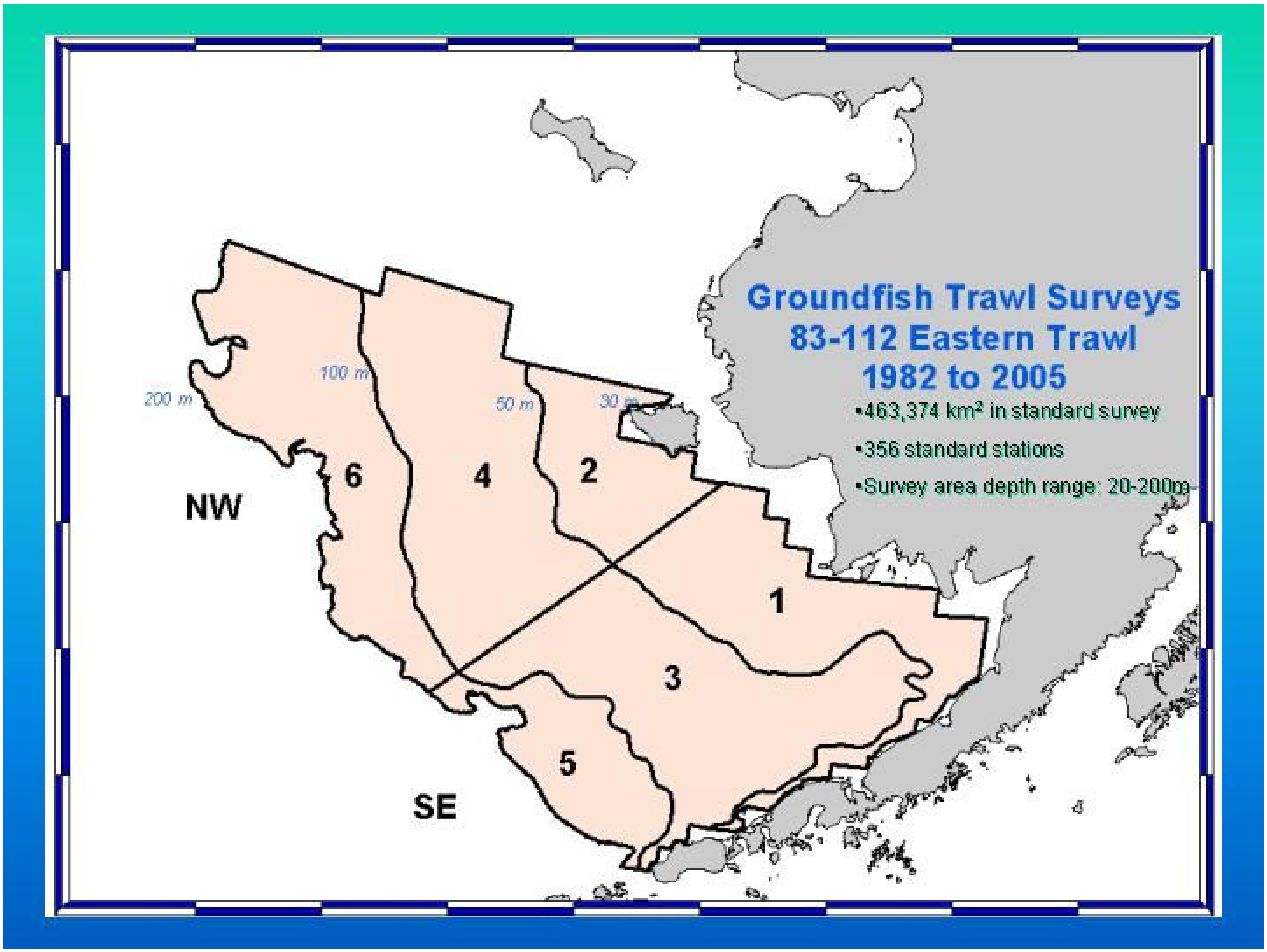


**Figure 2. Coverage of the NMFS trawl survey in the eastern Bering Sea.**

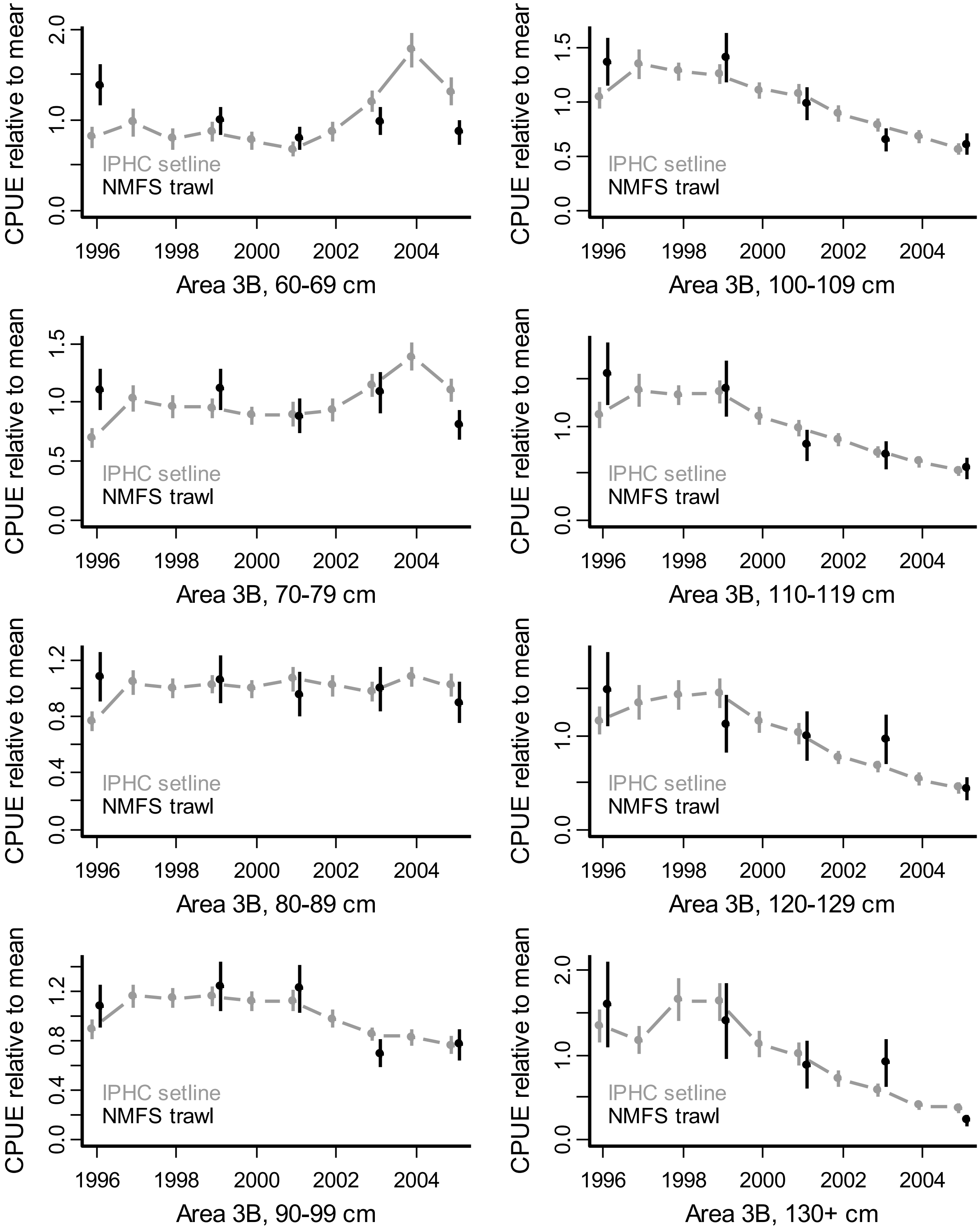


**Figure 3. Trends in setline and trawl survey CPUE at length in Area 3B.**

## Appendix A. Selected fishery and survey data summaries.

**Table A1. Commercial catch (million pounds, net weight). Figures include IPHC research catches. Sport catch in Areas 2A and 2B is *not* included in this table.**

| | 2A | 2B | 2C | 3A | 3B | 4 | 4A | 4B | 4C | 4D | 4E | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1974** | 0.52 | 4.62 | 5.60 | 8.19 | 1.67 | 0.71 | --- | --- | --- | --- | --- | 21.31 |
| **1975** | 0.46 | 7.13 | 6.24 | 10.60 | 2.56 | 0.63 | --- | --- | --- | --- | --- | 27.62 |
| **1976** | 0.24 | 7.28 | 5.53 | 11.04 | 2.73 | 0.72 | --- | --- | --- | --- | --- | 27.54 |
| **1977** | 0.21 | 5.43 | 3.19 | 8.64 | 3.19 | 1.22 | --- | --- | --- | --- | --- | 21.88 |
| **1978** | 0.10 | 4.61 | 4.32 | 10.30 | 1.32 | 1.35 | --- | --- | --- | --- | --- | 22.00 |
| **1979** | 0.05 | 4.86 | 4.53 | 11.34 | 0.39 | 1.37 | --- | --- | --- | --- | --- | 22.54 |
| **1980** | 0.02 | 5.65 | 3.24 | 11.97 | 0.28 | 0.71 | --- | --- | --- | --- | --- | 21.87 |
| **1981** | 0.20 | 5.66 | 4.01 | 14.23 | 0.45 | --- | 0.49 | 0.39 | 0.30 | 0.01 | 0.00 | 25.74 |
| **1982** | 0.21 | 5.54 | 3.50 | 13.52 | 4.80 | --- | 1.17 | 0.01 | 0.24 | 0.00 | 0.01 | 29.01 |
| **1983** | 0.26 | 5.44 | 6.38 | 14.14 | 7.75 | --- | 2.50 | 1.34 | 0.42 | 0.15 | 0.01 | 38.39 |
| **1984** | 0.43 | 9.05 | 5.87 | 19.77 | 6.69 | --- | 1.05 | 1.10 | 0.58 | 0.39 | 0.04 | 44.97 |
| **1985** | 0.49 | 10.39 | 9.21 | 20.84 | 10.89 | --- | 1.72 | 1.24 | 0.62 | 0.67 | 0.04 | 56.10 |
| **1986** | 0.58 | 11.22 | 10.61 | 32.80 | 8.82 | --- | 3.38 | 0.26 | 0.69 | 1.22 | 0.04 | 69.63 |
| **1987** | 0.59 | 12.25 | 10.68 | 31.31 | 7.76 | --- | 3.69 | 1.50 | 0.88 | 0.70 | 0.11 | 69.47 |
| **1988** | 0.49 | 12.86 | 11.36 | 37.86 | 7.08 | --- | 1.93 | 1.59 | 0.71 | 0.45 | 0.01 | 74.34 |
| **1989** | 0.47 | 10.43 | 9.53 | 33.74 | 7.84 | --- | 1.02 | 2.65 | 0.57 | 0.67 | 0.01 | 66.95 |
| **1990** | 0.32 | 8.57 | 9.73 | 28.85 | 8.69 | --- | 2.50 | 1.33 | 0.53 | 1.00 | 0.06 | 61.60 |
| **1991** | 0.36 | 7.19 | 8.69 | 22.93 | 11.93 | --- | 2.26 | 1.51 | 0.68 | 1.44 | 0.10 | 57.08 |
| **1992** | 0.44 | 7.63 | 9.82 | 26.78 | 8.62 | --- | 2.70 | 2.32 | 0.79 | 0.73 | 0.07 | 59.89 |
| **1993** | 0.50 | 10.63 | 11.29 | 22.74 | 7.86 | --- | 2.56 | 1.96 | 0.83 | 0.84 | 0.06 | 59.27 |
| **1994** | 0.37 | 9.91 | 10.38 | 24.84 | 3.86 | --- | 1.80 | 2.02 | 0.72 | 0.71 | 0.12 | 54.73 |
| **1995** | 0.30 | 9.62 | 7.77 | 18.34 | 3.12 | --- | 1.62 | 1.68 | 0.67 | 0.64 | 0.13 | 43.88 |
| **1996** | 0.30 | 9.54 | 8.87 | 19.69 | 3.66 | --- | 1.70 | 2.07 | 0.68 | 0.71 | 0.12 | 47.34 |
| **1997** | 0.41 | 12.42 | 9.92 | 24.63 | 9.07 | --- | 2.91 | 3.32 | 1.12 | 1.15 | 0.25 | 65.20 |
| **1998** | 0.46 | 13.17 | 10.20 | 25.70 | 11.16 | --- | 3.42 | 2.90 | 1.26 | 1.31 | 0.19 | 69.76 |
| **1999** | 0.45 | 12.70 | 10.14 | 25.32 | 13.84 | --- | 4.37 | 3.57 | 1.76 | 1.89 | 0.26 | 74.31 |
| **2000** | 0.48 | 10.81 | 8.44 | 19.27 | 15.41 | --- | 5.16 | 4.69 | 1.74 | 1.93 | 0.35 | 68.29 |
| **2001** | 0.68 | 10.29 | 8.40 | 21.54 | 16.34 | --- | 5.01 | 4.47 | 1.65 | 1.84 | 0.48 | 70.70 |
| **2002** | 0.85 | 12.07 | 8.60 | 23.13 | 17.31 | --- | 5.09 | 4.08 | 1.21 | 1.75 | 0.56 | 74.66 |
| **2003** | 0.82 | 11.79 | 8.41 | 22.75 | 17.23 | --- | 5.02 | 3.86 | 0.89 | 1.96 | 0.42 | 73.19 |
| **2004** | 0.88 | 12.16 | 10.23 | 25.17 | 15.46 | --- | 3.56 | 2.72 | 0.95 | 1.66 | 0.31 | 73.11 |
| **2005** | 0.82 | 12.33 | 10.64 | 25.86 | 13.29 | | 3.40 | 1.98 | 0.54 | 2.58 | 0.36 | 71.81 |

**Table A2. Bycatch mortality of legal-sized halibut (80+ cm; in million pounds net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **1974** | 0.252 | 0.900 | 0.371 | 4.477 | 2.816 | 1.892 | --- | --- | --- | 10.708 |
| **1975** | 0.252 | 0.902 | 0.451 | 2.610 | 1.661 | 1.097 | --- | --- | --- | 6.973 |
| **1976** | 0.252 | 0.941 | 0.503 | 2.741 | 1.944 | 1.181 | --- | --- | --- | 7.562 |
| **1977** | 0.254 | 0.725 | 0.407 | 3.366 | 1.544 | 1.976 | --- | --- | --- | 8.272 |
| **1978** | 0.253 | 0.551 | 0.213 | 2.441 | 1.308 | 3.400 | --- | --- | --- | 8.166 |
| **1979** | 0.253 | 0.694 | 0.638 | 4.488 | 0.688 | 3.446 | --- | --- | --- | 10.207 |
| **1980** | 0.253 | 0.514 | 0.418 | 4.927 | 0.870 | 5.713 | --- | --- | --- | 12.695 |
| **1981** | 0.252 | 0.533 | 0.403 | 3.989 | 1.096 | 4.369 | --- | --- | --- | 10.642 |
| **1982** | 0.252 | 0.299 | 0.199 | 3.197 | 1.683 | 2.944 | --- | --- | --- | 8.574 |
| **1983** | 0.253 | 0.291 | 0.200 | 2.083 | 1.218 | 2.472 | --- | --- | --- | 6.517 |
| **1984** | 0.252 | 0.516 | 0.211 | 1.508 | 0.919 | 2.291 | --- | --- | --- | 5.697 |
| **1985** | 0.252 | 0.548 | 0.201 | 0.797 | 0.341 | 2.246 | --- | --- | --- | 4.385 |
| **1986** | 0.253 | 0.558 | 0.202 | 0.674 | 0.197 | 2.617 | --- | --- | --- | 4.501 |
| **1987** | 0.253 | 0.793 | 0.202 | 1.588 | 0.396 | 2.674 | --- | --- | --- | 5.906 |
| **1988** | 0.253 | 0.773 | 0.202 | 2.126 | 0.042 | 3.273 | --- | --- | --- | 6.669 |
| **1989** | 0.253 | 0.720 | 0.202 | 1.805 | 0.437 | 1.944 | --- | --- | --- | 5.361 |
| **1990** | 0.253 | 1.029 | 0.674 | 2.633 | 1.215 | --- | 0.625 | 0.335 | 2.385 | 9.149 |
| **1991** | 0.253 | 1.221 | 0.546 | 3.126 | 1.035 | --- | 0.731 | 0.236 | 2.237 | 9.385 |
| **1992** | 0.276 | 1.017 | 0.574 | 2.644 | 1.116 | --- | 0.724 | 0.655 | 1.937 | 8.943 |
| **1993** | 0.276 | 0.651 | 0.333 | 1.919 | 0.466 | --- | 0.140 | 0.479 | 1.407 | 5.671 |
| **1994** | 0.276 | 0.571 | 0.396 | 2.352 | 0.848 | --- | 1.197 | 0.536 | 1.820 | 7.996 |
| **1995** | 0.381 | 0.705 | 0.219 | 1.460 | 0.825 | --- | 1.087 | 0.149 | 2.116 | 6.942 |
| **1996** | 0.473 | 0.166 | 0.233 | 1.403 | 0.960 | --- | 0.594 | 0.459 | 2.991 | 7.279 |
| **1997** | 0.473 | 0.109 | 0.240 | 1.549 | 0.729 | --- | 0.844 | 0.198 | 2.964 | 7.106 |
| **1998** | 0.834 | 0.117 | 0.238 | 1.471 | 0.731 | --- | 1.193 | 0.327 | 2.725 | 7.636 |
| **1999** | 0.761 | 0.107 | 0.230 | 1.283 | 0.743 | --- | 0.909 | 0.336 | 2.642 | 7.011 |
| **2000** | 0.634 | 0.128 | 0.254 | 1.286 | 0.646 | --- | 0.808 | 0.580 | 2.279 | 6.615 |
| **2001** | 0.645 | 0.149 | 0.184 | 1.617 | 0.632 | --- | 0.574 | 0.387 | 2.900 | 7.088 |
| **2002** | 0.286 | 0.152 | 0.166 | 1.073 | 0.719 | --- | 0.534 | 0.196 | 2.735 | 5.861 |
| **2003** | 0.355 | 0.133 | 0.144 | 1.177 | 0.500 | --- | 0.515 | 0.219 | 2.105 | 5.148 |
| **2004** | 0.367 | 0.140 | 0.149 | 1.520 | 0.393 | --- | 0.516 | 0.294 | 1.915 | 5.294 |
| **2005** | 0.172 | 0.191 | 0.144 | 1.321 | 0.360 | --- | 0.456 | 0.279 | 2.206 | 5.129 |

**Table A3. Commercial CPUE (net pounds per skate).**

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

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E |
|---|---|---|---|---|---|---|---|---|---|---|
| **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 | --- |
| **1985** | 62 | 147 | 370 | 537 | 602 | 333 | 234 | --- | 330 | --- |
| **1986** | 60 | 120 | 302 | 522 | 515 | 265 | --- | 427 | 239 | --- |
| **1987** | 57 | 131 | 260 | 504 | 476 | 341 | 220 | 384 | --- | --- |
| **1988** | 134 | 137 | 281 | 503 | 655 | 453 | 224 | --- | 201 | --- |
| **1989** | 124 | 134 | 258 | 455 | 590 | 409 | 268 | 331 | 384 | --- |
| **1990** | 168 | 175 | 269 | 353 | 484 | 434 | 209 | 288 | 381 | --- |
| **1991** | 158 | 148 | 233 | 319 | 466 | 471 | 329 | 223 | 398 | --- |
| **1992** | 115 | 171 | 230 | 397 | 440 | 372 | 278 | 249 | 412 | --- |
| **1993** | 147 | 208 | 256 | 393 | 514 | 463 | 218 | 257 | 851 | --- |
| **1994** | 93 | 215 | 207 | 353 | 377 | 463 | 198 | 167 | 480 | --- |
| **1995** | 116 | 219 | 234 | 416 | 476 | 349 | 189 | --- | 475 | --- |
| **1996** | 159 | 226 | 238 | 473 | 556 | 515 | 269 | --- | --- | --- |
| **1997** | 226 | 241 | 246 | 458 | 562 | 483 | 275 | 335 | 671 | --- |
| **1998** | 194 | 232 | 236 | 451 | 611 | 525 | 287 | 287 | 627 | --- |
| **1999** | --- | 213 | 199 | 437 | 538 | 500 | 310 | 270 | 535 | --- |
| **2000** | 263 | 229 | 186 | 443 | 577 | 547 | 318 | 223 | 556 | --- |
| **2001** | 169 | 226 | 196 | 469 | 431 | 474 | 270 | 203 | 511 | --- |
| **2002** | 181 | 222 | 244 | 507 | 399 | 402 | 245 | 148 | 503 | --- |
| **2003** | 184 | 231 | 233 | 487 | 364 | 355 | 196 | 105 | 389 | --- |
| **2004** | 145 | 212 | 240 | 485 | 328 | 315 | 202 | 120 | 444 | --- |
| **2005** | --- | 203 | 216 | 473 | 285 | 316 | 206 | 105 | 317 | --- |

**Table A4. IPHC setline survey CPUE of legal sized fish in weight (net pounds per skate).**

Figures for Area 2B refer to the Charlotte region only. Figures for all other areas refer to all stations fished. The eastward expansion of the 3A survey in 1996 lowered average CPUE by around 25%; the raw values in the table should not be taken at face value. Similarly the 4A value for 1999 is elevated because the Bering Sea edge in 4A was not fished that year. *No corrections* are applied; J-hook values are raw J-hook catch rates.

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E |
|---|---|---|---|---|---|---|---|---|---|---|
| **J-hook surveys:** | | | | | | | | | | |
| **1974** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1975** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1976** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1977** | --- | 15 | --- | 73 | --- | --- | --- | --- | --- | --- |
| **1978** | --- | 21 | --- | 34 | --- | --- | --- | --- | --- | --- |
| **1979** | --- | --- | --- | 51 | --- | --- | --- | --- | --- | --- |
| **1980** | --- | 28 | --- | 95 | --- | --- | --- | --- | --- | --- |
| **1981** | --- | 18 | --- | 162 | --- | --- | --- | --- | --- | --- |
| **1982** | --- | 21 | 145 | 180 | --- | --- | --- | --- | --- | --- |
| **1983** | --- | 20 | 142 | 147 | --- | --- | --- | --- | --- | --- |
| **1984** | --- | 28 | --- | 217 | --- | --- | --- | --- | --- | --- |
| **C-hook surveys:** | | | | | | | | | | |
| **1984** | --- | 64 | 260 | 446 | --- | --- | --- | --- | --- | --- |
| **1985** | --- | 47 | 260 | 466 | --- | --- | --- | --- | --- | --- |
| **1986** | --- | 42 | 283 | 377 | --- | --- | --- | --- | --- | --- |
| **1987** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1988** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1989** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1990** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1991** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1992** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1993** | --- | 105 | --- | 323 | --- | --- | --- | --- | --- | --- |
| **1994** | --- | --- | --- | 313 | --- | --- | --- | --- | --- | --- |
| **1995** | 29 | 166 | --- | 370 | --- | --- | --- | --- | --- | --- |
| **1996** | --- | 175 | 306 | 317 | 352 | --- | --- | --- | --- | --- |
| **1997** | 35 | 156 | 411 | 331 | 415 | 237 | 282 | 71 | 111 | --- |
| **1998** | --- | 92 | 232 | 281 | 435 | 310 | 216 | --- | --- | --- |
| **1999** | 37 | 95 | 204 | 241 | 438 | 382 | 203 | --- | --- | --- |
| **2000** | --- | 104 | 233 | 272 | 373 | 286 | 216 | --- | 213 | --- |
| **2001** | 41 | 117 | 237 | 256 | 357 | 207 | 171 | --- | 197 | --- |
| **2002** | 33 | 107 | 261 | 299 | 297 | 174 | 119 | --- | 257 | --- |
| **2003** | 22 | 84 | 223 | 229 | 262 | 159 | 104 | --- | 195 | --- |
| **2004** | 27 | 99 | 173 | 270 | 236 | 142 | 73 | --- | 132 | --- |
| **2005** | 28 | 76 | 171 | 276 | 211 | 111 | 86 | --- | 69 | --- |

# Assessment of the Pacific halibut stock at the end of 2004

**William G. Clark and Steven R. Hare**

## Abstract

This year's assessment uses the same methods as last year's to estimate exploitable biomass. Estimated coastwide exploitable biomass is 395 million pounds compared with 431 million last year, largely due to downward revisions of last year's estimates rather than a real decline in the stocks. A constant harvest rate of 22.5% rather than last year's 25% is used to calculate total CEY in Areas 2 and 3A. In Area 3B the target harvest rate is 20% this year rather than 25% last year. In Area 4 the target harvest rate remains at 20%. Fishery CEY totals 72.17 million pounds.

## Introduction

Each year the IPHC staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). Exploitable biomass in each of IPHC regulatory areas 2B, 2C, 3A, 3B, 4A, and 4B is estimated by fitting a detailed population model to the data from that area, going back to 1974 in the eastern areas and to 1996 in Areas 3B and 4. Exploitable biomass in Areas 2A and 4CDE is estimated by applying a survey-based estimate of relative abundance to the analytical estimate of biomass in the adjoining area (2B for 2A, 4A for 4CDE).

A biological target level for total removals is calculated by applying a fixed harvest rate to the estimate of exploitable biomass. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for catches in directed fisheries subject to allocation is called the fishery CEY. It comprises the commercial setline catch in all areas plus the sport catch in Areas 2A and 2B. It is calculated by subtracting from the total CEY an estimate of all unallocated removals—bycatch of legal-sized fish, wastage of legal-sized fish in the halibut fishery, fish taken for personal use, and sport catch except in Areas 2A and 2B.

Staff recommendations for catch limits in each area are based on the estimates of fishery CEY but may be higher or lower depending on a number of statistical, biological, and policy considerations. Similarly, the Commission's final quota decisions are based on the staff's recommendations but may be higher or lower.

## Evolution of assessment methods through 2003

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

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

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

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

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

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

The assessment model was simplified and recoded as a purely age-structured model in 2000 to eliminate some problems associated with the modeling of growth and the distribution of length at age (Clark and Hare 2001). 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 2002).

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.

## Features of the 2004 assessment

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 (Fig. 1), 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.

The second minor change was allowing sex-specific values for survey and commercial catchabilities. This was done only in the Area 3A assessment, where the standard model fitted the age composition of male catches well but the numbers of males in the catches were generally in excess of the predictions. In Area 3A males were estimated to be about twice as catchable as females of the same size; in other areas there was no difference. Even with higher catchability, males in Area 3A were estimated have quite low fishing mortality rates because they are so small.

## Analytical estimates of abundance and CEY

Like last year's, this year's model fits are generally good (Fig. 2) and recent retrospective performance is satisfactory. Changes in stock biomass from the beginning of 2004 to the beginning of 2005 as estimated within this year's assessment are all 5% or less except in Area 4B, where there was an estimated 20% decrease. Some of the estimates of stock biomass have changed much more than 5% from last year's assessment because the addition of the 2004 data to this year's model fit has revised last year's estimate of biomass at the beginning of 2004, in most cases downward.

| | 2004 biomass 2003 assessment | 2004 biomass 2004 assessment | 2005 biomass 2004 assessment |
|---|---|---|---|
| **Area 2A** | 8.5 | 7.9 | 7.0 |
| **Area 2B** | 65 | 61 | 58 |
| **Area 2C** | 80 | 65 | 66 |
| **Area 3A** | 146 | 154 | 146 |
| **Area 3B** | 65 | 54 | 56 |
| **Area 4A** | 21 | 20 | 20 |
| **Area 4B** | 15 | 12 | 10 |
| **Area 4CDE** | 30 | 28 | 32 |
| **Total** | 431 | 402 | 395 |

It is these downward revisions of last year's estimates that mainly account for the reduction of estimated coastwide exploitable biomass from 431 million pounds to 395. Female spawning biomass remains far above the minimum that occurred in the mid 1970s.

Table 1 shows estimates of exploitable biomass, total CEY, and fishery CEY. Exploitable biomass in Alaska is calculated with a fixed set of length-specific commercial selectivities that increase linearly from zero at 80 cm to one at 120 cm. In Area 2B the locally estimated selectivities are used because they are substantially higher than the values estimated for the Alaska areas.

Exploitable biomass in Area 2A is calculated as a proportion of the Area 2B analytical estimate. The proportion used is the ratio of survey CPUE's (three-year running mean) weighted by bottom areas:

$$\text{proportion} = \frac{(\text{2A CPUE}) \times (\text{2A bottom area})}{(\text{2B CPUE}) \times (\text{2B bottom area})}$$

The idea here is that survey CPUE is an index of density and multiplying it by the total bottom area gives an index of total biomass. The value of the scaling proportion this year is 12%, down from 13% last year as a result of updating the CPUE values. In the same way, exploitable biomass in Area 4CDE is calculated as 160% of the Area 4A biomass (up from 142% last year).

Total CEY is calculated by applying a harvest rate of 22.5% in Areas 2A, 2B, 2C, and 3A, and 20% in Areas 3B and 4 (Hare and Clark 2005). Last year the target harvest rate for Areas 2 and 3 was 25% pending a reanalysis of harvest policy using the new estimates of length-specific commercial selectivity.

## Reliability of model fits to short data series

In Areas 2B, 2C, and 3A the model is fitted to 31 years of data (1974-2004), but in Areas 3B, 4A, and 4B to only 9 years (1996-2004). The performance of fits to short data series can be examined by comparing fits to the full series and fits to shorter subsets in areas with long data series.

Figure 3a shows the Area 3A fit to the first 9 years of data (1974-1982), and on the same graph the estimates from this year's fit to the full series. The 1982 fit agrees quite well with the 2004 fit in respect of selectivities, numbers at age in 1974, and fishing mortality rates. Most of the 1982 estimates of recruitment are a bit high and as a result the estimate of exploitable biomass in 1983 is high by 15% or so, but as explained below that is well within the normal error range of fits based on many years of data.

Similarly Figure 3b compares this year's full Area 2C fit (1974-2004 data) with one that uses data from 1996-2004 only. Again the estimates from the short data series compare quite well with those from the full data set. In this case the exploitable biomass estimate from the short data series is about 10% lower than the full estimate.

Figure 3c shows the same comparison for Area 2B. In this case the 1996-2004 fit is pathological. Estimates of selectivities and numbers at age agree very well with the full assessment, but fishing mortality is greatly overestimated and as a result exploitable biomass is underestimated by more than 30%. This occurs because the survey CPUE series happens to begin with the very high 1996 and 1997 values. The later, lower survey catch rates suggest a substantial total mortality rate, which produces the high estimated fishing mortality rates and low abundance estimates. The commercial CPUE values show quite a different trend, so it is doubtful that this assessment would have been taken at face value even if no more data were available, but this example does show that an assessment based on a short data series can be strongly influenced by a few stray data points.

We do not believe that this year's 3B, 4A, and 4B assessments are suspect for this reason because in every case the survey and commercial CPUE series are very consistent and coherent in showing steady declines over the last 5-6 years. It is conceivable that these downward trends are an artifact of a widespread decline in setline catchability, and the low PIT tag recoveries certainly put the fishing mortality estimates in doubt, but the assessment data by themselves do not raise any suspicions about the fits or the estimates.

## Variance estimates

Our estimates are maximum-likelihood estimates, and their variances can be estimated by any of a number of standard methods. In practice all of the methods produce very similar estimates, and the estimates are much too low when the model is misspecified (Punt and Butterworth 1993), which is almost always true of stock assessment models. The usual estimates of standard deviation for our model fits are less than 5%, but this year's estimates of abundance at the beginning of 2004 differ from last year's estimates by up to 20%. Changes of this size do not result from statistical variability but from trends in the stock and the fishery that are not reflected in the necessarily parsimonious parameterization of the model (Clark et al. 2004). These trends cause the model fits to make large excursions and abrupt corrections that appear as year-to-year changes much larger than what would be expected from sampling errors.

Figure 4 illustrates this characteristic with the retrospective behavior of the Area 3A exploitable biomass estimates. The estimate shoots way up in the mid-1980s, drops way down in the early 1990s, and since 1993 tracks reasonably well.

By now we know the actual abundance of the stock in the 1980s and early 1990s because all of the year classes then present have by now passed through, and their abundance in the 2004 model fit is therefore entirely determined by the catch at age. We can configure the 2004 assessment model to calculate the trends in catchability and selectivity that were occurring at that time and see why the current estimates make the observed excursions and corrections. Doing that shows that selectivity has changed little over the years, but that both commercial and especially survey catchability were increasing quite rapidly in the late 1970s and early 1980s. This was a period when people in the industry spoke of a sudden increase in abundance that could only be explained by fish coming out of a "black hole." In retrospect it is clear that catchability was increasing, perhaps because halibut took up a more demersal habit after the 1977 regime shift. The assessment model fits for that period allow for a slow drift in commercial catchability but no change in survey selectivity, so the increasing catch rates can only be fitted in successive assessments by increasing the abundance estimates. The estimated value of (constant) survey selectivity also increases in successive assessments, but even so the model fits cannot match the observed increase in survey catch rates (Fig. 3a).

In the latter 1980s and early 1990s commercial catchability declined owing to the nature of the derby fishery. There were no surveys between 1986 and 1993, so the assessments of that period rely on commercial CPUE as an index of abundance; hence the downward excursion of the biomass estimate in the early 1990s and the abrupt correction in 1993 when the next survey index of abundance became available. At its worst in 1991 the biomass estimate was low by about 50%, but the model fit to the data was good and the nominal variance was small (Fig. 5). In the 2004 assessment (Fig. 2c) the 1985-1995 period appears as a time when commercial catchability fell (before increasing again after the adoption of individual quotas in 1995) but there was little change in exploitable biomass despite the wide swings in the assessment estimate.

Because the actual abundance is effectively known for the early years of the data series (say eight or more years before the last data year), it is possible to calculate an empirical error variance from the observed deviations between the first assessment estimate for a given year and the converged value that becomes known eight or more years later. The 1982 assessment error, for example, can be calculated as the difference between the estimate made in that year's assessment and the historical value for 1982 computed in this year's assessment. Doing that for all possible years and two different models in Areas 2B, 2C, and 3A produces a generic value of the standard deviation of the biomass estimate of about 20%. Most (not all) of the really large deviations occur in the earlier years. More recently the assessment has been tracking somewhat better, so a 10-15% standard deviation seems more reasonable as a working value.

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**Table 1. Estimates of exploitable biomass and CEY.**

| | Area 2A | Area 2B | Area 2C | Area 3A | Area 3B | Area 4A | Area 4B | Area 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|
| **2004 catch limit** | 1.48 | 13.80 | 10.50 | 25.06 | 15.60 | 3.47 | 2.81 | 3.79 | 76.51 |
| **2004 exploitable biomass** (2003 assessment) | 8.5[1] | 66 | 80 | 146 | 65 | 21 | 15 | 30[2] | 431.5 |
| **2005 exploitable biomass** (2004 assessment) | 7.0[1] | 58 | 66 | 146 | 56 | 20 | 10 | 32[2] | 395.0 |
| **Other removals** | | | | | | | | | |
| Sport catch | 0.51 | 1.37 | 2.31 | 4.74 | 0.01 | 0.02 | 0.00 | 0.00 | 8.96 |
| Legal-sized bycatch | 0.37 | 0.14 | 0.15 | 1.52 | 0.39 | 0.52 | 0.29 | 1.92 | 5.3 |
| Personal use | 0.02 | 0.30 | 0.63 | 0.28 | 0.03 | 0.02 | 0.00 | 0.08 | 1.36 |
| Legal-sized wastage | 0.00 | 0.02 | 0.03 | 0.07 | 0.03 | 0.02 | 0.00 | 0.01 | 0.18 |
| **Total** | 0.90 | 1.83 | 3.12 | 6.61 | 0.46 | 0.58 | 0.29 | 2.01 | 15.8 |
| …excluding sport catch | 0.39[3] | 0.44[4] | --- | --- | --- | --- | --- | --- | |
| **Total CEY at 20%** | 1.40 | 11.6 | 13.2 | 29.2 | 11.2 | 4.0 | 2.0 | 6.4 | 79 |
| **Fishery CEY at 20%** | 1.01 | 11.2 | 10.1 | 22.6 | **10.7** | **3.4** | **1.7** | **4.4** | **65.11** |
| **Total CEY at 22.5%** | 1.56 | 13.1 | 14.9 | 32.9 | 12.6 | 4.5 | 2.3 | 7.2 | 89.06 |
| **Fishery CEY at 22.5%** | **1.17**[3] | **12.7**[3,4] | **11.8** | **26.3** | 12.2 | 3.9 | 2.0 | 5.2 | 75.27 |

Notes:

1. Area 2A exploitable biomass estimated as 13% of Area 2B for 2004 and as 12% for 2005 due to changes in survey catch rates.
2. Area 4CDE exploitable biomass calculated as 142% of Area 4A biomass for 2004 and as 160% for 2005.
3. Fishery CEY includes sport catch in Areas 2A and 2B.
4. Combined sport and commercial CEY for Area 2B includes Area 2B sport catch landed in the U.S. (0.200 million lb) and legal sized wastage (0.02 million lb) to conform with the Canadian allocation program. If sport landings in the U.S. are left out of fishery CEY, they become a subtraction from total CEY and fishery CEY is reduced to 12.5 million lb.

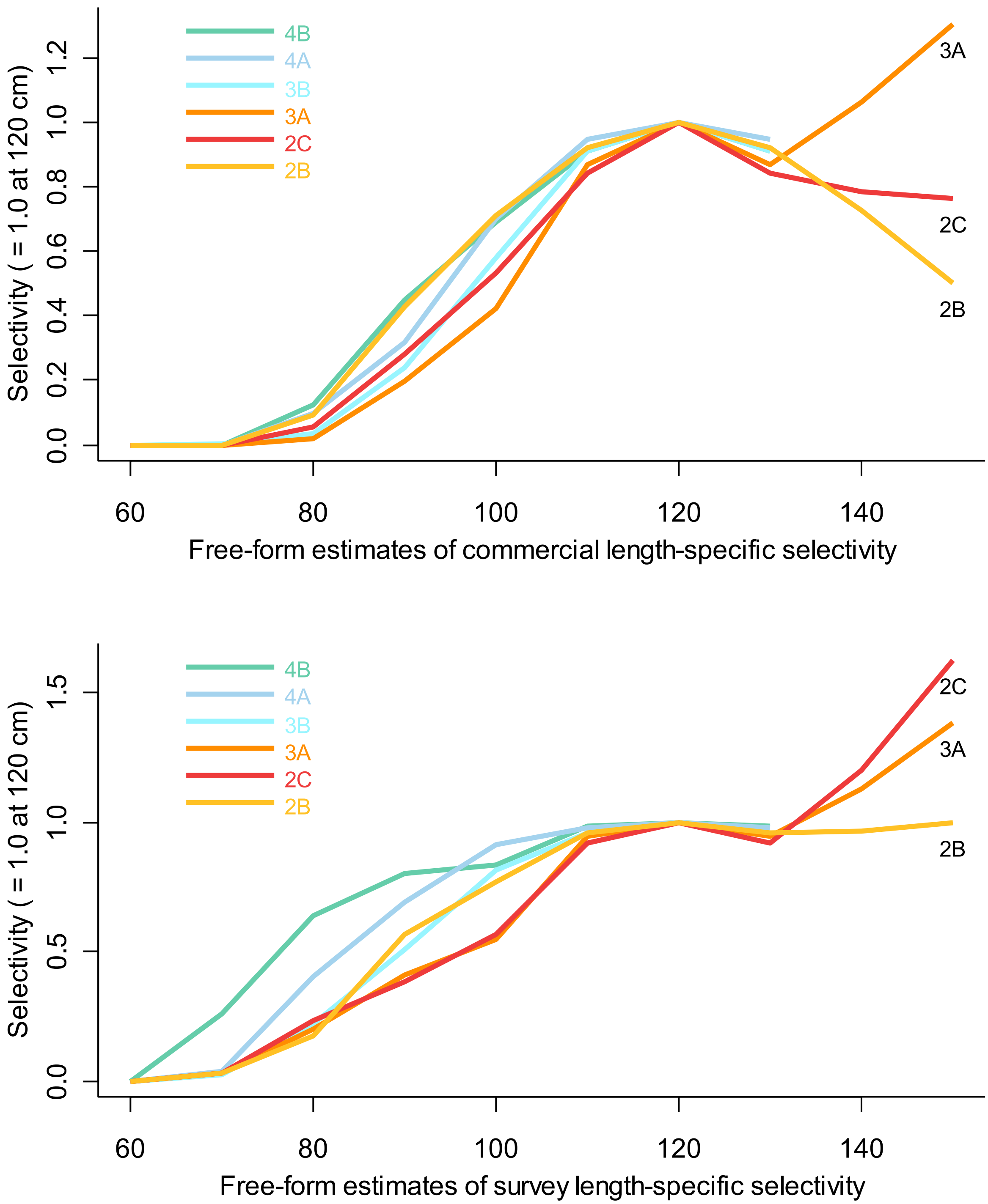


**Figure 1. Free-form estimates of length-specific commercial (above) and survey (below) selectivity from assessment model fits. In the production fits commercial selectivity was asymptotic, but not survey selectivity.**

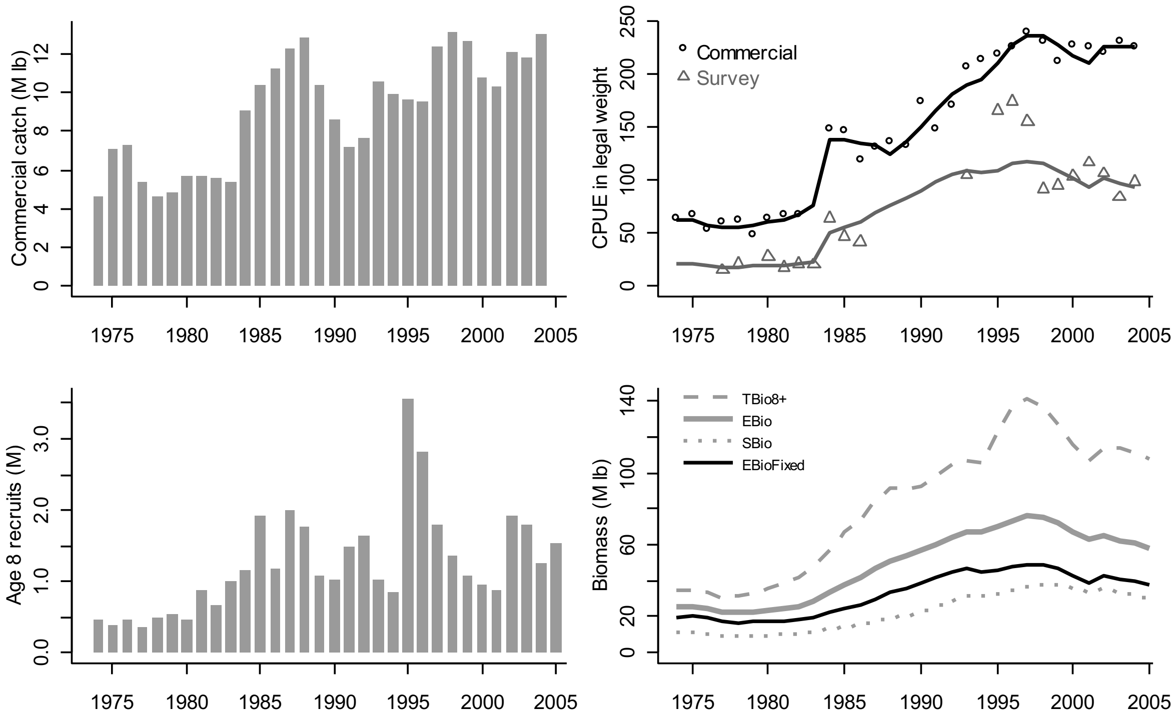


**Figure 2a. Features of the 2004 assessment in Area 2B.**

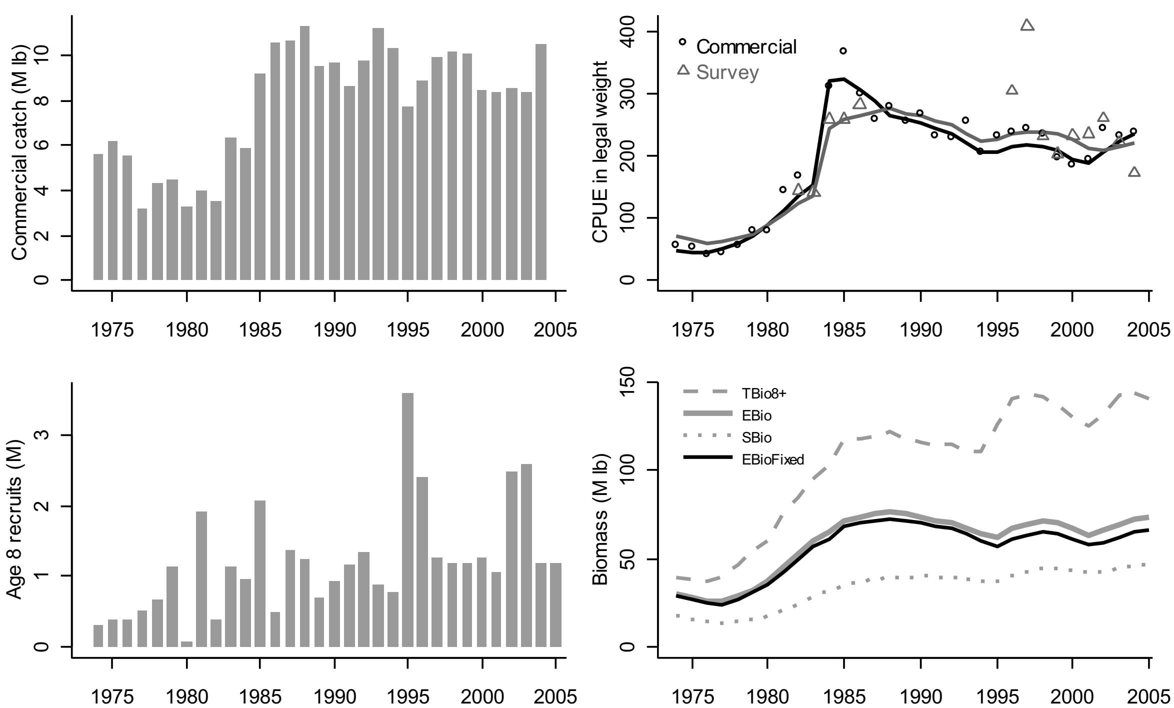


**Figure 2b. Features of the 2004 assessment in Area 2C.**

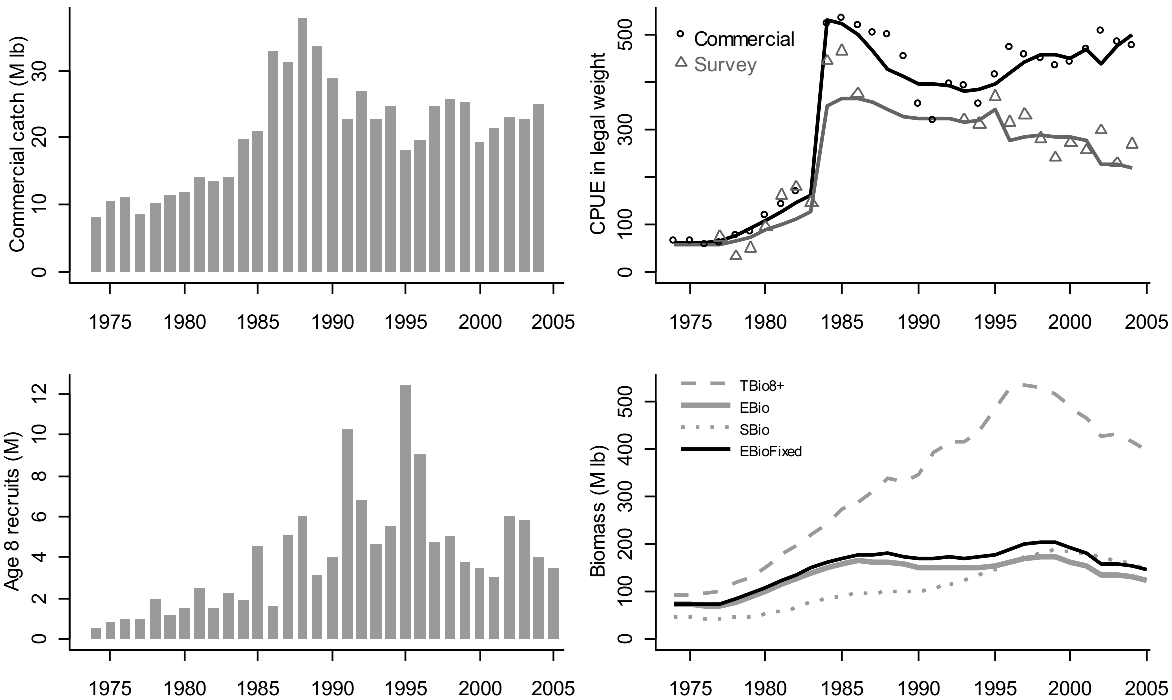


**Figure 2c. Features of the 2004 assessment in Area 3A.**

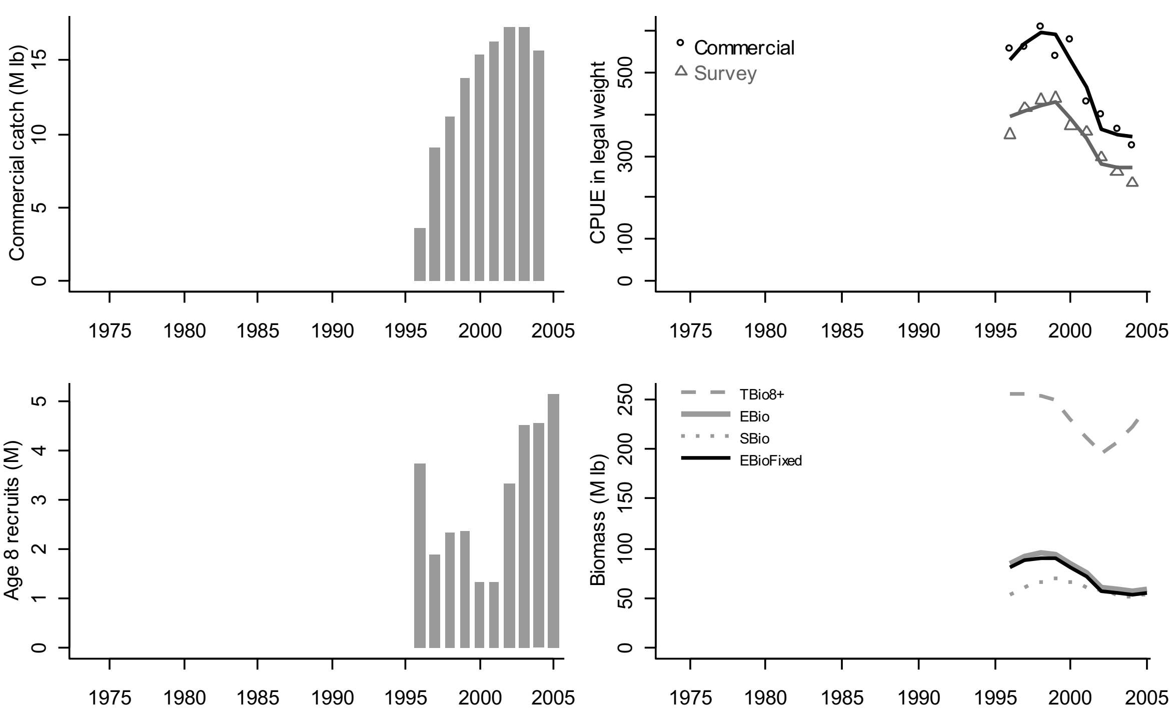


**Figure 2d. Features of the 2004 assessment in Area 3B.**

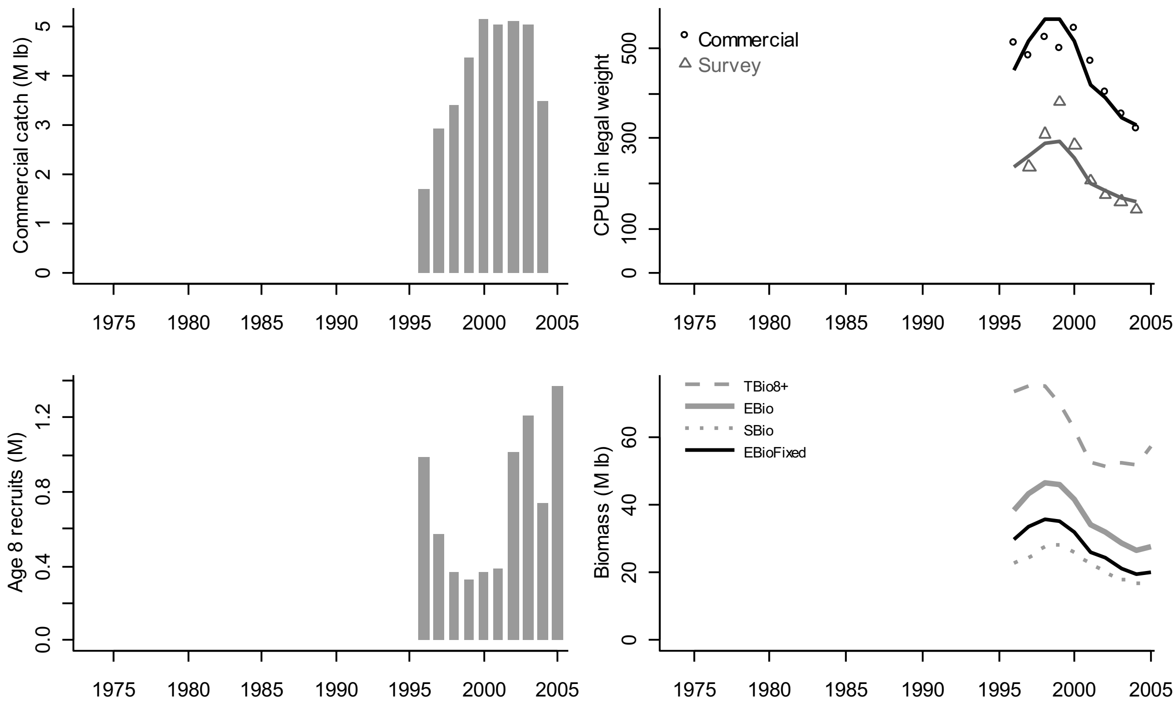


**Figure 2e. Features of the 2004 assessment in Area 4A.**

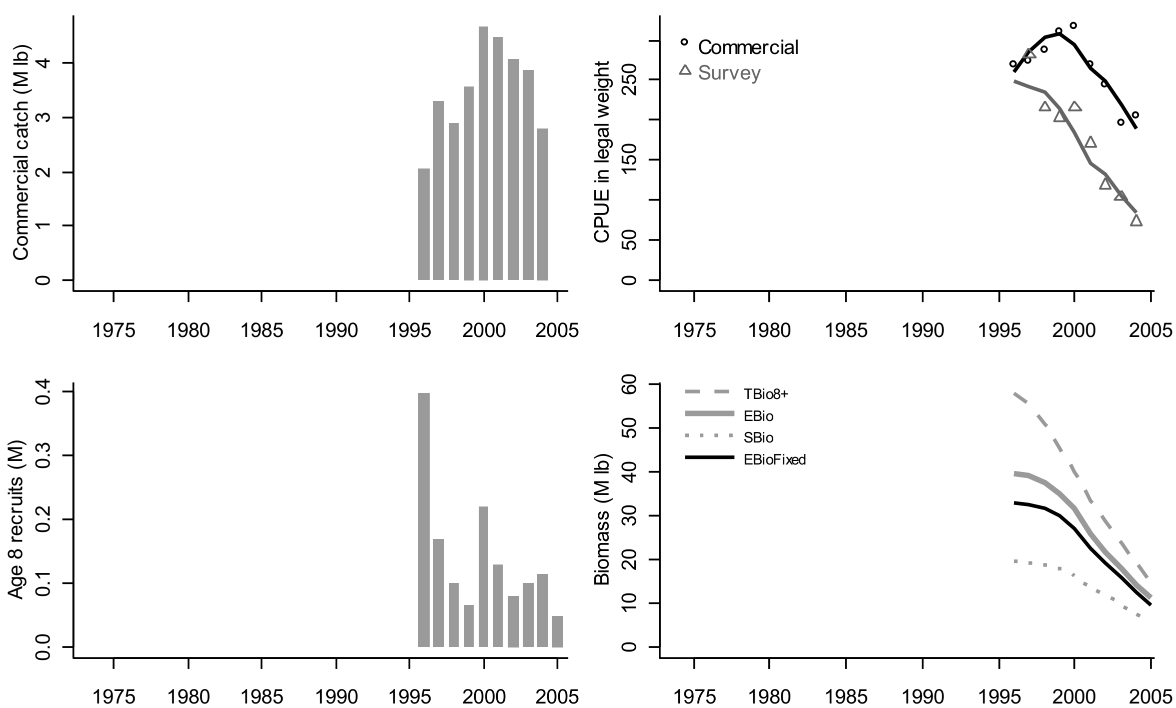


**Figure 2f. Features of the 2004 assessment in Area 4B.**

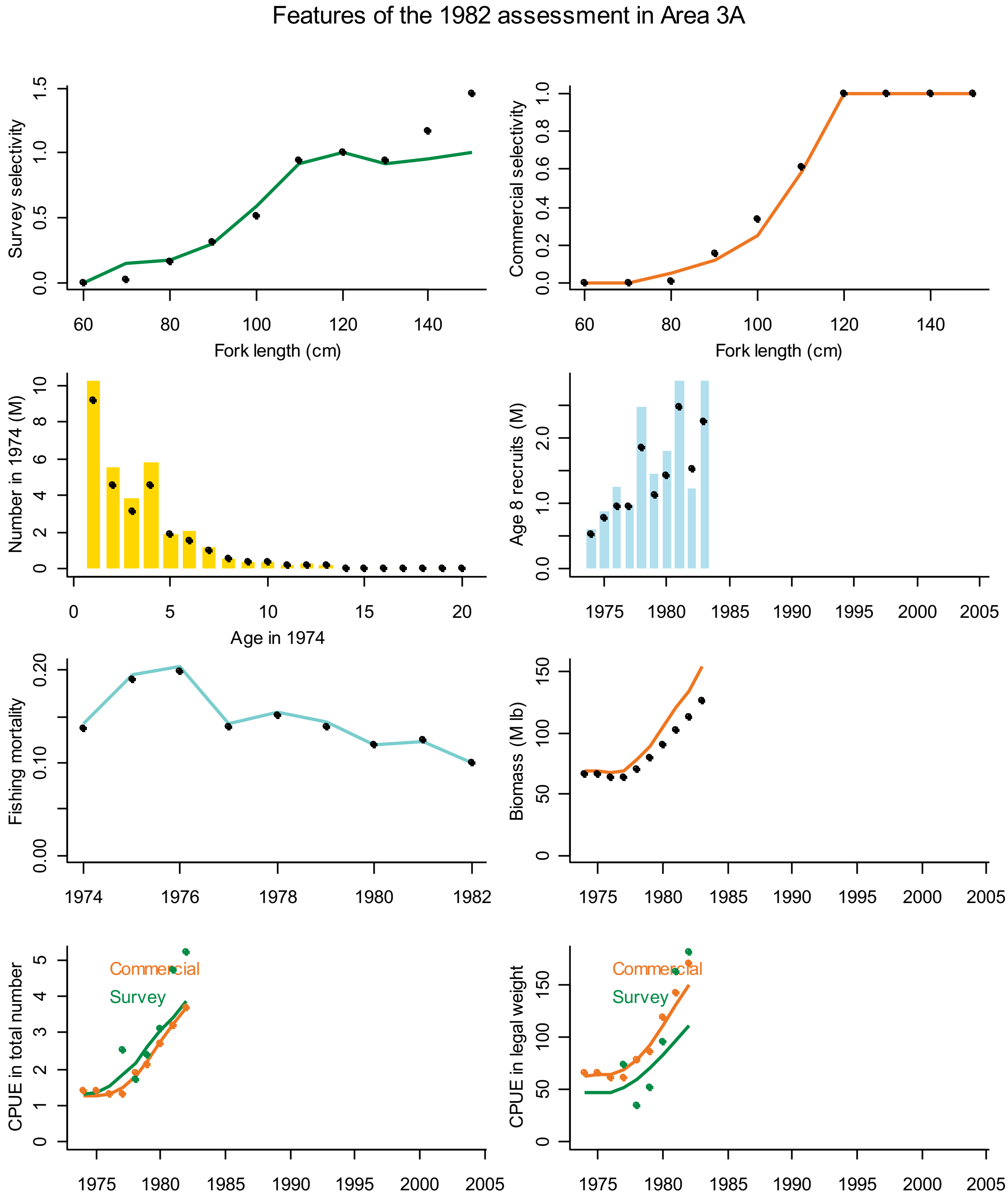


**Figure 3a. Estimates of the stock in Area 3A in 1982 from a 1974-1982 fit (lines in upper six panels) and this year's 1974-2004 fit (points in upper six panels). In the bottom two panels the points are observed values and the lines are predictions from the 1974-1982 fit.**

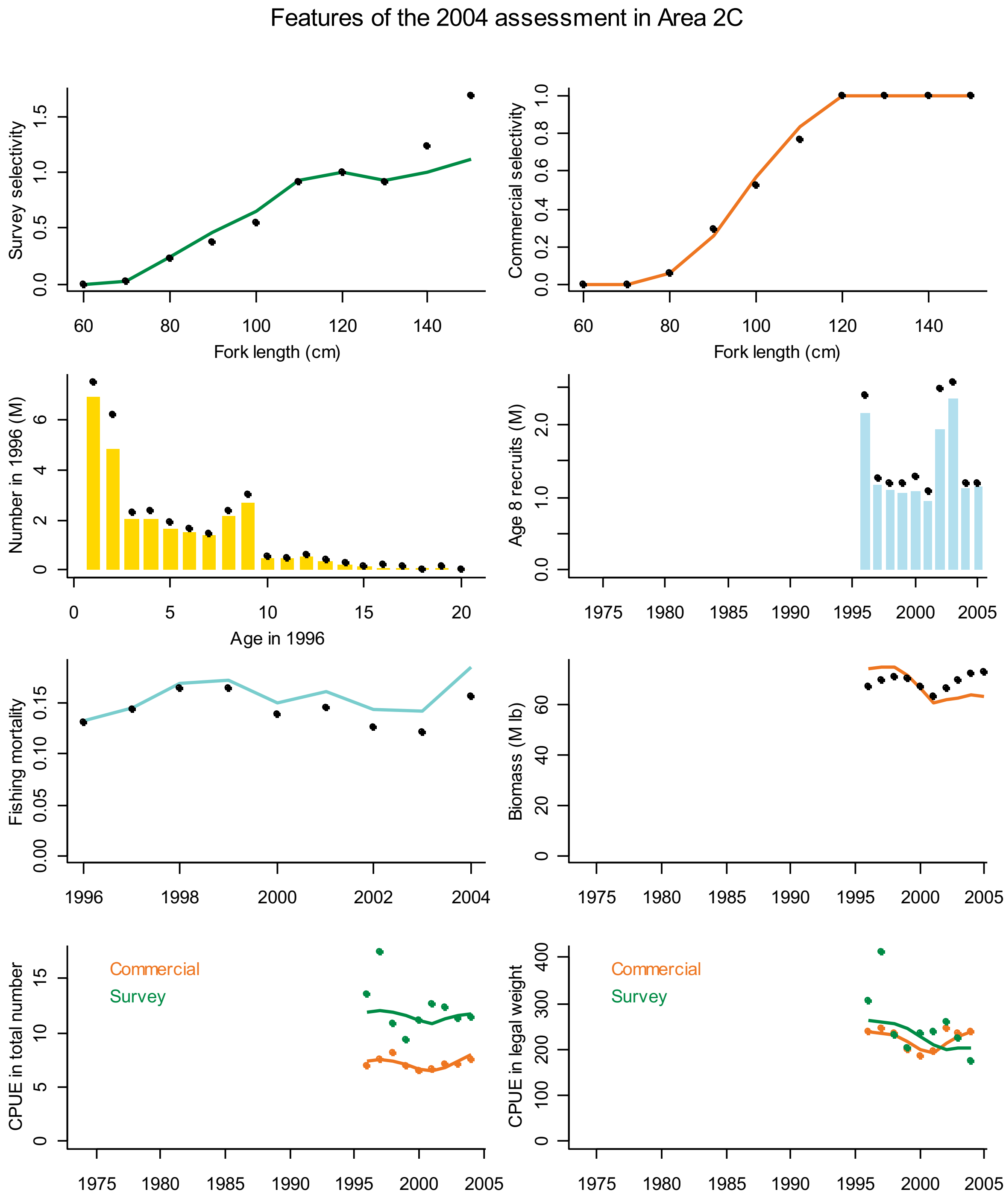


**Figure 3b. Estimates of the stock in Area 2C in 2005 from a 1996-2004 fit (lines in upper six panels) and this year's 1974-2004 fit (points in upper six panels). In the bottom two panels the points are observed values and the lines are predictions from the 1996-2004 fit.**

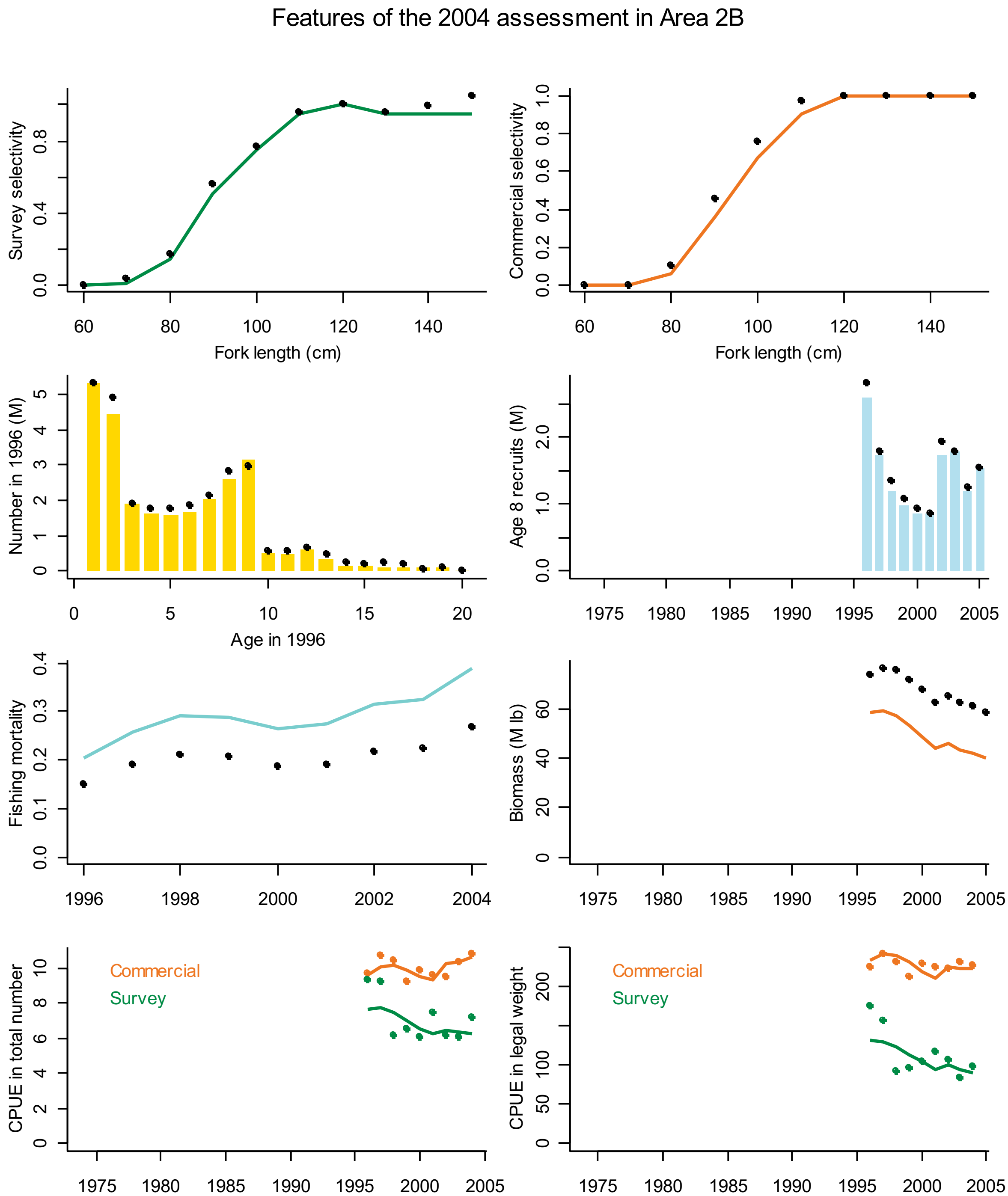


**Figure 3c. Estimates of the stock in Area 2B in 2005 from a 1996-2004 fit (lines in upper six panels) and this year's 1974-2004 fit (points in upper six panels). In the bottom two panels the points are observed values and the lines are predictions from the 1996-2004 fit.**

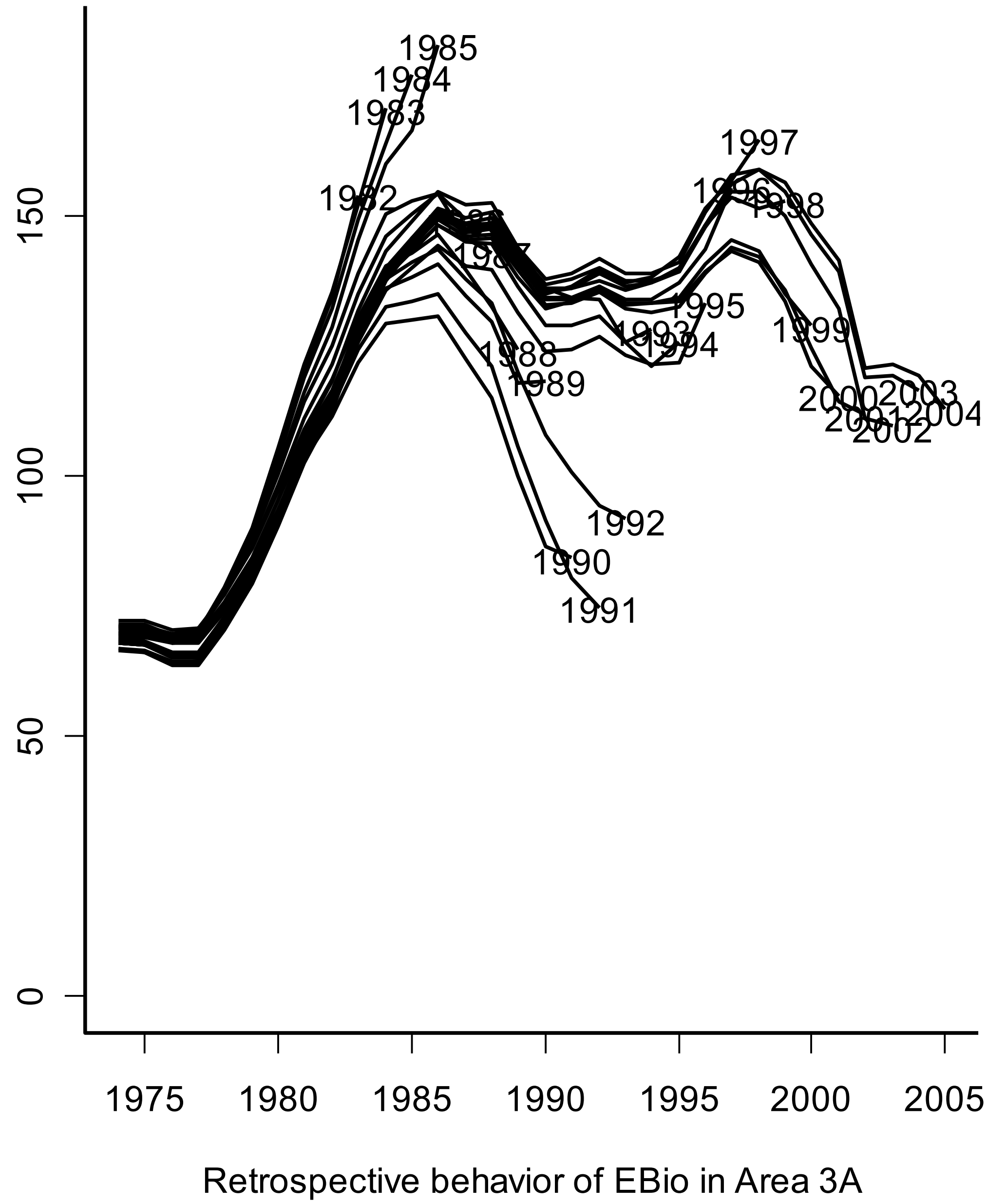


**Figure 4. Retrospective behavior of estimates of exploitable biomass by the 2004 assessment model.**

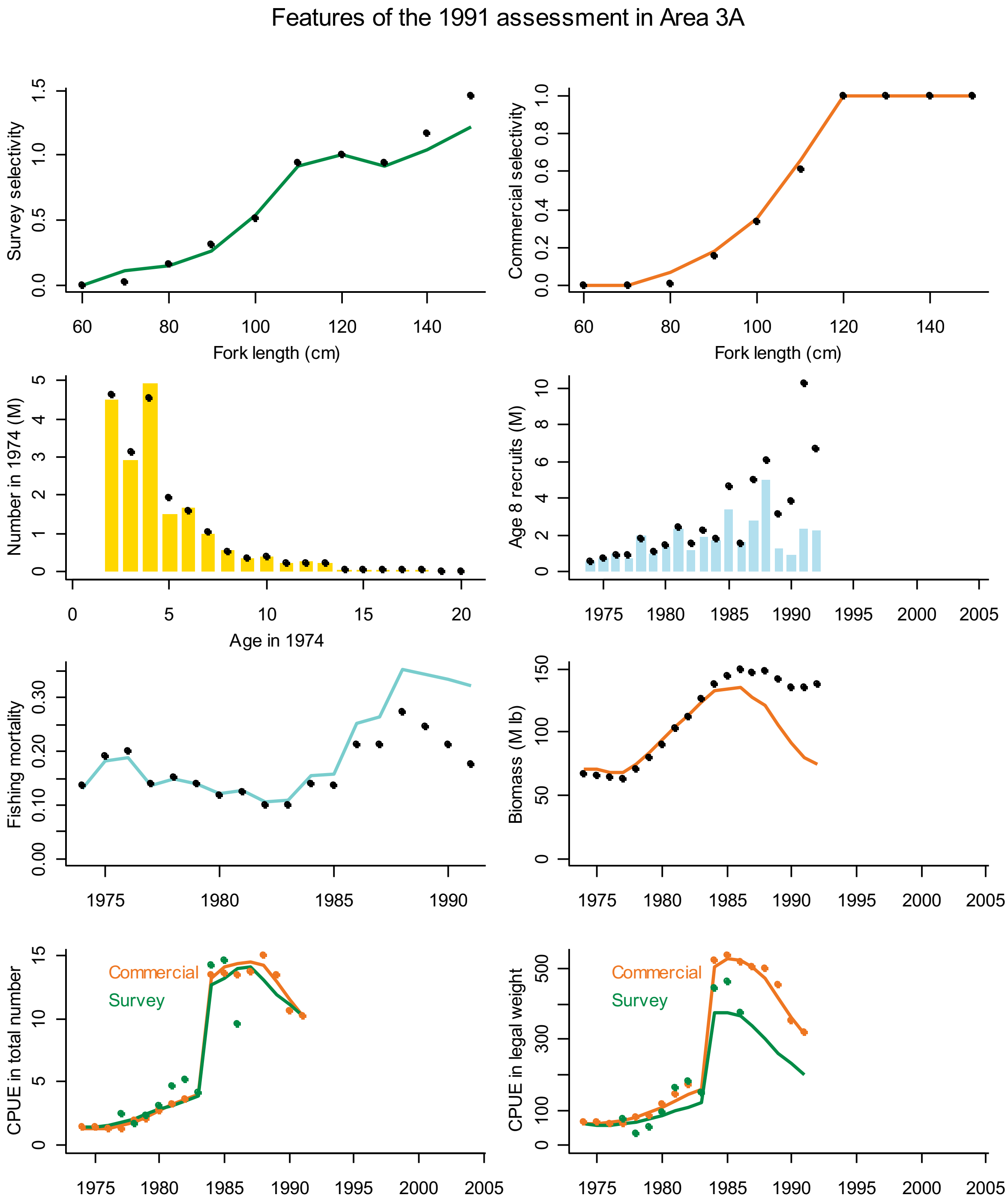


**Figure 5. Estimates obtained by fitting the assessment model to data from 1974-1991 (lines in the upper sex panels) and to the full 1974-2004 data set (points in the upper six panels). In the bottom two panels the points are observed CPUE values and the lines are predictions from the 1974-1991 model fit.**

