Population Assessment

Motivation and plan for a coastwide stock assessment

William G. Clark and Steven R. Hare

The figures in this paper make extensive use of color, which will not appear in the print version. To view the figures in color, see the version posted in the complete 2007 IPHC Report of Research and Assessment Activities at: www.iphc.washington.edu/halcom/pubs/rara/IPHCRARA.htm

Abstract

The closed-area assessments that have been standard for some years assume that the stock in each area is a closed population. There is now considerable evidence of a continuing west-to-east migration of legal-sized fish that violates the assumption. A coastwide assessment does not require any assumptions about migration, so this year the staff undertook to perform one. This paper summarizes the reasons for questioning the closed-area assessments and outlines a plan for compiling the necessary data and running the coastwide assessment.

Problems with the present closed-area assessments

Since the International Pacific Halibut Commission (IPHC) staff began doing closed-area assessments for Areas 3B, 4A, and 4B in 2003, there has been a growing divergence between the distribution of exploitable biomass as estimated by the stock assessment and as indicated by our survey data taken at face value. For example, Area 3B is twice the size of Area 2C and has a higher survey CPUE, but the assessment says there is more biomass in Area 2C. Here are the two biomass distributions from the 2005 assessment:

	Assessment	Survey CPUE x bottom area
Area 2A	0.020	0.009
Area 2B	0.160	0.071
Area 2C	0.160	0.083
Area 3A	0.374	0.373
Area 3B	0.118	0.208
Area 4A	0.050	0.074
Area 4B	0.024	0.041
Area 4CDE	0.094	0.141

On the whole, the assessment sees about twice as much biomass in Area 2 as the survey, and a bit more than half as much in Areas 3B and 4. This can happen because the assessment estimates different catchabilities and selectivities in each area, and in particular it estimates that setline catchability in Areas 3B and 4A is 2-3 times what it is in Areas 2 and 3A (Fig.1).

The high catchability estimates result from the high apparent rates of total mortality in Areas 3B and 4A (Fig. 2). The difference between the high apparent values of Z and M is taken to be fishing mortality, meaning that the present catches must be exerting a fishing mortality equal to or greater than the target. In 2005, the assessment estimates that approximately equal amounts of catch resulted in a higher fishing mortality rate in Area 3B than in Area 2C, so the Area 3B biomass had to be lower.

There are other indications that the high apparent mortality rates in Areas 3B and 4A are due in part to net emigration, in which case the assessment estimates of fishing mortality and setline catchability are too high, and estimates of biomass are too low. The indications are:

(i) Relative to trawl survey catch rates at length, setline survey catch rates at length in Areas 3B and 4A are no higher than in Area 3A (Fig. 3). This is strong evidence that the assessment estimates of much higher setline catchability in Areas 3B and 4A are wrong, and that setline survey catchability is in fact equal in the three areas.

(ii) While the PIT tag recovery data on the whole are puzzling, they do show a high proportion of out-of-area recoveries from Area 3B and 4A releases, and a high proportion of out-of-area releases among Area 2B recoveries.

The standard closed-area stock assessment assumes that net migration is negligible among fish older than six years. It now appears that this assumption is probably wrong, and that the closed-area estimates of biomass distribution among regulatory areas are probably also wrong. It is therefore necessary to conduct the assessment in a way that does not rely on the closed-population assumption. Because we do not have the kind and amount of data that would allow us to estimate migration rates reliably, we are obliged to consider the feasibility of a single coastwide assessment.

Checks for heterogeneity among areas

A coastwide assessment will estimate a single, average survey catchability and selectivity. For the purpose of estimating total biomass it is not necessary to assume that these parameters are in fact equal in all areas, but for the purpose of estimating the distribution of biomass it is necessary to assume equal survey catchability. NMFS trawl survey data provide some support for this assumption as regards Areas 3A, 3B, and 4A (Figure 3), but at this point we have no way to check it in Area 2.

Because of the need for survey data to estimate the sex composition of commercial catches, the assessment will be limited to the years beginning with 1996, like the recent closed-area assessments in western areas. With a simple length-specific model and a lot of data for each year, the parameters should be well determined with eleven years of data.

The catch at age will be summed over areas. If there were large, systematic differences among areas in age composition, one would be worried about the model's ability to predict the coastwide data, particularly if the distribution of effort varied substantially among years. But the area-specific commercial and survey age compositions (Fig. 4) are quite similar in most areas in most years. The major differences relate to the timing of the appearance of large year-classes (e.g., 1987 and 1994). These tend to appear in strength first in Areas 4A, 2B, and 2C, next in Areas 3B and 4B, and last in Area 3A. The coastwide estimated selectivities will be averages over areas and years.

Coastwide averages of mean length at age by sex in survey catches will be used to predict coastwide length-specific selectivities. This will involve averaging over some large differences in length at age among areas (Fig. 5) but that should not cause any new problems; we average over large differences among individuals within areas now. A subtle problem is that, strictly speaking, the coastwide mean length used to predict survey selectivity should be weighted by abundance in each area, while the mean length used to predict commercial selectivity should be weighted by catch in each area. Calculations show that the two means never differ by more than a few percent, so this issue can be ignored.

Unfortunately, there are some large and persistent differences in sex ratio among areas (Fig. 6). The overall proportion female in recent survey catches is about 60%, but for unknown reasons it drops steadily from about 70% in Area 2 to 40% in Area 4B. This may cause some problems in predicting commercial catch at age/sex. If so, estimating sex-specific selectivities may solve the problems.

If we assume survey catchability is the same in all areas, we have to recognize differences in commercial catchability, because the relative values differ. In Area 2C, for example, survey and commercial CPUE are the same, while next door in Area 2B commercial CPUE is twice survey CPUE. This is surely the result of lower commercial catchability in Area 2C. In each area, survey and commercial CPUE bear approximately the same ratio over time (Fig. 7), so it would be possible to standardize commercial CPUE among areas by multiplying commercial CPUE by the area-specific ratio of survey to commercial CPUE. Because the distribution of effort among areas has not changed greatly in recent years, we do not intend to standardize commercial CPUE.

Data elements

In the following sections, the term "area-weighted average" refers to the weighted average of area-specific values with bottom areas used as weights. The term "abundance-weighted average" refers to the weighted average of area-specific values with the weights calculated as bottom area times smoothed survey CPUE in total number.

Commercial catch at age/sex

This will be the sum of all the area-specific estimates, including Areas 2A and 4CDE. Variances will also add.

Commercial CPUE

This will be the area-weighted average of area-specific CPUE, with only the fished part of Area 4D (5000 sq nmi) counted, and Areas 2A, 4C, and 4E excluded because of unique features of the fisheries in those areas. A coefficient of variation will be assigned as in the closed-area assessments.

Survey age/sex composition and mean length at age/sex

This will be the abundance-weighted average of the area-specific values from all surveyed areas except 2A and 4D. The survey data from 2A and 4D are too spotty and sparse to allow for the calculation of smoothed area-specific values in the first place. For Area 2A, a dataset comprising 2A plus 2B data will be used; for Area 4D; a dataset comprising 4D plus 4A data. Trawl survey age/length data from Area 4CDE, when adjusted for setline survey selectivity, is very close to Area 4A data (Fig. 8), so that can be used for Area 4CDE.

Survey CPUE

This will be the area-weighted average of area-specific values, with ad hoc adjustments for missing data in Areas 2A, 4A, and 4D. For Area 4CDE, the swept-area estimate of biomass from the trawl survey can provide an index of setline survey CPUE that can be scaled by the ratio of the 2006 trawl and setline survey results. The ad hoc adjustments made to supply missing data are:

(i) In Area 2A, where no survey was done in 1996, 1998, and 2000, the missing values will be simply interpolated.

(ii) In Area 4A, where only the southern part was surveyed in 1999, the 1999 value was multiplied by 0.76 on the basis of a regression of the all-area CPUE on southern-area CPUE in years when the whole area was surveyed (Fig. 9a).

(iii) In Area 4D, where no survey was done in 1998 and 1999, the Area 4A values were used on the basis of a similar regression of Area 4D on Area 4A values that had a slope of 0.99 (Fig. 9b).

Sport and subsistence catch

The coastwide total poundage will be handled as in the closed-area assessments, by estimating a fishing mortality rate and applying the survey selectivity schedule.

Bycatch

The coastwide total poundage will be handled as in the closed-area assessments, by estimating a fishing mortality rate and applying the average bycatch selectivity schedule, which increases linearly from the origin to one at 40 cm and stays there.

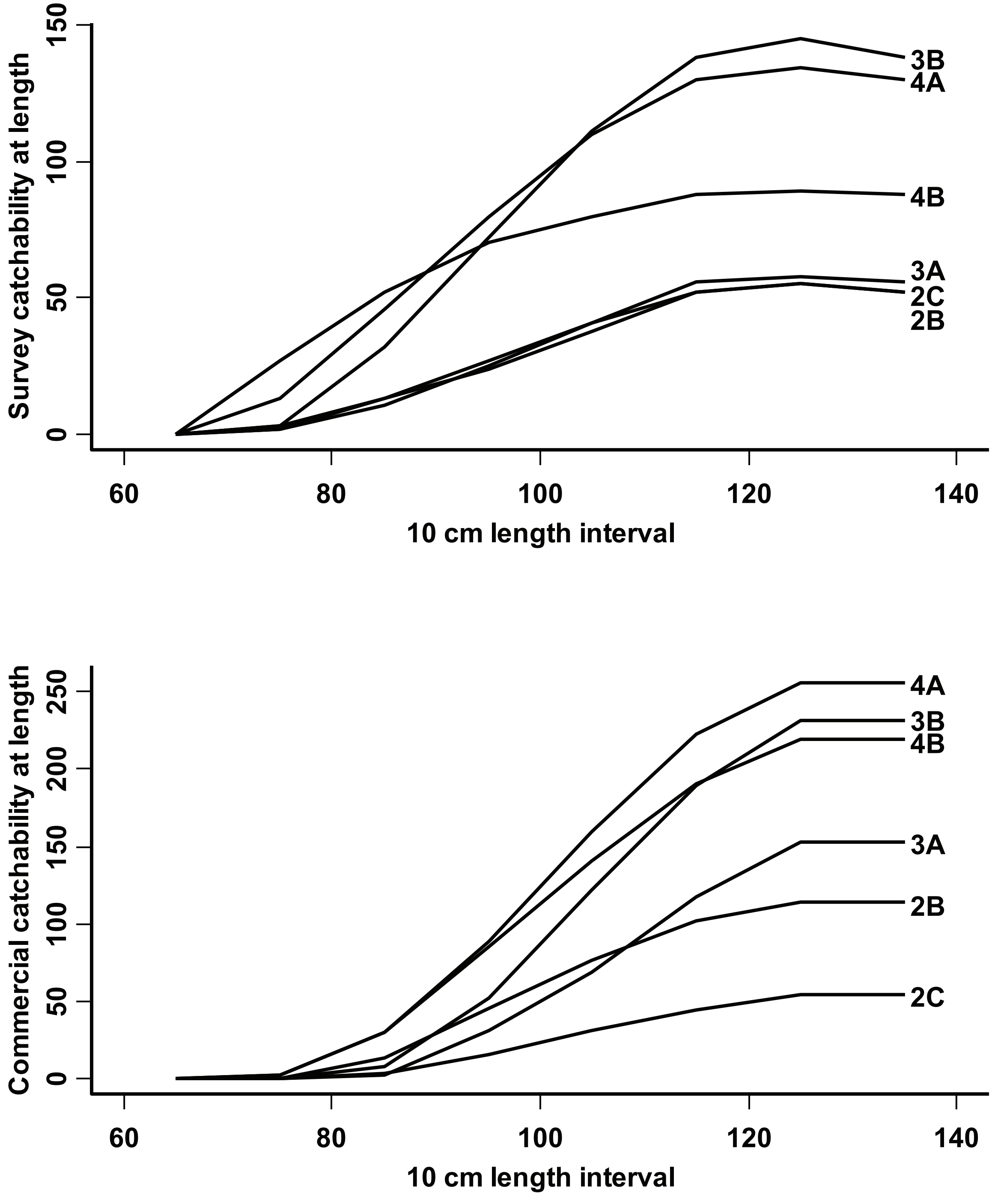

Figure 1. Estimates of survey (above) and commercial (below) catchability at length as estimated in the 2005 closed-area assessments. The values plotted are the assessment estimates multiplied by bottom area so that they all relate to stock density. The vertical scale is not meaningful.

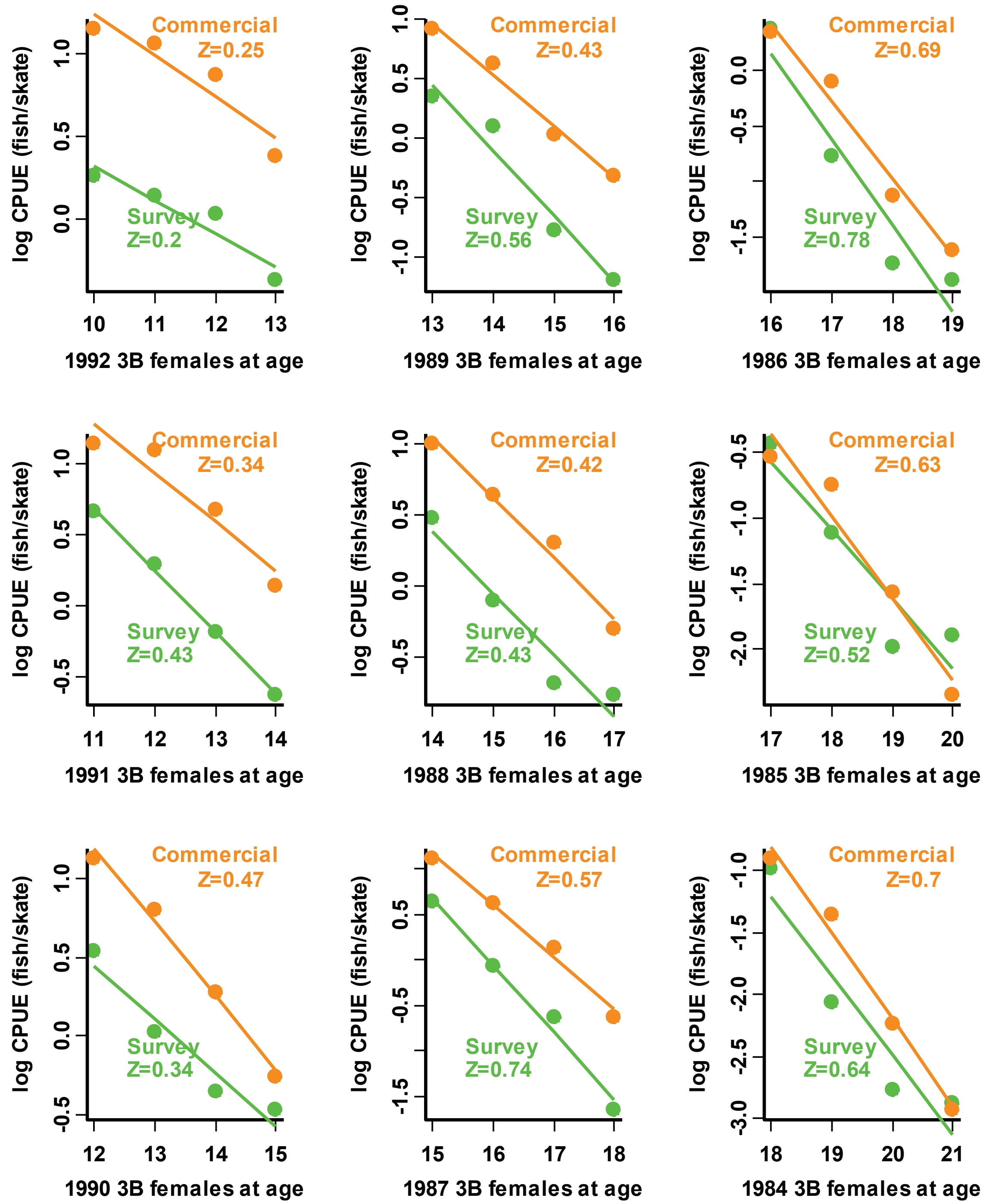

Figure 2. Model-free estimates of total mortality of Area 3B females. All graphs refer to the years 2002-2005.

