Sources of uncertainty in annual CEY estimates

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Abstract

This paper summarizes the development of IPHC catch limits and discusses the major elements of uncertainty in them, with special reference to the reliability of estimates of present abundance relative to the historical minimum.

Introduction

The present IPHC harvest policy is to limit total annual removals to 20% of exploitable biomass, a target called the Constant Exploitation Yield or CEY. Under an alternative policy put forward by the staff, called a Conditional Constant Catch or CCC policy, removals would be limited to the lesser of a target constant catch or 25% of exploitable biomass. Both policies are designed to achieve a large proportion of maximum yield in the long term while assuring that spawning biomass will remain above the historical minimum reached in the 1970s (when strong year-classes were produced despite relatively low spawning biomass).

The exploitable biomass estimates and the harvest policy are both based on the stock assessment. Along with an estimate of present biomass, the assessment produces estimates of historical abundance and recruitment. These historical estimates are the basis of the stock and fishery simulations that are conducted to evaluate alternative harvest policies (Fig. 1).

There are a number of uncertainties in both the stock assessment and the simulations, and they have different effects on different quantities of interest. For example, the working value of natural mortality has a large effect on the estimate of present biomass in absolute terms, but no effect on the estimate of present biomass relative to the historical minimum, because its effect is to scale all the abundance estimates similarly.

This paper attempts to catalogue (briefly) all sources of uncertainty in the annual estimates of CEY (or CCC) and their effect on: (1) estimates of present abundance, (2) estimates of present abundance relative to the historical minimum, and (3) estimates of stock productivity (i.e., the average long-term yield available at different constant harvest rates, including maximum sustainable yield MSY). Of these, the second is clearly the critical one because the Commission's paramount conservation goal is to maintain a healthy spawning stock. The following sections discuss the various sources of uncertainty; they are summarized in Table 1.

Statistical variability

Fitting the stock assessment model to the commercial and survey data consists of locating the best estimates of a number of parameters, the important ones being commercial catchability and selectivity, survey catchability and selectivity, and the initial abundance of each year-class present in the data series. Like all other statistical estimates, these estimates of model parameters have some variance due to random variability in the data (e.g., in age composition estimates and survey CPUE). But this random estimation error in the halibut assessment is only a few percent—negligible—because we are fitting models with a modest number of parameters (called "parsimonious" models) to a large number of data points. *Given a particular model,* therefore, the parameter estimates are very well determined and their statistical variance is very small.

Like the parameter estimates themselves, the variance estimates are conditional on the particular model being fitted. If the model is wrong, the estimated variances will be too low whether they are computed with the usual asymptotic approximation or by bootstrapping (Punt and Butterworth 1993). Still, the internal variances of the halibut parameter estimates are so low that statistical variability can be ignored even if the variances are underestimated by a factor of two.

Despite the small variances, a model can produce quite different estimates of, say, recent year-class strengths when another year of data is added to the fit, and different plausible models can do the same thing when fitted to the same data series. The year-to-year and model-to-model variability result from a different kind of uncertainty—model specification uncertainty, discussed below mainly in relation to survey catch rates.

Natural mortality

Historical estimates of the abundance of a year-class can be thought of as back-calculations of abundance at each age based on estimates of total subsequent fishery removals and natural deaths (e.g., total number alive at age 10 = total deaths at age 10 and older). The working value of the natural mortality rate therefore has a large effect on historical abundance estimates and through them on present abundance estimates.

Natural mortality is virtually impossible to estimate, so the working value (presently 15%) is almost certainly wrong and so are the absolute abundance estimates, but it turns out that the consequences are not serious. As mentioned above, the estimate of present biomass relative to the historical minimum is reliable. Estimates of stock productivity are not much affected by the natural mortality rate because the natural deaths are added in during back-calculations of stock abundance in the assessment and then subtracted out during the forward calculations of stock productivity in the fishery simulations. Estimates of long-term yield at a given harvest rate, including MSY, are therefore very robust to uncertainty in the natural mortality rate, at least for Pacific halibut (Clark 1999).

But what if natural mortality is not a single rate but different rates according to age, sex, and year? What if there was a large change in natural mortality coincident with the large change in recruitment after the 1977 regime shift, or coincident with the large decrease in growth rates in recent years? Differences of that sort cannot be detected or estimated. The number of possibilities is enormous, so it would not be a simple matter to formulate a set of plausible alternatives for routine consideration. The effect of various patterns could (and should) be investigated by conducting simulations as described in the discussion section below. Our estimates of abundance and productivity are probably not robust to large temporal swings in natural mortality.

Survey catchability and selectivity

The most important differences among IPHC assessment models in recent years have related to survey catchability and selectivity. Present abundance estimates are determined mostly by survey catch rates because we assume that there has been a constant proportional relationship since 1974 between average survey catch rates and abundance. (Abundance in 1974 is determined entirely by the catch at age data and the natural mortality rate, so in effect the survey catch rates are calibrated by the first part of the data series and then used to infer abundance in the latter part.) The devil is in the details of the proportional relationship.

When survey data were first used in the assessment in 1995, and for a few years thereafter, there were two models of survey catch rates. In what was called the "length-specific" version, vulnerability to capture was assumed to depend on length and a length-specific selectivity function was estimated that increased from zero at around 60 cm to one (100%) at 130 cm or less. In what was called the "age-specific" version, vulnerability to capture was assumed to depend on age and an age-specific selectivity function was estimated that increased from zero at around age 5 to one at age 17 or less. The catchability coefficient in these (and all other) models is the coefficient of proportionality between the abundance of fully selected fish and the survey catch rate of those fish (in our case, numbers of fish per standard skate). It has the same value in both models, so the only difference was in the assumed determinant of selectivity: length or age.

Various measures of goodness of fit provided no reason to prefer one model over the other (Clark and Parma 1999) so both fits were reported, but the CEY estimates and catch limit recommendations were based on the age-specific version because it produced lower estimates of present biomass. Poor retrospective performance of the age-specific model in recent years and independent data from the NMFS trawl survey (Clark 2003) have now shown that the length-specific model is in fact much more credible, and it will be used for the 2004 CEY estimates.

Another instance of competing models of survey data occurred in the 1999 assessment, when it was suspected that a change in survey bait had increased survey catchability in 1993. The effect was uncertain at the time of the assessment but again the CEY estimates were based on a model that assumed the suspected bait effect and therefore produced the lower abundance estimates. (An experiment done in 2000 showed that the effect of the bait change was negligible, and the adjustment was removed from the assessment.)

Similarly in the 2002 assessment when several models were fitted to account for anomalies that appeared in the 3A assessment, the lowest estimates of present abundance were used to calculate CEY (Clark and Hare 2003).

At present the question of survey selectivity appears to be settled in favor of a length-based schedule, but catchability is always a question. Is the survey catchability of a large halibut really the same as it was twenty years ago? Has the increase in dogfish in Area 3A, for example, reduced the catchability of halibut? Has the increase in halibut abundance reduced feeding opportunities and made a baited longline more attractive, thereby increasing catchability? Does bait quality have a large influence on a given year's survey CPUE? The generally good agreement between trends in setline and trawl survey CPUE of large fish gives some reason to believe that setline survey catchability has not changed dramatically over the last twenty years, but both survey data series are quite noisy and there is no assurance that catchability has not changed or will not change in the future. Any appreciable change in catchability would derail the assessment, because more than anything else the assessment relies on the survey CPUE of fully selected fish to index relative abundance.

Commercial catchability and selectivity

Before 1995 the assessment was done with CAGEAN, which did not use survey data at all but relied on commercial CPUE in the same way that the present assessment relies on survey CPUE. In particular it assumed constant catchability and age-specific selectivity, and when age-specific commercial selectivity changed owing to decreased growth in the early 1990s, CAGEAN began to perform poorly.

In the present model commercial catchability and age-specific selectivity parameters are allowed to change over time, so real changes can be accommodated in the model as they occur in the data series. The rate of change is limited, however, so the commercial data act to damp variations in the abundance estimates resulting from year-to-year swings in the noisier survey data. But it is the trend of the survey data that determines the estimated long-term change in relative abundance and therefore the estimate of present absolute abundance.

Other elements of model specification

This year the staff will attempt to fit a sex-specific model, and that will raise a number of questions about possible differences between females and males in natural mortality, catchability, and selectivity. These differences, if they exist, will probably not be detectable or at least not distinguishable owing to lack of data on the sex composition of the commercial catches and the strong interaction between natural mortality and selectivity estimates. But such differences cannot be ruled out, and their operation would presumably bias the estimates of a model that assumes no differences.

Recruitment and growth dynamics

Our present working hypotheses about stock dynamics are that recruitment is largely determined by the environment (over the range of observed stock sizes) and that growth is density-dependent (Clark and Hare 2002). These hypotheses do not enter the stock assessment in any way so they do not affect our estimates of abundance, but they are the whole basis of the fishery simulations and harvest policy. If they are wrong, the harvest policy will not perform as expected. In particular, if productivity is much lower than we believe, the harvest policy could eventually result in driving the stock down to a level near its historical minimum, which would require a drastic curtailment of the fishery. The stock would not be put at risk because the assessment would monitor its decline, but the fishery would. As a practical matter, the stock is so far above that level now that it would take some time to get there, and before that could happen there would be a change in our working hypotheses and a course correction in our harvest policy.

Ecosystem change

Apart from our specific working hypotheses about stock dynamics, we make the basic assumption that past stock performance informs us about present and future performance. Is that really true? How will global warming affect halibut in Canada and Alaska in the decades ahead? How has the development of other groundfish fisheries affected halibut, or the decline of Steller sea lions? If history is not a reliable guide, what is an appropriate harvest policy? In particular, what are appropriate reference points for minimum spawning biomass and maximum fishing mortality?

Discussion

The major source of uncertainty in the annual CEY estimates is model specification, meaning how the model goes about predicting the observations, especially the survey data. Once the model is specified, the parameter and abundance estimates are well determined by the data. Over the last ten years there have been a number of occasions when the model specification was in doubt, and the staff has dealt with the uncertainty by basing its recommendations on the model that produced the lowest estimates. As a routine procedure, this method of dealing with uncertainty can be expected to cost the fishery some yield from time to time, but it serves the stock well.

The problem of competing plausible models is very common in fisheries. Some authors (e.g. Punt and Hilborn 1997) advocate attempting to assign a probability or relative weight to every plausible model and then computing some kind of probability distribution for the estimate of abundance. We had no basis for choosing such weights on any of the occasions when the halibut model was in doubt, so we believe this approach would have been arbitrary, controversial, and risky in our case.

Like all other assessment models, ours is a highly simplified representation of one part of a complex and dynamic ecosystem (Schnute and Richards 2001). Natural mortality probably does differ by sex and vary with age and time, but we do not know and cannot estimate the differences, so we use a single value in the model. Survey catchability probably has varied over the years, but if we allowed it to vary in the model it would be confounded with the recruitment estimates and we would not get useful estimates of either, so we treat it as constant, in effect estimating an average value. We are obliged to keep the assessment model simple (parsimonious) so that we can estimate the parameters.

It is reasonable to think that even though it is a simplification, the fitted model does an adequate job of approximating stock trends and present relative abundance, but that is not certain. The fact is that any model that can be fitted will be misspecified in some respects, and we do not know how that will affect our abundance estimates, harvest policy evaluations, and eventually the stock and fishery. The question can be studied by building much more detailed and complex models (called operating models) to generate test data and then fitting the parsimonious assessment model to the data to generate estimates of historical and present abundance. A harvest policy can then be chosen based on the historical estimates and applied to the estimates of present abundance to set catch limits, and those catches can be taken from the stock in the operating models year after year to see how well the assessment and harvest policy perform when the data come from a system that does not match the assessment model.

This approach has been used successfully elsewhere (Cooke 1999, Punt and Smith 1999). It consists of two parts: the operating model (really a suite of operating models), and a management procedure, which consists of all the steps between the data produced by the operating model and the recommended catch limit. The management procedure can be more or less elaborate. It may be a simple rule based on CPUE (like IPHC quota setting in the old days), or a fitted production model, or a delay-difference model (Parma 2002), or a conventional age-structured assessment *cum* harvest policy evaluation like ours. The aim is to test different management procedures and find one that works well with a variety of operating models and is therefore robust to uncertainty about the detailed workings of the real stock.

References

Clark, W. G. 1999. Effects of an erroneous natural mortality rate on a simple age-structured stock assessment. Can. J. Fish. Aquat. Sci. 56:1721-1731.

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: 385-398.

Clark, W. G., and Hare, S. R. 2002. Effects of climate and stock size on recruitment and growth of Pacific halibut. N. Am. J. Fish. Manage. 22:852-862.

Clark, W. G., and Hare, S. R. 2003. Assessment of the Pacific halibut stock at the end of 2002. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2002:95-120.

Clark, W. G., and Parma, A. M. 1999. Assessment of the Pacific halibut stock in 1998. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1998: 89-112.

Cooke, J. G. 1999. Improvement of fishery-management advice through simulation testing of harvest algorithms. ICES J. Mar. Sci. 56:797-810.

Parma, A. M. 2002. In search of robust harvest rules for Pacific halibut in the face of uncertain assessments and decadal changes in productivity. Bull. Mar. Sci. 70:423-453.