## Appendix A. Selected fishery and survey data summaries.

**Table A1. Commercial catch (million pounds, net weight). Figures include IPHC research catches. Sport catch in Areas 2A and 2B is *not* included in this table.**

| | 2A | 2B | 2C | 3A | 3B | 4 | 4A | 4B | 4C | 4D | 4E | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1974** | 0.52 | 4.62 | 5.60 | 8.19 | 1.67 | 0.71 | --- | --- | --- | --- | --- | 21.31 |
| **1975** | 0.46 | 7.13 | 6.24 | 10.60 | 2.56 | 0.63 | --- | --- | --- | --- | --- | 27.62 |
| **1976** | 0.24 | 7.28 | 5.53 | 11.04 | 2.73 | 0.72 | --- | --- | --- | --- | --- | 27.54 |
| **1977** | 0.21 | 5.43 | 3.19 | 8.64 | 3.19 | 1.22 | --- | --- | --- | --- | --- | 21.88 |
| **1978** | 0.10 | 4.61 | 4.32 | 10.30 | 1.32 | 1.35 | --- | --- | --- | --- | --- | 22.00 |
| **1979** | 0.05 | 4.86 | 4.53 | 11.34 | 0.39 | 1.37 | --- | --- | --- | --- | --- | 22.54 |
| **1980** | 0.02 | 5.65 | 3.24 | 11.97 | 0.28 | 0.71 | --- | --- | --- | --- | --- | 21.87 |
| **1981** | 0.20 | 5.66 | 4.01 | 14.23 | 0.45 | --- | 0.49 | 0.39 | 0.30 | 0.01 | 0.00 | 25.74 |
| **1982** | 0.21 | 5.54 | 3.50 | 13.52 | 4.80 | --- | 1.17 | 0.01 | 0.24 | 0.00 | 0.01 | 29.01 |
| **1983** | 0.26 | 5.44 | 6.38 | 14.14 | 7.75 | --- | 2.50 | 1.34 | 0.42 | 0.15 | 0.01 | 38.39 |
| **1984** | 0.43 | 9.05 | 5.87 | 19.77 | 6.69 | --- | 1.05 | 1.10 | 0.58 | 0.39 | 0.04 | 44.97 |
| **1985** | 0.49 | 10.39 | 9.21 | 20.84 | 10.89 | --- | 1.72 | 1.24 | 0.62 | 0.67 | 0.04 | 56.10 |
| **1986** | 0.58 | 11.22 | 10.61 | 32.80 | 8.82 | --- | 3.38 | 0.26 | 0.69 | 1.22 | 0.04 | 69.63 |
| **1987** | 0.59 | 12.25 | 10.68 | 31.31 | 7.76 | --- | 3.69 | 1.50 | 0.88 | 0.70 | 0.11 | 69.47 |
| **1988** | 0.49 | 12.86 | 11.36 | 37.86 | 7.08 | --- | 1.93 | 1.59 | 0.71 | 0.45 | 0.01 | 74.34 |
| **1989** | 0.47 | 10.43 | 9.53 | 33.74 | 7.84 | --- | 1.02 | 2.65 | 0.57 | 0.67 | 0.01 | 66.95 |
| **1990** | 0.32 | 8.57 | 9.73 | 28.85 | 8.69 | --- | 2.50 | 1.33 | 0.53 | 1.00 | 0.06 | 61.60 |
| **1991** | 0.36 | 7.19 | 8.69 | 22.93 | 11.93 | --- | 2.26 | 1.51 | 0.68 | 1.44 | 0.10 | 57.08 |
| **1992** | 0.44 | 7.63 | 9.82 | 26.78 | 8.62 | --- | 2.70 | 2.32 | 0.79 | 0.73 | 0.07 | 59.89 |
| **1993** | 0.50 | 10.63 | 11.29 | 22.74 | 7.86 | --- | 2.56 | 1.96 | 0.83 | 0.84 | 0.06 | 59.27 |
| **1994** | 0.37 | 9.91 | 10.38 | 24.84 | 3.86 | --- | 1.80 | 2.02 | 0.72 | 0.71 | 0.12 | 54.73 |
| **1995** | 0.30 | 9.62 | 7.77 | 18.34 | 3.12 | --- | 1.62 | 1.68 | 0.67 | 0.64 | 0.13 | 43.88 |
| **1996** | 0.30 | 9.54 | 8.87 | 19.69 | 3.66 | --- | 1.70 | 2.07 | 0.68 | 0.71 | 0.12 | 47.34 |
| **1997** | 0.41 | 12.42 | 9.92 | 24.63 | 9.07 | --- | 2.91 | 3.32 | 1.12 | 1.15 | 0.25 | 65.20 |
| **1998** | 0.46 | 13.17 | 10.20 | 25.70 | 11.16 | --- | 3.42 | 2.90 | 1.26 | 1.31 | 0.19 | 69.76 |
| **1999** | 0.45 | 12.70 | 10.14 | 25.32 | 13.84 | --- | 4.37 | 3.57 | 1.76 | 1.89 | 0.26 | 74.31 |
| **2000** | 0.48 | 10.81 | 8.44 | 19.27 | 15.41 | --- | 5.16 | 4.69 | 1.74 | 1.93 | 0.35 | 68.29 |
| **2001** | 0.68 | 10.29 | 8.40 | 21.54 | 16.34 | --- | 5.01 | 4.47 | 1.65 | 1.84 | 0.48 | 70.70 |
| **2002** | 0.85 | 12.07 | 8.60 | 23.13 | 17.31 | --- | 5.09 | 4.08 | 1.21 | 1.75 | 0.56 | 74.66 |
| **2003** | 0.82 | 11.79 | 8.41 | 22.75 | 17.23 | --- | 5.02 | 3.86 | 0.89 | 1.96 | 0.42 | 73.19 |
| **2004** | 0.89 | 12.16 | 10.30 | 25.05 | 15.61 | --- | 3.48 | 2.71 | 0.96 | 1.67 | 0.31 | 73.13 |

**Table A2. Bycatch mortality of legal-sized halibut (80+ cm; in million pounds net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **1974** | 0.252 | 0.900 | 0.371 | 4.477 | 2.816 | 1.892 | --- | --- | --- | 10.708 |
| **1975** | 0.252 | 0.902 | 0.451 | 2.610 | 1.661 | 1.097 | --- | --- | --- | 6.973 |
| **1976** | 0.252 | 0.941 | 0.503 | 2.741 | 1.944 | 1.181 | --- | --- | --- | 7.562 |
| **1977** | 0.254 | 0.725 | 0.407 | 3.366 | 1.544 | 1.976 | --- | --- | --- | 8.272 |
| **1978** | 0.253 | 0.551 | 0.213 | 2.441 | 1.308 | 3.400 | --- | --- | --- | 8.166 |
| **1979** | 0.253 | 0.694 | 0.638 | 4.488 | 0.688 | 3.446 | --- | --- | --- | 10.207 |
| **1980** | 0.253 | 0.514 | 0.418 | 4.927 | 0.870 | 5.713 | --- | --- | --- | 12.695 |
| **1981** | 0.252 | 0.533 | 0.403 | 3.989 | 1.096 | 4.369 | --- | --- | --- | 10.642 |
| **1982** | 0.252 | 0.299 | 0.199 | 3.197 | 1.683 | 2.944 | --- | --- | --- | 8.574 |
| **1983** | 0.253 | 0.291 | 0.200 | 2.083 | 1.218 | 2.472 | --- | --- | --- | 6.517 |
| **1984** | 0.252 | 0.516 | 0.211 | 1.508 | 0.919 | 2.291 | --- | --- | --- | 5.697 |
| **1985** | 0.252 | 0.548 | 0.201 | 0.797 | 0.341 | 2.246 | --- | --- | --- | 4.385 |
| **1986** | 0.253 | 0.558 | 0.202 | 0.674 | 0.197 | 2.617 | --- | --- | --- | 4.501 |
| **1987** | 0.253 | 0.793 | 0.202 | 1.588 | 0.396 | 2.674 | --- | --- | --- | 5.906 |
| **1988** | 0.253 | 0.773 | 0.202 | 2.126 | 0.042 | 3.273 | --- | --- | --- | 6.669 |
| **1989** | 0.253 | 0.720 | 0.202 | 1.805 | 0.437 | 1.944 | --- | --- | --- | 5.361 |
| **1990** | 0.253 | 1.029 | 0.674 | 2.633 | 1.215 | --- | 0.625 | 0.335 | 2.385 | 9.149 |
| **1991** | 0.253 | 1.221 | 0.546 | 3.126 | 1.035 | --- | 0.731 | 0.236 | 2.237 | 9.385 |
| **1992** | 0.276 | 1.017 | 0.574 | 2.644 | 1.116 | --- | 0.724 | 0.655 | 1.937 | 8.943 |
| **1993** | 0.276 | 0.651 | 0.333 | 1.919 | 0.466 | --- | 0.140 | 0.479 | 1.407 | 5.671 |
| **1994** | 0.276 | 0.571 | 0.396 | 2.352 | 0.848 | --- | 1.197 | 0.536 | 1.820 | 7.996 |
| **1995** | 0.381 | 0.705 | 0.219 | 1.460 | 0.825 | --- | 1.087 | 0.149 | 2.116 | 6.942 |
| **1996** | 0.473 | 0.166 | 0.233 | 1.403 | 0.960 | --- | 0.594 | 0.459 | 2.991 | 7.279 |
| **1997** | 0.473 | 0.109 | 0.240 | 1.549 | 0.729 | --- | 0.844 | 0.198 | 2.964 | 7.106 |
| **1998** | 0.834 | 0.117 | 0.238 | 1.471 | 0.731 | --- | 1.193 | 0.327 | 2.725 | 7.636 |
| **1999** | 0.761 | 0.107 | 0.230 | 1.283 | 0.743 | --- | 0.909 | 0.336 | 2.642 | 7.011 |
| **2000** | 0.634 | 0.128 | 0.254 | 1.286 | 0.646 | --- | 0.808 | 0.580 | 2.279 | 6.615 |
| **2001** | 0.645 | 0.149 | 0.184 | 1.617 | 0.632 | --- | 0.574 | 0.387 | 2.900 | 7.088 |
| **2002** | 0.286 | 0.152 | 0.166 | 1.073 | 0.719 | --- | 0.534 | 0.196 | 2.735 | 5.861 |
| **2003** | 0.355 | 0.133 | 0.144 | 1.177 | 0.500 | --- | 0.515 | 0.219 | 2.105 | 5.148 |
| **2004** | 0.367 | 0.140 | 0.149 | 1.520 | 0.393 | --- | 0.516 | 0.294 | 1.915 | 5.294 |

**Table A3. Commercial CPUE (net pounds per skate).**

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

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E |
|---|---|---|---|---|---|---|---|---|---|---|
| **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 | --- |
| **1985** | 62 | 147 | 370 | 537 | 602 | 333 | 234 | --- | 330 | --- |
| **1986** | 60 | 120 | 302 | 522 | 515 | 265 | --- | 427 | 239 | --- |
| **1987** | 57 | 131 | 260 | 504 | 476 | 341 | 220 | 384 | --- | --- |
| **1988** | 134 | 137 | 281 | 503 | 655 | 453 | 224 | --- | 201 | --- |
| **1989** | 124 | 134 | 258 | 455 | 590 | 409 | 268 | 331 | 384 | --- |
| **1990** | 168 | 175 | 269 | 353 | 484 | 434 | 209 | 288 | 381 | --- |
| **1991** | 158 | 148 | 233 | 319 | 466 | 471 | 329 | 223 | 398 | --- |
| **1992** | 115 | 171 | 230 | 397 | 440 | 372 | 278 | 249 | 412 | --- |
| **1993** | 147 | 208 | 256 | 393 | 514 | 463 | 218 | 257 | 851 | --- |
| **1994** | 93 | 215 | 207 | 353 | 377 | 463 | 198 | 167 | 480 | --- |
| **1995** | 116 | 219 | 234 | 416 | 476 | 349 | 189 | --- | 475 | --- |
| **1996** | 159 | 226 | 238 | 473 | 556 | 515 | 269 | --- | --- | --- |
| **1997** | 226 | 241 | 246 | 458 | 562 | 483 | 275 | 335 | 671 | --- |
| **1998** | 194 | 232 | 236 | 451 | 611 | 525 | 287 | 287 | 627 | --- |
| **1999** | --- | 213 | 199 | 437 | 538 | 500 | 310 | 270 | 535 | --- |
| **2000** | 263 | 229 | 186 | 443 | 577 | 547 | 318 | 223 | 556 | --- |
| **2001** | 169 | 226 | 196 | 469 | 431 | 474 | 270 | 203 | 511 | --- |
| **2002** | 181 | 222 | 244 | 507 | 399 | 402 | 245 | 148 | 503 | --- |
| **2003** | 184 | 231 | 233 | 487 | 364 | 355 | 196 | 105 | 389 | --- |
| **2004** | 142 | 227 | 239 | 479 | 326 | 321 | 205 | 124 | 456 | --- |

**Table A4. IPHC setline survey CPUE of legal sized fish in weight (net pounds per skate).**

Figures for Area 2B refer to the Charlotte region only. Figures for all other areas refer to all stations fished. The eastward expansion of the 3A survey in 1996 lowered average CPUE by around 25%; the raw values in the table should not be taken at face value. Similarly the 4A value for 1999 is elevated because the Bering Sea edge in 4A was not fished that year. *No corrections* are applied; J-hook values are raw J-hook catch rates.

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E |
|---|---|---|---|---|---|---|---|---|---|---|
| **J-hook surveys:** | | | | | | | | | | |
| **1974** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1975** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1976** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1977** | --- | 15 | --- | 73 | --- | --- | --- | --- | --- | --- |
| **1978** | --- | 21 | --- | 34 | --- | --- | --- | --- | --- | --- |
| **1979** | --- | --- | --- | 51 | --- | --- | --- | --- | --- | --- |
| **1980** | --- | 28 | --- | 95 | --- | --- | --- | --- | --- | --- |
| **1981** | --- | 18 | --- | 162 | --- | --- | --- | --- | --- | --- |
| **1982** | --- | 21 | 145 | 180 | --- | --- | --- | --- | --- | --- |
| **1983** | --- | 20 | 142 | 147 | --- | --- | --- | --- | --- | --- |
| **1984** | --- | 28 | --- | 217 | --- | --- | --- | --- | --- | --- |
| **C-hook surveys:** | | | | | | | | | | |
| **1984** | --- | 64 | 260 | 446 | --- | --- | --- | --- | --- | --- |
| **1985** | --- | 47 | 260 | 466 | --- | --- | --- | --- | --- | --- |
| **1986** | --- | 42 | 283 | 377 | --- | --- | --- | --- | --- | --- |
| **1987** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1988** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1989** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1990** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1991** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1992** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1993** | --- | 105 | --- | 323 | --- | --- | --- | --- | --- | --- |
| **1994** | --- | --- | --- | 313 | --- | --- | --- | --- | --- | --- |
| **1995** | 29 | 166 | --- | 370 | --- | --- | --- | --- | --- | --- |
| **1996** | --- | 175 | 306 | 317 | 352 | --- | --- | --- | --- | --- |
| **1997** | 35 | 156 | 411 | 331 | 415 | 237 | 282 | 71 | 111 | --- |
| **1998** | --- | 92 | 232 | 281 | 435 | 310 | 216 | --- | --- | --- |
| **1999** | 37 | 95 | 204 | 241 | 438 | 382 | 203 | --- | --- | --- |
| **2000** | --- | 104 | 233 | 272 | 373 | 286 | 216 | --- | 213 | --- |
| **2001** | 41 | 117 | 237 | 256 | 357 | 207 | 171 | --- | 197 | --- |
| **2002** | 33 | 107 | 261 | 299 | 297 | 174 | 119 | --- | 257 | --- |
| **2003** | 22 | 84 | 223 | 229 | 262 | 159 | 104 | --- | 195 | --- |
| **2004** | 27 | 99 | 173 | 271 | 236 | 142 | 73 | --- | 132 | --- |

# Assessment of the Pacific halibut stock at the end of 2003

**William G. Clark and Steven R. Hare**


## Abstract

This year's assessment contains a number of major changes: the adoption of length-specific in place of age-specific selectivities, separate accounting of females and males, allowance for the bias and variance of age readings, and for the first time analytical rather than survey-based estimates of abundance in Areas 3B, 4A, and 4B. Estimates of average recruitment (1974-2004) in Areas 2B, 2C, and 3A are higher than last year's by 20-50%, but estimates of exploitable biomass in those areas are lower because they are computed with an updated set of length-specific commercial selectivities that accurately represent the lower size at age and the presence of a large number of small males. In Areas 3B, 4A, and 4B, the new analytical estimates are substantially lower than the survey-based estimates used for the last several years, mostly because selectivity (and in the case of Area 3B catchability) is estimated to be higher than in Area 3A. The new, lower selectivities will likely require an upward revision of the present 20% harvest rate, but at time of writing that analysis has not been completed, so the CEY estimates are calculated with a provisional harvest rate of 25% in Areas 2 and 3. In Area 4 the 20% harvest rate is used again because of uncertainty about the productivity of the stocks in that region. Coastwide setline CEY is estimated to be 90 million pounds.


## Introduction

Each year the IPHC staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). Exploitable biomass in each of IPHC regulatory areas 2B, 2C, and 3A is estimated by fitting a detailed population model to the data from that area, going back to 1974. This year for the first time the same model has been fitted to data from Areas 3B, 4A, and 4B, which go back to 1996. Before that there were no surveys conducted in those areas and catch limits were mostly much lower than they have been during the last several years. Exploitable biomass in Areas 2A and 4CDE is estimated by applying a survey-based estimate of relative abundance to the analytical estimate of biomass in the adjoining area (2B for 2A, 4A for 4CDE).

A biological target level for total removals is calculated by applying a fixed harvest rate to the estimate of exploitable biomass. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for directed setline catches, called the setline CEY, is calculated by subtracting from the total CEY an estimate of all other removals—sport catches, bycatch of legal-sized fish, wastage of legal-sized fish in the halibut fishery, and fish taken for personal use.

Staff recommendations for catch limits in each area are based on the estimates of setline 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.

## Evolution of assessment methods through 2002

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

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

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

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

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

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

The assessment model was simplified and recoded as a purely age-structured model in 2000 to eliminate some problems associated with the modeling of growth and the distribution of length at age (Clark and Hare 2001). 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 2002).

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.

## Features of the 2003 assessment

### Length-specific selectivity

Selectivity is an empirical function of observed mean length at age (by sex) in survey catches. (A point value is estimated every 10 cm, and the intervening values are interpolated.) No attempt is made to model individual growth or the distribution of length at age. Separate schedules are estimated for commercial and survey catches, but the same length-specific schedules are used for females and males. Because they differ in mean length at age, the derived age-specific selectivities of females and males are different.

Initially, separate length-specific schedules were fitted for J-hooks and C-hooks, and the commercial schedule was allowed to change gradually. There was hardly any difference among the estimated schedules, however, so in the production model fits only two schedules were estimated: one for commercial catches and one for survey catches.

### Separate accounting of females and males

In previous years the assessment model was a standard age-structured model of the stock, with the estimated number at each age in each year being the combined number of females and males. This was adequate when selectivity was treated as a function of age, but not now when selectivity is treated as a function of length, because females are larger at each age. More importantly, estimating abundance by sex provides estimates of the higher fishing mortality rates sustained by females and estimates of female spawning biomass. The staff was particularly concerned that size-selective fishing combined with the decline in size at age over the last several years could have resulted in a decrease in fishing mortality on males at the expense of females, and therefore a drop in female spawning biomass. As reported below, the sex-specific assessment shows that female spawning biomass is still well above the historical minimum that last occurred in the mid-1970s.

We have sampling data on the sex composition of survey catches but not commercial landings. The latter could be estimated internally by fitting the model to survey catch at age/sex and commercial catch at age only, but the survey sex ratio at age is in fact quite variable, so it was decided to estimate commercial sex composition external to the model and use the external estimates of commercial catch at age/sex as model data. It turned out to be quite feasible to use smoothed functional estimates of sex ratio at length within age in survey catches to key out the commercial length distributions at age to sex (Clark 2004a).

For sport and subsistence catches in most areas and years we have only the weight of removals, so the age and sex composition of those catches was estimated internally by using a fixed length-specific selectivity and locating the annual fishing mortality rates that generated the given catches in weight. The estimated length-specific survey selectivity was used for this purpose because like the survey both of these fisheries use hook and line and take sublegal fish. Comparison of survey and sport length compositions in Area 3A shows good agreement (Fig. 1).

We have estimates of bycatch at length, so the age and sex composition of the bycatch is calculated internally by estimating a length-specific bycatch selectivity schedule and an annual bycatch fishing mortality rate that generates the given amounts of bycatch in weight.

In previous years sport and subsistence catches were added to commercial landings, in effect imputing the commercial catch composition to those catches despite the presence of substantial numbers of sublegals. Meanwhile bycatch was divided into sublegal and legal-sized components, and only the legal-sized part went into the assessment. In this year's assessment all sizes of fish in all catches go into the assessment. The effect of this change on estimates of exploitable biomass at age 8+ is very small, but at least the accounting is more straight-forward and consistent.

**Explicit allowance for the bias and variance of age readings**

For many years the ages of halibut (and other species) were determined by counting the annuli seen when viewing the surface of the whole otolith. This method is reliable through about age 15 but thereafter underestimates the true age by an increasing margin. The true age can be determined by breaking and burning the otolith and counting rings as viewed on a cross section. The bias of surface readings can be corrected in the assessment by doing all the calculations with fish grouped by true age and then predicting and fitting the observed distribution of surface readings. The variance of both surface and break-and-burn readings can be handled the same way (Clark 2004b). Figure 2 shows how the same age composition would appear in the model calculations, as an observed surface age reading distribution, and as an observed break-and-burn age reading distribution.

These correction procedures require that the observed readings in a given year be either all surface readings or all break-and-burn. For this year's assessment the age database was reworked so that all the sample ages are surface ages through 2001 and all are break-and-burn thereafter. In addition, all of the 2002 sample otoliths were read both ways to provide a solid dataset for estimating the various components of the correction procedures.

**Analytical (model-based) estimates of abundance in Areas 3B, 4A, and 4B**

Estimating abundance by fitting an age-structured model requires a sufficiently long series of survey data that the decline of several year-classes can be tracked as they pass through the fishery, and sufficiently large catches that fishing mortality is a substantial fraction of total mortality. Lacking that kind of data, abundance in Areas 3B and 4 has been estimated with a survey-based method, wherein an index of abundance in all areas was computed by multiplying average survey CPUE by total bottom area, and the biomass in, for example, Area 3B was estimated by multiplying the model-based estimate of Area 3A biomass by the ratio of the Area 3B and Area 3A survey-based index values.

Surveys began in 1996 in Area 3B, and in 1997 in Areas 4A and 4B. Catch limits were raised substantially in 1997 and have remained at that higher level since. So we now have 7-8 years of survey data and higher catches, which in conjunction with this year's very simple length-based assessment model make it possible to fit the model and obtain analytical estimates in those areas. In Areas 2A and 4CDE the survey-based method is still used.

## Quality of model fits

The fitted model uses the same parameter values (natural mortality, survey and commercial catchabilities and length-specific selectivities) for females and males. It is therefore very parsimonious, but it nonetheless predicts the catch at age of females and males very well (Fig. 3). This is remarkable because mean size at age differs greatly between the sexes and has declined substantially for both during the period covered by the model fit (Fig. 4). The derived age-specific selectivities therefore vary tremendously by sex and among years, but the model predictions still do a very good job of tracking not only the age composition of the catch of each sex but also the relative magnitudes of the catches of females and males, which are quite different (Fig. 5). The ability of this simple model to predict the catches by age and sex over such a wide range of observed and predicted values leaves little doubt that variation in size at age accounts for the bulk of variation in selectivity at age.

The retrospective performance of the model is also satisfactory. In Area 3A there is still an upward shift when the 2002 data are added to the assessment, but it is less than 10% (Fig.6) and therefore well within the normal range of year-to-year variability of models fits. In Areas 2B and 2C the model tracks well over the last several years although both fits still make large excursions in the mid-1990s when two or three anomalously high survey CPUE values occurred.

## Effects of model changes on abundance estimates

The 2003 model can be fitted in various ways to show the incremental effect of the new features. Figure 7 shows the effects step by step in Area 2C, where they were largest. Fits are shown with data through 2001 (abundance estimates through 2002) to avoid confusing the effects of model changes with the effects of the change from surface to break-and-burn readings. The quantity plotted is estimated recruitment, which is the fundamental abundance estimate in any assessment.

The baseline at the bottom of Figure 7 shows the series of recruitment estimates from last year's assessment model, which had fixed age-specific survey selectivities and drifting age-specific commercial selectivities. The line above that shows the effect of switching to fixed length-specific survey and commercial selectivities but not treating females and males separately. (In this fit the calculations are actually performed separately for each sex, but age-specific selectivity is determined by the overall mean length at age rather than the mean length at age for each sex, so fishing mortality at age is the same for females and males. This model is basically the same as earlier length-specific models used by the staff, and it produces almost the same estimates as the alternative length-specific model reported in last year's assessment.) The next line up shows the added effect of treating females and males separately (i.e., having age- and sex-specific selectivities determined by sex-specific mean length at age). The topmost (black) line shows the added effect of correcting for the bias and variance of surface ages; it is the 2003 assessment model fit. At the left of the graph are the mean 1974-2001 recruitment levels for each model fit. In Area 2C the cumulative change in the mean is a 50% increase. The overall increases in other areas are smaller but still substantial: 20% in Area 2B and 35% in Area 3A.

Length-specific fits have always produced substantially higher estimates of abundance than age-specific fits in Alaska. (The effect has always been much less in British Columbia because the change in size at age was smaller there.) That component of the increase is therefore as expected, and it makes sense that treating the sexes separately would compound the effect, because it introduces a larger variation in length at age. It is somewhat surprising that correcting the ages not only redistributes but also increases the recruitment estimates. That feature must result from an increase in the number of natural deaths that occurs when lifespans are increased by allowing for greater ages and the same natural mortality rate is used.

## Estimates of length- and age-specific selectivities

As in previous length-specific model fits, commercial selectivity is estimated to be higher in Area 2B than in Area 3A, with Area 2C intermediate (Fig. 8). The estimates for Areas 3B, 4A, and 4B are similar to the Area 2C estimates.

Because length-specific commercial selectivity appears to have been the same for the last thirty years while mean length at age has declined greatly over the last fifteen years, age-specific commercial selectivity has also declined greatly over the last fifteen years (Fig. 9). And because males in the modal age range (10-15) were less vulnerable to begin with, the relative decline in age-specific selectivity of males has been greater than that of females. In Area 3A, males reached full vulnerability by age 15 in the 1970s and 1980s; now even the oldest males are only about 20% vulnerable, while the oldest females are still fully vulnerable. The same sort of change has occurred elsewhere. Females always sustained higher fishing mortality rates than males because they were larger, but twenty years ago females and males both reached the size of full vulnerability at some point. Males no longer reach that point, so an even larger share of fishing mortality is falling on the females.

## Calculation of exploitable biomass

Exploitable biomass is calculated as the fully selected equivalent of all the fully and partially selected age groups (really age/sex groups) in the stock, so it depends on the commercial selectivities that are used to scale the biomass of each group. The 1999-2002 assessments used a set of age-specific selectivities from the 1999 assessment averaged over regulatory areas, called the "fixed coastwide selectivities." Using a fixed set provided a common measure among areas and years. As shown in Figure 9, these fixed selectivities were a good compromise among areas and between the sexes a few years ago.

They are no longer appropriate, first because they are age-specific rather than length-specific as we now believe to be correct, and second because size at age has declined further since 1999 and the present selectivities are lower than the fixed ones. We therefore need to adopt a new set of length-specific selectivities to calculate exploitable biomass, and it will be lower than the old exploitable biomass, partly because of the decline in size at age since 1999 but mostly because the calculation will be done separately for females and males and the males will contribute less.

It is still desirable to adopt a single coastwide set of selectivities to provide a common measure among areas. Except for Area 3A, all of the regulatory areas in Alaska have selectivity schedules that are close to a line that increases linearly from zero at 80 cm to 1 at 120 cm, so that is a good fixed schedule for those areas. The Area 3A schedule is much lower, but through 120 cm it is a constant fraction (about 70%) of the fixed schedule, so for the great bulk of the stock the relative selectivities of all the age/sex groups are the same. This means that using the fixed schedule in Area 3A and applying a given full-recruitment harvest rate to that biomass will result in the same level of fishing mortality on the same age/sex groups as in the other Alaska areas. It will also provide a common measure of biomass.

The Area 2B schedule is substantially higher than the fixed schedule, and rather than being proportional it is shifted to the left. Using the same fixed selectivity schedule and the same harvest rate in Area 2B as in Alaska would result in a significant reduction in CEY in Area 2B at a time when the stock is clearly doing well at present harvest levels and we have not yet done the new harvest rate evaluation that the new assessment requires. At least for 2004, therefore, we have decided to use the locally estimated selectivity schedule to estimate exploitable biomass in Area 2B. This means that given the same nominal harvest rate, some age-specific fishing mortality rates will be higher in Canada than in Alaska, and that the exploitable biomass figures are not comparable between Canada and Alaska as they are among Alaska areas.

## Estimates of historical and present biomass in Areas 2B, 2C, and 3A

The Commission's paramount management objective is to maintain a healthy level of spawning biomass, meaning a level above the historical minimum that last occurred in the mid-1970s. Although low, this spawning stock nevertheless produced average or better year-classes. In the past we always calculated spawning biomass by applying the female maturity schedule to estimated total biomass at age (including males) because we did not have sex-specific estimates of abundance. One of the main reasons for implementing a sex-specific assessment was to obtain direct estimates of female mortality rates and female spawning biomass. We now have those estimates, and fortunately they show that female spawning biomass is 3-4 times what it was in the mid-1970s (Table 1). So on that score the stock is in good shape.

The numbers of fish aged 8 and older are now 5-10 times what they were in 1974, but their total biomass is only 3-5 times the 1974 level, and exploitable biomass (computed with the new length-specific commercial selectivities) only 2-3 times. The difference between the large increase in numbers and the more modest increase in biomass results from the dramatic decline in size at age and therefore selectivity that has occurred over the last fifteen years. A significant part of the age 8+

biomass now consists of males that never get large enough to be caught in any numbers, as shown by their near disappearance from commercial catches in Area 3A (Fig. 5b). Looked at another way, in 1974 a large fraction of the total age 8+ biomass was exploitable; now that fraction is much smaller (Figs. 10a-c).

## Estimates of present biomass in Area 3B, 4A, and 4B

In these areas the model is fitted to data from 1996-2003 only. Before that exploitation rates were low and there were no surveys, which among other things means that there is no way to estimate the sex composition of commercial landings. Although less data goes into the assessment in these areas, the model is simple enough that the abundance and selectivity estimates are very well determined; the coefficients of variation are less than 5%.

The survey-based method that we used for the last several years assumes that survey catchability is the same throughout Areas 3 and 4. The model fits indicate that survey catchability in Area 4B is about the same as in Area 3A, but that it is higher in Areas 3B and 4A. Consistent with those estimates, the new analytical estimates of Area 3B exploitable biomass are lower than the survey-based estimates (Fig. 11). In Area 4A they are lower in some years but quite close for the last couple of years, and in Area 4B the agreement is good throughout.

The estimates of exploitable biomass compared in Figure 11 are all calculated with the locally estimated commercial selectivities. For Areas 3B, 4A, and 4B those are close to the fixed length-specific selectivities used to compute a standardized exploitable biomass, but for Area 3A they are much lower. Using the fixed selectivities to calculate exploitable biomass increases the 3A value by about 40%, which has the effect of shrinking the other areas' estimates relative to the Area 3A estimate on the standardized scale, as shown in the table below. In short, the analytical estimates in all three areas are lower than the survey-based estimates relative to Area 3A mainly because selectivity is lower in Area 3A than in those areas. Another factor in the case of Area 3B is higher estimated survey catchability than in Area 3A; that accounts for the difference between 0.71 and 0.54 in the table below.

| | **Area 3B** | **Area 4A** | **Area 4B** |
|---|---|---|---|
| **Survey index**<br>as a fraction of 3A | 0.71 | 0.26 | 0.16 |
| **Exploitable biomass calculated with locally estimated selectivities**<br>as a fraction of 3A | 0.54 | 0.25 | 0.17 |
| Exploitable biomass calculated **with fixed selectivities**<br>as a fraction of 3A | 0.45 | 0.14 | 0.10 |

## Estimates of present biomass in Areas 2A and 4CDE

For these areas we cannot do an analytical assessment so we continue to use the survey-based estimate scaled to an adjoining area. For Area 2B this is 13% of the Area 2B estimate. For Area 4CDE we have been scaling to Area 3A because that was the nearest area with an analytical estimate. We now have an estimate for Area 4A, and by the same procedure can estimate the Area 4CDE biomass as 142% of the Area 4A biomass.

## Estimated CEY in 2004

A major change in this year's assessment is the adoption of a new set of length-specific commercial selectivities, which produce much lower estimates of exploitable biomass than the old fixed age-specific selectivities. (Table 1). In the past we calculated CEY by applying the established 20% harvest rate to exploitable biomass, but we cannot do the same thing now because the 20% harvest rate was chosen on the basis of simulations that used the old fixed age-specific selectivities. A new set of simulations with the new, lower selectivities can be expected to lead to a higher target harvest rate, but that work has not yet been done. For this year's CEY calculations, we have adopted a provisional target harvest rate of 25% for Areas 2 and 3. For Area 4 we have stuck with 20% because of uncertainty about the long-term productivity of the Bering Sea/Aleutians region relative to the Gulf of Alaska.

The resulting estimates of setline CEY (Table 2) are considerably higher than last year's in Areas 2A, 2B, and especially 2C, where this year's assessment changes had the largest total effect. In Area 3A setline CEY is a little lower. In Areas 3B and 4 the numbers are much lower – half or less – because of the lowered selectivities and in Area 4 the continued use of a 20% harvest rate.

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**Table 1. Various measures of abundance in 2004 compared with 1974. Biomass is in millions of net pounds, numbers in millions. Calculations of spawning and total biomass use mean weight at age/sex in the survey (i.e., including sublegals) while calculations of exploitable biomass use mean weight at age/sex in the commercial landings. This is why exploitable biomass can exceed total biomass. “Old exploitable biomass” is calculated with the fixed coastwide age-specific commercial selectivities used in the 1999-2002 assessments. “New exploitable biomass” is calculated with the length-specific commercial selectivities estimated in the 2003 assessment.**

| | Area 2B | | Area 2C | | Area 3A | |
|---|---|---|---|---|---|---|
| | 1974 | 2004 | 1974 | 2004 | 1974 | 2004 |
| Female spawning biomass | 11 | 35 | 18 | 56 | 40 | 144 |
| Total biomass age 8+ | 23 | 67 | 42 | 188 | 89 | 429 |
| Total numbers age 8+ | 1.5 | 7.5 | 1.5 | 9.7 | 2.5 | 25.1 |
| Mean weight age 8+ | 15 | 9 | 28 | 19 | 36 | 17 |
| Old exploitable biomass | 22 | 88 | 30 | 153 | 50 | 360 |
| New exploitable biomass | 26 | 65 | 30 | 80 | 73 | 146 |

**Table 2. Removals in 2003 and estimates of CEY in 2004 (millions of net pounds).**

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|
| **2003 setline CEY at 20%** [1,2] | 1.29 | 11.32 | 9.11 | 34.22 | 29.19 | 11.22 | 7.76 | 10.82 | 114.93 |
| **2003 catch limit** [2] | 1.31 | 11.75 | 8.50 | 22.63 | 17.13 | 4.97 | 4.18 | 4.45 | 74.92 |
| **2003 commercial landings** [3] | 0.82 | 11.75 | 8.45 | 22.68 | 17.41 | 4.97 | 3.87 | 3.25 | 73.20 |
| **Other removals** | | | | | | | | | |
| Sport catch | 0.40 | 1.07 | 2.60 | 5.00 | 0.01 | 0.04 | 0 | 0 | 9.12 |
| Legal-sized bycatch | 0.29 | 0.15 | 0.17 | 1.36 | 0.58 | 0.50 | 0.18 | 2.56 | 5.79 |
| Personal use | 0 | 0.30 | 0.17 | 0.07 | 0.02 | 0.17 | 0 | 0 | 0.73 |
| Legal-sized wastage | 0.01 | 0.02 | 0.03 | 0.09 | 0.04 | 0.02 | 0.01 | 0.01 | 0.23 |
| **Total other removals** | 0.70 | 1.54 | 2.97 | 6.52 | 0.65 | 0.73 | 0.19 | 2.57 | 15.87 |
| **...**excluding sport catch | 0.30 | 0.47 | --- | --- | --- | --- | --- | --- | --- |
| **Total removals** | 1.52 | 13.29 | 11.42 | 29.20 | 18.06 | 5.70 | 4.06 | 5.82 | 89.07 |
| **2004 exploitable biomass** [4] | 8.5 | 65 | 80 | 146 | 65 | 21 | 15 | 30 | 430.5 |
| **2004 total CEY at 25% (20% in Area 4)** | 2.1 | 16.3 | 20.0 | 36.5 | 16.3 | 4.2 | 3.0 | 6.0 | 104.4 |
| **2004 setline CEY** [5] | 1.8 | 15.8 | 17.0 | 30.0 | 15.7 | 3.5 | 2.8 | 3.4 | 90.0 |

Notes:

1. Estimates of 2003 setline CEY (first row) are the figures reported in the 2002 assessment.
2. In Area 2A the setline CEY and catch limit include sport catch and treaty subsistence catch.
3. Commercial landings include IPHC survey and other research catches, which can result in small overages.
4. 2004 exploitable biomass is computed with a new set of length-specific selectivities that are lower than the age-specific selectivities used in the 1999-2002 assessments, so these figures are not comparable with last year's exploitable biomass estimates.
5. In Area 2B the setline CEY for 2004 includes sport catch for the first time.

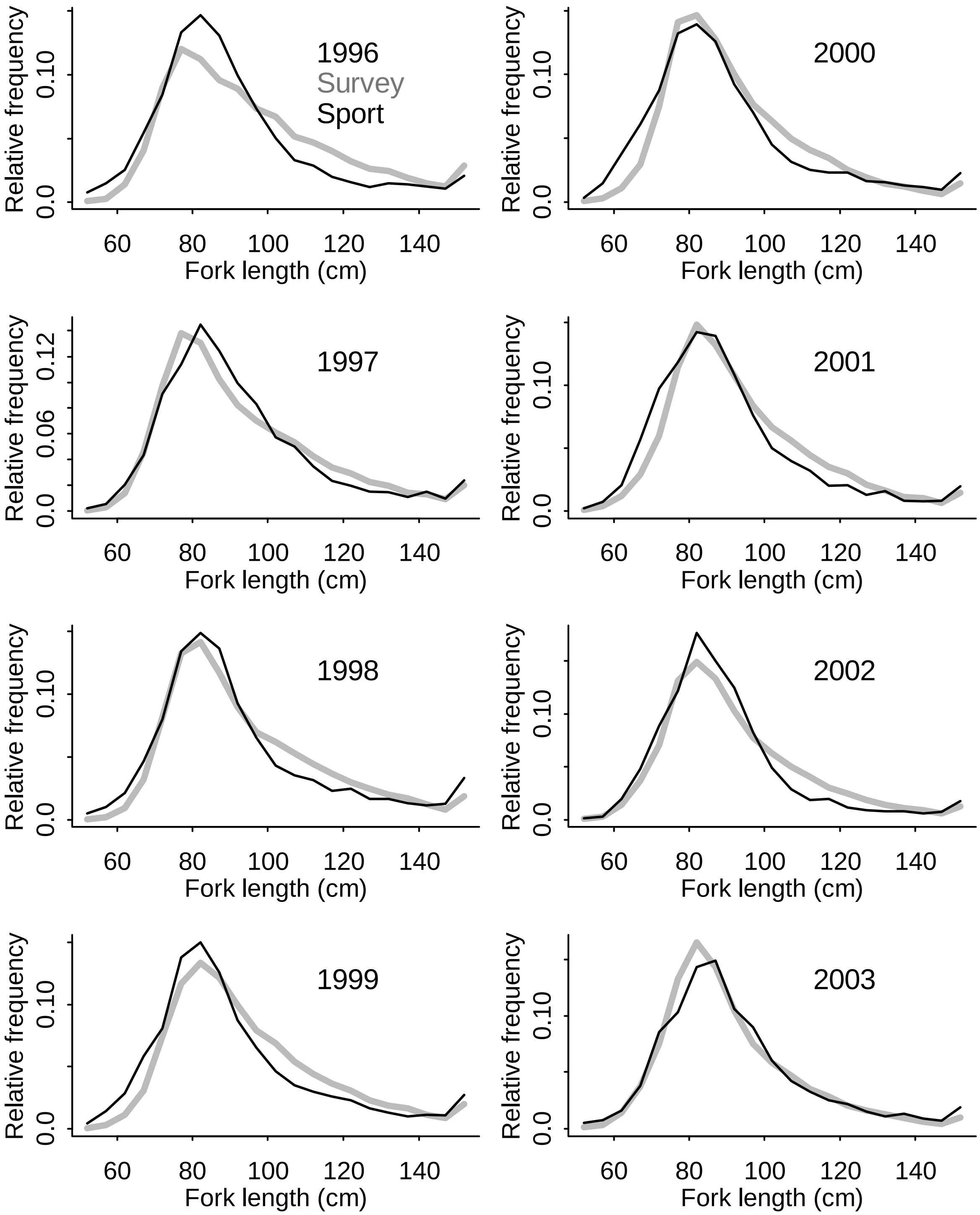


**Figure 1. Length frequencies of ADF&G sport catch samples and IPHC survey catch samples in Area 3A in recent years.**

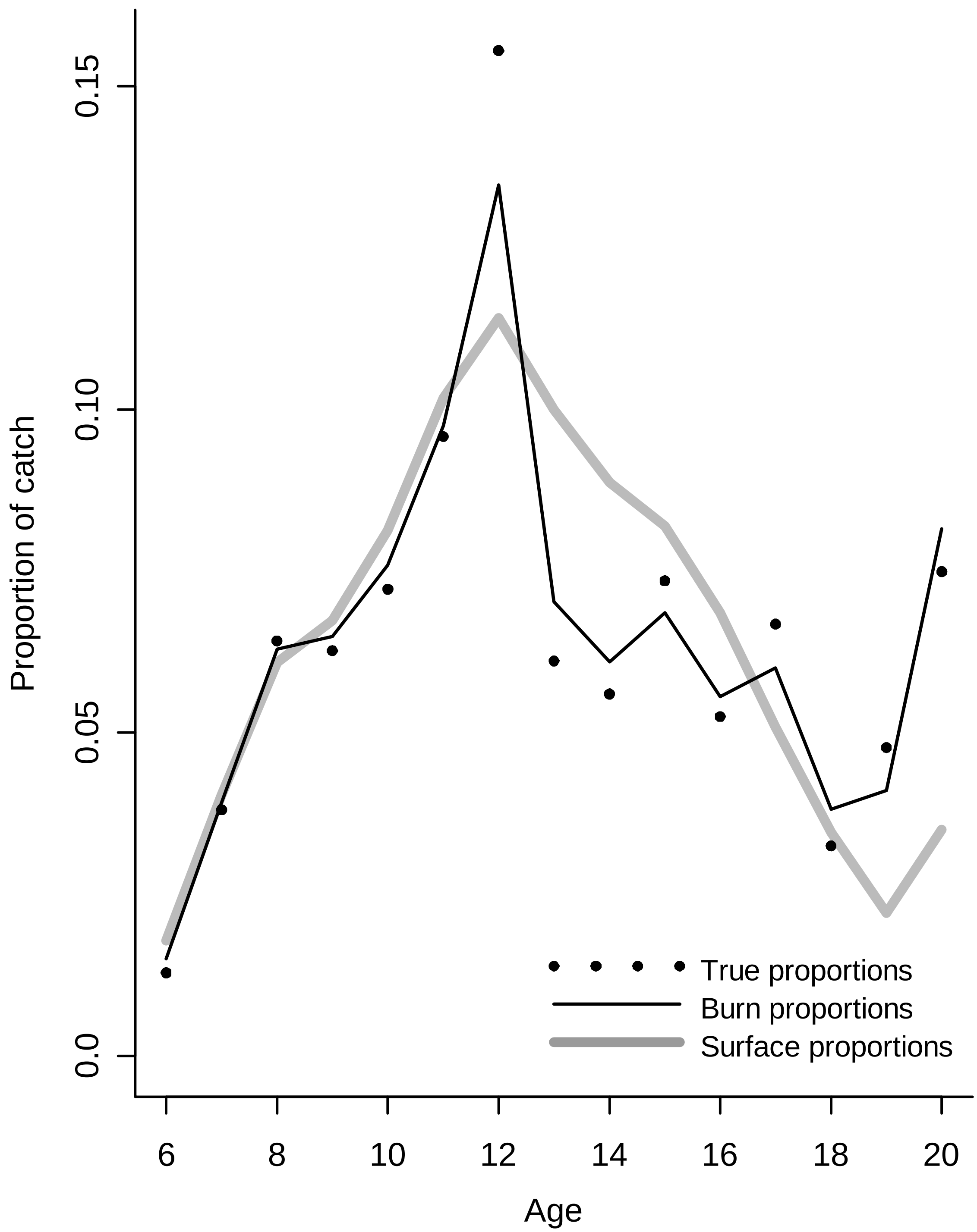


**Figure 2. An example of true age proportions in the catch and the corresponding observed distributions of surface and break-and-burn age readings. At ages beyond about 15 surface ages are biased and quite variable; break-and-burn ages are unbiased and less variable.**

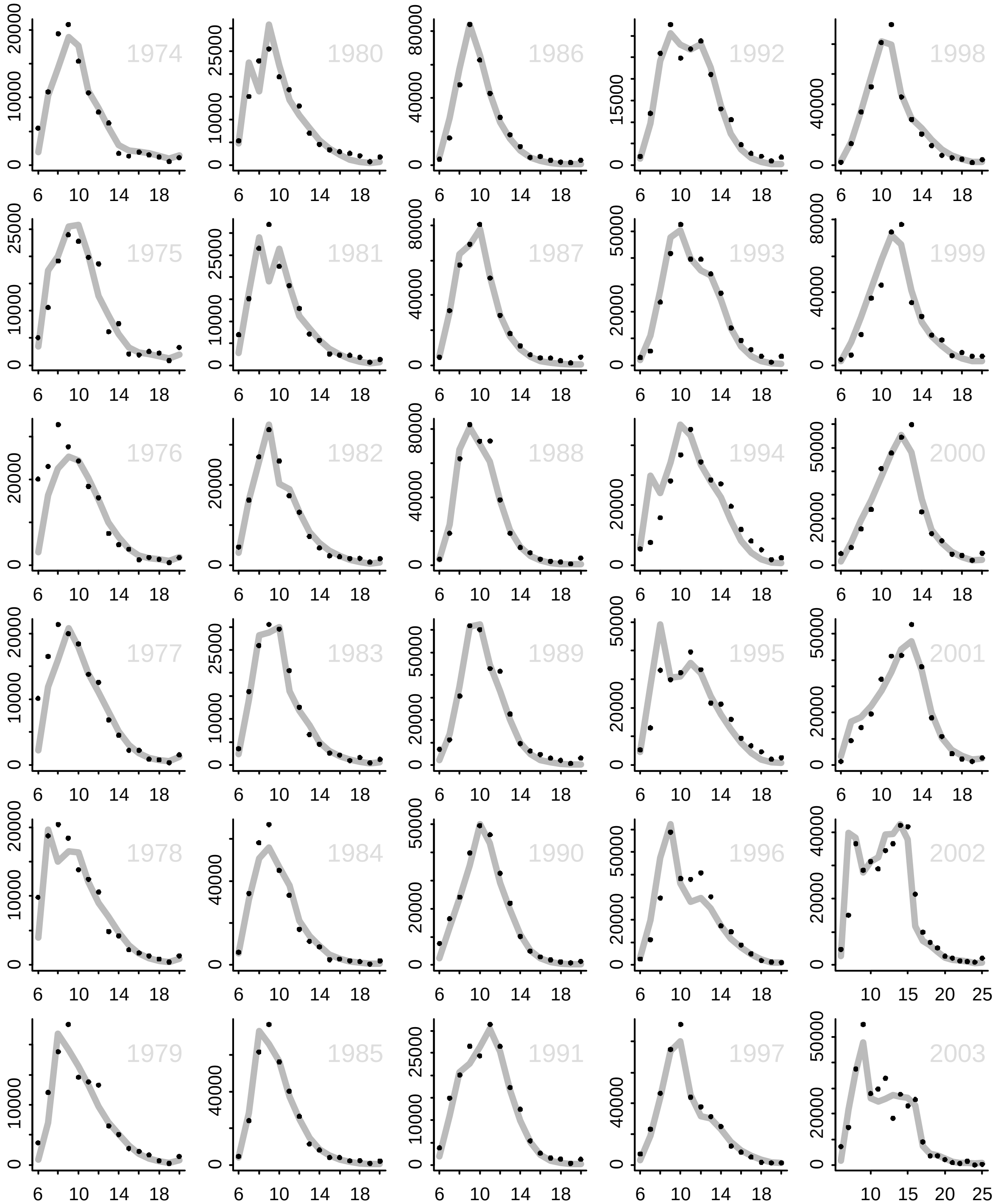


**Figure 3a. Observed catch at age of females in Area 2B (points) and model predictions (lines).**

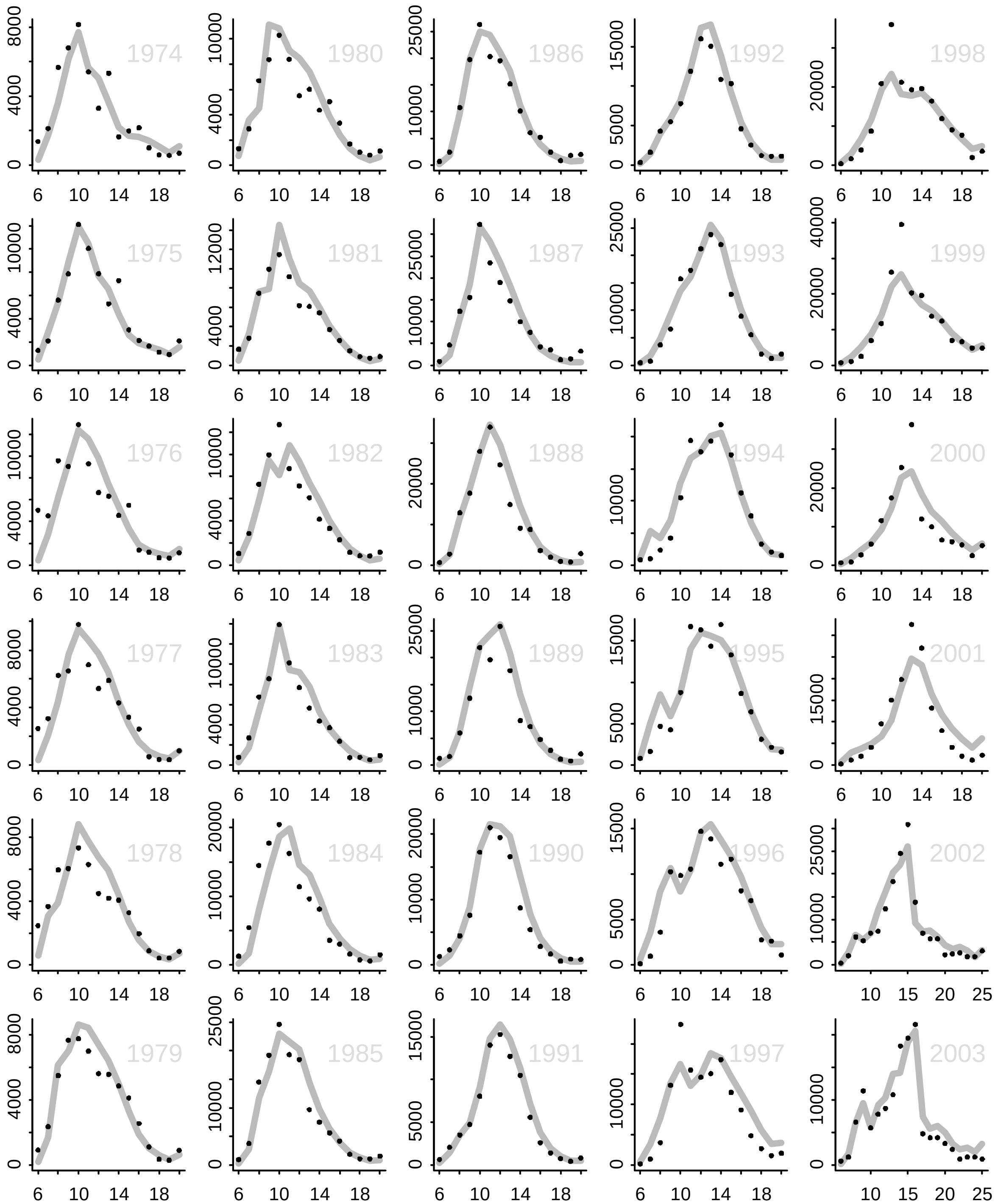


**Figure 3b. Observed catch at age of males in Area 2B (points) and model predictions (lines).**

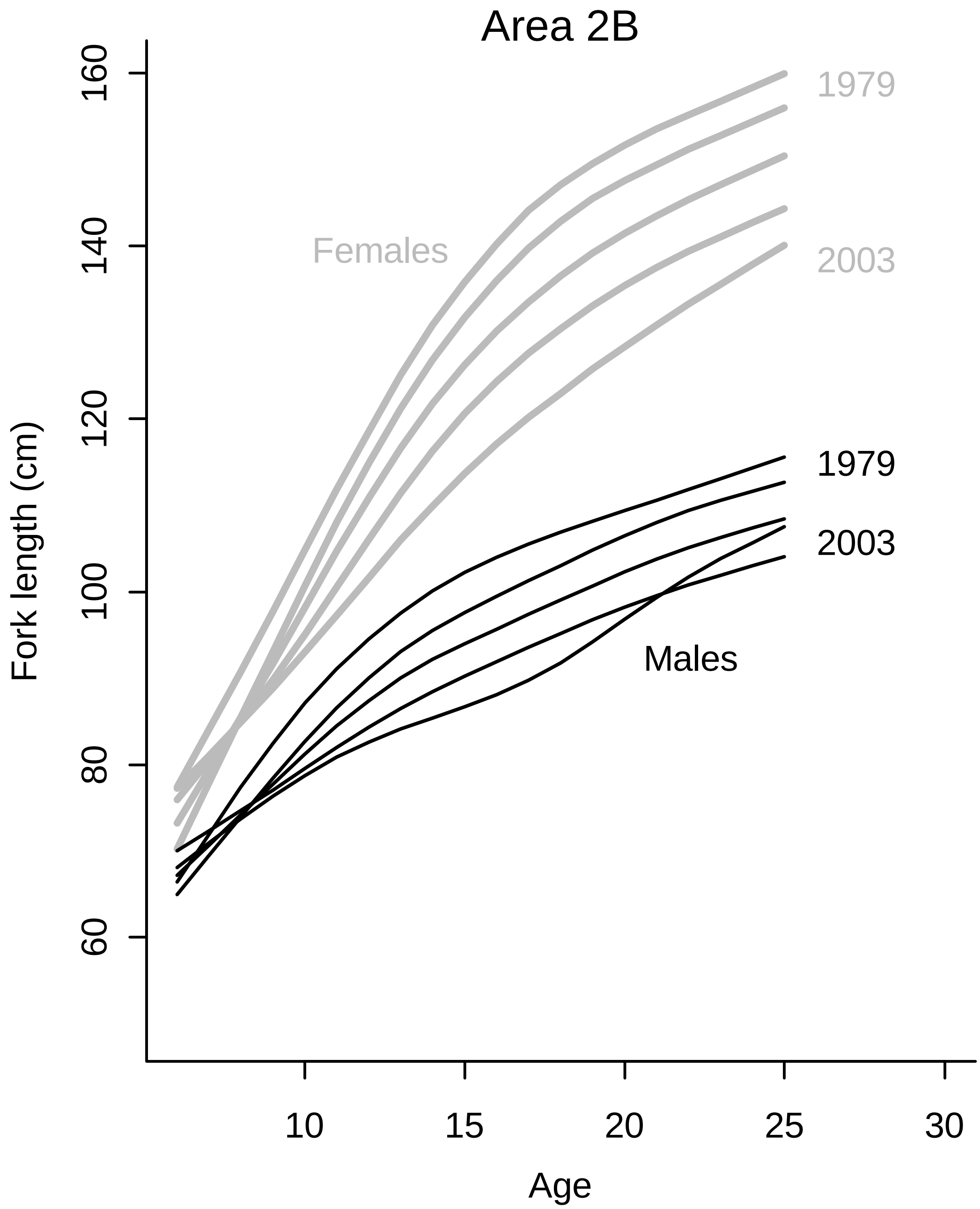


**Figure 4. Mean length at age of females and males in setline survey catches in Area 2B. For each sex, the graphs show the observed growth schedules in a sequence of years at intervals between 1979 and 2003. The upturn in the male growth schedule in 2003 is an artifact of the conversion from surface to break-and-burn readings.**

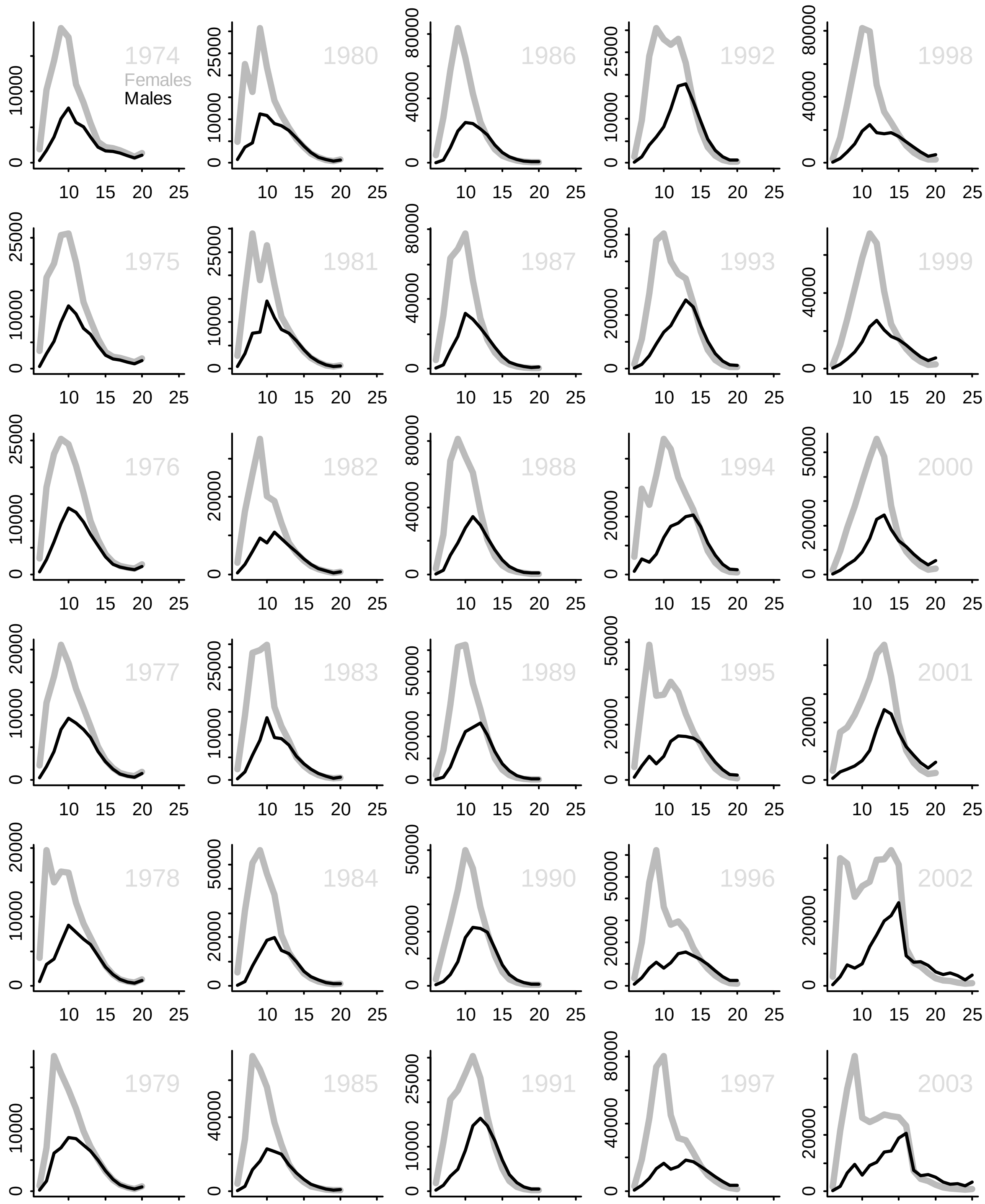


**Figure 5a. Catch at age of females and males in Area 2B, by year.**

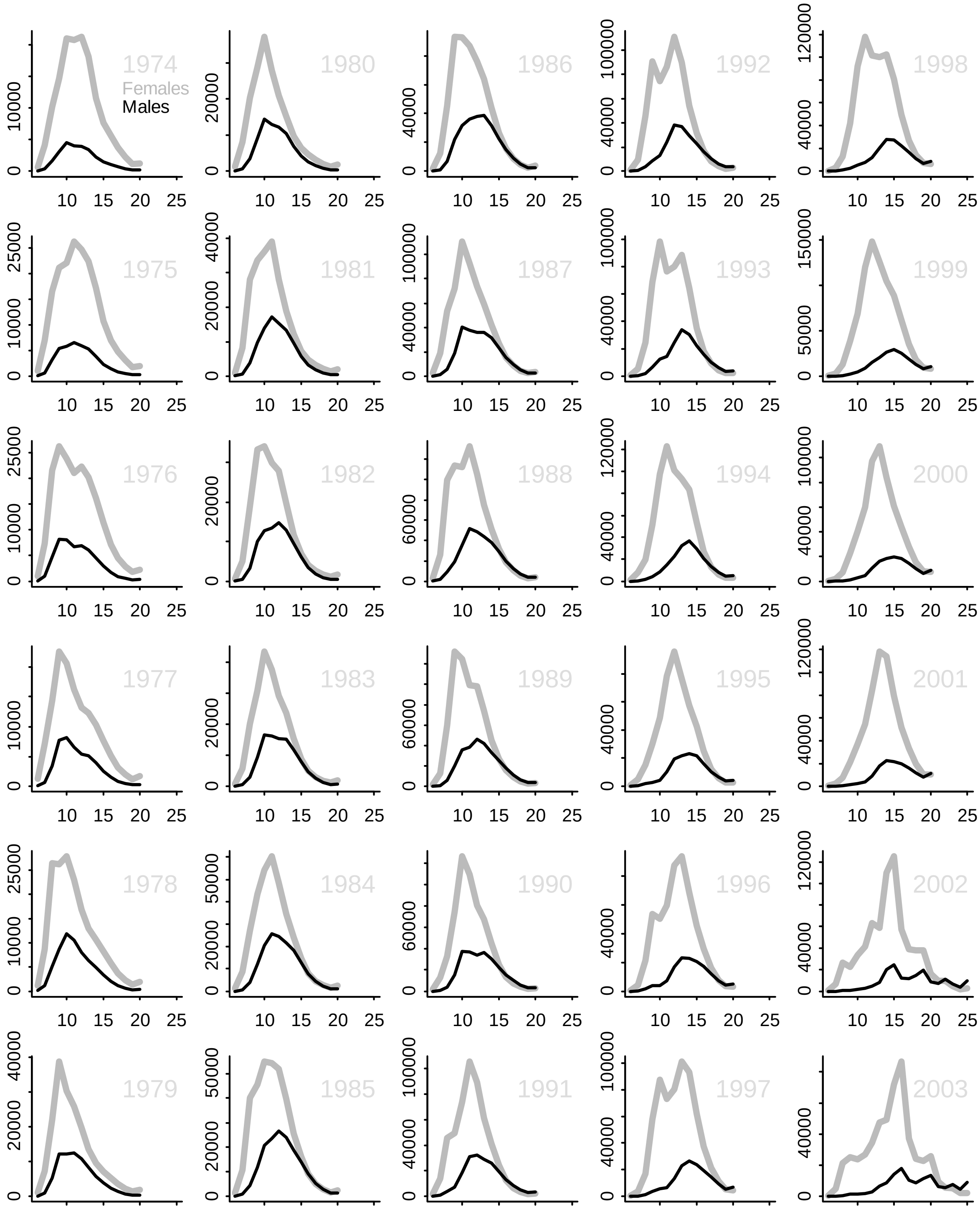


**Figure 5b. Catch at age of females and males in Area 3A, by year.**

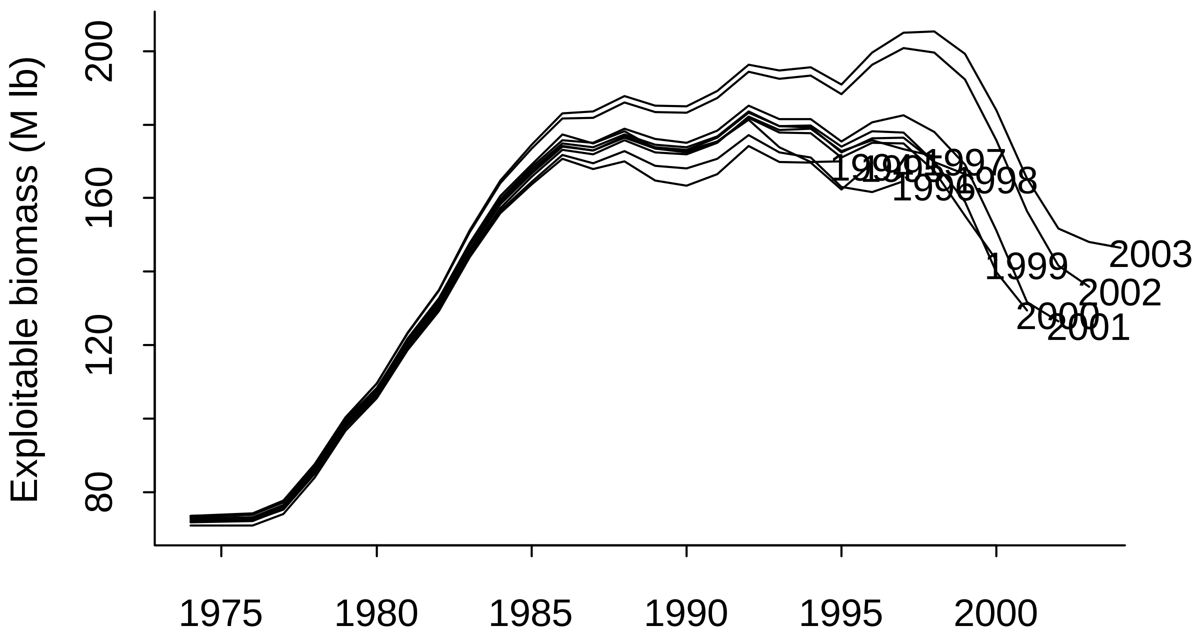


**Figure 6. Retrospective performance of the 2003 assessment in Area 3A.**

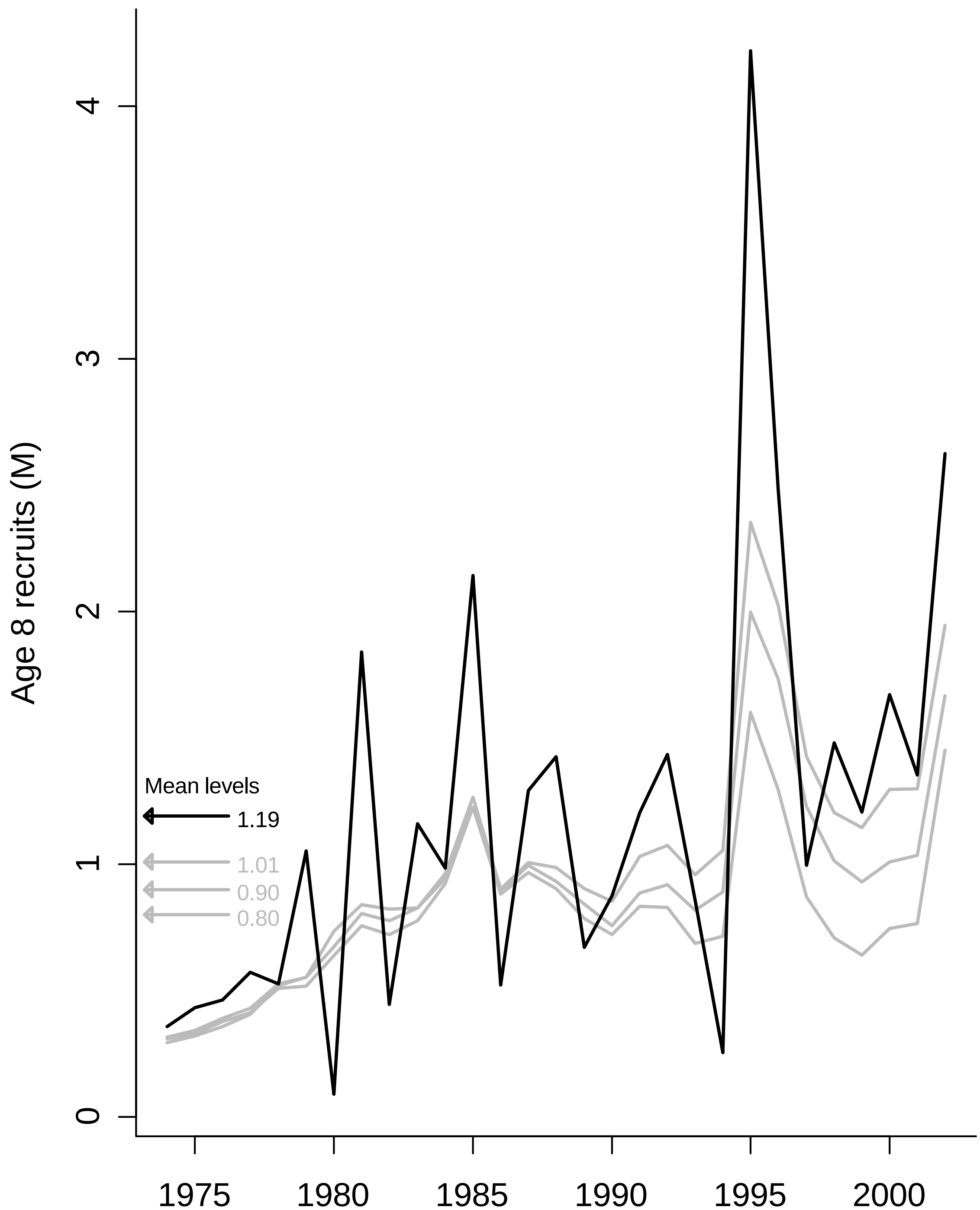


**Figure 7. Estimates of recruitment in Area 2C from fits of old and new models. Bottom line shows the 2002 assessment with fixed age-specific survey selectivities; next line up shows the effect of switching to length-specific selectivities; next line up the added effect of treating females and males separately; topmost (black) line the added effect of correcting for surface age bias and variance.**