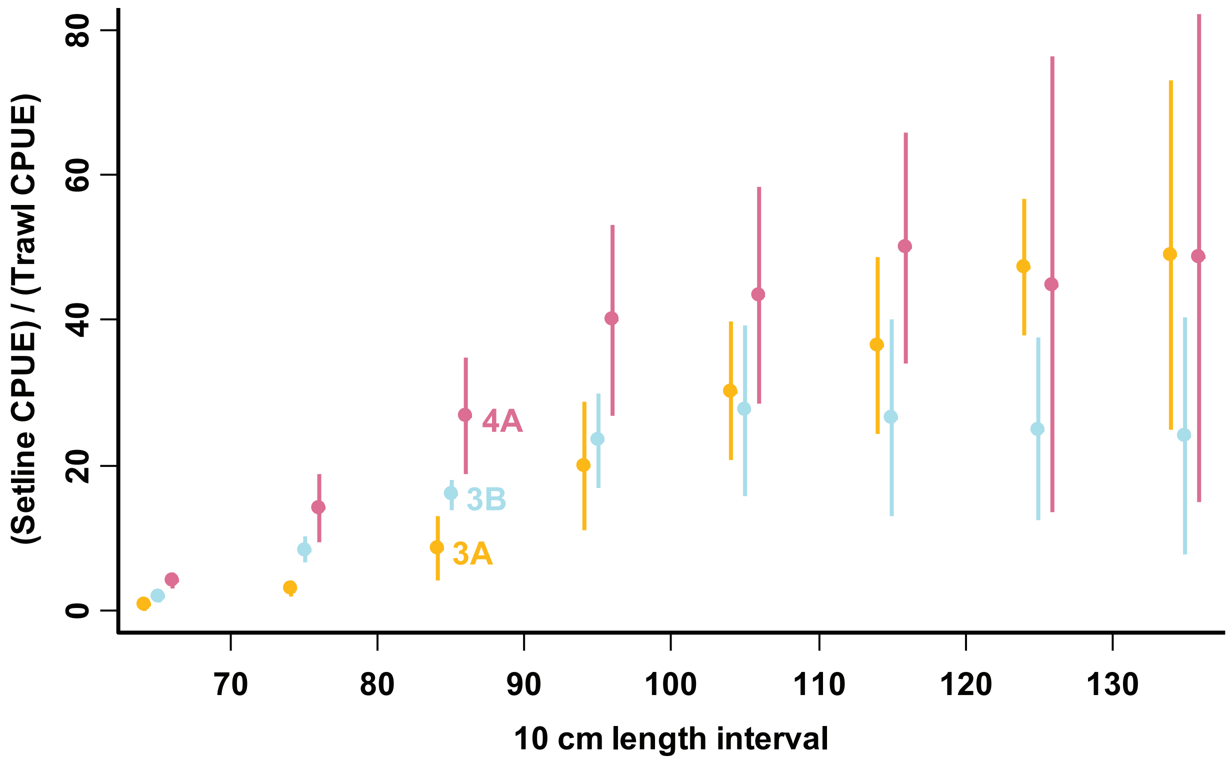

Figure 3. Ratio of setline survey catch rates at length (fish/skate) to trawl survey catch rates at length (fish/ha swept).

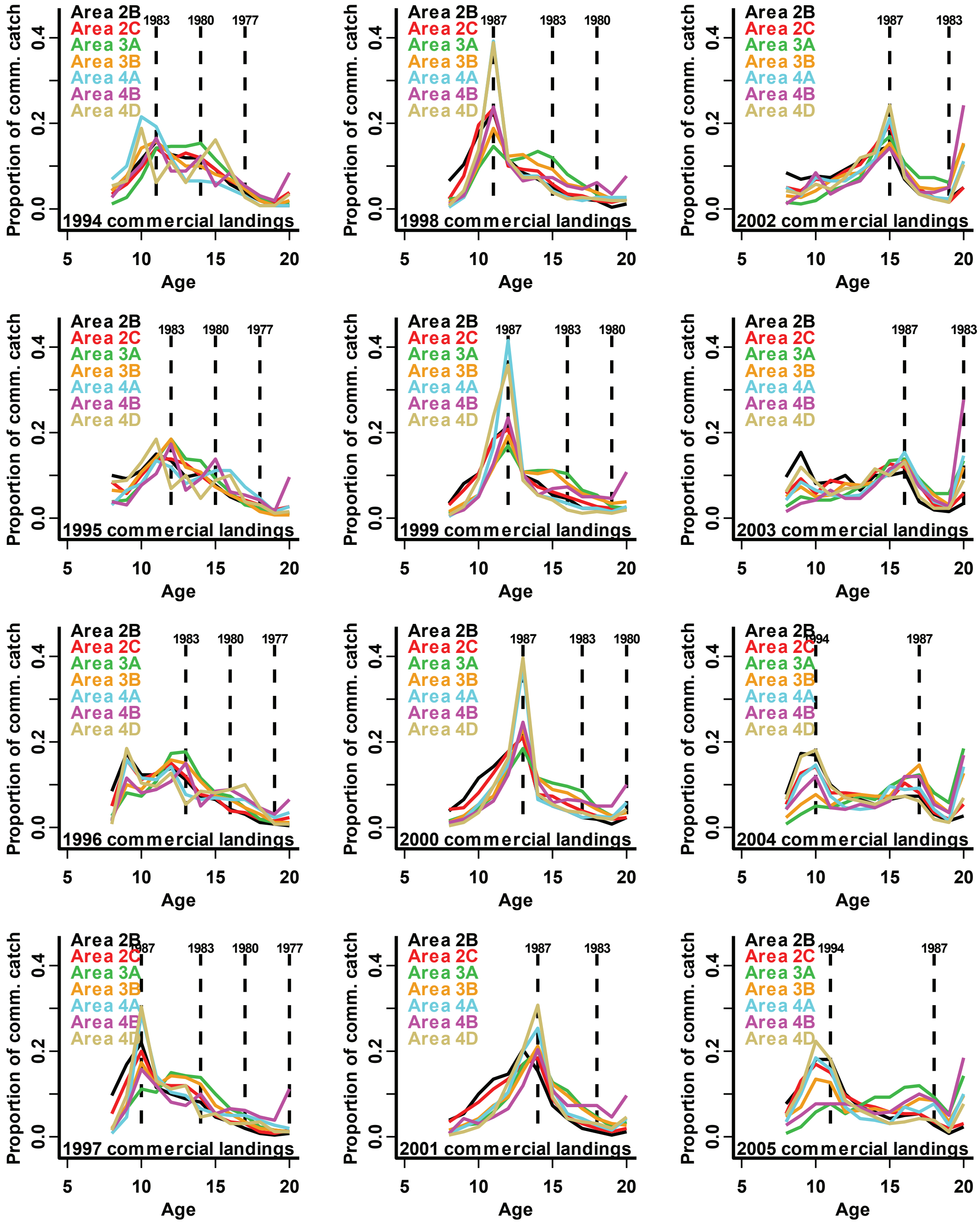

Figure 4a. Commercial age compositions by area, 1994-2005.

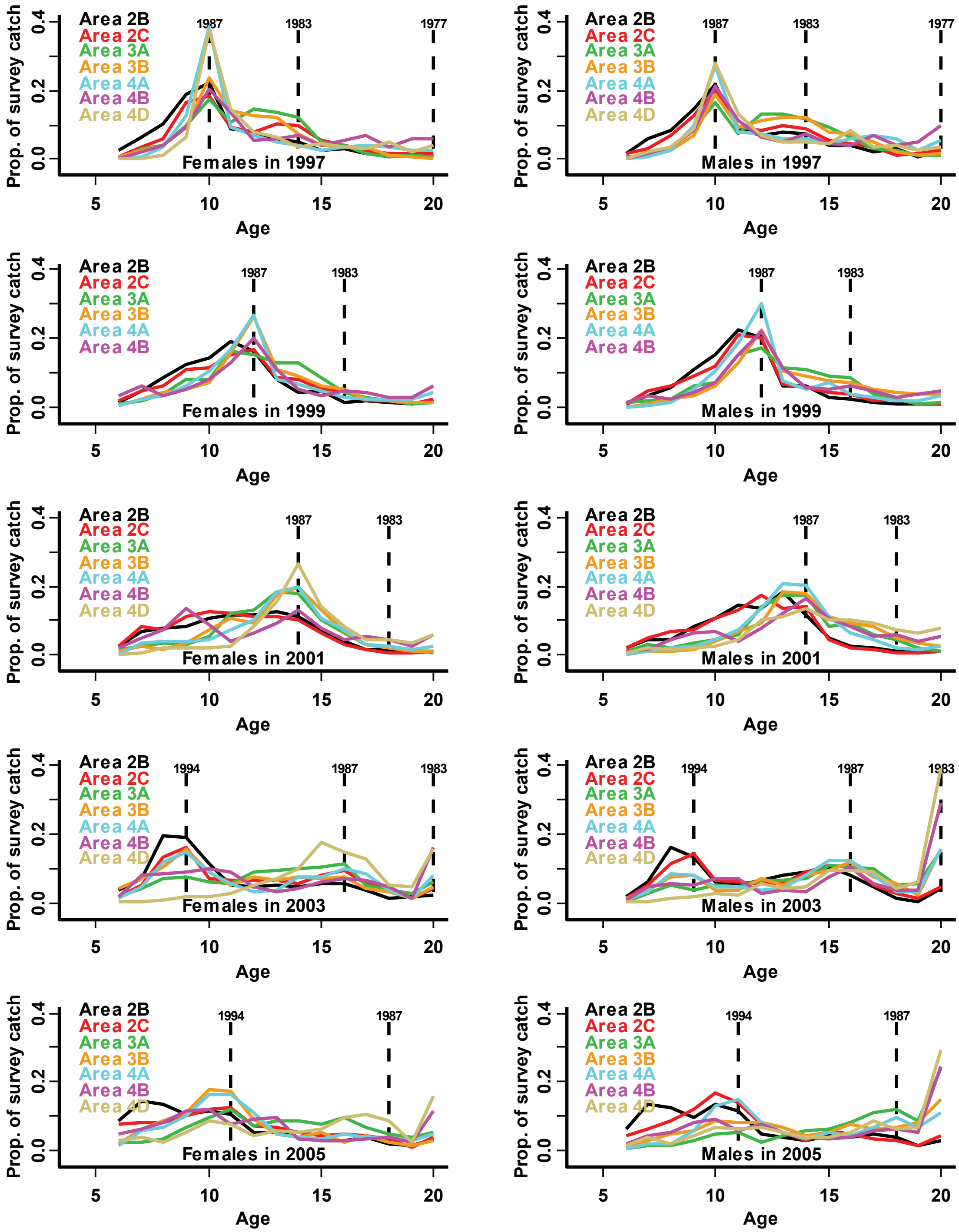

Figure 4b. Survey age compositions by area and sex, 1997-2005.

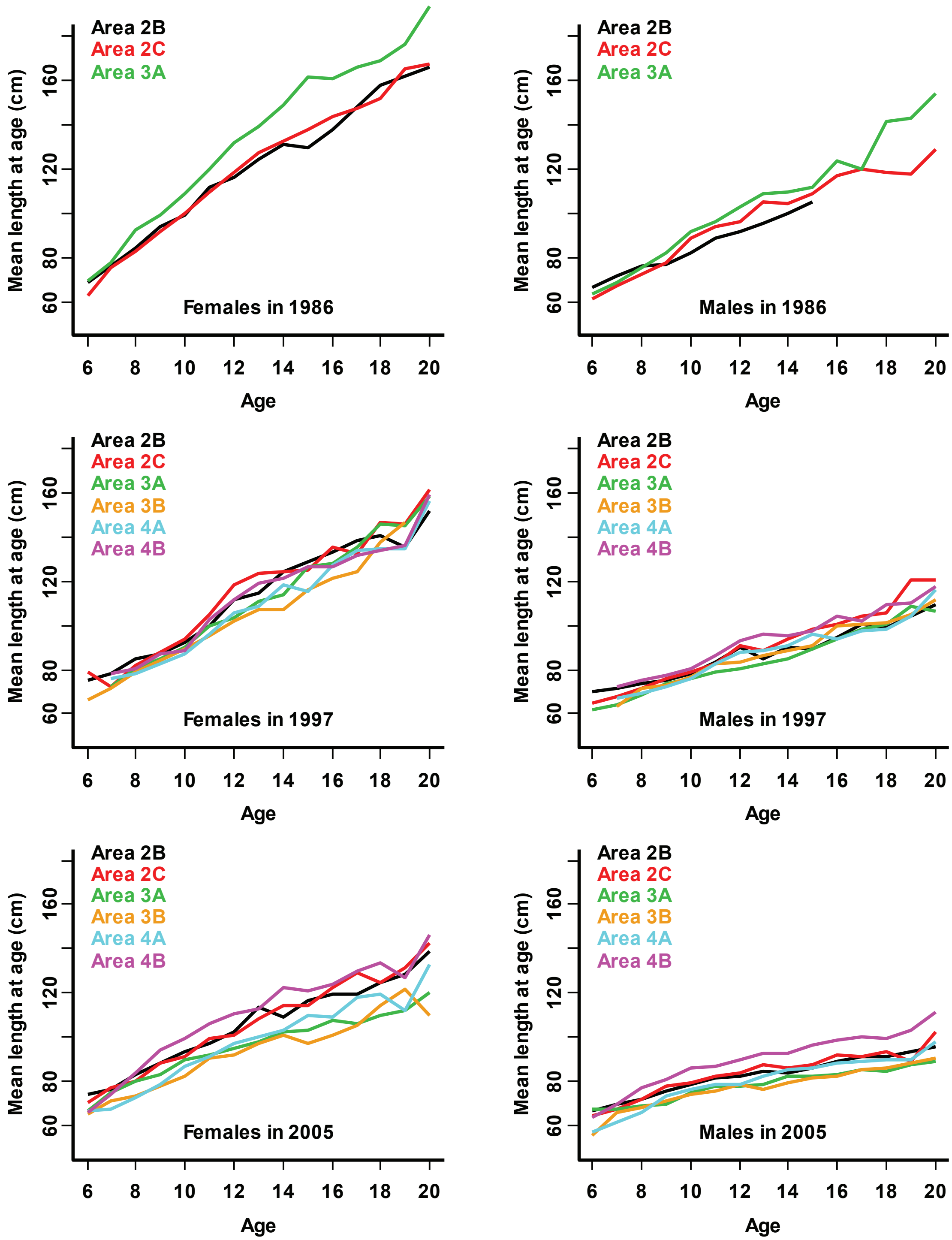

Figure 5. Mean length at age in survey catches, by area, year, and sex.