Punt, A. E., and Butterworth, D. S. 1993. Variance estimates for fisheries assessment: their importance and how best to evaluate them. p. 145-162. *In* S.J. Smith, J.J. Hunt, and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.

Punt, A.E., and R. Hilborn. 1997. Fisheries stock assessment and decision analysis: the Bayesian approach. Rev. Fish Biol. Fish. 7:35-63.

Punt, A. E., and Smith, A.D.M. 1999. Harvest strategy evaluation for the eastern stock of gemfish (*Rexea solandri).* ICES J. Mar. Sci. 56:860-875.

Schnute, J. T., and Richards, L. J. 2001. Use and abuse of fishery models. Can. J. Fish. Aquat. Sci. 58:10-17.

Table 1. Effects of various sources of uncertainty on estimates of stock abundance and productivity.

Source of uncertainty	Effect on estimates of present biomass	Effect on estimates of present biomass relative to minimum	Effect on estimates of stock productivity (yield curve)
Statistical variability of parameter estimates	Slight	Slight	Slight
Natural mortality rate	Major	Slight	Slight
Assumptions about survey catchability and selectivity	Major	Major	Slight
Assumptions about commercial catchability and selectivity	Minor	Minor	Slight
Other elements of assessment model specification	Major	Major	Slight
Working hypotheses about recruitment and growth dynamics	None	None	Major
Ecosystem change	None	None	Major

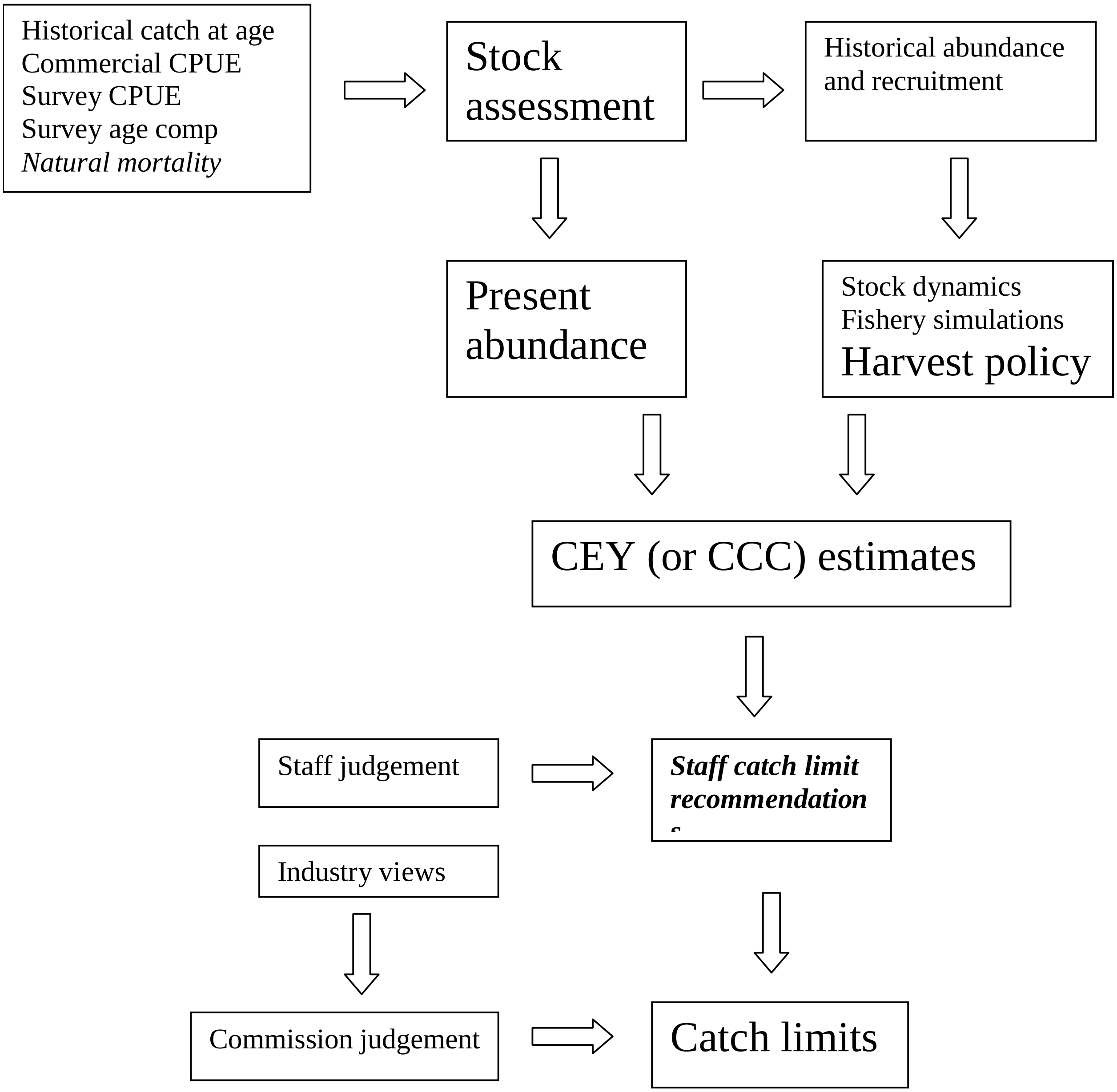

Figure 1. Evolution of IPHC catch limits.

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 as a fraction of 3A	0.71	0.26	0.16
Exploitable biomass calculated with locally estimated selectivities as a fraction of 3A	0.54	0.25	0.17
Exploitable biomass calculated **with fixed selectivities** 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.

References

Clark, W. G. 2004a. Estimated sex composition of commercial landings. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2003: this volume.

Clark, W. G. 2004b. Statistical distribution of IPHC age readings. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2003: this volume.

Clark, W. G., and Hare, S. R.. 2003. Assessment of the Pacific halibut stock at the end of 2002. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2002:95-120.

Clark, W. G., and Parma, A. M.. 1999. Assessment of the Pacific halibut stock in 1998. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1998: 89-112.

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. 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.

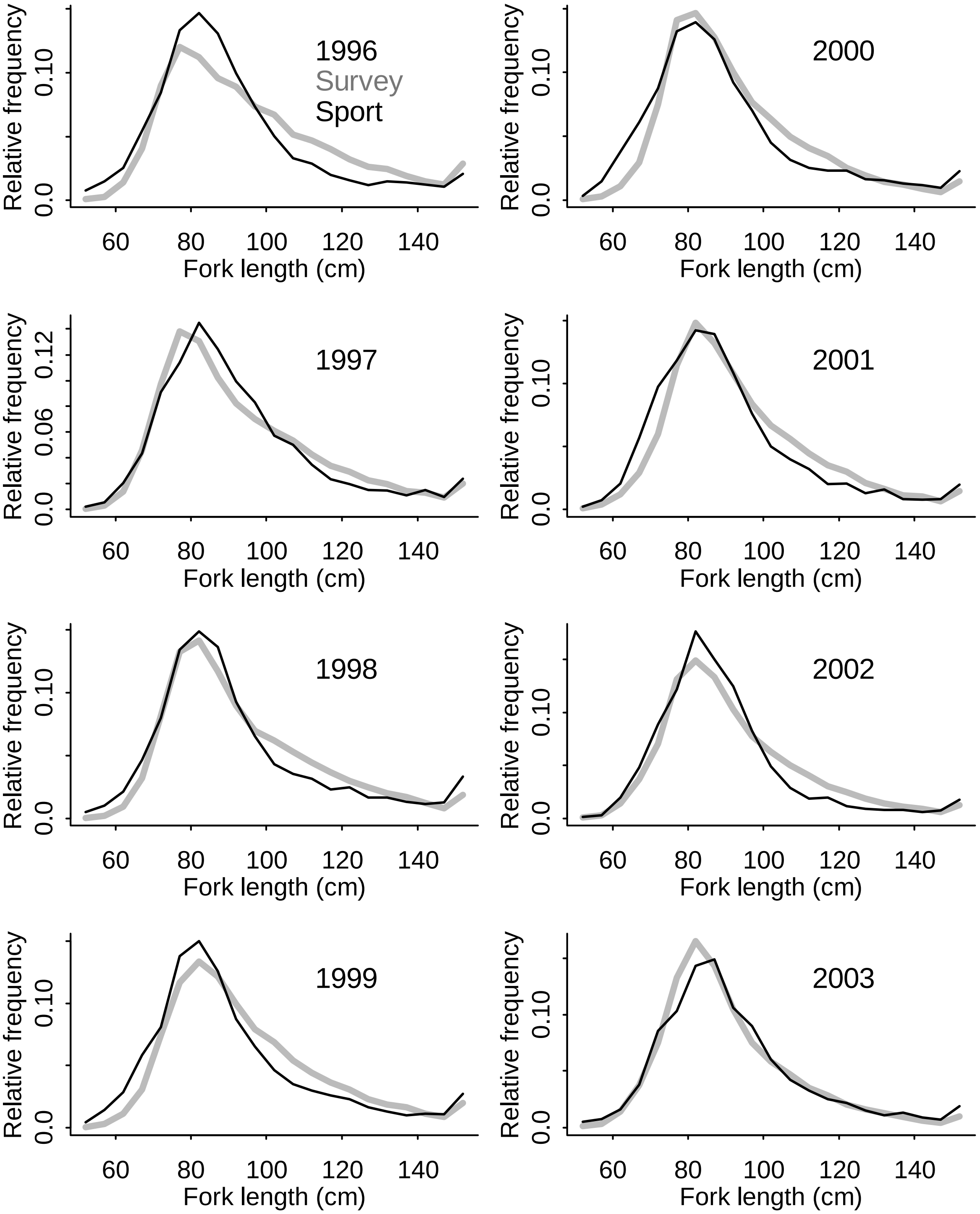

Figure 1. Length frequencies of ADF&G sport catch samples and IPHC survey catch samples in Area 3A in recent years.

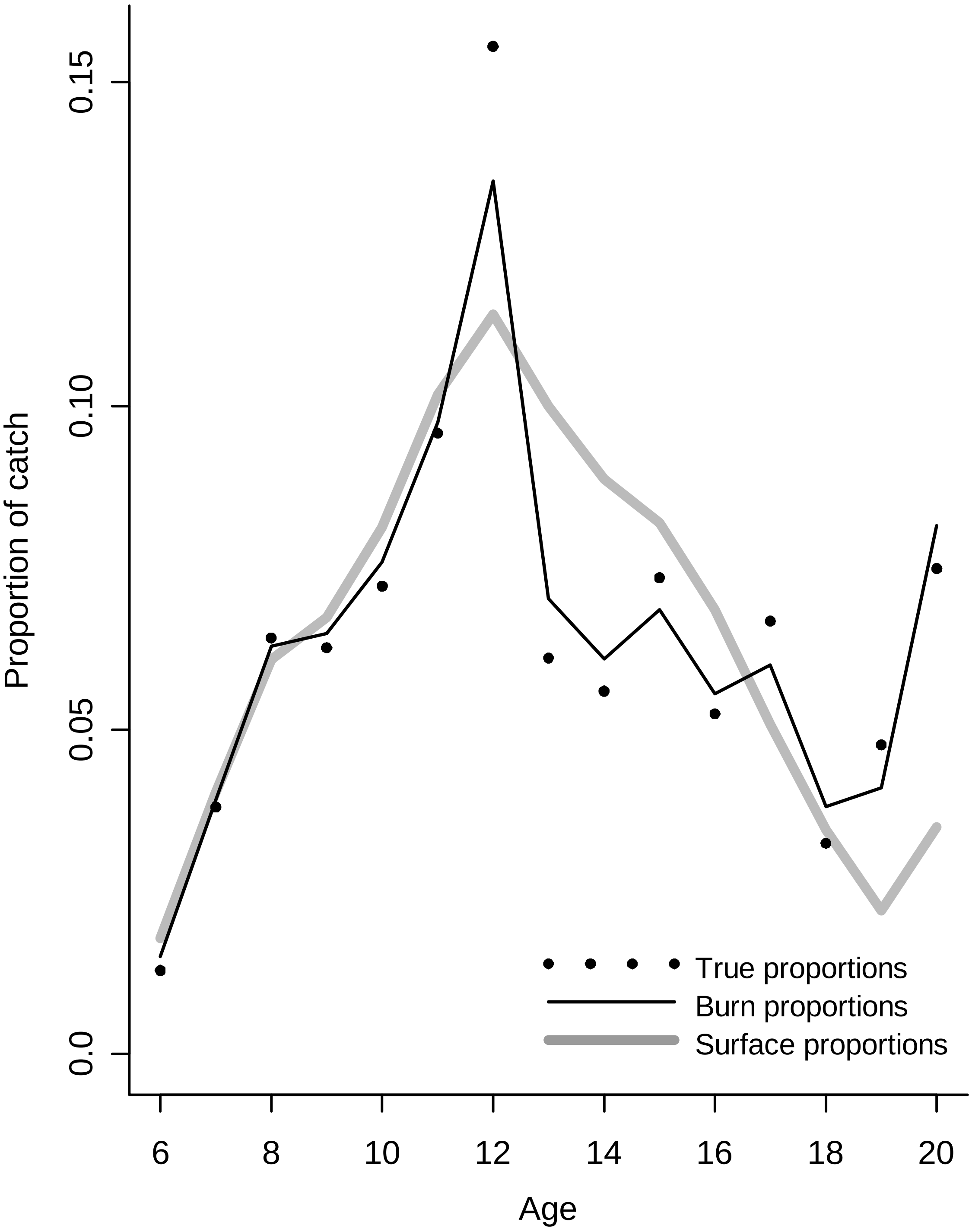

Figure 2. An example of true age proportions in the catch and the corresponding observed distributions of surface and break-and-burn age readings. At ages beyond about 15 surface ages are biased and quite variable; break-and-burn ages are unbiased and less variable.