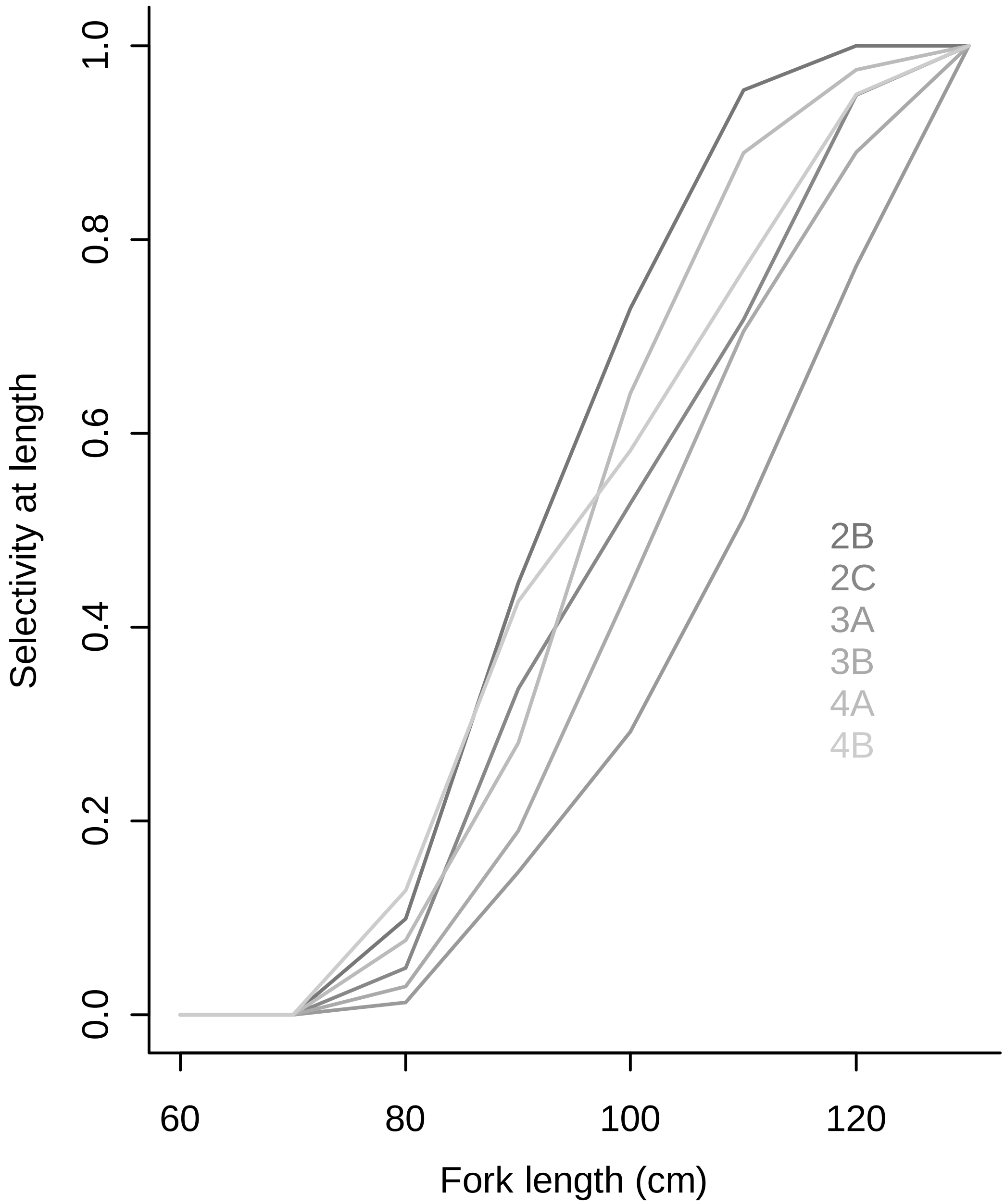


**Figure 8. Estimated length-specific commercial selectivity. The topmost line is Area 2B. The bottom line is Area 3A, and the other Alaska areas are clustered in the middle.**

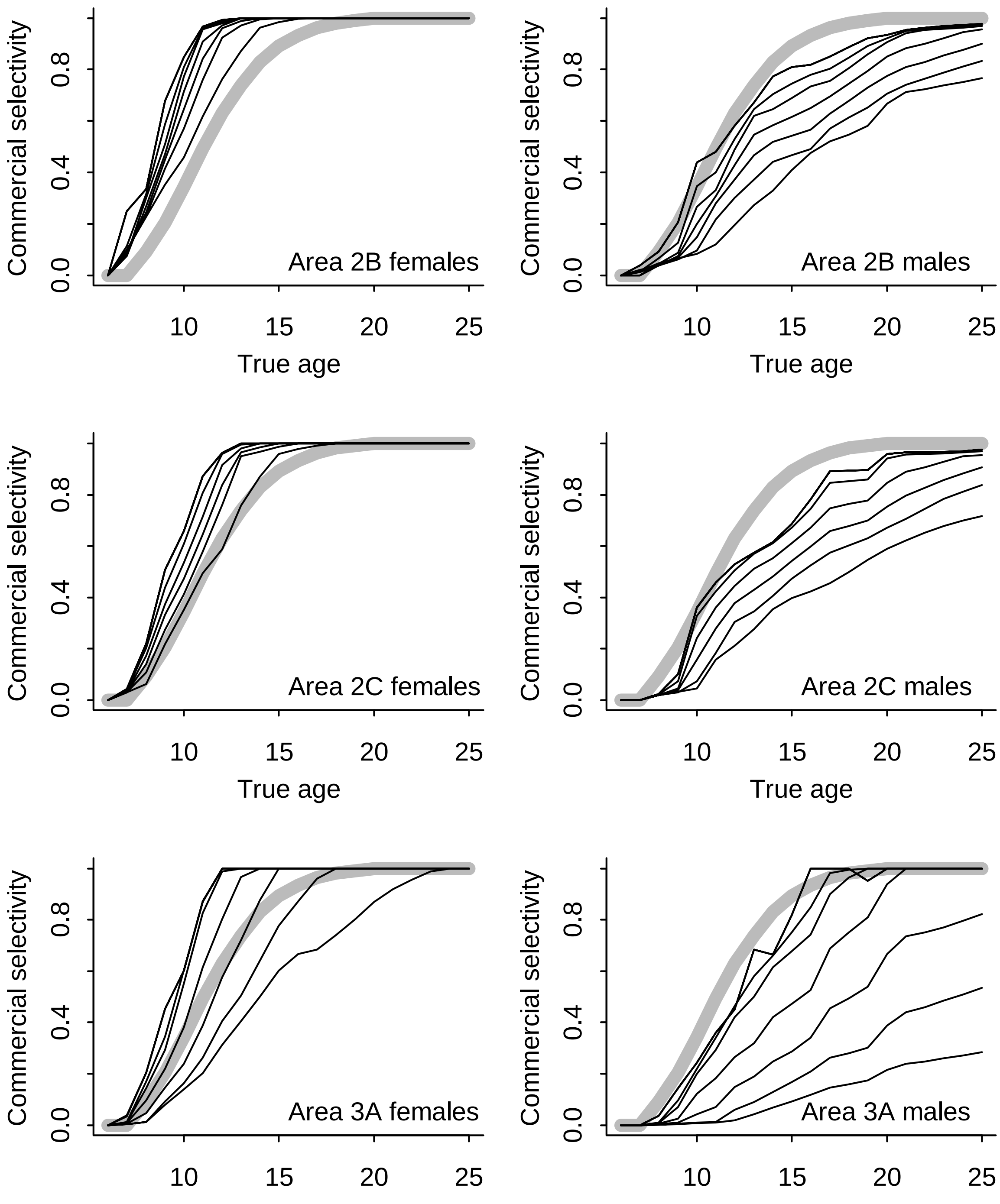


**Figure 9. The downward drift of age-specific commercial selectivities over time due to constant length-specific selectivity and declining size at age, plotted by area and sex. The thin black lines in each graph are the selectivities estimated for a particular year; the thick gray line is the set of fixed coastwide selectivities that were used to compute exploitable biomass in the 1999-2002 assessments.**

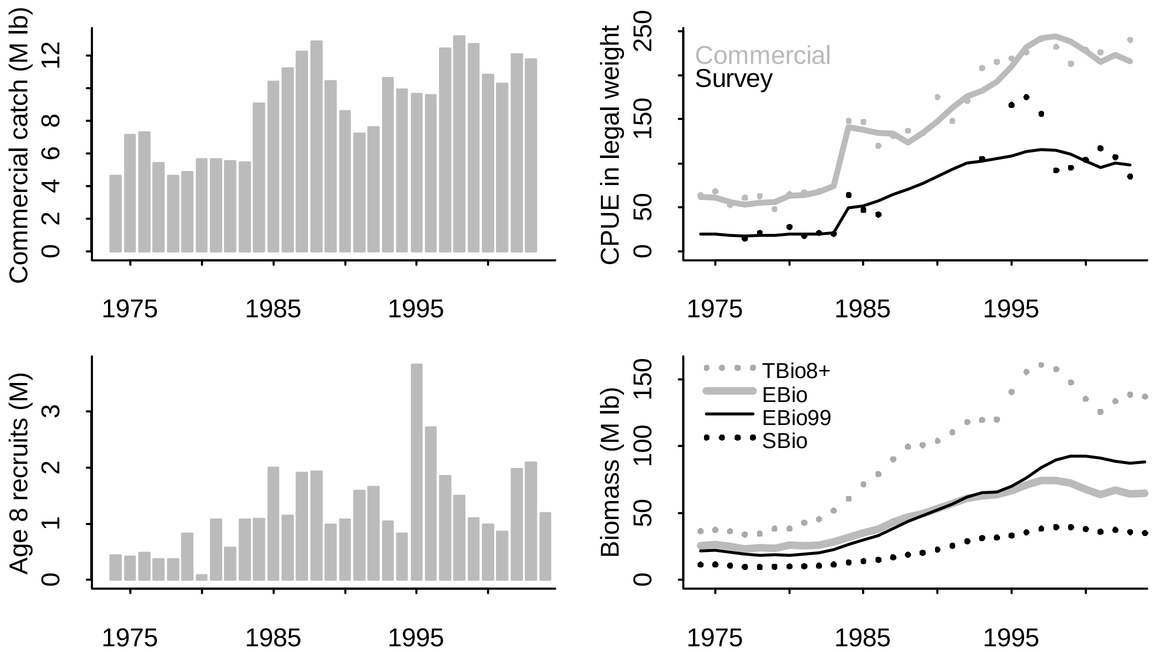


**Figure 10a. Features of the Area 2B assessment. In the upper right graph, the points are the observed CPUE values and the lines are the model predictions. In the lower right graph, "TBio8+" is total biomass of fish aged 8 and older, "EBio" is exploitable biomass as calculated this year, "EBio99" is exploitable biomass as calculated last year, and "SBio" is female spawning biomass.**

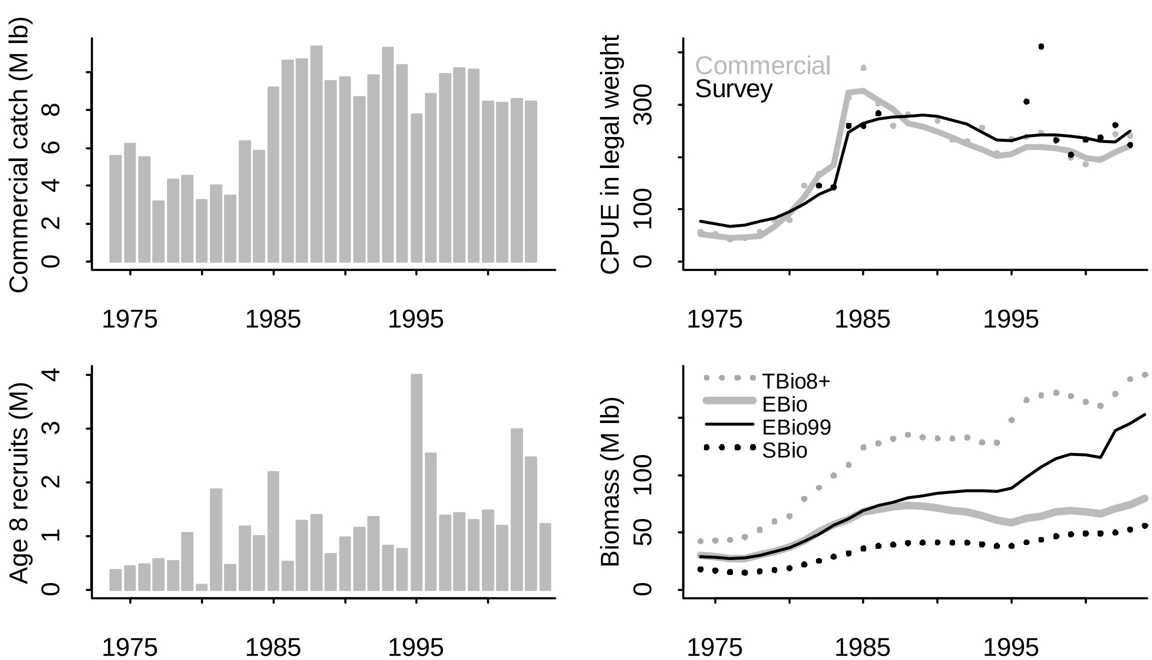


**Figure 10b. Features of the Area 2C assessment.**

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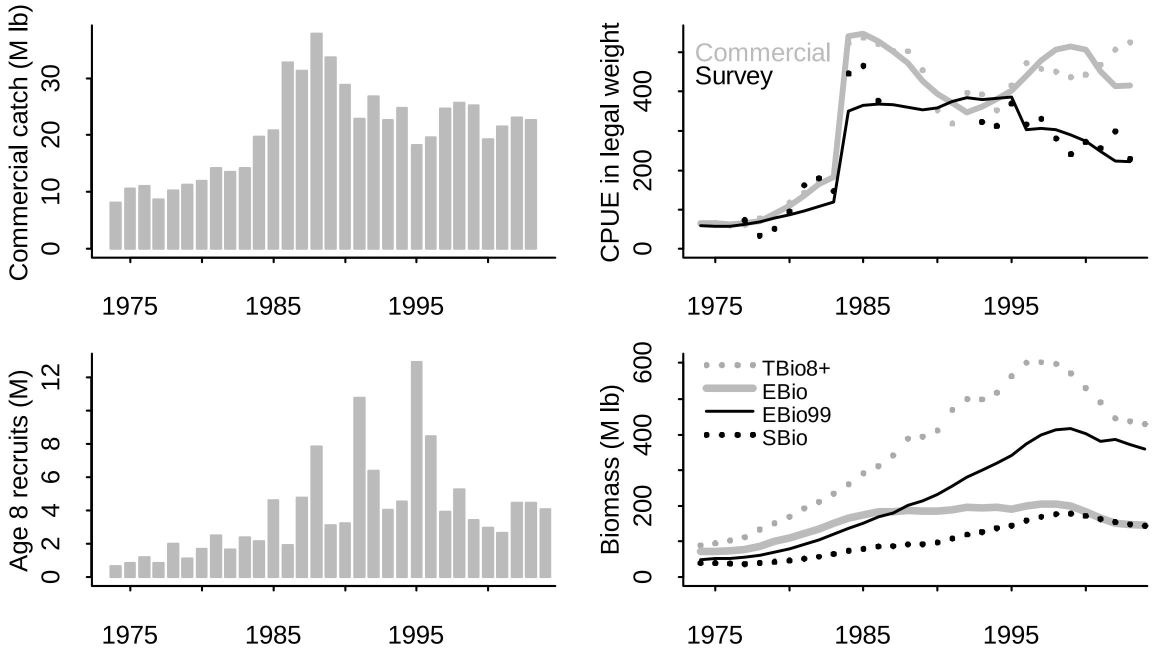


**Figure 10c. Features of the Area 3A assessment. (See Figure 10a legend for details.)**

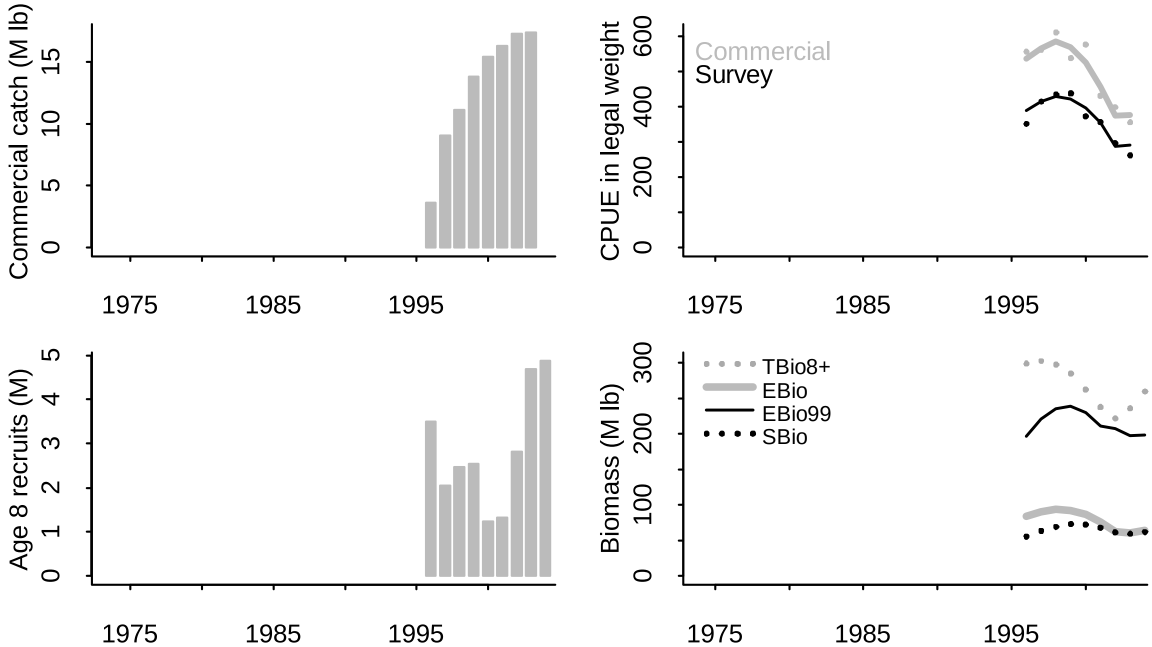


**Figure 10d. Features of the Area 3B assessment.**

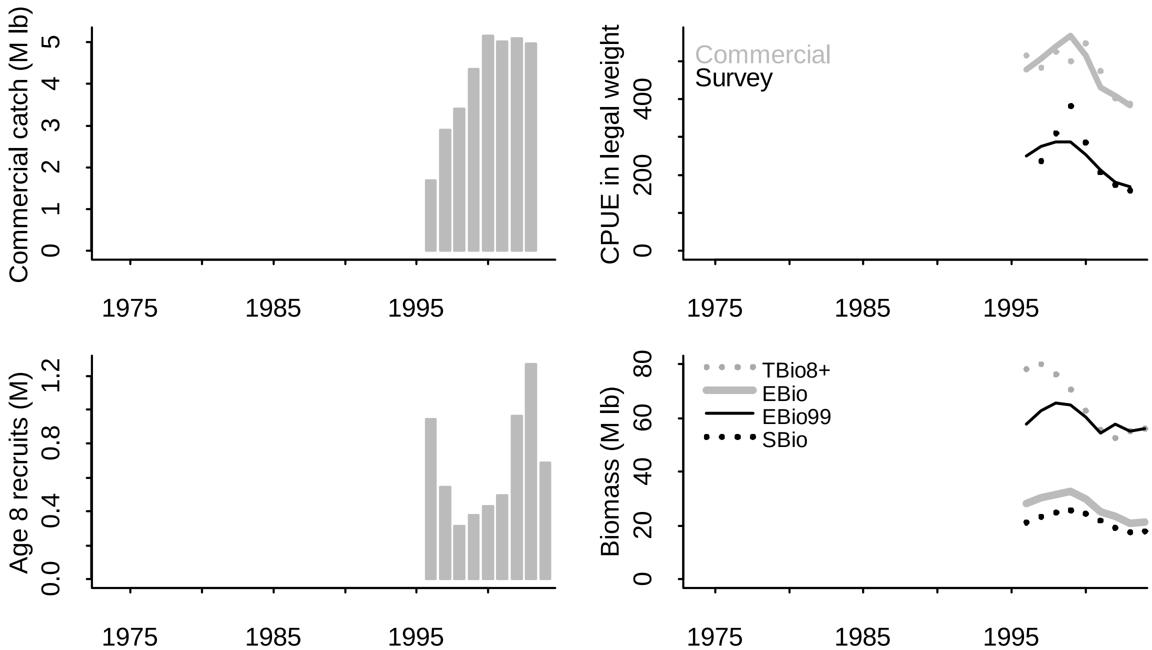


**Figure 10e. Features of the Area 4A assessment. (See Figure 10a legend for details.)**

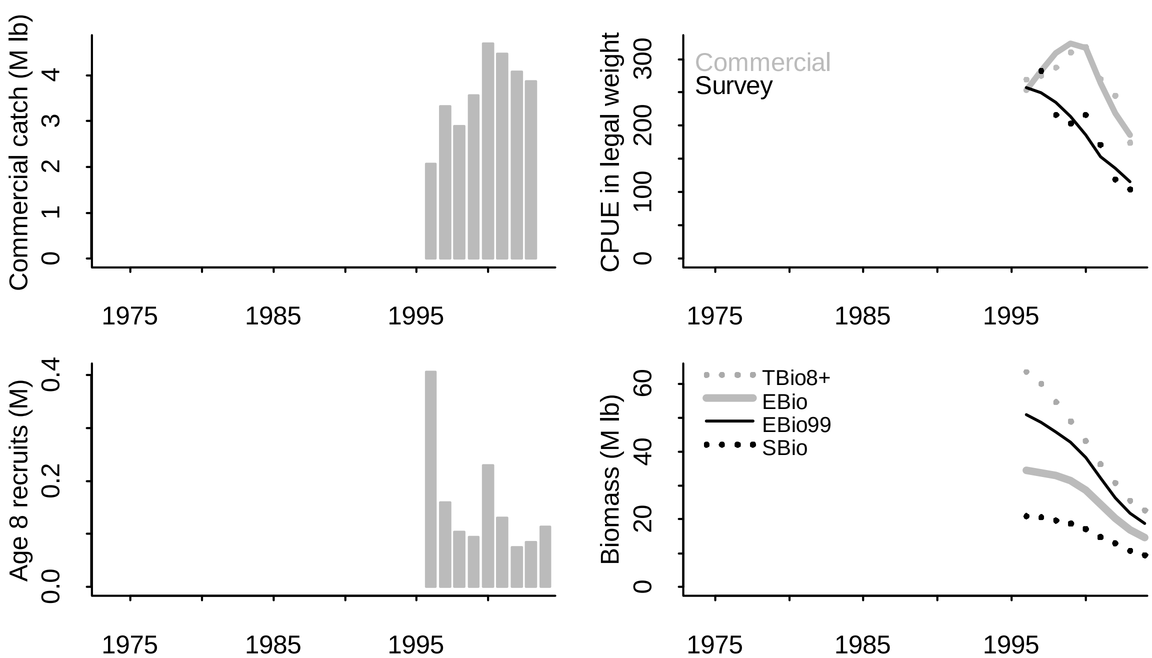


**Figure 10f. Features of the Area 4B assessment.**

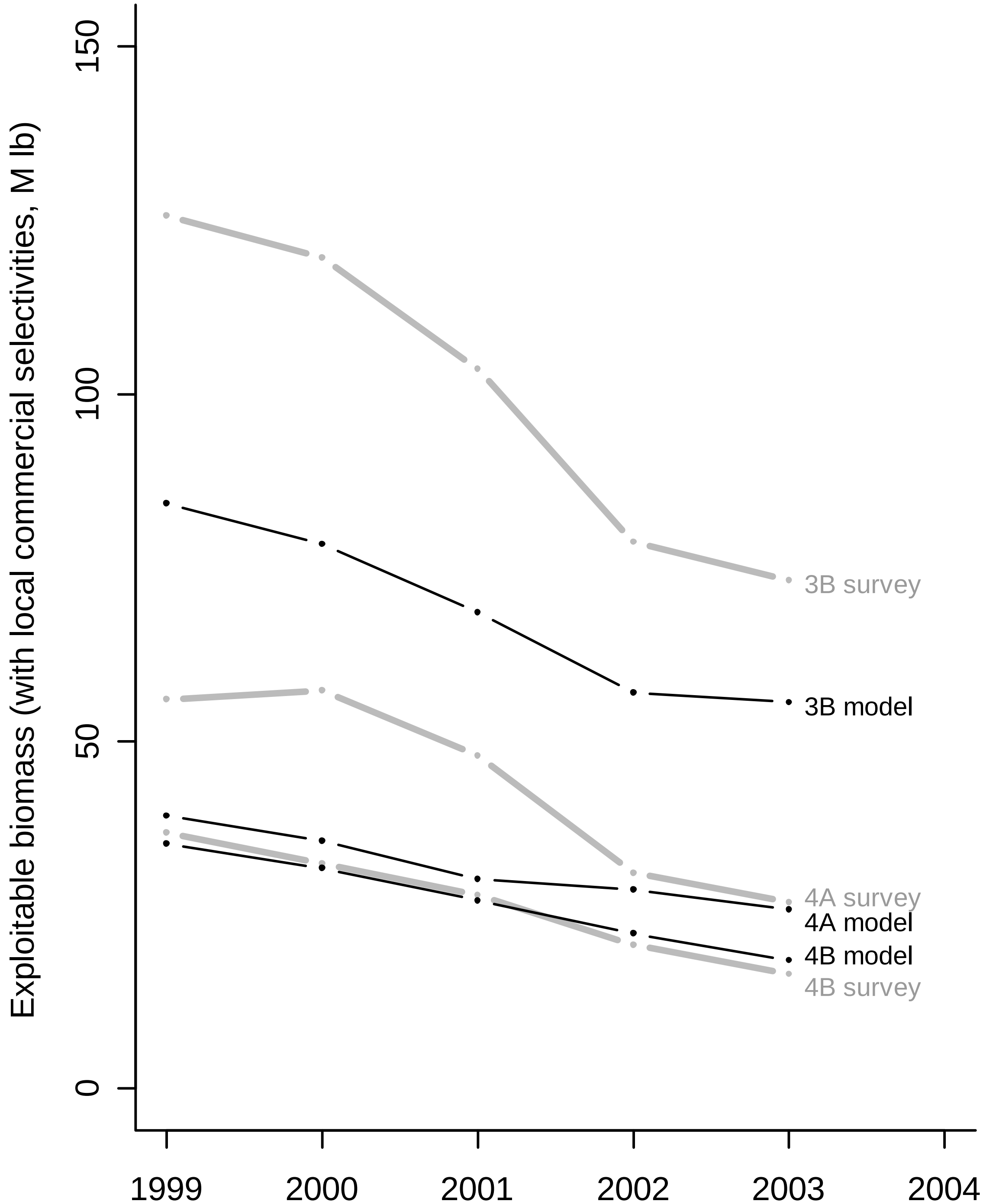


**Figure 11. Comparison of analytical estimates of exploitable biomass in Areas 3B, 4A, and 4B from the 2003 assessment ("model") and survey-based estimates scaled to the estimated exploitable biomass in Area 3A ("survey", also from the 2003 assessment).**

## Appendix A. Selected fishery and survey data summaries.

**Table A1. Commercial catch (million pounds, net weight). Figures include IPHC research catches. Sport catch in Areas 2A and 2B is *not* included in this table.**

| | 2A | 2B | 2C | 3A | 3B | 4 | 4A | 4B | 4C | 4D | 4E | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1974** | 0.52 | 4.62 | 5.60 | 8.19 | 1.67 | 0.71 | --- | --- | --- | --- | --- | 21.3 |
| **1975** | 0.46 | 7.13 | 6.24 | 10.60 | 2.56 | 0.63 | --- | --- | --- | --- | --- | 27.6 |
| **1976** | 0.24 | 7.28 | 5.53 | 11.04 | 2.73 | 0.72 | --- | --- | --- | --- | --- | 27.5 |
| **1977** | 0.21 | 5.43 | 3.19 | 8.64 | 3.19 | 1.22 | --- | --- | --- | --- | --- | 21.8 |
| **1978** | 0.10 | 4.61 | 4.32 | 10.30 | 1.32 | 1.35 | --- | --- | --- | --- | --- | 22.0 |
| **1979** | 0.05 | 4.86 | 4.53 | 11.34 | 0.39 | 1.37 | --- | --- | --- | --- | --- | 22.5 |
| **1980** | 0.02 | 5.65 | 3.24 | 11.97 | 0.28 | 0.71 | --- | --- | --- | --- | --- | 21.8 |
| **1981** | 0.20 | 5.66 | 4.01 | 14.23 | 0.45 | --- | 0.49 | 0.39 | 0.30 | 0.01 | 0.00 | 25.7 |
| **1982** | 0.21 | 5.54 | 3.50 | 13.52 | 4.80 | --- | 1.17 | 0.01 | 0.24 | 0.00 | 0.01 | 29.0 |
| **1983** | 0.26 | 5.44 | 6.38 | 14.14 | 7.75 | --- | 2.50 | 1.34 | 0.42 | 0.15 | 0.01 | 38.3 |
| **1984** | 0.43 | 9.05 | 5.87 | 19.77 | 6.69 | --- | 1.05 | 1.10 | 0.58 | 0.39 | 0.04 | 44.9 |
| **1985** | 0.49 | 10.39 | 9.21 | 20.84 | 10.89 | --- | 1.72 | 1.24 | 0.62 | 0.67 | 0.04 | 56.1 |
| **1986** | 0.58 | 11.22 | 10.61 | 32.80 | 8.82 | --- | 3.38 | 0.26 | 0.69 | 1.22 | 0.04 | 69.6 |
| **1987** | 0.59 | 12.25 | 10.68 | 31.31 | 7.76 | --- | 3.69 | 1.50 | 0.88 | 0.70 | 0.11 | 69.4 |
| **1988** | 0.49 | 12.86 | 11.36 | 37.86 | 7.08 | --- | 1.93 | 1.59 | 0.71 | 0.45 | 0.01 | 74.3 |
| **1989** | 0.47 | 10.43 | 9.53 | 33.74 | 7.84 | --- | 1.02 | 2.65 | 0.57 | 0.67 | 0.01 | 66.9 |
| **1990** | 0.32 | 8.57 | 9.73 | 28.85 | 8.69 | --- | 2.50 | 1.33 | 0.53 | 1.00 | 0.06 | 61.6 |
| **1991** | 0.36 | 7.19 | 8.69 | 22.93 | 11.93 | --- | 2.26 | 1.51 | 0.68 | 1.44 | 0.10 | 57.0 |
| **1992** | 0.44 | 7.63 | 9.82 | 26.78 | 8.62 | --- | 2.70 | 2.32 | 0.79 | 0.73 | 0.07 | 59.8 |
| **1993** | 0.50 | 10.63 | 11.29 | 22.74 | 7.86 | --- | 2.56 | 1.96 | 0.83 | 0.84 | 0.06 | 59.2 |
| **1994** | 0.37 | 9.91 | 10.38 | 24.84 | 3.86 | --- | 1.80 | 2.02 | 0.72 | 0.71 | 0.12 | 54.7 |
| **1995** | 0.30 | 9.62 | 7.77 | 18.34 | 3.12 | --- | 1.62 | 1.68 | 0.67 | 0.64 | 0.13 | 43.8 |
| **1996** | 0.30 | 9.54 | 8.87 | 19.69 | 3.66 | --- | 1.70 | 2.07 | 0.68 | 0.71 | 0.12 | 47.3 |
| **1997** | 0.41 | 12.42 | 9.92 | 24.63 | 9.07 | --- | 2.91 | 3.32 | 1.12 | 1.15 | 0.25 | 65.2 |
| **1998** | 0.46 | 13.17 | 10.20 | 25.70 | 11.16 | --- | 3.42 | 2.90 | 1.26 | 1.31 | 0.19 | 69.7 |
| **1999** | 0.45 | 12.70 | 10.14 | 25.32 | 13.84 | --- | 4.37 | 3.57 | 1.76 | 1.89 | 0.26 | 74.3 |
| **2000** | 0.48 | 10.81 | 8.44 | 19.27 | 15.41 | --- | 5.16 | 4.69 | 1.74 | 1.93 | 0.35 | 68.2 |
| **2001** | 0.68 | 10.29 | 8.40 | 21.54 | 16.34 | --- | 5.01 | 4.47 | 1.65 | 1.84 | 0.48 | 70.7 |
| **2002** | 0.85 | 12.07 | 8.60 | 23.13 | 17.31 | --- | 5.09 | 4.08 | 1.21 | 1.75 | 0.56 | 74.6 |
| **2003** | 0.82 | 11.74 | 8.45 | 22.68 | 17.41 | --- | 4.97 | 3.87 | 0.93 | 1.91 | 0.41 | 73.1 |

**Table A2. Bycatch mortality of legal-sized halibut (80+ cm; in million pounds** net weight).

| | 2A | 2B | 2C | 3A | 3B | 4 | 4A | 4B | 4CDE | Tota |
|---|---|---|---|---|---|---|---|---|---|---|
| **1974** | 0.252 | 0.900 | 0.371 | 4.477 | 2.816 | 1.892 | --- | --- | --- | 10.70 |
| **1975** | 0.252 | 0.902 | 0.451 | 2.610 | 1.661 | 1.097 | --- | --- | --- | 6.97 |
| **1976** | 0.252 | 0.941 | 0.503 | 2.741 | 1.944 | 1.181 | --- | --- | --- | 7.56 |
| **1977** | 0.254 | 0.725 | 0.407 | 3.366 | 1.544 | 1.976 | --- | --- | --- | 8.27 |
| **1978** | 0.253 | 0.551 | 0.213 | 2.441 | 1.308 | 3.400 | --- | --- | --- | 8.16 |
| **1979** | 0.253 | 0.694 | 0.638 | 4.488 | 0.688 | 3.446 | --- | --- | --- | 10.20 |
| **1980** | 0.253 | 0.514 | 0.418 | 4.927 | 0.870 | 5.713 | --- | --- | --- | 12.69 |
| **1981** | 0.252 | 0.533 | 0.403 | 3.989 | 1.096 | 4.369 | --- | --- | --- | 10.64 |
| **1982** | 0.252 | 0.299 | 0.199 | 3.197 | 1.683 | 2.944 | --- | --- | --- | 8.57 |
| **1983** | 0.253 | 0.291 | 0.200 | 2.083 | 1.218 | 2.472 | --- | --- | --- | 6.51 |
| **1984** | 0.252 | 0.516 | 0.211 | 1.508 | 0.919 | 2.291 | --- | --- | --- | 5.69 |
| **1985** | 0.252 | 0.548 | 0.201 | 0.797 | 0.341 | 2.246 | --- | --- | --- | 4.38 |
| **1986** | 0.253 | 0.558 | 0.202 | 0.674 | 0.197 | 2.617 | --- | --- | --- | 4.50 |
| **1987** | 0.253 | 0.793 | 0.202 | 1.588 | 0.396 | 2.674 | --- | --- | --- | 5.90 |
| **1988** | 0.253 | 0.773 | 0.202 | 2.126 | 0.042 | 3.273 | --- | --- | --- | 6.66 |
| **1989** | 0.253 | 0.720 | 0.202 | 1.805 | 0.437 | 1.944 | --- | --- | --- | 5.36 |
| **1990** | 0.253 | 1.029 | 0.674 | 2.633 | 1.215 | --- | 0.625 | 0.335 | 2.385 | 9.14 |
| **1991** | 0.253 | 1.221 | 0.546 | 3.126 | 1.035 | --- | 0.731 | 0.236 | 2.237 | 9.38 |
| **1992** | 0.276 | 1.017 | 0.574 | 2.644 | 1.116 | --- | 0.724 | 0.655 | 1.937 | 8.94 |
| **1993** | 0.276 | 0.651 | 0.333 | 1.919 | 0.466 | --- | 0.140 | 0.479 | 1.407 | 5.67 |
| **1994** | 0.276 | 0.571 | 0.396 | 2.352 | 0.848 | --- | 1.197 | 0.536 | 1.820 | 7.99 |
| **1995** | 0.381 | 0.705 | 0.219 | 1.460 | 0.825 | --- | 1.087 | 0.149 | 2.116 | 6.94 |
| **1996** | 0.473 | 0.166 | 0.233 | 1.403 | 0.960 | --- | 0.594 | 0.459 | 2.991 | 7.27 |
| **1997** | 0.473 | 0.109 | 0.240 | 1.549 | 0.729 | --- | 0.844 | 0.198 | 2.964 | 7.10 |
| **1998** | 0.834 | 0.117 | 0.238 | 1.471 | 0.731 | --- | 1.193 | 0.327 | 2.725 | 7.63 |
| **1999** | 0.761 | 0.107 | 0.230 | 1.283 | 0.743 | --- | 0.909 | 0.336 | 2.642 | 7.01 |
| **2000** | 0.634 | 0.128 | 0.254 | 1.286 | 0.646 | --- | 0.808 | 0.580 | 2.279 | 6.61 |
| **2001** | 0.645 | 0.149 | 0.184 | 1.617 | 0.632 | --- | 0.574 | 0.387 | 2.900 | 7.08 |
| **2002** | 0.286 | 0.152 | 0.166 | 1.073 | 0.719 | --- | 0.534 | 0.196 | 2.735 | 5.86 |
| **2003** | 0.286 | 0.154 | 0.167 | 1.364 | 0.584 | --- | 0.499 | 0.184 | 2.558 | 5.79 |

**Table A3. Commercial CPUE (net pounds per skate).**

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

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E |
|---|---|---|---|---|---|---|---|---|---|---|
| **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 | --- |
| **1985** | 62 | 147 | 370 | 537 | 602 | 333 | 234 | --- | 330 | --- |
| **1986** | 60 | 120 | 302 | 522 | 515 | 265 | --- | 427 | 239 | --- |
| **1987** | 57 | 131 | 260 | 504 | 476 | 341 | 220 | 384 | --- | --- |
| **1988** | 134 | 137 | 281 | 503 | 655 | 453 | 224 | --- | 201 | --- |
| **1989** | 124 | 134 | 258 | 455 | 590 | 409 | 268 | 331 | 384 | --- |
| **1990** | 168 | 175 | 269 | 353 | 484 | 434 | 209 | 288 | 381 | --- |
| **1991** | 158 | 148 | 233 | 319 | 466 | 471 | 329 | 223 | 398 | --- |
| **1992** | 115 | 171 | 230 | 397 | 440 | 372 | 278 | 249 | 412 | --- |
| **1993** | 147 | 208 | 256 | 393 | 514 | 463 | 218 | 257 | 851 | --- |
| **1994** | 93 | 215 | 207 | 353 | 377 | 463 | 198 | 167 | 480 | --- |
| **1995** | 116 | 219 | 234 | 416 | 476 | 349 | 189 | --- | 475 | --- |
| **1996** | 159 | 226 | 238 | 473 | 556 | 515 | 269 | --- | --- | --- |
| **1997** | 226 | 241 | 246 | 458 | 562 | 483 | 275 | 335 | 671 | --- |
| **1998** | 194 | 232 | 236 | 451 | 611 | 525 | 287 | 287 | 627 | --- |
| **1999** | --- | 213 | 199 | 437 | 538 | 500 | 310 | 270 | 535 | --- |
| **2000** | 263 | 229 | 186 | 443 | 577 | 547 | 318 | 223 | 556 | --- |
| **2001** | 169 | 226 | 196 | 469 | 431 | 474 | 270 | 203 | 511 | --- |
| **2002** | 181 | 222 | 244 | 507 | 399 | 402 | 245 | 148 | 503 | --- |
| **2003** | 183 | 240 | 240 | 526 | 356 | 388 | 174 | 100 | 443 | --- |

**Table A4. IPHC setline survey CPUE of legal sized fish in weight (net pounds per skate).**

Figures for Area 2B refer to the Charlotte region only. Figures for all other areas refer to all stations fished. The eastward expansion of the 3A survey in 1996 lowered average CPUE by around 25%; the raw values in the table should not be taken at face value. Similarly the 4A value for 1999 is elevated because the Bering Sea edge in 4A was not fished that year. *No corrections* are applied; J-hook values are raw J-hook catch rates.

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E |
|---|---|---|---|---|---|---|---|---|---|---|
| **J-hook surveys:** | | | | | | | | | | |
| **1974** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1975** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1976** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1977** | --- | 15 | --- | 73 | --- | --- | --- | --- | --- | --- |
| **1978** | --- | 21 | --- | 34 | --- | --- | --- | --- | --- | --- |
| **1979** | --- | --- | --- | 51 | --- | --- | --- | --- | --- | --- |
| **1980** | --- | 28 | --- | 95 | --- | --- | --- | --- | --- | --- |
| **1981** | --- | 18 | --- | 162 | --- | --- | --- | --- | --- | --- |
| **1982** | --- | 21 | 145 | 180 | --- | --- | --- | --- | --- | --- |
| **1983** | --- | 20 | 142 | 147 | --- | --- | --- | --- | --- | --- |
| **1984** | --- | 28 | --- | 217 | --- | --- | --- | --- | --- | --- |
| **C-hook surveys:** | | | | | | | | | | |
| **1984** | --- | 64 | 260 | 446 | --- | --- | --- | --- | --- | --- |
| **1985** | --- | 47 | 260 | 466 | --- | --- | --- | --- | --- | --- |
| **1986** | --- | 42 | 283 | 377 | --- | --- | --- | --- | --- | --- |
| **1987** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1988** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1989** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1990** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1991** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1992** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1993** | --- | 105 | --- | 323 | --- | --- | --- | --- | --- | --- |
| **1994** | --- | --- | --- | 313 | --- | --- | --- | --- | --- | --- |
| **1995** | 29 | 166 | --- | 370 | --- | --- | --- | --- | --- | --- |
| **1996** | --- | 175 | 306 | 317 | 352 | --- | --- | --- | --- | --- |
| **1997** | 35 | 156 | 411 | 331 | 415 | 237 | 282 | 71 | 111 | --- |
| **1998** | --- | 92 | 232 | 281 | 435 | 310 | 216 | --- | --- | --- |
| **1999** | 37 | 95 | 204 | 241 | 438 | 382 | 203 | --- | --- | --- |
| **2000** | --- | 104 | 233 | 272 | 373 | 286 | 216 | --- | 213 | --- |
| **2001** | 41 | 117 | 237 | 256 | 357 | 207 | 171 | --- | 197 | --- |
| **2002** | 33 | 107 | 261 | 299 | 297 | 174 | 119 | --- | 257 | --- |
| **2003** | 22 | 85 | 223 | 229 | 262 | 159 | 104 | --- | 195 | --- |

# Assessment of the Pacific halibut stock at the end of 2002

William G. Clark and Steven R. Hare


## Abstract

This paper reports estimates of halibut abundance and available setline yield in 2003 at a harvest rate of 20%. For the past several years these estimates have been computed by fitting a population model on the assumption of constant age-specific selectivity in IPHC setline surveys, even though size at age has declined further in some areas. Poor retrospective behavior of model fits in Area 3A has put this assumption in doubt. There is also an unexpectedly large number of old fish (20+ years old) in survey and commercial catches, especially in Area 3A, that almost certainly results from a change in age reading practices but nevertheless indicates a real age composition in the stock different from what has been estimated before. Further work is needed to treat these issues fully. For the present, a number of alternative fits have been done that approximately account for the likely effects of changes in selectivity and/or age reading practices. Rounded values at the low end of the range of estimates in each area have been taken as working values for exploitable biomass. Setline CEY is very close to last year's estimate in all areas except 3A, where it is higher.


## Introduction

Each year the IPHC staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). Exploitable biomass in each of IPHC Regulatory Areas 2B, 2C, and 3A is estimated by fitting a detailed population model to the data from that area.

A biological target level for total removals is then calculated by applying a fixed harvest rate—presently 20%—to the estimate of exploitable biomass. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for directed setline catches, called the setline CEY, is calculated by subtracting from the total CEY an estimate of all other removals—sport catches, bycatch of legal-sized fish, wastage of legal-sized fish in the halibut fishery, and fish taken for personal use.

In Areas 3B and 4 exploitation rates were low until very recently and no surveys were done before 1996. For both reasons an analytical assessment is not feasible. Instead, exploitable biomass in those areas relative to that in Area 3A is estimated from recent surveys and the analytical estimate of abundance in Area 3A is scaled accordingly to estimate exploitable biomass in Areas 3B and 4. The same procedure is used to estimate exploitable biomass in Area 2A by scaling the 2B estimate. Total and setline CEY for those areas are then calculated as explained above.

Staff recommendations for catch limits in each area are based on the estimates of setline 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.

## Evolution of assessment methods

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

Beginning in the late 1980s, halibut growth rates in Alaska declined dramatically. As a result, age-specific selectivity decreased. CAGEAN did not allow for that, and by the mid-1990s was seriously underestimating abundance. In effect, it interpreted lower catches as an indication of lower abundance, whereas the real cause was lower selectivity.

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 (Clark and Hare 2001). It retained the option of modeling survey selectivity as a function of mean length at age (observed not predicted), but the production fits have 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.

## Standard assessment results in 2002

### Comparison with last year's estimates

Estimated exploitable biomass in Area 2B at the end of 2002 is 63 M lb, close to last year's estimate (66 M) and consistent with the gradual decline indicated by the model (Fig. 1a). In Area 2C this year's estimate is 15% higher than last year's (61 vs 53 M lb; Fig. 1b) and in Area 3A nearly 30% higher (198 vs 155 M lb; Fig. 1c). To some extent these large increases are the result of higher survey and commercial CPUE in both areas in 2002, but the increases are too large to be explained entirely by that.

### Retrospective pattern in Area 3A

Examination of the retrospective performance of the 3A assessment shows a clear pattern in the last few years. Through 1999 the fits are quite consistent from year to year, with each year's estimates of historical abundance approximately matching the previous year's (Fig. 2, top). Since the 2000 assessment, however, the fits have drifted upward year by year, so that for example the 1997 biomass as estimated in 2002 is now much higher than the 1997 biomass as estimated in 1997 or 1999 (Fig. 2, bottom). This sort of pattern is symptomatic of a change in catchability or selectivity in the stock that is not allowed for in the model, just like what happened to the CAGEAN model fits in the early 1990s. The Area 2B assessment shows no such pattern, and the 2C assessment very little.

We believe the retrospective pattern in Area 3A is the result of the decline in size at age that has occurred over the last two decades. In the mid-1980s the oldest fish in Area 3A (ages 20+, meaning 20 years and older) averaged 189 cm in length (Fig. 3, bottom). At that time, full vulnerability to setline survey gear was reached by about age 14, corresponding to a mean length of 125-130 cm. Since then mean length at age has dropped steadily, and in the last few years even the oldest fish in Area 3A have dropped below a mean length of 120 cm. In Areas 2B and 2C the decline in size at age has been smaller in both absolute and relative terms.

The reappearance of a retrospective pattern in Area 3A is in itself evidence that setline survey selectivity depends at least partly on size and not just age. We also have by now a fairly long series of comparable IPHC setline and NMFS trawl surveys in Area 3A that show good agreement on long-term trends in CPUE at length (Fig. 4, from Clark 2003) during a period when the age composition of all the legal-sized length groups changed dramatically. This strongly indicates that selectivity in both surveys is mainly determined by length not age.

In the mid-1990s it was not clear whether setline survey selectivity should be treated as age-specific or length-specific, and the safe choice was made. That choice was not unwise, but the balance of evidence now appears to be on the other side.

### Excess old fish in Area 3A catches

Both survey and commercial catches in Area 3A contain a large and growing number of old fish (20+ years) in excess of predictions in the standard model fit. The discrepancy is only apparent in the last two years in survey catches, but in the commercial catch it begins in 1998 and by 2002 is very large (Fig. 5). An excess of old fish in the catches is worrisome because it means more fish are surviving to those ages than expected, which in turn means that actual mortality is lower and actual abundance higher than the model estimates. Once again, this feature appears strongly only in the Area 3A assessment, although it is detectable in Area 2C on close inspection.

After considering and rejecting some other possibilities (including highgrading in the commercial fishery), we have concluded that the unexpected increase in old fish in the catches is the result of a recent change in IPHC age reading practices, specifically an increase in the number of otoliths that are aged by breaking and burning rather than by surface reading. It has been known for some time that surface reading underestimates the age of older fish, but IPHC did not switch to breaking and burning because comparisons showed good agreement between surface and break/burn ages through about age 15 and at least in the 1980s and early 1990s there were few older fish in the catches. Beginning in 1994, however, IPHC age readers began breaking and burning otoliths that were difficult to age by surface reading, either because they were old or for some other reason (Forsberg 2001), and beginning in 2002 all otoliths with a surface age of 15 or more were broken and burned, along with all difficult otoliths.

At the same time, there really has been an increase of older fish in the catches as the large year classes spawned since the late 1970s have aged and as fishing mortality on younger fish has decreased as a result of reduced growth. Before the 1990s, the proportion of fish with a surface of 15 or greater was 5-15% in all areas. During the 1990s it rose to almost 25% in Areas 2B and 2C, and to almost 40% in Area 3A. (In Area 3B it was 46% in 2002.)

For both reasons, there was a steady increase in break/burn readings from 1994 on (Fig. 6). In 2002 the proportion of break/burn readings was higher in Area 3A than in 2B and 2C, and it was of course higher in the commercial samples than in the survey samples because the commercial size limit results in a higher proportion of older fish in commercial catches. The gradual increase of break/burn readings therefore explains both the appearance of the excess older fish and the differences among areas, years, and data types (survey/commercial). It is still true that surface and break/burn readings agree quite well through about age 15 (Fig. 7), but there are now many fish older than that in the catches.

## Alternative assessments

This year's results show that the standard assessment has been underestimating abundance, particularly in Area 3A, for two reasons. First, age-specific survey selectivity has declined in the stock but not in the model fits, so recent catch rates actually indicate higher abundance than estimated. Second, the surface ages that constituted the bulk of the data through the 1990s tend to understate survival; hence the excess of old fish in the catches. Actual survival must have been higher than estimated, and therefore abundance as well.

A definitive treatment of both these issues will require an overhaul of our age databases and thorough testing of a new standard model fit. For this year we have conducted a number of alternative assessments that account for the selectivity and aging effects in an approximate way.

**Variable age-specific survey selectivity**

In this fit, age-specific survey catchability is allowed to change in 1993 (when surveys resumed after a 7-year hiatus) and again in 1998. Survey catchability is allowed to change in 1996, as it was anyway in Area 3A to account for the expansion of the survey to the whole area. Thus while the model is still entirely age-structured, the effect of reduced length at age on survey selectivity is incorporated as a change in estimated age-specific selectivity. No allowance is made for the effect of age reading changes.

**Fixed length-specific survey selectivity**

Survey selectivity is treated as an empirical (not parametric) function of smoothed mean length at age in survey catches. A single function is used for all C-hook surveys in each area. No allowance is made for age reading changes.

Interestingly, the length-specific selectivity schedules are not so different among areas as previously estimated (Fig. 8), largely because the Area 2B schedule is more gradual. The implied age-specific selectivities change over time in accordance with the decline in length at age, especially in Area 3A where the estimated vulnerability of the oldest fish (20+) drops to about 60% of the mid-1980s value (Fig. 9).

As further evidence in favor of length rather than age as the more important determinant of selectivity, this fit's retrospective performance is dramatically better than the standard fit's (Fig. 10). There remains some tendency for the last few estimates to drift upward year by year, but the estimates of historical abundance further back do not change substantially. As expected, the biomass estimates are higher—about 250 M lb in 2003 as compared with 200 M in the standard fit.

**Age redistribution**

The effect of the change from surface reading of otoliths to breaking and burning is to shift fish abruptly from younger to older age groups. We allowed for that in an ad hoc model that permits fish aged 12 and above to be redistributed among age groups in each of the years 1993-2001. The redistribution is limited in size and direction, and controlled so that total estimated abundance is not altered. This mechanism introduces a lot of flexibility into the fit, so the abundance estimates are probably not very well determined. What is important is that this model fits the abundance of 20+ fish in the catches quite well; in this fit there is no excess of old fish.

## Estimates of present exploitable biomass

In Area 2B all of the fits give similar estimates of abundance (Table 1). In Areas 2C and 3A there is a range from the standard model fit at the low end to the fixed length-specific fit at the high end, about 25% greater. In view of the preliminary nature of the alternative fits, it seems reasonable and prudent to choose a value at the low end of the range in each area. This has been done by rounding the lowest value in each area to the nearest 5 M lb, and these estimates of exploitable biomass have been used to estimate total and setline CEY for 2003 in Areas 2B, 2C, and 3A.

For the other areas, where there is no analytical assessment, the standard procedure is to compute a survey index of absolute abundance in each area by multiplying the average of the three most recent survey CPUE values by the bottom area between 0 and 300 fm. For example, the Area 2A index is 14% of the 2B index, and 2A exploitable biomass is estimated as 14% of the analytical estimate for Area 2B. Estimates for Areas 3B, 4A, 4B, and 4CDE are similarly calculated from the Area 3A analytical estimate. The Area 2A:2B scaler is the same as last year's, but the scalers for 3B and 4 relative to 3A are all lower than last year (Table 2). In Area 3A a low 1999 value dropped out of the 3-year average and a high 2002 value entered. In Areas 3B, 4A, and 4B, relatively high 1999 values left the 3-year averages and relatively low 2002 values entered. Thus while the estimate of exploitable biomass in Area 3A is about 30% higher this year, the estimates of exploitable biomass in the western areas are little changed from last year. Except for Area 3A, setline CEY estimates for all areas are very close to last year's (Table 3).

## References

Clark, W. G. 2003. Estimates of juvenile halibut abundance and distribution in Area 3 from NMFS trawl surveys. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2002 (this volume).

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Clark, W. G., and Hare, S. R. 2001. Assessment of the Pacific halibut stock in 2000. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2000: 85-118.

Forsberg, J. 2001. Aging manual for Pacific halibut: procedures used at the International Pacific Halibut Commission (IPHC). Int. Pac. Halibut Comm. Tech. Rep. 46.

Sullivan, P. J., Parma, A. M., and Clark, W. G. 1999. The Pacific Halibut stock assessment of 1997. Int. Pac. Halibut Comm. Sci. Rep. 79.

**Table 1. Estimates of exploitable biomass in Areas 2B, 2C, and 3A from various model fits.**

| | Area 2B | | Area 2C | | Area 3A | |
|---|---|---|---|---|---|---|
| **Nature of fit** | **2002** | **2003** | **2002** | **2003** | **2002** | **2003** |
| Constant age-specific survey selectivity (standard fit; last year's assessment) | 66 | 63 | 53 | 61 | 155 | 198 |
| Variable age-specific survey selectivity (additional breaks in 1993 and 1998) | 67 | 63 | 47 | 61 | 180 | 230 |
| Constant length-specific survey selectivity | 70 | 65 | 62 | 76 | 214 | 251 |
| Constant length-specific survey selectivity with age redistribution (1993-2001) | 70 | 64 | 57 | 68 | 193 | 227 |

**Table 2. Scaling factors used to estimate exploitable biomass in other areas, based on bottom areas and average survey CPUE in the last three survey years.**

| | **2001 value** | **2002 value** |
|---|---|---|
| **2A:2B** | 14% | 14% |
| **3B:3A** | 94% | 76% |
| **4A:3A** | 42% | 30% |
| **4B:3A** | 25% | 20% |
| **4CDE:3A** | 47% | 35% |

**Table 3. Removals in 2002 and estimates of CEY in 2003 (millions of net pounds).**

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|
| **2002 setline CEY at 20%** [1,2] | 1.31 | 11.75 | 8.50 | 24.14 | 28.56 | 11.96 | 7.51 | 11.81 | 105.54 |
| **2002 catch limit** [2] | 1.31 | 11.75 | 8.50 | 22.63 | 17.13 | 4.97 | 4.18 | 4.45 | 74.92 |
| **2002 commercial landings** [3] | 0.83 | 12.05 | 8.61 | 22.97 | 17.36 | 5.04 | 4.03 | 3.53 | 74.42 |
| **Other removals** | | | | | | | | | |
| Sport catch | 0.40 | 1.19 | 2.51 | 4.51 | 0.01 | 0.04 | 0.00 | 0.00 | 8.66 |
| Legal-sized bycatch | 0.53 | 0.15 | 0.18 | 1.18 | 0.73 | 0.63 | 0.23 | 3.09 | 6.72 |
| Personal use | 0.00 | 0.30 | 0.17 | 0.07 | 0.02 | 0.09 | 0.00 | 0.08 | 0.73 |
| Legal-sized wastage | 0.00 | 0.04 | 0.03 | 0.02 | 0.05 | 0.02 | 0.01 | 0.01 | 0.18 |
| **Total other removals** | 0.93 | 1.68 | 2.89 | 5.78 | 0.81 | 0.78 | 0.24 | 3.18 | 16.30 |
| **Total removals** | 1.76 | 13.73 | 11.50 | 28.75 | 18.17 | 5.82 | 4.27 | 6.71 | 90.72 |
| **2003 exploitable biomass** [4] | 9.1 | 65 | 60 | 200 | 150 | 60 | 40 | 70 | 655 |
| **2003 total CEY at 20%** | 1.82 | 13.0 | 12.0 | 40.0 | 30.0 | 12.0 | 8.0 | 14.0 | 131 |
| **2003 setline CEY at 20%** | 1.29 | 11.32 | 9.11 | 34.22 | 29.19 | 11.22 | 7.76 | 10.82 | 115 |

Notes:
1. Estimates of 2002 setline CEY (first row) are the figures reported in the 2001 assessment.
2. In Area 2A the setline CEY and catch limit include sport catch and treaty subsistence catch.
3. Commercial landings include research catches, which can result in small overages.
4. The figure in this row is the low end of a range of estimates, rounded to the nearest 5 M lb.

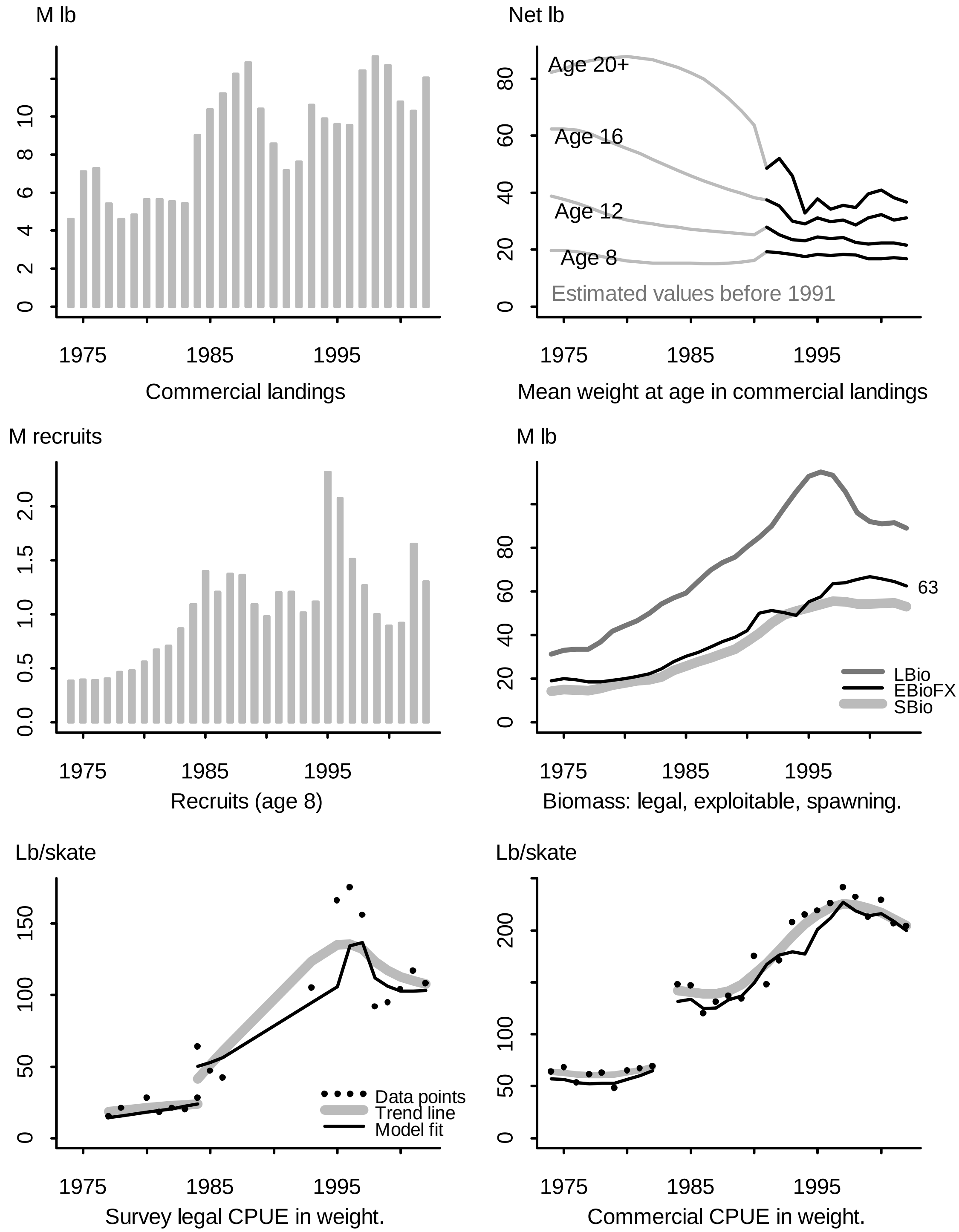


**Figure 1a. Various data and the standard assessment model fit for Area 2B, 1974-2002.**

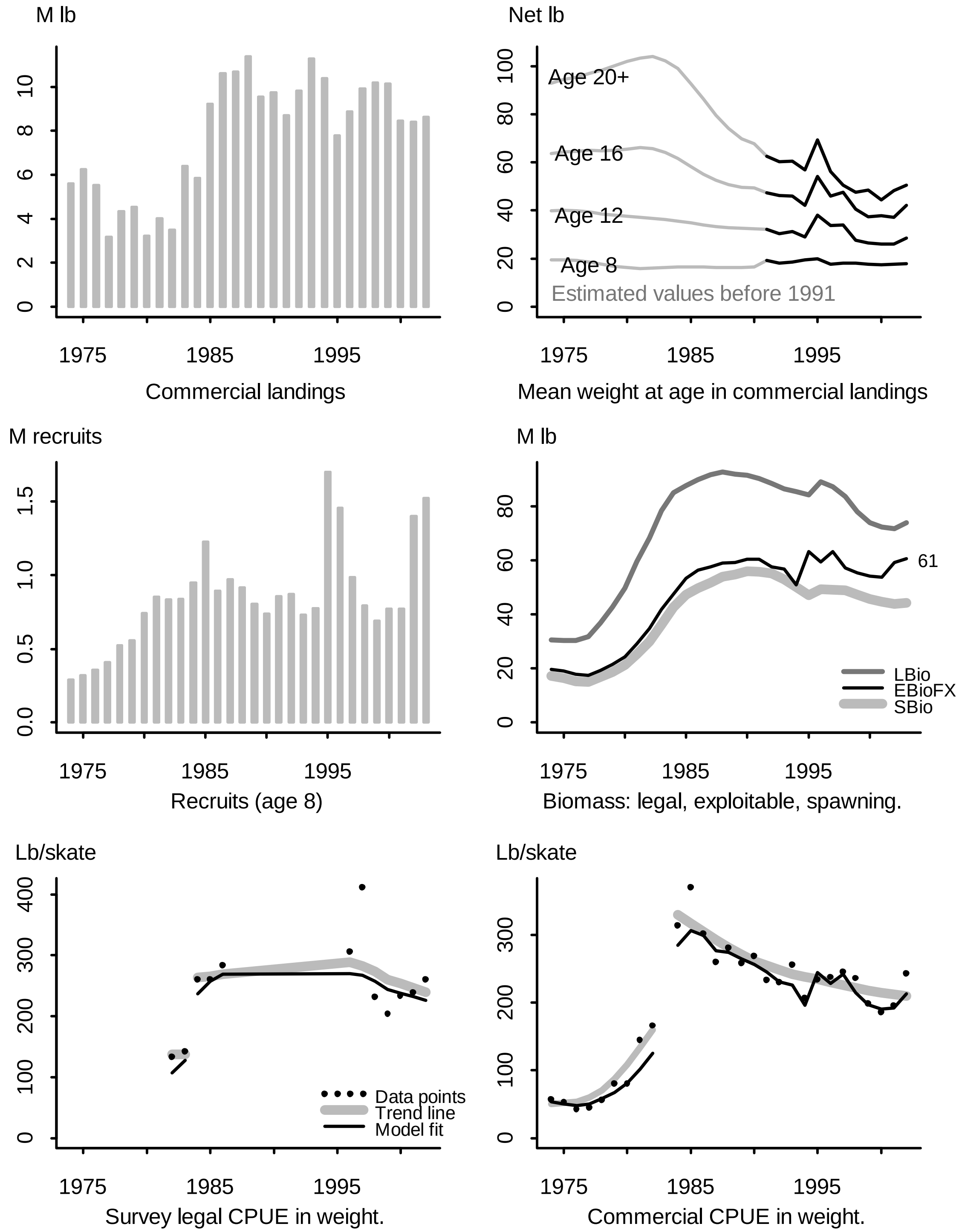


**Figure 1b. Various data and the standard assessment model fit for Area 2C, 1974-2002.**

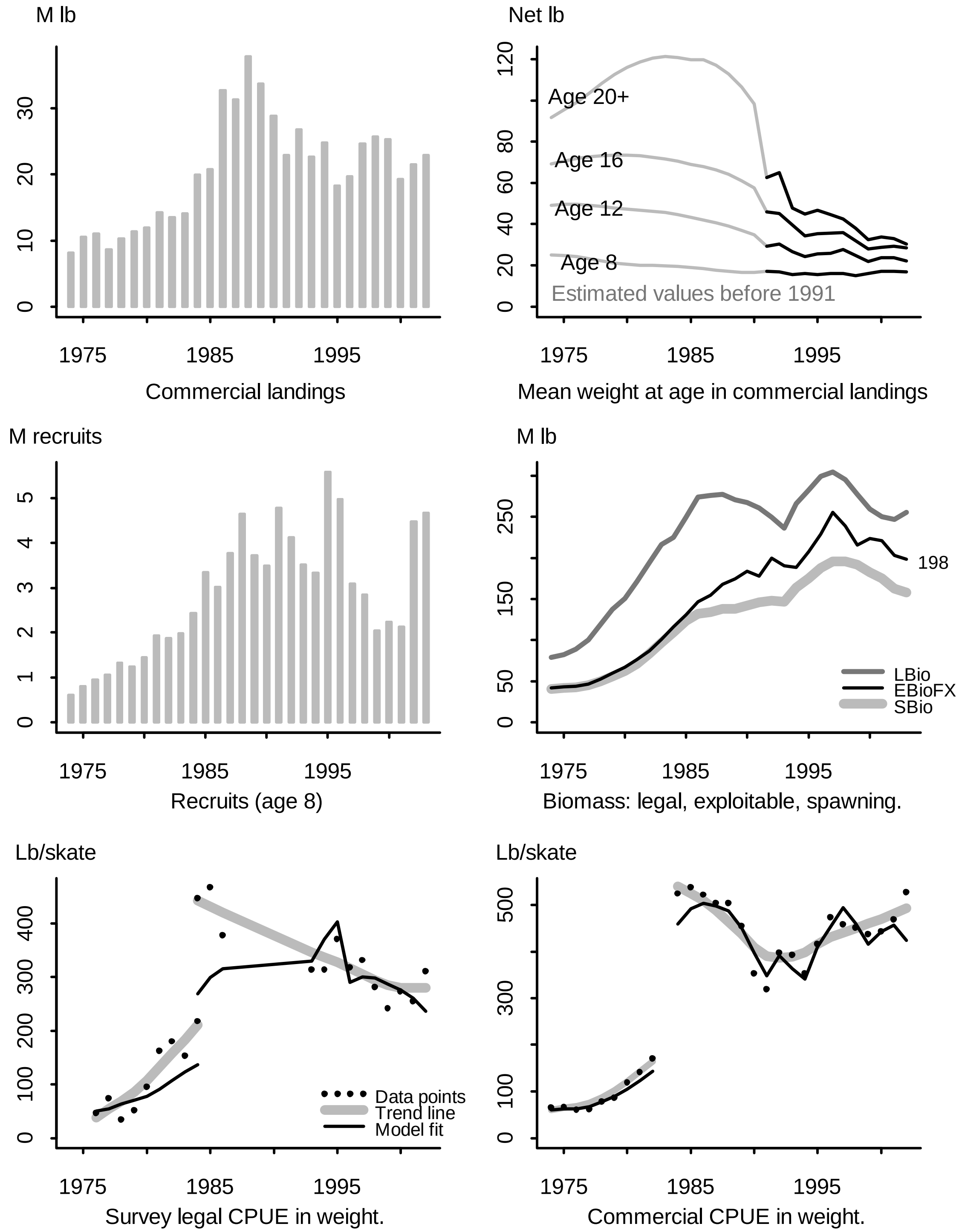


**Figure 1c. Various data and the standard assessment model fit for Area 3A, 1974-2002.**

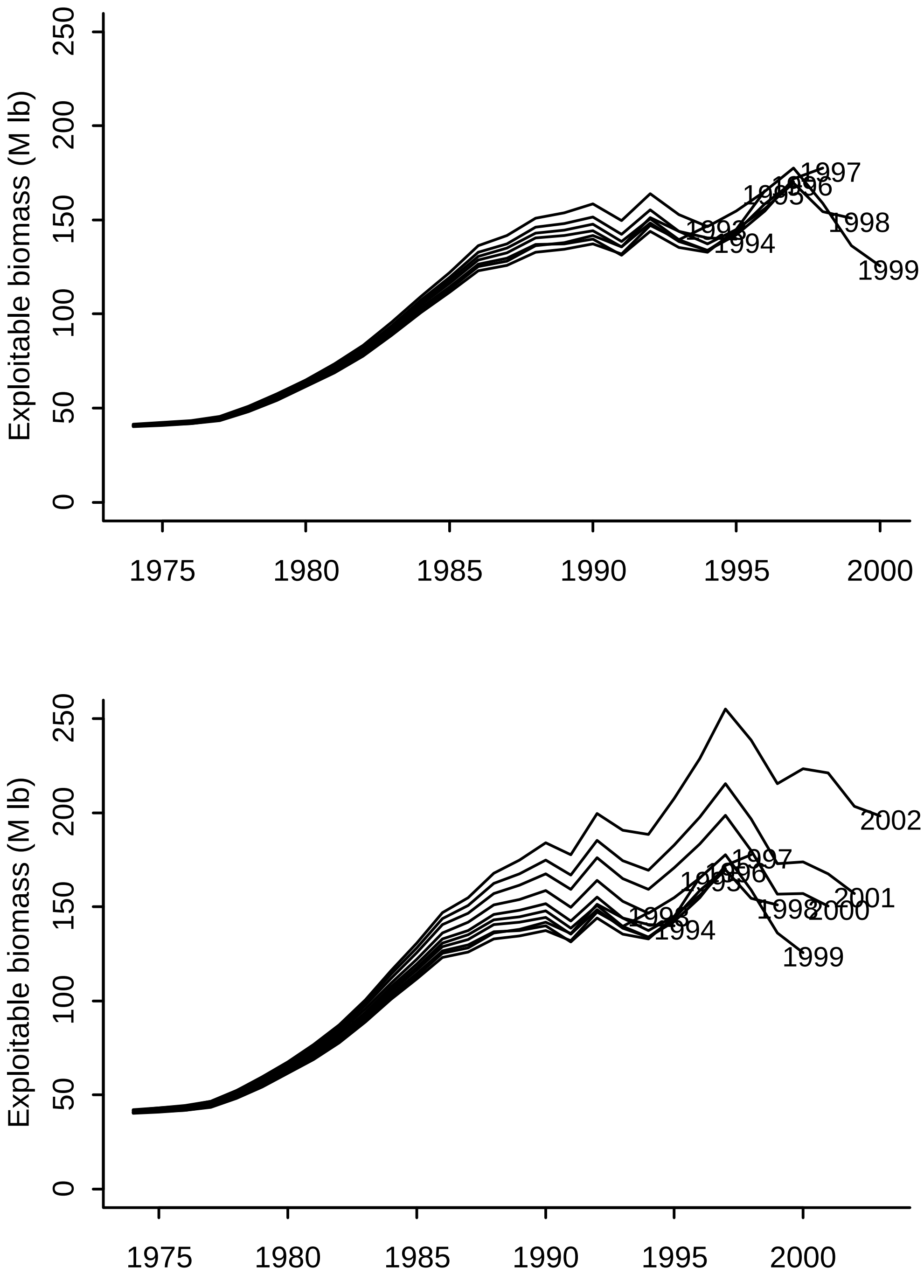


**Figure 2. Retrospective performance of the standard model fit in Area 3A, 1993-1999 (top) and 1993-2002 (bottom). The year shown at the end of each line is the last year in that fit. The 1993-1999 lines are exactly the same in both graphs.**