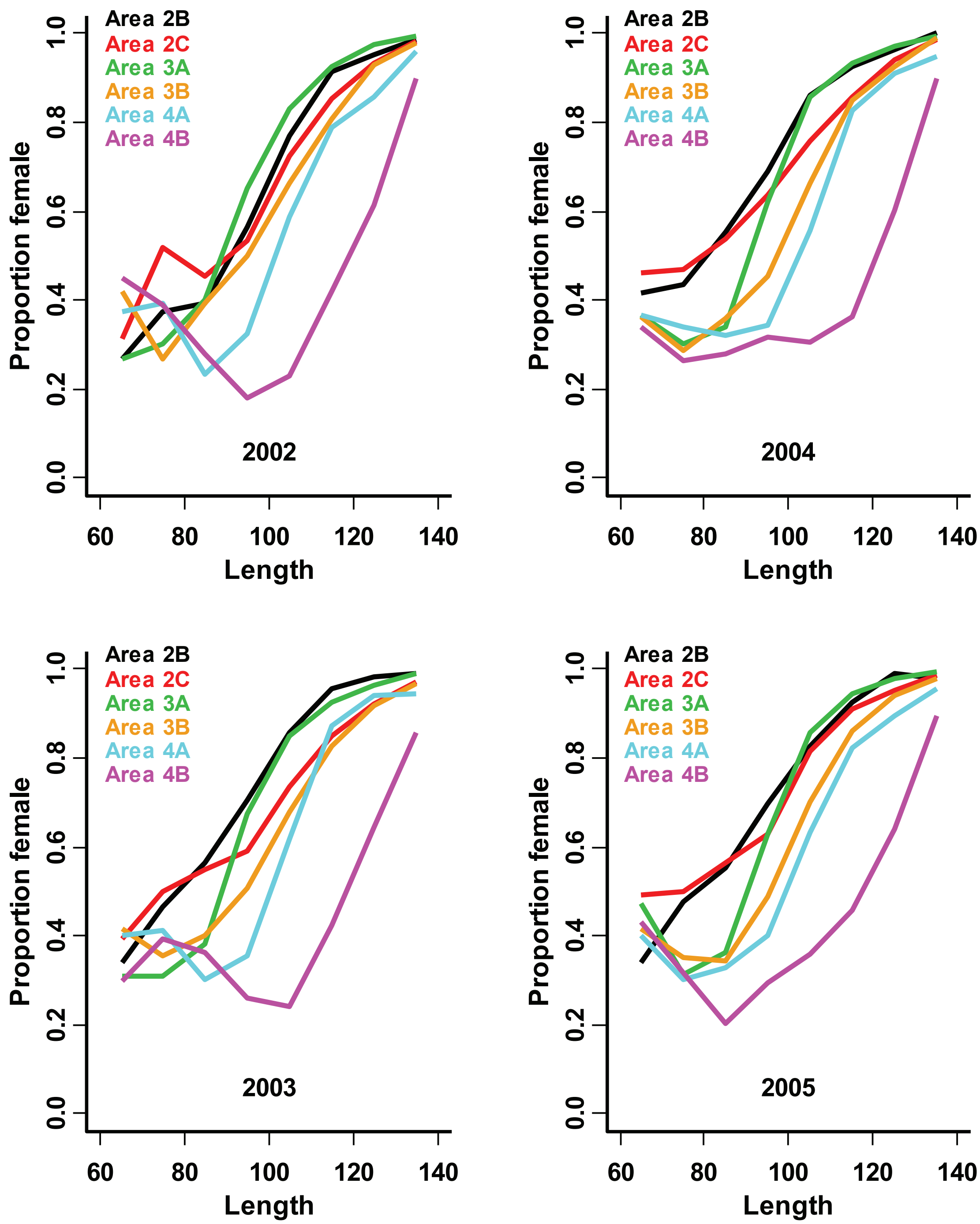

Figure 6. Sex ratio of survey catches, by area and year.

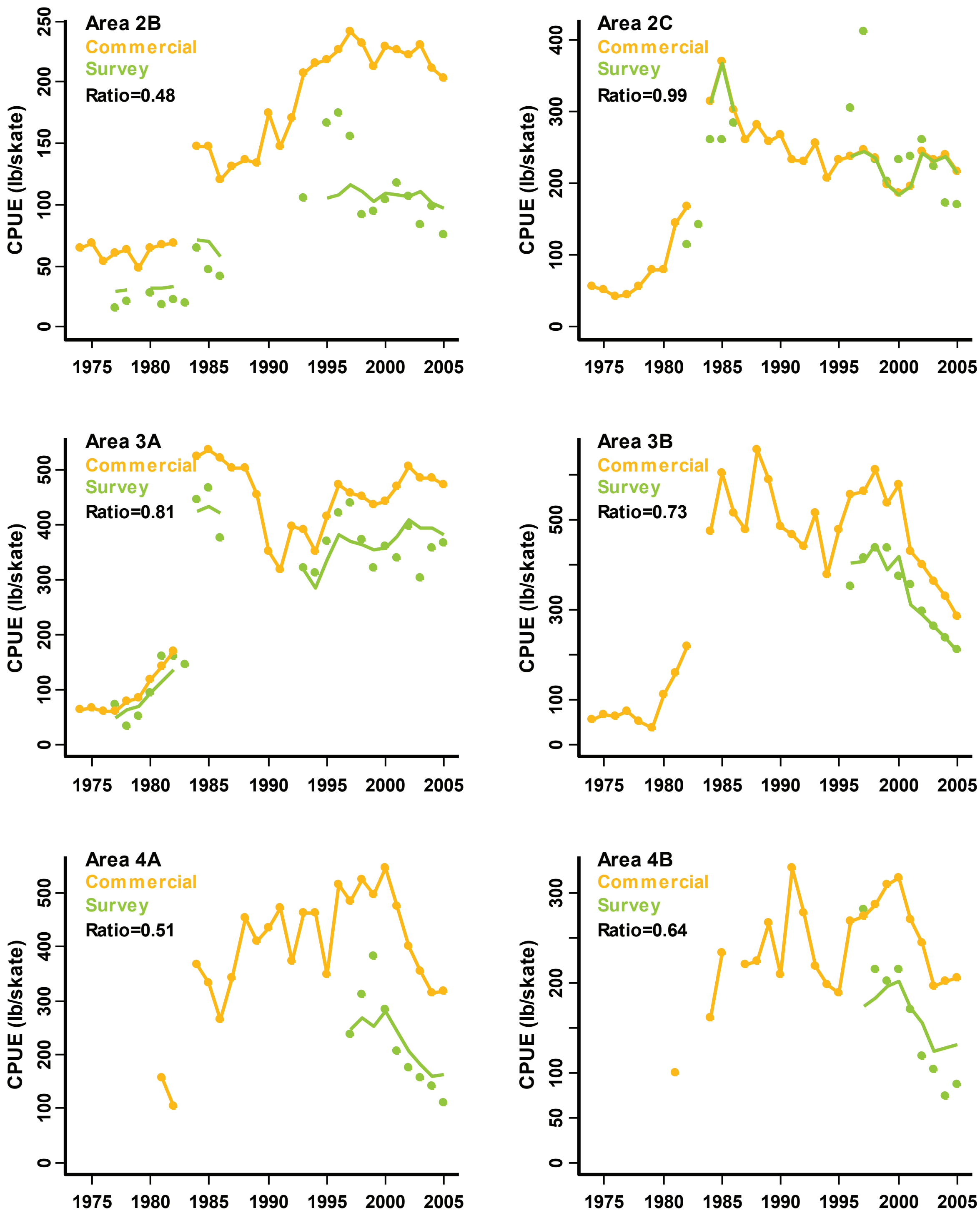

Figure 7. Commercial and survey CPUE by area and year. The green line is the overall ratio of survey to commercial CPUE, muliplied by each year's commercial CPUE.

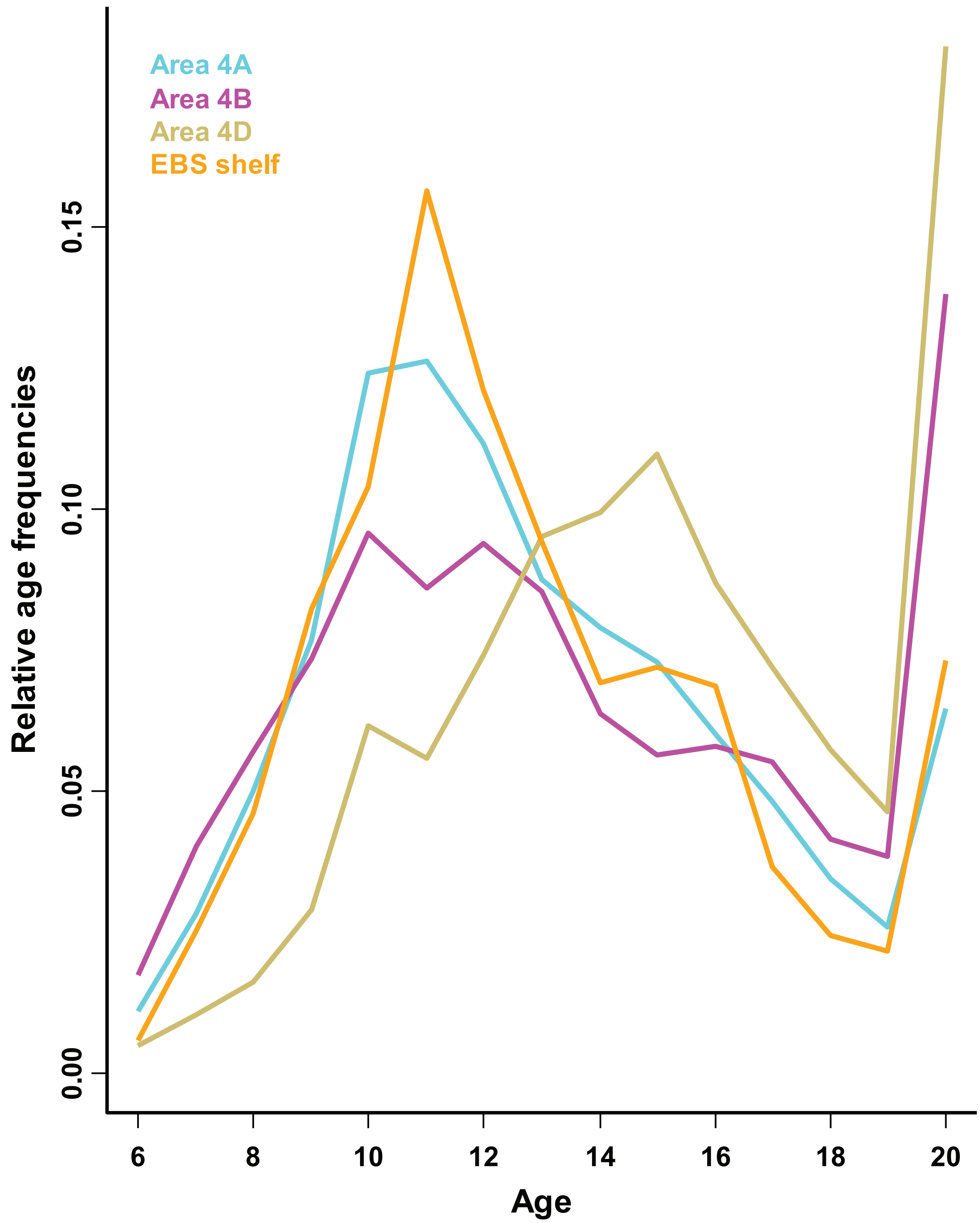

Figure 8. Setline survey age compositions in Areas 4A, 4B, 4D edge, and eastern Bering Sea shelf. The latter is estimated by applying the setline survey selectivity to age/length data from the NMFS trawl survey.

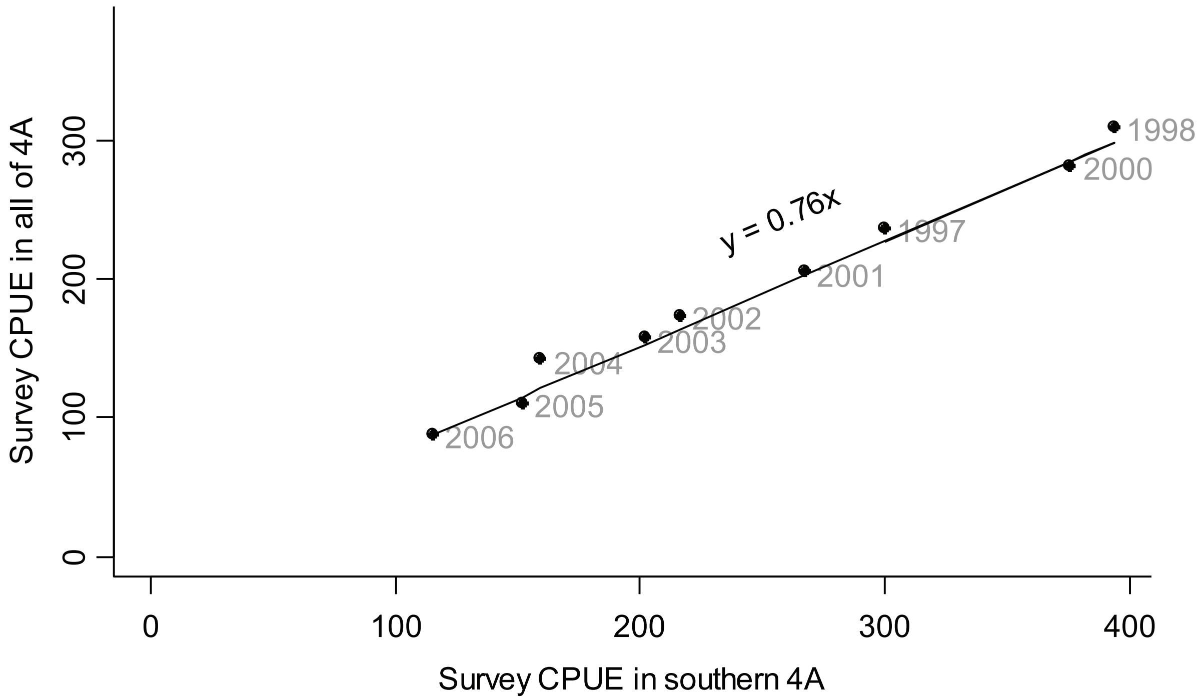

Figure 9a. Survey CPUE in all of Area 4A predicted from CPUE in southern Area 4A.

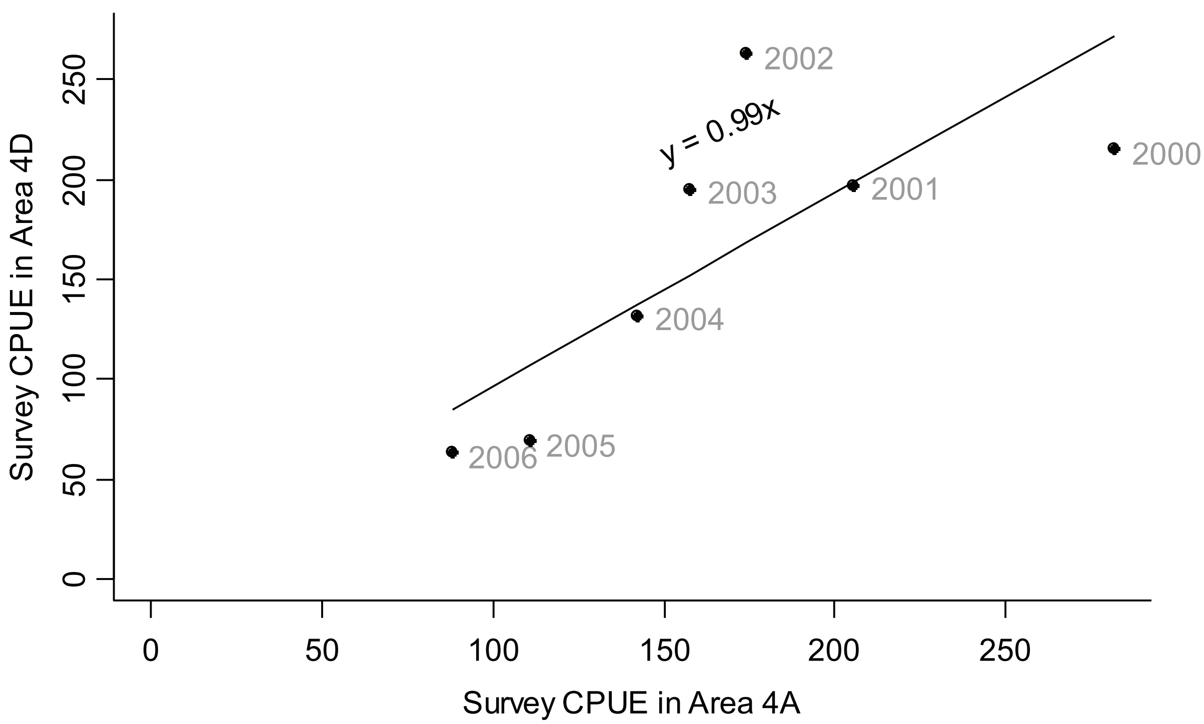

Figure 9b. Survey CPUE in Area 4D predicted from survey CPUE in Area 4A.