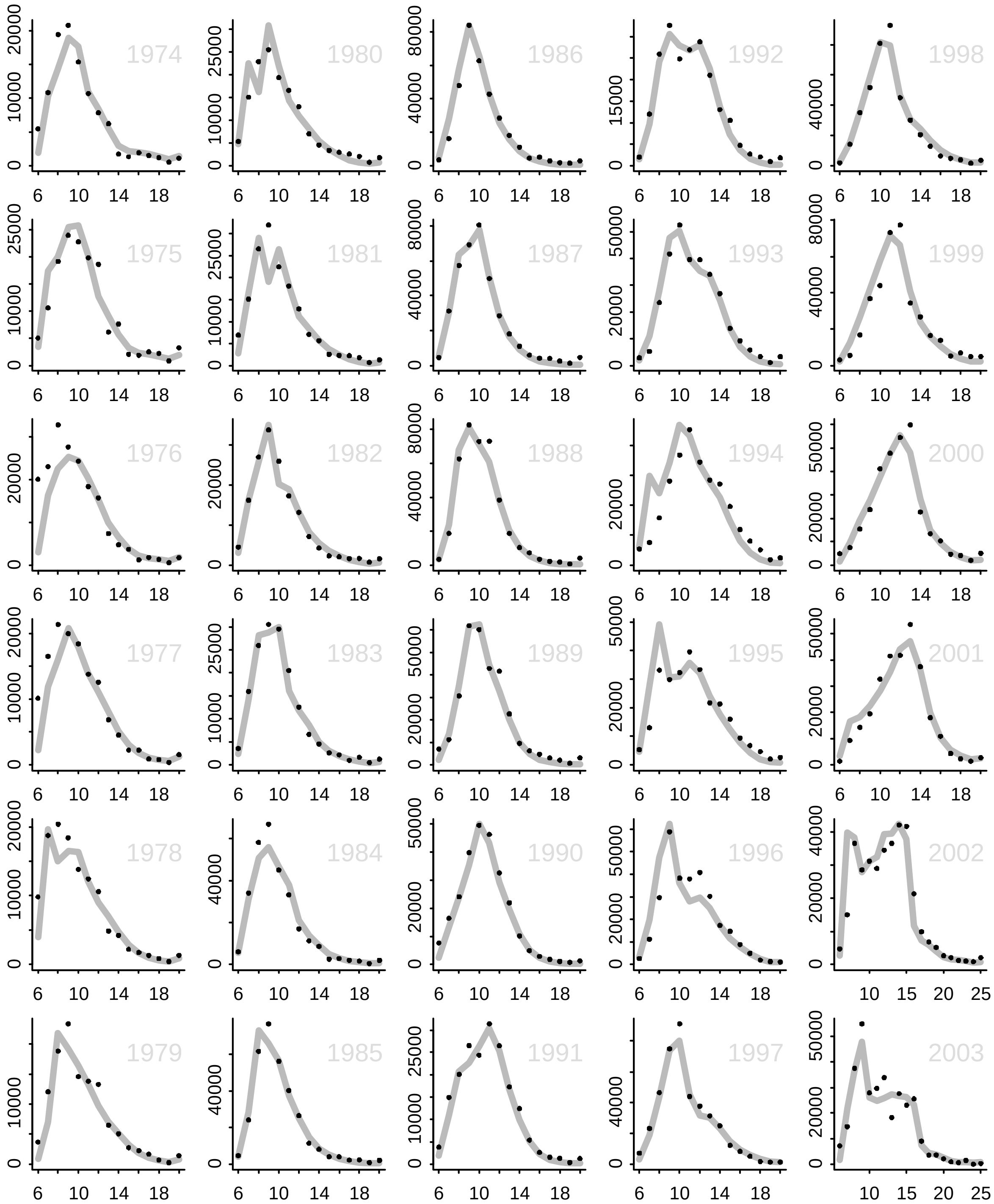

Figure 3a. Observed catch at age of females in Area 2B (points) and model predictions (lines).

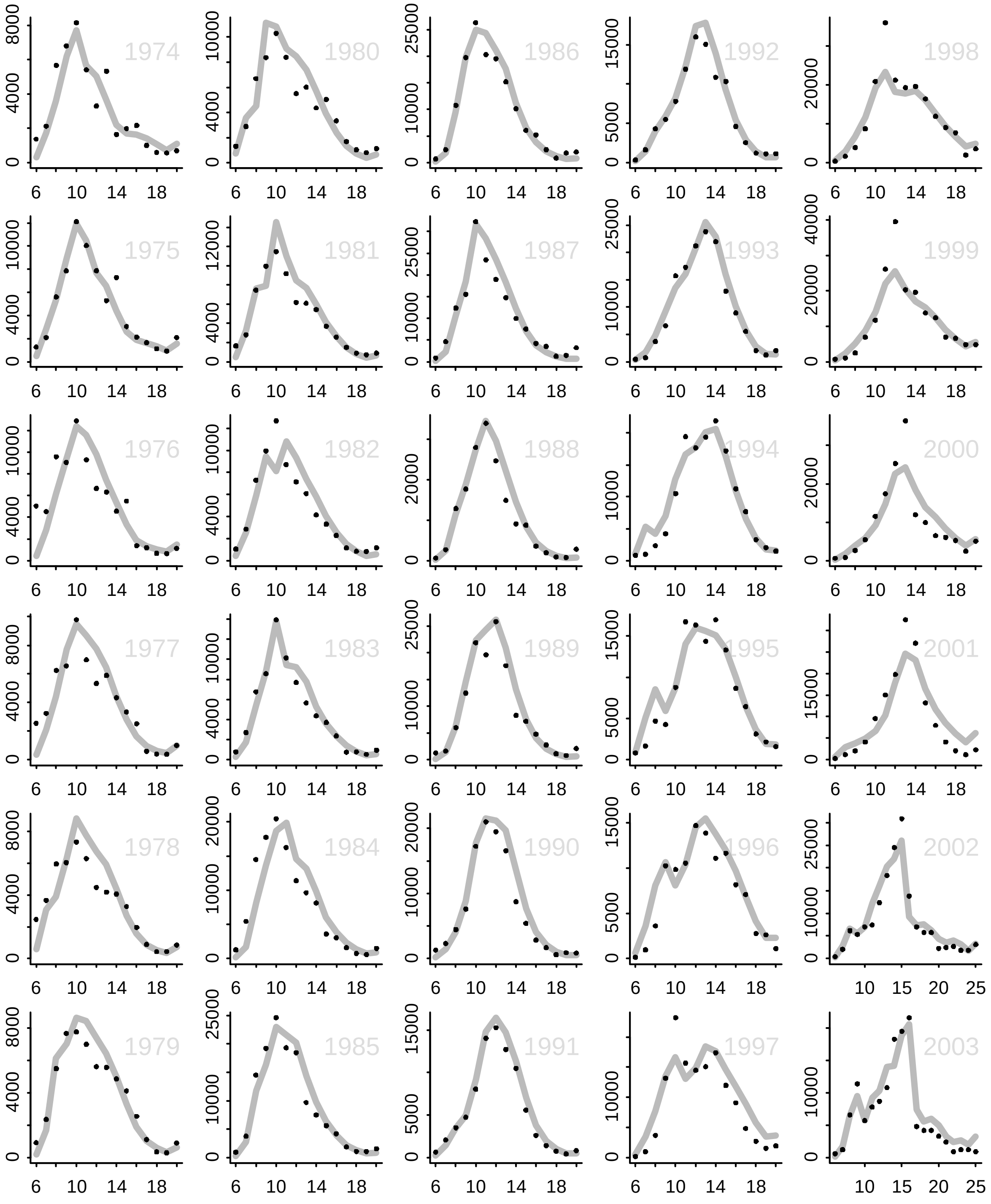

Figure 3b. Observed catch at age of males in Area 2B (points) and model predictions (lines).

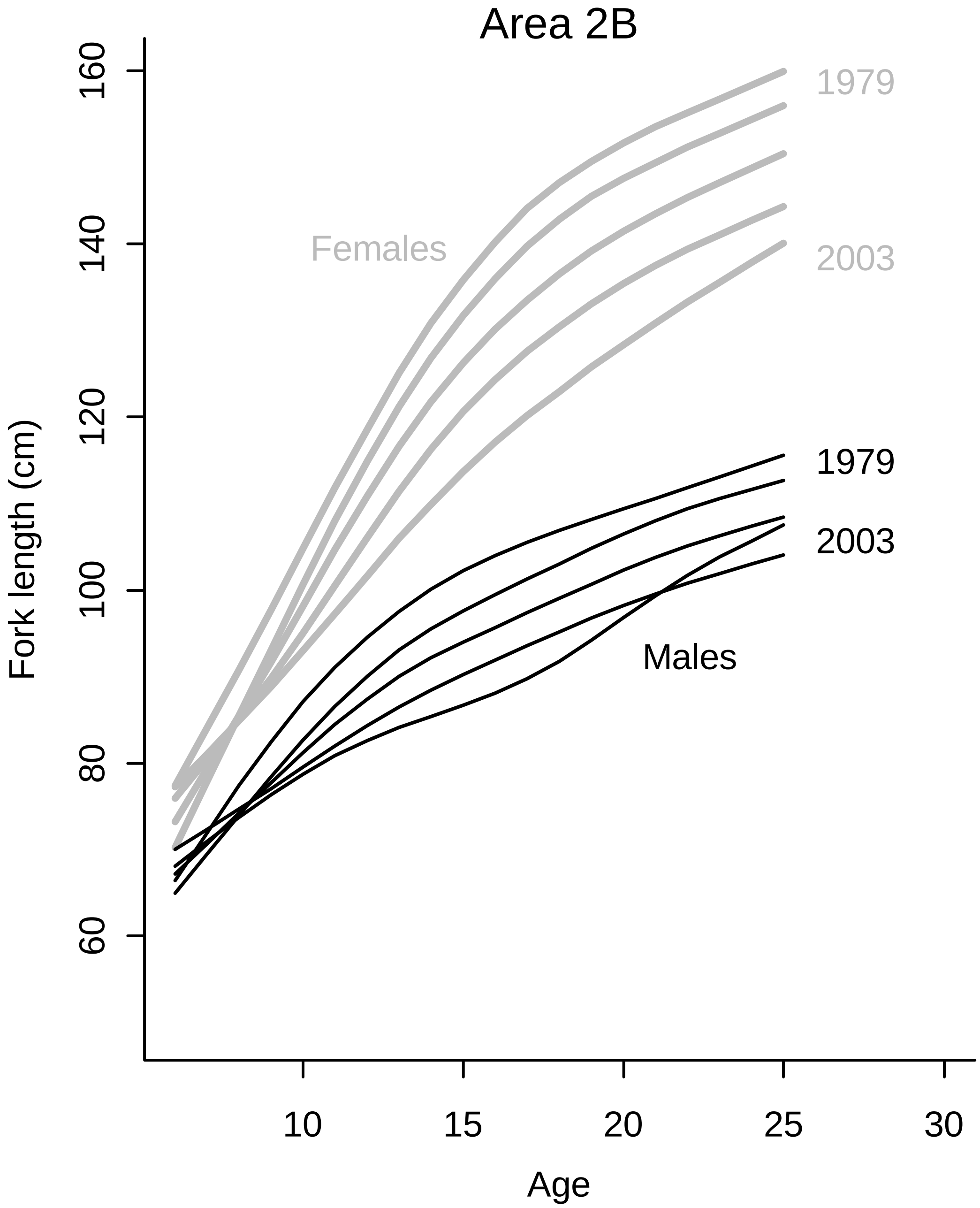

Figure 4. Mean length at age of females and males in setline survey catches in Area 2B. For each sex, the graphs show the observed growth schedules in a sequence of years at intervals between 1979 and 2003. The upturn in the male growth schedule in 2003 is an artifact of the conversion from surface to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