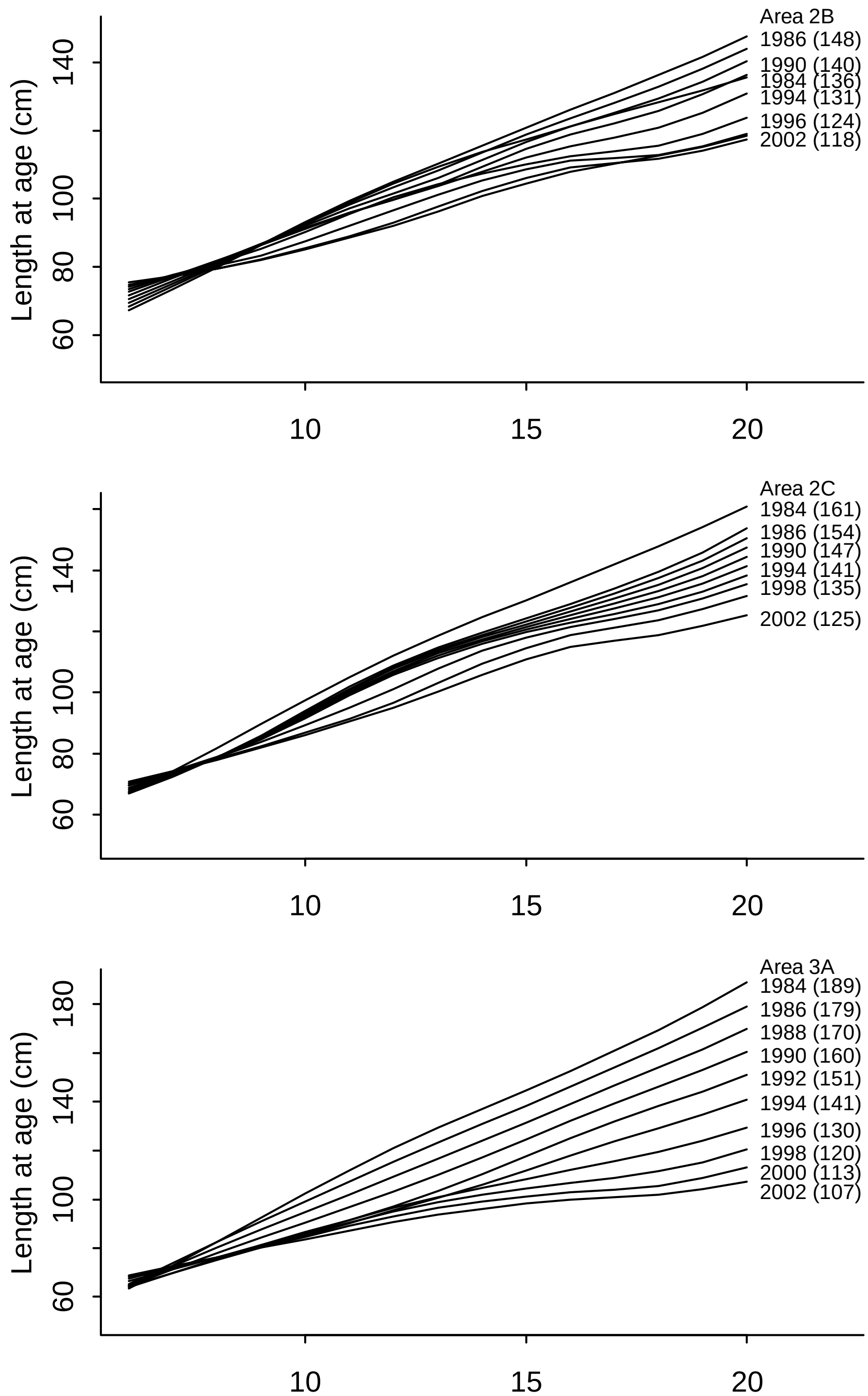


**Figure 3. Survey mean length at age by area going back to the mid-1980s.**

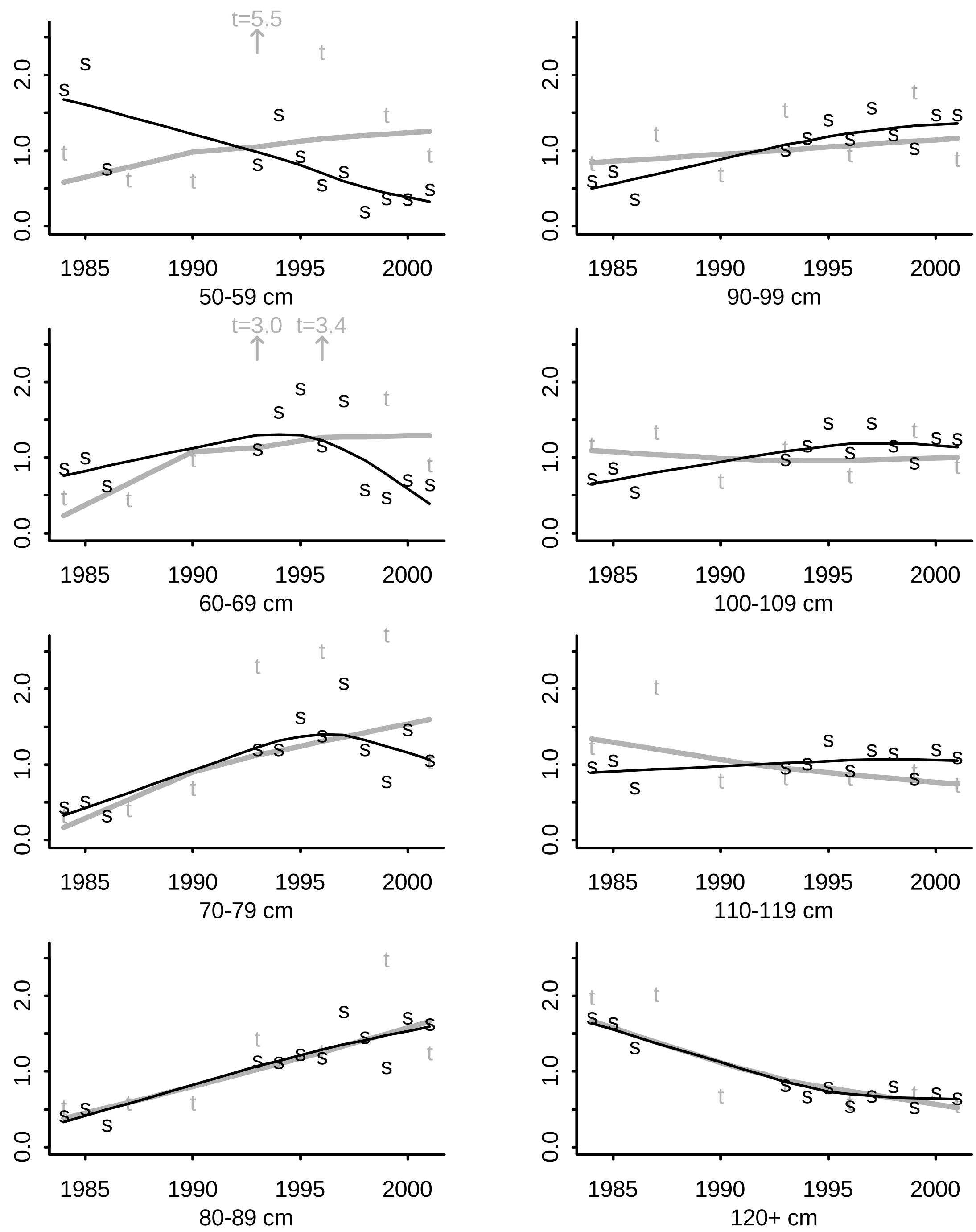


**Figure 4. Trends in setline (s) and trawl (t) survey CPUE at length in Area 3A. (Both series scaled to average 1.0.)**

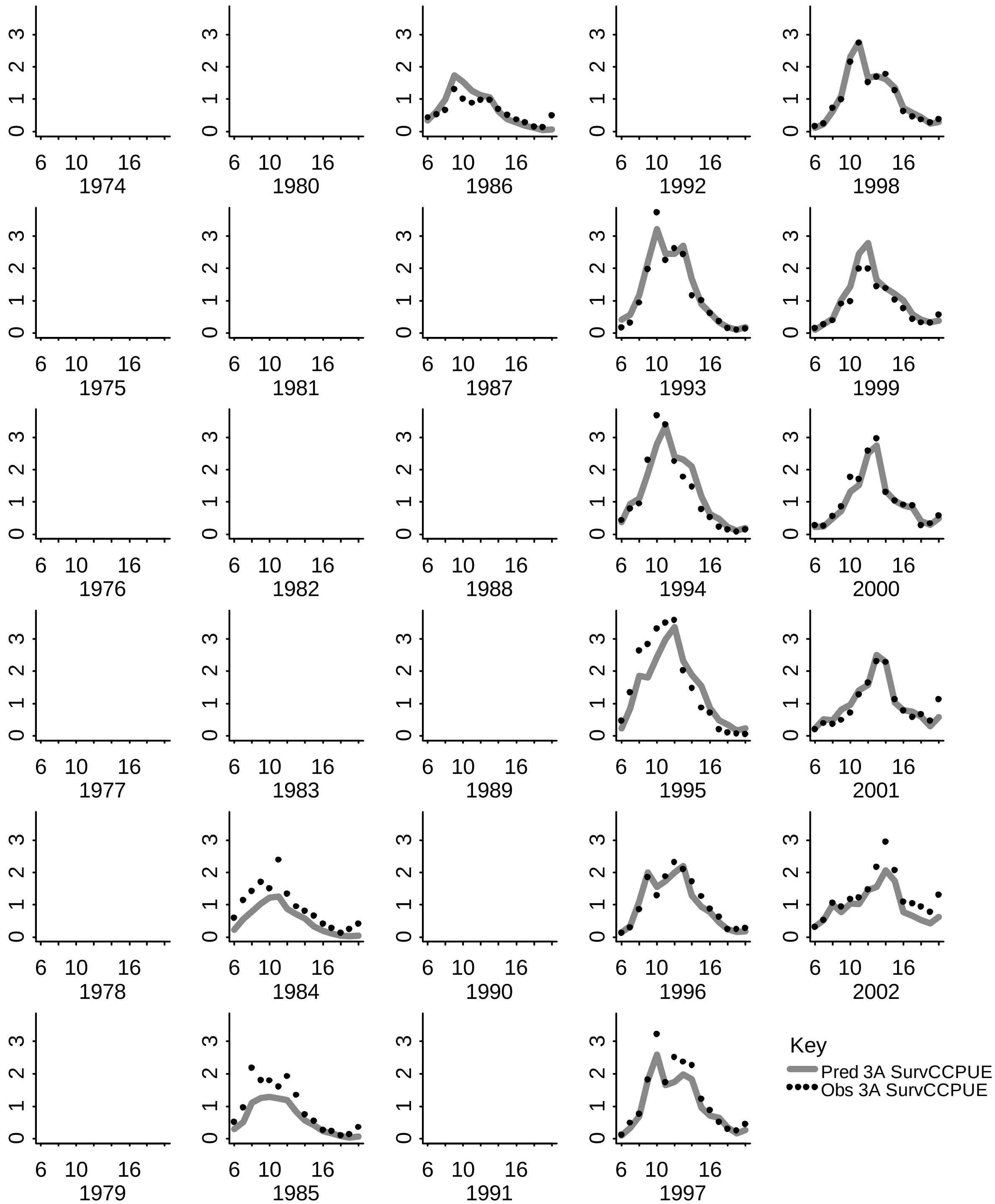


**Figure 5a. Observed and predicted setline survey CPUE at age in Area 3A.**

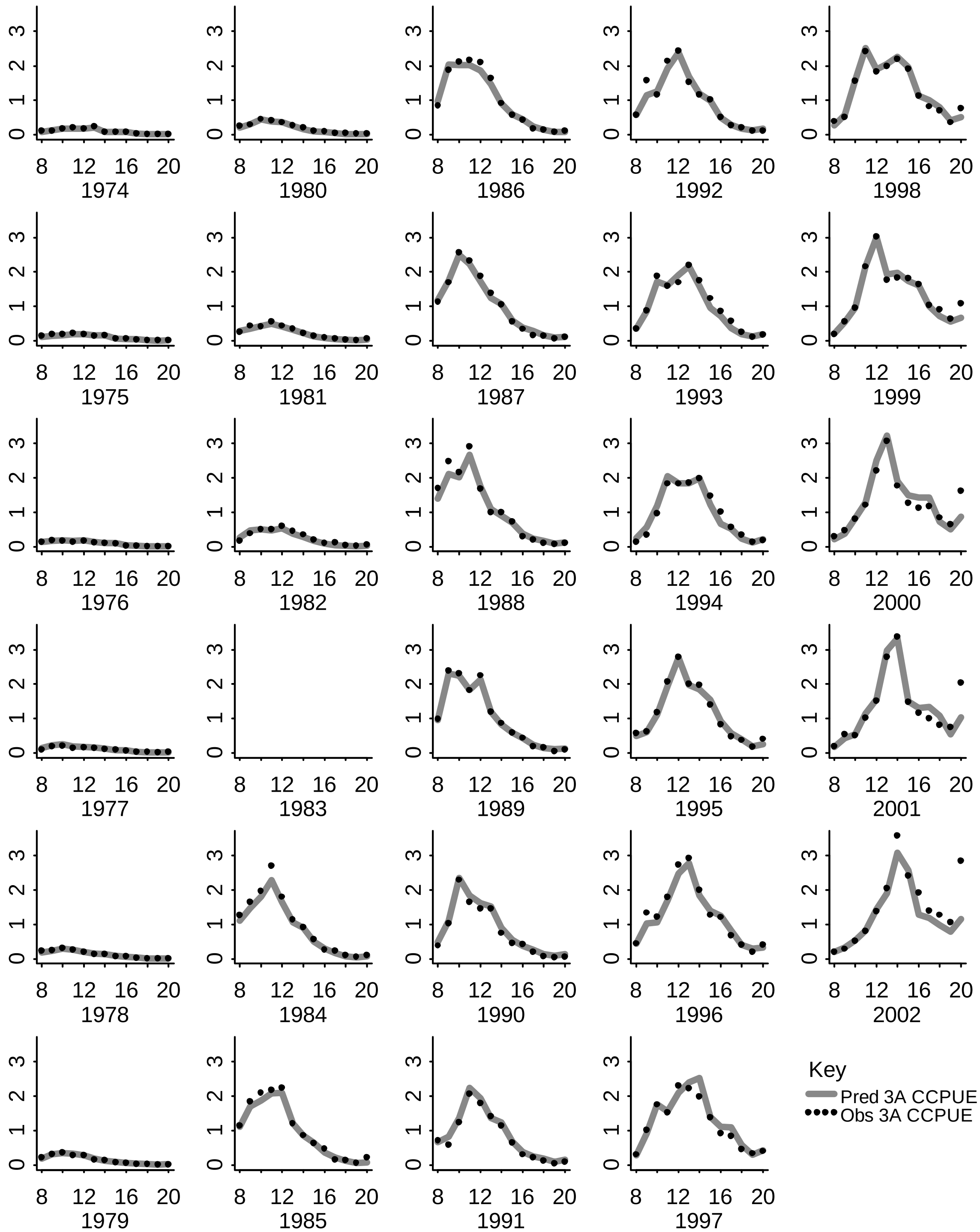


**Figure 5b. Observed and predicted commercial CPUE at age in 3A. Note the excess of fish aged 20+ in the last few years.**

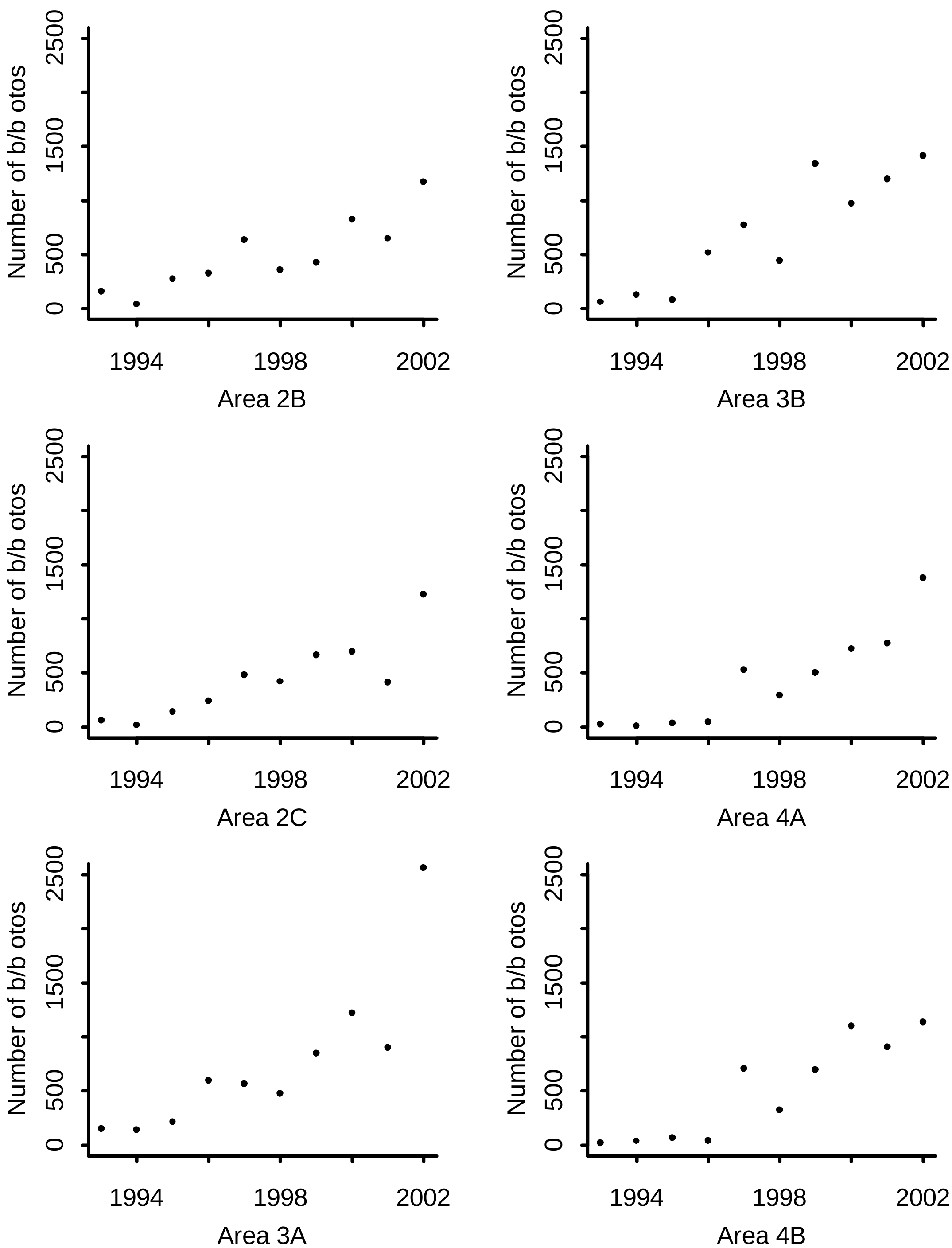


**Figure 6. Number of otoliths broken and burned (b/b) from each area, by year, out of a total of approximately 4000.**

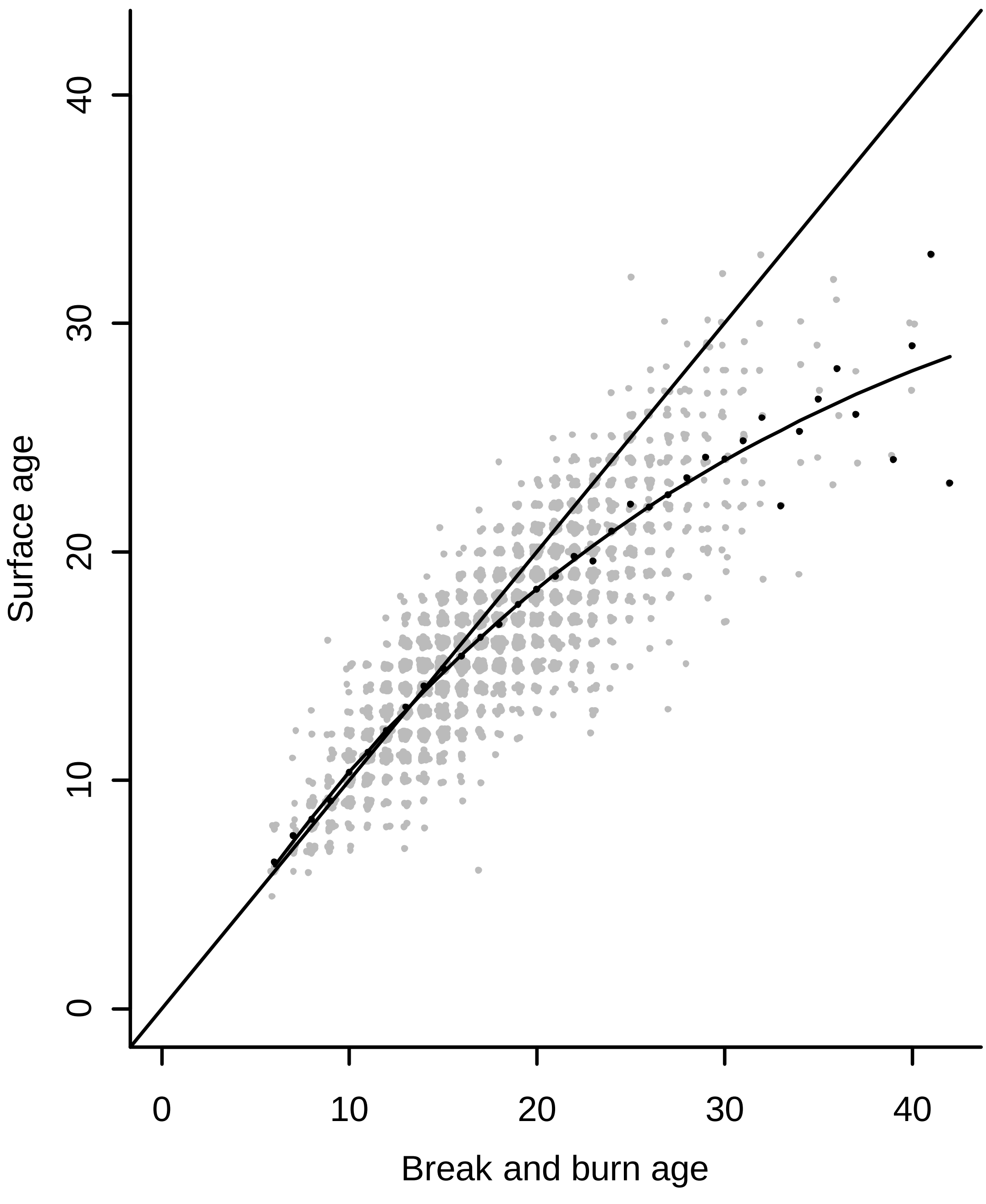


**Figure 7. Surface age plotted against break/burn age for otoliths from the 1990s. Gray points are individual readings (jittered); black points are mean surface age at each break/burn age. Straight line is 1:1; curved line is trend of surface ages.**

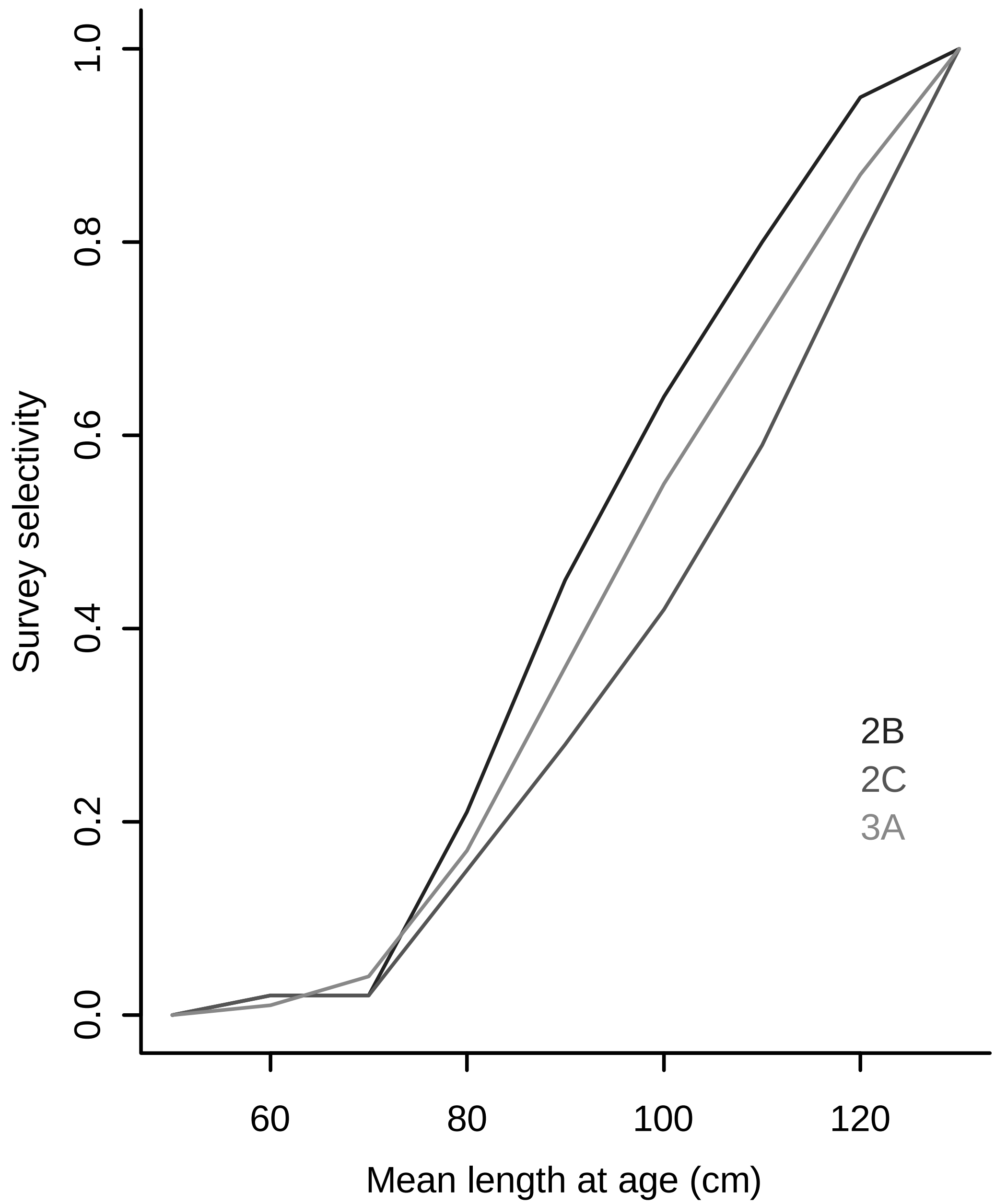


**Figure 8. Estimated length-specific survey selectivity. (Topmost is 2B, then 3A, then 2C.)**

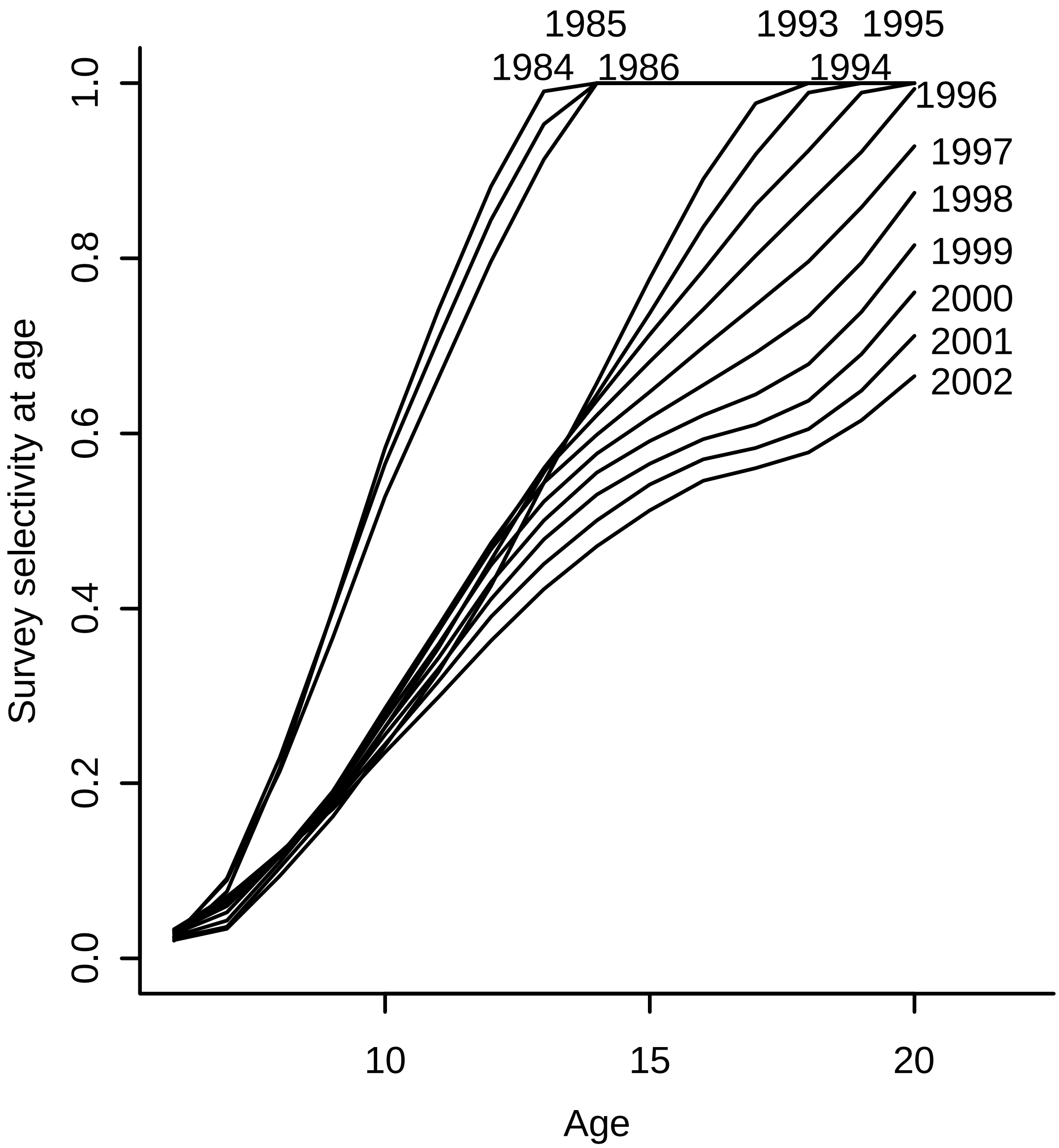


**Figure 9. Setline survey selectivity at age in Area 3A as determined by a fixed length-specific selectivity function and observed decreases in mean length at age over time.**

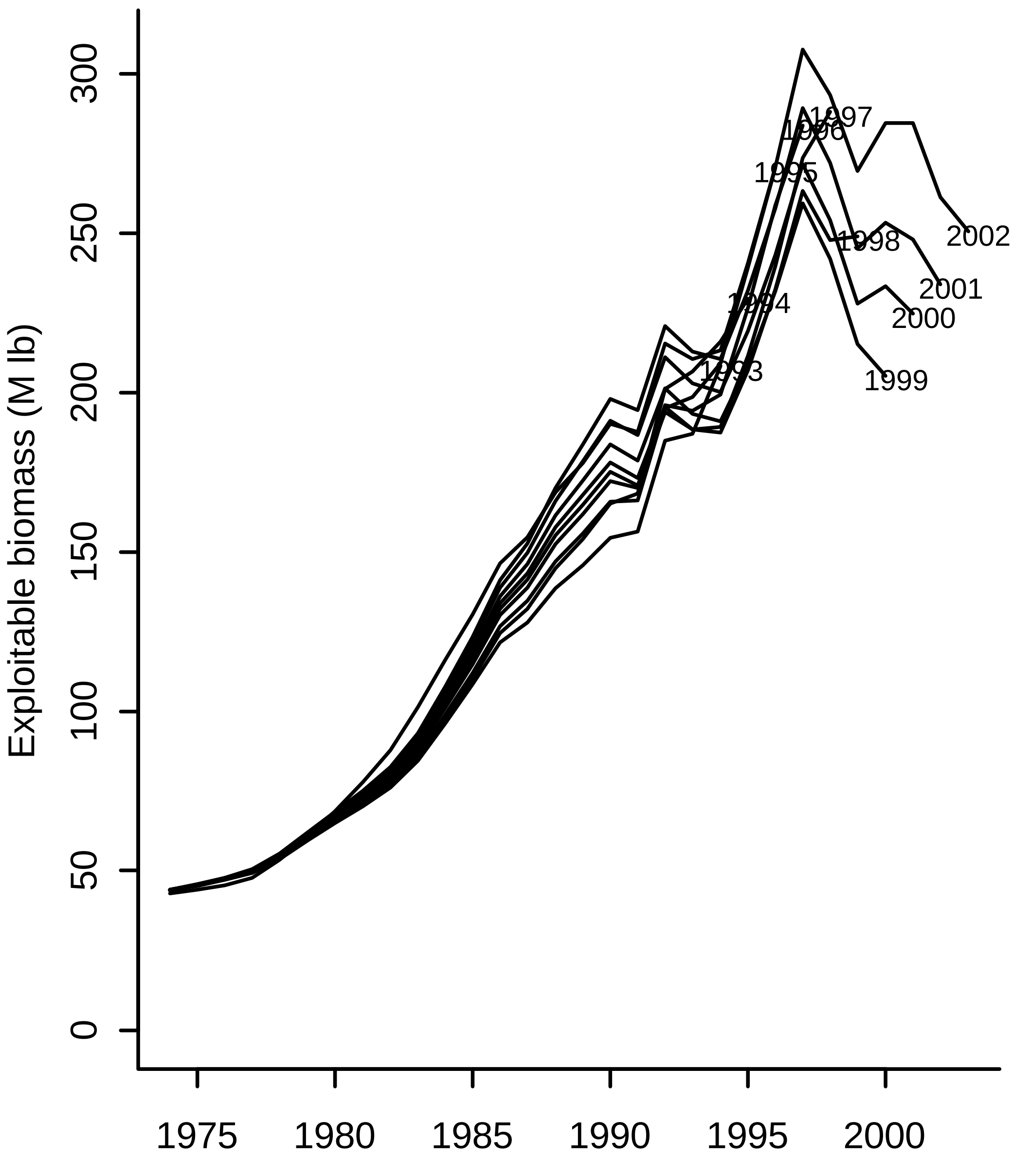


**Figure 10. Retrospective performance in 3A of the fit with fixed length-specific survey selectivity.**

**Appendix A. Selected fishery and survey data summaries.**

**Table A1. Commercial catch (million pounds, net weight). Figures include IPHC research catches. Sport catch in Area 2A is *not* included in this table.**

| | 2A | 2B | 2C | 3A | 3B | 4 | 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 |

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1981** | 0.20 | 5.66 | 4.01 | 14.23 | 0.45 | 0.49 | 0.39 | 0.30 | 0.01 | 0.00 | 25.74 |
| **1982** | 0.21 | 5.54 | 3.50 | 13.52 | 4.80 | 1.17 | 0.01 | 0.24 | 0.00 | 0.01 | 29.01 |
| **1983** | 0.27 | 5.44 | 6.38 | 14.13 | 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 | 11.23 | 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 | 0.09 | 69.45 |
| **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 | 33.73 | 7.84 | 1.02 | 2.65 | 0.57 | 0.67 | 0.01 | 66.95 |
| **1990** | 0.33 | 8.57 | 9.73 | 28.85 | 8.69 | 2.50 | 1.33 | 0.53 | 1.01 | 0.06 | 61.60 |
| **1991** | 0.35 | 7.19 | 8.69 | 22.93 | 11.93 | 2.25 | 1.51 | 0.68 | 1.44 | 0.10 | 57.08 |
| **1992** | 0.43 | 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 | 0.71 | 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 | 9.55 | 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 | 13.83 | 4.37 | 3.57 | 1.76 | 1.89 | 0.26 | 74.31 |
| **2000** | 0.48 | 10.81 | 8.44 | 19.29 | 15.41 | 5.15 | 4.69 | 1.74 | 1.93 | 0.35 | 68.30 |
| **2001** | 0.70 | 10.29 | 8.40 | 21.54 | 16.34 | 5.02 | 4.47 | 1.65 | 1.84 | 0.48 | 70.70 |
| **2002** | 0.81 | 12.05 | 8.61 | 22.97 | 17.36 | 5.04 | 4.03 | 1.19 | 1.79 | 0.55 | 74.40 |

**Table A2. Bycatch mortality of legal-sized halibut (80+ cm; in million pounds net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | Total |
|---|---|---|---|---|---|---|---|
| **1974** | 0.25 | 0.90 | 0.37 | 4.48 | 2.82 | 1.89 | 10.71 |
| **1975** | 0.25 | 0.90 | 0.45 | 2.61 | 1.66 | 1.10 | 6.97 |
| **1976** | 0.25 | 0.94 | 0.50 | 2.74 | 1.94 | 1.18 | 7.56 |
| **1977** | 0.25 | 0.72 | 0.41 | 3.37 | 1.54 | 1.98 | 8.27 |
| **1978** | 0.25 | 0.55 | 0.21 | 2.44 | 1.31 | 3.40 | 8.17 |
| **1979** | 0.25 | 0.69 | 0.64 | 4.49 | 0.69 | 3.45 | 10.21 |
| **1980** | 0.25 | 0.51 | 0.42 | 4.93 | 0.87 | 5.71 | 12.69 |
| **1981** | 0.25 | 0.53 | 0.40 | 3.99 | 1.10 | 4.37 | 10.64 |
| **1982** | 0.25 | 0.30 | 0.20 | 3.20 | 1.68 | 2.94 | 8.57 |
| **1983** | 0.25 | 0.29 | 0.20 | 2.08 | 1.22 | 2.47 | 6.52 |
| **1984** | 0.25 | 0.52 | 0.21 | 1.51 | 0.92 | 2.29 | 5.70 |
| **1985** | 0.25 | 0.55 | 0.20 | 0.80 | 0.34 | 2.25 | 4.38 |
| **1986** | 0.25 | 0.56 | 0.20 | 0.67 | 0.20 | 2.62 | 4.50 |
| **1987** | 0.25 | 0.79 | 0.20 | 1.59 | 0.40 | 2.67 | 5.91 |
| **1988** | 0.25 | 0.77 | 0.20 | 2.13 | 0.04 | 3.27 | 6.67 |
| **1989** | 0.25 | 0.72 | 0.20 | 1.80 | 0.44 | 1.94 | 5.36 |
| **1990** | 0.25 | 1.03 | 0.67 | 2.63 | 1.21 | 4.15 | 9.96 |
| **1991** | 0.25 | 1.22 | 0.55 | 3.13 | 1.04 | 2.92 | 9.10 |
| **1992** | 0.28 | 1.02 | 0.57 | 2.64 | 1.12 | 3.35 | 8.97 |
| **1993** | 0.28 | 0.65 | 0.33 | 1.92 | 0.47 | 2.01 | 5.66 |
| **1994** | 0.28 | 0.57 | 0.40 | 2.35 | 0.85 | 3.48 | 7.93 |
| **1995** | 0.38 | 0.71 | 0.22 | 1.46 | 0.83 | 3.21 | 6.80 |
| **1996** | 0.47 | 0.17 | 0.23 | 1.40 | 0.96 | 3.57 | 6.80 |
| **1997** | 0.47 | 0.11 | 0.24 | 1.55 | 0.73 | 3.80 | 6.90 |
| **1998** | 0.83 | 0.12 | 0.24 | 1.47 | 0.73 | 3.72 | 7.09 |
| **1999** | 0.76 | 0.11 | 0.23 | 1.28 | 0.74 | 3.34 | 6.36 |
| **2000** | 0.63 | 0.13 | 0.25 | 1.29 | 0.65 | 3.23 | 6.09 |
| **2001** | 0.53 | 0.15 | 0.18 | 1.18 | 0.73 | 3.96 | 6.73 |
| **2002** | 0.53 | 0.15 | 0.18 | 1.18 | 0.73 | 3.96 | 6.73 |

**Table A3. Total removals: commercial catch + sport catch + legal-sized wastage + legal-sized bycatch + personal use (millions of pounds net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | 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 | 17.38 | 1.15 | 6.42 | 35.41 |
| **1981** | 0.47 | 6.20 | 4.73 | 18.96 | 1.55 | 5.57 | 37.47 |
| **1982** | 0.51 | 5.87 | 4.19 | 17.44 | 6.48 | 4.38 | 38.88 |
| **1983** | 0.58 | 5.78 | 7.15 | 17.14 | 8.97 | 6.89 | 46.51 |
| **1984** | 0.80 | 9.63 | 6.68 | 22.50 | 7.42 | 5.46 | 52.50 |
| **1985** | 0.94 | 11.30 | 10.31 | 23.79 | 11.43 | 6.69 | 64.45 |
| **1986** | 1.17 | 12.17 | 11.97 | 37.23 | 9.43 | 8.53 | 80.50 |
| **1987** | 1.29 | 13.48 | 12.03 | 36.48 | 8.50 | 9.84 | 81.62 |
| **1988** | 0.99 | 13.93 | 12.85 | 44.76 | 7.24 | 8.07 | 87.85 |
| **1989** | 1.05 | 11.51 | 11.48 | 40.00 | 8.47 | 7.03 | 79.55 |
| **1990** | 0.78 | 10.06 | 11.98 | 36.02 | 10.12 | 9.84 | 78.79 |
| **1991** | 0.77 | 8.83 | 11.95 | 32.42 | 13.46 | 9.49 | 76.92 |
| **1992** | 0.97 | 9.09 | 12.68 | 34.46 | 9.98 | 10.23 | 77.40 |
| **1993** | 1.04 | 12.00 | 13.74 | 30.59 | 8.46 | 8.56 | 74.39 |
| **1994** | 0.83 | 11.18 | 13.11 | 32.86 | 4.83 | 9.12 | 71.93 |
| **1995** | 0.92 | 11.55 | 9.80 | 24.51 | 4.02 | 8.11 | 58.91 |
| **1996** | 1.00 | 10.93 | 11.28 | 26.11 | 4.70 | 9.09 | 63.10 |
| **1997** | 1.25 | 13.75 | 12.37 | 31.86 | 9.92 | 12.79 | 81.94 |
| **1998** | 1.68 | 14.53 | 12.98 | 32.12 | 12.00 | 13.03 | 86.34 |
| **1999** | 1.56 | 14.01 | 12.45 | 31.02 | 14.69 | 15.55 | 89.27 |
| **2000** | 1.47 | 12.29 | 11.16 | 25.97 | 16.15 | 17.41 | 84.46 |
| **2001** | 1.68 | 11.80 | 10.72 | 27.50 | 17.13 | 17.69 | 86.52 |
| **2002** | 1.76 | 13.73 | 11.51 | 28.75 | 18.17 | 16.80 | 90.72 |

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

Values before 1984 are multiplied by the J-C hook correction for catch in weight of legal-sized fish (2.2). 1983 is excluded because it consists of a mixture of J- and C-hook data. No value is shown for area/years after 1980 with fewer than 500 skates of reported catch/effort data.

| | **2A** | **2B** | **2C** | **3A** | **3B** | **4** |
|---|---|---|---|---|---|---|
| **1974** | 131 | 141 | 126 | 142 | 125 | 301 |
| **1975** | 131 | 149 | 117 | 145 | 149 | 211 |
| **1976** | 72 | 117 | 93 | 131 | 142 | 184 |
| **1977** | 182 | 135 | 99 | 135 | 161 | 176 |
| **1978** | 86 | 138 | 124 | 172 | 116 | 167 |
| **1979** | 110 | 106 | 177 | 189 | 81 | 146 |
| **1980** | 82 | 144 | 175 | 261 | 249 | 124 |

| | **2A** | **2B** | **2C** | **3A** | **3B** | **4A** | **4B** | **4C** | **4D** | **4E** |
|---|---|---|---|---|---|---|---|---|---|---|
| **1981** | --- | 147 | 318 | 312 | --- | --- | 217 | 243 | --- | --- |
| **1982** | 47 | 151 | 366 | 375 | 478 | 226 | --- | 199 | --- | --- |
| **1983** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1984** | 63 | 148 | 314 | 524 | 475 | 366 | 161 | --- | 197 | --- |
| **1985** | 62 | 147 | 370 | 536 | 602 | 333 | 234 | --- | 330 | --- |
| **1986** | 60 | 120 | 302 | 522 | 515 | 265 | --- | 427 | 238 | --- |
| **1987** | 57 | 131 | 260 | 504 | 476 | 341 | 220 | 384 | --- | --- |
| **1988** | 134 | 137 | 281 | 503 | 655 | 453 | 224 | --- | 201 | --- |
| **1989** | 124 | 134 | 258 | 455 | 590 | 409 | 268 | 331 | 384 | --- |
| **1990** | 168 | 175 | 269 | 353 | 484 | 434 | 208 | 288 | 381 | --- |
| **1991** | 158 | 148 | 233 | 319 | 466 | 471 | 329 | 223 | 398 | --- |
| **1992** | 115 | 171 | 230 | 397 | 440 | 372 | 278 | 249 | 412 | --- |
| **1993** | 147 | 208 | 256 | 393 | 514 | 463 | 218 | 256 | 851 | --- |
| **1994** | 93 | 215 | 207 | 354 | 377 | 463 | 198 | 167 | 480 | --- |
| **1995** | 116 | 219 | 234 | 416 | 476 | 349 | 189 | --- | 475 | --- |
| **1996** | 159 | 226 | 238 | 473 | 556 | 515 | 269 | --- | --- | --- |
| **1997** | 226 | 241 | 246 | 458 | 562 | 482 | 275 | 335 | 671 | --- |
| **1998** | 194 | 232 | 236 | 451 | 611 | 525 | 287 | 287 | 627 | --- |
| **1999** | 342 | 213 | 199 | 437 | 538 | 498 | 310 | 270 | 535 | --- |
| **2000** | 263 | 227 | 186 | 443 | 577 | 548 | 318 | 223 | 556 | --- |
| **2001** | 169 | 207 | 196 | 469 | 431 | 474 | 270 | 203 | 511 | --- |
| **2002** | 318 | 204 | 243 | 527 | 412 | 395 | 264 | 147 | 471 | --- |

**Table A5. IPHC setline survey CPUE of legal sized fish in weight (net pounds per skate).**

Figures for Area 2B refer to the Charlotte region only. Figures for all other areas refer to all stations fished. This is a change from previous years and the series for Areas 2C, 3A, and 4A have changed as a result. The eastward expansion of the 3A survey in 1996 lowered average CPUE by around 25%; the raw values in the table should not be taken at face value.

Similarly the 4A value for 1999 is elevated because the Bering Sea edge in 4A was not fished that year. *No corrections* are applied; values before 1984 are raw J-hook catch rates.

**J-hook surveys**

| | 2A | 2B | 2C | 3A |
|---|---|---|---|---|
| **1974** | --- | --- | --- | --- |
| **1975** | --- | --- | --- | --- |
| **1976** | --- | --- | --- | --- |
| **1977** | --- | 15 | --- | 73 |
| **1978** | --- | 21 | --- | 34 |
| **1979** | --- | --- | --- | 51 |
| **1980** | --- | 28 | --- | 95 |
| **1981** | --- | 18 | --- | 162 |
| **1982** | --- | 21 | 133 | 180 |
| **1983** | --- | 20 | 142 | 153 |

**C-hook surveys**

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D |
|---|---|---|---|---|---|---|---|---|---|
| **1984** | --- | 64 | 260 | 446 | --- | --- | --- | --- | --- |
| **1985** | --- | 47 | 260 | 466 | --- | --- | --- | --- | --- |
| **1986** | --- | 42 | 283 | 377 | --- | --- | --- | --- | --- |
| **1987** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1988** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1989** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1990** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1991** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1992** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1993** | --- | 105 | --- | 313 | --- | --- | --- | --- | --- |
| **1994** | --- | --- | --- | 313 | --- | --- | --- | --- | --- |
| **1995** | 29 | 166 | --- | 370 | --- | --- | --- | --- | --- |
| **1996** | --- | 175 | 306 | 317 | 352 | --- | --- | --- | --- |
| **1997** | 35 | 156 | 411 | 331 | 415 | 237 | 282 | 71 | 111 |
| **1998** | --- | 92 | 232 | 281 | 436 | 304 | 216 | --- | --- |
| **1999** | 37 | 95 | 204 | 241 | 441 | 367 | 204 | --- | --- |
| **2000** | --- | 104 | 232 | 273 | 378 | 286 | 216 | --- | 213 |
| **2001** | 41 | 117 | 239 | 255 | 365 | 209 | 171 | --- | 201 |
| **2002** | 33 | 108 | 262 | 310 | 304 | 174 | 119 | --- | 263 |

# Assessment of the Pacific halibut stock at the end of 2001

**William G. Clark and Steven R. Hare**

## Abstract

This paper reports estimates of halibut abundance and available setline yield in 2002 at a harvest rate of 20%—about 105 million pounds coastwide, up from 95 million pounds last year. In the past, Areas 2A and 2B were combined for assessment purposes; this year they are treated separately. The analytical assessment in Areas 2C and 3A this year uses all setline survey stations rather than just a standard subarea, resulting in a small decrease in estimated abundance in 2C and a small increase in 3A. An update of survey-based estimates of relative abundance in Area 4 has resulted in a reduction of estimated abundance in Area 4B and an increase in 4CDE.

## Introduction

Each year the IPHC staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). Exploitable biomass in each of IPHC regulatory areas 2B, 2C, and 3A is estimated by fitting a detailed population model to the data from that area.

A biological target level for total removals is then calculated by applying a fixed harvest rate—presently 20%—to the estimate of exploitable biomass. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for directed setline catches, called the setline CEY, is calculated by subtracting from the total CEY an estimate of all other removals—sport catches, bycatch of legal-sized fish, wastage of legal-sized fish in the halibut fishery, and fish taken for personal use.

In Areas 3B and 4 exploitation rates were low until very recently and no surveys were done before 1996. For both reasons an analytical assessment is not feasible. Instead, exploitable biomass in those areas relative to that in Area 3A is estimated from recent surveys and the analytical estimate of abundance in Area 3A is scaled accordingly to estimate exploitable biomass in Areas 3B and 4. Total and setline CEY for those areas are then calculated as explained above. A similar procedure is used to estimate exploitable biomass in Area 2A on the basis of the 2B assessment and survey results.

Staff recommendations for catch limits in each area are based on the estimates of setline 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.

This paper reports the staff's estimates of total abundance, recruitment trends, exploitable biomass, and total and setline CEY by area, as calculated at the end of 2001 for the 2002 fishery.

## Evolution of assessment methods

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

Beginning in the late 1980s, halibut growth rates in Alaska declined dramatically. As a result, age-specific selectivity decreased, particularly for younger fish near the minimum size limit. CAGEAN did not allow for that, and by the mid-1990s was seriously underestimating the strength of incoming year-classes. In effect, it interpreted lower catches of young fish as an indication of lower abundance, whereas the real cause was lower selectivity.

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.

While appropriate in principle, this age-structured model with length-based selectivities resulted in some puzzling fits and poor estimates of historical abundance (Clark and Hare 2001). As a result the staff in the 2000 assessment reverted to a simpler model (the "2000 model") that really is quite similar to CAGEAN. No attempt is made to predict or fit the distribution of size at age, and age-specific selectivities are fundamental model parameters, estimated directly. Commercial catchability and selectivities are allowed to drift slowly. The model structure provides for the possibility of breaks and/or drift in the survey parameters as well, but the staff catch limit recommendations are based on the most parsimonious form of the model, in which survey catchability and selectivity are held constant (except for breaks at the time of conversion from J-hooks to C-hooks).

## Changes in the analytical assessment between 2000 and 2001

The 2000 model was used unchanged in this year's assessment (except for the break in survey catchability in Area 3A, explained below). There were three changes in the input data that resulted in changes in the estimates, and for the first time Area 2B was assessed separately rather than being combined with Area 2A.

### Correction of Area 2AB input data error

In the 2000 assessment the combined Area 2AB assessment model fit was inadvertently run with the Area 2B data file, meaning that the reported Area 2AB abundance estimates in fact reflected only the abundance in Area 2B. The reported (incorrect) estimates were:

| *Reported (incorrect) values* | **Area 2A** | **Area 2B** | **2A+2B** |
|---|---|---|---|
| **2001 exploitable biomass** | 7.34 | 59.36 | 66.71 |
| **2001 total CEY** | 1.47 | 11.87 | 13.34 |
| **2001 setline CEY** | 1.12 | 10.51 | 11.63 |

These are the estimates calculated with the lower of two alternative series of Canadian sport catch estimates, which were the ones that the Commission based its quota decision on. Slightly different values (based on a higher series of sport catch estimates) were reported in last year's assessment tables. The corrected estimates (i.e., the values obtained when the 2000 model is fitted to last year's combined Area 2AB data file with the lower sport catch series) are:

| *Corrected values* | **Area 2A** | **Area 2B** | **2A+2B** |
|---|---|---|---|
| **2001 exploitable biomass** | 7.72 | 62.68 | 70.14 |
| **2001 total CEY** | 1.54 | 12.54 | 14.08 |
| **2001 setline CEY** | 1.19 | 11.18 | 12.37 |

As a result of the data error, the 2AB abundance estimate was low by about 5% last year. The setline CEY estimate was low by about 70,000 pounds in 2A and 700,00 pounds in 2B. Using the correct data file naturally results in an increase of about 5% in the 2A and 2B estimates.

**Separate treatment of Areas 2A and 2B**

Areas 2A and 2B have been combined for assessment purposes since the beginning of model-based analytical assessments in the early 1980s. There is some biological rationale for doing so: clearly there is a seasonal migration of 2A fish between 2B and 2A, and there is some indication from tagging of greater mixing between 2A and 2B than elsewhere. Equally important, though, were the obstacles to performing a standalone 2A assessment: no survey data before 1995, spotty age composition data, uncertainty about the level of bycatch, and sparse and highly variable commercial CPUE data. Combining 2A with 2B effectively swamped these defects in the 2A data.

There is no serious obstacle to doing a standalone 2B assessment. The data for 2B are the best on the coast: a long history of full commercial utilization, good commercial and survey data series, and less change in growth than in Alaska. While there may be some migration of older fish from 2A into 2B, the numbers cannot be large enough to have any practical effect on the analytical estimate of 2B abundance.

Recent surveys have provided a direct measure of the present distribution of biomass between 2A and 2B. The 2B biomass amounted to about 92% of the total in the 1995 and 1997 surveys, and 85% in the 1999 and 2001 surveys.

The analytical estimate of exploitable biomass in 2B is 95% of the analytical estimate for 2A and 2B combined. It is clear from the difference between the analytical estimates and the survey results that the analytical assessment is underestimating abundance in 2A. For management purposes, therefore, it makes most sense to do a standalone assessment of abundance in 2B, and to use that value along with the survey results to estimate present biomass in 2A.

The values that would have appeared in the 2000 assessment following this procedure (when 2A biomass was estimated to be 11% of the 2AB total, equivalent to 12% of the 2B value alone) are:

| *2A and 2B separated* | Area 2A | Area 2B | 2A+2B |
|---|---|---|---|
| **2001 exploitable biomass** | 8.01 | 66.71 | 74.72 |
| **2001 total CEY** | 1.60 | 13.34 | 14.94 |
| **2001 setline CEY** | 1.25 | 11.98 | 13.23 |

Treating 2A and 2B separately increases the biomass estimates for the two areas by about 7%, this on top of the 5% resulting from correcting the data error.

**Use of all survey stations in Area 2C and 3A**

Before 1996, the setline survey in Area 3A only covered the shelf west of 148° W. The eastern part of the shelf was added in 1996, and stations in Shelikof Strait, Cook Inlet, and Prince William Sound in 1998. Until this year, only stations in the western part of 3A surveyed in all years were used in the assessment.

Similarly in Area 2C, only outside stations were used in the assessment even though inside stations were fished in all surveys, because before 1996 the inside stations were distributed purposively on known commercial grounds rather than being placed systematically.

In Area 2B only the northern part has been surveyed consistently. The Vancouver region was surveyed in 1997, 1999, and 2001, but there is no plan to survey it on a regular basis as it accounts for only about 10% of 2B biomass (Clark 2002a).

Using all the survey stations in 3A and 2C provides a more representative and less variable survey index of abundance in those areas. In Area 2C there is no difference between the survey CPUE series based on all stations and the one based on just the outside stations, but in 3A it appears that the stations added in the east generally have a lower CPUE than the stations in the west, so the survey CPUE series based on all stations shows a drop that does not appear in the series based on just the western stations. That feature of the 3A survey data can be accounted for in the assessment by allowing survey catchability to decrease in 1996. The size of the decrease in CPUE due to the survey expansion is estimated to be 22% when the model is fitted.

Using all survey stations in the assessment increases the 2001 biomass estimate by about 7% in 3A (where a catchability change is allowed) but decreases the estimate in 2C (where catchability does not change) by a surprising 15% (Table 1). The reason for this large effect is that in 2C the survey data (either series) while quite noisy show an increase in CPUE between the mid-1980s and the mid-1990s, while the commercial data show a decrease. The trends in the two 2C survey series are the same, but on average the series based on all stations shows only about a 25% increase in abundance between the mid-1980s and the mid-1990s, whereas the series based on just the outside stations shows a 50% increase. Using all stations therefore allows the model fit to agree better with the commercial data and therefore show a larger decrease since the mid-1980s.

In 2C there were fewer surveys than in 2B and 3A, and the survey data are quite variable whereas the commercial CPUE series is complete and very consistent from year to year. Model fits that essentially ignore the survey data produce estimates very close to the value obtained with the survey CPUE series based on all stations, so the lower estimate in 2C appears to be the right one.

**Reweighting of fixed-hook and snap CPUE in Areas 2A and 2B**

In Alaska a substantial part of the catch is still taken with fixed-hook gear, and only fixed-hook CPUE has ever been used in the assessment. In 2A and 2B only about 10% of the catch is taken with fixed-hook gear, and snap CPUE has been used in the assessment for several years. In those areas fixed-hook CPUE has consistently been about a third higher than snap CPUE, and the practice in the assessment has been to compute an average fixed-hook CPUE and an average snap CPUE multiplied by 1.34, and then to use the simple average of those two as the overall commercial CPUE.

The weakness in this method is that it gives equal weight to the two gears even though fixed-hook effort is only a small part of the total. This year the gear-specific CPUE values were weighted in proportion to the gear-specific effort, which should provide a less variable estimate and a consistent CPUE series even if fixed-hook gear continues to fade (Clark 2002c). This change in the CPUE computation has very little effect on the CPUE series or the biomass estimates: the estimate of 2B biomass in 2001 is increased by 1.5% (Table 1).

## Explanation of assessment terms and figures

Fits of the 2001 model in Areas 2B, 2C, and 3A are shown in Figure 1. Estimates of biomass and CEY are in Table 2. These figures are projected forward to the beginning of 2002. Abundance at age 8 in 2002 can be estimated (roughly) because that year-class has been observed in setline survey catches at ages 6 and 7.

The top panels in Figure 1 show historical landings and mean weight at age in the catch. The center left panel shows recruitment at age 8 by year. The center upper right panel shows four measures of biomass: legal-sized (LBio), spawning (SBio), exploitable biomass calculated with internally estimated commercial selectivities that drift over years (EBio or variable ebio), and exploitable biomass calculated with an externally fixed set of selectivities (EBioFX or fixed ebio) that are intermediate between the higher 2AB and lower 3A selectivities. Commercial CPUE should be proportional to EBio; allowable removals are calculated by applying the 20% harvest rate to EBioFX, because the fixed selectivities were the ones used in the simulations that led to the choice of the 20% harvest rate.

The bottom panels show the series of survey and commercial CPUE values, the general trend of the data (a data smoother), and the model predictions. The break in both graphs occurs at the time of conversion from J-hooks to C-hooks. In the standard model survey catchability and selectivity are held constant after 1984 (except for the 1996 break in 3A), but commercial catchability and selectivity are allowed to drift.

## Assessment results for Area 2B

The 2B assessment is quite stable from year to year. As explained above, the estimated biomass in 2B has increased in this year's assessment not because the 2B assessment itself has changed but because a data error was corrected and 2B was assessed separately rather than in combination with 2A.

In last year's assessment the estimates of recent year-class strength in 2B were dismal. Those estimates have now increased; recent year-classes (at age 8) appear to be near average.

## Extrapolation of the Area 2B estimate to Area 2A

Setline surveys were conducted in all of Area 2A and 2B in 1995, 1997, 1999 and 2001. Average CPUE values for all of 2A and all of 2B are shown below. The 2B values are different from those that appear in the assessment tables because they include the Vancouver Island shelf. The proportion of biomass in 2A was calculated from the relative areas: 28.1 thousand square nautical miles in 2B and 12.1 in 2A.

| | CPUE in 2A | CPUE in 2B | Proportion of 2AB biomass in 2A |
|---|---|---|---|
| **1995** | 29 | 144 | 0.08 |
| **1997** | 35 | 158 | 0.09 |
| **1999** | 37 | 88 | 0.15 |
| **2001** | 41 | 102 | 0.15 |

Using the average CPUE from the last three surveys in each area as an estimate of density gives a present estimate of relative abundance in 2A as 12% of the total or equivalently 14% of the 2B biomass.

## Comparison of combined and separate estimates of 2A and 2B biomass

Under the procedure used before this year, abundance in 2A and 2B was estimated by fitting the assessment model to the pooled data and then dividing the estimated total between the two. If that procedure were applied this year, Area 2A would be estimated as 12% of the 2AB total estimate and the results would be as follows:

| *Old method:*<br>*2A = 12% of 2AB estimate* | Area 2A | Area 2B | Area 2AB |
|---|---|---|---|
| **2002 ebio** | 8.62 | 63.24 | 71.86 |
| **Total CEY at 20%** | 1.72 | 12.65 | 14.37 |
| **Setline CEY** | 1.18 | 11.18 | 12.36 |

Under the procedure actually used, the assessment model was fitted to just the Area 2B data to obtain an estimate of 2B abundance, and that was extrapolated to 2A by calculating the 2A estimate as 14% of the 2B estimate. The results (from Table 2) are:

| *New method:*<br>*2A = 14% of 2B estimate* | Area2A | Area 2B | Area 2AB |
|---|---|---|---|
| **2002 ebio** | 9.25 | 66.10 | 75.35 |
| **Total CEY at 20%** | 1.85 | 13.22 | 15.07 |
| **Setline CEY** | 1.31 | 11.75 | 13.06 |

Similar to the comparison reported above for the 2000 assessment, the new procedure results in about a 5% increase in the biomass estimate.

## Assessment results for Area 2C

In 2C the survey and commercial CPUE series are still somewhat discordant, mostly because of the very high survey values in 1996 and 1997. As explained above, the fit agrees with the more consistent commercial series. While the addition of inside survey stations to the assessment this year reduced the biomass estimate, the addition of 2001 commercial and survey data increased the estimate, so that estimated CEY is only slightly lower than last year.

The 1994 year-class is estimated to be very strong in 2C but this is probably an overestimate. Eventually that year-class is likely to be above average but not greatly so, as in 2B and 3A.

## Assessment results for Area 3A

Estimated abundance in 3A increased as a result of the change in survey data (and the associated change in survey catchability in 1996), and the addition of the 2001 data. This estimate has tended to be more variable from year to year than either the 2B or 2C estimate.

The stock in 3A is declining slowly as a series of weak year-classes replaces strong ones. At age 8 all of the year-classes spawned from 1977 through 1988 were above the 1974-1994 mean (by 50% on average), and all of the year-classes spawned between 1989 and 1993 were below the mean. The 1994 year-class, which last year appeared to be as strong as 1988, now appears to be above average but not by a great deal.

## Extrapolation of the Area 3A estimate to Areas 3B and 4

In Areas 3B and 4, exploitation rates were very low until recently and there are no survey data before 1996. Exploitable biomass in those areas is estimated by extrapolating the analytical estimate of abundance in Area 3A to each area on the basis of total bottom area and the average of the last three survey catch rates. Specifically, an index of total biomass in each area (including 3A) is computed as the product of setline survey CPUE and total bottom area. Absolute biomass is then obtained by scaling the absolute 3A estimate by the ratio of the indices. For example, 4A biomass is estimated as the absolute 3A estimate multiplied by the ratio of the 4A to the 3A survey index.

In recent years "total bottom area" was defined as the area between 0 and 500 fm, but in fact the survey only goes down to 275 fm and halibut densities below 300 fm are probably very low in the summer when the surveys are conducted. This year the total bottom area used for calculating the survey-based index was redefined as the area between 0 and 300 fm. In most places the change is inconsequential because there is little bottom area between 300 and 500 fm, but 4B is reduced by about 30% (Table 3, reproduced from Clark 2002b).

Various methods of estimating present density from the time series of survey catch rates were examined, and the average of the last three was found to be best. This is a filtering problem, and the two principal candidate procedures are locally-weighted regression smoothers that attempt to follow the trend of the last few points, and moving averages. The former do not work well on short and noisy series like the setline survey data. The latter do not attempt to determine the local trend and are biased if a trend is present, but up to a certain sample size the reduction in variance outweighs the bias. That optimal sample size depends on the steepness of the trend in the series and the variance of the observations. With trends of 5-10% per year and a coefficient of variation of 10-

20% in the survey results, the optimal sample size was about 5, but a sample of 3 performed nearly as well and would perform better in the event of a large real change in the survey index, so that was adopted.

A setline survey index cannot be computed directly for the eastern Bering Sea shelf (4CDE) because no setline survey is done there. NMFS conducts a trawl survey there every year, and a setline survey CPUE is predicted from the average trawl CPUE and the ratio of setline to trawl CPUE in areas of overlap in 4A and 4D. For the last few years the predicted value was 30 lb/skate (Clark 1998). An update this year (Clark 2002) produced a prediction of 40 lb/skate, which has the effect of increasing the 4CDE scaling factor.

The scaling factors (abundance relative to 3A) used last year and this year are:

| | 3B | 4A | 4B | 4CDE |
|---|---|---|---|---|
| **Factor used in 2000** | 94% | 38% | 37% | 37% |
| **Factor used in 2001** | 94% | 41% | 25% | 47% |

## Recent trends in weight at age

Between the late 1970s and the late 1990s there was a dramatic decrease in the average weight of halibut in commercial landings. At the modal age of 12 years, average weight declined by about 50% in Area 3A and 40% in Area 2B. In recent years weight at age has leveled off in Area 2 and Area 3A, but is still declining farther west (Figure 2).

## References

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Clark, W.G. 2002c. Comparison of fixed-hook and snap-hook CPUE. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2001 (this volume).

Clark, W.G., and S.R. Hare. 2001. Assessment of the Pacific halibut stock in 2000. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2000:85-118.

**Table 1. Changes in analytical biomass estimates due to various changes in assessment data and methods between the 2000 and 2001 assessments. All of the 2000 assessment figures for Area 2AB and 2B are the ones calculated with the higher of two Canadian sport catch series as shown in last year's report. The value shown is exploitable biomass ("ebio") in millions of net pounds.**

| | Area 2AB | Area 2B | Area 2C | Area 3A |
|---|---|---|---|---|
| **2000 assessment estimates of 2001 ebio with preliminary 2000 data:** Estimates of ebio in 2001 as reported in late 2000. *Area 2B estimates were erroneously reported as estimates of abundance in Areas 2A and 2B combined.* | 73.3 | 67.6 | 56.4 | 138.7 |
| **2000 assessment estimates of 2001 ebio with final 2000 data:** The same values computed with final 2000 data. | 72.2 | 66.7 | 56.7 | 140.3 |
| **2000 assessment estimates of 2001 ebio using all 2C and 3A survey stations rather than only standard subareas:** Add 2C inside stations, available in all years, and eastern and northern 3A stations added in 1996. Allow a change in survey catchability in 3A in 1996 but not in 2C. | No effect | No effect | 48.3 | 150.4 |
| **2000 assessment estimates of 2001 ebio with 2AB CPUE reweighted:** Give equal weight to fixed-hook and scaled snap-hook effort. Continue to use only fixed-hook effort in Alaska. | 73.5 | 67.7 | No effect | No effect |
| **2001 assessment estimates of 2001 ebio:** Estimates of ebio in 2001 with 2001 commercial and survey data added to the fit. | 74.3 | 69.0 | 52.3 | 166.3 |
| **2001 assessment estimates of 2002 ebio:** Estimates of ebio in 2002 from the same fits, still using the higher (mail survey) estimates of B.C. sport catches. | 72.4 | 67.9 | 53.3 | 154.8 |
| **2001 assessment estimates of 2002 ebio using the lower B.C. sport catch series:** Estimates of ebio in 2002 using the lower estimates of B.C. sport catch. | 70.5 | 66.1 | No effect | No effect |

**Table 2. Removals in 2001 and estimates of CEY in 2002 (millions of net pounds).**

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|
| **2001 setline CEY at 20%** [1] | 1.14 | 10.51 | 8.78 | 21.89 | 25.46 | 9.82 | 10.06 | 7.63 | 95.29 |
| **2001 catch limit** | 1.14 | 10.51 | 8.78 | 21.89 | 16.53 | 4.97 | 4.91 | 4.45 | 73.18 |
| **2001 commercial landings** [2] | 1.15 | 10.10 | 8.40 | 21.94 | 16.55 | 4.98 | 4.48 | 4.07 | 71.67 |
| **Other removals** | | | | | | | | | |
| Sport catch (except 2A) [3] | --- | 1.02 | 1.73 | 5.02 | 0.01 | 0.08 | 0.00 | 0.00 | 7.86 |
| Legal-sized bycatch | 0.54 | 0.11 | 0.22 | 1.70 | 0.48 | 0.54 | 0.20 | 2.64 | 6.43 |
| Personal use | 0.00 | 0.30 | 0.17 | 0.07 | 0.02 | 0.09 | 0.00 | 0.08 | 0.73 |
| Legal-sized wastage | 0.00 | 0.04 | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.23 |
| **Total other removals** | 0.54 | 1.47 | 2.16 | 6.82 | 0.54 | 0.74 | 0.23 | 2.75 | 15.25 |
| **Total removals** | 1.69 | 11.57 | 10.56 | 28.76 | 17.09 | 5.72 | 4.71 | 6.82 | 86.92 |
| **2002 exploitable biomass** [4] | 9.25 | 66.10 | 53.30 | 154.80 | 145.50 | 63.50 | 38.70 | 72.80 | 603.95 |
| **2002 total CEY at 20%** | 1.85 | 13.22 | 10.66 | 30.96 | 29.10 | 12.70 | 7.74 | 14.56 | 120.79 |
| **2002 setline CEY at 20%** [5] | 1.31 | 11.75 | 8.50 | 24.14 | 28.56 | 11.96 | 7.51 | 11.81 | 105.54 |

Notes:

1. Estimates of 2001 setline CEY (first row) are the figures reported in the 2000 assessment. The value shown for Area 2B is the one calculated with the lower estimates of Canadian sport catch.

2. Figures for commercial landings in the second row include research catches, which are the reason for the small overages in some areas.

3. In Area 2A only, the 2001 catch limit, 2001 commercial landings, and 2002 setline CEY include sport catch and treaty subsistence catch. The figure for "total other removals" does not include sport catch. The breakdown of commercial and sport catches in 2A in 2001 was: treaty commercial 0.412 million pounds, non-treaty commercial 0.264, research 0.017, sport 0.441, treaty subsistence 0.02.

4. Area 2A ebio is calculated as 14% of the 2B ebio.

5. In Area 2B, the results are based on the lower of two alternative series of sport catch estimates. The higher sport catch estimates produce an estimate of exploitable biomass in 2B in 2002 of 67.9 M lb (vs 66.1). At a 20% harvest rate, setline CEY is 11.55 M lb in 2B (vs 11.75).