Assessment of the Pacific halibut stock at the end of 2006

William G. Clark and Steven R. Hare

Abstract

Growing concerns about net migration from the western to the eastern Gulf of Alaska have led the staff to doubt the accuracy of the closed-area assessments that have been done for many years. A coastwide assessment with survey apportionment was therefore done in addition to the closed-area assessments this year, and was used to calculate the available yield in each area. The two kinds of assessments produced very similar estimates of total abundance (total exploitable biomass about 400 M lb, total available yield about 80 M lb) but the distribution among areas was quite different, with the coastwide assessment showing more biomass and available yield in Areas 3B and 4 than the closed-area assessments and less in Area 2. Area 3A is about the same in both assessments.

Introduction

Each year the International Pacific Halibut Commission (IPHC) staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). A biological target level for total removals from each regulatory area is calculated by applying a fixed harvest rate to the estimate of exploitable biomass in that area. This target level is called the "constant exploitation yield" or CEY for that area in the coming year. The corresponding target level for catches in directed fisheries subject to allocation is called the fishery CEY. It comprises the commercial setline catch in all areas plus the sport catch in 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.

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

In order to obtain an unbiased estimate of the coastwide stock this year, the staff built a coastwide data set and fitted the model to it. The coastwide estimate of exploitable biomass (414 M lb) is close to the sum of the closed-area estimates. To estimate the exploitable biomass in each regulatory area, the staff apportioned the coastwide total according to the setline survey index of exploitable biomass in each area (survey CPUE of legal-sized fish multiplied by bottom area). Comparison of this distribution to the closed-area assessments shows that the closed-area assessments were too high by 50-100% in Area 2, meaning that the actual harvest rates there have been 50-100% above the coastwide target.

The closed-area assessments overestimate present abundance in Area 2 because in effect they include fish that are migrating to Area 2 from areas to westward. It could be fairly argued that these really are Area 2 fish, so apportioning yield on the basis of the closed-area assessments is appropriate. And it would certainly be feasible. According to the present estimates, it would mean taking 25% of the coastwide yield from Area 2, which contains 16% of the coastwide biomass. This would not be a conservation issue for the stock as a whole. The fishery has been prosecuted in that fashion for decades, and it is probably sustainable, although harvest rates in the western areas (the source of the migrating fish) have been higher since 1996 than in previous years.

On the other hand, the general practice and the stated policy of the Commission is to harvest in proportion to actual abundance in each area, which means reducing the exploitation rate in Area 2 to the target level, now 20% (Hare and Clark 2007).

In calculating the CEY (Constant Exploitation Yield) estimates for each area, the staff has taken a middle course, applying a 25% harvest rate in Area 2 instead of the target. This approach moves the exploitation rate closer to the target but at the same time recognizes the stock distribution implied by the eastward migration, and the historical distribution of catches.

Development of a coastwide assessment

In 2006 growing concerns about evidence of migration of legal-sized fish from the western Gulf of Alaska (Areas 3B and 4) to the east (Area 2) led the staff to question the accuracy of the customary closed-area assessments, which assume that the stock in each area is a closed population (Clark and Hare 2007). The effect of migration on the customary closed-area assessments is to produce underestimates of present abundance in the areas from which fish are emigrating (Areas 3B and 4) and overestimates in the areas into which they are immigrating (Area 2). This happens because emigration inflates the closed-area estimates of fishing mortality in the source areas and immigration shrinks them in the receiving area. Moreover, there is no assurance that the sum of the biased estimates from faulty closed-area assessments will be an accurate estimate of the total coastwide abundance, so the staff was concerned about our estimates of total abundance as well as our estimates of abundance in each regulatory area.

In order to obtain accurate estimates of abundance both coastwide and by area, the staff conducted a coastwide assessment and then estimated the proportion in each regulatory area using the survey index of exploitable biomass in each area (survey CPUE of legal-sized fish multiplied by bottom area). The coastwide assessment is not affected by migration because fish on the move contribute to the single series of commercial and survey catch rates wherever they go. The estimate of total abundance can therefore expected to be accurate, and it is also more precise than the area-specific estimates because the coastwide data series are much less noisy than the data from individual areas.

Apportionment of the estimated coastwide biomass among regulatory areas is a difficult problem. Our best estimate of relative abundance in each area is certainly the survey index, but that relies on the assumption that survey catchability is the same in all areas, which is uncertain.

It seems likely that catchability is similar in Areas 2B and 2C, and in Areas 3A and 3B, but what about Areas 2A and 4B? Some checks for differences in survey catchability are reported below.

Data compilation

The first stage of work was to assemble coastwide series of commercial and survey data. Commercial catch-at-age and CPUE data series could be compiled straightforwardly because IPHC has collected specimen and logbook data from all areas for many years. Commercial CPUE data from Areas 2A and 4C were not included in the coastwide series because of unique features of the fisheries in those areas. Like the data series used for the closed-area assessments in Areas 3B and 4, the coastwide data series goes back only to 1996 because survey data are required to estimate the sex composition of commercial landings.

Survey data were more challenging because even in recent years there have been gaps in our survey coverage in Areas 2A, 4A, and 4D, and until 2006 no surveys at all on the eastern Bering Sea shelf, which comprises about half the continental shelf in the Commission area. The gaps in recent survey data in Areas 2A, 4A, and 4D were filled by interpolation in some cases and predictive relationships in others (Clark and Hare 2007). A setline survey was done on the eastern Bering Sea shelf for the first time in 2006 (Dykstra et al. 2007). The 2006 survey CPUE (18 lb/skate) was used to scale an index of exploitable biomass calculated from the swept-area estimates of total abundance at length obtained from the annual NMFS trawl survey of the eastern Bering Sea shelf in 1982-2006.

Bycatch, sport catch, and personal use catches were similarly combined. In the end we had catch data sets including all removals, and properly weighted commercial and survey age composition and CPUE series representing the entire Commission area, including Area 4CDE. The coastwide data set is the same as any of the area-specific data sets; it just refers to the whole coast.

Model-free estimates of mortality and abundance

When a stock assessment model is fitted, total mortality is estimated from the year-to-year decline in the CPUE of individual cohorts, fishing mortality is estimated as the difference between total mortality and natural mortality, and abundance is estimated from the known removals at the estimated rate of fishing mortality. The same estimates can be approximated external to the full assessment model from plots of CPUE at age by cohort in recent years (Fig. 1). The year-to-year change in CPUE has to be adjusted for the year-to-year change in selectivity, which is taken from the full stock assessment, but those selectivity estimates are very well determined, and they hardly affect the estimates of total mortality of fish that are at least 50% selected.

The 1992-1995 year-classes were 11-14 years old in 2006, 90-100 cm long, and about 50% selected. Their average total mortality (Z) in recent years was about 0.25, so with natural mortality M = 0.15, fishing mortality (F) for them was about 0.1, implying a fully selected F of 0.2. Similarly, fishing mortality was about 0.15 for the 1989-1991 year-classes which were 80% selected, again suggesting a fully selected F around 0.2. All of the older year-classes in the plots were fully selected in 2006 and had estimated total mortality of 0.4-0.5, implying a fully selected F of .25-.35. The highest values doubtless reflect some senescent mortality among the oldest fish, so on the whole the plots suggest a fully selected F of 0.2-0.3. With F = 0.25 and M = 0.15, the exploitation rate was about 20%. Coastwide removals by all fisheries in 2006 were about 80 million pounds, so exploitable biomass was roughly 400 million pounds. The commercial fishery accounted for 80% of all removals, so commercial fishing mortality was about 0.2.

Model fits

The model fitted to the coastwide data is the one described by Clark and Hare (2006) that has been used since 2003 for the closed-area assessments. Like other stock assessment models, it estimates initial numbers, subsequent recruitments, fishing mortality, and fishery and survey catchability and selectivity parameters by predicting commercial catch at age, survey age composition, and commercial and survey CPUE. Selectivity is determined by length, and females and males are tracked separately because growth differs by sex. The likelihood that is maximized follows Fournier et al. (1990): all errors are treated as being normally distributed, and the externally estimated sampling variance of each observation is multiplied by a variance scaler to standardize the variances. During the final phase of fitting the deviations are computed with a robust formula that limits the influence of extreme deviations. In the coastwide assessment some 2150 observations are fitted and the sum of squares is similar in size, so the variance scaling is effective overall and the root mean squared errors for all data types are near one. There is some double fitting involved; for example the total catch at age is fitted as well as the catch at age of females and males. The calculated likelihood is scaled down accordingly to obtain accurate variance estimates based on the inverse Hessian and to provide appropriate deviances for calculating the Akaike Information Criterion (AIC) in the model selection table below.

The model can be fitted in various ways, the differences lying in what data types are fitted, how the errors are weighted, and how many parameters are estimated. Seven coastwide fits were done this year, summarized below. (A detailed specification of each fit is given in Table 2.) Fit 0 is the customary closed-area fit. It is parsimonious and heavily reliant on the series of total commercial and survey CPUE data. It does not attempt to fit CPUE at age. All of these features help to stabilize the closed-area fits where in some cases the data are noisy and the abundance estimates are quite sensitive to how the model is fitted. The coastwide data set is very orderly and the abundance estimates are not very sensitive to how the model is fitted, so other alternatives can be considered.

Fit 1 removes the heavy weight on total CPUE and adds CPUE at age to the fit. Fits 1-6 all calculate the same sum of squares but it is different from the one calculated by Fit 0, so no AIC value is shown for Fit 0. Fit 2 estimates separate selectivity, catchability, and natural mortality parameters for females and males; it is a major improvement on Fit 1.

Fit 3 is an attempt to allow for the variations in survey catchability that have taken place during the last ten years. These variations can be estimated by running the assessment model as a Virtual Population Analysis (VPA). This is done by fixing the value of F in 2006 and then freely estimating the catchabilities in each year. The true value of F in 2006 is unknown, but it is clear from the model-free estimates above and all the model fits that it must be near 0.2. The plotted values (Fig. 2) show that survey catchability is quite variable and that it was relatively high in 1997 and low in 2006. (There is no coastwide survey value for 1996.) This happenstance produces a spurious trend in the data. To avoid that, three survey catchability parameters are estimated in Fit 3: one for 1997, one for 1998-2005, and one for 2006. It is a slight improvement on Fit 2 but the AIC is almost the same.

Fit 4 mimics the assessments done for most Alaska stocks by the National Marine Fisheries Service: the commercial catch at age is fitted with a separable model, but commercial CPUE is not used, so the trends in estimated abundance are determined by survey CPUE. This results in a worthwhile reduction in the AIC. Despite this, we prefer to continue to use commercial CPUE in the assessment with commercial catchability allowed to drift subject to a penalty. VPA runs show that commercial catchability, while not constant, is much less variable than survey catchability (Fig. 3), and we believe this can improve the year-to-year continuity of the assessment.

Fit 5 is the opposite of Fit 4; it holds commercial catchability constant and so gives equal weight to commercial and survey CPUE in estimating trends in abundance. We do not believe that commercial catchability can be expected to remain constant for any extended period of time, but for the number of years in this assessment it might be a reasonable working assumption. The AIC is similar to Fits 2 and 3.

Fit 6 harks back to CAGEAN, the model that was used by IPHC from the mid-1980s to the mid-1990s, except that survey as well as commercial data are used and selectivity is determined by length rather than age. It is a substantially worse fit than the others.

Our choice for a reference assessment is Fit 3. It has the lowest AIC except for Fit 4, it is not affected by some of the recent ups and downs in survey catchability, and the biomass estimate is near the middle of the range of plausible fits.

Description of fit	**Number of parameters**	**AIC**	**Commercial F in 2006**	**Biomass in 2007**
0. The customary closed-area fit: same parameters for females and males, constant survey catchability, penalized drift in commercial catchability, heavy weight (10) on total commercial and survey CPUE; CPUE at age not fitted.	104	NA	0.22	377
1. Same as Fit 0 except: neutral error weighting, and fit to commercial and survey CPUE at age added to likelihood.	104	1318	0.24	345
2. Same as Fit 1 except: separate parameters estimated for females and males.	119	1142	0.22	378
3. Same as Fit 2 except: three survey catchabilities estimated: 1997, 1998-2005, and 2006.	121	1138	0.21	414
4. Same as Fit 3 except: commercial catchability estimated freely each year.	129	1128	0.20	425
5. Same as Fit 3 except: constant commercial catchability.	119	1141	0.18	469
6. Same as Fit 3 except: constant commercial and survey catchability (CAGEAN).	117	1160	0.19	445

Quality of fits

For the most part the fitted model predicts the observations quite well, even down to the sex-specific CPUE at age (Figs. 4 and 5). As in the area-specific fits, the model negotiates the change from surface ages to break-and-burn ages in 2002 smoothly, and the fit to the data in years since then is generally better than in earlier years when the surface age compositions are predicted by a misclassification matrix that smears the older ages widely. The total commercial and survey CPUE values are perforce also fitted well (Fig. 6).

Variance estimates

The coefficient of variation of the 2007 exploitable biomass estimate, calculated from the inverse Hessian, is about 7%, which is half the value found in closed-area assessments (Clark and Hare 2006). A normal approximation of the marginal distribution of the estimate is quite close to the calculated likelihood profile (Fig. 7). The spread of the distribution is similar to the spread of point estimates among plausible model fits.

Area apportionment

The estimated coastwide exploitable biomass in 2007 is 414 M lb. To estimate the biomass in each regulatory area, we used a survey index of biomass calculated as the average of the last three years' survey CPUE of legal-sized fish multiplied by the bottom area lying between zero and 300 fathoms in each regulatory area. The proportions and biomass estimates are shown in Table 1 in the section relating to the 2006 coastwide assessment.

Selectivity, target harvest rate, and CEY

In the coastwide assessment, exploitable biomass is calculated with the commercial length-specific selectivity schedule estimated in the assessment, and we have adopted that schedule as our standard commercial selectivity for use in the fishery simulations and calculations of spawning biomass per recruit that are done to choose a target harvest rate. The old standard was an average of Alaska commercial selectivities estimated in the closed-area assessments. The new coastwide schedule is a little higher, so a new harvest rate analysis produced a reduction in the target harvest rate, from 0.225 to 0.20 (Hare and Clark 2007).

The new coastwide target harvest rate of 0.20 was used to calculate total CEY in Areas 3A, 3B, and 4A. A lower rate was applied in Areas 4B and 4CDE for reasons given by Hare and Clark (2007). A higher rate—25%—was applied in Area 2. As explained below, this rate is at present midway between the coastwide target and the rate that would have to be applied to match the CEY that would be estimated by closed-area assessments in Area 2.

Comparison of the coastwide and closed-area assessments

The staff's biomass and CEY estimates are based mainly on the coastwide assessment with survey apportionment. We have also done the customary closed-area assessments for comparison, meaning we have performed Fit 0 to the data from each area (Fig. 9).

Standardization of commercial selectivities

In order to make the results of the coastwide and closed-area assessments comparable, we have calculated exploitable biomass in all areas with the new standard coastwide commercial selectivity, and we have generally used the new coastwide target harvest rate of 0.20 (0.15 in Areas 4B and 4CDE) to calculate CEY. For most areas this change has little effect, because for any given set of life history parameters, there is a tradeoff between the selectivity schedule used and the target harvest rate chosen, such that the target length-specific harvest rates come out about the same when a new selectivity and a new target harvest rate are adopted. The exception is Area 2B (and implicitly 2A), where exploitable biomass has been calculated in an irregular fashion for the last three years.

In 2003, when the present assessment model was adopted, the staff chose a standard commercial selectivity schedule that was near the middle of the schedules estimated in the closed-area assessments (Fig. 8). In fact it was very close to the average of all the locally estimated Alaska schedules, so it has been called the Alaska fixed schedule. This schedule was used in the harvest rate analysis that produced the old 0.225 target harvest rate, and it was used to calculate exploitable biomass in all areas except Area 2B (and implicitly 2A). It did not matter that it differed from the locally estimated schedules so long as the same schedule was used to do the harvest rate analysis and to calculate exploitable biomass. The locally estimated Area 2B schedule was substantially higher than the Alaska fixed schedule, and using the latter in Area 2B would have reduced the estimated exploitable biomass there by a third. The staff was unwilling to make such a drastic reduction on the strength of a new assessment and so used the locally estimated schedule for Area 2B. The same practice was followed in 2004 and 2005. This practice was irregular because we used the same target harvest rate in Area 2B as elsewhere, so in the case of Area 2B we were using one selectivity schedule for the harvest rate analysis and another for the exploitable biomass calculation. In effect we were overstating the exploitable biomass in Area 2B (and 2A) by using a different yardstick there. Stated another way, we were fishing at a rate about 25% above the target rate appropriate to the higher selectivity.