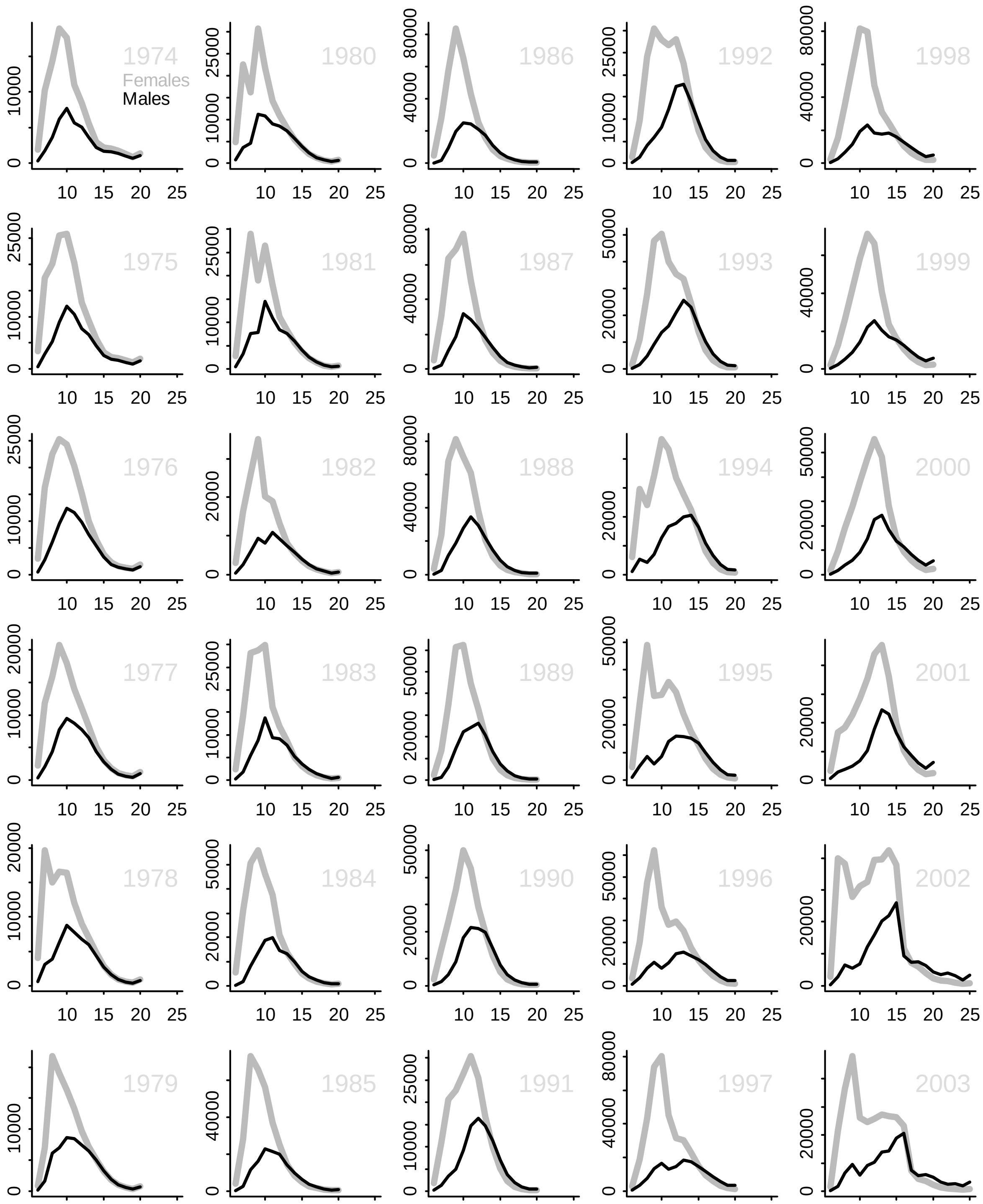

Figure 5a. Catch at age of females and males in Area 2B, by year.

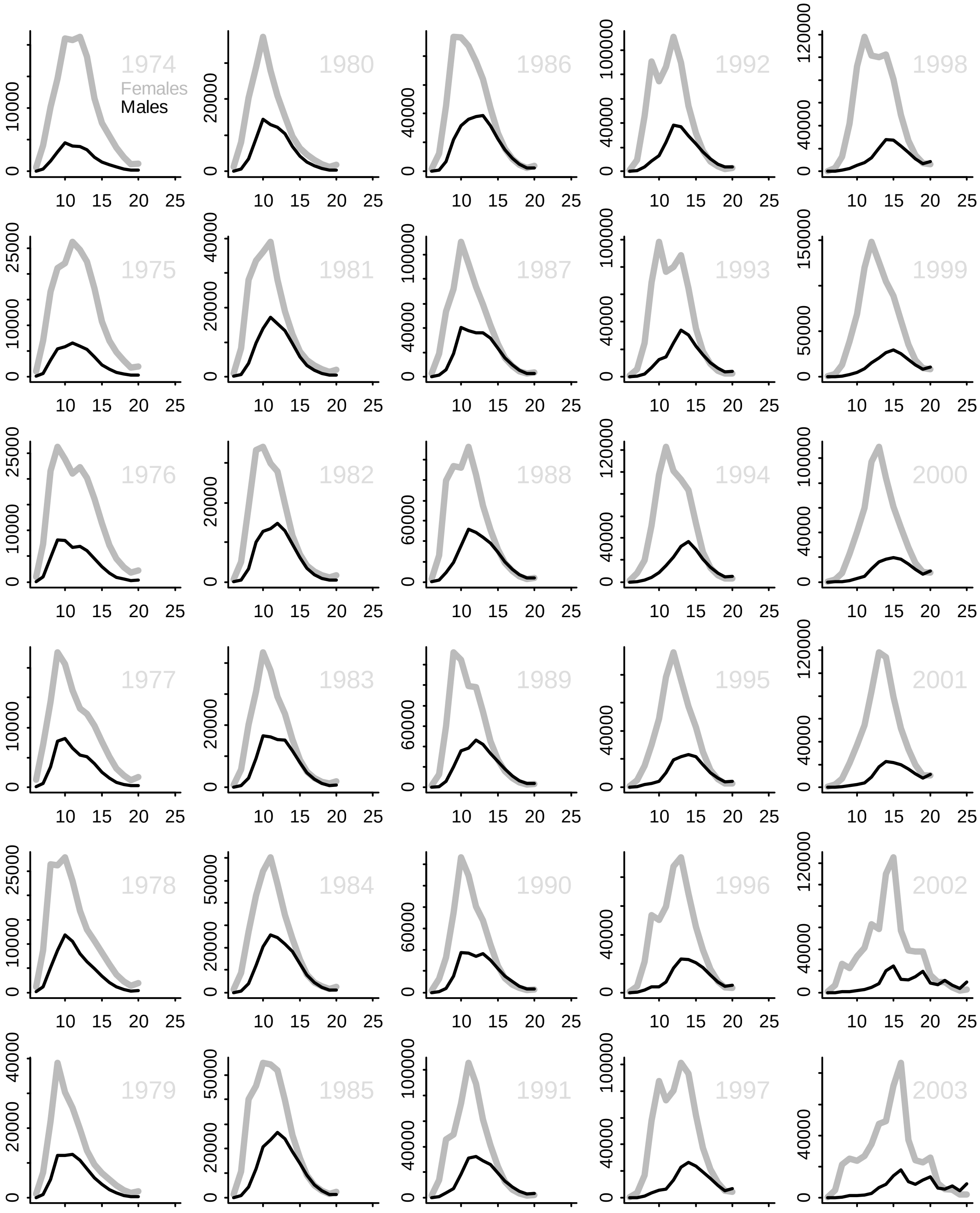

Figure 5b. Catch at age of females and males in Area 3A, by year.

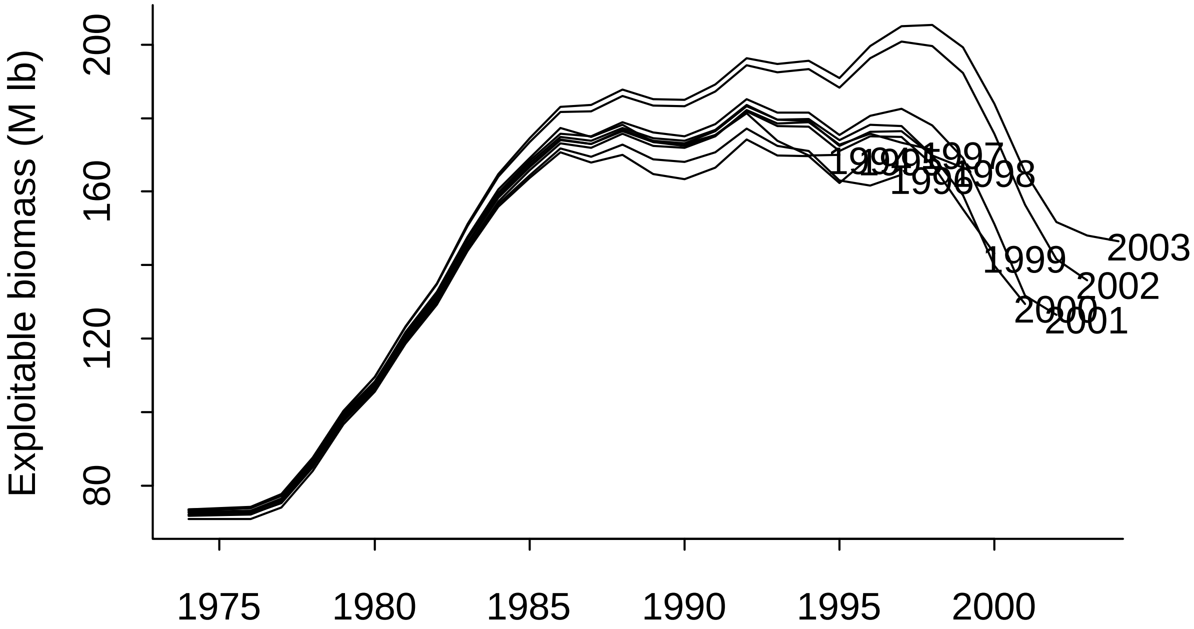

Figure 6. Retrospective performance of the 2003 assessment in Area 3A.

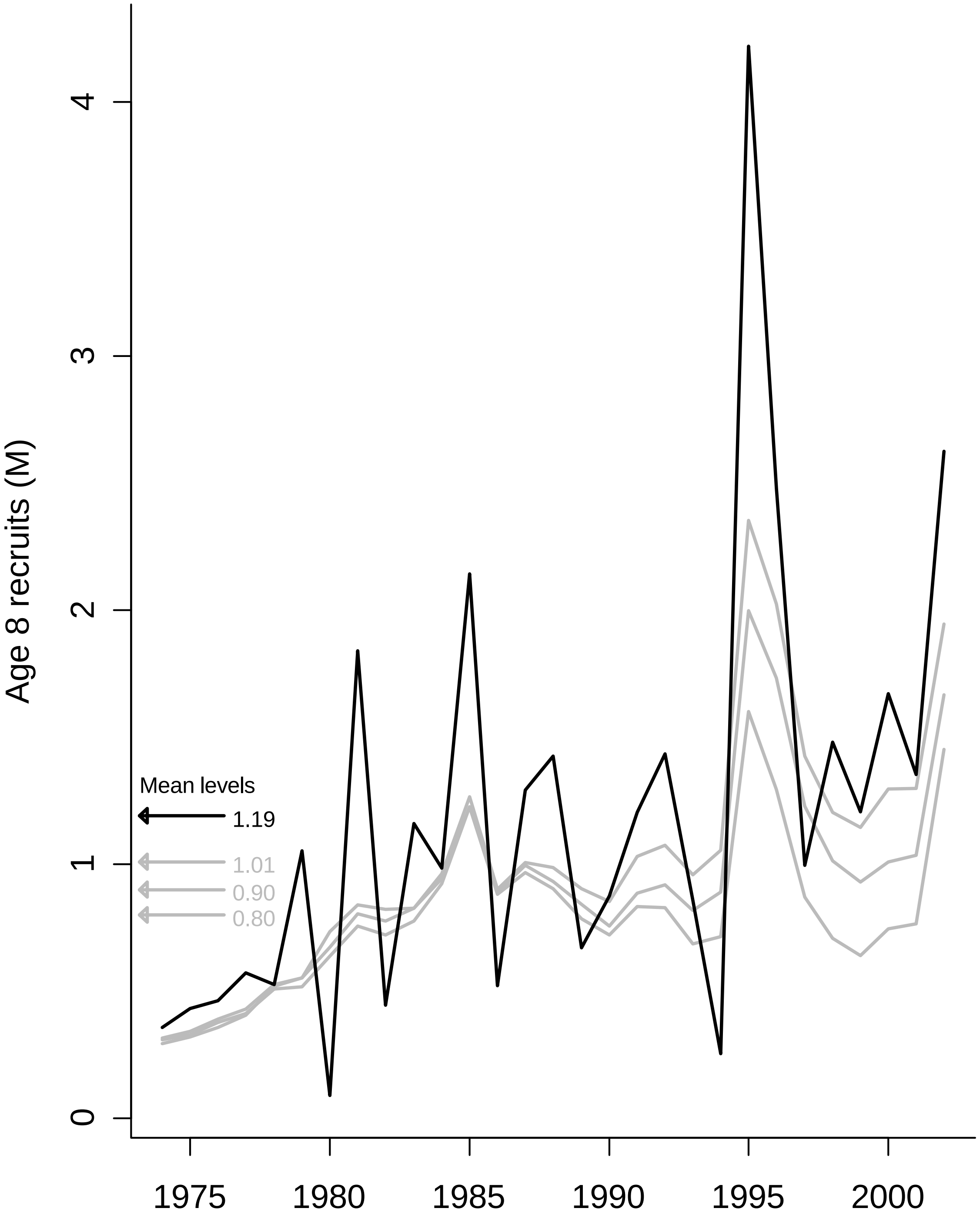

Figure 7. Estimates of recruitment in Area 2C from fits of old and new models. Bottom line shows the 2002 assessment with fixed age-specific survey selectivities; next line up shows the effect of switching to length-specific selectivities; next line up the added effect of treating females and males separately;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