**Table 3. Bottom areas (thousand square nautical miles), recent setline survey CPUE (pounds/skate), and relative exploitable biomass by regulatory area. Area 2A does not include California. The Closed Area is included in Area 4CDE.**

| .Area | Bottom area 0-500 fm | Bottom area 0-300 fm | Setline CPUE (average of last 3 survey years) | Exploitable biomass relative to Area 3A | Proportion of coastwide biomass |
|---|---|---|---|---|---|
| **2A** | 14.1 | 12.1 | 38 | 0.04 | 0.01 |
| **2B** | 29.7 | 28.1 | 117 | 0.26 | 0.07 |
| **2C** | 16.1 | 15.0 | 225 | 0.27 | 0.07 |
| **3A** | 51.2 | 49.5 | 256 | 1.00 | 0.28 |
| **3B** | 31.8 | 30.2 | 395 | 0.94 | 0.26 |
| **4A** | 21.6 | 18.5 | 339 | 0.41 | 0.11 |
| **4B** | 23.2 | 16.2 | 197 | 0.25 | 0.07 |
| **4D edge** | 5.0 | 5.0 | 175 | 0.07 | 0.02 |
| **4CDE shelf** | 120.0 | 120.0 | 42 | 0.40 | 0.11 |

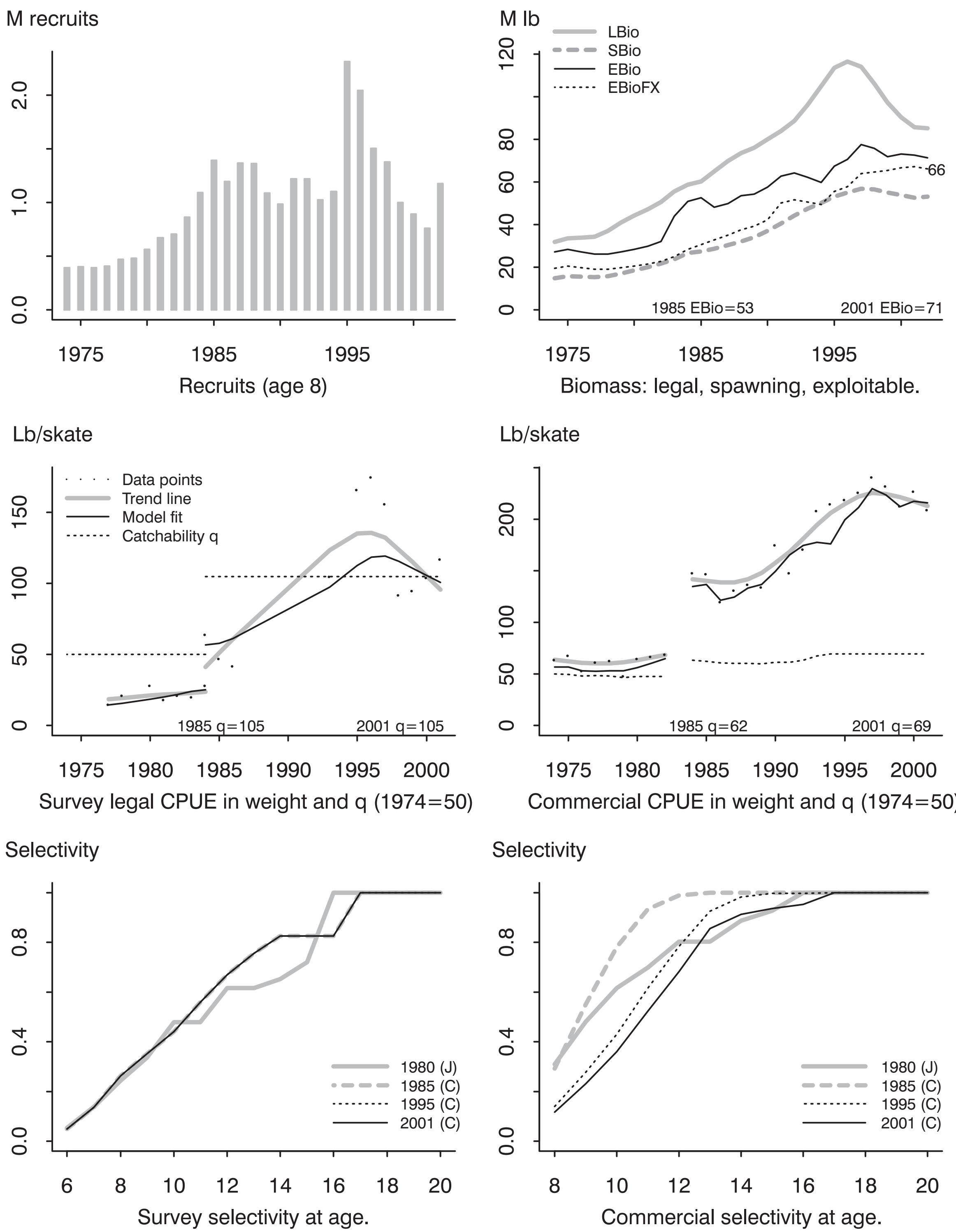



**Figure 1a. Features of the assessment data and standard model fit in Area 2B.**

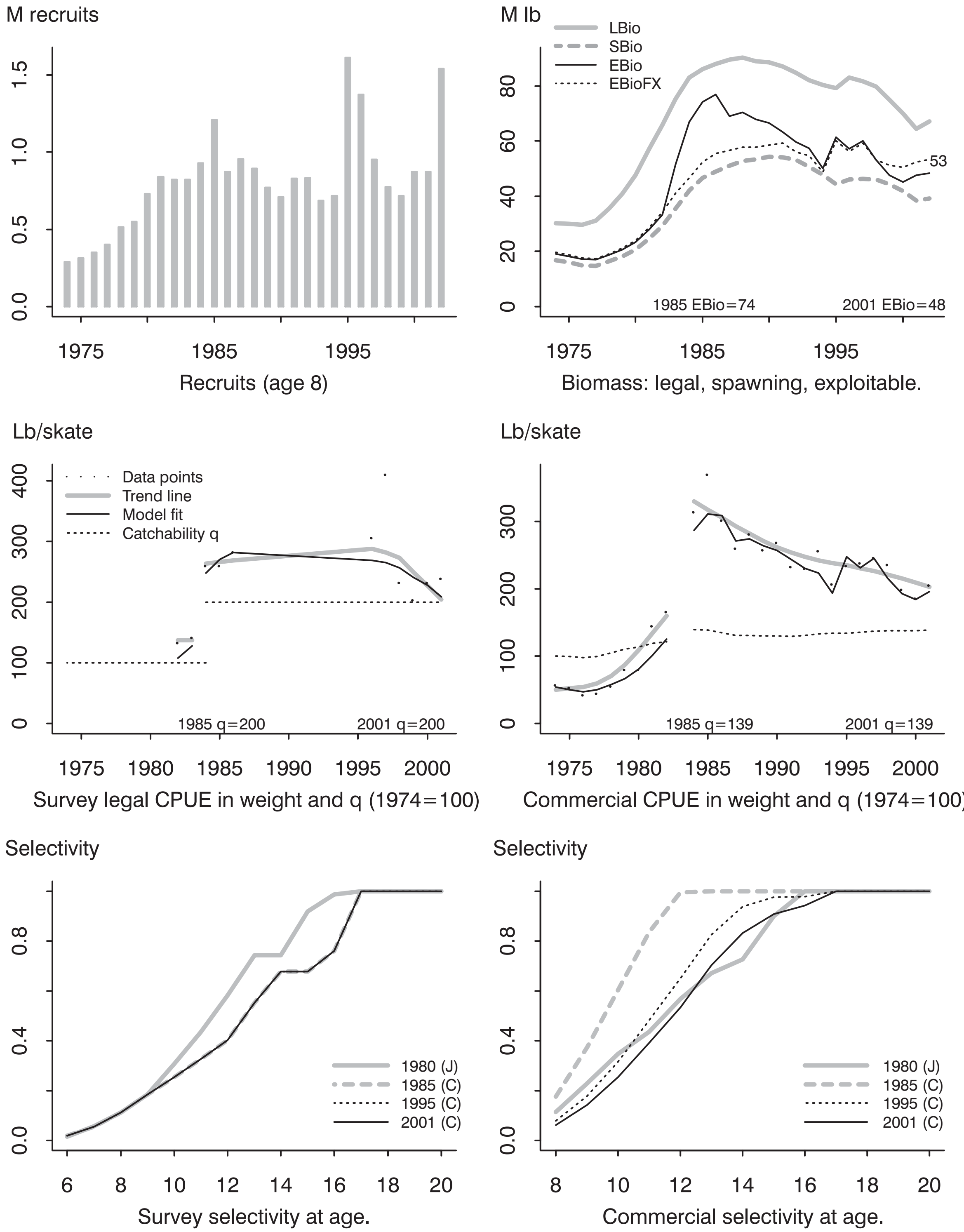



**Figure 1b. Features of the assessment data and standard model fit in Area 2C.**

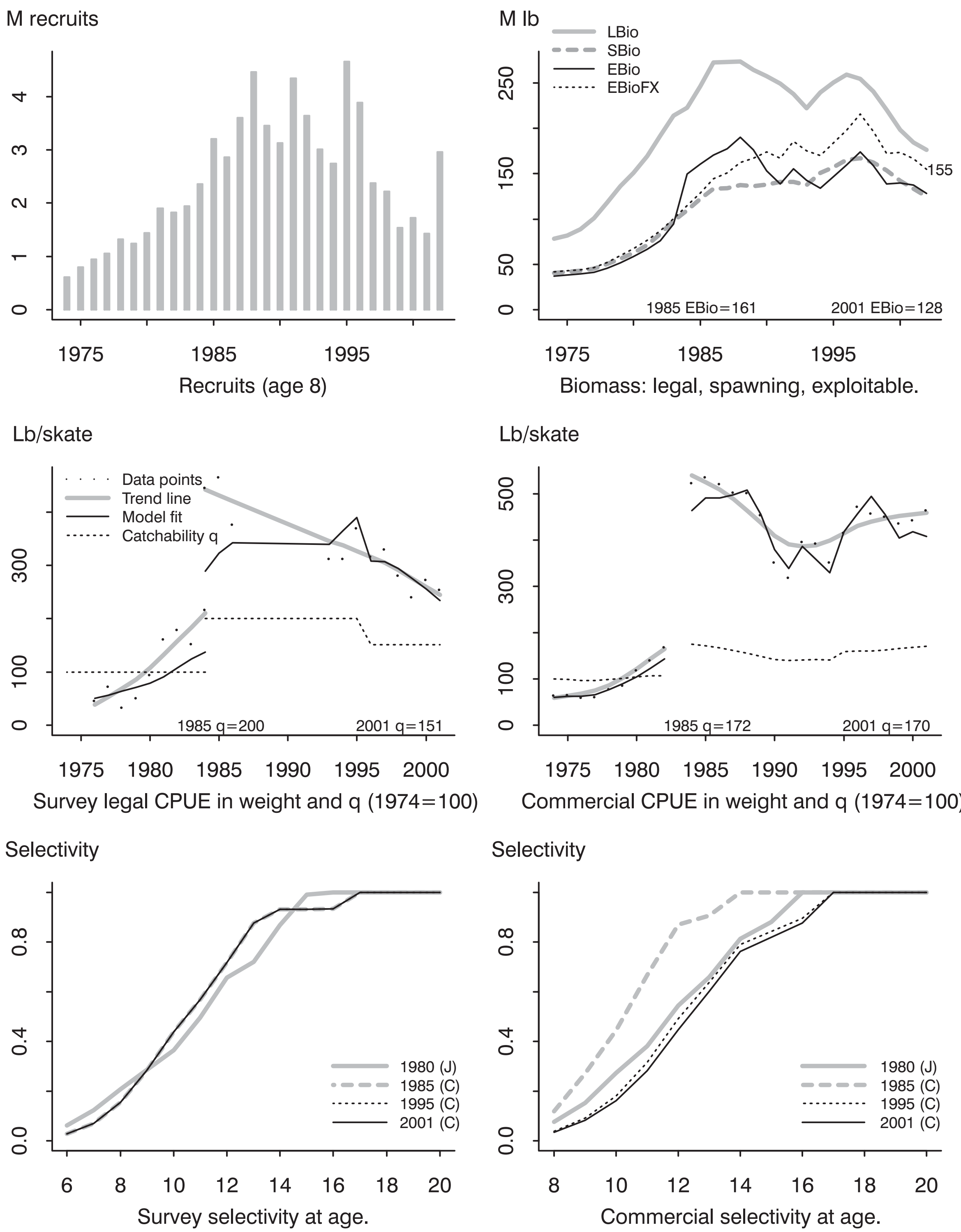



**Figure 1c. Features of the assessment data and standard model fit in Area 3A.**

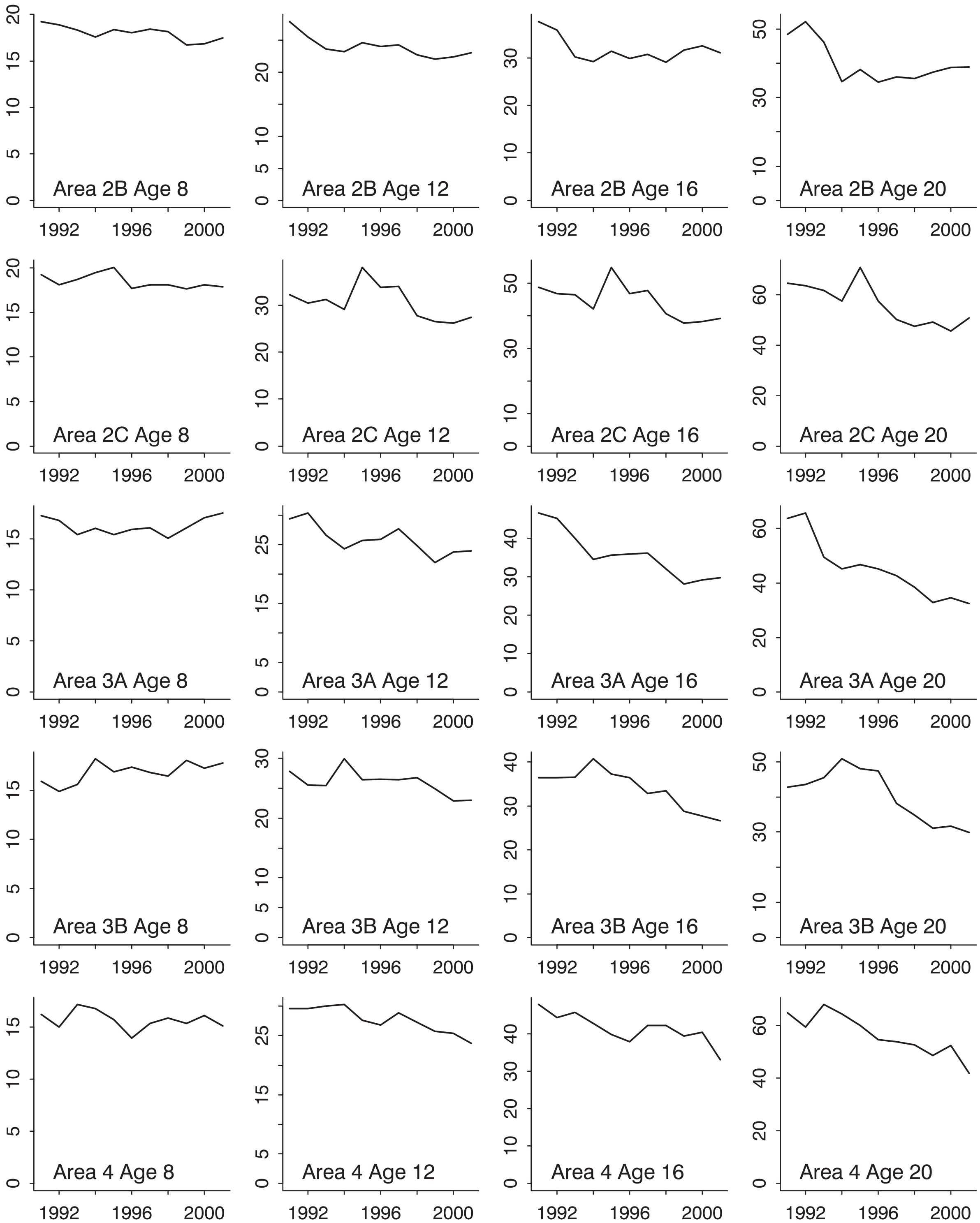



**Figure 2. Trends in mean weight at age in the commercial catch, 1991-2001.**

## Appendix A. Selected fishery and survey data summaries.

**Table A1. Commercial catch (million pounds, net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | 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 |

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1981** | 0.20 | 5.66 | 4.01 | 14.23 | 0.45 | 0.49 | 0.39 | 0.30 | 0.01 | 0.00 | 25.74 |
| **1982** | 0.21 | 5.54 | 3.50 | 13.52 | 4.80 | 1.17 | 0.01 | 0.24 | 0.00 | 0.01 | 29.01 |
| **1983** | 0.27 | 5.44 | 6.38 | 14.13 | 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 | 11.23 | 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 | 0.09 | 69.45 |
| **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 | 33.73 | 7.84 | 1.02 | 2.65 | 0.57 | 0.67 | 0.01 | 66.95 |
| **1990** | 0.33 | 8.57 | 9.73 | 28.85 | 8.69 | 2.50 | 1.33 | 0.53 | 1.01 | 0.06 | 61.60 |
| **1991** | 0.35 | 7.19 | 8.69 | 22.93 | 11.93 | 2.25 | 1.51 | 0.68 | 1.44 | 0.10 | 57.08 |
| **1992** | 0.43 | 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 | 0.71 | 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 | 9.55 | 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 | 13.83 | 4.37 | 3.57 | 1.76 | 1.89 | 0.26 | 74.31 |
| **2000** | 0.48 | 10.81 | 8.44 | 19.29 | 15.41 | 5.15 | 4.69 | 1.74 | 1.93 | 0.35 | 68.30 |
| **2001** | 0.69 | 10.10 | 8.40 | 21.94 | 16.55 | 4.98 | 4.48 | 1.74 | 1.87 | 0.46 | 71.20 |

**Table A2. Bycatch mortality of legal-sized halibut (80+ cm; in million pounds net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | Total |
|---|---|---|---|---|---|---|---|
| **1974** | 0.25 | 0.90 | 0.37 | 4.48 | 2.82 | 1.89 | 10.71 |
| **1975** | 0.25 | 0.90 | 0.45 | 2.61 | 1.66 | 1.10 | 6.97 |
| **1976** | 0.25 | 0.94 | 0.50 | 2.74 | 1.94 | 1.18 | 7.56 |
| **1977** | 0.25 | 0.72 | 0.41 | 3.37 | 1.54 | 1.98 | 8.27 |
| **1978** | 0.25 | 0.55 | 0.21 | 2.44 | 1.31 | 3.40 | 8.17 |
| **1979** | 0.25 | 0.69 | 0.64 | 4.49 | 0.69 | 3.45 | 10.21 |
| **1980** | 0.25 | 0.51 | 0.42 | 4.93 | 0.87 | 5.71 | 12.69 |
| **1981** | 0.25 | 0.53 | 0.40 | 3.99 | 1.10 | 4.37 | 10.64 |
| **1982** | 0.25 | 0.30 | 0.20 | 3.20 | 1.68 | 2.94 | 8.57 |
| **1983** | 0.25 | 0.29 | 0.20 | 2.08 | 1.22 | 2.47 | 6.52 |
| **1984** | 0.25 | 0.52 | 0.21 | 1.51 | 0.92 | 2.29 | 5.70 |
| **1985** | 0.25 | 0.55 | 0.20 | 0.80 | 0.34 | 2.25 | 4.38 |
| **1986** | 0.25 | 0.56 | 0.20 | 0.67 | 0.20 | 2.62 | 4.50 |
| **1987** | 0.25 | 0.79 | 0.20 | 1.59 | 0.40 | 2.67 | 5.91 |
| **1988** | 0.25 | 0.77 | 0.20 | 2.13 | 0.04 | 3.27 | 6.67 |
| **1989** | 0.25 | 0.72 | 0.20 | 1.80 | 0.44 | 1.94 | 5.36 |
| **1990** | 0.25 | 1.03 | 0.67 | 2.63 | 1.21 | 4.15 | 9.96 |
| **1991** | 0.25 | 1.22 | 0.55 | 3.13 | 1.04 | 2.92 | 9.10 |
| **1992** | 0.28 | 1.02 | 0.57 | 2.64 | 1.12 | 3.35 | 8.97 |
| **1993** | 0.28 | 0.65 | 0.33 | 1.92 | 0.47 | 2.01 | 5.66 |
| **1994** | 0.28 | 0.57 | 0.40 | 2.35 | 0.85 | 3.48 | 7.93 |
| **1995** | 0.38 | 0.71 | 0.22 | 1.46 | 0.83 | 3.21 | 6.80 |
| **1996** | 0.47 | 0.17 | 0.23 | 1.40 | 0.96 | 3.57 | 6.80 |
| **1997** | 0.47 | 0.11 | 0.24 | 1.55 | 0.73 | 3.80 | 6.90 |
| **1998** | 0.81 | 0.12 | 0.24 | 1.47 | 0.73 | 3.72 | 7.09 |
| **1999** | 0.66 | 0.11 | 0.23 | 1.28 | 0.74 | 3.34 | 6.36 |
| **2000** | 0.54 | 0.13 | 0.25 | 1.29 | 0.65 | 3.23 | 6.09 |
| **2001** | 0.54 | 0.11 | 0.22 | 1.70 | 0.48 | 3.39 | 6.44 |

**Table A3. Total removals: commercial catch + sport catch + legal-sized wastage + legal-sized bycatch + personal use (millions of pounds net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | 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 | 17.38 | 1.15 | 6.42 | 35.41 |
| **1981** | 0.47 | 6.20 | 4.73 | 18.96 | 1.55 | 5.57 | 37.47 |
| **1982** | 0.51 | 5.87 | 4.19 | 17.44 | 6.48 | 4.38 | 38.88 |
| **1983** | 0.58 | 5.78 | 7.15 | 17.14 | 8.97 | 6.89 | 46.51 |
| **1984** | 0.80 | 9.63 | 6.68 | 22.50 | 7.42 | 5.46 | 52.50 |
| **1985** | 0.94 | 11.30 | 10.31 | 23.79 | 11.43 | 6.69 | 64.45 |
| **1986** | 1.17 | 12.17 | 11.97 | 37.23 | 9.43 | 8.53 | 80.50 |
| **1987** | 1.29 | 13.48 | 12.03 | 36.48 | 8.50 | 9.84 | 81.62 |
| **1988** | 0.99 | 13.93 | 12.85 | 44.76 | 7.24 | 8.07 | 87.85 |
| **1989** | 1.05 | 11.51 | 11.48 | 40.00 | 8.47 | 7.03 | 79.55 |
| **1990** | 0.78 | 10.06 | 11.98 | 36.02 | 10.12 | 9.84 | 78.79 |
| **1991** | 0.77 | 8.83 | 11.95 | 32.42 | 13.46 | 9.49 | 76.92 |
| **1992** | 0.97 | 9.09 | 12.68 | 34.46 | 9.98 | 10.23 | 77.40 |
| **1993** | 1.04 | 12.00 | 13.74 | 30.59 | 8.46 | 8.56 | 74.39 |
| **1994** | 0.83 | 11.18 | 13.11 | 32.86 | 4.83 | 9.12 | 71.93 |
| **1995** | 0.92 | 11.55 | 9.80 | 24.51 | 4.02 | 8.11 | 58.91 |
| **1996** | 1.00 | 10.93 | 11.28 | 26.11 | 4.70 | 9.09 | 63.10 |
| **1997** | 1.25 | 13.75 | 12.37 | 31.86 | 9.92 | 12.79 | 81.94 |
| **1998** | 1.66 | 14.53 | 12.98 | 32.12 | 12.00 | 13.03 | 86.32 |
| **1999** | 1.45 | 14.01 | 12.45 | 31.02 | 14.69 | 15.55 | 89.17 |
| **2000** | 1.38 | 12.29 | 11.17 | 25.98 | 16.14 | 17.41 | 84.37 |
| **2001** | 1.68 | 11.58 | 10.56 | 28.76 | 17.10 | 17.25 | 86.92 |

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

Values before 1984 are multiplied by the J-C hook correction for catch in weight of legal-sized fish (2.2). 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. Values for Areas 2A and 2B are slightly different from past years because of the reweighting of fixed-hook and snap CPUE described in the text.

| | 2A | 2B | 2C | 3A | 3B | 4 |
|---|---|---|---|---|---|---|
| **1974** | 131 | 141 | 126 | 142 | 125 | 301 |
| **1975** | 131 | 149 | 117 | 145 | 149 | 211 |
| **1976** | 72 | 117 | 93 | 131 | 142 | 184 |
| **1977** | 182 | 135 | 99 | 135 | 161 | 176 |
| **1978** | 86 | 138 | 124 | 172 | 116 | 167 |
| **1979** | 110 | 106 | 177 | 189 | 81 | 146 |
| **1980** | 82 | 144 | 175 | 261 | 249 | 124 |

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E |
|---|---|---|---|---|---|---|---|---|---|---|
| **1981** | --- | 147 | 318 | 312 | --- | --- | 217 | 243 | --- | --- |
| **1982** | 47 | 151 | 366 | 375 | 478 | 226 | --- | 199 | --- | --- |
| **1983** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1984** | 63 | 148 | 314 | 524 | 475 | 366 | 161 | --- | 197 | --- |
| **1985** | 62 | 147 | 370 | 536 | 602 | 333 | 234 | --- | 330 | --- |
| **1986** | 60 | 120 | 302 | 522 | 515 | 265 | --- | 427 | 238 | --- |
| **1987** | 57 | 131 | 260 | 504 | 476 | 341 | 220 | 384 | --- | --- |
| **1988** | 134 | 137 | 281 | 503 | 655 | 453 | 224 | --- | 201 | --- |
| **1989** | 124 | 134 | 258 | 455 | 590 | 409 | 268 | 331 | 384 | --- |
| **1990** | 168 | 175 | 269 | 353 | 484 | 434 | 208 | 288 | 381 | --- |
| **1991** | 158 | 148 | 233 | 319 | 466 | 471 | 329 | 223 | 398 | --- |
| **1992** | 115 | 171 | 230 | 397 | 440 | 372 | 278 | 249 | 412 | --- |
| **1993** | 147 | 208 | 256 | 393 | 514 | 463 | 218 | 256 | 851 | --- |
| **1994** | 93 | 215 | 207 | 354 | 377 | 463 | 198 | 167 | 480 | --- |
| **1995** | 116 | 219 | 234 | 416 | 476 | 349 | 189 | --- | 475 | --- |
| **1996** | 159 | 226 | 238 | 473 | 556 | 515 | 269 | --- | --- | --- |
| **1997** | 226 | 241 | 246 | 458 | 562 | 482 | 275 | 335 | 671 | --- |
| **1998** | 194 | 232 | 236 | 451 | 611 | 525 | 287 | 287 | 627 | --- |
| **1999** | 342 | 213 | 199 | 437 | 538 | 498 | 310 | 270 | 535 | --- |
| **2000** | 263 | 227 | 186 | 443 | 577 | 548 | 318 | 223 | 556 | --- |
| **2001** | 142 | 209 | 205 | 465 | 405 | 459 | 284 | 197 | 517 | --- |

**Table A5. IPHC setline survey CPUE of legal sized fish in weight (net pounds per skate).**

Figures for Area 2B refer to the Charlotte region only. Figures for all other areas refer to all stations fished. This is a change from previous years and the series for Areas 2C, 3A, and 4A have changed as a result. The eastward expansion of the 3A survey in 1996 lowered average CPUE by around 25%; the raw values in the table should not be taken at face value.

Similarly the 4A value for 1999 is elevated because the Bering Sea edge in 4A was not fished that year. *No corrections* are applied; values before 1984 are raw J-hook catch rates.

**J-hook surveys**

| | 2A | 2B | 2C | 3A |
|---|---|---|---|---|
| **1974** | --- | --- | --- | --- |
| **1975** | --- | --- | --- | --- |
| **1976** | --- | --- | --- | --- |
| **1977** | --- | 15 | --- | 73 |
| **1978** | --- | 21 | --- | 34 |
| **1979** | --- | --- | --- | 51 |
| **1980** | --- | 28 | --- | 95 |
| **1981** | --- | 18 | --- | 162 |
| **1982** | --- | 21 | 133 | 180 |
| **1983** | --- | 20 | 142 | 153 |

**C-hook surveys**

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D |
|---|---|---|---|---|---|---|---|---|---|
| **1984** | --- | 64 | 260 | 446 | --- | --- | --- | --- | --- |
| **1985** | --- | 47 | 260 | 466 | --- | --- | --- | --- | --- |
| **1986** | --- | 42 | 283 | 377 | --- | --- | --- | --- | --- |
| **1987** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1988** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1989** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1990** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1991** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1992** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1993** | --- | 105 | --- | 313 | --- | --- | --- | --- | --- |
| **1994** | --- | --- | --- | 313 | --- | --- | --- | --- | --- |
| **1995** | 29 | 166 | --- | 370 | --- | --- | --- | --- | --- |
| **1996** | --- | 175 | 306 | 317 | 352 | --- | --- | --- | --- |
| **1997** | 35 | 156 | 411 | 331 | 415 | 237 | 282 | 71 | 111 |
| **1998** | --- | 92 | 232 | 281 | 436 | 304 | 216 | --- | --- |
| **1999** | 37 | 95 | 204 | 241 | 441 | 367 | 204 | --- | --- |
| **2000** | --- | 104 | 232 | 273 | 378 | 286 | 216 | --- | 213 |
| **2001** | 41 | 117 | 239 | 255 | 365 | 209 | 171 | --- | 201 |

## Appendix B. Recent changes in assessment methods and harvest policy.

**1982-1994:** stock size was estimated with CAGEAN, a strictly age-structured model fitted to commercial catch-at-age and catch-per-effort data. Because of a decrease in growth rates between the late 1970s and early 1990s, there were persistent underestimates of incoming recruitment and total stock size in the assessments done in the early 1990s.

Until 1985, allowable removals were calculated as a proportion of estimated annual surplus production (ASP), the remaining production being allocated to stock rebuilding. In 1985 the Commission adopted a constant harvest rate policy, meaning that allowable removals are determined by applying a fixed harvest rate to estimated exploitable biomass. This harvest level is called the Constant Exploitation Yield, or CEY. The fixed harvest rate was set at 28% in 1985, increased to 35% in 1987, and lowered to 30% in 1993.

**1995:** a new age- and length-structured model was implemented that accounted for the change in growth and was fitted to survey as well as commercial catch-at-age and catch-per-effort data. The new model produced substantially higher biomass estimates. In Area 3A this resulted from accounting for the change in growth schedule. In Area 2B, where the change in growth had been much less than in Alaska, it resulted from fitting the model to survey catch-per-effort, which showed a larger stock increase since the mid-1980s than commercial catch-per-effort. Quotas were held at the 1995 level to allow time for a complete study of the new model and results,

**1996:** differences in estimated selectivity between British Columbia and Alaska led to the consideration of two alternatives for fitting the model, one in which survey selectivity was a fixed function of age and the other in which it was a function of length. Spawner-recruit estimates from the new model resulted in a lowering of the target harvest rate to 20%. Quotas were increased somewhat, but not to the level indicated by the new biomass estimates.

**1997:** setline surveys of the entire Commission area indicated substantially more halibut in western Alaska (IPHC Areas 3B and 4) than the analytical assessment. Biomass in those areas was estimated by scaling the analytical estimates of absolute abundance in Areas 2 and 3A by the survey estimate of relative abundance in western Alaska. CEY estimates increased again, and quotas were increased again, but still to a level well below the CEY's.

**1998:** the working value of natural mortality was lowered from 0.20 to 0.15, reducing analytical estimates of biomass in Areas 2 and 3A by about 30%. At the same time setline survey estimates of abundance in Areas 3B and 4 relative to Areas 2 and 3A increased, so biomass estimates in the western area decreased by a smaller amount.

**1999:** setline survey catch rates in the 1990s were adjusted downward to account for the effect of changing to all-salmon bait when the surveys resumed in 1993. This reduced biomass estimates by 20-30%.

**2000:** the bait adjustment applied in 1999 was removed, which increased biomass estimates by 30-40%, approximately back to the level in the 1998 assessment. In addition, a purely age-structured model was adopted in place of the age- and size-structured model used in 1999. The 2000 model produced similar estimates of present biomass but lower estimates of historical biomass.

**2001:** instead of a combined Area 2AB assessment, a standalone assessment of Area 2B was done and the biomass estimate extrapolated to 2A on the basis of survey results, which increased the abundance estimate by 7%. Also in 2A and 2B, snap CPUE (scaled up by 1.35) was given the same weight as fixed-hook CPUE; negligible effect. All survey stations in 2C and 3A were used in the assessment rather than just the standard survey areas, which increased the biomass estimate by 7% in 3A and lowered it by 15% in 2C.

## Appendix C. Selected historical estimates from the 2001 assessment.

The following tables show trends in recruitment, stock size, and exploitation rate estimated with the model used in 2000. Except for the catches, all of these estimates are liable to change in later years, sometimes dramatically, as new data and methods are used in the assessment.

The columns in the tables are:

**R** = age 8 recruits (millions)
**N** = total abundance of age 8+ fish (millions)
**C** = total catch in number of age 8+ fish (million net lb)
**C/N** = exploitation rate in number of age 8+ fish
**B** = total biomass of legal-sized fish (million net lb)
**Y** = total catch in weight of age 8+ fish (million net lb)
**Y/B** = exploitation rate in weight

The “catches” are actually total removals except for bycatch. Total biomass is calculated using estimated mean size at age in the sea rather than in the catch, and is not directly comparable with estimates of exploitable biomass.

**Table C1. Historical estimates for Area 2B**

| | R | N | C | C/N | B | Y | Y/B |
|---|---|---|---|---|---|---|---|
| **1974** | 0.39 | 1.42 | 0.13 | 0.09 | 31.76 | 4.27 | 0.13 |
| **1975** | 0.40 | 1.47 | 0.19 | 0.13 | 33.61 | 6.77 | 0.20 |
| **1976** | 0.39 | 1.45 | 0.20 | 0.14 | 33.84 | 6.34 | 0.19 |
| **1977** | 0.41 | 1.45 | 0.16 | 0.11 | 34.29 | 4.91 | 0.14 |
| **1978** | 0.47 | 1.55 | 0.14 | 0.09 | 37.08 | 4.05 | 0.11 |
| **1979** | 0.48 | 1.67 | 0.16 | 0.09 | 41.04 | 4.57 | 0.11 |
| **1980** | 0.57 | 1.83 | 0.18 | 0.10 | 44.18 | 5.29 | 0.12 |
| **1981** | 0.67 | 2.05 | 0.20 | 0.10 | 47.24 | 5.27 | 0.11 |
| **1982** | 0.70 | 2.26 | 0.20 | 0.09 | 50.50 | 5.22 | 0.10 |
| **1983** | 0.86 | 2.61 | 0.21 | 0.08 | 55.61 | 5.16 | 0.09 |
| **1984** | 1.09 | 3.13 | 0.36 | 0.12 | 58.83 | 8.44 | 0.14 |
| **1985** | 1.39 | 3.73 | 0.44 | 0.12 | 60.33 | 10.27 | 0.17 |
| **1986** | 1.20 | 3.97 | 0.47 | 0.12 | 64.91 | 11.28 | 0.17 |
| **1987** | 1.37 | 4.33 | 0.50 | 0.12 | 69.80 | 12.08 | 0.17 |
| **1988** | 1.36 | 4.60 | 0.55 | 0.12 | 73.61 | 12.78 | 0.17 |
| **1989** | 1.09 | 4.51 | 0.43 | 0.10 | 76.04 | 10.45 | 0.14 |
| **1990** | 0.99 | 4.44 | 0.36 | 0.08 | 79.92 | 8.54 | 0.11 |
| **1991** | 1.22 | 4.68 | 0.27 | 0.06 | 83.97 | 7.21 | 0.09 |
| **1992** | 1.22 | 4.96 | 0.30 | 0.06 | 88.66 | 7.75 | 0.09 |
| **1993** | 1.02 | 4.98 | 0.46 | 0.09 | 96.04 | 11.15 | 0.12 |
| **1994** | 1.10 | 4.94 | 0.43 | 0.09 | 104.83 | 10.33 | 0.10 |
| **1995** | 2.31 | 6.16 | 0.42 | 0.07 | 113.51 | 10.43 | 0.09 |
| **1996** | 2.04 | 6.92 | 0.44 | 0.06 | 116.61 | 10.45 | 0.09 |
| **1997** | 1.50 | 7.04 | 0.56 | 0.08 | 114.12 | 13.06 | 0.11 |
| **1998** | 1.38 | 6.90 | 0.62 | 0.09 | 106.06 | 14.08 | 0.13 |
| **1999** | 1.00 | 6.34 | 0.58 | 0.09 | 97.16 | 13.71 | 0.14 |
| **2000** | 0.89 | 5.81 | 0.49 | 0.08 | 90.33 | 11.88 | 0.13 |
| **2001** | 0.76 | 5.30 | 0.45 | 0.09 | 85.64 | 11.24 | 0.13 |

**Table C2. Historical estimates for Area 2C.**

| | R | N | C | C/N | B | Y | Y/B |
|---|---|---|---|---|---|---|---|
| **1974** | 0.29 | 1.15 | 0.13 | 0.12 | 30.20 | 5.50 | 0.18 |
| **1975** | 0.32 | 1.17 | 0.15 | 0.13 | 29.98 | 6.13 | 0.20 |
| **1976** | 0.35 | 1.20 | 0.13 | 0.11 | 29.59 | 5.45 | 0.18 |
| **1977** | 0.40 | 1.30 | 0.08 | 0.06 | 31.08 | 3.17 | 0.10 |
| **1978** | 0.52 | 1.54 | 0.12 | 0.08 | 35.60 | 4.21 | 0.12 |
| **1979** | 0.55 | 1.76 | 0.13 | 0.07 | 40.87 | 4.58 | 0.11 |
| **1980** | 0.73 | 2.12 | 0.10 | 0.05 | 47.50 | 3.49 | 0.07 |
| **1981** | 0.84 | 2.56 | 0.13 | 0.05 | 57.12 | 4.25 | 0.07 |
| **1982** | 0.82 | 2.90 | 0.11 | 0.04 | 65.69 | 3.91 | 0.06 |
| **1983** | 0.82 | 3.21 | 0.19 | 0.06 | 75.37 | 6.82 | 0.09 |
| **1984** | 0.93 | 3.51 | 0.19 | 0.05 | 83.02 | 6.32 | 0.08 |
| **1985** | 1.21 | 4.05 | 0.29 | 0.07 | 86.07 | 10.03 | 0.12 |
| **1986** | 0.87 | 4.08 | 0.37 | 0.09 | 87.98 | 11.63 | 0.13 |
| **1987** | 0.96 | 4.10 | 0.35 | 0.09 | 89.40 | 11.75 | 0.13 |
| **1988** | 0.89 | 4.09 | 0.39 | 0.10 | 90.30 | 12.49 | 0.14 |
| **1989** | 0.77 | 3.92 | 0.34 | 0.09 | 88.90 | 11.15 | 0.13 |
| **1990** | 0.71 | 3.77 | 0.33 | 0.09 | 88.42 | 11.19 | 0.13 |
| **1991** | 0.83 | 3.74 | 0.31 | 0.08 | 87.04 | 11.14 | 0.13 |
| **1992** | 0.83 | 3.75 | 0.36 | 0.10 | 84.66 | 11.99 | 0.14 |
| **1993** | 0.69 | 3.57 | 0.37 | 0.10 | 82.01 | 13.33 | 0.16 |
| **1994** | 0.72 | 3.44 | 0.38 | 0.11 | 80.36 | 12.57 | 0.16 |
| **1995** | 1.62 | 4.21 | 0.23 | 0.06 | 79.09 | 9.47 | 0.12 |
| **1996** | 1.38 | 4.77 | 0.33 | 0.07 | 82.99 | 10.95 | 0.13 |
| **1997** | 0.95 | 4.75 | 0.37 | 0.08 | 81.71 | 12.03 | 0.15 |
| **1998** | 0.78 | 4.51 | 0.44 | 0.10 | 79.71 | 12.64 | 0.16 |
| **1999** | 0.72 | 4.18 | 0.42 | 0.10 | 74.88 | 12.09 | 0.16 |
| **2000** | 0.87 | 4.08 | 0.37 | 0.09 | 70.02 | 10.77 | 0.15 |
| **2001** | 0.88 | 4.04 | 0.34 | 0.08 | 64.44 | 10.23 | 0.16 |

**Table C3. Historical estimates for Area 3A.**

| | R | N | C | C/N | B | Y | Y/B |
|---|---|---|---|---|---|---|---|
| **1974** | 0.61 | 2.30 | 0.17 | 0.07 | 78.44 | 8.10 | 0.10 |
| **1975** | 0.80 | 2.54 | 0.22 | 0.09 | 82.00 | 10.43 | 0.13 |
| **1976** | 0.95 | 2.86 | 0.23 | 0.08 | 88.75 | 10.92 | 0.12 |
| **1977** | 1.06 | 3.24 | 0.18 | 0.06 | 101.15 | 8.73 | 0.09 |
| **1978** | 1.32 | 3.86 | 0.24 | 0.06 | 118.12 | 10.35 | 0.09 |
| **1979** | 1.24 | 4.27 | 0.27 | 0.06 | 136.19 | 11.33 | 0.08 |
| **1980** | 1.44 | 4.78 | 0.27 | 0.06 | 150.89 | 12.28 | 0.08 |
| **1981** | 1.91 | 5.65 | 0.33 | 0.06 | 169.20 | 14.75 | 0.09 |
| **1982** | 1.83 | 6.28 | 0.30 | 0.05 | 192.29 | 14.10 | 0.07 |
| **1983** | 1.94 | 6.98 | 0.35 | 0.05 | 214.15 | 14.91 | 0.07 |
| **1984** | 2.36 | 7.97 | 0.51 | 0.06 | 222.68 | 20.56 | 0.09 |
| **1985** | 3.21 | 9.52 | 0.57 | 0.06 | 246.72 | 22.77 | 0.09 |
| **1986** | 2.86 | 10.48 | 0.92 | 0.09 | 272.58 | 36.21 | 0.13 |
| **1987** | 3.60 | 11.68 | 0.93 | 0.08 | 273.31 | 34.41 | 0.13 |
| **1988** | 4.45 | 13.56 | 1.22 | 0.09 | 274.12 | 41.93 | 0.15 |
| **1989** | 3.45 | 13.87 | 1.11 | 0.08 | 264.52 | 37.88 | 0.14 |
| **1990** | 3.13 | 13.96 | 0.98 | 0.07 | 257.72 | 33.08 | 0.13 |
| **1991** | 4.34 | 15.37 | 0.95 | 0.06 | 249.78 | 28.93 | 0.12 |
| **1992** | 3.64 | 15.89 | 1.02 | 0.06 | 238.03 | 31.71 | 0.13 |
| **1993** | 3.01 | 15.66 | 0.98 | 0.06 | 222.51 | 28.62 | 0.13 |
| **1994** | 2.74 | 15.26 | 1.10 | 0.07 | 239.96 | 30.38 | 0.13 |
| **1995** | 4.66 | 16.73 | 0.82 | 0.05 | 250.93 | 22.95 | 0.09 |
| **1996** | 3.89 | 17.48 | 0.87 | 0.05 | 259.21 | 24.65 | 0.10 |
| **1997** | 2.38 | 16.58 | 1.02 | 0.06 | 254.88 | 30.22 | 0.12 |
| **1998** | 2.22 | 15.53 | 1.12 | 0.07 | 240.90 | 30.59 | 0.13 |
| **1999** | 1.54 | 13.86 | 1.19 | 0.09 | 220.67 | 29.65 | 0.13 |
| **2000** | 1.72 | 12.55 | 0.92 | 0.07 | 198.22 | 24.58 | 0.12 |
| **2001** | 1.43 | 11.38 | 0.99 | 0.09 | 184.48 | 26.99 | 0.15 |

# Assessment of the Pacific halibut stock in 2000

**William G. Clark and Steven R. Hare**

## Abstract

This paper reports estimates of halibut abundance and available setline yield in 2001 at a harvest rate of 20%—about 95 million pounds coastwide. This figure is a return to approximately the level of the 1998 assessment. Estimated abundance was substantially lower in last year's assessment because of an adjustment to recent survey catch rates to account for a bait change in 1993, but field work done in 2000 showed that the bait adjustment was unnecessary. The model used this year is somewhat simpler and more flexible than the one used in 1995-1999. It produces similar estimates of present abundance but lower estimates of historical abundance.

## Introduction

Each year the IPHC staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). Exploitable biomass in each of IPHC regulatory areas 2AB, 2C, and 3A is estimated by fitting a detailed population model to the data from that area.

A biological target level for total removals is then calculated by applying a fixed harvest rate—presently 20%—to the estimate of exploitable biomass. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for directed setline catches, called the setline CEY, is calculated by subtracting from the total CEY an estimate of all other removals—sport catches, bycatch of legal-sized fish, wastage of legal-sized fish in the halibut fishery, and fish taken for personal use.

In Areas 3B and 4 exploitation rates were low until very recently and no surveys were done before 1996. For both reasons an analytical assessment is not feasible. Instead, exploitable biomass in those areas relative to that in Area 3A is estimated from recent surveys and the analytical estimate of abundance in Area 3A is scaled accordingly to estimate exploitable biomass in Areas 3B and 4. Total and setline CEY for those areas are then calculated as explained above.

Staff recommendations for catch limits in each area are based on the estimates of setline 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.

This paper reports the staff's estimates of total abundance, recruitment trends, exploitable biomass, and total and setline CEY by area, as calculated at the end of 2000 for the 2001 fishery.

## Evolution of assessment models

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

Beginning in the late 1980s, halibut growth rates in Alaska declined dramatically. As a result, age-specific selectivity decreased, particularly for younger fish near the minimum size limit. CAGEAN did not allow for that, and by the mid-1990s was seriously underestimating the strength of incoming year-classes. In effect, it interpreted lower catches of young fish as an indication of lower abundance, whereas the real cause was lower selectivity.

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.

When this model was fitted to data from Area 2AB 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. This fit of the model was the basis for staff catch limit recommendations in 1997, 1998, and 1999. For brevity it is referred to hereafter in this paper as the "1999 model".

The 1999 model is similar to CAGEAN fitted to survey and commercial data, but it is different in that the fundamental selectivity parameters are not the age-specific selectivities themselves, but rather the two parameters of a length-based function from which the age-specific selectivities are calculated. This simple length-based function places subtle constraints on the pattern of age-specific selectivities that are achievable when the "age-specific" form is fitted, so the fit is not the same as what would be obtained with directly estimated age-specific selectivities.

This year's assessment reverts to a simpler model (the "2000 model") that really is quite similar to CAGEAN. No attempt is made to predict or fit the distribution of size at age, and age-specific selectivities are fundamental model parameters, estimated directly. Commercial catchability and selectivities are allowed to drift slowly. The model structure provides for the possibility of breaks and/or drift in the survey parameters as well, but the staff catch limit recommendations were based on the most parsimonious form of the model, in which survey catchability and selectivity are held constant (except for breaks at the time of conversion from J-hooks to C-hooks).

In this form the 2000 model is virtually identical to the 1999 model except for the parameterization of selectivity (and the absence of a submodel dealing with growth and size at age). Figure 1 compares fits of the two models in the context of the 1999 assessment (i.e., using data through 1999 and applying a bait adjustment to survey catchability in 1993). The fits and present biomass estimates are similar for Area 2AB (Fig. 1a), except for higher estimates of some recent recruitments in fits of the 2000 model. That is also true for Area 2C (Fig. 1b) and Area 3A (Fig. 1c), but in addition the estimates of historical abundance differ between the two fits in these areas, with the 2000 model fits showing substantially lower abundance 20 years ago.

In principle the two fits should produce almost the same estimates of historical abundance, because they use the same natural mortality rate and the same series of catch at age estimates. The fact that they differ substantially indicates a difference in the predictions of catch at age generated internally by the two models. This is surprising; normally any conventional model will fit the catch-at-age estimates very closely, and a routine plot of the fits for Area 3A appears to show that both of them fit the catch at age data well in this case (Fig. 2). But these plots are deceptive. Many of the vertical deviations are large, even though all the points may appear to be close to the line. The average absolute value of the percentage error of the predictions is 32% for the 1999 model and 16% for the 2000 model.

More important is that the 1999 model predictions are biased while the 2000 model predictions are not. The unweighted average error over all year/age cells is +23% for the 1999 model and +1% for the 2000 model. The pattern of the errors is also important. The 1999 model tends to overestimate the catch at age of the youngest and oldest fish, and to underestimate (but only slightly) in between (Fig. 3, top panel), while the 2000 model stays close to zero error across the age range and shows no pattern. We believe the difference between the two fits in this regard results from the constraints imposed on the 1999 model fit by the rigid two-parameter length-based selectivity function. The best fit of the 1999 model is one that does well in the middle of the age range where the bulk of the catch is. That section determines the position and slope of the function, even though the two ends of the range may be poorly fitted. The 2000 model is completely flexible and can accommodate any pattern of age-specific selectivities, so it can predict the catch at age with no systematic error over the whole age range.

In summary, both of these models assume constant age-specific survey selectivity, but they differ in implementation. The 1999 model was more rigid in its treatment of selectivity, and it attempted to predict size at age as well as catch rates at age. It now appears that these features caused some problems: the catch at age was predicted incorrectly, the estimated length-specific survey selectivity in recent years in Area 3A was not very credible (Clark and Parma 2000, p. 122), and in some cases the size at age was poorly fitted. In contrast the 2000 model is more flexible and simpler. Its estimates of historical abundance are in close agreement with the catch-at-age data, and its estimates of present abundance, while they may or may not be correct, are at least not affected by the simultaneous fitting of growth parameters.

## Changes in the assessment between 1999 and 2000

The model changes described above resulted in lower estimates of historical abundance but very similar estimates of present abundance. Another change—removal of last year's bait adjustment—resulted in substantially higher estimates of present abundance.

In the 1999 assessment, biomass estimates were reduced by an adjustment to recent survey catch rates that was applied to account for a bait change in 1993. That adjustment was dropped in the 2000 assessment, which brought abundance estimates back up to approximately the levels reported in the 1998 assessment. A brief explanation is given here; see Chen and Clark (2001) for full details.

Systematic setline surveys were suspended after 1986 and resumed in 1993. At that time chum salmon was adopted as a standard bait, whereas salmon and herring on alternate hooks had been used as bait in the 1980s.

Experiments done in 1999 showed that skates baited entirely with salmon caught about twice as many halibut as skates baited entirely with herring. These results suggested that if half of survey hooks had been baited with herring in the 1990s, catch rates would have been 25% lower. This was not certain because of the additional difference in baiting pattern (full skates vs. alternate hooks), but as a precaution the staff applied a 25% downward adjustment to recent survey catch rates when doing the 1999 assessment, and that lowered biomass estimates by 20-30%.

In summer 2000 the staff conducted a direct comparison of survey catch rates using the two bait configurations (all salmon and alternating salmon/herring) and found no practical difference between them. All-salmon skates caught about 10% more halibut (in number) than salmon/herring skates in Alaska and about 10% fewer in Canada, but the difference was not statistically significant except among legal-sized fish in Alaska. Even there it was small (20% in both numbers and weight) relative to the year-to-year variability of the survey and the size of the long-term changes in abundance that survey is intended to track. We therefore chose not to implement an adjustment in any area.

The incremental effects of the model change, removal of the bait adjustment, and addition of the 2000 commercial survey data are shown in Table 1. The model change has little effect. Removal of the bait adjustment increases the estimates by 30-40%. The only other important change is the large (25%) increase in the Area 3A estimate due to the addition of the 2000 data, which is discussed in the section on Area 3A results below.

## Explanation of assessment terms and figures

Fits of the 2000 model in Areas 2AB, 2C, and 3A are shown in Fig. 4. The upper left panel shows recruitment at age 8 by year. The upper right panel shows four measures of biomass: legal-sized (LBio), spawning (SBio), exploitable biomass calculated with internally estimated commercial selectivities that drift over years (EBio or variable ebio), and exploitable biomass calculated with an externally fixed set of selectivities (EBioFX or fixed ebio) that are intermediate between then higher 2AB and lower 3A selectivites. Commercial CPUE should be proportional to EBio; allowable removals are calculated by applying the 20% harvest rate to EBioFX, because the fixed selectivities were the ones used in the simulations that led to the choice of the 20% harvest rate.

The center panels show the series of survey and commercial CPUE values, the general trend of the data (a data smoother), and the model predictions. Also shown are the annual values of survey and commercial catchability, scaled to an arbitrary 50 or 100 in 1974. In the standard model both have a break at the time of the switch to C-hooks in 1983-1984, and commercial catchability is allowed to drift over years after 1984.

The bottom panels show internally estimated survey and commercial selectivities. Here, too, there is just one break in survey selectivity in the 2000 model, but commercial selectivity is allowed to drift lower after 1984, when especially in Alaska average size at age decreased and a larger proportion of the younger age groups fell below the minimum size limit (81 cm).

## Assessment results for Area 2AB

Stock size in 1985 is well determined by the catch at age data, because by now all the year classes that were present in the fishery have passed through it. In terms of variable ebio, stock size was 53 M lb in 1985. Since 1985 commercial catch rates have increased by about 50% (Figure 1, center right panel). In the mid-1990s survey catch rates were about triple the level of survey catch rates in the mid-1980s, but the last three years have indicated a relative change of about 100%, much closer to what the commercial data indicate (Figure 4a, center left panel). A commonsense estimate of present abundance would therefore be a variable ebio of 50-100% above the 1985 level. The fitted estimate is 73 M lb or about 40% above 1985, which essentially follows the commercial trend but allows for an estimated 10% increase in commercial catchability (fishing power) between 1985 and now. In terms of fixed ebio, the 2001 estimate is 68 M lb, of which 11% is assigned to Area 2A and 89% to 2B (Table 2).

In the mid-1990s survey and commercial data indicated quite similar trends in Area 3A but quite different trends in 2AB. After the last three years of much lower survey catch rates in 2AB, the survey and commercial data now agree reasonably well there, too. As a result, the degree of variability allowed in commercial catchability was reduced this year (standard deviation used to penalize annual changes was reduced from 3% to 1%), meaning that the fit relies more on the commercial CPUE trend, which is less variable from year to year.

This year's fit is quite pessimistic as regards recent recruitment (Figure 4a, top left panel), but in this respect it is at odds with the 2C assessment. We believe the two will agree closely when the estimates firm up, because relative year-class strengths have always been similar in 2B and 2C.

## Assessment results for Area 2C

As in Area 2AB, survey catch rates have been low for the past three years after two high values in the mid-1990s (Fig. 4b, center left panel). There are many fewer early survey points in 2C than in 2AB, and the recent ones are highly variable. Overall the survey results indicate little or no difference in abundance between 1985 and now, but the scatter makes any conclusion questionable. Meanwhile the commercial catch rates are very consistent in showing a decline of about one-third between 1985 and now (Fig. 4b, center right panel), and this is what the model fit reflects, estimating a variable ebio of 48 M lb (56 M fixed) in 2001.

Estimates of recent recruitment in 2C are substantially higher than in 2AB, but this difference will diminish in the future if year-class strengths turn out to be similar in 2AB and 2C, as they have in the past.

## Assessment results for Area 3A

Survey and commercial catch rates agree quite well in 3A, survey values declining 20-25% from the 1985 level of 150 M lb and commercial values 10-15% (Fig. 3, center panels). The model estimate of 111 M lb is 25% below the 1985 level. This may be a little low; on the other hand the high survey value in 2000 appears anomalously high, and it is propping up the estimate to some extent. In terms of fixed ebio, the 2001 estimate is 139 M lb.

Adding this year's commercial and survey data increased the estimate of fixed ebio at the beginning of 2000 from 116 to 144 M lb. This resulted from a general increase in the estimated abundance of younger fish—up to age 13 or so (Fig. 5). These are the 1987 and later year-classes.

Estimates of recent recruitment in Area 3A are still low but not dismal (near the 1974 level) as in last year's assessment.

## Extrapolation to Areas 3B and 4

In Areas 3B and 4, exploitation rates were very low until recently and there are no survey data before 1996. Exploitable biomass in those areas is estimated by extrapolating the analytical estimate of abundance in Area 3A to each area on the basis of total bottom area (0-500 fathoms) and a forward-weighted average of recent survey catch rates relative to 3A. The scaling factors this year are very similar to last year's (3B = 94% of 3A; each of 4A, 4B and 4CDE = 35-40% of 3A) , but the estimates of exploitable biomass are all substantially higher because the 3A estimate is substantially higher (Table 2).

## Quality of the fits

The 2000 assessment model is fitted to the commercial catch at age, commercial CPUE at age, and survey CPUE at age. The commercial catch at age is fitted quite well by this model, as would be expected because commercial catchability and individual age-specific selectivities are allowed to drift over years. They are not allowed to drift very fast, and commercial catchability does not drift very far, but there is enough flexibility to assure good fits to the commercial catch at age. The commercial CPUE at age is also fitted well in most years, partly because of the flexibility in the parameters and partly because it varies smoothly over time. The fit to commercial CPUE at age in Area 3A is shown as an example in Fig. 6.

Survey CPUE is much more variable than commercial CPUE, both overall and at age, and the model fits are not as close. In Areas 2AB and 2C, fits to the surveys in the mid-1990s (when survey CPUE was high) are poor, but the 1998-2000 surveys are all fitted pretty well (Fig. 7A & 7b). In Area 3A the fit is poor in most years, and the survey signal from the large 1987 year-class has been particularly variable—high in 1995 and 1997, low in 1999, high again in 2000 (Fig. 7c). The 1999 and 2000 surveys are at odds with respect to the 1987-1990 year-classes. These mixed signals contribute to the variability of the 3A assessment and in particular the large increase in estimated abundance due to addition of the 2000 data.

## Year-to-year continuity

Year-to-year changes in abundance estimates obtained with a given model result in part from real changes in the stock but mostly from variability in the assessment data and consequently the model fit.

All recent assessments have shown a gradually increasing trend in abundance in Area 2AB, but the estimate of abundance in 1997 in the present assessment based on data through 2000 is about 30 M lb less than the estimate obtained by fitting the same model to data through 1996 (Fig. 8, top panel). The reason for the large decrease in the estimate for this area is the recent pattern of survey catch rates, with high values in 1995-1997 followed by much lower values in 1998-2000. The model fit to data through 1996 or 1997 is influenced by the high survey values, but as soon as the survey catch rate drops the estimate drops. The same pattern is seen for the same reason in Area 2C (Fig. 8, middle panel).

In Area 3A the year-to-year variability is not as large in relative terms, but as noted above the estimate of (fixed) exploitable biomass in 2000 did increase by 30 M lb when the 2000 data were brought into the fit. In past years the 3A assessment has shown a retrospective pattern, with the estimated stock trajectory tending to rise with each addition of another year of data. This is still the case when variable ebio or legal-sized biomass is plotted, but fixed ebio does not show a consistent retrospective pattern in fits of the 2000 model (Fig. 8, bottom panel).

## References

Chen, D.G., and W.G. Clark. 2001. Survey bait comparison. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2000 (this volume).

Clark, W.G., and A.M. Parma. 2000. Assessment of the Pacific halibut stock in 1999. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1999:109-137.

**Table 1. Changes in biomass estimates due to various changes in the assessment between 1999 and 2000. The value shown is exploitable biomass calculated with the fixed commercial selectivities.**

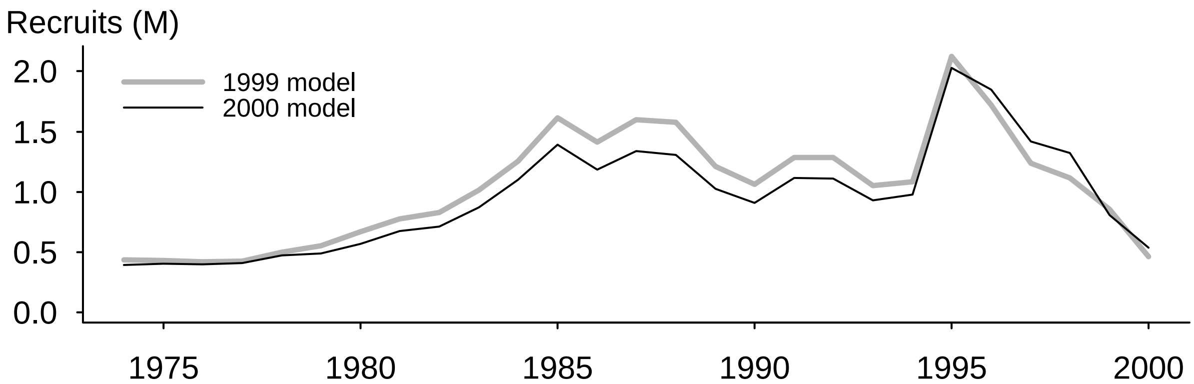
| Assessment | Area 2AB | Area 2C | Area 3A |
|---|---|---|---|
| **1999 assessment:** Estimate of ebio in 2000 using 1999 model with bait adjustment and data through 1999. | 54.0 | 42.2 | 93.3 |
| **1999 assessment with 2000 model:** Estimate of ebio in 2000 using 2000 model with bait adjustment and data though 1999. | 52.0 | 40.1 | 90.1 |
| **Remove bait adjustment:** Estimate of ebio in 2000 using 2000 model with no bait adjustment and data through 1999. | 69.5 | 55.7 | 115.6 |
| **Add 2000 data:** Estimate of ebio in 2000 using 2000 model with no bait adjustment and data through 2000. | 68.4 | 55.1 | 144.4 |
| **2000 assessment:** Estimate of ebio in 2001 using 2000 model with no bait adjustment and data through 2000. | 67.6 | 56.4 | 138.7 |

**Table 2. Removals in 2000 and CEY in 2001 (in millions of net pounds).**

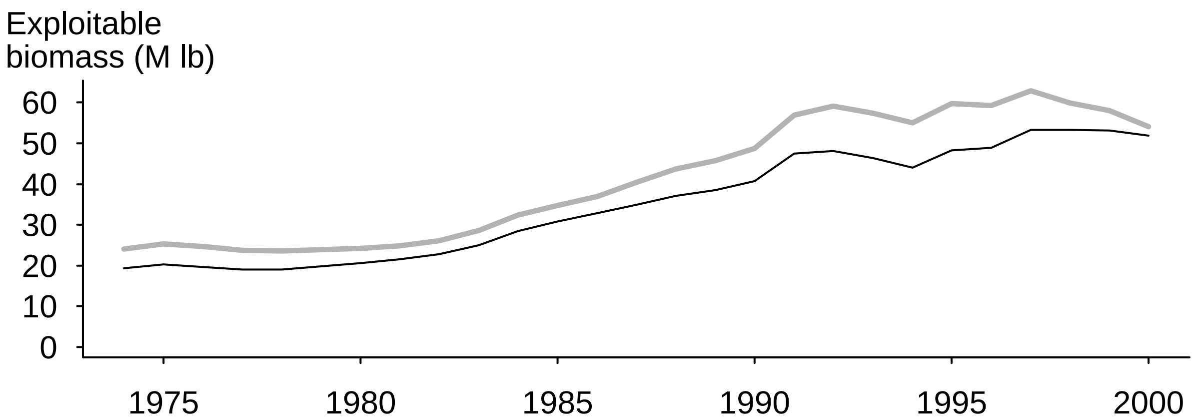
| Area | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **2000 catch limit** | 0.83[1] | 10.60 | 8.40 | 18.31 | 15.03 | 4.97 | 4.91 | 4.45 | 67.50 |
| | | | | | | | | | |
| **2000 commercial landings** | 0.46 | 10.78 | 8.46 | 19.33 | 15.44 | 5.04 | 4.71 | 4.04 | 68.26 |
| **Other removals** | | | | | | | | | |
| Sport catch | 0.34 | 1.58 | 1.98 | 4.60 | 0.02 | 0.10 | — | — | 8.62 |
| Legal-sized bycatch | 0.34 | 0.14 | 0.23 | 1.21 | 0.58 | 0.52 | 0.20 | 2.55 | 5.77 |
| Personal use | 0.00 | 0.30 | 0.17 | 0.07 | 0.02 | 0.09 | 0.00 | 0.08 | 0.73 |
| Legal-sized wastage | 0.01 | 0.03 | 0.04 | 0.03 | 0.05 | 0.03 | 0.03 | 0.03 | 0.25 |
| Total other removals | 0.69 | 2.05 | 2.42 | 5.91 | 0.67 | 0.74 | 0.23 | 2.66 | 15.37 |
| **Total removals** | 1.15 | 12.83 | 10.88 | 25.24 | 16.11 | 5.78 | 4.94 | 6.70 | 83.63 |
| | | | | | | | | | |
| **2001 exploitable biomass** | 7.44 | 60.18 | 56.00 | 139.00 | 130.66 | 52.82 | 51.43 | 51.43 | 548.96 |
| **2001 total CEY** | 1.49 | 12.04 | 11.20 | 27.80 | 26.13 | 10.56 | 10.29 | 10.29 | 109.80 |
| **2001 setline CEY** | 1.14[1] | 9.99[2] | 8.78 | 21.89 | 25.46 | 9.82 | 10.06 | 7.63 | 94.77 |

[1] Catch limit and setline CEY include sport catch in Area 2A only.

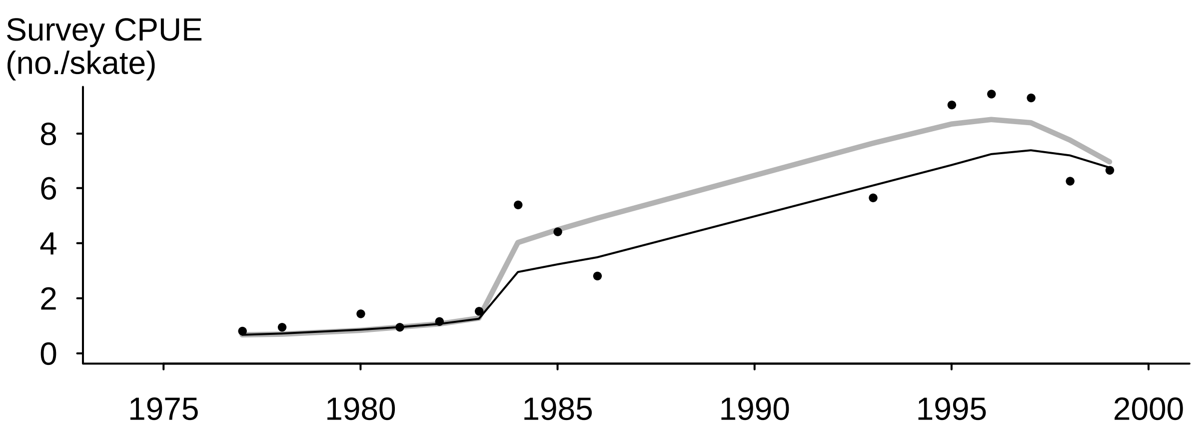
[2] With the lower series of 2B sport catch estimates (including 0.887 M lb in recent years), 2AB exploitable biomass is 66.71 instead of 67.62 as in the table. With 11% of the total in 2A, this change results in a 2001 setline CEY of 1.12 M lb in 2A and 10.51 M lb in 2B.




Estimated recruitment at age 8.

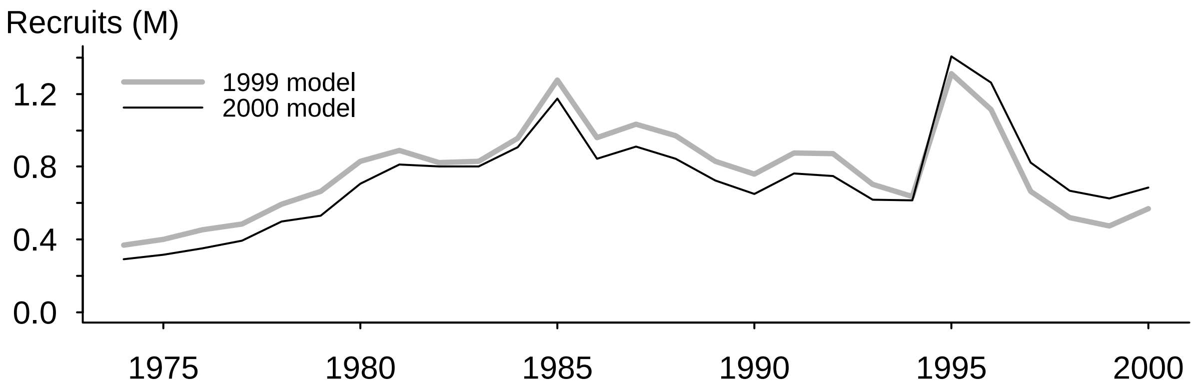



Estimated exploitable biomass (using 1999 fixed selectivities).

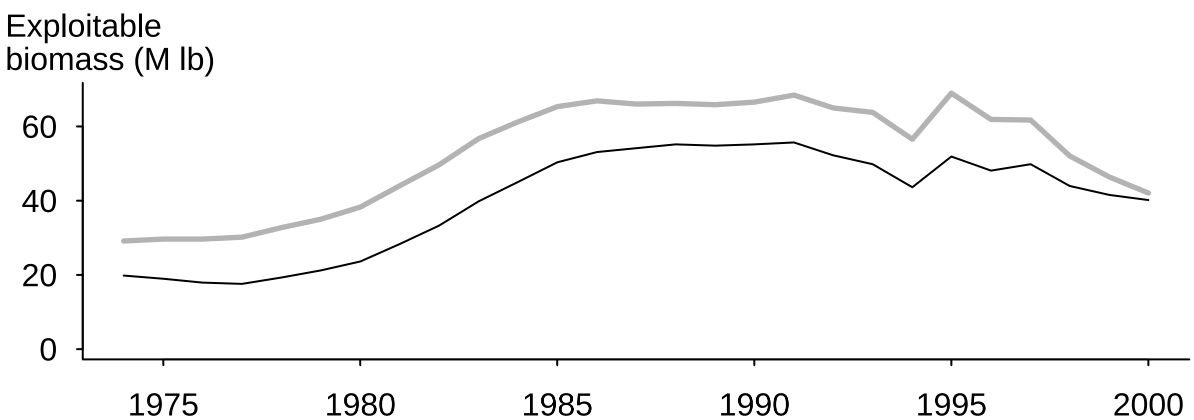



Survey CPUE (points) and model predictions (lines).

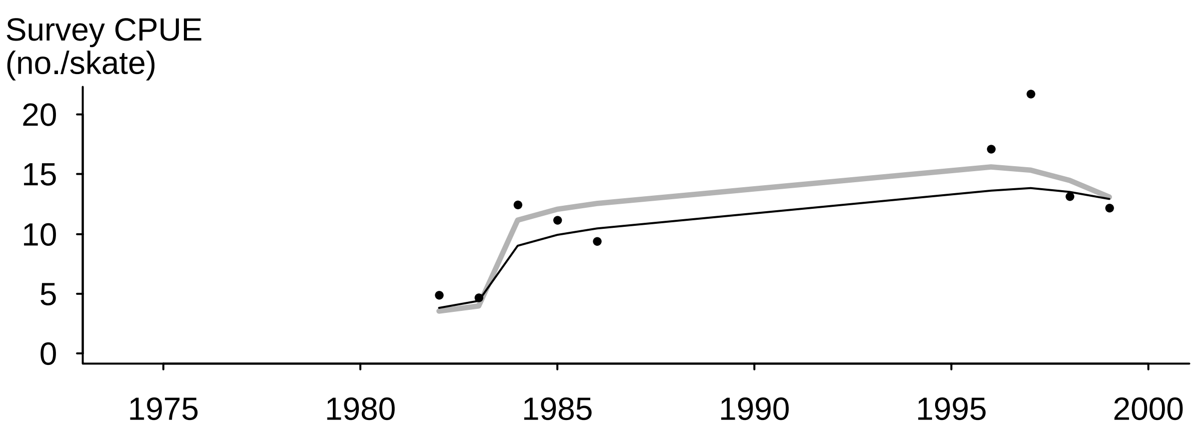
**Figure 1a. Fits of the 1999 model and the 2000 model (both with the bait adjustment) to Area 2AB data through 1999.**




Estimated recruitment at age 8.

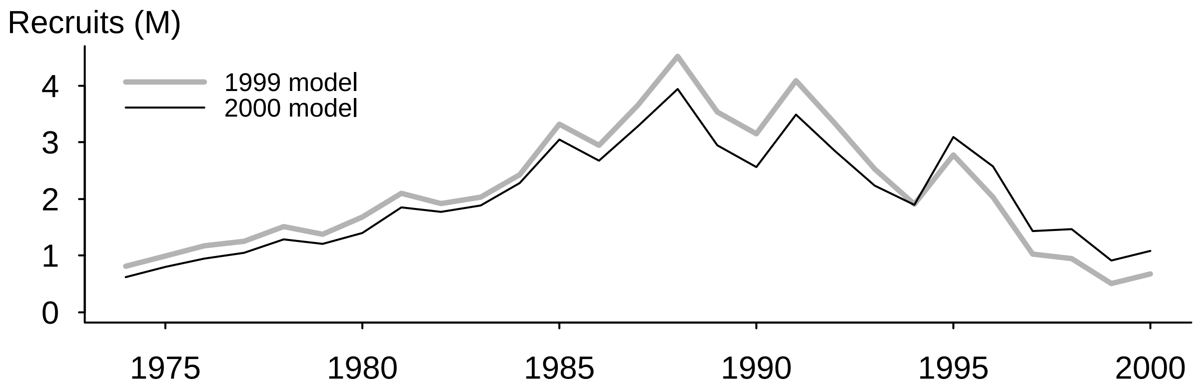



Estimated exploitable biomass (using 1999 fixed selectivities).