In this year's closed-area assessments we have used the same commercial selectivity schedule—the coastwide standard—to calculate exploitable biomass in all areas including 2B (and 2A), and we have generally used the new coastwide target harvest rate (0.20). Except in Area 2B (and 2A), this just means applying a lower harvest rate to a higher exploitable biomass, because the coastwide schedule is higher than the old Alaska fixed schedule. But in Area 2B (and 2A) it means applying a lower harvest rate to a substantially lower biomass, because the coastwide schedule is lower than the locally estimated one. It is not as much lower as the old Alaska fixed schedule, but it lowers the calculated biomass by about a fifth (rather than a third).

Area-specific results

Along with the coastwide assessment results apportioned to areas according to the survey biomass index, Table 1 shows the evolution of closed-area results from last year's numbers to this year's. Last year's assessment estimated abundance at the beginning of 2006. This year's assessment re-estimates abundance at the beginning of 2006 in light of the 2006 data and also estimates abundance at the beginning of 2007. The 2007 exploitable biomass estimates are shown as they would have been calculated with the old standard commercial selectivities (local in Area 2B/2A, Alaska fixed elsewhere) and with the new coastwide standard.

In Area 2B, last year's closed-area estimate of biomass at the beginning of 2006 was 61 M lb, but that is revised downward sharply to 48 M lb in this year's closed-area assessment. This year's closed-area assessment estimates biomass at the beginning of 2007 to be 50 M lb as calculated with the old (local) selectivities, but only 39 M lb when calculated with the coastwide selectivity.

Applying the coastwide target harvest rate of 20% to that gives a total CEY of 7.8 M lb, less than 60% of last year's 13.73 M lb. The main reasons for the decrease are the downward revision of estimated abundance at the start of 2006 (which also occurs in the 2C and 3B assessments) and the switch from local to coastwide selectivities. The lower harvest rate plays a small part. This year's estimate of exploitable biomass in Area 2B is 9.4% of the sum of closed-area estimates of exploitable biomass in 2007 (416 M lb, virtually the same as the 414 M lb estimated by the coastwide assessment). In contrast, last year's estimate of 61 M lb was 16% of the total. Even if we continued with the closed-area assessments, therefore, the estimated 2007 biomass in Area 2B would be much lower than last year, in both absolute and relative terms.

The survey estimate of the proportion of coastwide biomass in Area 2B is 6.5%, which applied to the coastwide estimate of 414 M lb gives 27 M lb in Area 2B. Given this biomass estimate, we would have to fish at 50% above the target rate to obtain the same CEY that would have been estimated for Area 2B if we had continued the closed-area assessments. The same is true in Areas 2A and 2C. And that is not unthinkable. It now appears that we have been fishing well above target in Area 2 for decades, and the fishery is clearly sustainable so long as total removals from the entire stock are on target. Rather than ignore this longstanding pattern of exploitation, the staff has calculated CEY in Area 2 using a harvest rate of 25% that is intermediate between the coastwide target (20%) and the historical practice (50% above 20% = 30% using this year's numbers). The estimated CEY of 6.75 M lb in Area 2B is therefore 25% of the biomass estimate of 27 M lb from the coastwide assessment.

Area 2A follows much the same course as Area 2B. The closed-area estimate of biomass in Area 2A is 12.5% of Area 2B biomass based on the survey index, and this relative value is naturally the same when abundance in both areas is estimated by distributing the coastwide total according to the survey index.

The closed-area assessment in Area 2C follows a different course. There last year's closed-area estimate of biomass at the beginning of 2006 was 61 M lb, just as in Area 2B, and this estimate was also revised down sharply (to 47 M lb) in this year's closed-area assessment. But the change to coastwide selectivity then raises the Area 2C estimate to 57 M lb, close to last year's, with a CEY of 11.4 M lb. The 57 M lb estimated in Area 2C is 13.7% of the coastwide total, but the survey sees only 8.0% of the total in Area 2C, or 33 M lb, not much more than in Area 2B. At a harvest rate of 25%, this gives a total CEY of 8.25 M lb. Unlike Area 2B, therefore, Area 2C would not be greatly affected by changes in this year's closed-area assessment with coastwide selectivity, but it is greatly affected by the change to a coastwide assessment with survey apportionment.

In Area 3A, despite some ups and downs in the closed-area estimates, the total CEY is about the same in both kinds of assessment. Area 3A is the man in the middle, where exploitation rates have probably been close to the target in recent years.

As would be expected, Area 3B gains substantially from the coastwide assessment. This year's closed area estimate of CEY (10.4 M lb) is not much different from last year's (9.0 M lb), but the survey sees 20.8% of the coastwide biomass in Area 3B, giving a total CEY (at a 20% harvest rate) of 17.2 M lb. The relative increases are similar in Areas 4A and 4B although the absolute amounts are smaller.

Area 4CDE is unlike the other areas in that exploitable biomass there was calculated last year from the NMFS trawl survey estimate of total abundance. Last year's estimate was 36 M lb, which was calculated using a trawl survey catchability of 1.3 (rather than 1.0) to allow for herding. We have since been advised that halibut are probably not herded by the trawl cables, so when we update that estimate this year we get 50 M lb. The setline survey of the eastern Bering Sea shelf in 2006 had a CPUE of 18 lb/skate, which when included in the survey index implies 10.1% share of coastwide biomass, or 41 M lb. Both of these estimates are valid, and either could be used this year. The trawl survey estimate is less variable than this year's setline survey CPUE (which a coefficient of variation of 20% vs 10% for the trawl survey), and there is no assurance that the setline survey will be repeated. In future years, therefore, it is likely that we will revert to using the trawl survey.

Checks for differences among areas in survey catchability

The area apportionments of exploitable biomass in this year's coastwide assessment rely on the survey index of abundance (survey CPUE multiplied by bottom area). Specifically, they assume that survey catchability is the same in all areas, meaning that a skate of survey gear fishing on the same density of fish on the bottom will have the same CPUE in all areas. This is not certain. It was long thought, for example, that survey catchability was lower in Area 2B because of competition with dogfish for the bait. Similarly, strong tides in some areas might be thought to reduce catchability.

In trawlable areas it is possible to check for differences in setline catchability among areas by comparing trawl and setline catch rates of fish of the same size. Figure 10 (reproduced from Clark and Hare 2007) shows the ratio of IPHC setline to NMFS trawl survey catch rates at length in Areas 3A, 3B, and 4A, where the trawl survey can be expected to provide a reliable index of abundance. Unfortunately, this is not the case in other parts of the Gulf of Alaska. At least in Areas 3A, 3B, and 4A, however, there is no indication of any large differences. The data are too noisy to rule out small or even moderate differences.

Another indication of differences among areas in survey catchability would be differences in the relative frequency of PIT tags in catches. The PIT tag release was done by tagging all fish caught on three skates of gear at every survey station in order to mark in proportion to abundance in all areas, so if survey catchability really is the same in all areas PIT tags should be recovered at the same rate (tags recovered per 10,000 fish scanned) in all areas. On the other hand, if survey catchability is low in some area, there should be fewer recoveries per 10,000 fish scanned from that area because a smaller proportion of the stock would have been marked on the survey. Table 3 shows the recovery rates of fish released coastwide in 2003 by year and area (Forsberg 2007 and references therein). In commercial catches there is no difference among Areas 2B, 3A, and 3B, but recovery rates were consistently and significantly higher in Area 2C, and there were some significant differences among ports in Area 3A. The recovery rate in Homer was consistently about half that in Kodiak and Seward.

In 2006 all fish caught on the IPHC setline survey were scanned as well, and there recovery rates were much higher than in commercial landings and consisted overwhelmingly of fish released at the station where they were caught. We thought we had achieved a very even distribution of marked fish by releasing them in proportion to abundance on the 10 nautical mile survey grid, but evidently the probability of catching a tagged fish depends on precisely where a boat fishes. There is probably some difference in the distribution of commercial fishing relative to the location of survey stations that accounts for the higher recovery rates in Area 2C and the lower rates in Homer. Whatever the reason, it reduces confidence in the finding that there is no difference in recovery rates among Areas 2B, 3A, and 3B.

The one clean comparison among areas is the recovery rates observed in the survey (last section of Table 3), which unfortunately were very few in Area 2. For what they are worth, however, they show no significant differences among areas with the exception of a marginally significant lower rate in Area 3B. In particular, like the commercial data they show no evidence of a lower recovery rate, and therefore a lower survey catchability, in Area 2.

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Table 1. Estimates of exploitable biomass and CEY from the 2006 assessment.

	Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4A	Area 4B	Area 4CDE	Total
2006 total CEY	1.71	13.73	13.73	32.18	9.00	3.80	1.35	5.40	80.90
2006 catch limit [1]	1.38	13.22	10.63	25.20	10.86	3.35	1.67	3.55	69.86
2006 exploitable biomass									
2005 area assessments	7.6 [2]	61	61	143	45	19	9	36	382
2006 area assessments	6.0	48	47	163	35	16	11	50	376
2007 exploitable biomass									
2006 area assessments									
—Using old selectivities	6.3	50	48	159	40	15	10	50 [3]	378
—Using new selectivities	4.9	39	57	186	52	17	10	50	416
—Proportion of total	0.012	0.094	0.137	0.447	0.125	0.041	0.024	0.120	1.000
—Total CEY [4]	1.00	7.8	11.4	37.2	10.4	3.4	1.50	7.5	80.2
—Fishery CEY [5]	0.73	7.27	7.61	29.31	9.97	2.83	1.21	5.20	64.13
2006 coastwide assessment with survey apportionment									
—Survey proportion	0.009	0.065	0.080	0.423	0.208	0.069	0.045	0.101	1.000
—Exploitable biomass	3.7	27	33	176	86	29	19	41	414
—Total CEY [4]	0.93	6.75	8.25	35.2	17.2	5.8	2.85	6.15	83.13
—Fishery CEY [5]	0.66	6.22	4.46	27.31	16.77	5.23	2.56	3.85	67.06
Other removals									
Sport catch	0.52	2.26	3.03	6.09	0.01	0.06	---	---	11.97
Legal-sized bycatch	.23	.19	.14	1.32	0.36	0.46	0.28	2.21	5.19
Personal use	0.04	0.30	0.60	0.43	0.05	0.04	0.00	0.09	1.55
Legal-sized wastage	0.00	0.04	0.02	0.05	0.01	0.01	0.01	0.00	0.14
Total	0.79	2.79	3.79	7.89	0.43	0.57	0.29	2.30	18.85
…excluding sport catch	0.27	0.53	---	---	---	---	---	---	---

Notes on Table 1:
1. 2006 catch limit and 2007 fishery CEY include sport catch in Areas 2A and 2B.
2. Area 2A exploitable biomass estimated as 12.5% of Area 2B.
3. Increase in 4CDE results from a reduction of the working value of trawl survey catchability from 1.3 to 1.0.
4. In the area-specific assessments, total CEY is calculated as 20% of exploitable biomass in Areas 2A through 4A, and 15% in Areas 4B and 4CDE. In the coastwide assessment with survey apportionment, total CEY is calculated as 25% of exploitable biomass in Area 2, 20% in Areas 3 and 4A, and 15% in Areas 4B and 4CDE.
5. Fishery CEY is calculated as Total CEY less the other removals detailed below.

Table 2. Specification of the alternative model fits reported above.

	Fit						
Feature	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Fit commercial catch at age	x	x	x	x	x	x	x
Fit total commercial CPUE	x	x	x	x	x	x	x
Fit commercial CPUE at age		x	x	x	x	x	x
Fit survey age composition	x	x	x	x	x	x	x
Fit total survey CPUE	x	x	x	x	x	x	x
Fit survey CPUE at age		x	x	x	x	x	x
Same parameters used for females and males	x	x					
Heavy weight (10) on total commercial and survey CPUE	x						
Penalized drift in commercial catchability	x	x	x	x			
Constant survey catchability	x	x	x				x
Neutral error weighting (all weights = 1)		x	x	x	x	x	x
Estimate separate parameters for females and males			x	x	x	x	x
Estimate 3 survey catchabilities: 1997, 1998-2005, and 2006				x	x	x	
Estimate commercial catchability each year (no drift penalty)					x		
Constant commercial catchability						x	x

Table 3. Relative frequency of PIT tags released in 2003 in subsequent catches.

Type and year	Area of catch	Fish scanned (thousands)	Number of recoveries	Recoveries per 10,000 scanned ± std. dev.
2004 commercial	2B	209	72	3.4±0.4
	2C	125	92	7.4±0.8
	3A	448	128	2.9±0.3
	3B	320	80	2.5±0.3
2005 commercial	2B	196	57	2.9±0.4
	2C	147	86	5.9±0.6
	3A	511	194	3.8±0.3
	3B	276	117	4.2±0.4
2006 commercial	2B	219	73	3.3±0.4
	2C	138	69	5.0±0.6
	3A	511	183	3.6±0.3
	3B	203	67	3.3±0.4
Total commercial	2B	624	202	3.2±0.3
	2C	410	247	6.0±0.4
	3A	1469	505	3.4±0.2
	3B	799	264	3.3±0.2
2006 survey	2B	2.5	10	39±12
	2C	4.0	5	12±5
	3A	23.7	45	19±3
	3B	13.1	13	10±3
	Total	30.2	60	20±3

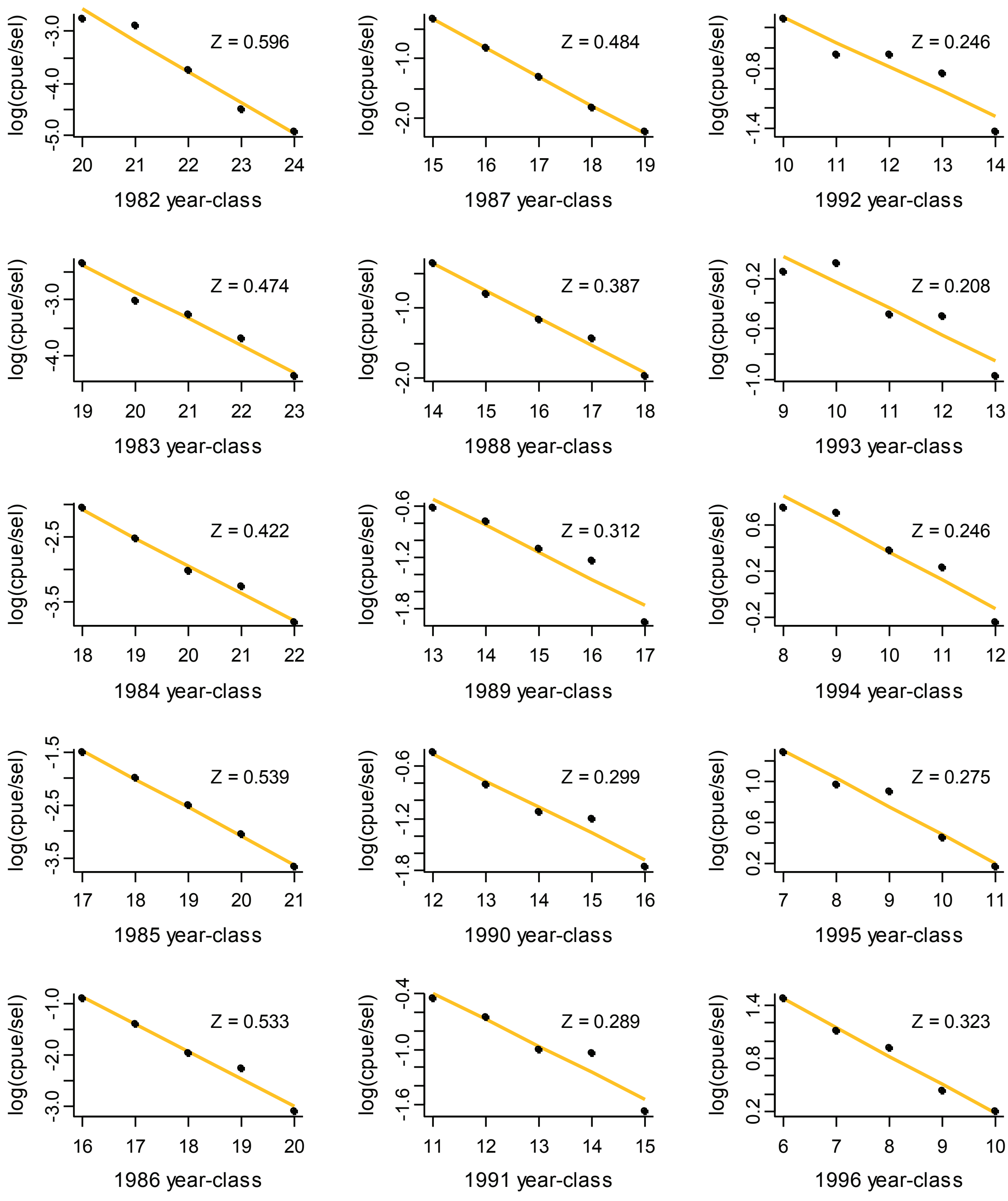

Figure 1. Instantaneous rate of total mortality (Z) estimated from the coastwide decline of survey CPUE of females of each year-class at the ages shown. The points plotted in every graph are from the years 2002-2006, for which break-and-burn ages are available. The value on the y-axis is log(CPUE) corrected for selectivity.