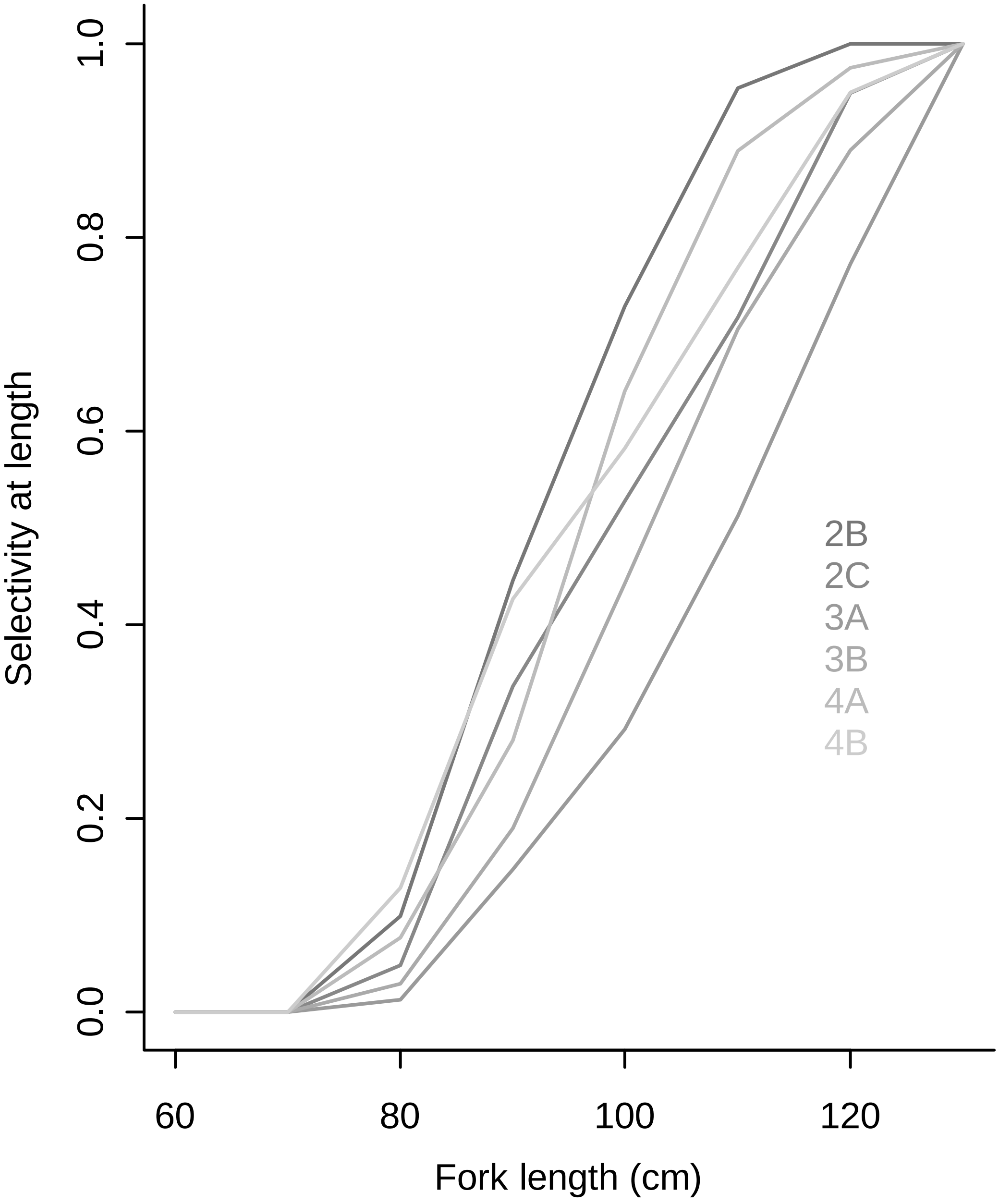

Figure 8. Estimated length-specific commercial selectivity. The topmost line is Area 2B. The bottom line is Area 3A, and the other Alaska areas are clustered in the middle.

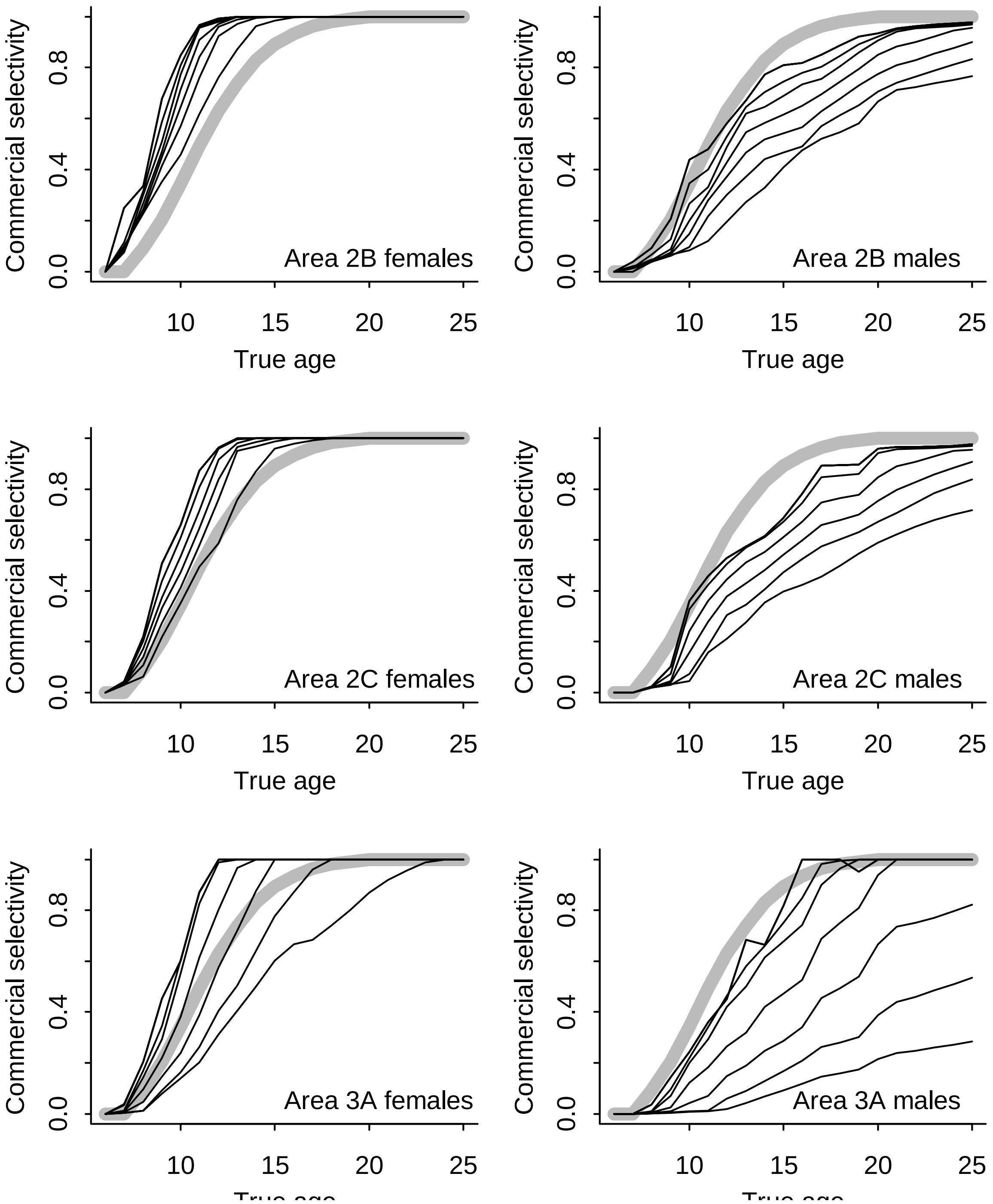

Figure 9. The downward drift of age-specific commercial selectivities over time due to constant length-specific selectivity and declining size at age, plotted by area and sex. The thin black lines in each graph are the selectivities estimated for a particular year; the thick gray line is the set of fixed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

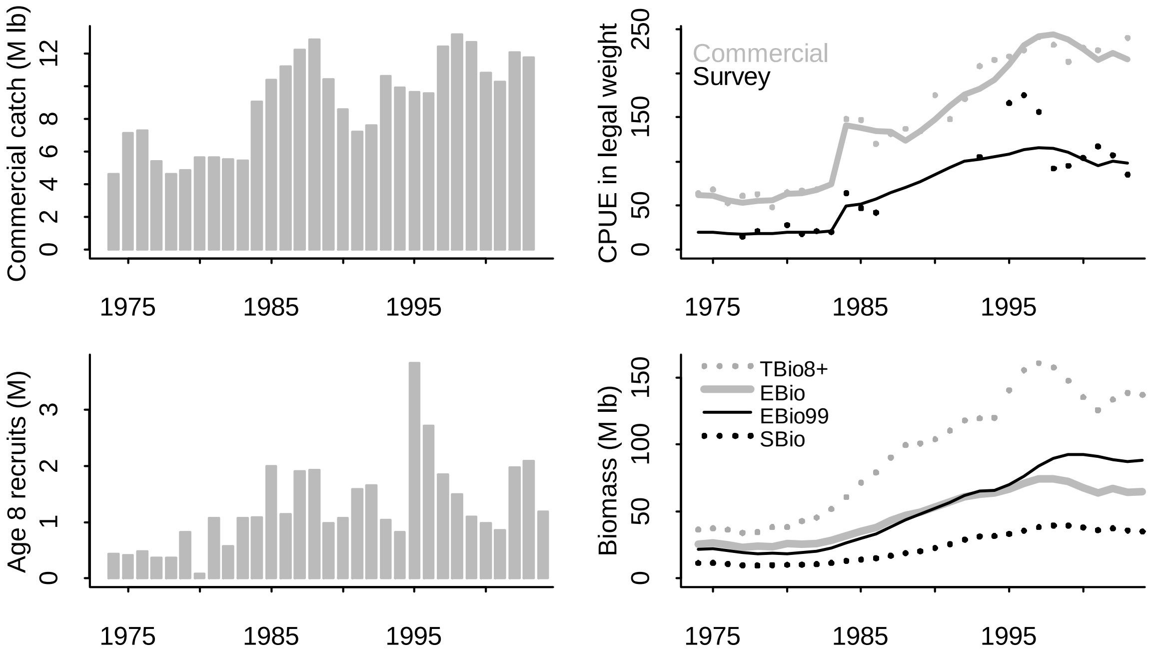

Figure 10a. Features of the Area 2B assessment. In the upper right graph, the points are the observed CPUE values and the lines are the model predictions. In the lower right graph, "TBio8+" is total biomass of fish aged 8 and older, "EBio" is exploitable biomass as calculated this year, "EBio99" is exploitable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

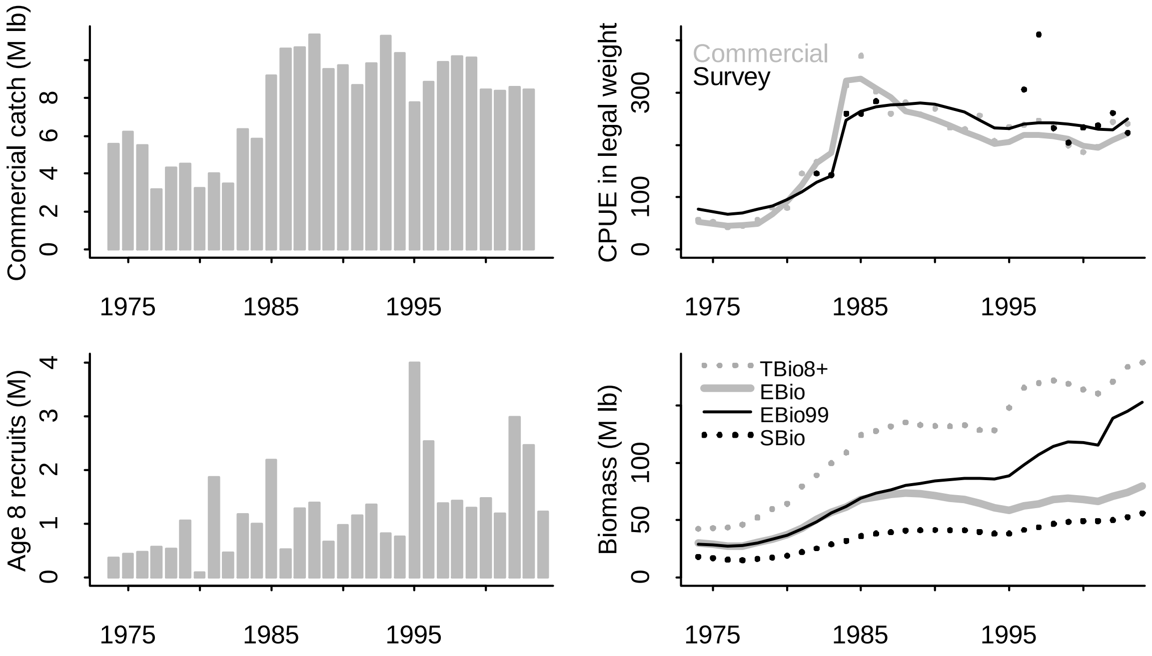

Figure 10b. Features of the Area 2C assessment.