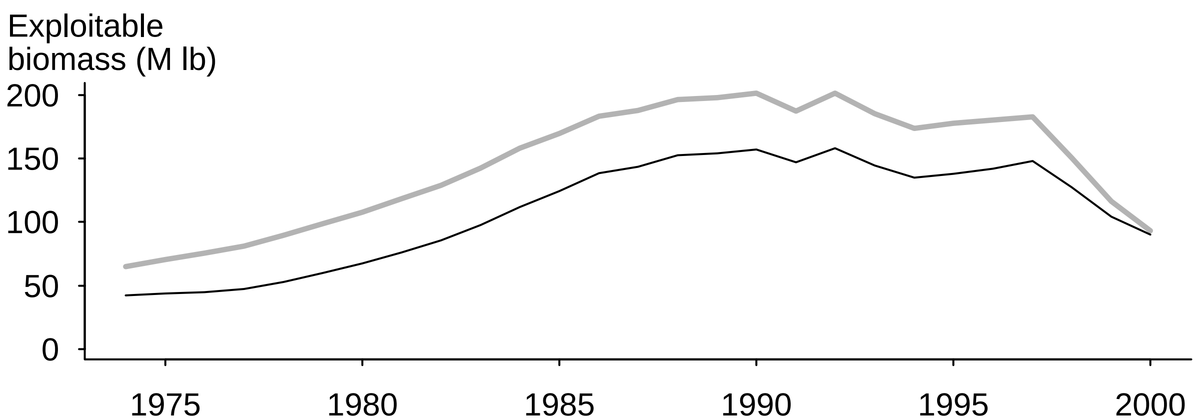



Survey CPUE (points) and model predictions (lines).

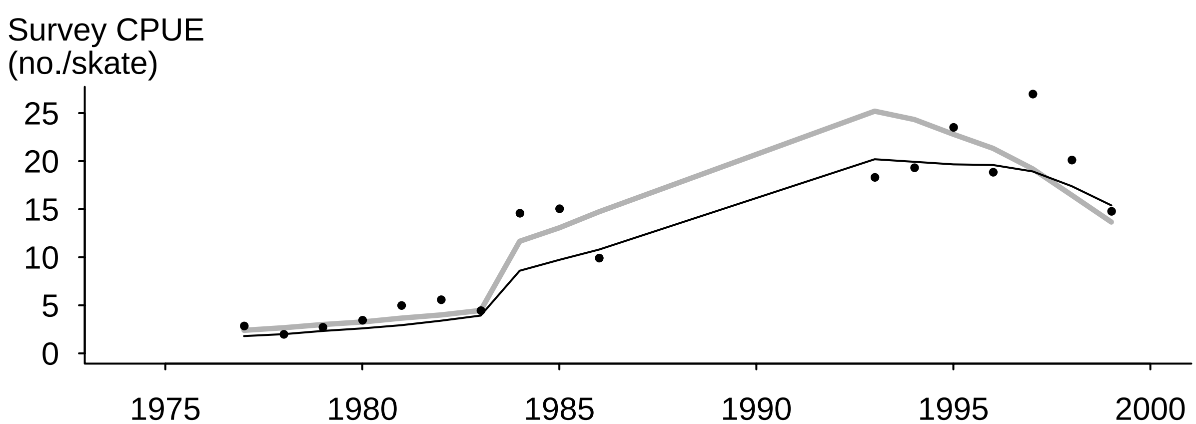
**Figure 1b. Fits of the 1999 model and the 2000 model (both with the bait adjustment) to Area 2C data through 1999.**




Estimated recruitment at age 8.




Estimated exploitable biomass (using 1999 fixed selectivities).




Survey CPUE (points) and model predictions (lines).

**Figure 1c. Fits of the 1999 model and the 2000 model (both with the bait adjustment) to Area 3A data through 1999.**

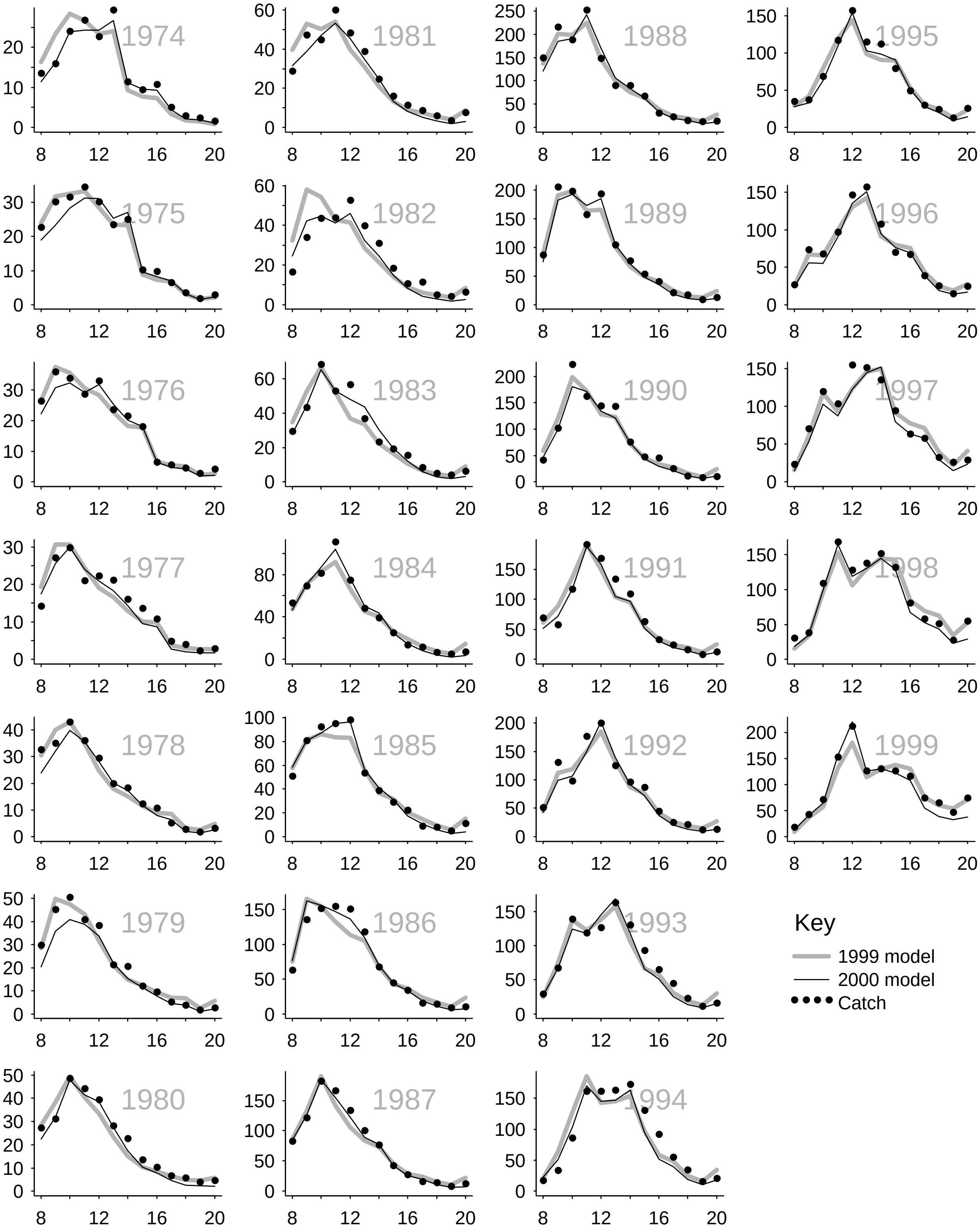



**Figure 2. Actual (estimated) catch at age and predicted catch at age in fits of the 1999 model (gray lines) and the 2000 model to Area 3A data through 1999.**

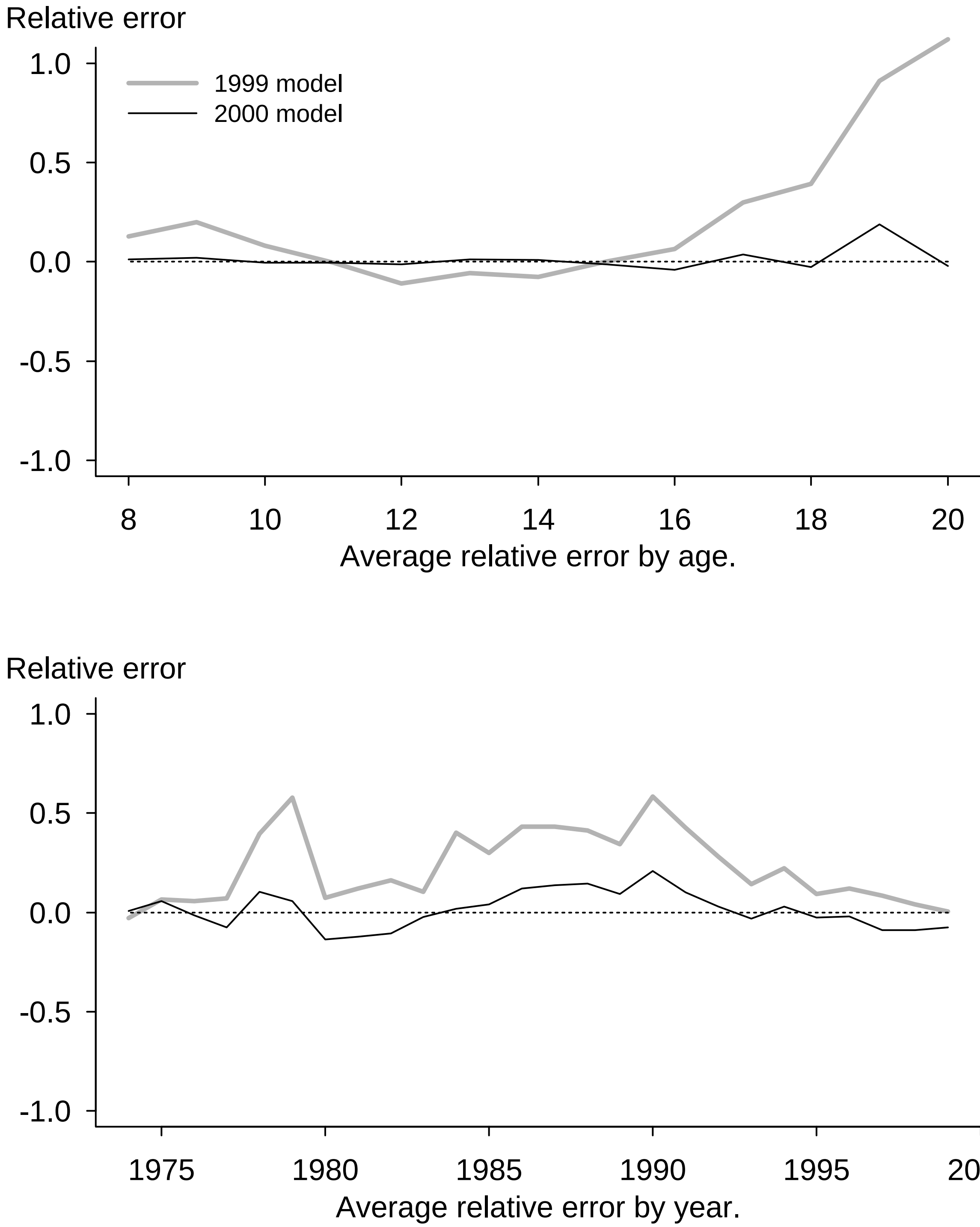



**Figure 3. Relative errors in the predicted catch at age in fits of the 1999 model (gray lines) and the 2000 model (black lines) to data from Area 3A through 1999.**

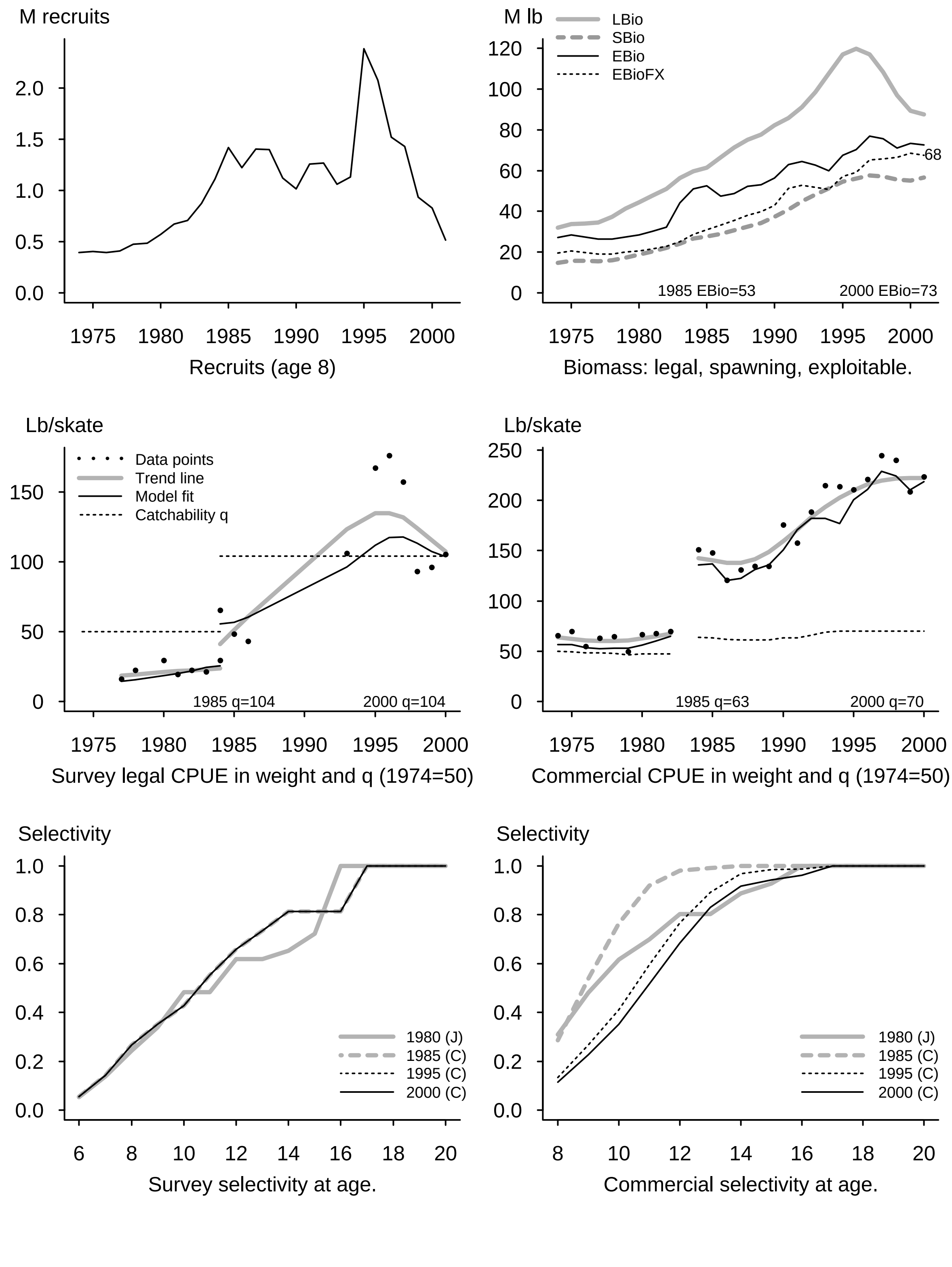



**Figure 4a. Fit of the standard assessment model in Area 2AB.**

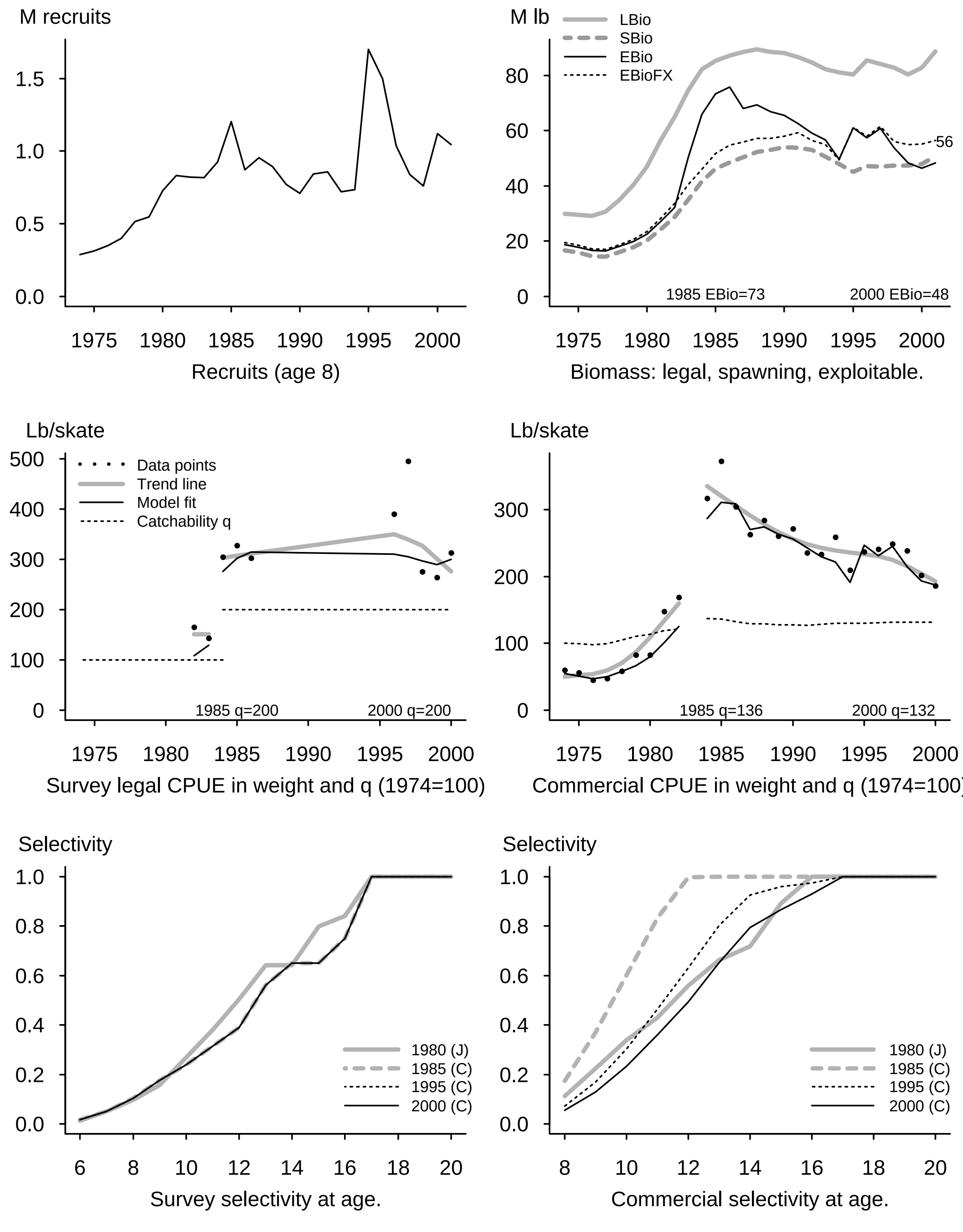



**Figure 4b. Fit of the standard model in Area 2C.**

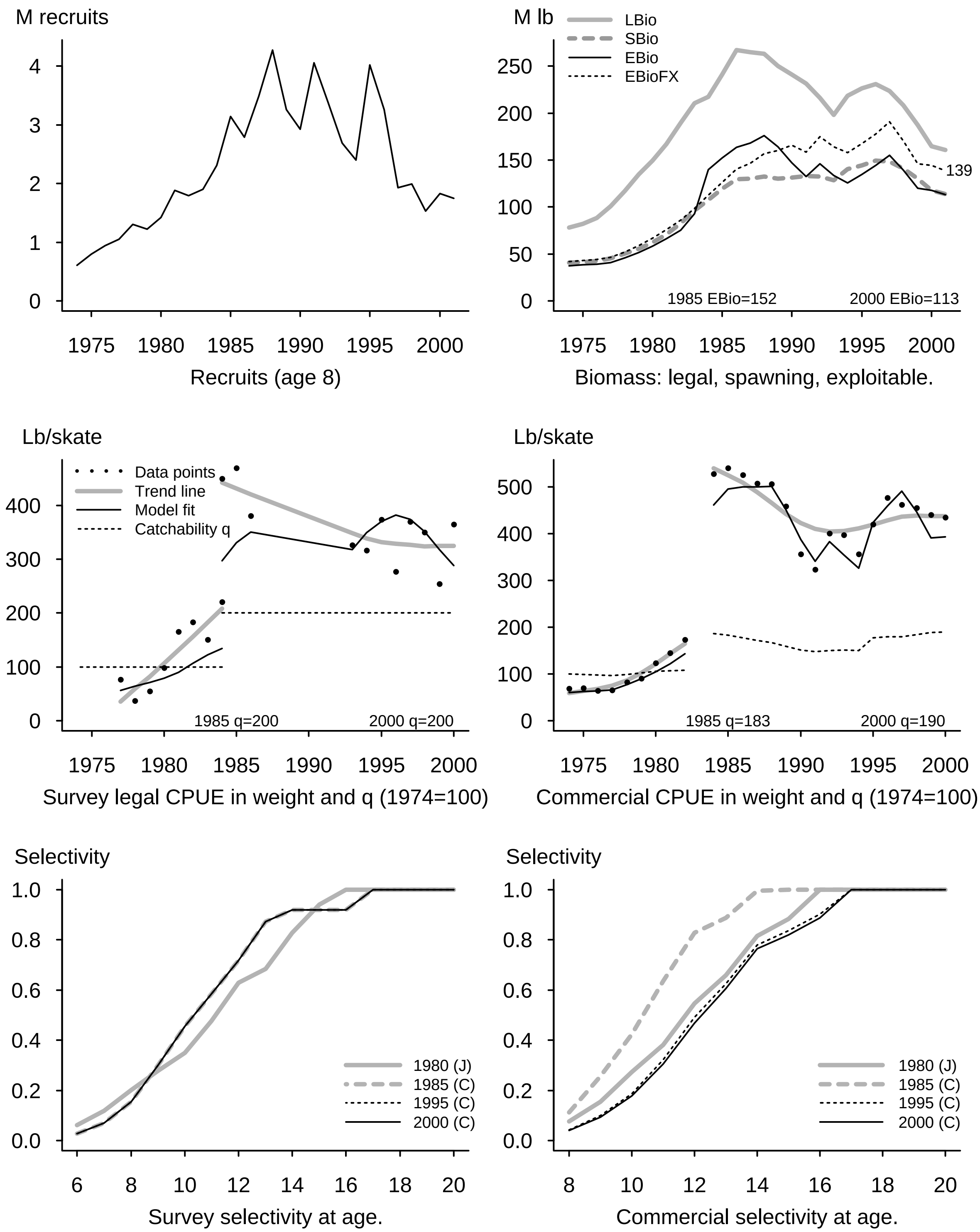



**Figure 4c. Fit of the standard model in Area 3A.**

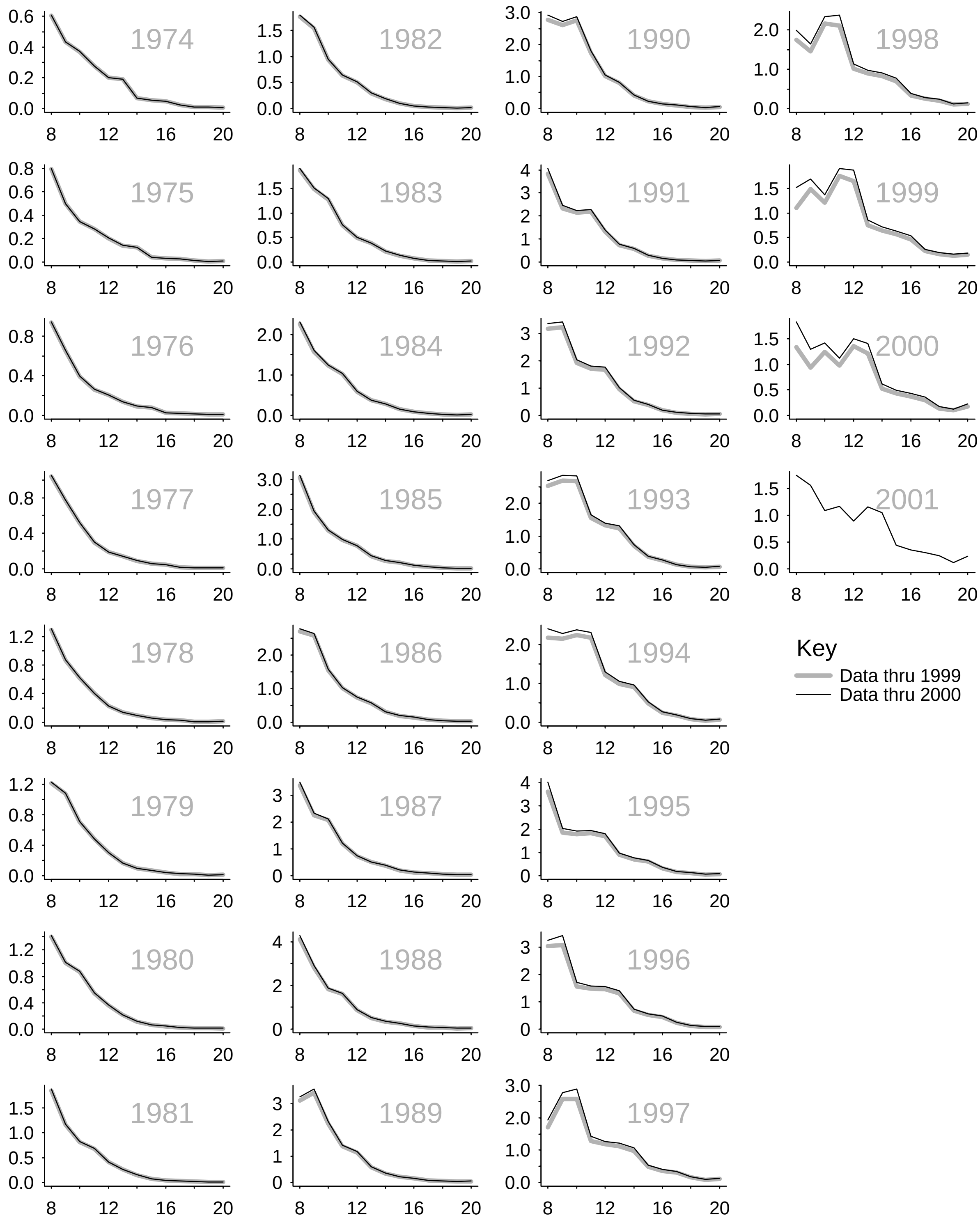



**Figure 5. Estimates of abundance at age (millions) in Area 3A in model fits using data through 1999 (gray line) and 2000 (black line).**

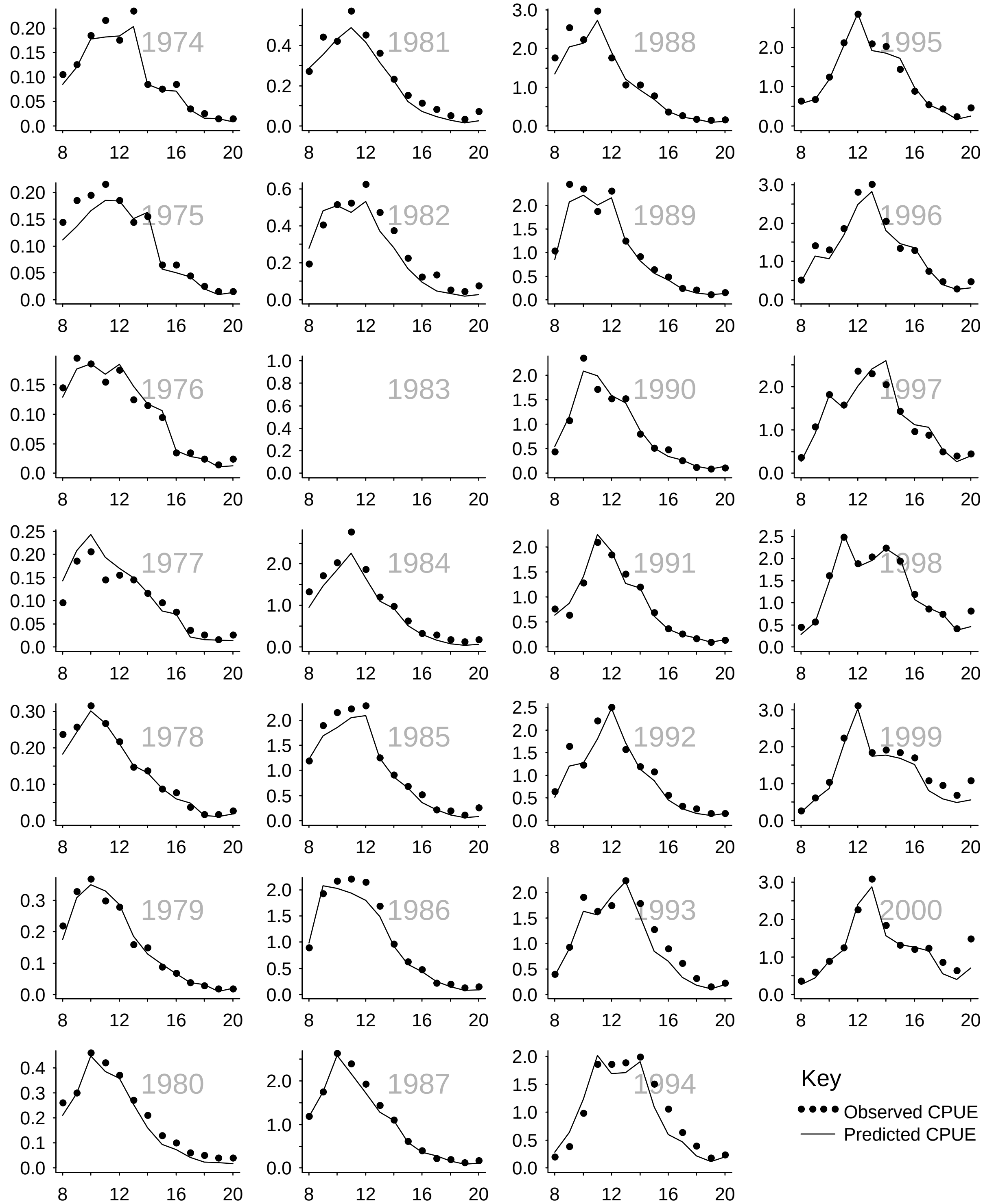



**Figure 6. Observed and predicted commercial CPUE at age (no./skate) in Area 3A.**

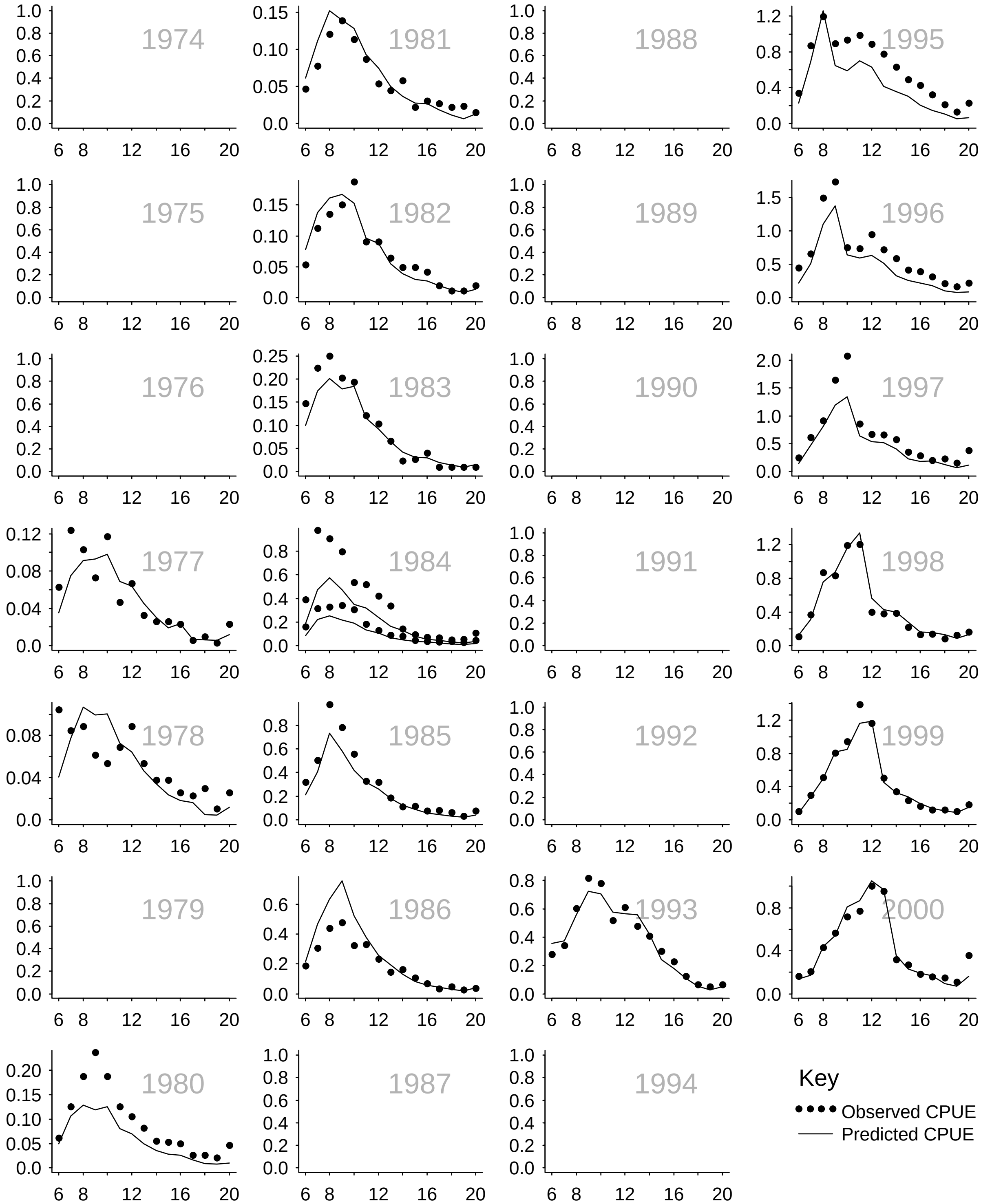



**Figure 7a. Observed and predicted survey CPUE at age (no./skate) in Area 2B. In 1984 the survey was done once with J-hooks and once with C-hooks.**

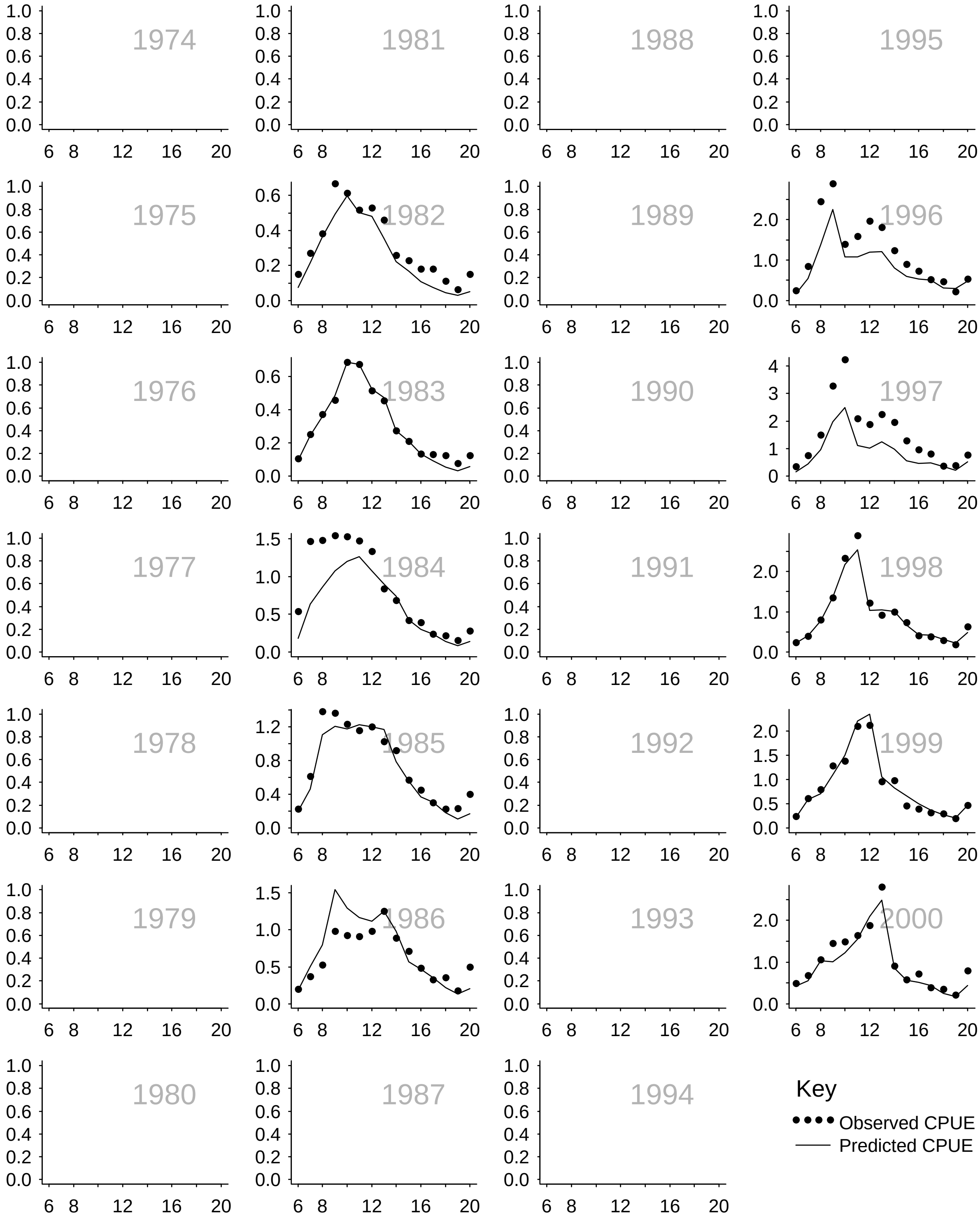



**Figure 7b. Observed and predicted survey CPUE at age (no./skate) in Area 2C.**

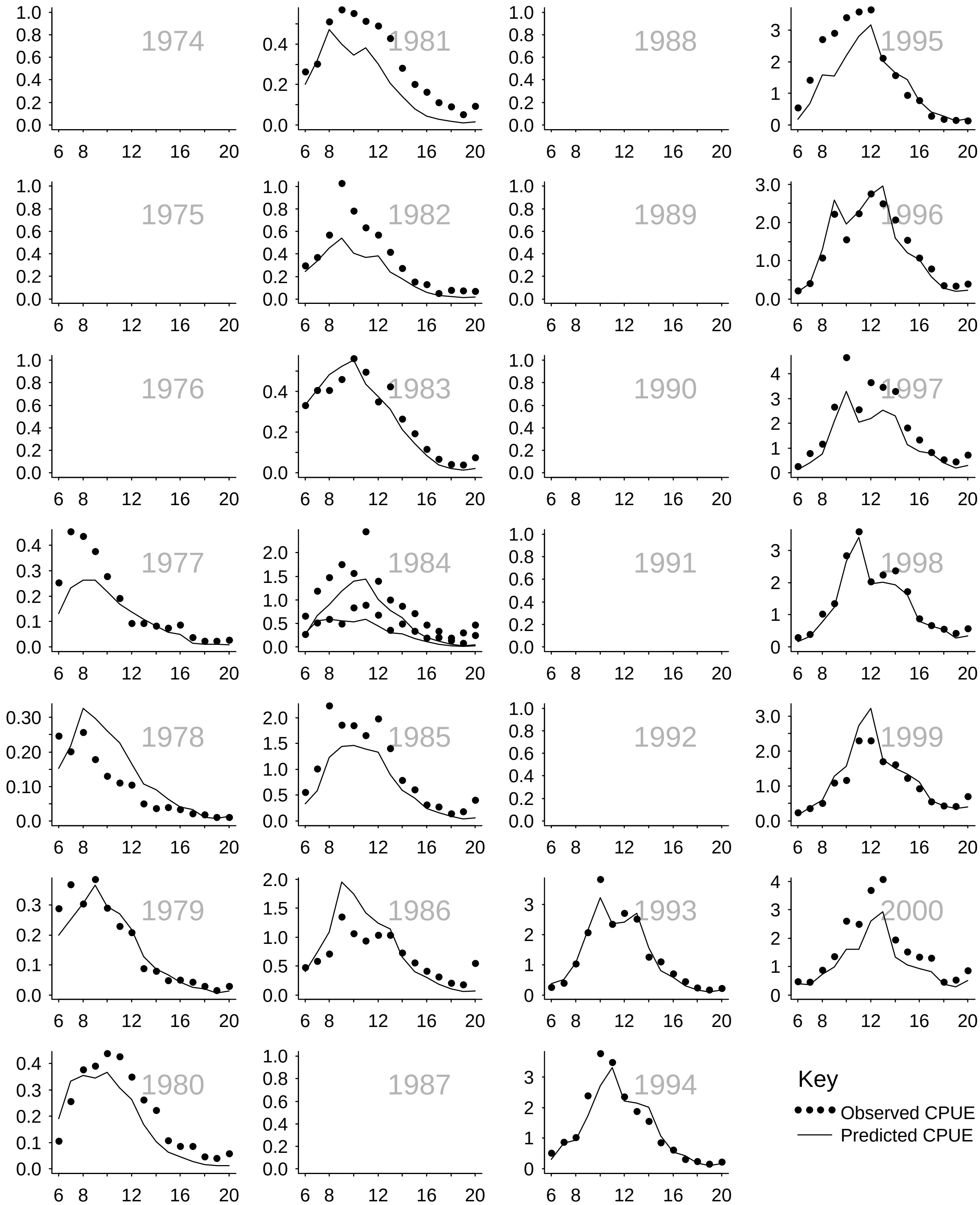



**Figure 7c. Observed and predicted survey CPUE at age (no./skate) in Area 3A. In 1984 the survey was done once with J-hooks and once with C-hooks.**

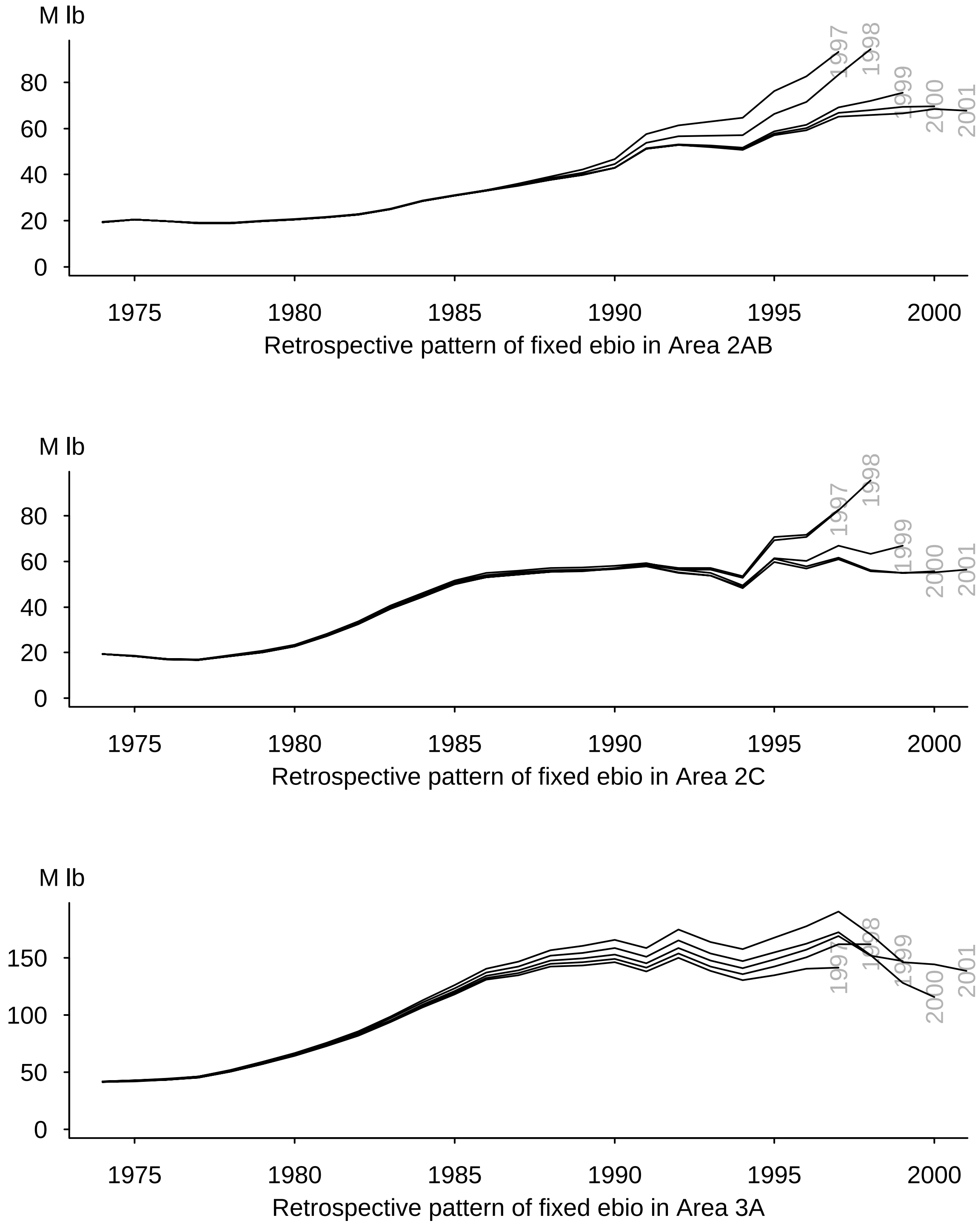



**Figure 8. Year-to-year changes in the estimate of fixed ebio due to the addition of another year of data. The year plotted vertically is the year of the estimate; e.g., 1997 indicates an estimate of abundance in 1997 based on data from 1974-1996.**

## Appendix A. Selected fishery and survey data summaries.

**Table A1. Commercial catch (million pounds, net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | 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 |

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1981** | 0.20 | 5.66 | 4.01 | 14.23 | 0.45 | 0.49 | 0.39 | 0.30 | 0.01 | 0.00 | 25.74 |
| **1982** | 0.21 | 5.54 | 3.50 | 13.52 | 4.80 | 1.17 | 0.01 | 0.24 | 0.00 | 0.01 | 29.01 |
| **1983** | 0.27 | 5.44 | 6.38 | 14.13 | 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 | 11.23 | 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 | 0.09 | 69.45 |
| **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 | 33.73 | 7.84 | 1.02 | 2.65 | 0.57 | 0.67 | 0.01 | 66.95 |
| **1990** | 0.33 | 8.57 | 9.73 | 28.85 | 8.69 | 2.50 | 1.33 | 0.53 | 1.01 | 0.06 | 61.60 |
| **1991** | 0.35 | 7.19 | 8.69 | 22.93 | 11.93 | 2.25 | 1.51 | 0.68 | 1.44 | 0.10 | 57.08 |
| **1992** | 0.43 | 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 | 0.71 | 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 | 9.55 | 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 | 13.15 | 10.20 | 25.70 | 11.16 | 3.42 | 2.90 | 1.26 | 1.31 | 0.19 | 69.74 |
| **1999** | 0.45 | 12.70 | 10.17 | 25.29 | 13.83 | 4.37 | 3.57 | 1.76 | 1.89 | 0.26 | 74.31 |
| **2000** | 0.46 | 10.78 | 8.46 | 19.33 | 15.44 | 5.04 | 4.71 | 1.75 | 1.95 | 0.35 | 68.27 |

**Table A2. Bycatch mortality of legal-sized halibut (80+ cm; in million pounds net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | Total |
|---|---|---|---|---|---|---|---|
| **1974** | 0.25 | 0.90 | 0.37 | 4.48 | 2.82 | 1.90 | 10.71 |
| **1975** | 0.25 | 0.90 | 0.45 | 2.61 | 1.66 | 1.10 | 6.98 |
| **1976** | 0.25 | 0.94 | 0.50 | 2.74 | 1.94 | 1.18 | 7.56 |
| **1977** | 0.25 | 0.73 | 0.41 | 3.37 | 1.55 | 1.98 | 8.27 |
| **1978** | 0.25 | 0.55 | 0.21 | 2.44 | 1.31 | 3.40 | 8.16 |
| **1979** | 0.25 | 0.69 | 0.64 | 4.49 | 0.69 | 3.45 | 10.21 |
| **1980** | 0.25 | 0.51 | 0.42 | 4.93 | 0.87 | 5.71 | 12.69 |
| **1981** | 0.25 | 0.53 | 0.40 | 3.99 | 1.09 | 4.37 | 10.64 |
| **1982** | 0.25 | 0.30 | 0.20 | 3.20 | 1.68 | 2.95 | 8.58 |
| **1983** | 0.25 | 0.29 | 0.20 | 2.08 | 1.22 | 2.47 | 6.51 |
| **1984** | 0.25 | 0.52 | 0.21 | 1.51 | 0.92 | 2.29 | 5.70 |
| **1985** | 0.25 | 0.55 | 0.20 | 0.80 | 0.34 | 2.25 | 4.39 |
| **1986** | 0.25 | 0.56 | 0.20 | 0.67 | 0.20 | 2.62 | 4.50 |
| **1987** | 0.25 | 0.79 | 0.20 | 1.59 | 0.40 | 2.68 | 5.91 |
| **1988** | 0.25 | 0.77 | 0.20 | 2.13 | 0.04 | 3.27 | 6.67 |
| **1989** | 0.25 | 0.72 | 0.20 | 1.80 | 0.44 | 1.95 | 5.37 |
| **1990** | 0.25 | 1.03 | 0.67 | 2.63 | 1.21 | 4.15 | 9.96 |
| **1991** | 0.25 | 1.22 | 0.55 | 3.12 | 1.03 | 2.91 | 9.09 |
| **1992** | 0.28 | 1.02 | 0.57 | 2.65 | 1.12 | 3.34 | 8.97 |
| **1993** | 0.28 | 0.65 | 0.33 | 1.92 | 0.47 | 2.01 | 5.65 |
| **1994** | 0.28 | 0.57 | 0.40 | 2.35 | 0.85 | 3.48 | 7.93 |
| **1995** | 0.38 | 0.71 | 0.22 | 1.46 | 0.82 | 3.21 | 6.80 |
| **1996** | 0.38 | 0.17 | 0.23 | 1.40 | 0.96 | 3.57 | 6.71 |
| **1997** | 0.38 | 0.11 | 0.24 | 1.55 | 0.73 | 3.80 | 6.81 |
| **1998** | 0.38 | 0.12 | 0.24 | 1.47 | 0.73 | 3.72 | 6.66 |
| **1999** | 0.34 | 0.11 | 0.23 | 1.28 | 0.74 | 3.33 | 6.04 |
| **2000** | 0.34 | 0.14 | 0.23 | 1.21 | 0.58 | 3.28 | 5.77 |

**Table A3. Total removals: commercial catch + sport catch + legal-sized wastage + legal-sized bycatch + personal use (millions of pounds net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | Total |
|---|---|---|---|---|---|---|---|
| **1974** | 0.77 | 5.52 | 5.97 | 12.67 | 4.48 | 2.61 | 32.02 |
| **1975** | 0.71 | 8.03 | 6.69 | 13.21 | 4.22 | 1.73 | 34.60 |
| **1976** | 0.49 | 8.22 | 6.03 | 13.78 | 4.67 | 1.90 | 35.10 |
| **1977** | 0.48 | 6.17 | 3.67 | 12.20 | 4.73 | 3.20 | 30.45 |
| **1978** | 0.36 | 5.17 | 4.62 | 13.02 | 2.63 | 4.75 | 30.55 |
| **1979** | 0.32 | 5.57 | 5.34 | 16.19 | 1.08 | 4.82 | 33.32 |
| **1980** | 0.29 | 6.18 | 3.99 | 17.39 | 1.15 | 6.42 | 35.41 |
| **1981** | 0.47 | 6.21 | 4.73 | 18.96 | 1.54 | 5.57 | 37.48 |
| **1982** | 0.51 | 5.91 | 4.19 | 17.44 | 6.48 | 4.39 | 38.92 |
| **1983** | 0.58 | 5.83 | 7.15 | 17.14 | 8.97 | 6.89 | 46.56 |
| **1984** | 0.80 | 9.69 | 6.68 | 22.50 | 7.42 | 5.47 | 52.56 |
| **1985** | 0.94 | 11.57 | 10.31 | 23.79 | 11.43 | 6.69 | 64.71 |
| **1986** | 1.17 | 12.35 | 11.97 | 37.23 | 9.43 | 8.53 | 80.68 |
| **1987** | 1.29 | 13.74 | 12.03 | 36.48 | 8.50 | 9.84 | 81.88 |
| **1988** | 0.99 | 14.19 | 12.85 | 44.76 | 7.24 | 8.06 | 88.10 |
| **1989** | 1.05 | 11.83 | 11.48 | 40.00 | 8.47 | 7.03 | 79.87 |
| **1990** | 0.78 | 10.44 | 11.98 | 36.02 | 10.12 | 9.84 | 79.17 |
| **1991** | 0.77 | 9.10 | 11.96 | 32.35 | 13.46 | 9.48 | 77.12 |
| **1992** | 0.97 | 9.38 | 12.68 | 34.46 | 9.98 | 10.23 | 77.69 |
| **1993** | 1.05 | 12.33 | 13.74 | 30.59 | 8.46 | 8.55 | 74.72 |
| **1994** | 0.83 | 11.51 | 13.11 | 32.86 | 4.83 | 9.12 | 72.26 |
| **1995** | 0.92 | 12.25 | 9.79 | 24.52 | 4.01 | 8.11 | 59.60 |
| **1996** | 0.91 | 11.63 | 11.27 | 26.11 | 4.70 | 9.13 | 63.75 |
| **1997** | 1.16 | 14.45 | 12.37 | 31.86 | 9.92 | 12.83 | 82.59 |
| **1998** | 1.23 | 15.20 | 12.97 | 32.13 | 12.00 | 13.04 | 86.56 |
| **1999** | 1.14 | 14.73 | 12.48 | 30.99 | 14.69 | 15.54 | 89.57 |
| **2000** | 1.15 | 12.82 | 10.87 | 25.24 | 16.11 | 17.42 | 83.61 |

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

Values before 1984 are multiplied by the J-C hook adjustment for catch in weight of legal-sized fish (2.2). 1983 is excluded because it consists of a mixture of J- and C-hook data. No value is shown for area/years after 1980 with fewer than 500 skates of reported catch/effort data.

| | 2A | 2B | 2C | 3A | 3B | 4 |
|---|---|---|---|---|---|---|
| **1974** | 131 | 141 | 126 | 142 | 125 | 301 |
| **1975** | 131 | 149 | 117 | 145 | 149 | 211 |
| **1976** | 72 | 117 | 93 | 131 | 142 | 184 |
| **1977** | 182 | 135 | 99 | 135 | 161 | 176 |
| **1978** | 86 | 138 | 124 | 172 | 116 | 167 |
| **1979** | 110 | 106 | 177 | 189 | 81 | 146 |
| **1980** | 82 | 144 | 175 | 261 | 249 | 124 |

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D | 4E |
|---|---|---|---|---|---|---|---|---|---|---|
| **1981** | --- | 146 | 318 | 312 | --- | --- | 217 | 243 | --- | --- |
| **1982** | --- | 149 | 366 | 375 | 478 | 226 | --- | 199 | --- | --- |
| **1983** | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1984** | 69 | 149 | 314 | 524 | 475 | 366 | 161 | --- | 197 | --- |
| **1985** | 69 | 146 | 370 | 536 | 602 | 333 | 234 | --- | 330 | --- |
| **1986** | 61 | 119 | 302 | 522 | 515 | 265 | --- | 427 | 238 | --- |
| **1987** | 59 | 129 | 260 | 504 | 476 | 341 | 220 | 384 | --- | --- |
| **1988** | 171 | 133 | 281 | 503 | 655 | 453 | 224 | --- | 201 | --- |
| **1989** | 124 | 133 | 258 | 455 | 590 | 409 | 268 | 331 | 384 | --- |
| **1990** | 168 | 174 | 269 | 353 | 484 | 434 | 208 | 288 | 381 | --- |
| **1991** | 164 | 156 | 233 | 319 | 466 | 471 | 329 | 223 | 398 | --- |
| **1992** | 114 | 187 | 230 | 397 | 440 | 372 | 278 | 249 | 412 | --- |
| **1993** | 155 | 213 | 256 | 393 | 514 | 463 | 218 | 256 | 851 | --- |
| **1994** | 97 | 212 | 207 | 354 | 377 | 463 | 198 | 167 | 480 | --- |
| **1995** | 132 | 209 | 234 | 416 | 476 | 349 | 189 | --- | 475 | --- |
| **1996** | 168 | 219 | 238 | 473 | 556 | 515 | 269 | --- | --- | --- |
| **1997** | 216 | 243 | 246 | 458 | 562 | 482 | 275 | 335 | 671 | --- |
| **1998** | 197 | 238 | 236 | 451 | 611 | 525 | 287 | 287 | 627 | --- |
| **1999** | 311 | 207 | 199 | 437 | 538 | 498 | 310 | 270 | 535 | --- |
| **2000** | --- | 222 | 182 | 431 | 577 | 532 | 319 | 226 | 565 | --- |

**Table A5. IPHC setline survey CPUE of legal sized fish in weight (net pounds per skate).**

Series refer to standard survey areas: all of 2A, 2B north of Vancouver Is., outside stations in 2C, 3A west of 147°W, all of 3B, the Aleutian portion of 4A, all of 4B, 4C, and 4D. *No adjustments* are applied; values before 1984 are raw J-hook catch rates.

**J-hook surveys**

| | 2A | 2B | 2C | 3A |
|---|---|---|---|---|
| **1974** | --- | --- | --- | --- |
| **1975** | --- | --- | --- | --- |
| **1976** | --- | --- | --- | --- |
| **1977** | --- | 15 | --- | 73 |
| **1978** | --- | 21 | --- | 34 |
| **1979** | --- | --- | --- | 51 |
| **1980** | --- | 28 | --- | 95 |
| **1981** | --- | 18 | --- | 162 |
| **1982** | --- | 21 | 162 | 180 |
| **1983** | --- | 20 | 140 | 147 |

**C-hook surveys**

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4C | 4D |
|---|---|---|---|---|---|---|---|---|---|
| **1984** | --- | 64 | 301 | 446 | --- | --- | --- | --- | --- |
| **1985** | --- | 47 | 324 | 466 | --- | --- | --- | --- | --- |
| **1986** | --- | 42 | 299 | 377 | --- | --- | --- | --- | --- |
| **1987** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1988** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1989** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1990** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1991** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1992** | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1993** | --- | 105 | --- | 323 | --- | --- | --- | --- | --- |
| **1994** | --- | --- | --- | 313 | --- | --- | --- | --- | --- |
| **1995** | 29 | 166 | --- | 370 | --- | --- | --- | --- | --- |
| **1996** | --- | 175 | 387 | 273 | 352 | --- | --- | --- | --- |
| **1997** | 35 | 156 | 492 | 366 | 415 | 300 | 282 | 71 | 111 |
| **1998** | --- | 92 | 272 | 346 | 436 | 394 | 216 | --- | --- |
| **1999** | 37 | 95 | 260 | 251 | 441 | 367 | 204 | --- | --- |
| **2000** | --- | 104 | 309 | 361 | 378 | 382 | 218 | --- | 212 |

## Appendix B. Recent changes in assessment methods and harvest policy.

**1982-1994:** stock size was estimated with CAGEAN, a strictly age-structured model fitted to commercial catch-at-age and catch-per-effort data. Because of a decrease in growth rates between the late 1970s and early 1990s, there were persistent underestimates of incoming recruitment and total stock size in the assessments done in the early 1990s.

Until 1985, allowable removals were calculated as a proportion of estimated annual surplus production (ASP), the remaining production being allocated to stock rebuilding. In 1985 the Commission adopted a constant harvest rate policy, meaning that allowable removals are determined by applying a fixed harvest rate to estimated exploitable biomass. This harvest level is called the Constant Exploitation Yield, or CEY. The fixed harvest rate was set at 28% in 1985, increased to 35% in 1987, and lowered to 30% in 1993.

**1995:** a new age- and length-structured model was implemented that accounted for the change in growth and was fitted to survey as well as commercial catch-at-age and catch-per-effort data. The new model produced substantially higher biomass estimates. In Area 3A this resulted from accounting for the change in growth schedule. In Area 2B, where the change in growth had been much less than in Alaska, it resulted from fitting the model to survey catch-per-effort, which showed a larger stock increase since the mid-1980s than commercial catch-per-effort. Quotas were held at the 1995 level to allow time for a complete study of the new model and results,

**1996:** differences in estimated selectivity between British Columbia and Alaska led to the consideration of two alternatives for fitting the model, one in which survey selectivity was a fixed function of age and the other in which it was a function of length. Spawner-recruit estimates from the new model resulted in a lowering of the target harvest rate to 20%. Quotas were increased somewhat, but not to the level indicated by the new biomass estimates.

**1997:** setline surveys of the entire Commission area indicated substantially more halibut in western Alaska (IPHC Areas 3B and 4) than the analytical assessment. Biomass in those areas was estimated by scaling the analytical estimates of absolute abundance in Areas 2 and 3A by the survey estimate of relative abundance in western Alaska. CEY estimates increased again, and quotas were increased again, but still to a level well below the CEY's.

**1998:** the working value of natural mortality was lowered from 0.20 to 0.15, reducing analytical estimates of biomass in Areas 2 and 3A by about 30%. At the same time setline survey estimates of abundance in Areas 3B and 4 relative to Areas 2 and 3A increased, so biomass estimates in the western area decreased by a smaller amount.

**1999:** setline survey catch rates in the 1990s were adjusted downward to account for the effect of changing to all-salmon bait when the surveys resumed in 1993. This reduced biomass estimates by 20-30%.

**2000:** the bait adjustment applied in 1999 was removed, which increased biomass estimates by 30-40%, approximately back to the level in the 1998 assessment. In addition, a purely age-structured model was adopted in place of the age- and size-structured model used in 1995-1999. The 2000 model produced similar estimates of present biomass but lower estimates of historical biomass.

## Appendix C. Selected historical estimates from the 2000 assessment.

The following tables show trends in recruitment, stock size, and exploitation rate estimated with the model used in 2000. Except for the catches, all of these estimates are liable to change in later years, sometimes dramatically, as new data and methods are used in the assessment.

The columns in the tables are:

**R** = age 8 recruits (millions)
**N** = total abundance of age 8+ fish (millions)
**C** = total catch in number of age 8+ fish (million net lb)
**C/N** = exploitation rate in number of age 8+ fish
**B** = total biomass of legal-sized fish (million net lb)
**Y** = total catch in weight of age 8+ fish (million net lb)
**Y/B** = exploitation rate in weight

The "catches" are actually total removals except for bycatch. Total biomass is calculated using estimated mean size at age in the sea rather than in the catch, and is not directly comparable with estimates of exploitable biomass.

**Table C1. Historical estimates for Area 2AB.**

| | R | N | C | C/N | B | Y | Y/B |
|---|---|---|---|---|---|---|---|
| **1974** | 0.39 | 1.42 | 0.13 | 0.09 | 31.87 | 4.27 | 0.13 |
| **1975** | 0.40 | 1.48 | 0.19 | 0.13 | 33.74 | 6.77 | 0.20 |
| **1976** | 0.40 | 1.46 | 0.20 | 0.14 | 34.02 | 6.34 | 0.19 |
| **1977** | 0.41 | 1.45 | 0.16 | 0.11 | 34.50 | 4.91 | 0.14 |
| **1978** | 0.47 | 1.56 | 0.14 | 0.09 | 37.33 | 4.05 | 0.11 |
| **1979** | 0.48 | 1.68 | 0.16 | 0.09 | 41.33 | 4.58 | 0.11 |
| **1980** | 0.57 | 1.84 | 0.18 | 0.10 | 44.52 | 5.30 | 0.12 |
| **1981** | 0.67 | 2.07 | 0.20 | 0.10 | 47.65 | 5.28 | 0.11 |
| **1982** | 0.71 | 2.28 | 0.21 | 0.09 | 51.01 | 5.25 | 0.10 |
| **1983** | 0.88 | 2.64 | 0.21 | 0.08 | 56.24 | 5.21 | 0.09 |
| **1984** | 1.11 | 3.18 | 0.36 | 0.11 | 59.73 | 8.50 | 0.14 |
| **1985** | 1.42 | 3.79 | 0.45 | 0.12 | 61.57 | 10.52 | 0.17 |
| **1986** | 1.22 | 4.05 | 0.48 | 0.12 | 66.42 | 11.46 | 0.17 |
| **1987** | 1.40 | 4.42 | 0.51 | 0.12 | 71.48 | 12.33 | 0.17 |
| **1988** | 1.40 | 4.70 | 0.56 | 0.12 | 75.23 | 13.02 | 0.17 |
| **1989** | 1.12 | 4.62 | 0.44 | 0.10 | 77.74 | 10.76 | 0.14 |
| **1990** | 1.01 | 4.56 | 0.37 | 0.08 | 82.19 | 8.90 | 0.11 |
| **1991** | 1.26 | 4.80 | 0.28 | 0.06 | 85.85 | 7.46 | 0.09 |
| **1992** | 1.27 | 5.11 | 0.31 | 0.06 | 91.04 | 8.03 | 0.09 |
| **1993** | 1.06 | 5.13 | 0.48 | 0.09 | 98.42 | 11.48 | 0.12 |
| **1994** | 1.13 | 5.09 | 0.44 | 0.09 | 107.79 | 10.64 | 0.10 |
| **1995** | 2.39 | 6.34 | 0.44 | 0.07 | 117.05 | 11.11 | 0.09 |
| **1996** | 2.07 | 7.09 | 0.47 | 0.07 | 119.96 | 11.14 | 0.09 |
| **1997** | 1.52 | 7.17 | 0.59 | 0.08 | 117.09 | 13.73 | 0.12 |
| **1998** | 1.43 | 7.04 | 0.65 | 0.09 | 108.48 | 14.74 | 0.14 |
| **1999** | 0.93 | 6.38 | 0.60 | 0.09 | 97.08 | 14.42 | 0.15 |
| **2000** | 0.83 | 5.75 | 0.50 | 0.09 | 89.48 | 12.33 | 0.14 |

**Table C2. Historical estimates for Area 2C.**

| | R | N | C | C/N | B | Y | Y/B |
|---|---|---|---|---|---|---|---|
| **1974** | 0.29 | 1.13 | 0.13 | 0.12 | 29.91 | 5.50 | 0.18 |
| **1975** | 0.31 | 1.15 | 0.15 | 0.13 | 29.64 | 6.13 | 0.21 |
| **1976** | 0.35 | 1.19 | 0.13 | 0.11 | 29.20 | 5.45 | 0.19 |
| **1977** | 0.40 | 1.28 | 0.08 | 0.06 | 30.66 | 3.17 | 0.10 |
| **1978** | 0.51 | 1.53 | 0.12 | 0.08 | 35.14 | 4.21 | 0.12 |
| **1979** | 0.55 | 1.75 | 0.13 | 0.07 | 40.35 | 4.58 | 0.11 |
| **1980** | 0.73 | 2.10 | 0.10 | 0.05 | 46.93 | 3.49 | 0.07 |
| **1981** | 0.83 | 2.54 | 0.13 | 0.05 | 56.48 | 4.25 | 0.08 |
| **1982** | 0.82 | 2.88 | 0.11 | 0.04 | 64.99 | 3.91 | 0.06 |
| **1983** | 0.82 | 3.19 | 0.19 | 0.06 | 74.62 | 6.82 | 0.09 |
| **1984** | 0.93 | 3.49 | 0.19 | 0.05 | 82.31 | 6.32 | 0.08 |
| **1985** | 1.20 | 4.02 | 0.29 | 0.07 | 85.32 | 10.03 | 0.12 |
| **1986** | 0.87 | 4.05 | 0.37 | 0.09 | 87.10 | 11.63 | 0.13 |
| **1987** | 0.95 | 4.08 | 0.35 | 0.09 | 88.55 | 11.75 | 0.13 |
| **1988** | 0.89 | 4.07 | 0.39 | 0.10 | 89.51 | 12.49 | 0.14 |
| **1989** | 0.77 | 3.91 | 0.34 | 0.09 | 88.50 | 11.15 | 0.13 |
| **1990** | 0.71 | 3.75 | 0.33 | 0.09 | 88.06 | 11.19 | 0.13 |
| **1991** | 0.84 | 3.75 | 0.31 | 0.08 | 86.58 | 11.15 | 0.13 |
| **1992** | 0.86 | 3.78 | 0.35 | 0.09 | 84.69 | 11.99 | 0.14 |
| **1993** | 0.72 | 3.63 | 0.37 | 0.10 | 82.17 | 13.33 | 0.16 |
| **1994** | 0.74 | 3.51 | 0.38 | 0.11 | 81.17 | 12.57 | 0.15 |
| **1995** | 1.70 | 4.36 | 0.23 | 0.05 | 80.38 | 9.46 | 0.12 |
| **1996** | 1.50 | 5.03 | 0.32 | 0.06 | 85.45 | 10.94 | 0.13 |
| **1997** | 1.04 | 5.05 | 0.37 | 0.07 | 84.09 | 12.03 | 0.14 |
| **1998** | 0.84 | 4.84 | 0.44 | 0.09 | 82.74 | 12.64 | 0.15 |
| **1999** | 0.76 | 4.50 | 0.42 | 0.09 | 80.30 | 11.95 | 0.15 |
| **2000** | 1.12 | 4.60 | 0.36 | 0.08 | 82.78 | 10.37 | 0.13 |

**Table C3. Historical estimates for Area 3A.**

| | R | N | C | C/N | B | Y | Y/B |
|---|---|---|---|---|---|---|---|
| **1974** | 0.61 | 2.30 | 0.17 | 0.07 | 78.30 | 8.10 | 0.10 |
| **1975** | 0.80 | 2.53 | 0.22 | 0.09 | 81.80 | 10.43 | 0.13 |
| **1976** | 0.94 | 2.85 | 0.23 | 0.08 | 88.43 | 10.92 | 0.12 |
| **1977** | 1.05 | 3.22 | 0.18 | 0.06 | 100.62 | 8.73 | 0.09 |
| **1978** | 1.31 | 3.83 | 0.24 | 0.06 | 117.30 | 10.35 | 0.09 |
| **1979** | 1.23 | 4.23 | 0.27 | 0.06 | 134.99 | 11.33 | 0.08 |
| **1980** | 1.42 | 4.72 | 0.27 | 0.06 | 149.28 | 12.28 | 0.08 |
| **1981** | 1.88 | 5.57 | 0.33 | 0.06 | 167.05 | 14.75 | 0.09 |
| **1982** | 1.80 | 6.19 | 0.30 | 0.05 | 189.41 | 14.10 | 0.07 |
| **1983** | 1.90 | 6.87 | 0.35 | 0.05 | 210.53 | 14.91 | 0.07 |
| **1984** | 2.31 | 7.81 | 0.51 | 0.07 | 217.58 | 20.56 | 0.09 |
| **1985** | 3.14 | 9.32 | 0.57 | 0.06 | 241.02 | 22.77 | 0.09 |
| **1986** | 2.79 | 10.23 | 0.92 | 0.09 | 267.40 | 36.21 | 0.14 |
| **1987** | 3.49 | 11.35 | 0.93 | 0.08 | 265.19 | 34.41 | 0.13 |
| **1988** | 4.28 | 13.11 | 1.22 | 0.09 | 263.45 | 41.93 | 0.16 |
| **1989** | 3.26 | 13.31 | 1.11 | 0.08 | 250.33 | 37.88 | 0.15 |
| **1990** | 2.92 | 13.27 | 0.98 | 0.07 | 241.08 | 33.08 | 0.14 |
| **1991** | 4.06 | 14.50 | 0.95 | 0.07 | 231.65 | 28.87 | 0.12 |
| **1992** | 3.37 | 14.87 | 1.02 | 0.07 | 216.35 | 31.70 | 0.15 |
| **1993** | 2.69 | 14.47 | 0.98 | 0.07 | 198.16 | 28.62 | 0.14 |
| **1994** | 2.40 | 13.90 | 1.09 | 0.08 | 218.72 | 30.38 | 0.14 |
| **1995** | 4.02 | 14.94 | 0.82 | 0.05 | 226.25 | 22.95 | 0.10 |
| **1996** | 3.26 | 15.31 | 0.87 | 0.06 | 230.74 | 24.65 | 0.11 |
| **1997** | 1.93 | 14.26 | 1.02 | 0.07 | 223.43 | 30.22 | 0.14 |
| **1998** | 1.99 | 13.32 | 1.12 | 0.08 | 208.29 | 30.60 | 0.15 |
| **1999** | 1.53 | 11.94 | 1.19 | 0.10 | 187.41 | 29.63 | 0.16 |
| **2000** | 1.83 | 11.01 | 0.90 | 0.08 | 164.65 | 24.02 | 0.15 |

# Assessment of the Pacific Halibut Stock in 1999

by

William G. Clark and Ana M. Parma

## Abstract

The Pacific halibut assessment is based on fitting an age- and length-structured model to data from the fishery and IPHC setline surveys. The only major change this year was a lowering of setline survey catch rates from the 1990s to account for a bait change, which reduced the population estimates by 20-30% in the eastern and central Gulf of Alaska (Areas 2 and 3A). A continuing decline in size at age also affected the estimates in Area 2C and Area 3A. Very low estimated recruitment in Area 3A in recent years implies a rapidly declining biomass in that area, but trawl surveys indicate continuing high abundance of 60-80 cm fish in that area, so this may be a false alarm. However, it does now appear that recruitment has declined from the high levels of 1985-1995. Farther west (Areas 3B and 4), biomass is estimated by extrapolating the Area 3A estimate on the basis of setline survey results. Total setline CEY (available yield at a harvest rate of 20%) is estimated to be 63 million pounds, down from almost 100 million last year. Most of the decrease in Areas 2AB and 2C is due to the bait correction, while lower weight at age and recruitment are equally influential in Area 3A.