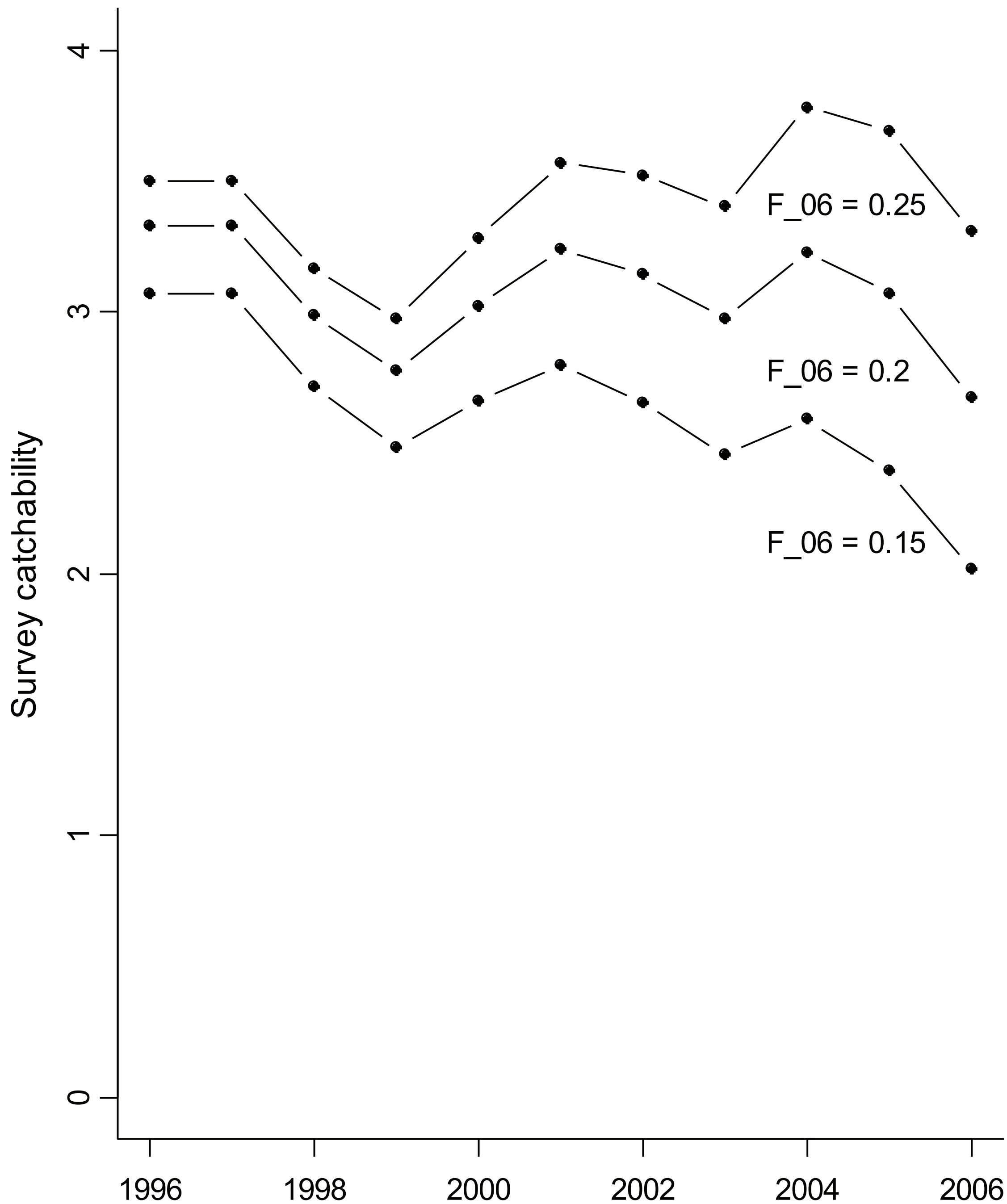

Figure 2. Values of survey catchability calculated in coastwide VPA runs with fishing mortality in 2006 (F_06) fixed at different levels.

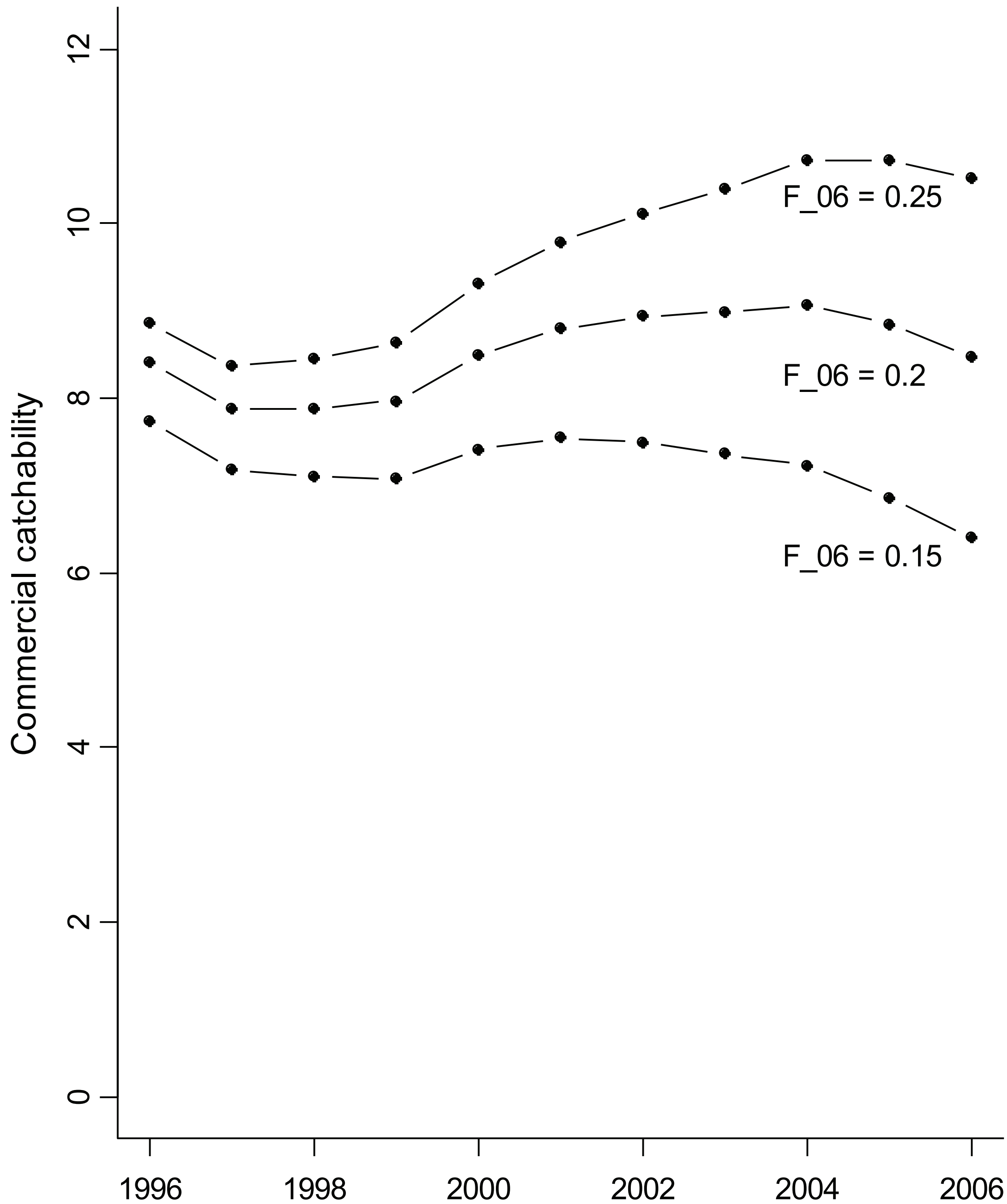

Figure 3. Values of commercial catchability calculated in coastwide VPA runs with fishing mortality in 2006 (F_06) fixed at different levels.

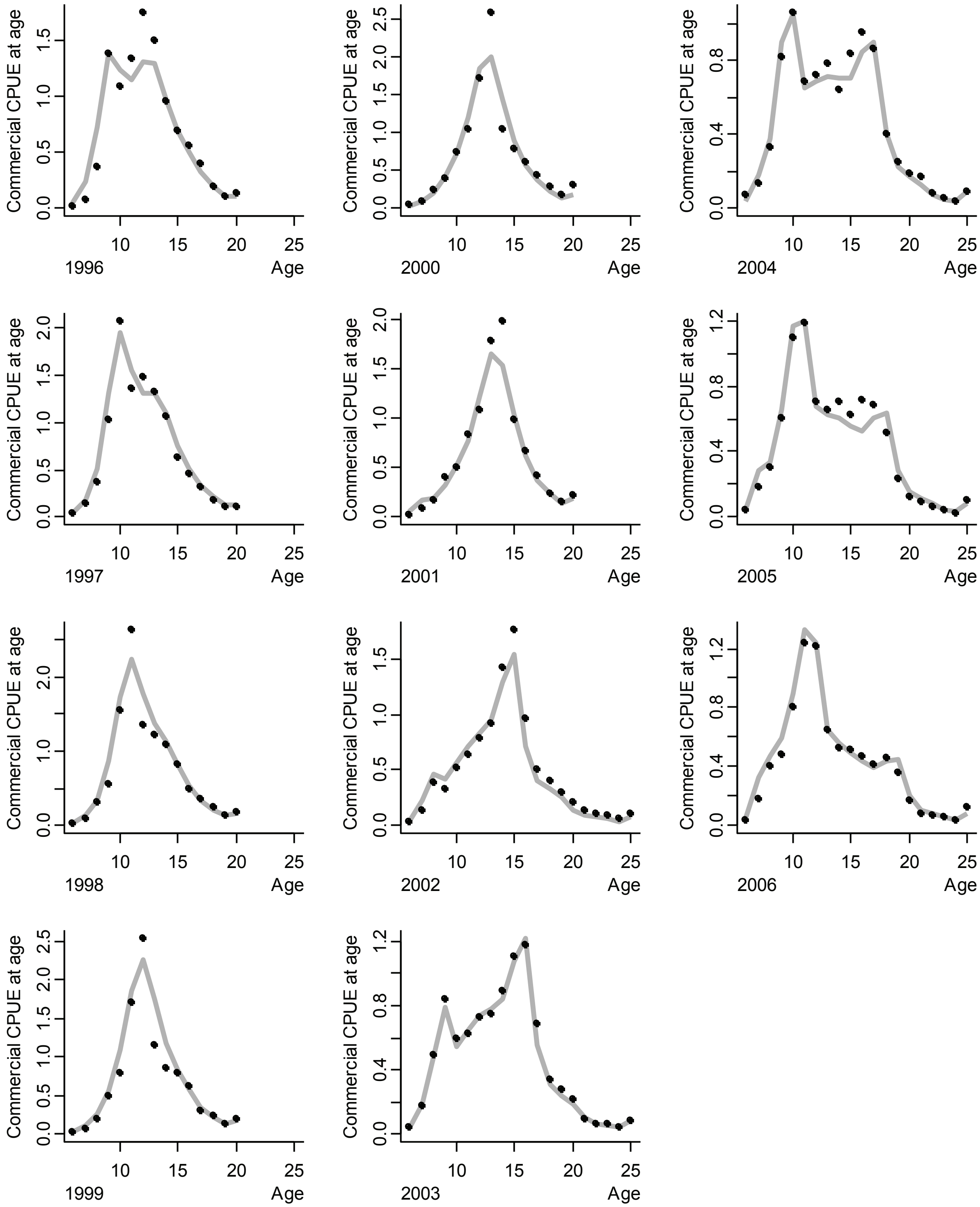

Figure 4a. Observed (points) and predicted (lines) commercial CPUE at age (fish/skate) of females from the coastwide assessment.

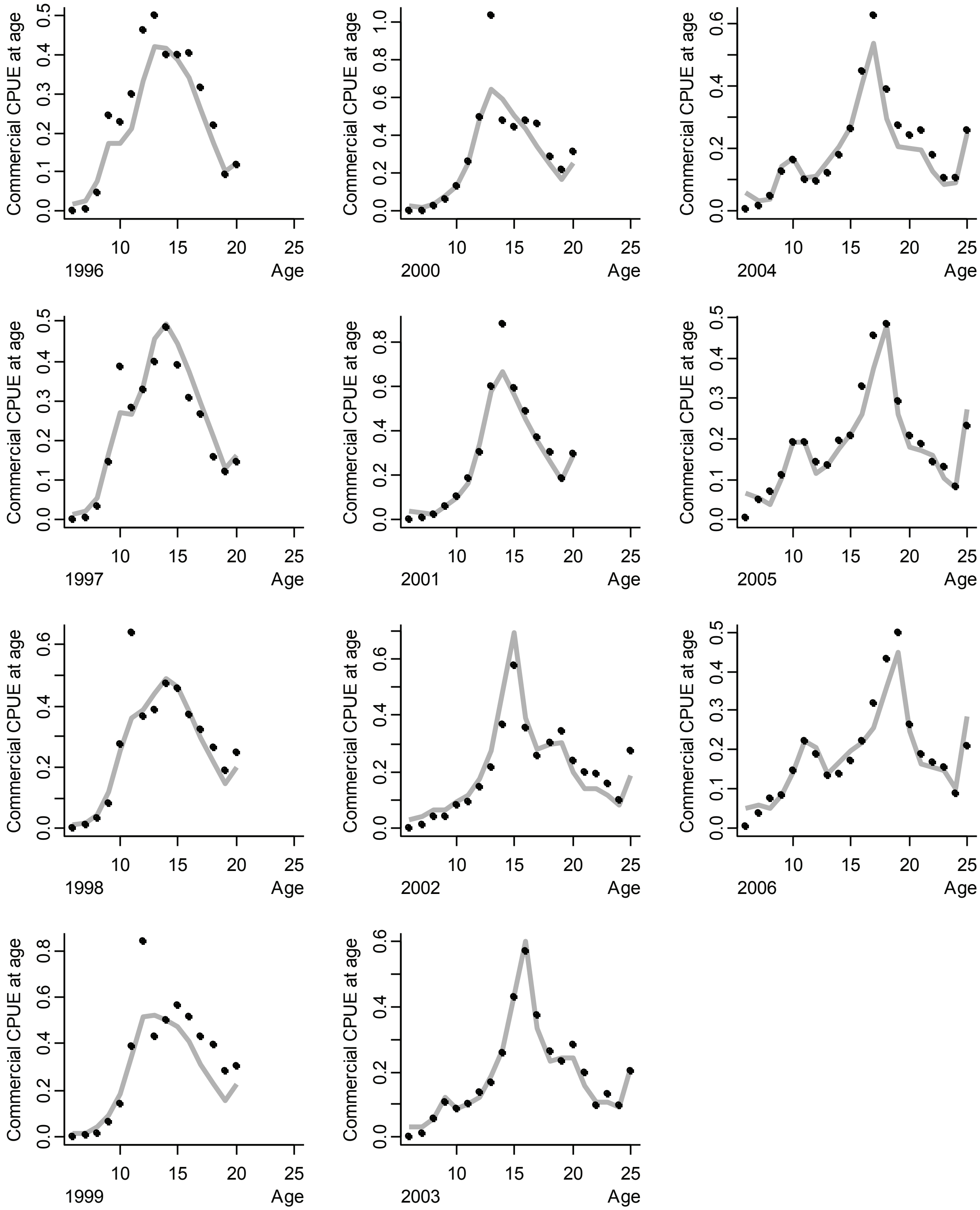

Figure 4b. Observed (points) and predicted (lines) commercial CPUE at age (fish/skate) of males from the coastwide assessment.