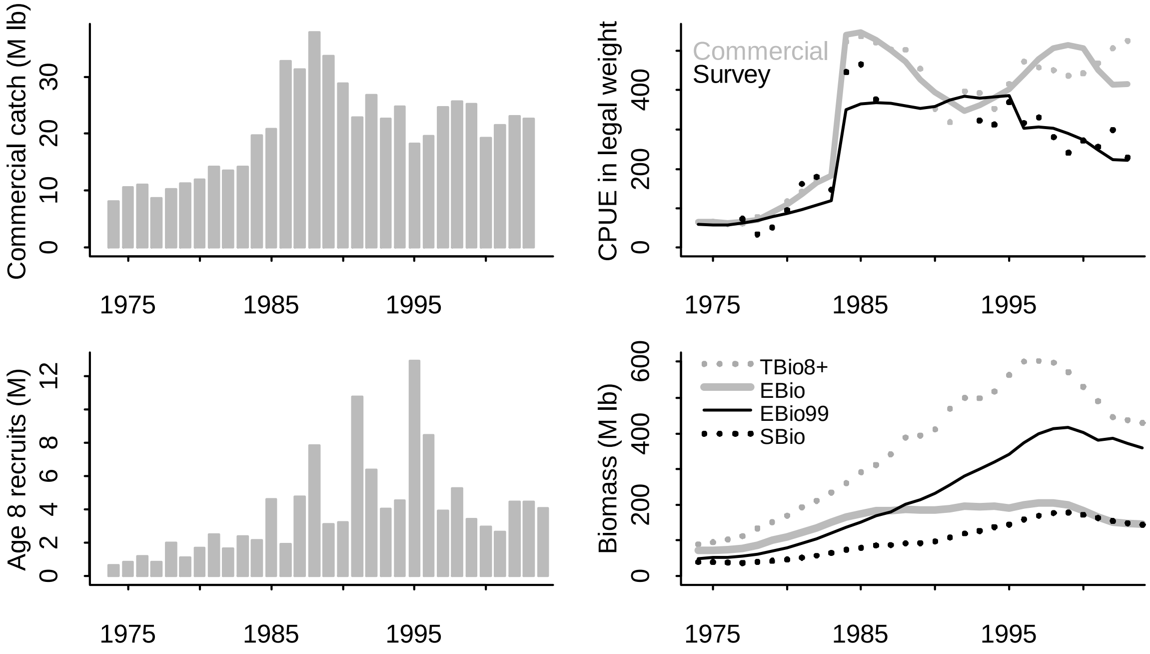

Figure 10c. Features of the Area 3A assessment. (See Figure 10a legend for details.)

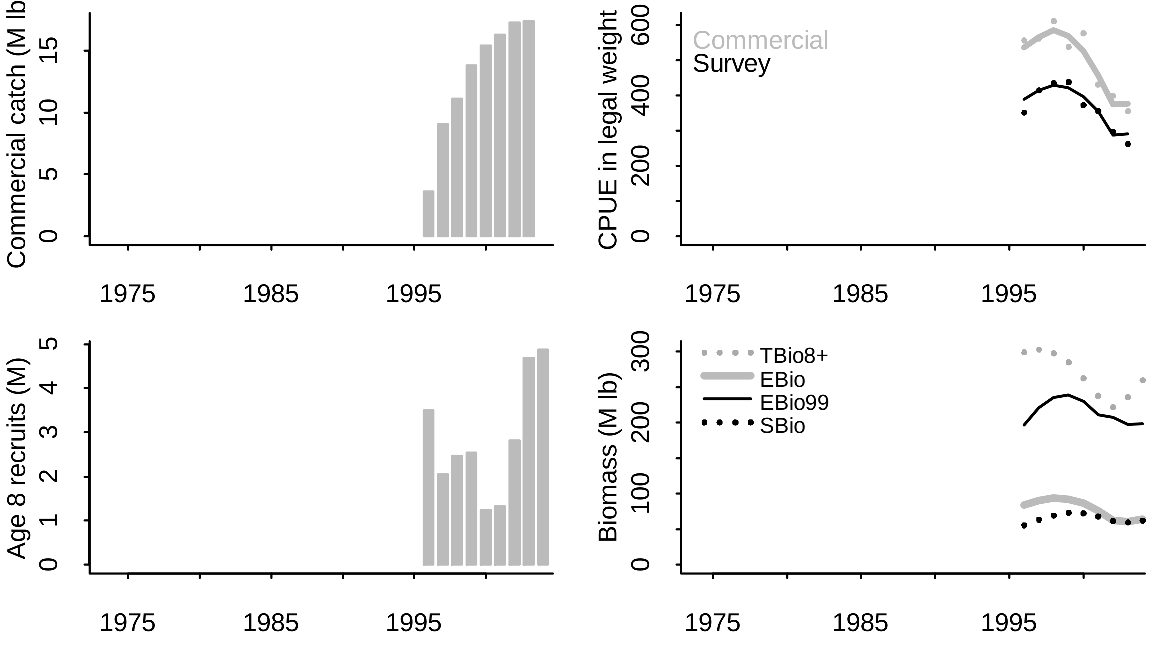

Figure 10d. Features of the Area 3B assessment.

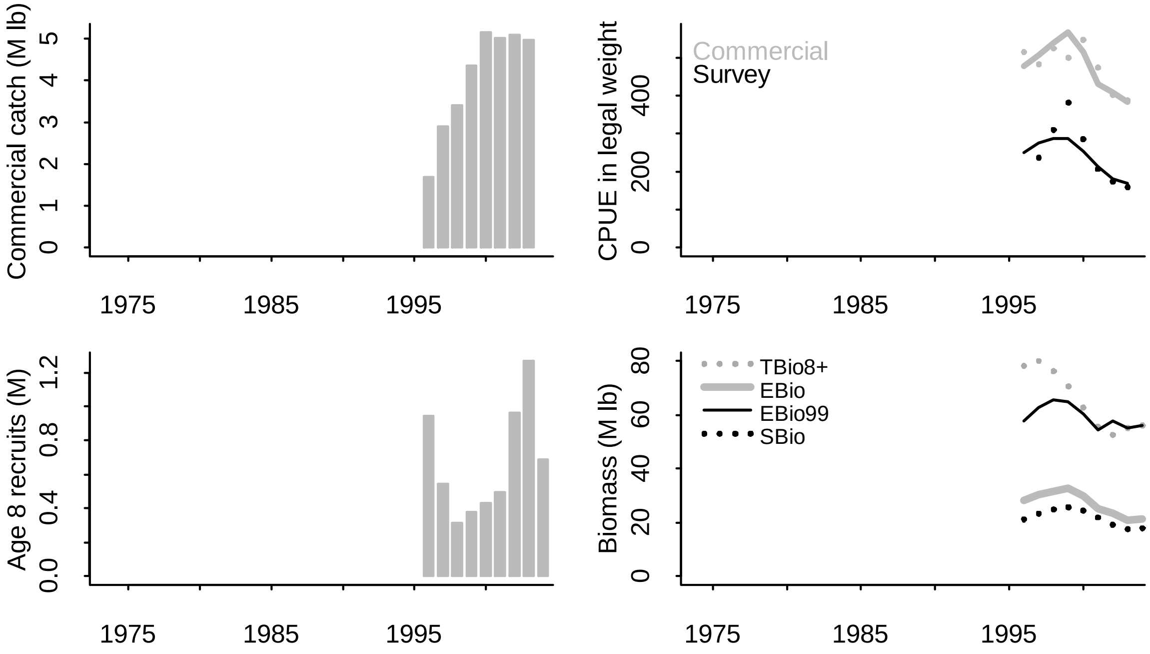

Figure 10e. Features of the Area 4A assessment. (See Figure 10a legend for details.)

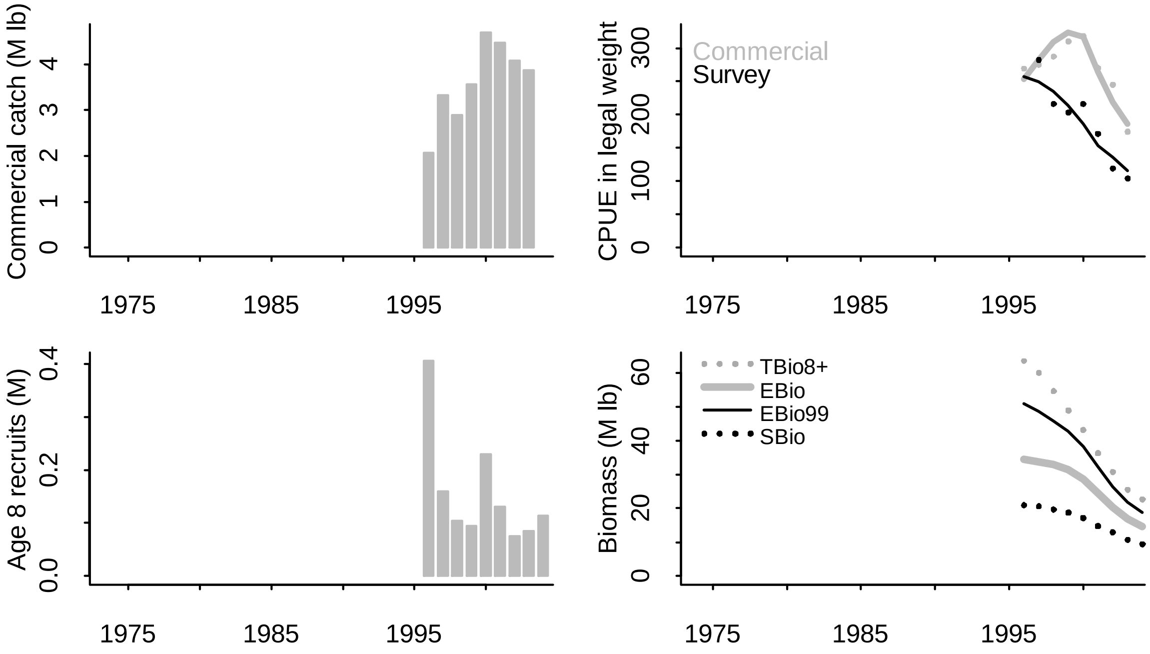

Figure 10f. Features of the Area 4B assessment.

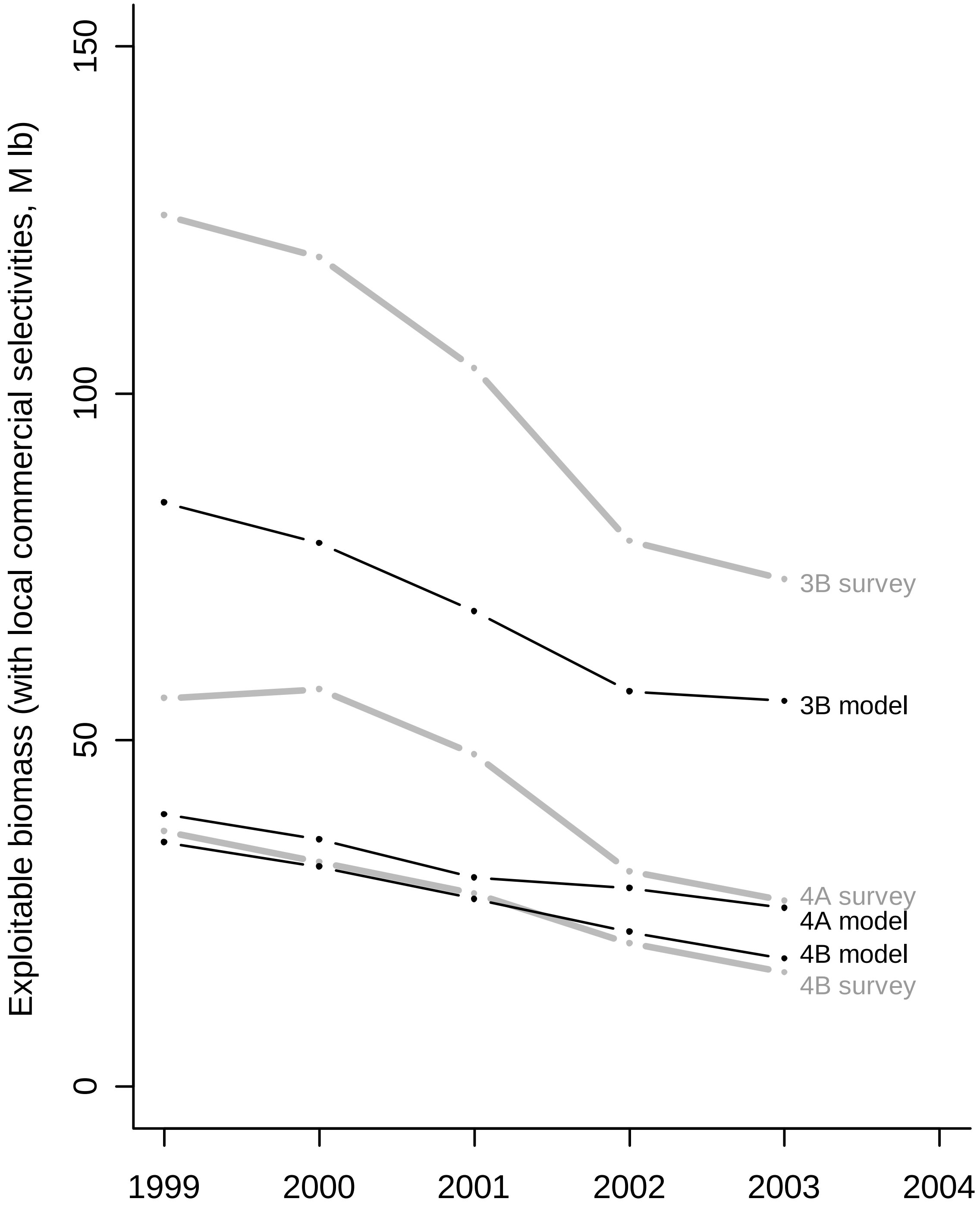

Figure 11. Comparison of analytical estimates of exploitable biomass in Areas 3B, 4A, and 4B from the 2003 assessment ("model") and survey-based estimates scaled to the estimated exploitable biomass in Area 3A ("survey", also from the 2003 assessment).