## Introduction

Each year the IPHC staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). Exploitable biomass in each IPHC regulatory area is estimated by fitting a detailed population model to the data from that area. A biological target level for total removals is then calculated by applying a fixed harvest rate—presently 20%—to the estimate of exploitable biomass. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for directed setline catches, called the setline CEY, is calculated by subtracting from the total CEY an estimate of all other removals—sport catches, bycatch of legal sized fish, wastage in the halibut fishery, and fish taken for personal use.

Staff recommendations for quotas in each area are based on the estimates of setline 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.

This paper reports the staff's estimates of total abundance, recruitment trends, exploitable biomass, and total and setline CEY by area as calculated at the end of 1999 for the 2000 fishery.

## The Assessment Model

From 1982 through 1994, stock size was estimated by fitting an age-structured model (CAGEAN) to commercial catch-at-age and catch-per effort data. In the early 1990s it became apparent that age-specific selectivity in the commercial fishery had shifted as a result of a decline in halibut growth rates, which was more dramatic in Alaska than in Canada. An age- and length-structured model was developed and implemented in 1995 that that accounted for the change in growth. It also incorporated survey (as well as commercial) catch-at-age and catch-per effort data. The survey data contain much more information on younger fish, many of which are now smaller than the commercial size limit, and are standardized to provide a consistent index of relative abundance over time and among areas.

At first the model was fitted on the assumption that survey catchability and length-specific survey selectivity were constant, while commercial catchability and selectivity were allowed to vary over time (subject to some restraints). The resulting fits showed quite different length-specific survey selectivities in Area 2B and 3A, however, which suggested that age could still be influencing selectivity. To reflect that possibility, the new model has been fitted in two ways since 1996: by requiring constant length-specific survey selectivity (as in 1995), and by requiring constant age-specific survey selectivity. The age-specific fits generally produce lower estimates of recent recruitment and therefore present abundance, and to be conservative the staff has used those estimates to calculate CEY's.

With either fitting criterion, the abundance estimates depend strongly on the natural mortality rate $M$ used in the population model. Until 1998 the estimate $M = 0.20$ had been used in all assessments. This estimate is quite imprecise, and an analysis done by the staff suggested that a lower working value would be appropriate. The value $M = 0.15$ was chosen and used as a standard, which lowered abundance estimates in the 1998 assessment by about 30%.

The only significant change to the assessment in 1999 was introducing an increase in setline survey catchability, beginning with the 1993 survey data, to account for a change in bait between the 1980s and the 1990s. When setline surveys resumed in 1993 (after being suspended since 1986), chum salmon was adopted as the standard bait, whereas in the 1980s the bait was herring and salmon on alternate hooks. Experiments done within the last year showed that salmon bait catches 50-150% more halibut than herring. Further experiments are planned for this summer in which mixed bait will be compared directly with salmon. In the meantime, a working value of 100% was used in the assessment. This translates to a 33% increase in overall survey catchability after the 1980s. (For every two hooks, in terms of hooks baited with salmon, the survey switched from the equivalent of 1½ hooks to 2 hooks, an increase of one third.)

Further details on the history of IPHC assessment methods and harvest strategy are given in Appendix B and in a detailed account of the 1997 assessment (Sullivan et al. 1999). Details of changes to the model made in 1998 and 1999 are given in Appendix C.

## Stock Size Estimates in Areas 3B and 4

Until 1997 the analytical model was used to estimate halibut abundance for the entire Commission area, including lightly fished regions in the western Gulf of Alaska (Area 3B) and the Bering Sea/Aleutians region (Area 4). Because there is no historical survey data for western Alaska, the assessment relied entirely on commercial data for those areas. In 1997 the Commission first did setline surveys of the entire Commission area, and they showed substantially more halibut to be available in western Alaska (relative to other areas) than the analytical model had estimated. The reason for the discrepancy is almost certainly that the analytical model, when fitted to commercial data alone, only estimates the size of the *exploited population*, and in western Alaska fishing intensity is very low or nil over large areas, so a substantial part of the stock is effectively unexploited and therefore invisible to the model but not to the surveys.

In light of the survey results, analytical estimates of stock size in Areas 3B and 4 were suspended in 1997. The procedure now is to calculate analytical estimates for Areas 2A, 2B, 2C, and 3A, and then to scale those absolute estimates by survey estimates of relative abundance in Area 3B and 4 to obtain absolute estimates for the western areas. In 1997 the sum of the abundance estimates for Areas 2A through 3A was used as the reference point. Since then the absolute estimate for Area 3A only has been used as the reference point, on the grounds that survey catch rates there are more comparable to survey catch rates farther west.

## Analytical Estimates of Abundance in 1998

### Narrative account of the assessment

A stepwise summary of the 1999 assessment is shown in Table 1. The “housekeeping update” of the 1998 assessment (Step 2) consisted of a number of small items, none of which had an important effect on the estimates except as noted:

(i) Adding the 1998 survey ages, which increased the 3A estimate by about 5 M lb. and reduced the 2C estimate by 2.5 M lb.
(ii) Recomputing some of the early commercial size-at-age estimates and correcting some of the survey CPUE estimates. The latter increased the 2AB estimate by about 5 M lb.
(iii) Smoothing the commercial mean weight-at-age over ages within years rather than over years within ages, as was done in the past. The old procedure did not accurately track year-to-year changes in mean weight in the catch. The new procedure reduced the 2C estimate by about 5 M lb as a result of a drop in mean weight between 1998 and 1999 that had been ignored by the old smoother.
(iv) Slightly altering the growth equations, which raised the 3A estimate by about 5 M lb.

Increasing survey catchability by 35% in the 1990s (Step 3) to account for the bait change has the effect of reducing the apparent increase in halibut abundance since the 1980s by 25% (to 1/1.35 of the former value), but it does not reduce the estimates of 1999 biomass by the same amount because other things play a role, including commercial catch per effort. As it turned out, the 2AB and 2C estimates for 1999 decreased by about 20% and the 3A estimate by almost 30%.

The addition of the 1999 commercial data (Step 4) can affect the 1999 estimates through the commercial CPUE, the age composition of the catch, and the mean weight at age in the catch. The only sizable effect was a large decrease in the 3A estimate caused almost entirely by a decline in the mean weights. This trend has been going on for some time (Table 2). It appeared to have leveled off

in the mid-1990s, but in 2C and 3A it has resumed since 1997, reducing biomass estimates in Alaska by a full 20% over the last two years.
The addition of the 1999 survey data (Step 5) had little effect in Area 2AB and a positive effect on estimated 1999 abundance in Alaska, despite the low survey catch rates. This can happen when the survey catch at age increases the estimated abundance of some year-classes.

When the estimated numbers at age are projected forward to 2000 (using the 1999 mean weights to calculate biomass), the change in the biomass estimate depends on the estimated abundance of all the year-classes in the stock, which at ages 8 to, say, 20 in 2000 will be the 1980 through 1992 year-classes. Generally the year-classes coming into the stock are now weaker than the ones passing out of it, so the projections for 2000 are lower than the 1999 estimates (Table 3). The drop is bigger in 3A (20%) than in 2AB and 2C (10%) because the assessment shows that recruitment to 3A peaked in 1980 and has been declining steeply since, to levels that are now on a par with the mid-1970s. In 2AB and 2C the 1987 and 1988 year-classes were strong, and the most recent ones appear to be mediocre but not really poor as in 3A.

In summary, this year's estimates are substantially lower than last year's because of the allowance for increased survey catchability, lower mean weights at age, and recent declines in recruitment. In Alaska (2C and 3A) the cumulative effect is a 35-40% reduction; in Area 2AB about 15%.

**Plots of fitted values**

There is very little difference between the age- and length-specific fits in Area 2, so only the age-specific fits are illustrated for Area 2AB (Fig.1) and Area 2C (Fig.2). In Area 3A there is more of a difference, so both fits are illustrated (Figs. 3a and 3b). Most of the plotted values are tabled in Appendix D.

Except for the age-specific fit in Area 3A, all of the fits show the 1987 year-class to be strong. All of the fits show a drop in recruitment after the 1987 year-class, which in Area 3A has been steep and sustained, to the point where estimated recruitment at age 8 in 1999 is the lowest in the 1974-1999 series. As explained below, this severe decline in recruitment is likely overstated. The age- and length-specific fits in 3A show very similar recruitment trends. The length-specific estimates are slightly higher from 1980 on, with the cumulative result that the length-specific estimate of exploitable biomass in 2000 is 121.4 M lb compared with the age-specific value of 94.9.

In the plot of survey catch rates (center left panel), the broad shaded line is a data smoother that shows the general trend of the survey data points. The thin black line is the model predictions of survey catch rates. There is quite a wide scatter of the data points around the general trend, which means that the survey data are quite variable from year to year. Thus while the surveys are an essential index of the general level of stock abundance, the year-to-year changes are not very meaningful.

In the center right panel, commercial catch per effort is plotted as points and the model estimates of exploitable biomass as a dotted line. Predicted commercial CPUE is plotted as a solid line; it reflects estimated changes in commercial catchability ("q") as well as the trend in exploitable biomass. The values of exploitable biomass in this graph are calculated with the model estimates of commercial selectivity in each area in each year, and are not the same as the estimates of exploitable biomass that appear below in the calculation of setline CEY. Those are calculated with a fixed coastwide selectivity.

The estimated selectivities in the lower panels are unremarkable except for the very steep length-specific survey selectivities in recent years estimated with the age-specific model. In light of other evidence of length-specific vulnerability to hooking (from marking and video observations), these curves are probably too steep and shifted too far to the left.

## Estimates of Exploitable Biomass and Cey

As explained above, exploitable biomass in 3B and 4 is estimated by scaling the analytical estimate for 3A by survey estimates of relative abundance. For that purpose, average survey catch rates in 3B and 4 relative to 3A were calculated by a procedure that uses all available 1996-1999 data but places more weight on the more recent values. These relative catch rates are then scaled by relative total bottom areas (0-500 fathoms) to estimate relative total biomass levels in 3B, 4A, and 4B. There are no recent survey data for 4CDE, so last year's estimate is carried over. Estimated abundance in Area 3B and 4 relative to 3A is higher this year than last because of lower survey catch rates in 3A in 1999 and continued good catch rates farther west. The full set of exploitable biomass estimates is:

| | 2AB | 2C | 3A | 3B | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|
| **Exploitable biomass (ebio) relative to 3A** | --- | --- | 1.00 | 1.02 | 0.38 | 0.37 | 0.37 | --- |
| **Ebio (M lb)** | 55.5 | 42.2 | 94.9 | 96.8 | 36.1 | 35.1 | 35.1 | 395.7 |

The target harvest rate of 20% was chosen on the basis of calculations of stock productivity that used a coastwide average of the estimates of commercial selectivity from the age-specific fit of the model, so the biomass estimates from the age-specific fits are used to calculate exploitable biomass and CEY (Table 4).

Some ad hoc procedures were required to estimate non-commercial removals and setline CEY by subarea within Area 4. Wastage was distributed among subareas in proportion to commercial catch. Sport catch and personal use were allocated 90% to 4A and 10% to 4CDE. Legal sized bycatch mortality was distributed in proportion to total (legal + sublegal) bycatch mortality recorded by NMFS observers. This procedure requires two assumptions. First, the distribution of observer coverage by IPHC regulatory area should be proportional to total fishing effort. Second, the size distribution within each regulatory area should be equal (since we subtracting out just the legal portion of the bycatch). It is likely that both of these assumptions are roughly met and this procedure is almost certainly more accurate than other alternatives such as distributing mortality in proportion to biomass. In 1998, observed mortality of halibut was distributed among regulatory areas as follows: 4A 16%, 4B 6%, 4CDE 24%, Closed area 54%. As the Closed Area is on the eastern Bering shelf, it is treated as part of Area 4CDE.

## Outlook

It now appears likely that coastwide recruitment has declined from the high levels of the 1985-1995 period, and size at age is still going down. Thus while abundance in number is still quite high relative to the levels of 1975 or 1980 (Table 3), biomass levels are not as good and the prospect is for a continuing decline as relatively strong year-classes pass out of the stock and relatively weak ones enter (and grow more slowly).

The prospect is worst in 3A, but the apparent near-failure of recruitment there may not be real. NMFS trawl surveys indicate a much higher abundance of 8-year-old halibut in Area 3A than our analytical assessment based on setline data. This is a puzzle, because for legal-sized halibut trawl and setline surveys agree reasonably well on trends in relative abundance, but since 1990 trawl survey catch rates of sublegal halibut have greatly outpaced setline survey catch rates (Fig. 4).

Another cause for suspicion is the re-emergence of a retrospective pattern in the 3A estimates (and only there), with the estimate of exploitable biomass in a given year increasing in each succeeding assessment (Table 5). This is consistent with an over-estimate of the selectivity of young fish, whose abundance is consequently underestimated initially. The estimate is then corrected in later assessments as the year-class moves through the fishery. In the past this pattern was caused by declining size at age, but size at ages 8 and below has changed very little, so some other factor must be at work.

It therefore seems very possible that exploitable biomass in 3A is underestimated and that incoming recruitment will turn out to be no worse in 3A than in 2AB and 2C. But even that would be low by recent standards.

## References

Sullivan, P.J., Parma, A.M., and Clark, W.G. 1999. Pacific halibut assessment: data and methods. Int. Pac. Halibut Comm. SCI. Rept. 97. 84 p.

**Table 1.** **Steps in performing the 1999 assessment and corresponding estimates of exploitable biomass, by area. These estimates are from the model with fixed age-specific survey selectivity; length-specific estimates are about 10% higher in 2AB and 2C, and 25% higher in 3A.**

**Area 2AB**

| | **1997** | **1998** | **1999** | **2000** |
|---|---|---|---|---|
| **1. 1998 assessment** | 71.9 | 70.1 | **66.8** | --- |
| **2. Housekeeping update** | 76.1 | 73.3 | 71.8 | --- |
| **3. Increase survey catchability in 1990s** | 80.8 | 74.5 | 57.2 | --- |
| **4. Add 1999 commercial data** | 67.5 | 63.6 | 61.6 | 57.0 |
| **5. Add 1999 survey data** | 66.4 | 62.5 | 60.3 | **55.5** |

**Area2C**

| | **1997** | **1998** | **1999** | **2000** |
|---|---|---|---|---|
| **1. 1998 assessment** | 66.7 | 64.7 | **63.9** | --- |
| **2. Housekeeping update** | 67.1 | 57.8 | 54.5 | --- |
| **3. Increase survey catchability in 1990s** | 56.5 | 47.1 | 42.5 | --- |
| **4. Add 1999 commercial data** | 56.6 | 47.5 | 41.5 | 37.4 |
| **5. Add 1999 survey data** | 61.6 | 52.3 | 46.4 | **42.2** |

**Area 3A**

| | **1997** | **1998** | **1999** | **2000** |
|---|---|---|---|---|
| **1. 1998 assessment** | 188.5 | 180.0 | **158.8** | --- |
| **2. Housekeeping update** | 224.7 | 190.2 | 171.6 | --- |
| **3. Increase survey catchability in 1990s** | 178.4 | 145.8 | 125.5 | --- |
| **4. Add 1999 commercial data** | 172.8 | 141.0 | 106.5 | 85.2 |
| **5. Add 1999 survey data** | 185.4 | 152.9 | 117.5 | **94.9** |

**Table 2.** **Effect of declining weight at age on exploitable biomass: what estimated ebio would be in 1999 if calculated with estimated numbers at age in 1999 and mean weights at age from previous years. This shows the full effect of smaller sizes across the whole age range, and is larger than the effect on the modal age groups (particularly in Area 2B), which is what is usually shown.**

| | Area 2AB | Area 2C | Area 3A |
|---|---|---|---|
| **Ebio with 1999 nos. and weights from:** | | | |
| **1974** | 105.4 | 70.9 | 278.3 |
| **1975** | 103.6 | 71.4 | 283.2 |
| **1976** | 101.6 | 71.5 | 286.7 |
| **1977** | 98.7 | 71.4 | 288.8 |
| **1978** | 95.0 | 70.7 | 289.9 |
| **1979** | 91.8 | 70.4 | 289.5 |
| **1980** | 89.4 | 70.3 | 288.2 |
| **1981** | 86.8 | 70.1 | 286.1 |
| **1982** | 84.7 | 69.5 | 283.0 |
| **1983** | 82.8 | 68.4 | 278.7 |
| **1984** | 81.4 | 66.6 | 273.9 |
| **1985** | 79.7 | 64.1 | 267.8 |
| **1986** | 78.0 | 61.8 | 261.9 |
| **1987** | 76.3 | 59.7 | 254.3 |
| **1988** | 74.5 | 58.1 | 245.0 |
| **1989** | 72.6 | 57.1 | 233.1 |
| **1990** | 70.7 | 56.7 | 218.8 |
| **1991** | 72.4 | 57.8 | 180.6 |
| **1992** | 69.8 | 54.7 | 179.7 |
| **1993** | 63.6 | 55.2 | 157.3 |
| **1994** | 59.9 | 51.5 | 141.0 |
| **1995** | 64.0 | 65.9 | 144.8 |
| **1996** | 61.1 | 57.2 | 144.7 |
| **1997** | 62.3 | 56.5 | 149.2 |
| **1998** | 59.3 | 48.4 | 133.1 |
| **1999** | 60.3 | 46.4 | 117.5 |

**Table 3.** **Estimated abundance at age in 2000 as a proportion of estimated abundance at the same age in selected earlier years. (E.g., in the table below for Area 2AB, the value 6.06 at age 13 in 1975 means that estimated abundance at age 13 in 2000 is 6.06 times the estimated abundance at age 13 in 1975.)**

**Area 2AB.** Total estimated age10+ abundance in 2000 = 91% of 1999 level.

| Age | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1975** | 1.06 | 1.74 | 2.50 | 2.70 | 4.41 | 6.06 | 2.34 | 5.19 | 4.93 | 3.79 | 3.23 | 4.32 | 4.40 |
| **1980** | 0.67 | 1.29 | 2.20 | 2.98 | 4.76 | 5.41 | 2.72 | 2.55 | 3.04 | 3.23 | 3.20 | 2.78 | 4.45 |
| **1985** | 0.28 | 0.59 | 1.06 | 1.43 | 2.30 | 2.98 | 1.85 | 2.16 | 3.33 | 3.56 | 2.98 | 3.39 | 3.33 |
| **1990** | 0.42 | 0.58 | 0.68 | 0.72 | 1.27 | 1.37 | 0.98 | 1.30 | 2.13 | 2.40 | 2.39 | 3.47 | 4.89 |
| **1995** | 0.23 | 0.71 | 1.00 | 0.84 | 1.21 | 1.59 | 0.68 | 0.54 | 0.67 | 0.79 | 0.64 | 1.05 | 2.05 |
| **1999** | 0.64 | 0.68 | 0.93 | 0.66 | 0.84 | 1.89 | 0.93 | 0.75 | 0.92 | 1.07 | 0.79 | 0.73 | 1.00 |
| **2000** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

**Area2C.** Total estimated age10+ abundance in 2000 = 86% of 1999 level.

| Age | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1975** | 1.41 | 1.31 | 1.57 | 2.13 | 3.29 | 3.84 | 1.23 | 2.23 | 1.93 | 1.68 | 1.51 | 2.20 | 3.05 |
| **1980** | 0.68 | 0.72 | 0.87 | 1.33 | 2.28 | 3.00 | 1.52 | 1.71 | 2.07 | 1.84 | 1.48 | 1.08 | 1.79 |
| **1985** | 0.44 | 0.49 | 0.61 | 0.75 | 1.07 | 1.24 | 0.68 | 0.75 | 1.01 | 0.99 | 0.89 | 1.03 | 1.15 |
| **1990** | 0.74 | 0.57 | 0.53 | 0.62 | 1.10 | 0.95 | 0.60 | 0.72 | 0.83 | 0.71 | 0.58 | 0.75 | 1.04 |
| **1995** | 0.43 | 0.74 | 0.74 | 0.77 | 1.26 | 1.73 | 0.73 | 0.64 | 0.71 | 0.75 | 0.46 | 0.68 | 0.93 |
| **1999** | 1.18 | 0.91 | 0.78 | 0.59 | 0.82 | 1.98 | 0.86 | 0.76 | 0.91 | 1.07 | 0.79 | 0.72 | 0.86 |
| **2000** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

**Area 3A.** Total estimated age 10+ abundance in 2000 = 79% of 1999 level.

| Age | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1975** | 0.65 | 0.62 | 1.34 | 1.38 | 2.71 | 3.67 | 1.95 | 5.09 | 5.88 | 5.35 | 6.23 | 8.96 | 12.46 |
| **1980** | 0.38 | 0.37 | 0.64 | 0.84 | 1.72 | 2.79 | 2.29 | 3.29 | 3.83 | 4.40 | 3.07 | 2.42 | 3.54 |
| **1985** | 0.19 | 0.21 | 0.46 | 0.53 | 0.91 | 1.55 | 1.28 | 1.47 | 2.17 | 2.60 | 2.17 | 2.63 | 1.85 |
| **1990** | 0.20 | 0.14 | 0.21 | 0.29 | 0.72 | 0.91 | 0.87 | 1.37 | 1.84 | 1.93 | 1.73 | 2.15 | 1.59 |
| **1995** | 0.23 | 0.26 | 0.36 | 0.29 | 0.45 | 0.81 | 0.51 | 0.55 | 0.95 | 1.50 | 1.05 | 1.57 | 1.57 |
| **1999** | 1.29 | 0.53 | 0.91 | 0.50 | 0.68 | 1.35 | 0.69 | 0.69 | 0.73 | 1.15 | 0.80 | 0.71 | 1.04 |
| **2000** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

**Table 4. Estimates of exploitable biomass and CEY.**

| Area | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4CDE | Tota |
|---|---|---|---|---|---|---|---|---|---|
| **1999 exploitable biomass (from the 1998 assessment)** | 5.36 | 61.64 | 64.00 | 159.00 | 138.33 | 46.11 | 34.98 | 58.83 | 568.2 |
| **1999 Setline CEY (from the 19998 assessment)** | 0.69 | 11.21 | 10.49 | 24.67 | 26.83 | 8.42 | 6.71 | 9.80 | 98.8 |
| **1999 quota** | 0.76 | 12.10 | 10.49 | 24.67 | 13.37 | 4.24 | 3.98 | 4.45 | 74.0 |
| | | | | | | | | | |
| **2000 exploitable biomass (from the 1999 assessment)** | 4.44 | 51.06 | 42.20 | 94.90 | 96.80 | 36.10 | 35.10 | 35.10 | 395.7 |
| **Total CEY at 20%** | 0.89 | 10.21 | 8.44 | 18.98 | 19.36 | 7.22 | 7.02 | 7.02 | 79.1 |
| **Non-commercial removals** | | | | | | | | | |
| **Bycatch** | 0.38 | 0.11 | 0.23 | 1.60 | 0.88 | 0.58 | 0.22 | 2.83 | 6.8 |
| **Sport catch** | 0.34 | 1.58 | 1.83 | 5.24 | 0.02 | 0.10 | 0.00 | 0.01 | 9.1 |
| **Personal use** | 0.00 | 0.30 | 0.00 | 0.10 | 0.04 | 0.08 | 0.00 | 0.01 | 0.5 |
| **Wastage** | 0.01 | 0.04 | 0.07 | 0.10 | 0.07 | 0.04 | 0.04 | 0.04 | 0.3 |
| **2000 Setline CEY** | 0.54 | 8.18 | 6.31 | 11.94 | 18.36 | 6.42 | 6.77 | 4.13 | 62.6 |
| | | | | | | | | | |
| **2000/1999 total CEY** | 0.83 | 0.83 | 0.66 | 0.60 | 0.70 | 0.78 | 1.00 | 0.60 | 0.7 |
| **2000/1999 setline CEY** | 0.79 | 0.73 | 0.60 | 0.48 | 0.68 | 0.76 | 1.01 | 0.42 | 0.6 |

**Table 5.** **An apparent retrospective pattern in the estimates of exploitable biomass in Area 3A.**

| **Year estimated:** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** |
|---|---|---|---|---|---|---|---|---|---|
| **Last data year:** | | | | | | | | | |
| **1995** | 173 | 182 | 163 | 148 | 146 | | | | |
| **1996** | 179 | 190 | 172 | 158 | 157 | 154 | | | |
| **1997** | 185 | 199 | 182 | 170 | 173 | 173 | 172 | | |
| **1998** | 185 | 199 | 184 | 172 | 176 | 177 | 178 | 146 | |
| **1999** | 188 | 203 | 187 | 176 | 180 | 183 | 185 | 153 | 118 |

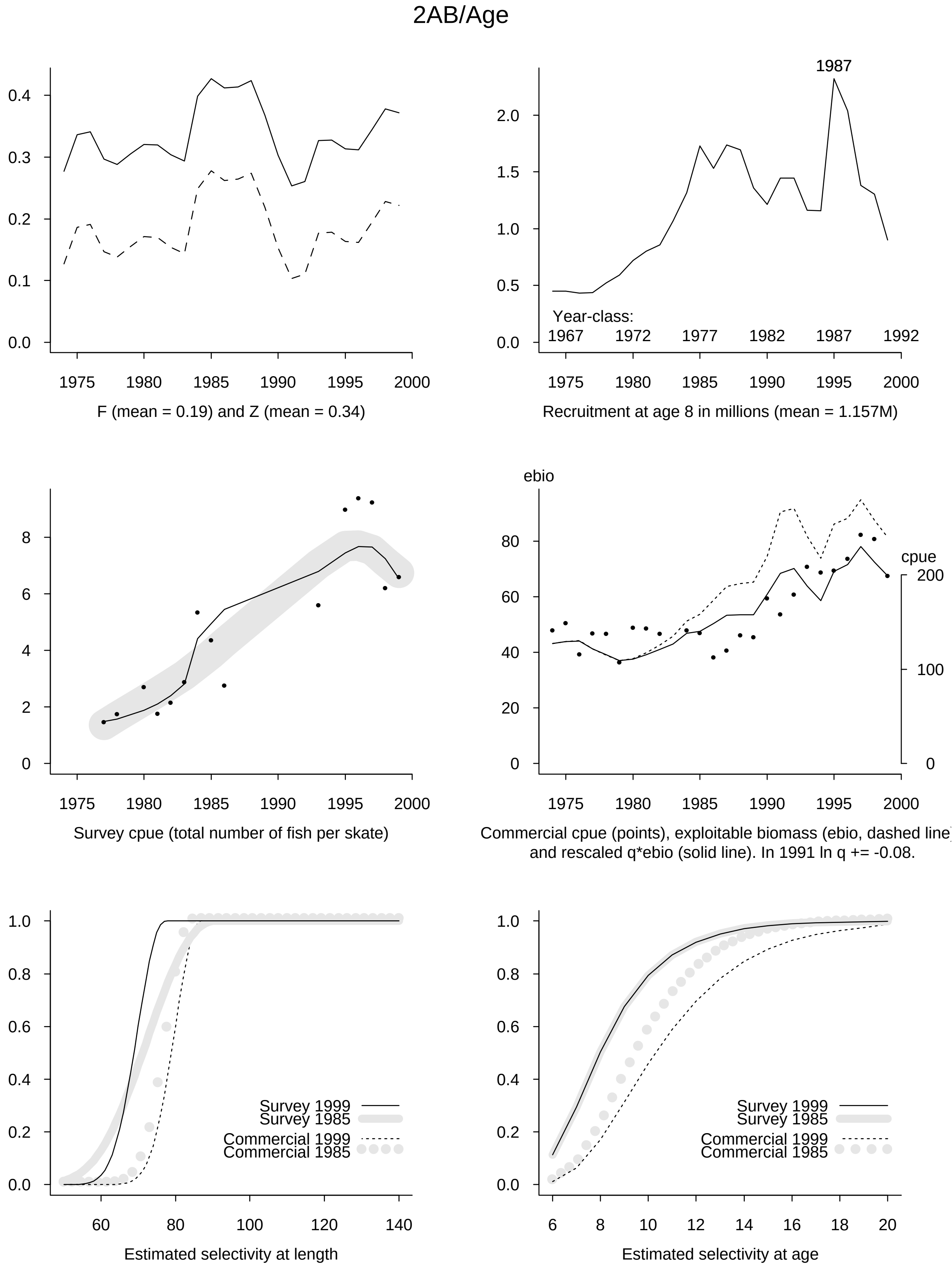



**Figure 1. Features of the age-specific model fit in Area 2AB.**

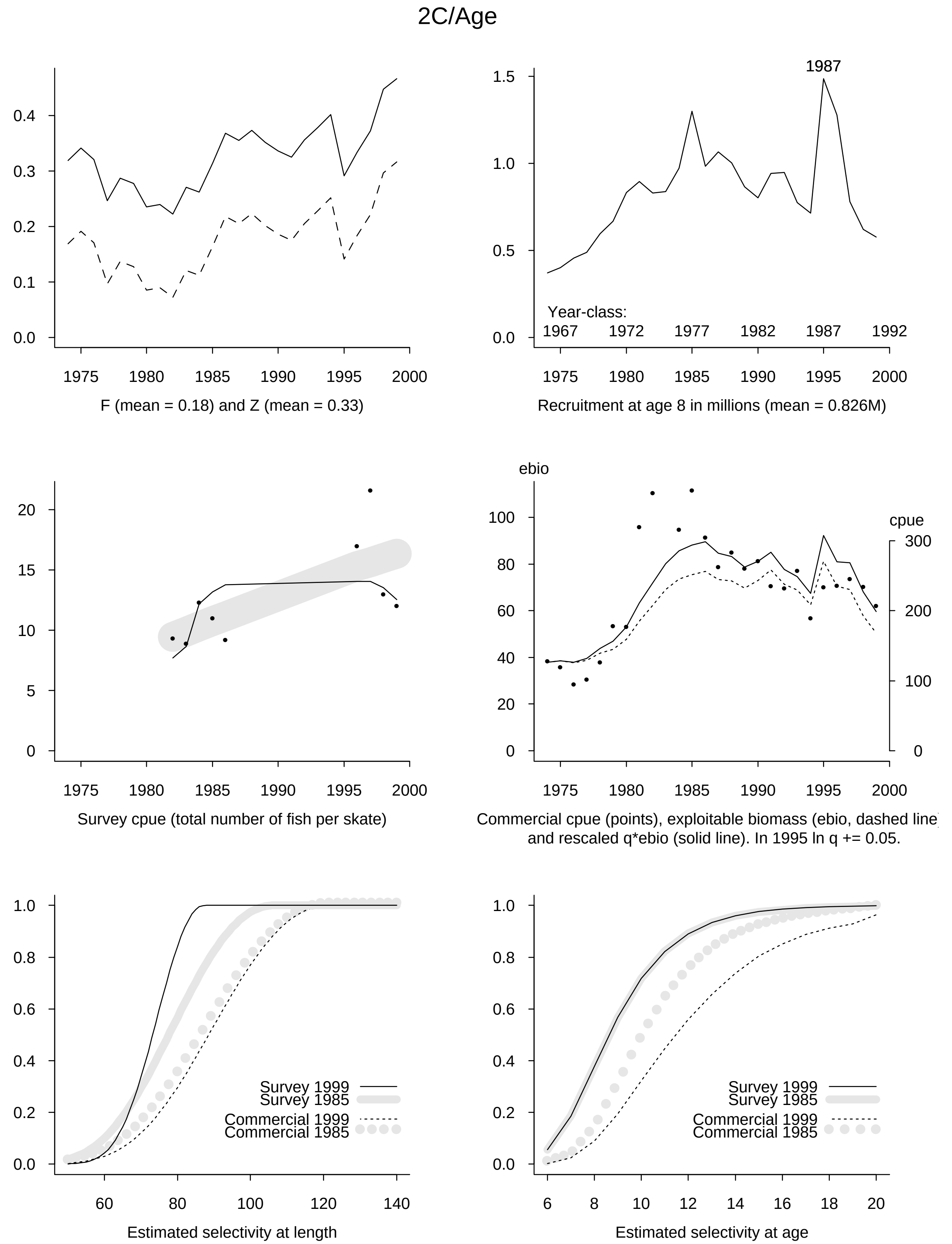



**Figure 2. Features of the age-specific model fit in Area 2C.**

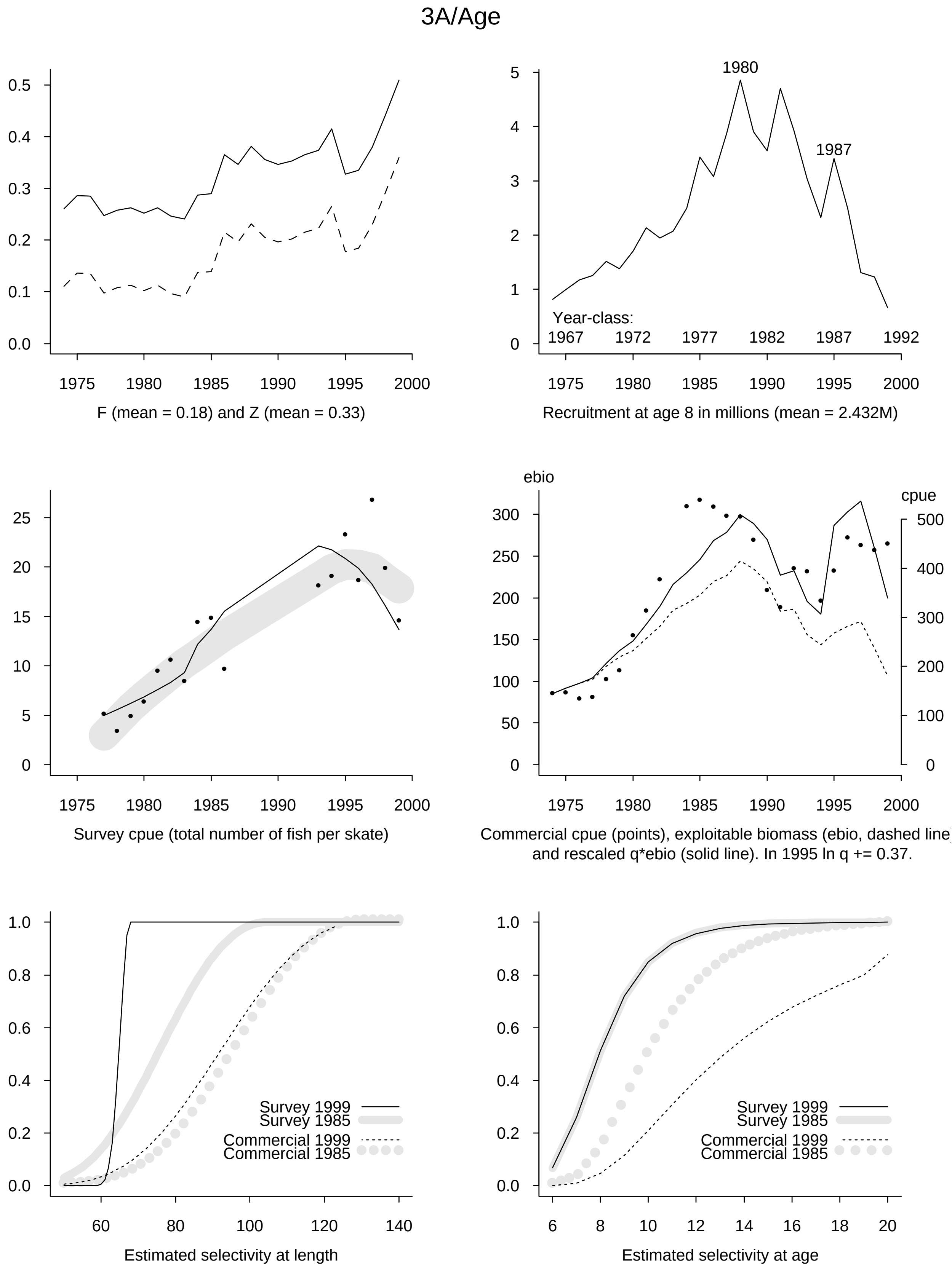



**Figure 3a. Features of the age-specific model fit in Area 3A.**

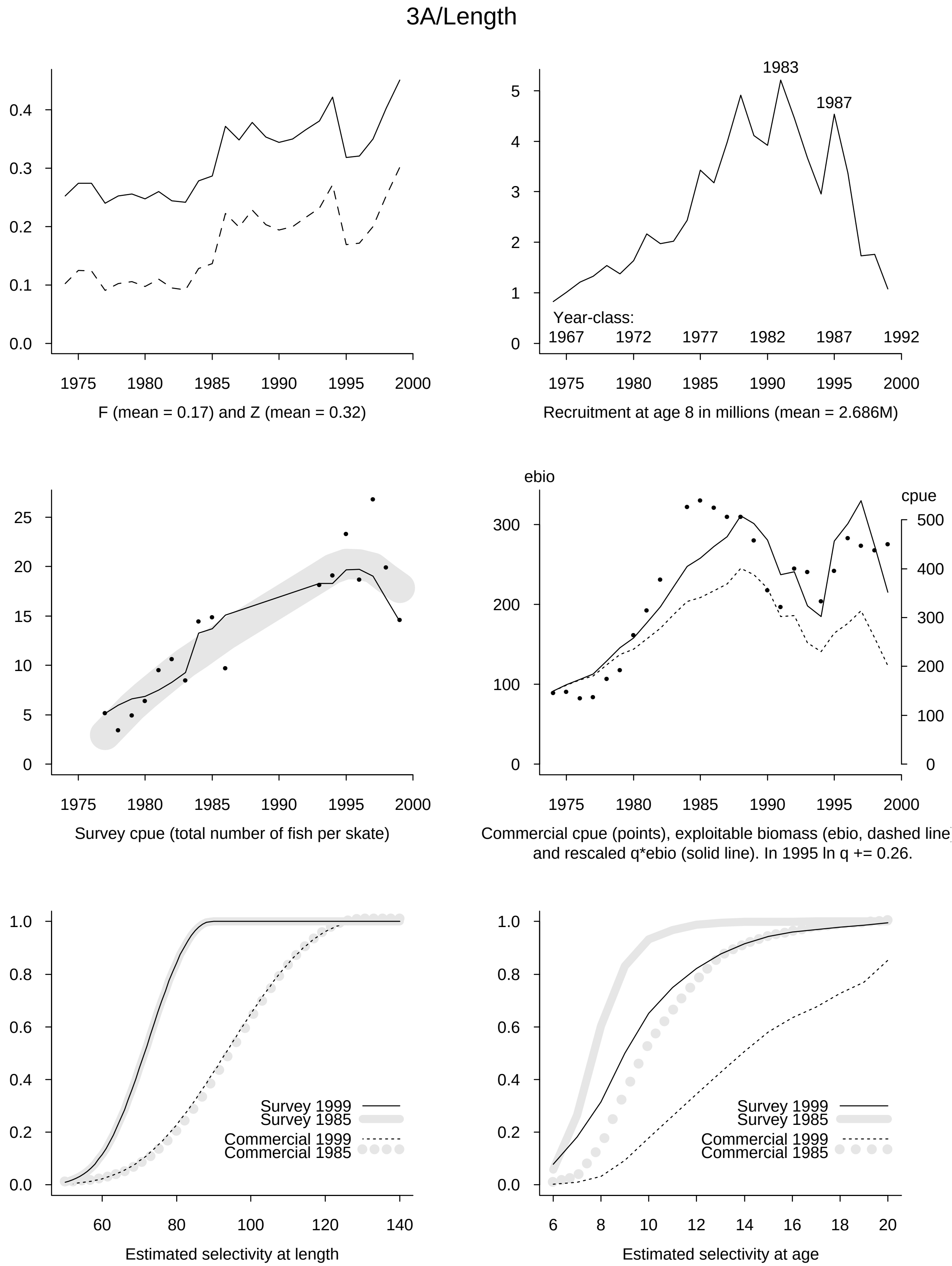



**Figure 3b. Features of the length-specific model fit in Area 3A.**

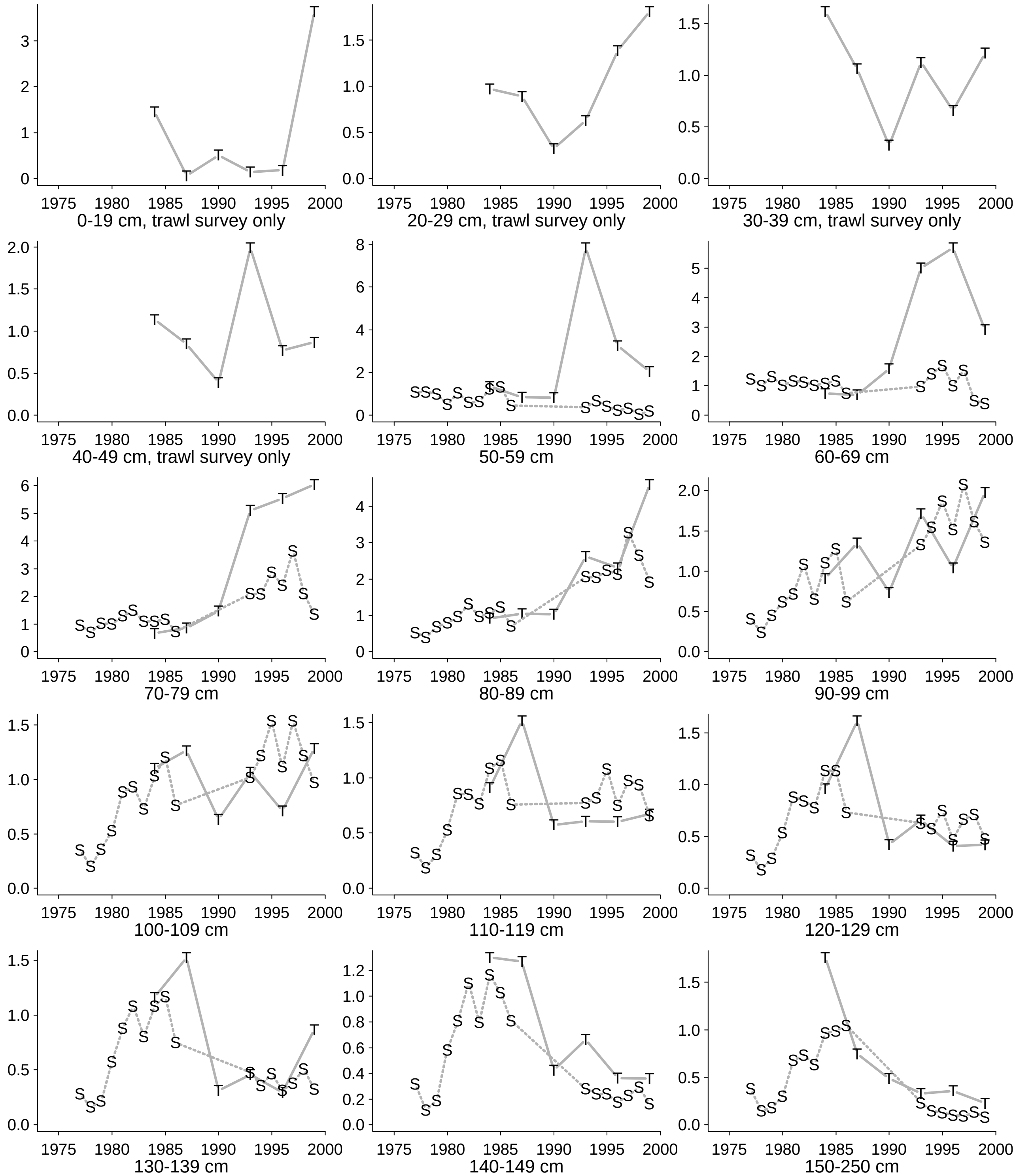



**Figure 4. IPHC setline survey (S) and NMFS trawl survey (T) catch rates at length in Area 3A. In each graph, both series are scaled to average 1.0 over the years 1984-1990. Setline catch rates are adjusted for estimated catchability and selectivity.**

# Appendix A. Selected Fishery and Survey Data Summaries

**Table A1. Commercial catch (million pounds, net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | 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 | 5.65 | 4.01 | 14.22 | 0.45 | 1.19 | 25.72 |
| **1982** | 0.21 | 5.54 | 3.50 | 13.53 | 4.80 | 1.43 | 29.01 |
| **1983** | 0.26 | 5.44 | 6.40 | 14.11 | 7.75 | 4.42 | 38.38 |
| **1984** | 0.43 | 9.05 | 5.85 | 19.97 | 6.50 | 3.16 | 44.96 |
| **1985** | 0.49 | 10.39 | 9.21 | 20.85 | 10.89 | 4.28 | 56.11 |
| **1986** | 0.58 | 11.22 | 10.61 | 32.79 | 8.83 | 5.59 | 69.62 |
| **1987** | 0.59 | 12.25 | 10.68 | 31.32 | 7.76 | 6.88 | 69.48 |
| **1988** | 0.49 | 12.86 | 11.37 | 37.86 | 7.08 | 4.69 | 74.35 |
| **1989** | 0.47 | 10.43 | 9.53 | 33.73 | 7.84 | 4.93 | 66.93 |
| **1990** | 0.32 | 8.57 | 9.73 | 28.85 | 8.69 | 5.43 | 61.59 |
| **1991** | 0.36 | 7.17 | 8.69 | 22.86 | 11.93 | 5.99 | 57.00 |
| **1992** | 0.44 | 7.63 | 9.82 | 26.78 | 8.62 | 6.61 | 59.90 |
| **1993** | 0.52 | 10.63 | 11.29 | 22.74 | 7.86 | 6.25 | 59.28 |
| **1994** | 0.37 | 9.91 | 10.38 | 24.84 | 3.86 | 5.37 | 54.73 |
| **1995** | 0.30 | 9.62 | 7.76 | 18.34 | 3.12 | 4.74 | 43.88 |
| **1996** | 0.30 | 9.56 | 8.86 | 19.70 | 3.66 | 5.31 | 47.38 |
| **1997** | 0.41 | 12.42 | 9.92 | 24.63 | 9.07 | 8.79 | 65.24 |
| **1998** | 0.46 | 13.15 | 10.19 | 25.70 | 11.16 | 9.07 | 69.74 |
| **1999** | 0.45 | 12.73 | 10.20 | 25.29 | 13.87 | 11.88 | 74.42 |

**Table A2. Bycatch mortality of legal-sized halibut (80+ cm; in million pounds net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | Total |
|---|---|---|---|---|---|---|---|
| **1974** | 0.25 | 0.90 | 0.37 | 4.48 | 2.82 | 1.90 | 10.71 |
| **1975** | 0.25 | 0.90 | 0.45 | 2.61 | 1.66 | 1.10 | 6.98 |
| **1976** | 0.25 | 0.94 | 0.50 | 2.74 | 1.94 | 1.18 | 7.56 |
| **1977** | 0.25 | 0.72 | 0.41 | 3.37 | 1.54 | 1.98 | 8.27 |
| **1978** | 0.25 | 0.55 | 0.21 | 2.44 | 1.31 | 3.40 | 8.16 |
| **1979** | 0.25 | 0.69 | 0.64 | 4.49 | 0.69 | 3.45 | 10.21 |
| **1980** | 0.25 | 0.51 | 0.42 | 4.93 | 0.87 | 5.71 | 12.69 |
| **1981** | 0.25 | 0.53 | 0.40 | 3.99 | 1.09 | 4.37 | 10.64 |
| **1982** | 0.25 | 0.30 | 0.20 | 3.20 | 1.68 | 2.95 | 8.58 |
| **1983** | 0.25 | 0.29 | 0.20 | 2.08 | 1.22 | 2.47 | 6.51 |
| **1984** | 0.25 | 0.52 | 0.21 | 1.51 | 0.92 | 2.29 | 5.70 |
| **1985** | 0.25 | 0.55 | 0.20 | 0.80 | 0.34 | 2.25 | 4.38 |
| **1986** | 0.25 | 0.56 | 0.20 | 0.67 | 0.20 | 2.62 | 4.50 |
| **1987** | 0.25 | 0.79 | 0.20 | 1.59 | 0.40 | 2.68 | 5.91 |
| **1988** | 0.25 | 0.77 | 0.20 | 2.13 | 0.04 | 3.27 | 6.66 |
| **1989** | 0.25 | 0.72 | 0.20 | 1.80 | 0.44 | 1.95 | 5.37 |
| **1990** | 0.25 | 1.03 | 0.67 | 2.63 | 1.21 | 4.16 | 9.96 |
| **1991** | 0.25 | 1.22 | 0.55 | 3.12 | 1.03 | 2.91 | 9.09 |
| **1992** | 0.28 | 1.02 | 0.57 | 2.65 | 1.12 | 3.34 | 8.97 |
| **1993** | 0.28 | 0.65 | 0.33 | 1.92 | 0.47 | 2.01 | 5.65 |
| **1994** | 0.28 | 0.57 | 0.40 | 2.35 | 0.85 | 3.48 | 7.93 |
| **1995** | 0.38 | 0.70 | 0.22 | 1.46 | 0.83 | 3.21 | 6.81 |
| **1996** | 0.38 | 0.17 | 0.23 | 1.43 | 0.97 | 3.58 | 6.76 |
| **1997** | 0.38 | 0.11 | 0.24 | 1.55 | 0.73 | 3.80 | 6.81 |
| **1998** | 0.38 | 0.12 | 0.24 | 1.47 | 0.73 | 3.63 | 6.56 |
| **1999** | 0.38 | 0.11 | 0.23 | 1.60 | 0.88 | 3.46 | 6.65 |

**Table A3.** **Total removals: commercial catch + legal-sized bycatch + sport catch + personal use (millions of pounds net weight).**

| | 2A | 2B | 2C | 3A | 3B | 4 | 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** | 0.22 | 5.45 | 3.26 | 8.84 | 3.19 | 1.22 | 22.18 |
| **1978** | 0.11 | 4.62 | 4.40 | 10.58 | 1.32 | 1.35 | 22.38 |
| **1979** | 0.06 | 4.88 | 4.70 | 11.70 | 0.39 | 1.37 | 23.11 |
| **1980** | 0.04 | 5.66 | 3.57 | 12.46 | 0.28 | 0.71 | 22.72 |
| **1981** | 0.22 | 5.67 | 4.33 | 14.97 | 0.45 | 1.20 | 26.84 |
| **1982** | 0.26 | 5.61 | 3.99 | 14.25 | 4.80 | 1.44 | 30.34 |
| **1983** | 0.32 | 5.54 | 6.95 | 15.05 | 7.75 | 4.42 | 40.05 |
| **1984** | 0.55 | 9.17 | 6.47 | 21.00 | 6.50 | 3.17 | 46.86 |
| **1985** | 0.68 | 11.02 | 10.11 | 22.99 | 11.09 | 4.44 | 60.33 |
| **1986** | 0.92 | 11.80 | 11.77 | 36.55 | 9.23 | 5.91 | 76.18 |
| **1987** | 1.04 | 12.95 | 11.83 | 34.89 | 8.10 | 7.17 | 75.97 |
| **1988** | 0.74 | 13.41 | 12.65 | 42.63 | 7.20 | 4.80 | 81.43 |
| **1989** | 0.80 | 11.11 | 11.28 | 38.19 | 8.03 | 5.08 | 74.51 |
| **1990** | 0.52 | 9.41 | 11.30 | 33.38 | 8.91 | 5.69 | 69.21 |
| **1991** | 0.52 | 7.88 | 11.41 | 29.23 | 12.42 | 6.57 | 68.03 |
| **1992** | 0.70 | 8.36 | 12.10 | 31.81 | 8.86 | 6.89 | 68.72 |
| **1993** | 0.77 | 11.68 | 13.40 | 28.67 | 8.00 | 6.54 | 69.07 |
| **1994** | 0.56 | 10.94 | 12.72 | 30.51 | 3.98 | 5.63 | 64.33 |
| **1995** | 0.54 | 11.55 | 9.57 | 23.05 | 3.19 | 4.91 | 52.81 |
| **1996** | 0.52 | 11.47 | 10.44 | 24.79 | 3.74 | 5.55 | 56.52 |
| **1997** | 0.77 | 14.34 | 11.67 | 30.44 | 9.19 | 9.03 | 75.45 |
| **1998** | 0.85 | 15.09 | 12.95 | 31.12 | 11.28 | 9.32 | 80.61 |
| **1999** | 0.79 | 14.67 | 12.08 | 30.78 | 13.99 | 12.13 | 84.43 |

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

Values before 1984 are multiplied by the J-C hook correction for catch in weight of legal-sized fish (2.2). 1983 is excluded because it consists of a mixture of J- and C-hook data.

| | 2A | 2B | 2C | 3A | 3B | 4 |
|---|---|---|---|---|---|---|
| **1974** | 131 | 141 | 126 | 142 | 125 | 301 |
| **1975** | 131 | 149 | 117 | 145 | 149 | 211 |
| **1976** | 72 | 117 | 93 | 131 | 142 | 184 |
| **1977** | 182 | 135 | 99 | 135 | 161 | 176 |
| **1978** | 86 | 138 | 124 | 172 | 116 | 167 |
| **1979** | 110 | 106 | 177 | 189 | 81 | 146 |
| **1980** | 82 | 144 | 175 | 261 | 249 | 124 |
| **1981** | 82 | 146 | 318 | 311 | 353 | 242 |
| **1982** | 47 | 149 | 366 | 375 | 479 | 220 |
| **1983** | --- | --- | --- | --- | --- | --- |
| **1984** | 69 | 149 | 314 | 524 | 475 | 236 |
| **1985** | 69 | 146 | 370 | 537 | 602 | 305 |
| **1986** | 61 | 119 | 302 | 522 | 515 | 276 |
| **1987** | 59 | 129 | 260 | 504 | 476 | 298 |
| **1988** | 171 | 133 | 281 | 503 | 655 | 296 |
| **1989** | 124 | 133 | 258 | 455 | 590 | 306 |
| **1990** | 168 | 174 | 269 | 353 | 484 | 339 |
| **1991** | 164 | 156 | 233 | 319 | 466 | 366 |
| **1992** | 114 | 187 | 230 | 397 | 440 | 312 |
| **1993** | 155 | 212 | 255 | 391 | 505 | 337 |
| **1994** | 97 | 213 | 187 | 331 | 369 | 247 |
| **1995** | 131 | 209 | 232 | 393 | 476 | 272 |
| **1996** | 161 | 219 | 233 | 460 | 543 | 355 |
| **1997** | 216 | 243 | 243 | 445 | 569 | 364 |
| **1998** | 224 | 238 | 232 | 434 | 595 | 394 |
| **1999** | 127 | 203 | 205 | 448 | 542 | 421 |

**Table A5. IPHC setline survey CPUE of legal sized fish in weight (net pounds per skate).**

Series refer to standard survey areas: all of 2A, 2B north of Vancouver Is., outside stations in 2C, 3A west of 147°W, all of 3B, the Aleutian portion of 4A, all of 4B.

Values before 1984 are multiplied by a J-C hook correction for legal-sized catch in weight (2.2), although this does not fully account for the difference in selectivity between hook types. Values before 1992 are multiplied by a bait correction (1.35) to account for the switch from mixed bait to all salmon in the 1990s. Mean catch rates have coefficients of variation of 5-10%.

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B |
|---|---|---|---|---|---|---|---|
| **1974** | --- | --- | --- | --- | --- | --- | --- |
| **1975** | --- | --- | --- | --- | --- | --- | --- |
| **1976** | --- | --- | --- | --- | --- | --- | --- |
| **1977** | --- | 45 | --- | 217 | --- | --- | --- |
| **1978** | --- | 62 | --- | 101 | --- | --- | --- |
| **1979** | --- | --- | --- | 151 | --- | --- | --- |
| **1980** | --- | 83 | --- | 282 | --- | --- | --- |
| **1981** | --- | 53 | --- | 481 | --- | --- | --- |
| **1982** | --- | 62 | 481 | 535 | --- | --- | --- |
| **1983** | --- | 59 | 416 | 437 | --- | --- | --- |
| **1984** | --- | 86 | 406 | 602 | --- | --- | --- |
| **1985** | --- | 63 | 437 | 629 | --- | --- | --- |
| **1986** | --- | 57 | 404 | 509 | --- | --- | --- |
| **1987** | --- | --- | --- | --- | --- | --- | --- |
| **1988** | --- | --- | --- | --- | --- | --- | --- |
| **1989** | --- | --- | --- | --- | --- | --- | --- |
| **1990** | --- | --- | --- | --- | --- | --- | --- |
| **1991** | --- | --- | --- | --- | --- | --- | --- |
| **1992** | --- | --- | --- | --- | --- | --- | --- |
| **1993** | --- | 105 | --- | 323 | --- | --- | --- |
| **1994** | --- | --- | --- | 313 | --- | --- | --- |
| **1995** | --- | 166 | --- | 370 | --- | --- | --- |
| **1996** | --- | 175 | 387 | 273 | 352 | --- | --- |
| **1997** | --- | 156 | 492 | 366 | 415 | 237 | 282 |
| **1998** | --- | 92 | 272 | 346 | 436 | 304 | 216 |
| **1999** | 37 | 95 | 260 | 251 | 441 | 367 | 204 |

**Table A6. IPHC setline survey CPUE of all fish (incl. sublegals) in number (per skate).**

Series refer to standard survey areas: all of 2A, 2B north of Vancouver Is., outside stations in 2C, 3A west of 147°W, all of 3B, the Aleutian portion of 4A, all of 4B.

Values before 1984 are multiplied by a J-C hook correction for total catch in number (2.6), although this does not fully account for the difference in selectivity between hook types. Values before 1992 are multiplied by a bait correction (1.35) to account for the switch from mixed bait to all salmon in the 1990s. Mean catch rates have coefficients of variation of 5-10%.

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B |
|---|---|---|---|---|---|---|---|
| **1974** | --- | --- | --- | --- | --- | --- | --- |
| **1975** | --- | --- | --- | --- | --- | --- | --- |
| **1976** | --- | --- | --- | --- | --- | --- | --- |
| **1977** | --- | 2.5 | --- | 8.8 | --- | --- | --- |
| **1978** | --- | 2.9 | --- | 5.8 | --- | --- | --- |
| **1979** | --- | --- | --- | 8.4 | --- | --- | --- |
| **1980** | --- | 4.7 | --- | 11.0 | --- | --- | --- |
| **1981** | --- | 3.0 | --- | 16.5 | --- | --- | --- |
| **1982** | --- | 3.7 | 16.1 | 18.4 | --- | --- | --- |
| **1983** | --- | 4.9 | 15.4 | 14.6 | --- | --- | --- |
| **1984** | --- | 7.1 | 16.5 | 19.3 | --- | --- | --- |
| **1985** | --- | 5.8 | 14.7 | 19.9 | --- | --- | --- |
| **1986** | --- | 3.6 | 12.3 | 12.9 | --- | --- | --- |
| **1987** | --- | --- | --- | --- | --- | --- | --- |
| **1988** | --- | --- | --- | --- | --- | --- | --- |
| **1989** | --- | --- | --- | --- | --- | --- | --- |
| **1990** | --- | --- | --- | --- | --- | --- | --- |
| **1991** | --- | --- | --- | --- | --- | --- | --- |
| **1992** | --- | --- | --- | --- | --- | --- | --- |
| **1993** | --- | 5.5 | --- | 18.0 | --- | --- | --- |
| **1994** | --- | --- | --- | 19.0 | --- | --- | --- |
| **1995** | --- | 8.9 | --- | 23.2 | --- | --- | --- |
| **1996** | --- | 9.3 | 16.8 | 18.5 | 20.8 | --- | --- |
| **1997** | --- | 9.2 | 21.5 | 26.7 | 27.2 | 13.3 | 12.2 |
| **1998** | --- | 6.2 | 12.9 | 19.8 | 26.3 | 16.4 | 10.6 |
| **1999** | 2.0 | 6.6 | 11.9 | 14.5 | 26.6 | 19.3 | 9.7 |

## Appendix B. Recent changes in IPHC assessment methods and Harvest Policy

**1982-1994:** stock size was estimated with CAGEAN, a strictly age-structured model fitted to commercial catch-at-age and catch-per-effort data. Because of a decrease in growth rates between the late 1970s and early 1990s, there were persistent underestimates of incoming recruitment and total stock size in the assessments done in the early 1990s.

Until 1985, allowable removals were calculated as a proportion of estimated annual surplus production (ASP), the remaining production being allocated to stock rebuilding. In 1985 the Commission adopted a constant harvest rate policy, meaning that allowable removals are determined by applying a fixed harvest rate to estimated exploitable biomass. This harvest level is called the Constant Exploitation Yield, or CEY. The fixed harvest rate was set at 28% in 1985, increased to 35% in 1987, and lowered to 30% in 1993.

**1995:** a new age- and length-structured model was implemented that accounted for the change in growth and was fitted to survey as well as commercial catch-at-age and catch-per-effort data. The new model produced substantially higher biomass estimates. In Area 3A this resulted from accounting for the change in growth schedule. In Area 2B, where the change in growth had been much less than in Alaska, it resulted from fitting the model to survey catch-per-effort, which showed a larger stock increase since the mid-1980s than commercial catch-per-effort. Quotas were held at the 1995 level to allow time for a complete study of the new model and results,

**1996:** differences in estimated selectivity between British Columbia and Alaska led to the consideration of two alternatives for fitting the model, one in which survey selectivity was a fixed function of age and the other in which it was a function of length. Spawner-recruit estimates from the new model resulted in a lowering of the target harvest rate to 20%. Quotas were increased somewhat, but not to the level indicated by the new biomass estimates.

**1997:** setline surveys of the entire Commission area indicated substantially more halibut in western Alaska (IPHC Areas 3B and 4) than the analytical assessment. Biomass in those areas was estimated by scaling the analytical estimates of absolute abundance in Areas 2 and 3A by the survey estimate of relative abundance in western Alaska. CEY estimates increased again, and quotas were increased again, but still to a level well below the CEY's.

**1998:** the working value of natural mortality was lowered from 0.20 to 0.15, reducing analytical estimates of biomass in Areas 2 and 3A by about 30%. At the same time setline survey estimates of abundance in Areas 3B and 4 relative to Areas 2 and 3A increased, so biomass estimates in the western area decreased by a smaller amount.

**1999:** setline survey catch rates in the 1990s were adjusted downward to account for the effect of changing to all-salmon bait when the surveys resumed in 1993. This reduced biomass estimates by 20-30%.

# Appendix C. Changes made to the assessment model since 1997

The 1997 assessment fully documented in IPHC Scientific Report No. 79. This appendix lists changes made since then.

## Changes made in 1998

The only major change was a reduction of the natural mortality rate from 0.20 to 0.15, which had the effect, other things being equal, of lowering abundance estimates by about 30%. A number of other changes, listed below, were made in order to make the model more realistic or more fittable, but on balance they did not change any of the abundance estimates by more than 5%.

### 1. Working value of natural mortality lowered from 0.20 to 0.15.

Analysis done during the year by the staff showed that in the short term an overestimate of natural mortality could lead to a substantial overestimate of stock size when past fishing mortality rates were low, as they have been for Pacific halibut. On the other side, the consequences of an underestimate of natural mortality are less serious. (See the abstract by Clark in this volume.)

The true value of natural mortality is not known. Analysis of catch curves and tagging data in the early 1960's produced a wide range of estimates with a center of 0.15-0.20. Age compositions of commercial catches of fish aged 20-30 in the western Aleutians (Area 4B) in the mid-1990s show an apparent total mortality of 0.24. A small part of this is fishing mortality, and about 0.05 results from an increasing trend in year-class strength among these particular year-classes (spawned during the late 1960's and early 1970's). The remainder is natural mortality, which is therefore something less than 0.20 and perhaps less than 0.15, but probably not much less than 0.15.

### 2. Break in commercial catchability allowed in the first year of IQ management.

When the model is fitted, commercial catchability is allowed to change from year to year but a prior distribution for the changes is specified and used to calculate a penalty function that is added to the objective function. This serves to prevent large year-to-year changes which would be unrealistic in the absence of a major change in the conduct of the fishery. The implementation of individual quota (IQ) schemes in Canada (1991) and Alaska (1995) was such a major change, so for in those years commercial catchability was allowed to jump with no penalty.

### 3. Size-at-age data screened and weighted more heavily.

In previous years all available size-at-age data was used but it was down-weighted relative to other data types because some of the estimates of means and variances were based on very small samples and were clearly wild. This year outliers were removed from the data, and the estimates for a given age group in a given year were used only if the sample size was at least 15 (in both the commercial and survey data). In addition, an error that had been present in the calculation of the estimated variance of the estimated variance [*sic*] of length at age in commercial landings, was corrected. Finally, commercial size-at-age data for ages 6-8 were not used in the fit. A large fraction of fish in those age groups are now below the minimum size limit so the mean and variance of the lengths of the few fish of those ages in the commercial catch do not contain much information about the corresponding population parameters. With the size-at-age data cleaned up, there was no reason to down-weight it, so the ISD was reduced from 5 to 2, the same as most other data types.

**3. Requirement of full recruitment at age 20 dropped.**

In previous years a large penalty was charged if age-specific selectivity at age 20 was less than one, which effectively forced the oldest fish to be fully recruited. An examination of length distributions at age 20 (actually 20+) this year showed a substantial proportion of fish in the 100-120 cm range where recruitment is not complete, so the penalty was dropped. This resulted in a much better fit to recent size-at-age data. The model had been overestimating size at age to meet the full-recruitment requirement.

**4. Some parameters not estimated.**

In Area 2B, fish appear to be almost fully recruited at the minimum size limit. As a result the two parameters of the commercial selectivity function are poorly defined and attempts to estimate changes over time led to numerical difficulties. To cure those, the slope parameter was fixed (i.e., estimated as a constant).

In Areas 2C and 3A the length at full recruitment to the commercial fishery tended to drift to unrealistically large values, even with a penalty. In order to constrain that parameter, it was estimated as a fixed parameter and bounded.

**Changes made in 1999**

**1. Setline survey catchability increased as of 1993.**

It became apparent late in 1999 that setline survey catchability had increased when the survey adopted all-salmon bait when the surveys were resumed in 1993. Preliminary data indicated that catchability might have increased by 25-50%. Model-based estimates of the change averaged 35% (with one of three area-by-area estimates hitting the upper constraint of 50%). That average was used as a fixed value in all areas, implemented as an addition of 0.3 to the log of survey catchability in 1993.

**2. Growth equations slightly modified.**

The $\alpha$ parameter of the equation for annual growth in median length was modeled as a random walk rather than as a cubic polynomial of time, mainly to improve computational stability.

## Appendix D. Selected Estimates from the 1999 Assessment

The following tables show trends in recruitment, stock size, and exploitation rate estimated with the model used in 1999. Except for the catches, all of these estimates are liable to change in later years, sometimes dramatically, as new data and methods are used in the assessment.

The columns in the tables are:

**R** = age 8 recruits (millions)
**N** = total abundance of age 8+ fish (millions)
**C** = total catch in number of age 8+ fish (million net lb)
**C/N** = exploitation rate in number of age 8+ fish
**B** = total biomass of age 8+ fish (million net lb)
**Y** = total catch in weight of age 8+ fish (million net lb)
**Y/B** = exploitation rate in weight

The “catches” are actually total removals except for bycatch. Total biomass is calculated using estimated mean size at age in the sea rather than in the catch, and is not directly comparable with estimates of exploitable biomass.

## Area 2AB

| | R | N | C | C/N | B | Y | Y/B |
|---|---|---|---|---|---|---|---|
| **1974** | 0.45 | 1.71 | 0.14 | 0.08 | 44.55 | 4.81 | 0.11 |
| **1975** | 0.45 | 1.75 | 0.21 | 0.12 | 45.14 | 7.28 | 0.16 |
| **1976** | 0.43 | 1.70 | 0.21 | 0.12 | 49.10 | 6.69 | 0.14 |
| **1977** | 0.44 | 1.66 | 0.16 | 0.10 | 45.84 | 5.15 | 0.11 |
| **1978** | 0.52 | 1.77 | 0.14 | 0.08 | 43.02 | 4.20 | 0.10 |
| **1979** | 0.59 | 1.94 | 0.16 | 0.08 | 39.99 | 4.66 | 0.12 |
| **1980** | 0.72 | 2.20 | 0.19 | 0.08 | 41.96 | 5.35 | 0.13 |
| **1981** | 0.80 | 2.48 | 0.21 | 0.08 | 45.86 | 5.52 | 0.12 |
| **1982** | 0.85 | 2.75 | 0.22 | 0.08 | 49.98 | 5.51 | 0.11 |
| **1983** | 1.06 | 3.20 | 0.22 | 0.07 | 53.73 | 5.54 | 0.10 |
| **1984** | 1.29 | 3.82 | 0.39 | 0.10 | 60.84 | 9.05 | 0.15 |
| **1985** | 1.69 | 4.57 | 0.48 | 0.10 | 65.77 | 11.20 | 0.17 |
| **1986** | 1.49 | 4.92 | 0.52 | 0.11 | 74.18 | 12.32 | 0.17 |
| **1987** | 1.67 | 5.38 | 0.56 | 0.10 | 80.91 | 13.34 | 0.16 |
| **1988** | 1.62 | 5.66 | 0.60 | 0.11 | 78.08 | 13.75 | 0.18 |
| **1989** | 1.29 | 5.55 | 0.49 | 0.09 | 76.01 | 11.58 | 0.15 |
| **1990** | 1.14 | 5.41 | 0.40 | 0.07 | 84.25 | 9.47 | 0.11 |
| **1991** | 1.35 | 5.57 | 0.30 | 0.05 | 98.70 | 7.98 | 0.08 |
| **1992** | 1.33 | 5.77 | 0.34 | 0.06 | 102.94 | 8.73 | 0.08 |
| **1993** | 1.06 | 5.64 | 0.51 | 0.09 | 95.70 | 12.27 | 0.13 |
| **1994** | 1.04 | 5.38 | 0.47 | 0.09 | 88.02 | 11.22 | 0.13 |
| **1995** | 2.05 | 6.21 | 0.46 | 0.07 | 98.86 | 11.65 | 0.12 |
| **1996** | 1.77 | 6.62 | 0.50 | 0.08 | 104.08 | 11.66 | 0.11 |
| **1997** | 1.18 | 6.38 | 0.63 | 0.10 | 104.36 | 14.49 | 0.14 |
| **1998** | 1.09 | 5.95 | 0.69 | 0.12 | 95.85 | 15.60 | 0.16 |
| **1999** | 0.74 | 5.20 | 0.64 | 0.12 | 83.70 | 15.26 | 0.18 |

**Area 2C**

| | R | N | C | C/N | B | Y | Y/B |
|---|---|---|---|---|---|---|---|
| **1974** | 0.37 | 1.55 | 0.13 | 0.09 | 44.15 | 5.51 | 0.12 |
| **1975** | 0.40 | 1.59 | 0.15 | 0.10 | 45.54 | 6.13 | 0.13 |
| **1976** | 0.45 | 1.66 | 0.13 | 0.08 | 45.00 | 5.45 | 0.12 |
| **1977** | 0.49 | 1.77 | 0.08 | 0.05 | 47.26 | 3.17 | 0.07 |
| **1978** | 0.59 | 2.03 | 0.12 | 0.06 | 51.29 | 4.22 | 0.08 |
| **1979** | 0.66 | 2.28 | 0.13 | 0.06 | 52.91 | 4.58 | 0.09 |
| **1980** | 0.83 | 2.65 | 0.10 | 0.04 | 58.98 | 3.49 | 0.06 |
| **1981** | 0.89 | 3.07 | 0.13 | 0.04 | 68.89 | 4.25 | 0.06 |
| **1982** | 0.82 | 3.33 | 0.11 | 0.03 | 76.29 | 3.91 | 0.05 |
| **1983** | 0.83 | 3.58 | 0.19 | 0.05 | 82.87 | 6.83 | 0.08 |
| **1984** | 0.96 | 3.85 | 0.19 | 0.05 | 89.08 | 6.32 | 0.07 |
| **1985** | 1.27 | 4.39 | 0.29 | 0.07 | 93.65 | 10.03 | 0.11 |
| **1986** | 0.96 | 4.46 | 0.37 | 0.08 | 97.25 | 11.63 | 0.12 |
| **1987** | 1.03 | 4.49 | 0.35 | 0.08 | 93.66 | 11.75 | 0.13 |
| **1988** | 0.97 | 4.48 | 0.39 | 0.09 | 92.72 | 12.49 | 0.13 |
| **1989** | 0.83 | 4.31 | 0.34 | 0.08 | 87.15 | 11.15 | 0.13 |
| **1990** | 0.76 | 4.13 | 0.33 | 0.08 | 90.20 | 11.19 | 0.12 |
| **1991** | 0.88 | 4.10 | 0.31 | 0.07 | 92.79 | 11.16 | 0.12 |
| **1992** | 0.88 | 4.07 | 0.35 | 0.09 | 88.58 | 12.00 | 0.14 |
| **1993** | 0.70 | 3.85 | 0.37 | 0.10 | 83.00 | 13.33 | 0.16 |
| **1994** | 0.64 | 3.59 | 0.38 | 0.10 | 79.68 | 12.58 | 0.16 |
| **1995** | 1.31 | 4.02 | 0.23 | 0.06 | 85.26 | 9.47 | 0.11 |
| **1996** | 1.11 | 4.33 | 0.30 | 0.07 | 84.01 | 10.35 | 0.12 |
| **1997** | 0.67 | 4.09 | 0.35 | 0.09 | 79.39 | 11.58 | 0.15 |
| **1998** | 0.52 | 3.69 | 0.44 | 0.12 | 71.58 | 12.86 | 0.18 |
| **1999** | 0.47 | 3.22 | 0.42 | 0.13 | 61.07 | 11.95 | 0.20 |

**Area 3A**

| | R | N | C | C/N | B | Y | Y/B |
|---|---|---|---|---|---|---|---|
| **1974** | 0.82 | 3.32 | 0.17 | 0.05 | 103.58 | 8.10 | 0.08 |
| **1975** | 1.00 | 3.59 | 0.22 | 0.06 | 112.10 | 10.43 | 0.09 |
| **1976** | 1.18 | 3.99 | 0.23 | 0.06 | 120.81 | 10.92 | 0.09 |
| **1977** | 1.26 | 4.39 | 0.18 | 0.04 | 127.98 | 8.73 | 0.07 |
| **1978** | 1.52 | 5.03 | 0.24 | 0.05 | 152.50 | 10.35 | 0.07 |
| **1979** | 1.38 | 5.40 | 0.27 | 0.05 | 167.46 | 11.34 | 0.07 |
| **1980** | 1.70 | 5.95 | 0.27 | 0.05 | 175.63 | 12.28 | 0.07 |
| **1981** | 2.12 | 6.85 | 0.33 | 0.05 | 197.50 | 14.76 | 0.07 |
| **1982** | 1.92 | 7.37 | 0.30 | 0.04 | 218.68 | 14.10 | 0.06 |
| **1983** | 2.03 | 7.97 | 0.35 | 0.04 | 246.48 | 14.91 | 0.06 |
| **1984** | 2.43 | 8.90 | 0.51 | 0.06 | 251.25 | 20.56 | 0.08 |
| **1985** | 3.33 | 10.44 | 0.57 | 0.05 | 266.25 | 22.77 | 0.09 |
| **1986** | 2.95 | 11.37 | 0.92 | 0.08 | 288.71 | 36.21 | 0.13 |
| **1987** | 3.67 | 12.53 | 0.93 | 0.07 | 303.76 | 34.42 | 0.11 |
| **1988** | 4.54 | 14.38 | 1.22 | 0.09 | 338.05 | 41.93 | 0.12 |
| **1989** | 3.58 | 14.69 | 1.11 | 0.08 | 323.82 | 37.88 | 0.12 |
| **1990** | 3.19 | 14.71 | 0.98 | 0.07 | 298.26 | 33.09 | 0.11 |
| **1991** | 4.15 | 15.75 | 0.94 | 0.06 | 279.12 | 28.87 | 0.10 |
| **1992** | 3.39 | 15.88 | 1.02 | 0.06 | 267.55 | 31.70 | 0.12 |
| **1993** | 2.57 | 15.16 | 0.97 | 0.06 | 238.86 | 28.62 | 0.12 |
| **1994** | 1.93 | 13.98 | 1.08 | 0.08 | 224.63 | 30.38 | 0.14 |
| **1995** | 2.78 | 13.67 | 0.81 | 0.06 | 226.79 | 22.95 | 0.10 |
| **1996** | 1.99 | 12.91 | 0.87 | 0.07 | 224.29 | 24.74 | 0.11 |
| **1997** | 1.02 | 11.25 | 1.02 | 0.09 | 208.17 | 30.34 | 0.15 |
| **1998** | 0.94 | 9.59 | 1.13 | 0.12 | 175.50 | 31.07 | 0.18 |
| **1999** | 0.50 | 7.63 | 1.22 | 0.16 | 139.00 | 30.75 | 0.22 |

# Assessment of the Pacific Halibut Stock in 1998

by

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## ABSTRACT

The Pacific halibut assessment is based on fitting an age- and length-structured model to data from the fishery and IPHC setline surveys. The only major change in the model this year was a lowering of the working value of natural mortality from 0.20 to 0.15, which reduced the population estimates by about 30% in the eastern and central Gulf of Alaska (Areas 2 and 3A). Farther west (Areas 3B and 4), biomass is estimated by extrapolating the Area 3A estimate on the basis of setline survey results, and the decrease was only about 20% owing to an increase in the scaling factor resulting from the 1998 surveys. Total setline CEY (available yield at a harvest rate of 20%) is still estimated to be very high at just under 100 million pounds.