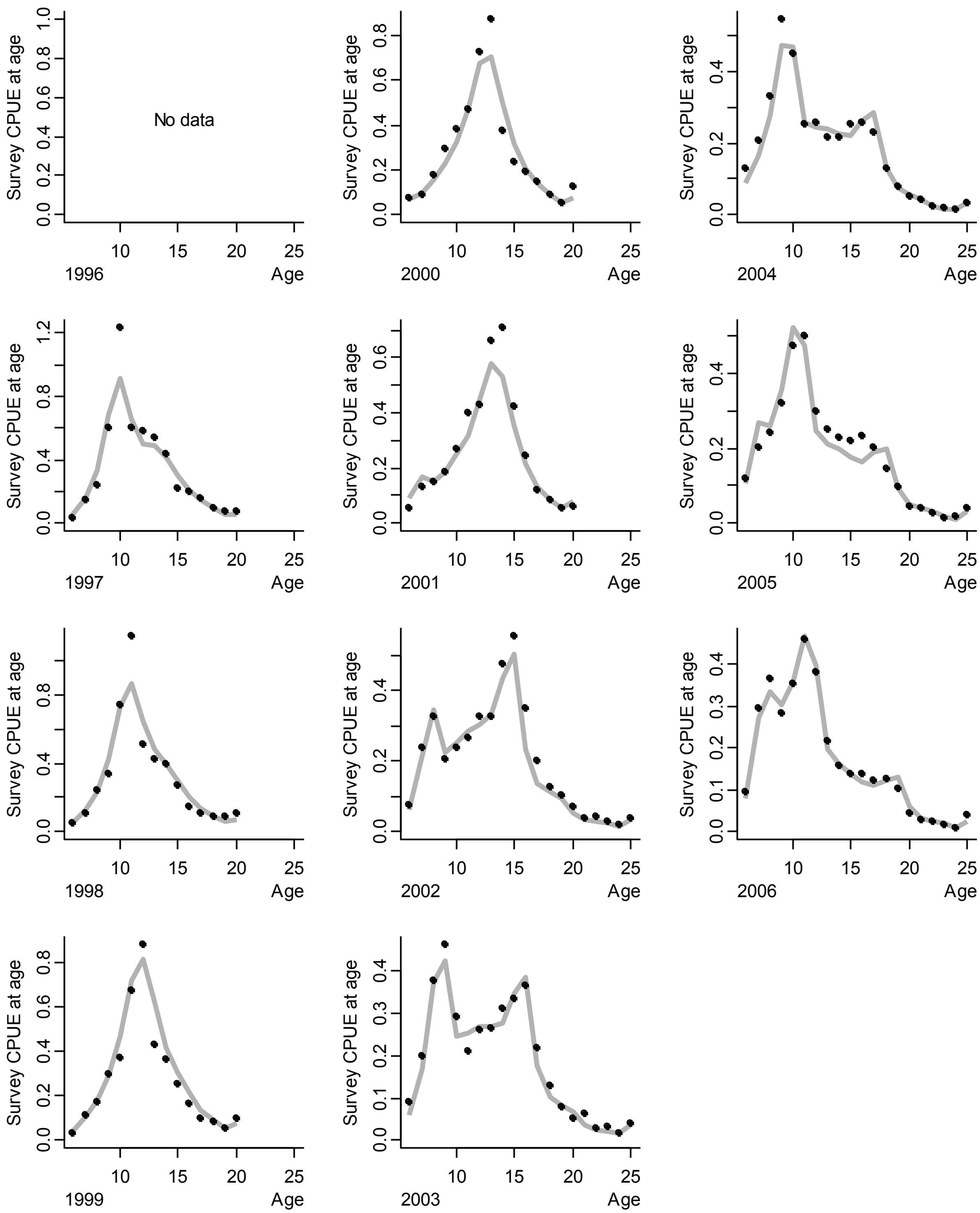

Figure 5a. Observed (points) and predicted (lines) survey CPUE at age (fish/skate) of females from the coastwide assessment.

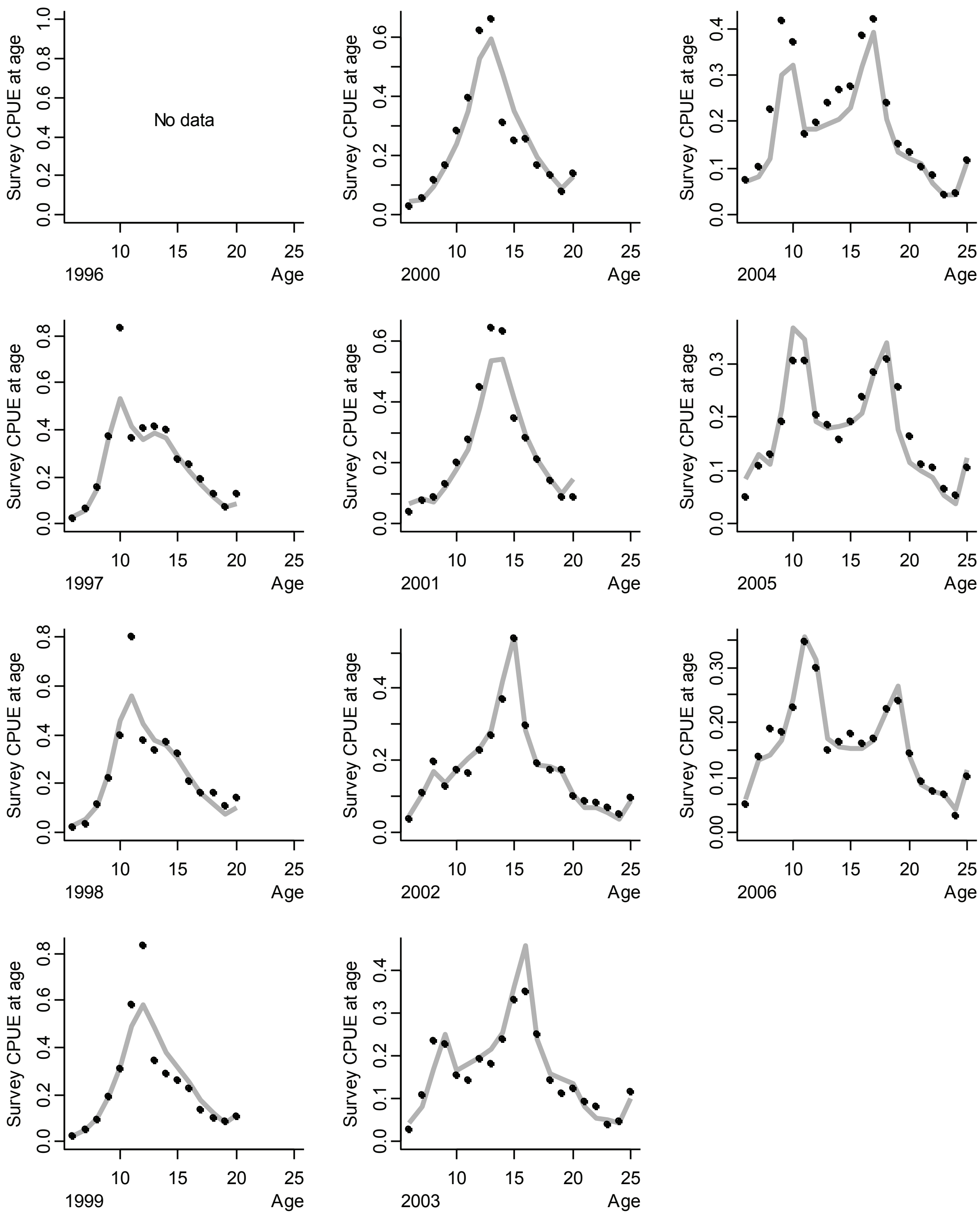

Figure 5b. Observed (points) and predicted (lines) survey CPUE at age (fish/skate) of males from the coastwide assessment.

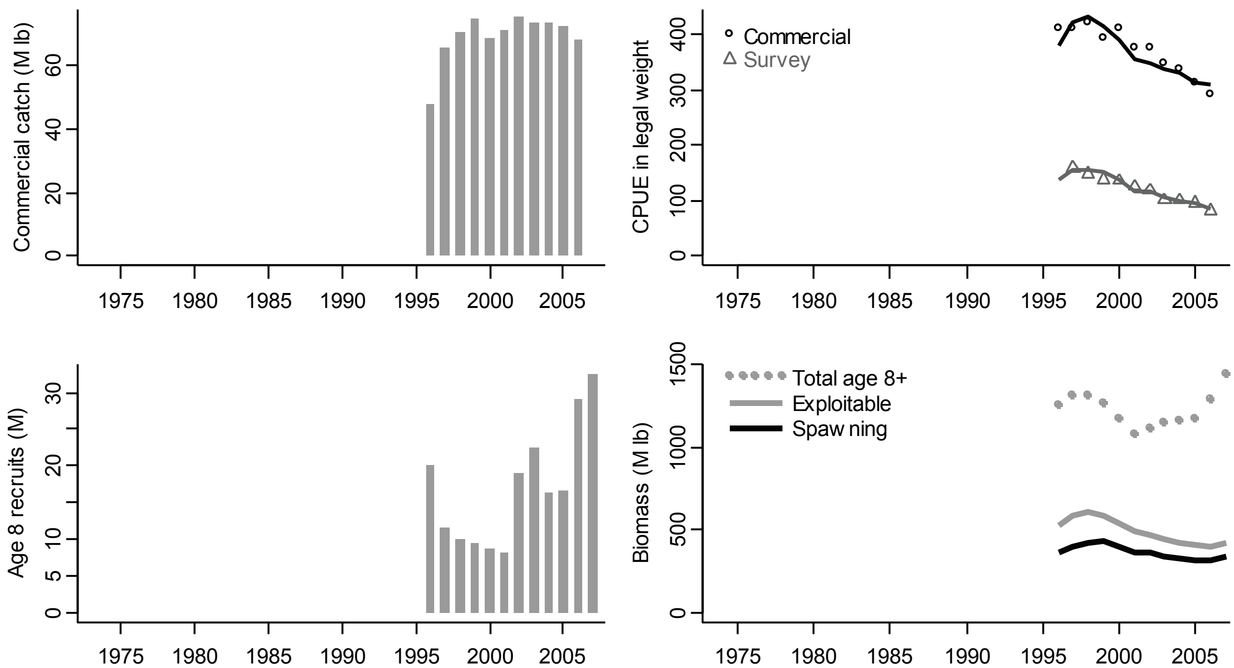

Figure 6. Features of the 2006 coastwide assessment. In the upper right panel, the points are observed CPUE (lb/skate) and the lines are model predictions.

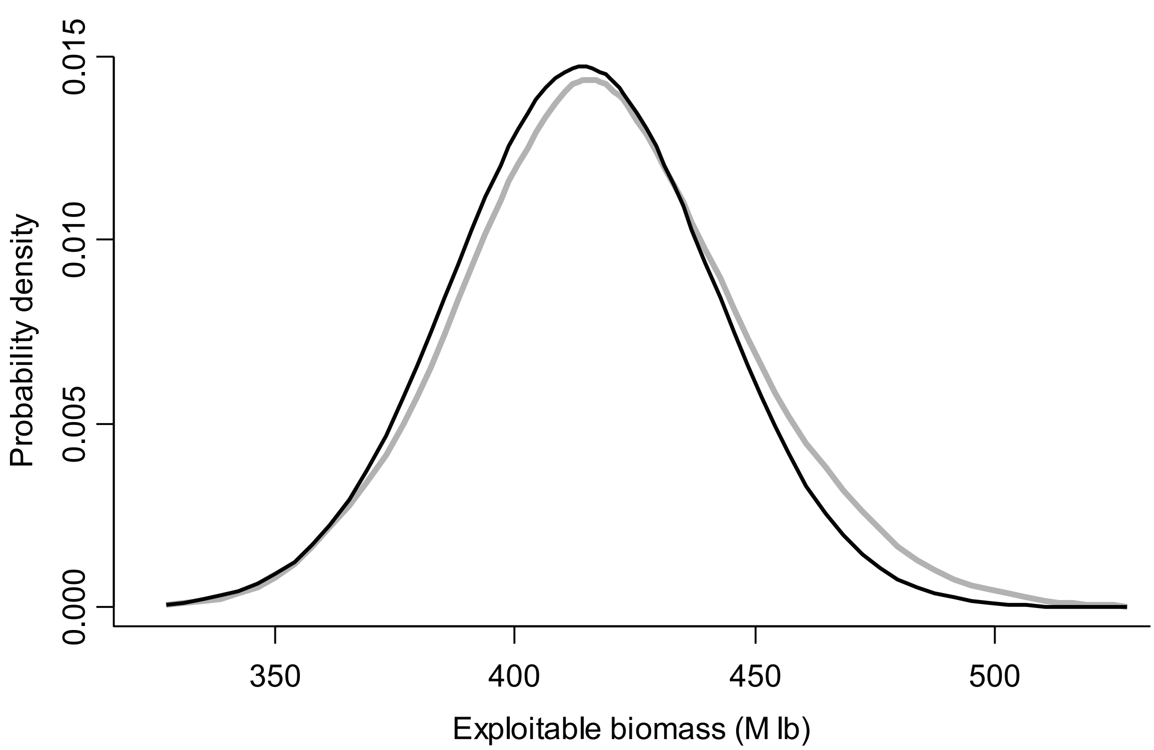

Figure 7. Normal approximation of the marginal distribution of the estimate of 2007 coastwide exploitable biomass (black line) and likelihood profile (gray line).