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	---

The conditional constant catch (CCC) harvest policy: Summary and estimated CCC yield for 2004

Steven R. Hare, William G. Clark, and Bruce M. Leaman

Abstract

The CCC harvest policy is summarized and parameters required for its implementation updated. Rationale for the chosen policy parameters is given. An analysis is conducted to estimate how much of the catch that is forfeited due to imposition of the catch ceiling during times of high abundance is eventually recaptured by the fishery in subsequent years.

Introduction

In 2002, the IPHC put forward for consideration a new harvest policy, termed the "Conditional Constant Catch ("CCC") policy. Details of the policy can be found in Clark and Hare (in press) and Hare and Clark (2003). Following presentation of the proposed policy both at the IPHC 2002 Annual Meeting and at a subsequent retreat with the IPHC Commissioners, the decision was made to formally recommend adoption of the CCC policy in setting of catches for 2004. Pursuant to that end, this document provides the details required to implement the policy and updates some aspects not reported upon in the two previous documents.

Summary of CCC policy

The CCC policy, if adopted, requires selection of a catch ceiling, a ceiling harvest rate, and two minimum spawning biomass safeguard levels or reference points. The catch ceiling provides an upper cap on total removals; the ceiling harvest rate an upper cap on the maximum harvest rate. It is important to note that "catch" in this context refers to total removals, i.e., commercial catch, bycatch, sport catch, personal use, and wastage. The lower this ceiling, the more often the annual removals will be equal to the catch ceiling thereby giving greater stability in year to year removals. The ceiling harvest rate is implemented when the projected removals (harvest rate multiplied by exploitable biomass) are lower than the catch ceiling. This is in essence the current harvest policy. A constant harvest rate policy has been shown to be quite robust but can lead to substantial year to year variability in removals. At the lower biomass range, the ceiling harvest rate would be in effect until the projected removals would result in the spawning biomass dropping below a specified threshold. Below the minimum spawning biomass threshold is a minimum spawning biomass limit. All removals would cease should the limit be reached, i.e., the harvest rate is set to zero. At spawning biomass levels that fall between the biomass reference points, the harvest rate is scaled down linearly from the maximum at the threshold, to zero at the limit. A graphic of how the CCC policy would operate is illustrated in Figure 1.

To assess the performance of the CCC policy, simulations were conducted for IPHC Regulatory Areas 2B, 2C, and 3A – both individually and as one large management area (Hare and Clark

2003). The population dynamics were modeled according to our current understanding (Clark and Hare 2002). The most important dynamic factors are individual growth rate and recruitment. Growth rate is now believed to be related to the density of the stock while recruitment, at least over the range of observed stock sizes, is environmentally driven. To check the robustness of the CCC policy, simulations were conducted over a range of alternative growth and recruitment hypotheses. Policy performance was measured with a variety of indicators, including average annual catch, catch variability, effect on spawning biomass, and frequency that catch is within 90% of the catch ceiling. A range of catch ceilings and ceiling harvest rates were examined for each area. For Area 2B, the catch ceilings ranged from 12.5 to 17.5 million pounds; for Area 2C the ceilings were 10.0 to 15.0 million pounds and in Area 3A the ceilings examined were 25 to 35 million pounds (25 to 30 million pounds in Hare and Clark 2003, updated in this report). Maximum harvest rates of 0.20 to 0.40 (in increments of 0.05) were examined for all areas. Finally, minimum spawning biomass thresholds and limits were established for each area. The rationale used was to set the limit (i.e., the biomass level at which all removals ceased) equal to the minimum observed biomass. The biomass threshold (i.e., the level at which the harvest begins to be scaled down) was set at 1.5 times the biomass limit.

Tables 1-3 summarize the results of the simulations. These tables are the same as those in Hare and Clark 2003, except for the updated range of catch ceilings for Area 3A. In Hare and Clark (2003), summary tables were presented for a range of hypotheses and recruitment distributions. The tables presented here are for a single subset of the simulations, i.e., representing our "Most Likely" scenario of halibut population dynamics. These simulations included the designated minimum biomass thresholds and limits. Recruitment was assumed to follow Recruitment Distribution 1, explained below under the heading of "Catch ceilings".

Ceiling harvest rates

While the CCC policy does incorporate a threshold reference point to trigger remedial action, an overriding concern is conservation of the stock and avoiding any approach to the limit reference point. Considering that the highest modeled harvest rate resulted in the highest average yield under the most likely scenarios of growth and recruitment, one might argue for a substantially higher harvest rate than our present value of 0.20, but the increases in yield are quite modest. Likewise, the increase in proportion of time that 90% of the ceiling removals are obtained is modest above a harvest rate of 0.25.

In the absence of threshold and limit reference points, the probability of spawning stock biomass dropping below the historical minimum increases substantially at harvest rates above 0.25 (Hare and Clark 2003, p. 136). Inclusion of these reference points in the management policy should avoid this occurrence, if the reference points are determined accurately. The reference points are determined through assessing the average performance of the stock over the long term but the performance during a particular climate regime can vary from the long-term average. In view of this and the fact that the benefits in yield at harvest rates above 0.25 are relatively minor, we recommend adoption of a harvest rate of 0.25 as a conservative operational value for the CCC policy.

Catch ceilings

Catch ceilings will need to be established for each area. Using the 0.25 harvest rate established above, we examined simulation results across a range of catch ceilings. As an operational guideline, we recommend using a combination of a catch ceiling and 0.25 harvest rate that achieves 90% of the catch ceiling e" 60% of the time. The rationale for this choice is that it achieves a substantial portion of the maximum possible yield and protects the stock over the long term, while not introducing a substantial and destabilizing shift in removals at current biomass levels. A further issue concerns future geographic distribution of recruitment in the northeast Pacific. The distribution of recruitment has varied over time and we recommend choosing the more conservative assumption about recruitment, i.e., that recruitment in the future will be more similar to the previous twenty years (Recruitment Distribution 1) than to the long-term average (Recruitment Distribution 2). The logic for this is that distribution is associated with long-term climate warming and this directional trend appears unlikely to reverse in the foreseeable future. This implies that recruitment will be stronger into the central part of the halibut range than into the more southerly portions.

2004 CCC yield guidelines

For Areas 2B, 2C and 3A, the CCC harvest policy can be used to directly compute the 2004 estimated yields once the exploitable biomass has been estimated in the stock assessment. Using the decision rule described above, the catch ceiling for Area 2B is 13 millions lbs, for 2C it is 12 million lbs, and for 3A it is 35 million lbs. With a harvest rate of 0.25, the catch ceiling is imposed when the exploitable biomass is four times the catch ceiling, i.e., 52 millions lbs in 2B, 48 million lbs in 2C and 140 million lbs in 3A. Below those exploitable biomass levels, the recommended harvest rate of 0.25 applies. This harvest rate applies until the spawning biomass drops down to the threshold. Currently, the spawning biomass is well above the threshold in all areas and is unlikely to be a factor in the near future.

For Areas 3B, 4A, and 4B there are now stand alone assessments that provide estimates of exploitable biomass. The input data and assessment model output are of insufficient duration to allow a dynamic analysis of catch and harvest rate ceilings as was made for Areas 2B, 2C, and 3A. We elected not to establish catch ceilings for Areas 3B, 4A and 4B, but to base recommended harvest rate on the 3A ceiling harvest rate. Area 3B we consider to be approximately as productive as Area 3A and therefore adopted a 0.25 harvest rate ceiling. Areas 4A and 4B have less of an exploitation history than the central Gulf areas and conservatism arguments lead us to adopt a lower ceiling harvest rate of 0.20 for those two areas.

Areas 2A and 4CDE remain without standalone assessment models and thus all harvest policy parameters must be leveraged from other areas. Area 2A is leveraged by Area 2B while Area 4CDE is leveraged by Area 3A. Recent survey catch rates show Area 2A biomass approximately 13% of Area 2B biomass. This fraction was used to obtain the 2A ceiling catch of 1.69 million pounds. The Area 2B maximum harvest catch rate of 0.25 is also adopted for Area 2A. Area 4CDE has a production fraction of 0.37 compared to Area 3A. We also elected not to establish a ceiling catch for 4CDE. Similar concerns as were voiced for Areas 4A and 4B led to a ceiling harvest rate of 0.20. The complete set of ceiling catches and harvest rates are given in Table 4.

Recapture of catch forfeited due to imposition of catch ceiling

If the CCC harvest policy is adopted, there will be years in which total removals will be limited by the catch ceiling. A natural question is how much of the forfeited catch will be recaptured in subsequent years, particularly in years where the biomass is cycling downwards. Due to the dynamic nature of the halibut population, this question cannot be answered analytically but must be investigated via simulation. The amount of foregone catch that will be recaptured depends on several interacting factors. These include the duration of recruitment regimes (both positive and negative), the magnitude of the catch ceiling, and the ceiling harvest rate.

To estimate the fraction of forfeited catch recaptured in subsequent years, we compared the harvest trajectories for policies with no catch ceiling (such as our current harvest policy) with policies utilizing a range of catch ceilings. To compare the trajectories the same sequence of recruits must be used. Figure 2 shows catch trajectories for the combined Areas 2B/2C/3A for three different ceiling harvest rates (0.20, 0.25, 0.30) and three different catch ceilings (50, 55, 60, million pounds). In the plots, the amount of catch foregone is that part of the curves above the catch ceiling and below the trajectory for the No Ceiling harvest policy. Following a negative recruitment regime there is a decline in biomass and, therefore, in removals. With a catch ceiling, some biomass is conserved and therefore removals do not drop as quickly as for a No Ceiling harvest policy. The extra amount of removals in these periods of declining harvest are shown by the regions where the trajectories for the harvest ceiling policies are above the No Ceiling trajectory. Summed over many years, or over many Monte Carlo simulations, the fraction of forfeited catch recaptured is the ratio of the amount of extra removals during downward times to the amount of removals forfeited due to the ceiling.

The fraction of forfeited catch eventually recaptured, by area, across a range of ceiling harvest rates and ceiling removal levels is summarized in Table 5. Across the different ceilings and areas the fraction of forfeited catch recaptured varies from nearly zero to nearly 1.0. The fractions near 1.0 however occur only where there is a combination of a very low ceiling harvest rate and a high catch ceiling level. Under those circumstances very little harvest is forfeited since the ceiling is generally not reached. In these cases, catch limit variability is also very high. Conversely, the cases where the least amount of forfeited harvest is recaptured is the combination of a high harvest rate and low harvest ceiling. In these cases, the ceiling is frequently reached and a large amount of harvest is forfeited. Between these extremes, in the ranges that are considered reasonable for all the areas, the fraction of forfeited catch that would be recaptured is generally around 0.2 for Areas 2B and 2C and 0.1 for Area 3A.

Conclusions

The CCC harvest policy was developed in response to a perceived need to reduce annual variability in harvest recommendations as well a desire to insulate the harvest policy from the annual stock assessment. As a long lived animal exploited at a relatively low level, annual halibut catches should not be expected to sharply rise or fall from year to year. With the Constant Harvest Rate (CHR) policy however, this was sometimes the case since the policy mandated that a constant fraction of the estimated exploitable biomass be taken each year. If the assessment model is overhauled, or important parameters such as natural mortality change, annual estimates of the exploitable biomass can, and have, abruptly changed from one year to the next. Recognition that it was not the stock biomass, only our perception of it, that varied so greatly generally resulted in harvest recommendations that differed from the CHR computation.

A major advantage to the CCC policy is that it is a policy based on the long term, repeatedly demonstrated, productivity of the halibut stock rather than exclusively on annual estimates of production. The catch ceilings and ceiling harvest rates ensure that the spawning stock will be conserved even in times of low productivity. At the current high biomass levels in the center of the halibut range (Areas 2 and 3A), the catch ceilings are likely to be a factor for the next few years. Over the long term, the average catch with the ceilings are not much lower than catches that are not limited by a ceiling. When biomass declines in times of lower recruitment, some of the forfeited catch – up to 20% - will be recaptured thus tempering the catch decline.

The CCC harvest policy is currently being investigated as a sex-specific policy in response to the assessment now being sex specific. The largest concern is the impact of the current harvest policy on the abundance of older females in the population. A yield per recruit analysis of halibut with and without an 81 cm size limit provides an initial view of the impact on females. Results from a dynamic analysis – with updated estimates of recruitment, size at age, and selectivity at length – will help to further refine the parameters of the CCC harvest policy.

References

Clark, W.G. and Hare, S. R. In Press. A conditional constant catch policy for managing the Pacific halibut fishery. N. Am. J. Fish. Mgmt.