## INTRODUCTION

Each year the IPHC staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). Exploitable biomass in each IPHC regulatory area (Fig. 1) is estimated by fitting a detailed population model to

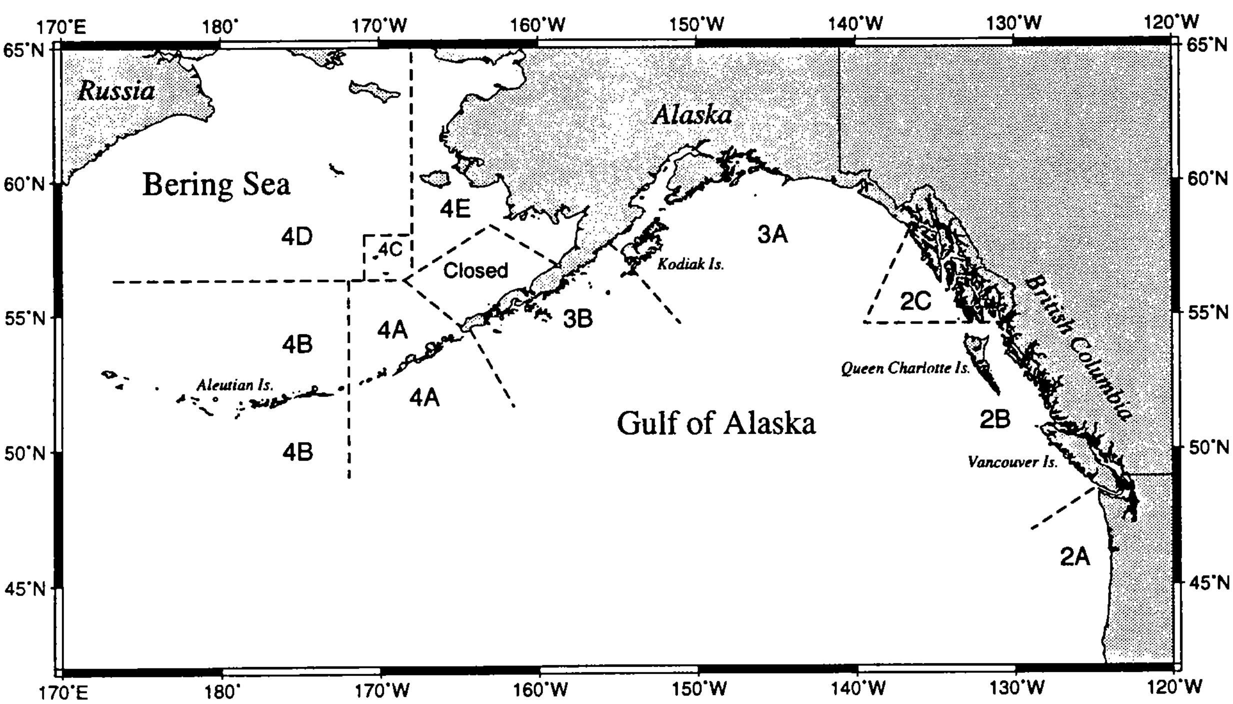



**Figure 1.** **IPHC regulatory areas.**

the data from that area. A biological target level for total removals is then calculated by applying a fixed harvest rate—presently 20%—to the estimate of exploitable biomass. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for directed setline catches, called the setline CEY, is calculated by subtracting from the total CEY an estimate of all other removals—sport catches, bycatch of legal sized fish, wastage in the halibut fishery, and fish taken for personal use.

Staff recommendations for quotas in each area are based on the estimates of setline 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.

This paper reports the staff's estimates of total abundance, recruitment trends, exploitable biomass, and total and setline CEY by area as calculated at the end of 1998 for the 1999 fishery.

## THE ASSESSMENT MODEL

From 1982 through 1994, stock size was estimated by fitting an age-structured model (CAGEAN) to commercial catch-at-age and catch-per-effort data. In the early 1990's it became apparent that age-specific selectivity in the commercial fishery had shifted as a result of a decline in halibut growth rates, which was more dramatic in Alaska than in Canada. An age- and length-structured model was developed and implemented in 1995 that accounted for the change in growth. It also incorporated survey (as well as commercial) catch-at-age and catch-per effort data. The survey data contain much more information on younger fish, many of which are now smaller than the commercial size limit, and in Canada survey catch rates appear to provide a better index of relative abundance than commercial catch rates.

At first the model was fitted on the assumption that survey catchability and length-specific survey selectivity were constant, while commercial catchability and selectivity were allowed to vary over time (subject to some restraints). The resulting fits showed quite different length-specific survey selectivities in Area 2B and 3A, however, which suggested that age could still be influencing selectivity. To reflect that possibility, the new model has been fitted in two ways since 1996: by requiring constant length-specific survey selectivity (as in 1995), and by requiring constant age-specific survey selectivity. The age-specific fits generally produce lower estimates of recent recruitment and therefore present abundance, and to be conservative the staff has used those estimates to calculate CEY's.

With either fitting criterion, the abundance estimates depend strongly on the natural mortality rate $M$ used in the population model. Until 1998 the estimate $M = 0.20$ had been used in all assessments. This estimate is quite imprecise, and analysis done by the staff during the year suggested that a lower working value would be appropriate. The value $M = 0.15$ was chosen and used as a standard, which lowered abundance estimates by about 30%.

Further details on the history of IPHC assessment methods and harvest strategy are given in Appendix B and in a detailed account of the 1997 assessment (Sullivan et al. 1999). Details of changes to the model made in 1998 are given in Appendix C.

## STOCK SIZE ESTIMATES IN AREAS 3B AND 4

Until 1997 the analytical model was used to estimate halibut abundance for the entire Commission area, including lightly fished regions in the western Gulf of Alaska (Area 3B) and the Bering Sea/Aleutians region (Area 4). Because there is no historical survey data series for western Alaska, the assessment relied entirely on commercial data for those areas. In 1997 the Commission first did setline surveys of the entire Commission area, and they showed substantially more halibut to be available in western Alaska (relative to other areas) than the analytical model had estimated. The reason for the discrepancy is almost certainly that the analytical model, when fitted to commercial data alone, only estimates the size of the *exploited population*, and in western Alaska fishing intensity is very low or nil over large areas, so a substantial part of the stock is effectively unexploited and therefore invisible to the model but not to the surveys.

In light of the survey results, analytical estimates of stock size in Areas 3B and 4 were suspended in 1997. The procedure now is to calculate analytical estimates for Areas 2A, 2B, 2C, and 3A, and then to scale those absolute estimates by survey estimates of relative abundance in Area 3B and 4 to obtain absolute estimates for the western areas. In 1997 the sum of the abundance estimates for Areas 2A through 3A was used as the reference point. This year the absolute estimate for Area 3A only is used as the reference point, on the grounds that survey catch rates there are more comparable to survey catch rates farther west.

## ANALYTICAL ESTIMATES OF ABUNDANCE IN 1998

There is very little difference between the age- and length-specific fits in Area 2, so only the age-specific fits are illustrated for Area 2AB (Fig.2) and Area 2C (Fig.3). In Area 3A there is more of a difference, so both fits are illustrated (Figs. 4a and 4b).

Except for the age-specific fit in Area 3A, all of the fits show the 1987 year-class to be strong. All of the fits show a drop in recruitment after the 1987 year-class, but these age-groups (ages 8, 9, and 10 in 1998) are still estimated imprecisely.

In the plot of survey catch rates (center left panel), the broad shaded line is a data smoother that shows the general trend of the survey data points. The thin black line is the model predictions of survey catch rates. There is quite a wide scatter of the data points around the general trend, which means that the survey data are quite variable from year to year. Thus while the surveys are an essential index of the general level of stock abundance, the year-to-year changes are not very meaningful.

In the center right panel, commercial catch per effort is plotted as points and the model estimates of exploitable biomass as a thin black line. The values of exploitable biomass in this graph are calculated with the model estimates of commercial selectivity in each area in each year, and are not the same as the estimates of exploitable biomass that appear below in the calculation of setline CEY. Those are calculated with a fixed coastwide selectivity.

Figure 5 shows estimated recruitment at age 8 and total biomass of fish aged 8 and older for both kinds of fit. The two results are very similar in Area 2AB and Area 2C. Even in Area 3A they are close until the last few years. An important change from last year's assessment is that this year both the age- and length-specific fits in Area 3A show a downturn in recruitment after the 1987 year-class. In last year's results the length-specific fit showed recruitment carrying on at approximately the level of the 1987 year-class. The change resulted mainly from the screening and heavier weighting of size-at-age data described in Appendix C.

Figure 6 compares relative year-class strength in Area 2AB and Area 3A for both kinds of fit. The two series are fairly coherent, especially in the early part of the series where year-class strengths are by now well estimated because those year-classes have largely passed through the fishery.

## EVALUATION OF AGE- AND LENGTH-SPECIFIC FITS

The relative performance of the two versions of the assessment model was evaluated for Areas 2A+2B and 3A based on goodness-of-fit criteria and retrospective analyses.

Overall goodness of fit, as indicated by the square root of the mean sum of weighted squared residuals, is better under the assumption of length-specific selectivity than under constant selectivity at age. But the difference is small (Tables 1 and 2). Residual plots for all likelihood components (not shown) are remarkably similar for the two versions of the model. A comparison of the goodness of fit by data category indicates that, under the chosen weighting scheme, some types of data are fitted much better than others, but the relative goodness of fit of the different components is very similar for both model versions. In Area 3A, where the decrease in size at age was most dramatic, results are most sensitive to the different assumptions about survey selectivity. In that area, however, neither of the models was able to fit survey data well. In particular, age compositions observed during the early series of surveys prior to 1986 were fitted poorly under both model assumptions and show strong, persistent patterns in the residuals. In general, the survey age compositions indicate higher relative abundance of young fish in the 1970's than predicted by either model, while the opposite is true in the 1980's. Survey age compositions and CPUE have the highest residual variance in both models in Area 3A(Table 1). Residual patterns in survey data are less problematic in Area 2B.

Retrospective analyses were also conducted to evaluate the consistency of successive estimates of the same year's abundance when the two assessment models are applied to data covering different assessment periods. Because surveys were suspended between 1987 and 1992, the analysis could not be carried all the way back into the past without substantially affecting the database used for the assessment. Therefore, only retrospective assessments for the periods 1974-1993, 1974-1994, and so forth up to 1974-1998 were conducted.

Results indicate that neither of the models shows a consistent and strong retrospective pattern such as was observed under the old assessment model (CAGEAN). Under CAGEAN, exploitable biomass was initially underestimated and later revised upward as more data became available. The age-specific version of the current assessment model does show a slight tendency to initially underestimate year-class strength in both Areas 2A+2B and 3A, as would be expected if the vulnerability of the young age classes to the survey was at least partially a function of fish length (Figs. 7 and 8). In Area 3A, the assumption of length-specific selectivity results in more consistent estimates of exploitable biomass among successive assessments. The opposite is true in Area 2A+2B where the length-specific fit tends to overestimate biomass initially. This type of retrospective analysis will be more powerful to diagnose model mis-specification when more data become available.

In summary, neither the analysis of residuals and goodness of fit, nor the retrospective analyses clearly favors one model structure over the other at this point.

## ESTIMATES OF EXPLOITABLE BIOMASS AND CEY

The target harvest rate of 20% was chosen on the basis of calculations of stock productivity that used a coastwide average of the estimates of commercial selectivity from the age-specific fit of the model, so the biomass estimates from the age-specific fits are used to calculate exploitable biomass and CEY.

Table 3a shows the analytical (age-specific) estimates of exploitable biomass for Areas 2A, 2B, 2C, and 3A. Estimates for the other areas were based on survey estimates of abundance in those areas relative to 3A: 3B = 87%, 4A = 29%, 4B = 22%, 4CDE = 37%.

The analytical estimates of exploitable biomass in Areas 2A through 3A are about 30% lower than last year's as a result of the lower working value of natural mortality ($M = 0.15$ instead of $M = 0.20$). In Areas 3B and 4 the estimates are only about 20% lower than last year's because the 1998 surveys showed an increase in biomass in those areas relative to the central and eastern Gulf of Alaska. Overall the estimated setline CEY is still very high—99 million pounds. The comparable 1997 figure was 136 million pounds, about the same as this year's total would be if stock size had been estimated with $M = 0.20$ (Table 3b).

## REFERENCES

Sullivan, P.J., Parma, A.M., and Clark, W.G *In Press*. Pacific halibut assessment: data and methods. IPHC Scientific Report.

**Table 1.** **Goodness of fit of the two assessment models applied to data from Area 3A. Age- and length-specific fit correspond to the two different assumptions about survey selectivity. Natural mortality was set to 0.15. Goodness of fit is measured by the square root of the mean of the weighted squared residuals.**

| Area 3A | Age-specific fit | Length-specific fit |
|---|---|---|
| Total | 1.323 | 1.318 |
| Commercial: | | |
| Catch at age | 1.444 | 1.331 |
| Effort | 0.968 | 1.006 |
| Mean length at age | 1.127 | 1.143 |
| Variance of length at age | 1.047 | 1.093 |
| Survey: | | |
| Cpue | 2.182 | 2.042 |
| Mean length at age | 1.193 | 1.123 |
| Variance of length at age | 1.243 | 1.508 |
| Age composition | 1.652 | 1.601 |

**Table 2. Goodness of fit of the two assessment models applied to data from Areas 2A+2B. Age- and length-specific fit correspond to the two different assumptions about survey selectivity. Natural mortality was set to 0.15. Goodness of fit is measured by the square root of the mean of the weighted squared residuals.**

| Area 2A+2B | Age-specific fit | Length-specific fit |
|---|---|---|
| Total | 1.150 | 1.040 |
| Commercial: | | |
| Catch at age | 1.335 | 1.130 |
| Effort | 0.800 | 0.633 |
| Mean length at age | 1.193 | 1.023 |
| Variance of length at age | 0.889 | 0.894 |
| Survey: | | |
| Cpue | 1.324 | 1.176 |
| Mean length at age | 1.100 | 1.035 |
| Variance of length at age | 1.127 | 1.121 |
| Age composition | 0.960 | 0.882 |

**Table 3a.** **Estimates of total and setline CEY from the age-specific model fit ($M = 0.15$) in Areas 2AB, 2C, and 3A, extrapolated to Areas 3B and 4 on the basis of survey estimates of relative abundance.**

| Area | 2A* | 2B | 2C | 3A | 3B | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1998 quota | 0.82 | 13.00 | 10.50 | 26.00 | 11.00 | 3.50 | 3.50 | 3.50 | 71.82 |
| 1999 exploitable biomass | 5.36 | 61.64 | 64.00 | 159.00 | 138.33 | 46.11 | 34.98 | 58.83 | 568.25 |
| Total CEY at 20% | 1.07 | 12.33 | 12.80 | 31.80 | 27.67 | 9.22 | 7.00 | 11.77 | 113.65 |
| Non-commercial removals | 0.39 | 1.12 | 2.14 | 7.15 | 0.86 | 0.79 | 0.29 | 1.91 | 14.65 |
| Setline CEY | 0.68 | 11.21 | 10.66 | 24.65 | 26.81 | 8.43 | 6.71 | 9.86 | 99.00 |

* In Area 2A only, sport catch is combined with setline CEY rather than other non-commercial removals.

**Table 3b.** **Same as Table 3a, but with biomass estimates computed with $M = 0.20$ for purposes of comparison with 1997 estimates.**

| Area | 2A* | 2B | 2C | 3A | 3B | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1998 quota | 0.82 | 13.00 | 10.50 | 26.00 | 11.00 | 3.50 | 3.50 | 3.50 | 71.82 |
| 1999 exploitable biomass | 6.80 | 78.20 | 88.00 | 202.00 | 175.74 | 58.58 | 44.44 | 74.74 | 728.50 |
| Total CEY at 20% | 1.36 | 15.64 | 17.60 | 40.40 | 35.15 | 11.72 | 8.89 | 14.95 | 145.70 |
| Non-commercial removals | 0.39 | 1.12 | 2.14 | 7.15 | 0.86 | 0.79 | 0.29 | 1.91 | 14.65 |
| Setline CEY | 0.97 | 14.52 | 15.46 | 33.25 | 34.29 | 10.93 | 8.60 | 13.04 | 131.05 |

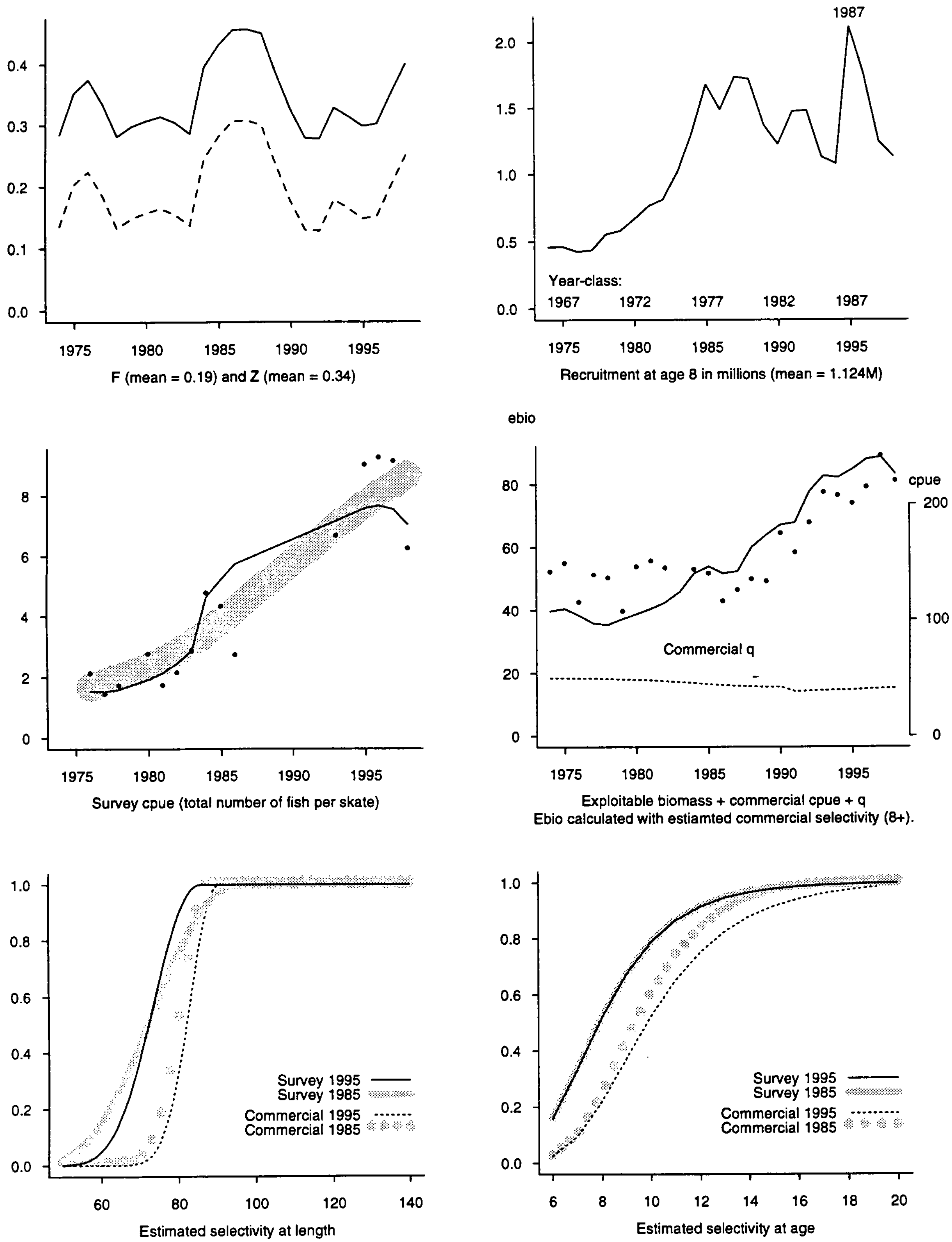



**Figure 2. Features of the age-specific model fit in Area 2AB (natural mortality = 0.15).**

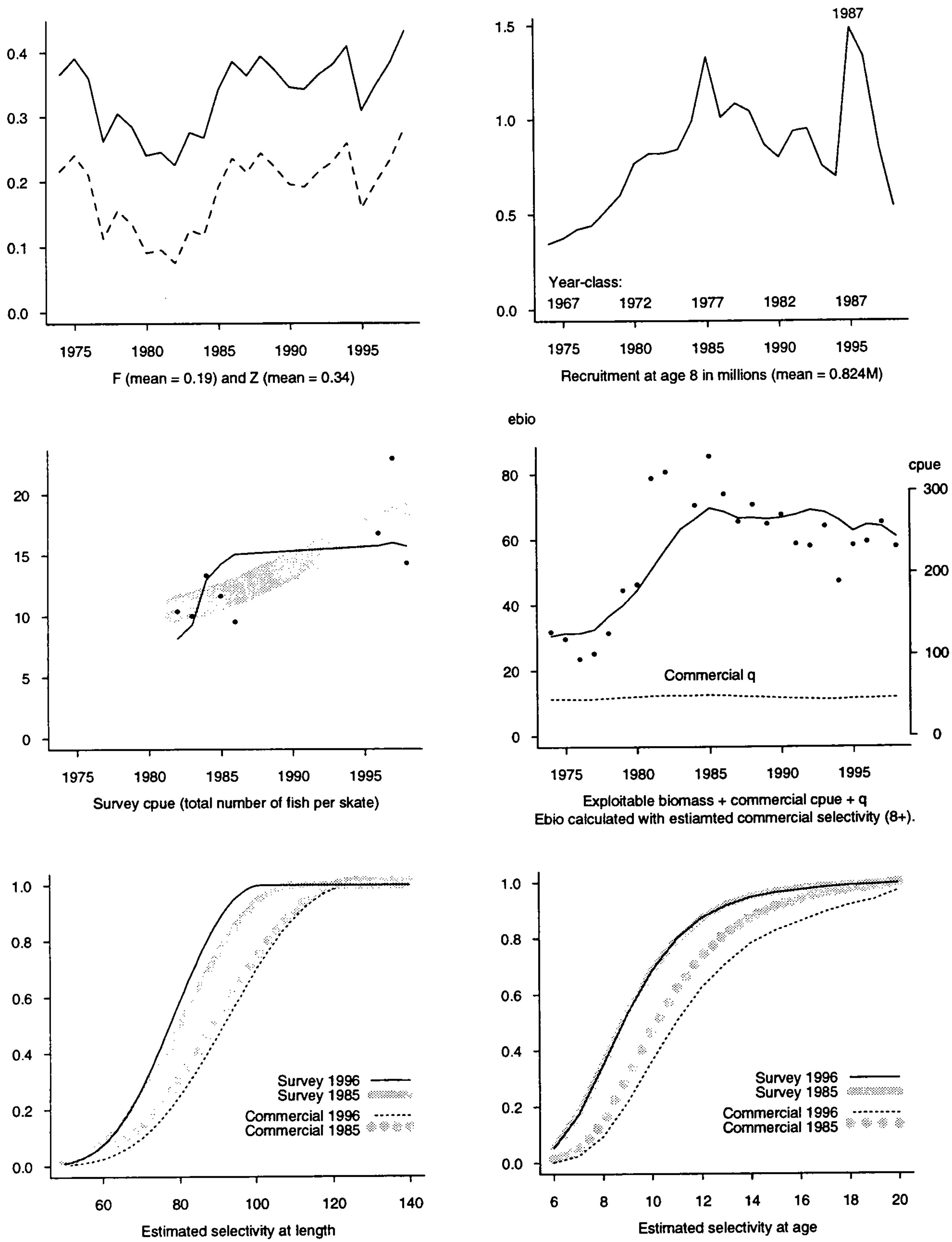



**Figure 3.** **Features of the age-specific model fit in Area 2C (natural mortality = 0.15).**

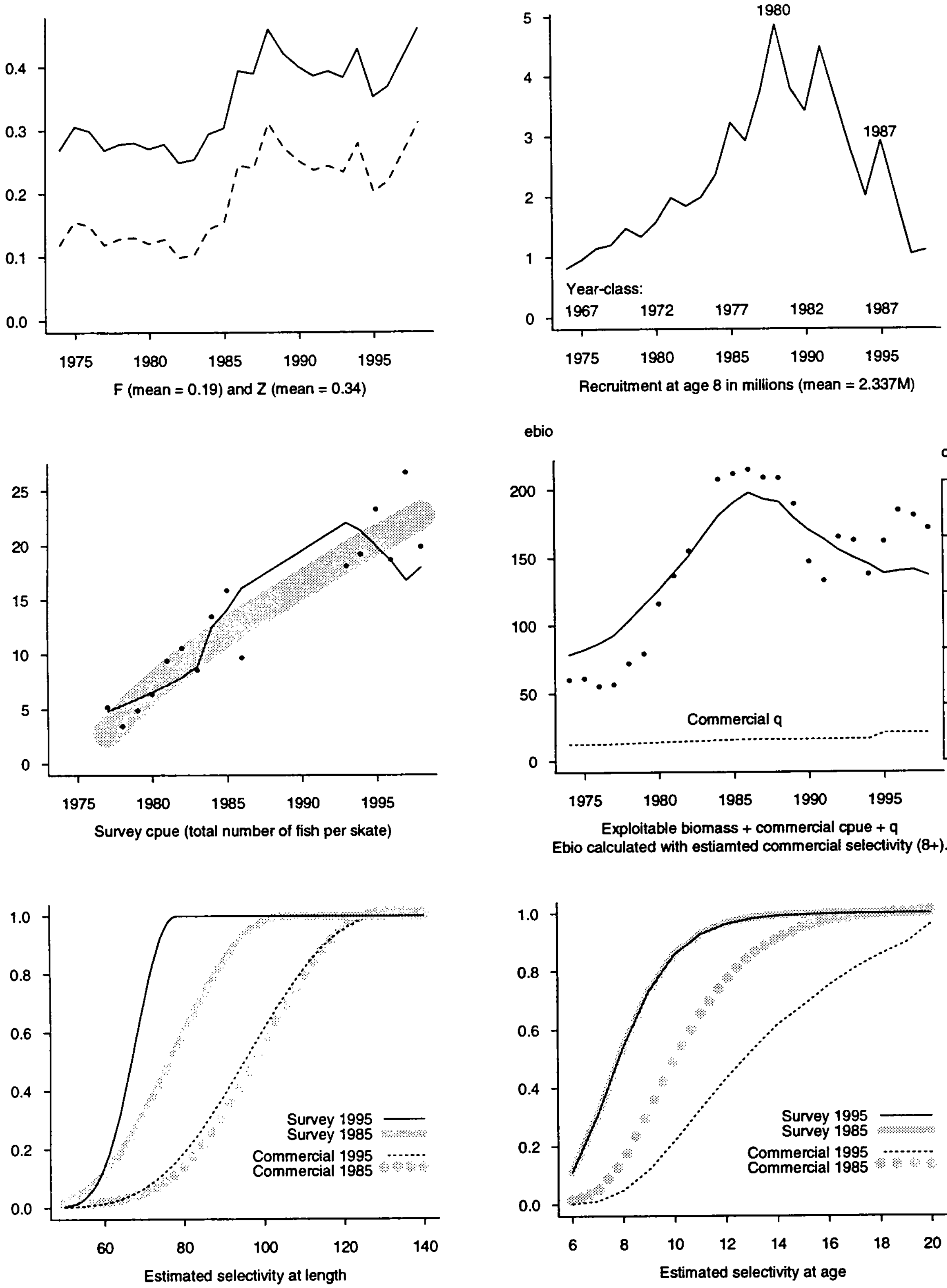



**Figure 4a. Features of the age-specific model fit in Area 3A (natural mortality = 0.15).**

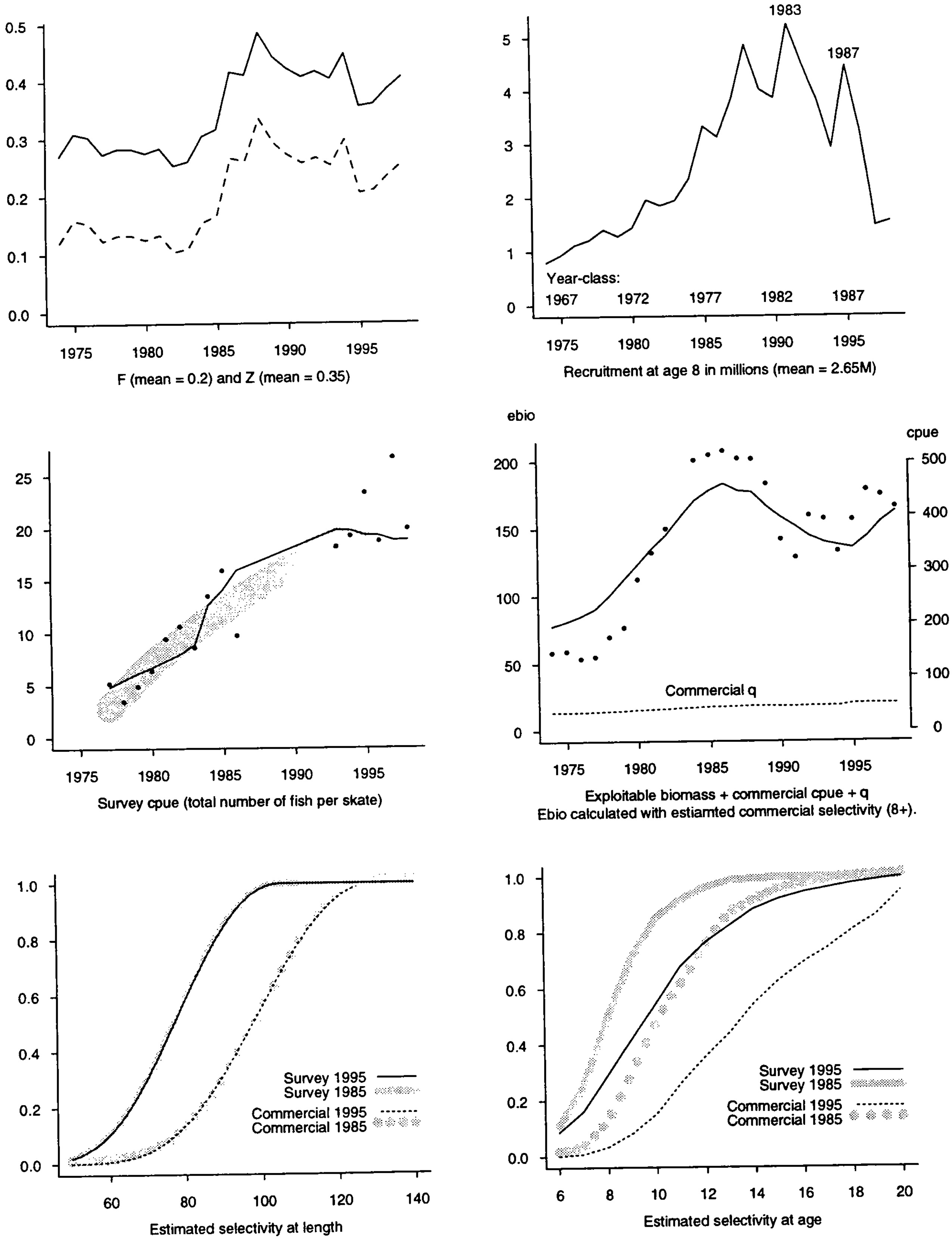



**Figure 4b.** **Features of the length-specific model fit in Area 3A (natural mortality = 0.15).**

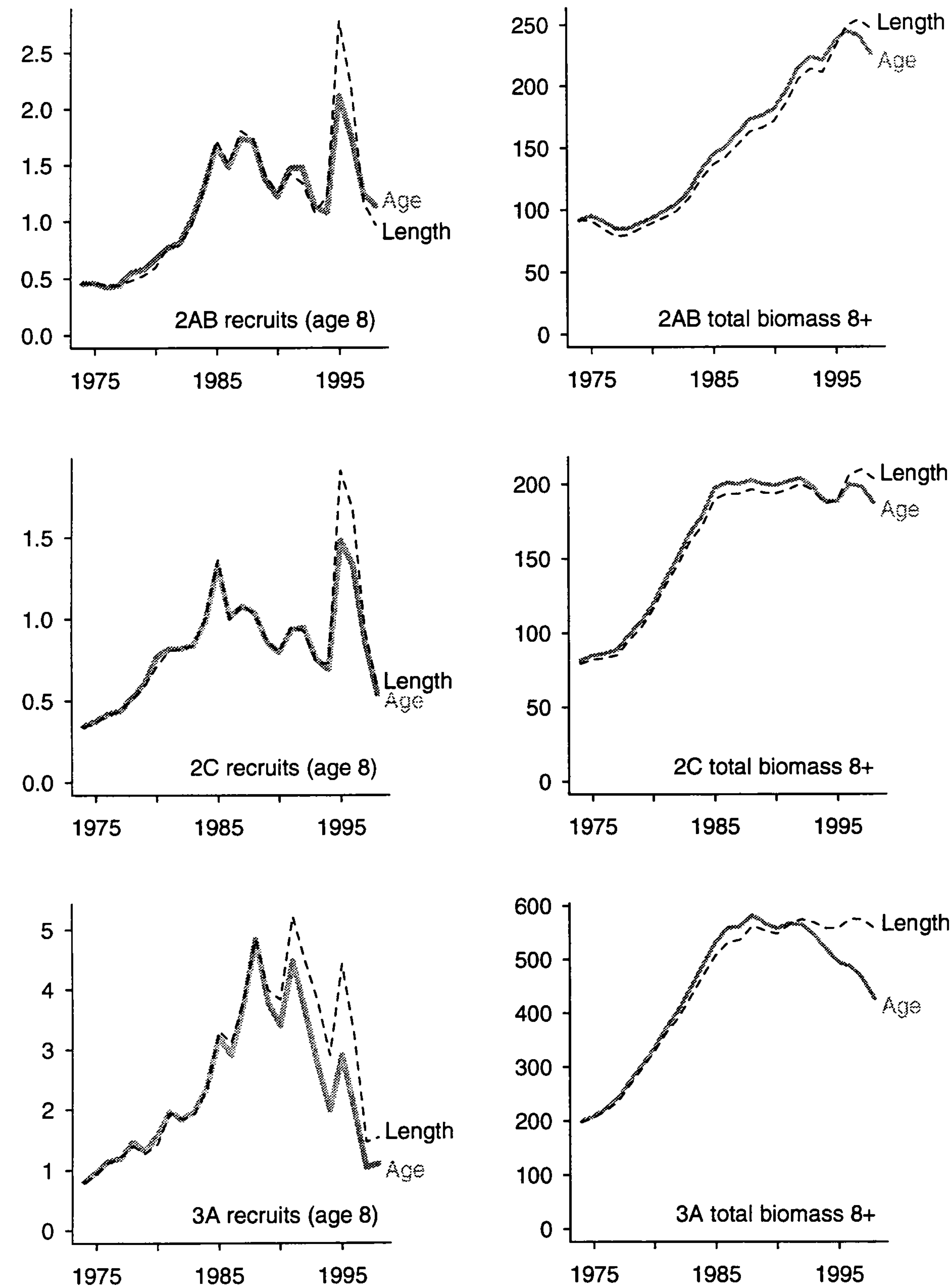
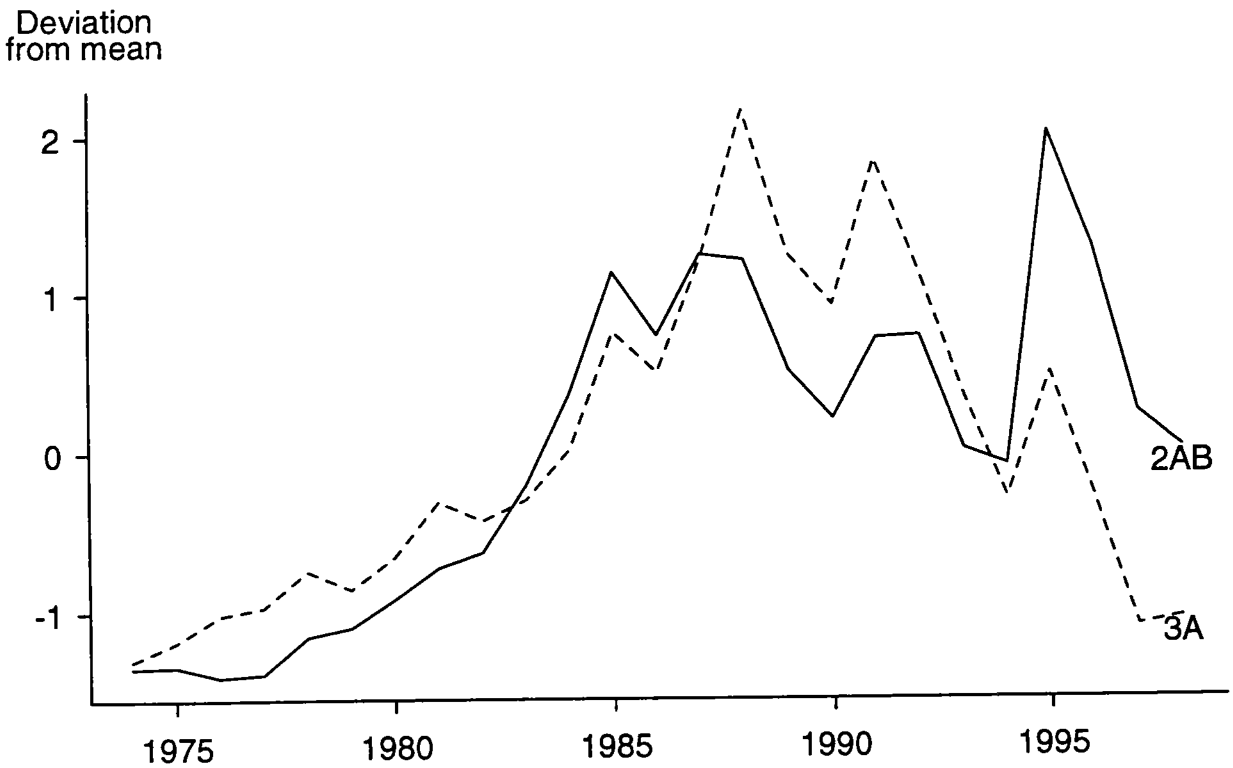



**Figure 5.** **Estimates of recruitment (millions) and total biomass (millions of net pounds) for both kinds of fit.**



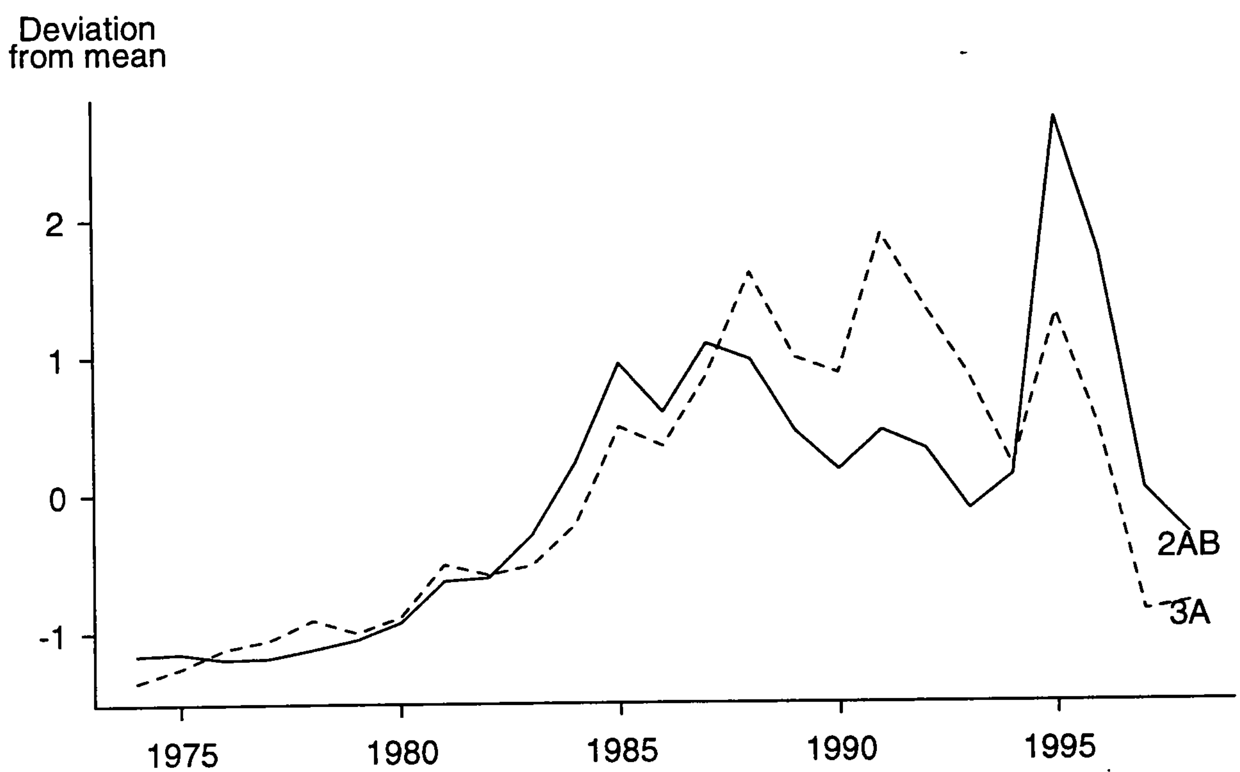




**Figure 6.** **Relative year-class strengths in Areas 2AB and 3A according to the age-specific fit (upper panel) and length-specific fit (lower panel).**

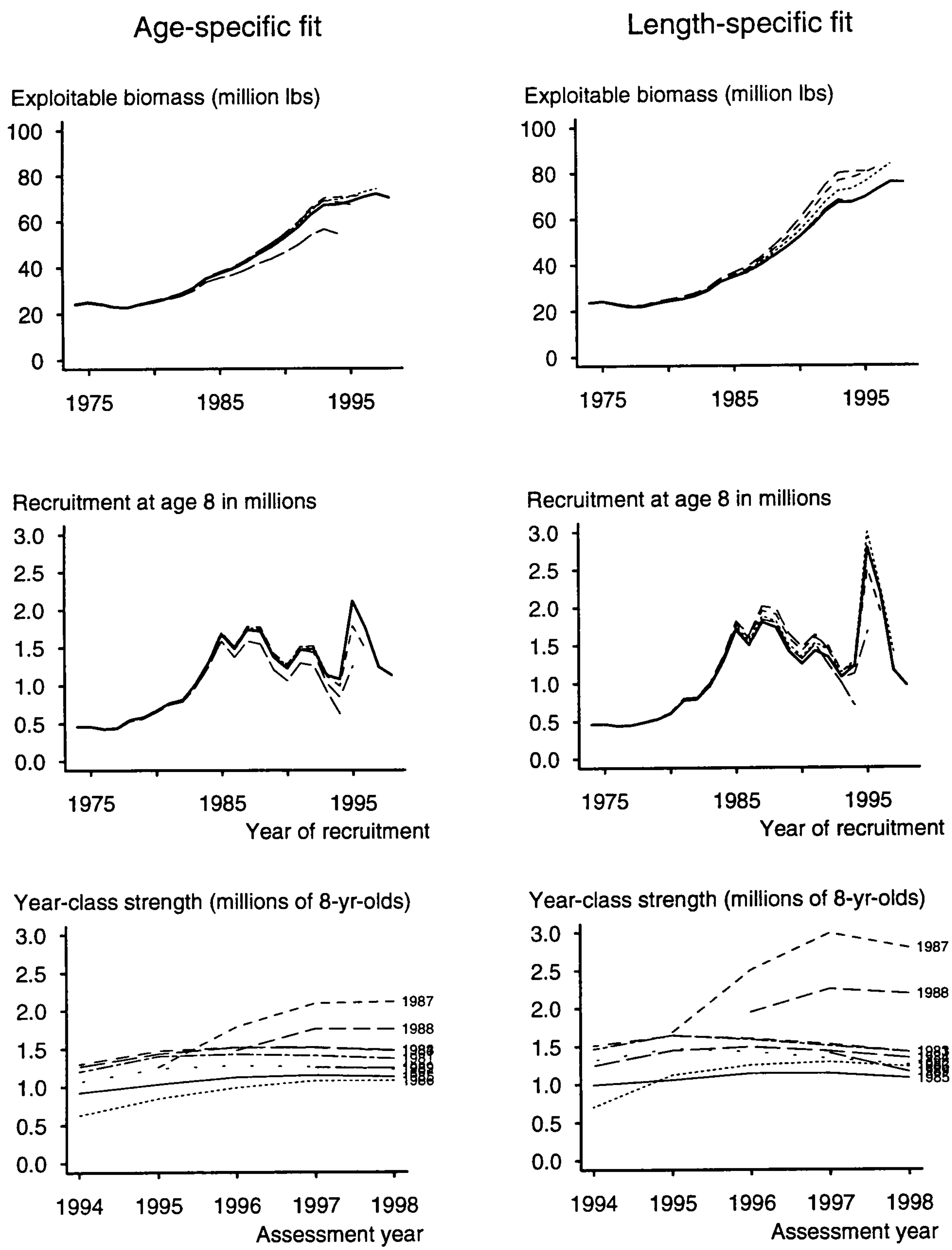



**Figure 7.** **Retrospective assessments for Area 2AB for the two kinds of fit. Exploitable biomass is computed using a coastwide fixed selectivity schedule.**

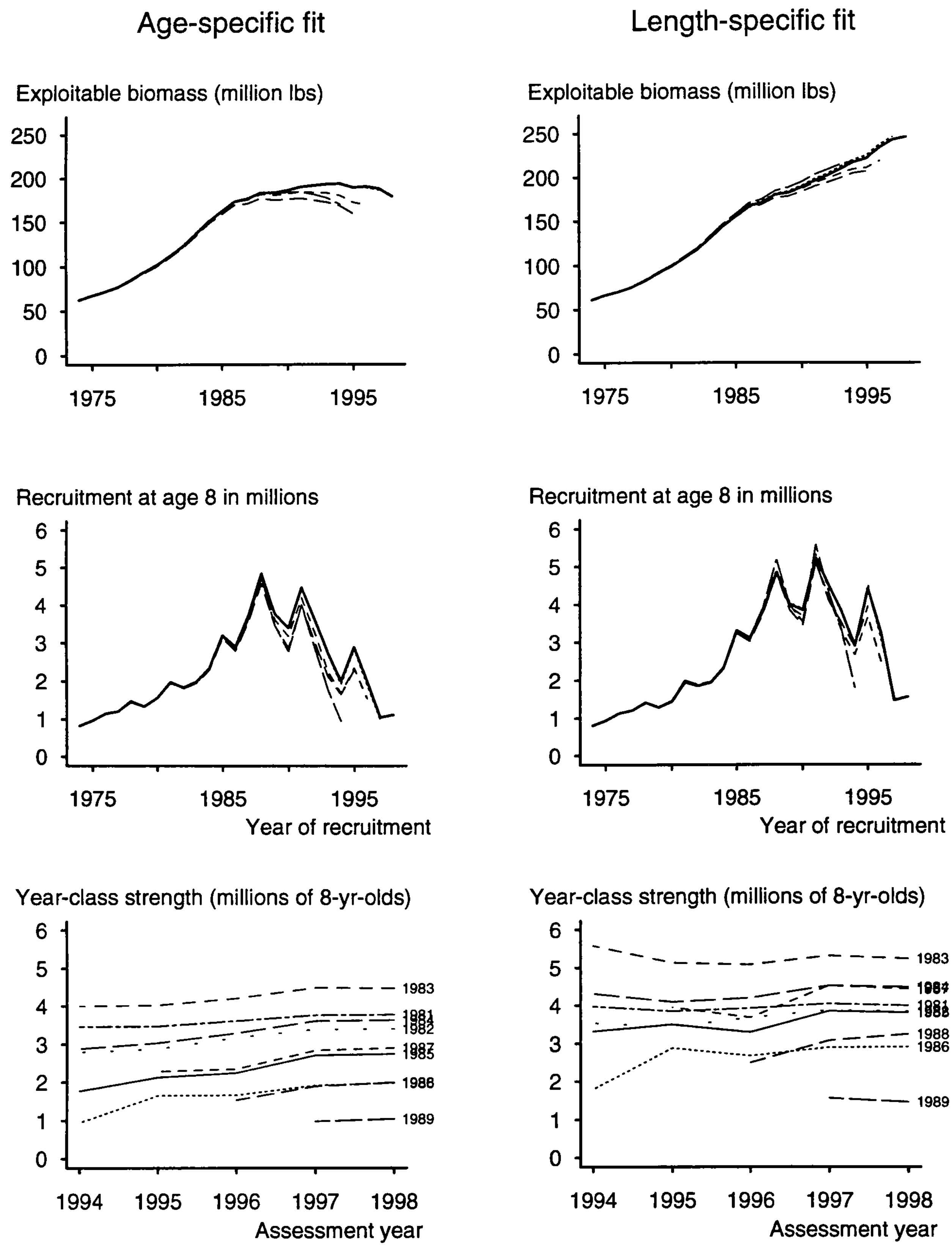



**Figure 8.** **Retrospective assessments for Area 3A. Exploitable biomass is computed using a coastwide fixed selectivity schedule.**

# APPENDIX A. SELECTED FISHERY AND SURVEY DATA SUMMARIES

**Table A1. Commercial Catch (million pounds, net weight)**

| | 2A | 2B | 2C | 3A | 3B | 4 | 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 | 5.65 | 4.01 | 14.22 | 0.45 | 1.19 | 25.72 |
| **1982** | 0.21 | 5.54 | 3.50 | 13.53 | 4.80 | 1.43 | 29.01 |
| **1983** | 0.26 | 5.44 | 6.40 | 14.11 | 7.75 | 4.42 | 38.38 |
| **1984** | 0.43 | 9.05 | 5.85 | 19.97 | 6.50 | 3.16 | 44.96 |
| **1985** | 0.49 | 10.39 | 9.21 | 20.85 | 10.89 | 4.28 | 56.11 |
| **1986** | 0.58 | 11.22 | 10.61 | 32.79 | 8.83 | 5.59 | 69.62 |
| **1987** | 0.59 | 12.25 | 10.68 | 31.32 | 7.76 | 6.88 | 69.48 |
| **1988** | 0.49 | 12.86 | 11.37 | 37.86 | 7.08 | 4.69 | 74.35 |
| **1989** | 0.47 | 10.43 | 9.53 | 33.73 | 7.84 | 4.93 | 66.93 |
| **1990** | 0.32 | 8.57 | 9.73 | 28.85 | 8.69 | 5.43 | 61.59 |
| **1991** | 0.36 | 7.17 | 8.69 | 22.86 | 11.93 | 5.99 | 57.00 |
| **1992** | 0.44 | 7.63 | 9.82 | 26.78 | 8.62 | 6.61 | 59.90 |
| **1993** | 0.52 | 10.63 | 11.29 | 22.74 | 7.86 | 6.25 | 59.28 |
| **1994** | 0.39 | 9.91 | 10.38 | 24.84 | 3.86 | 5.37 | 54.75 |
| **1995** | 0.31 | 9.62 | 7.76 | 18.34 | 3.12 | 4.74 | 43.89 |
| **1996** | 0.30 | 9.53 | 8.80 | 19.69 | 3.81 | 5.31 | 47.44 |
| **1997** | 0.40 | 12.20 | 9.89 | 24.68 | 9.10 | 8.79 | 65.05 |
| **1998** | 0.46 | 13.14 | 10.23 | 25.87 | 11.35 | 9.15 | 70.20 |

**Table A2. Bycatch mortality of legal-sized fish (80+ cm; in million pounds net weight).**

(Bycatch estimates are calculated by 5-cm intervals; the legal-sized part begins with 80-84 cm.)

| | 2A | 2B | 2C | 3A | 3B | 4 | Total |
|---|---|---|---|---|---|---|---|
| **1974** | 0.25 | 0.90 | 0.37 | 4.48 | 2.82 | 1.89 | 10.71 |
| **1975** | 0.25 | 0.90 | 0.45 | 2.61 | 1.66 | 1.10 | 6.98 |
| **1976** | 0.25 | 0.94 | 0.50 | 2.74 | 1.94 | 1.18 | 7.56 |
| **1977** | 0.25 | 0.72 | 0.41 | 3.37 | 1.54 | 1.98 | 8.27 |
| **1978** | 0.25 | 0.55 | 0.21 | 2.44 | 1.31 | 3.40 | 8.16 |
| **1979** | 0.25 | 0.69 | 0.64 | 4.49 | 0.69 | 3.44 | 10.20 |
| **1980** | 0.25 | 0.51 | 0.42 | 4.93 | 0.87 | 5.71 | 12.69 |
| **1981** | 0.25 | 0.53 | 0.40 | 3.99 | 1.09 | 4.37 | 10.64 |
| **1982** | 0.25 | 0.30 | 0.20 | 3.20 | 1.68 | 2.95 | 8.58 |
| **1983** | 0.25 | 0.29 | 0.20 | 2.08 | 1.22 | 2.47 | 6.51 |
| **1984** | 0.25 | 0.52 | 0.21 | 1.51 | 0.92 | 2.29 | 5.70 |
| **1985** | 0.25 | 0.55 | 0.20 | 0.80 | 0.34 | 2.25 | 4.38 |
| **1986** | 0.25 | 0.56 | 0.20 | 0.67 | 0.20 | 2.61 | 4.50 |
| **1987** | 0.25 | 0.79 | 0.20 | 1.59 | 0.40 | 2.67 | 5.90 |
| **1988** | 0.25 | 0.77 | 0.20 | 2.13 | 0.04 | 3.27 | 6.66 |
| **1989** | 0.25 | 0.72 | 0.20 | 1.80 | 0.44 | 1.95 | 5.36 |
| **1990** | 0.25 | 1.03 | 0.68 | 2.63 | 1.21 | 4.16 | 9.97 |
| **1991** | 0.25 | 1.22 | 0.55 | 3.13 | 1.03 | 2.92 | 9.10 |
| **1992** | 0.28 | 1.02 | 0.57 | 2.64 | 1.12 | 3.34 | 8.97 |
| **1993** | 0.28 | 0.65 | 0.33 | 1.92 | 0.47 | 2.01 | 5.65 |
| **1994** | 0.28 | 0.57 | 0.40 | 2.35 | 0.85 | 3.48 | 7.93 |
| **1995** | 0.38 | 0.71 | 0.24 | 1.57 | 0.90 | 3.31 | 7.11 |
| **1996** | 0.38 | 0.14 | 0.23 | 1.40 | 0.96 | 3.57 | 6.68 |
| **1997** | 0.38 | 0.10 | 0.24 | 1.55 | 0.73 | 3.80 | 6.80 |
| **1998** | 0.38 | 0.11 | 0.22 | 1.49 | 0.74 | 3.65 | 6.59 |

**Table A3. Total removals: commercial + legal-sized bycatch + sport + wastage + personal use (in million pounds, net weight).**

| Year | 2A | 2B | 2C | 3A | 3B | 4 | Total |
|---|---|---|---|---|---|---|---|
| **1974** | 0.77 | 5.52 | 5.97 | 12.67 | 4.49 | 2.60 | 32.02 |
| **1975** | 0.71 | 8.03 | 6.69 | 13.21 | 4.22 | 1.73 | 34.60 |
| **1976** | 0.49 | 8.22 | 6.03 | 13.78 | 4.67 | 1.90 | 35.10 |
| **1977** | 0.48 | 6.17 | 3.67 | 12.20 | 4.73 | 3.20 | 30.45 |
| **1978** | 0.36 | 5.17 | 4.61 | 13.02 | 2.63 | 4.75 | 30.55 |
| **1979** | 0.32 | 5.57 | 5.34 | 16.19 | 1.08 | 4.81 | 33.32 |
| **1980** | 0.29 | 6.17 | 3.99 | 17.38 | 1.15 | 6.42 | 35.41 |
| **1981** | 0.47 | 6.21 | 4.73 | 18.96 | 1.54 | 5.57 | 37.48 |
| **1982** | 0.51 | 5.91 | 4.19 | 17.44 | 6.48 | 4.39 | 38.92 |
| **1983** | 0.58 | 5.83 | 7.15 | 17.14 | 8.97 | 6.89 | 46.56 |
| **1984** | 0.80 | 9.69 | 6.68 | 22.50 | 7.42 | 5.46 | 52.56 |
| **1985** | 0.94 | 11.56 | 10.31 | 23.78 | 11.43 | 6.68 | 64.71 |
| **1986** | 1.17 | 12.35 | 11.98 | 37.23 | 9.43 | 8.53 | 80.68 |
| **1987** | 1.29 | 13.74 | 12.03 | 36.48 | 8.50 | 9.84 | 81.88 |
| **1988** | 0.99 | 14.19 | 12.85 | 44.76 | 7.24 | 8.06 | 88.09 |
| **1989** | 1.05 | 11.83 | 11.48 | 40.00 | 8.47 | 7.03 | 79.87 |
| **1990** | 0.78 | 10.44 | 11.98 | 36.02 | 10.12 | 9.85 | 79.18 |
| **1991** | 0.77 | 9.10 | 11.96 | 32.35 | 13.46 | 9.49 | 77.13 |
| **1992** | 0.97 | 9.38 | 12.68 | 34.46 | 9.98 | 10.23 | 77.69 |
| **1993** | 1.05 | 12.33 | 13.74 | 30.59 | 8.46 | 8.56 | 74.73 |
| **1994** | 0.85 | 11.51 | 13.11 | 32.86 | 4.83 | 9.12 | 72.27 |
| **1995** | 0.93 | 11.33 | 9.79 | 24.52 | 4.02 | 8.11 | 58.69 |
| **1996** | 0.91 | 10.66 | 10.61 | 26.19 | 4.85 | 9.12 | 62.34 |
| **1997** | 1.14 | 13.29 | 11.89 | 32.03 | 9.94 | 12.83 | 81.12 |
| **1998** | 1.23 | 14.26 | 12.37 | 33.02 | 12.21 | 13.00 | 86.08 |

**Table A4.** **Commercial CPUE (pounds per skate, C hook equivalent).**

1983 is excluded because it consists of a mixture of J- and C-hook data.

| Year | 2A | 2B | 2C | 3A | 3B | 4 | Total |
|---|---|---|---|---|---|---|---|
| **1974** | 130.7 | 141.0 | 126.0 | 142.4 | 124.7 | 301.1 | 137.9 |
| **1975** | 130.6 | 148.7 | 117.4 | 145.3 | 149.3 | 210.7 | 139.7 |
| **1976** | 71.7 | 116.7 | 92.8 | 131.5 | 142.2 | 184.2 | 118.5 |
| **1977** | 182.2 | 135.3 | 99.4 | 134.6 | 161.3 | 176.2 | 133.1 |
| **1978** | 85.5 | 138.0 | 124.1 | 171.9 | 116.4 | 166.6 | 148.0 |
| **1979** | 110.0 | 105.8 | 176.6 | 189.0 | 80.8 | 146.1 | 154.6 |
| **1980** | 82.0 | 148.3 | 183.7 | 278.3 | 315.1 | 177.7 | 210.9 |
| **1981** | 67.7 | 154.3 | 313.7 | 327.7 | 387.2 | 249.9 | 254.6 |
| **1982** | 47.3 | 149.1 | 321.4 | 373.1 | 461.7 | 219.9 | 274.2 |
| **1983** | NA | NA | NA | NA | NA | NA | NA |
| **1984** | 69.0 | 146.6 | 280.8 | 500.3 | 475.2 | 235.6 | 288.0 |
| **1985** | 69.2 | 143.1 | 340.7 | 509.9 | 602.4 | 304.8 | 310.0 |
| **1986** | 60.9 | 118.2 | 294.0 | 517.9 | 514.8 | 276.5 | 287.7 |
| **1987** | 58.6 | 128.4 | 260.3 | 503.6 | 476.1 | 298.1 | 276.9 |
| **1988** | 171.4 | 131.6 | 281.3 | 502.8 | 654.2 | 296.4 | 309.4 |
| **1989** | 112.4 | 133.2 | 258.0 | 456.0 | 590.0 | 306.4 | 300.2 |
| **1990** | 168.4 | 173.9 | 269.1 | 352.9 | 483.6 | 336.2 | 302.0 |
| **1991** | 164.3 | 156.4 | 233.2 | 318.6 | 466.4 | 366.3 | 284.9 |
| **1992** | 113.9 | 186.6 | 230.5 | 397.1 | 440.2 | 312.4 | 304.4 |
| **1993** | 155.0 | 211.9 | 255.1 | 390.8 | 504.6 | 336.9 | 312.1 |
| **1994** | 92.4 | 212.5 | 187.5 | 330.2 | 355.9 | 247.1 | 255.5 |
| **1995** | 88.9 | 205.5 | 231.5 | 389.7 | 476.6 | 271.9 | 283.4 |
| **1996** | 168.9 | 216.1 | 236.1 | 444.9 | 476.3 | 355.1 | 317.5 |
| **1997** | 189.6 | 243.4 | 259.5 | 436.1 | 521.7 | 317.9 | 339.3 |
| **1998** | 178.8 | 221.0 | 229.8 | 413.5 | 577.3 | 375.2 | 326.3 |

**Table A5.** **IPHC setline survey CPUE in number of halibut per effective skate and associated coefficient of variation.**

| | Area 2B | | | | Area 3A | | Area 3B | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **CPUE** | **CV** | **CPUE** | **CV** | **CPUE** | **CV** | **CPUE** | **CV** |
| **1974** | | | | | | | | |
| **1975** | | | | | | | | |
| **1976** | 2.30 | 0.12 | | | | | | |
| **1977** | 1.56 | 0.13 | | | 5.56 | 0.06 | | |
| **1978** | 1.84 | 0.12 | | | 3.66 | 0.06 | | |
| **1979** | | | | | 5.25 | 0.07 | | |
| **1980** | 2.99 | 0.10 | | | 6.86 | 0.06 | | |
| **1981** | 1.86 | 0.11 | | | 10.21 | 0.06 | | |
| **1982** | 2.31 | 0.12 | 11.28 | 0.09 | 11.53 | 0.06 | | |
| **1983** | 3.11 | 0.14 | 10.89 | 0.09 | 9.29 | 0.04 | | |
| **1984** | 4.74 | 0.08 | 13.21 | 0.11 | 13.33 | 0.04 | | |
| **1985** | 4.30 | 0.11 | 11.53 | 0.10 | 15.74 | 0.04 | | |
| **1986** | 2.70 | 0.10 | 9.44 | 0.09 | 9.58 | 0.06 | | |
| **1987** | | | | | | | | |
| **1988** | | | | | | | | |
| **1989** | | | | | | | | |
| **1990** | | | | | | | | |
| **1991** | | | | | | | | |
| **1992** | | | | | | | | |
| **1993** | 6.63 | 0.10 | | | 17.94 | 0.06 | | |
| **1994** | | | | | 19.01 | 0.05 | | |
| **1995** | 8.95 | 0.08 | | | 23.10 | 0.06 | | |
| **1996** | 9.20 | 0.09 | 16.62 | 0.09 | 18.54 | 0.07 | 20.76 | 0.04 |
| **1997** | 9.07 | 0.08 | 22.76 | 0.09 | 26.46 | 0.06 | 25.95 | 0.05 |
| **1998** | 6.20 | 0.08 | 14.20 | 0.08 | 19.71 | 0.06 | 26.35 | 0.04 |

## APPENDIX B. RECENT CHANGES IN IPHC ASSESSMENT METHODS AND HARVEST POLICY

**1982-1994:** stock size was estimated with CAGEAN, a strictly age-structured model fitted to commercial catch-at-age and catch-per-effort data. Because of a decrease in growth rates between the late 1970s and early 1990s, there were persistent underestimates of incoming recruitment and total stock size in the assessments done in the early 1990s.

Until 1985, allowable removals were calculated as a proportion of estimated annual surplus production (ASP), the remaining production being allocated to stock rebuilding. In 1985 the Commission adopted a constant harvest rate policy, meaning that allowable removals are determined by applying a fixed harvest rate to estimated exploitable biomass. This harvest level is called the Constant Exploitation Yield, or CEY. The fixed harvest rate was set at 28% in 1985, increased to 35% in 1987, and lowered to 30% in 1993.

**1995:** a new age- and length-structured model was implemented that accounted for the change in growth and was fitted to survey as well as commercial catch-at-age and catch-per-effort data. The new model produced substantially higher biomass estimates. In Area 3A this resulted from accounting for the change in growth schedule. In Area 2B, where the change in growth had been much less than in Alaska, it resulted from fitting the model to survey catch-per-effort, which showed a larger stock increase since the mid-1980s than commercial catch-per-effort. Quotas were held at the 1995 level to allow time for a complete study of the new model and results,

**1996:** differences in estimated selectivity between British Columbia and Alaska led to the consideration of two alternatives for fitting the model, one in which survey selectivity was a fixed function of age and the other in which it was a function of length. Spawner-recruit estimates from the new model resulted in a lowering of the target harvest rate to 20%. Quotas were increased somewhat, but not to the level indicated by the new biomass estimates.

**1997:** setline surveys of the entire Commission area indicated substantially more halibut in western Alaska (IPHC Areas 3B and 4) than the analytical assessment. Biomass in those areas was estimated by scaling the analytical estimates of absolute abundance in Areas 2 and 3A by the survey estimate of relative abundance in western Alaska. CEY estimates increased again, and quotas were increased again, but still to a level well below the CEY's.

**1998:** the working value of natural mortality was lowered from 0.20 to 0.15, reducing analytical estimates of biomass in Areas 2 and 3A by about 30%. At the same time setline survey estimates of abundance in Areas 3B and 4 relative to Areas 2 and 3A increased, so biomass estimates in the western area decreased by a smaller amount.

## APPENDIX C. CHANGES MADE TO THE ASSESSMENT MODEL IN 1998.

The only major change was a reduction of the natural mortality rate from 0.20 to 0.15, which had the effect, other things being equal, of lowering abundance estimates by about 30%. A number of other changes, listed below, were made in order to make the model more realistic or more fittable, but on balance they did not change any of the abundance estimates by more than 5%.

### 1. Working value of natural mortality lowered from 0.20 to 0.15.

Analysis done during the year by the staff showed that in the short term an overestimate of natural mortality could lead to a substantial overestimate of stock size when past fishing mortality rates were low, as they have been for Pacific halibut. On the other side, the consequences of an underestimate of natural mortality are less serious. (See the abstract by Clark in this volume.)

The true value of natural mortality is not known. Analysis of catch curves and tagging data in the early 1960's produced a wide range of estimates with a center of 0.15-0.20. Age compositions of commercial catches of fish aged 20-30 in the western Aleutians (Area 4B) in the mid-1990s show an apparent total mortality of 0.24. A small part of this is fishing mortality, and about 0.05 results from an increasing trend in year-class strength among these particular year-classes (spawned during the late 1960's and early 1970's). The remainder is natural mortality, which is therefore something less than 0.20 and perhaps less than 0.15, but probably not much less than 0.15.

### 2. Break in commercial catchability allowed in the first year of IQ management.

When the model is fitted, commercial catchability is allowed to change from year to year but a prior distribution for the changes is specified and used to calculate a penalty function that is added to the objective function. This serves to prevent large year-to-year changes which would be unrealistic in the absence of a major change in the conduct of the fishery. The implementation of individual quota (IQ) schemes in Canada (1991) and Alaska (1995) was such a major change, so for in those years commercial catchability was allowed to jump with no penalty.

### 3. Size-at-age data screened and weighted more heavily.

In previous years all available size-at-age data was used but it was down-weighted relative to other data types because some of the estimates of means and variances were based on very small samples and were clearly wild. This year outliers were removed from the data, and the estimates for a given age group in a given year were used only if the sample size was at least 15 (in both the commercial and survey data). In addition, an error that had been present in the calculation of the estimated variance of the estimated variance [*sic*] of length at age in commercial landings, was corrected. Finally, commercial size-at-age data for ages 6-8 were not used in the fit. A large fraction of fish in those age groups are now below the minimum size limit so the mean and variance of the lengths of the few fish of those ages in the commercial catch do not contain much information about the corresponding population parameters. With the size-at-age data cleaned up, there was no reason to down-weight it, so the ISD was reduced from 5 to 2, the same as most other data types.

**3. Requirement of full recruitment at age 20 dropped.**

In previous years a large penalty was charged if age-specific selectivity at age 20 was less than one, which effectively forced the oldest fish to be fully recruited. An examination of length distributions at age 20 (actually 20+) this year showed a substantial proportion of fish in the 100-120 cm range where recruitment is not complete, so the penalty was dropped. This resulted in a much better fit to recent size-at-age data. The model had been overestimating size at age to meet the full-recruitment requirement.

**4. Some parameters not estimated.**

In Area 2B, fish appear to be almost fully recruited at the minimum size limit. As a result the two parameters of the commercial selectivity function are poorly defined and attempts to estimate changes over time led to numerical difficulties. To cure those, the slope parameter was fixed (i.e., estimated as a constant).

In Areas 2C and 3A the length at full recruitment to the commercial fishery tended to drift to unrealistically large values, even with a penalty. In order to constrain that parameter, it was estimated as a fixed parameter and bounded.