Clark, W.G. and Hare, S.R. 2002. Effects of climate and stock size on recruitment and growth of Pacific halibut . N. Am. J. Fish. Mgmt. 22: 852-862.

Clark, W.G. and Hare, S.R. 2004. Assessment of the Pacific halibut stock at the end of 2003. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2003: this volume.

Hare, S.R. and Clark, W.G. 2003. Issues and tradeoffs in the implementation of a conditional constant catch harvest policy. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2002: 121-161.

Table 1. Performance measures for a CCC harvest policy in Area 2B.

Average annual yield (million lbs.)

Max. HR	Catch ceiling 12.5	15.0	17.5	No ceiling
0.00	0	0	0	0
0.20	11.0	11.4	11.4	11.4
0.25	11.5	12.3	12.5	12.5
0.30	11.7	12.8	13.3	13.4
0.35	11.9	13.1	13.8	14.0
0.40	12.0	13.3	14.1	14.5

Standard deviation of yield (million lbs.)

Max. HR	Catch ceiling 12.5	15.0	17.5	No ceiling
0.00	0	0	0	0
0.20	1.7	2.3	2.3	2.3
0.25	1.5	2.5	2.8	2.9
0.30	1.3	2.5	3.2	3.3
0.35	1.1	2.4	3.3	3.7
0.40	1.1	2.3	3.4	4.1

Average spawning biomass (million lbs.)

Max. HR	Catch ceiling 12.5	15.0	17.5	No ceiling
0.00	131	131	131	131
0.20	56	53	53	53
0.25	53	47	46	46
0.30	51	44	41	41
0.35	49	42	37	36
0.40	48	40	35	33

Yield ≥ 90% of Constant catch (percent of years)

Max. HR	Catch ceiling 12.5	15.0	17.5	No ceiling
0.00	0	0	0	0
0.20	56	25	1	0
0.25	66	46	15	0
0.30	74	54	33	0
0.35	80	58	42	0
0.40	85	62	47	0

Table 2. Performance measures for a CCC harvest policy in Area 2C.

Average annual yield (million lbs.)

	Catch ceiling			
Max. HR	10.0	12.5	15.0	No ceiling
0.00	0	0	0	0
0.20	9.3	10.0	10.0	10.0
0.25	9.6	10.7	11.0	11.0
0.30	9.8	11.1	11.7	11.8
0.35	9.9	11.3	12.1	12.4
0.40	9.9	11.4	12.3	12.8

Standard deviation of yield (million lbs.)

	Catch ceiling			
Max. HR	10.0	12.5	15.0	No ceiling
0.00	0	0	0	0
0.20	1.0	1.8	1.8	1.8
0.25	0.7	1.9	2.3	2.3
0.30	0.6	1.8	2.6	2.7
0.35	0.5	1.7	2.8	3.2
0.40	0.5	1.8	2.9	3.6

Average spawning biomass (million lbs.)

	Catch ceiling			
Max. HR	10.0	12.5	15.0	No ceiling
0.00	127	127	127	127
0.20	54	50	49	49
0.25	52	44	43	43
0.30	51	41	38	37
0.35	50	40	35	33
0.40	50	39	33	30

Yield ≥ 90% of Constant catch (percent of years)

	Catch ceiling			
Max. HR	10.0	12.5	15.0	No ceiling
0.00	0	0	0	0
0.20	69	32	2	0
0.25	83	52	15	0
0.30	90	60	37	0
0.35	95	65	46	0
0.40	96	69	51	0

Table 3. Performance measures for a CCC harvest policy in Area 3A.

Average annual yield
(million lbs.)

	Catch ceiling			
Max. HR	25.0	30.0	35.0	No ceiling
0.00	0	0	0	0
0.20	24.8	27.6	27.8	28.1
0.25	25.0	29.0	31.0	31.6
0.30	25.0	29.6	32.3	34.6
0.35	25.0	29.8	33.0	36.9
0.40	25.0	29.9	33.4	38.8

Standard deviation of yield
(million lbs.)

	Catch ceiling			
Max. HR	25.0	30.0	35.0	No ceiling
0.00	0	0	0	0
0.20	0.6	2.7	3.3	3.3
0.25	0.1	1.9	4.0	4.6
0.30	0.0	1.2	3.6	5.9
0.35	0.0	0.8	3.2	7.3
0.40	0.0	0.7	3.0	8.5

Average spawning biomass
(million lbs.)

	Catch ceiling			
Max. HR	25.0	30.0	35.0	No ceiling
0.00	240	240	240	240
0.20	137	126	124	124
0.25	136	120	112	112
0.30	136	117	106	102
0.35	136	116	102	93
0.40	136	115	99	85

Yield ≥ 90% of Constant catch
(percent of years)

	Catch ceiling			
Max. HR	25.0	30.0	35.0	No ceiling
0.00	0			0
0.20	97	65	12	0
0.25	100	84	55	0
0.30	100	93	65	0
0.35	100	97	73	0
0.40	100	98	79	0

Table 4. Harvest and biomass specifications required to implement the CCC harvest policy. See text for area specific rationale on ceiling harvest rates and catches. The catch ceilings are implemented when exploitable biomass (Ebio) level is greater then the values listed in the fourth column. Spawning biomass threshold and limits have only been determined for Areas 2B, 2C, and 3A.

IPHC Area	Ceiling harvest rate	Catch ceiling (M lbs)	Ebio for catch ceiling	Spawning biomass threshold	Spawning biomass limit
2A	0.25	1.69	6.76		
2B	0.25	13.00	52.00	27	18
2C	0.25	12.00	48.00	24	16
3A	0.25	35.00	140.00	66	44
3B	0.25				
4A	0.20				
4B	0.20				
4CDE	0.20				

Table 5. The fraction of forfeited catch that would be subsequently recaptured under the CCC harvest policy across a range of ceiling harvest rates and catch ceilings.

Area 2B/2C/3A combined

	Catch ceiling		
ceiling HR	50	55	60
0.20	0.14	0.18	0.35
0.25	0.11	0.15	0.17
0.30	0.09	0.14	0.16
0.35	0.07	0.13	0.16
0.40	0.05	0.12	0.16

Area 2C

	Catch ceiling		
ceiling HR	10	12.5	15
0.20	0.16	0.42	0.85
0.25	0.15	0.22	0.65
0.30	0.13	0.21	0.32
0.35	0.12	0.22	0.26
0.40	0.12	0.22	0.27

Area 2B

	Catch ceiling		
ceiling HR	12.5	15	17.5
0.20	0.19	0.58	0.86
0.25	0.18	0.24	0.59
0.30	0.18	0.23	0.32
0.35	0.17	0.23	0.28
0.40	0.17	0.24	0.29

Area 3A

	Catch ceiling		
ceiling HR	25	30	35
0.20	0.06	0.21	0.79
0.25	0.02	0.12	0.22
0.30	0.01	0.09	0.14
0.35	0.00	0.07	0.14
0.40	0.00	0.06	0.13

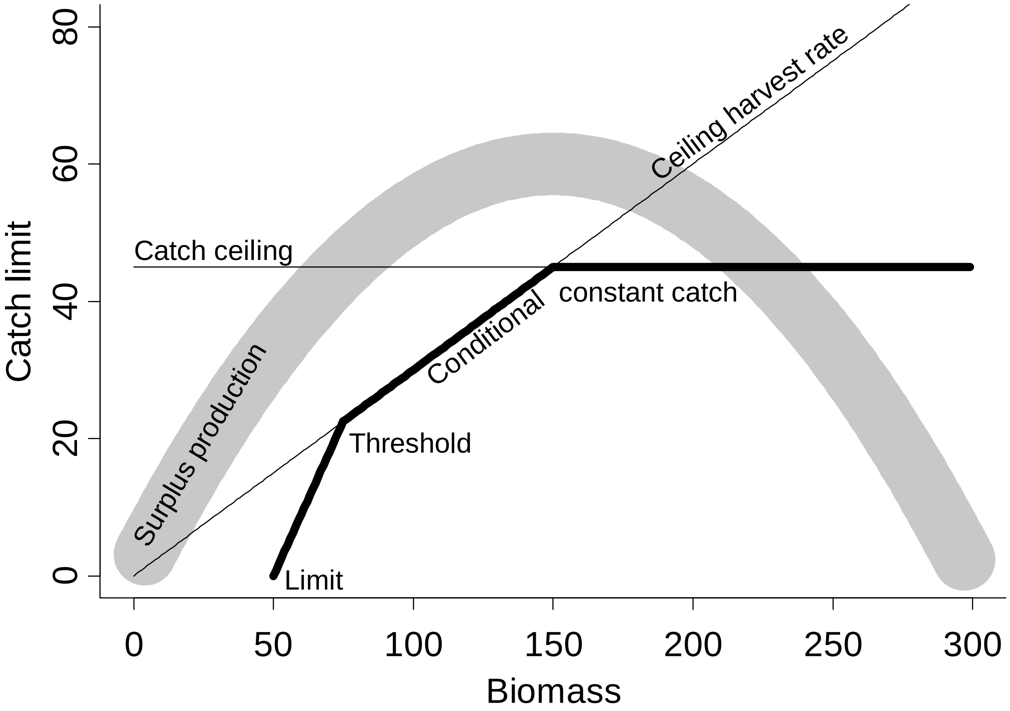

Figure 1. A graphic illustration of the conditional constant catch harvest policy in relation to biomass level and surplus production (modified from Clark and Hare, In Press).

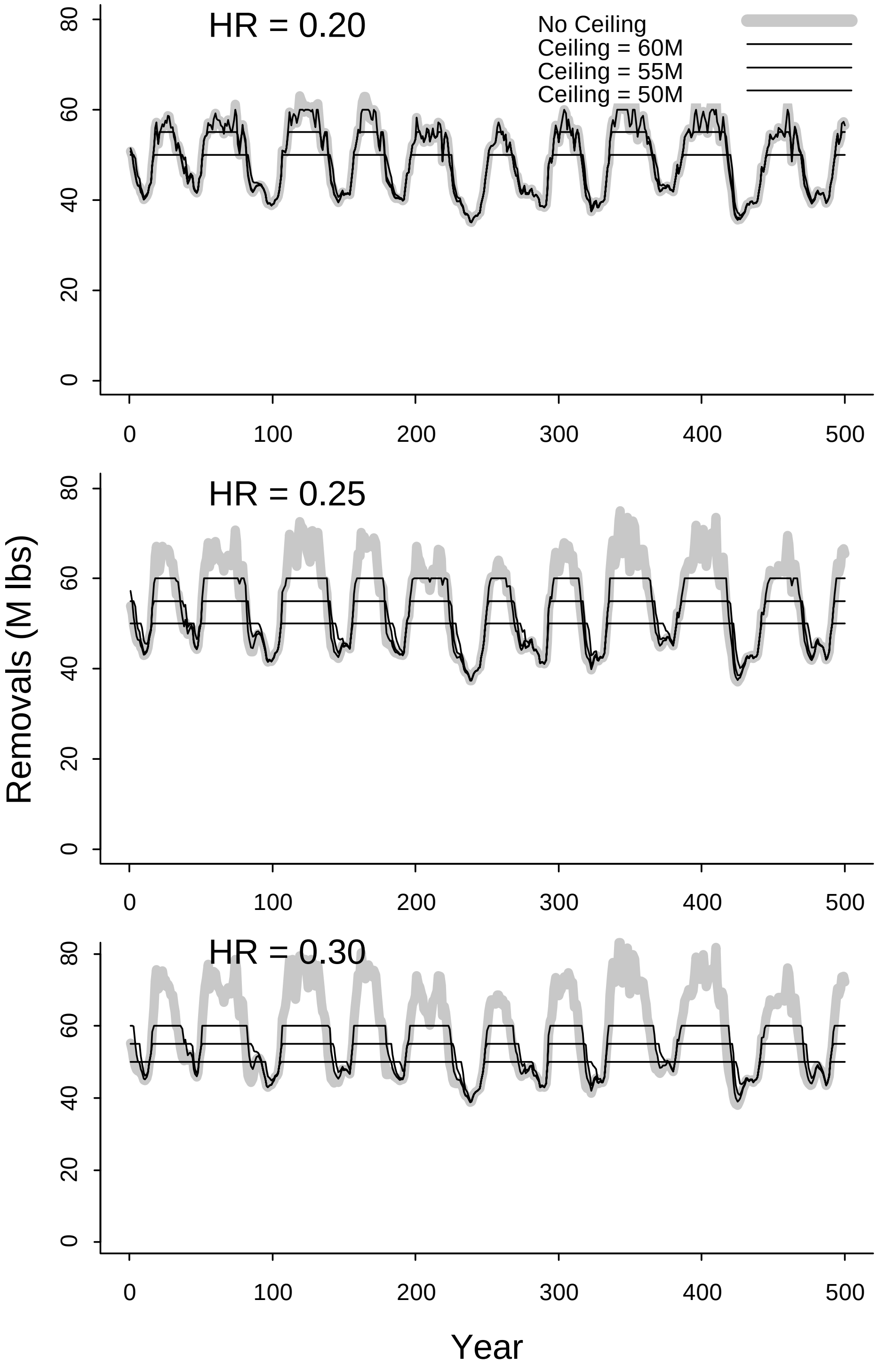

Figure 2. Yield trajectories under three different ceiling harvest rates and three different catch ceiling levels.