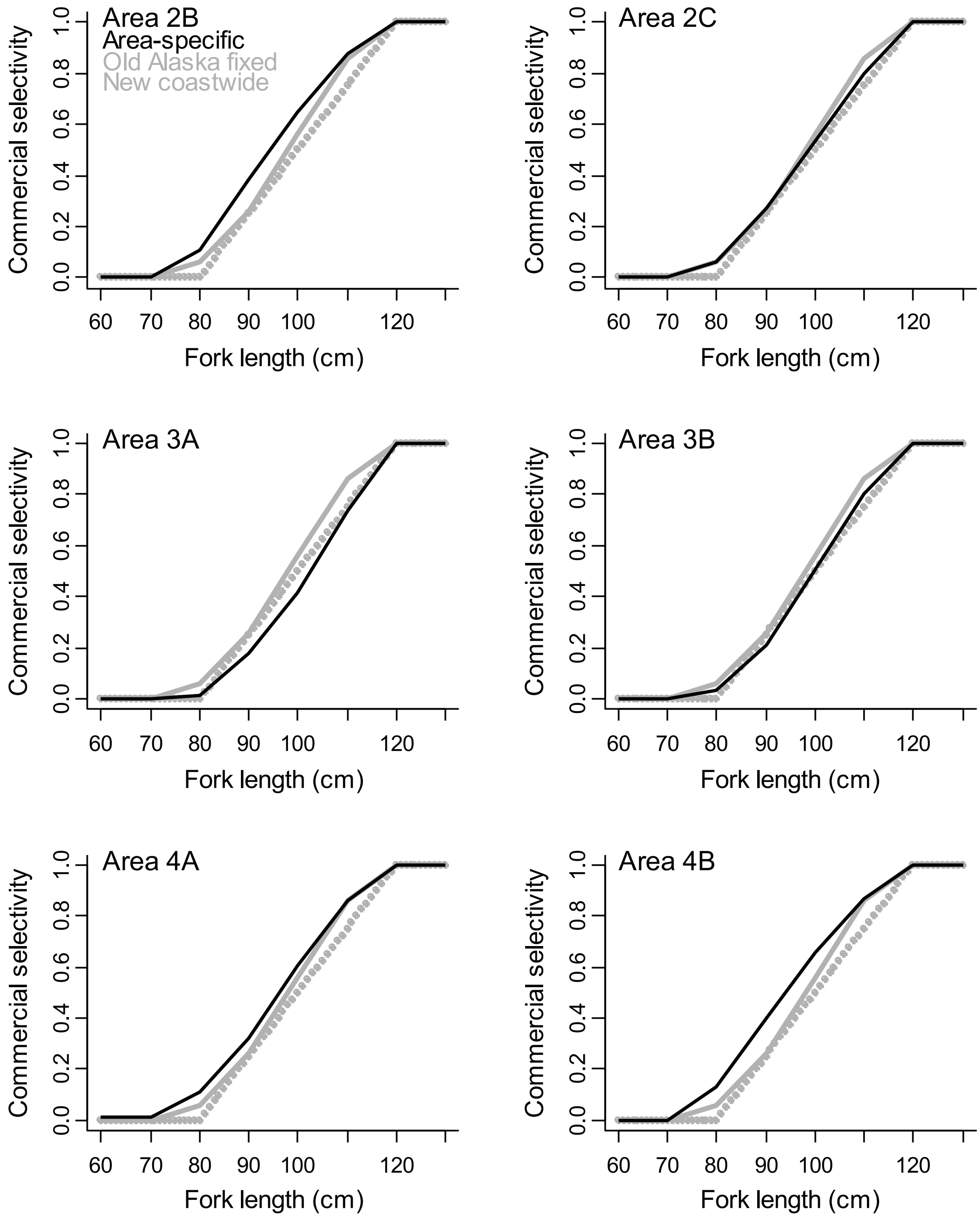

Figure 8. Commercial selectivity schedules. In each graph the broken gray line is the old standard (Alaska fixed) schedule, the solid gray line is the new coastwide standard schedule, and the black line is area-specific schedule estimated in the closed-area assessment for that area.

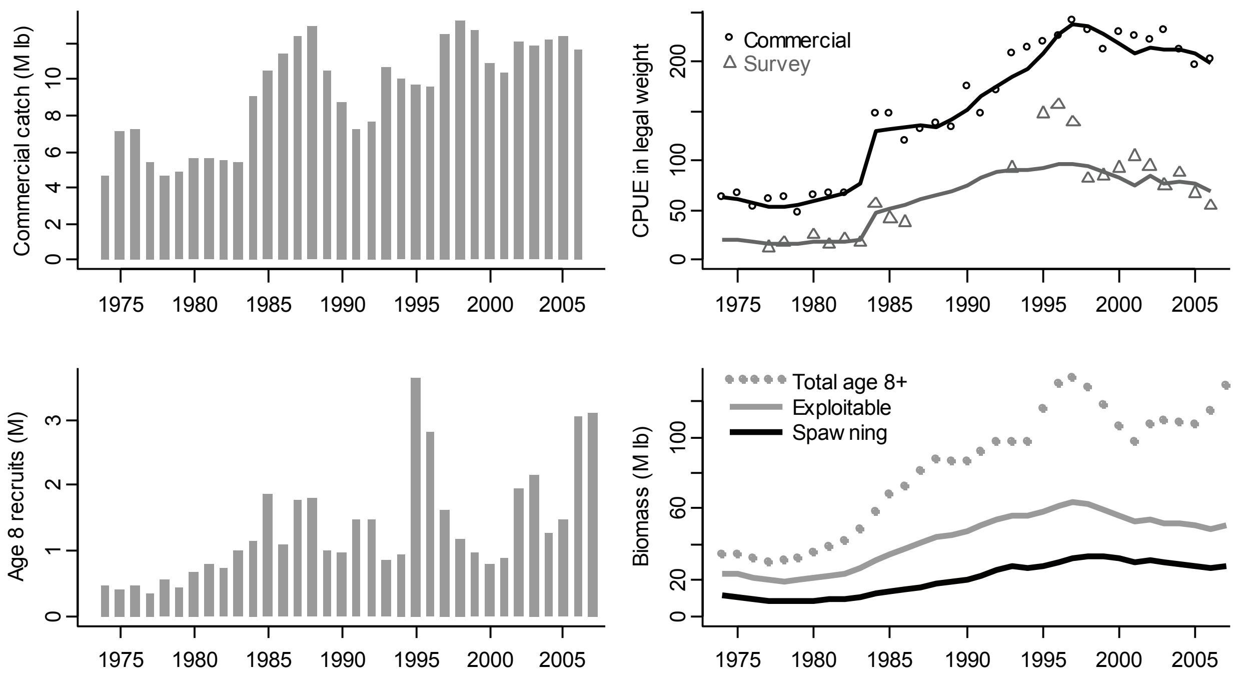

Fig. 9a. Features of the 2006 closed-area assessment in Area 2B.

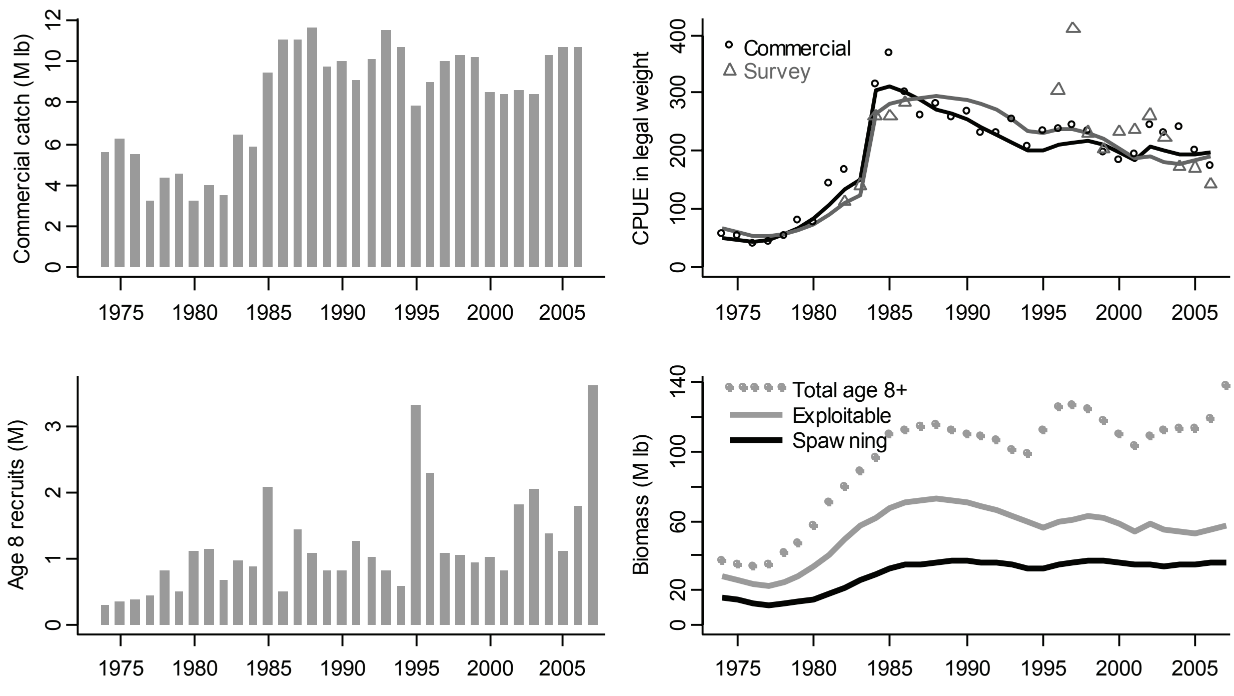

Fig. 9b. Features of the 2006 closed-area assessment in Area 2C.

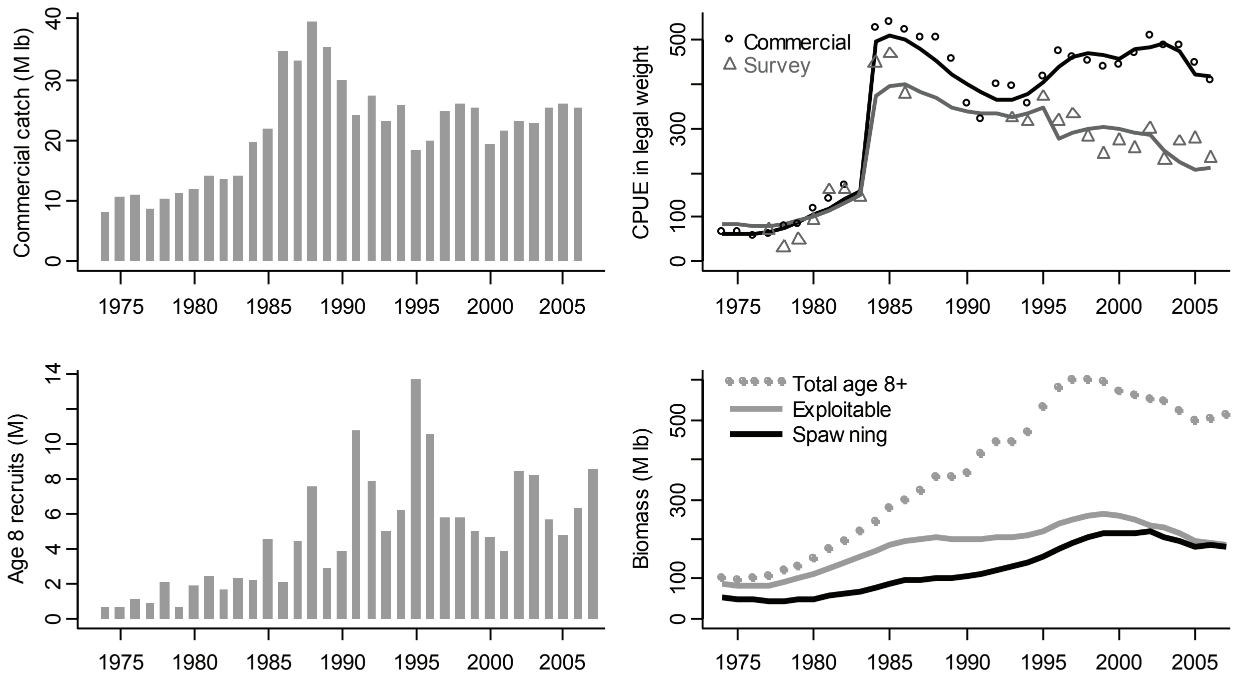

Figure 9c. Features of the 2006 closed-area assessment in Area 3A.

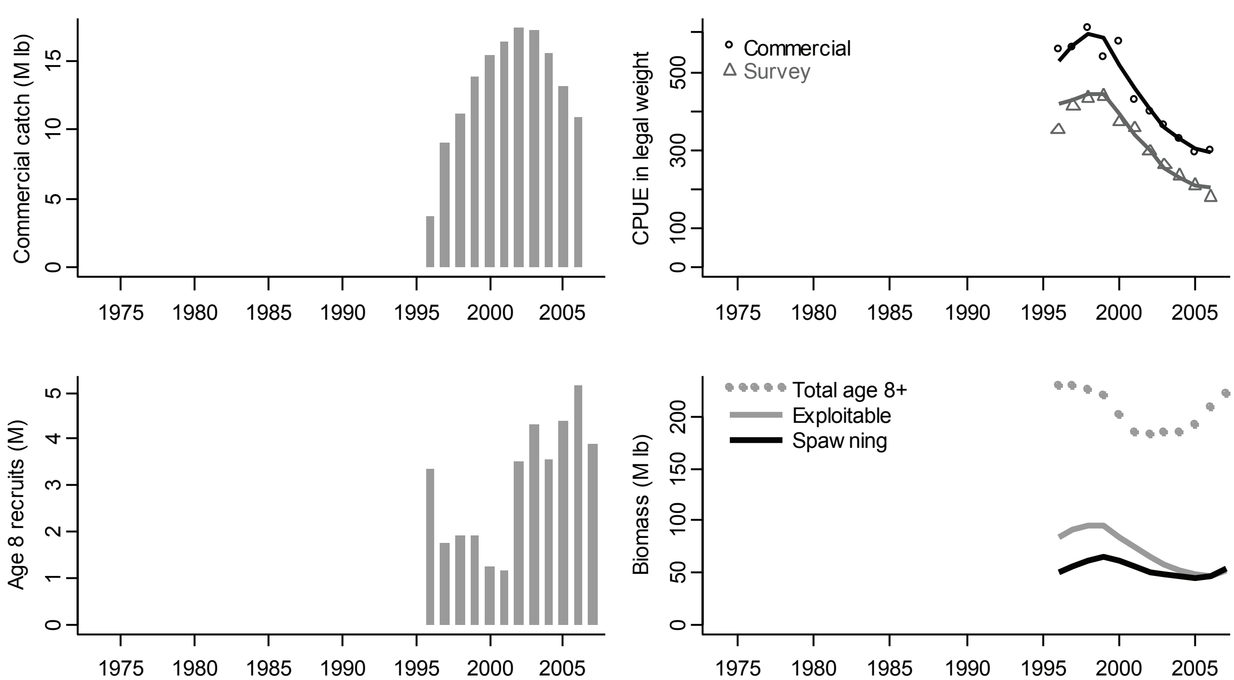

Figure 9d. Features of the 2006 closed-area assessment in Area 3B.

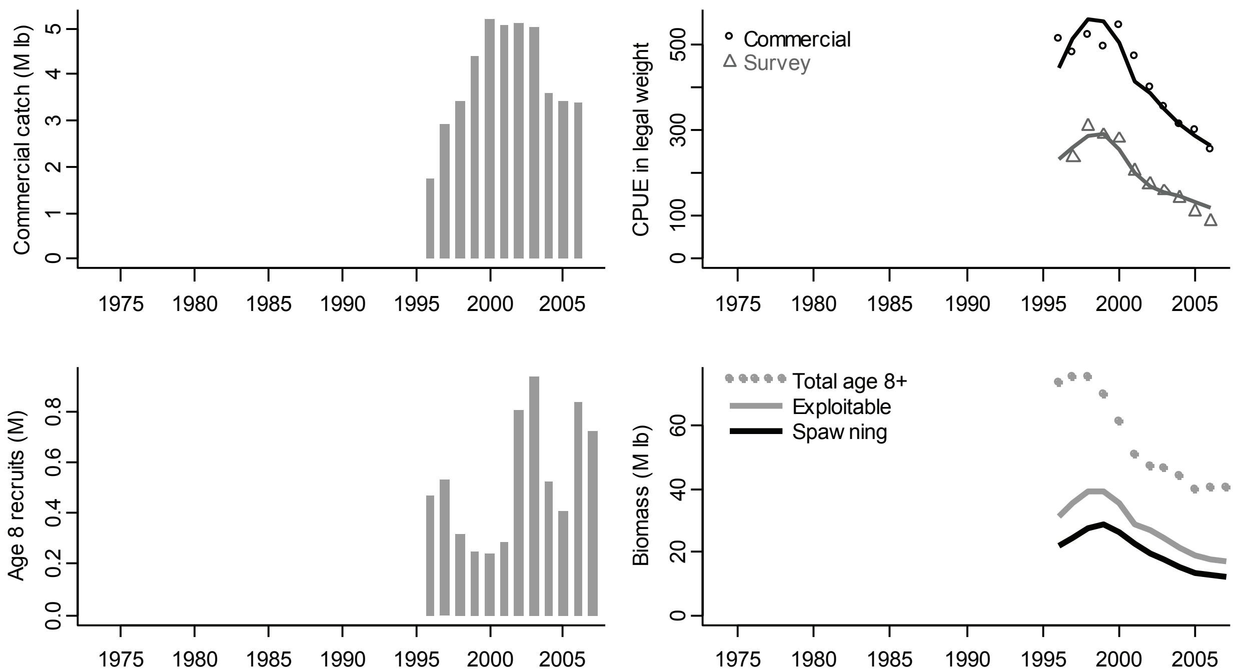

Figure 9e. Features of the 2006 closed-area assessment in Area 4A.

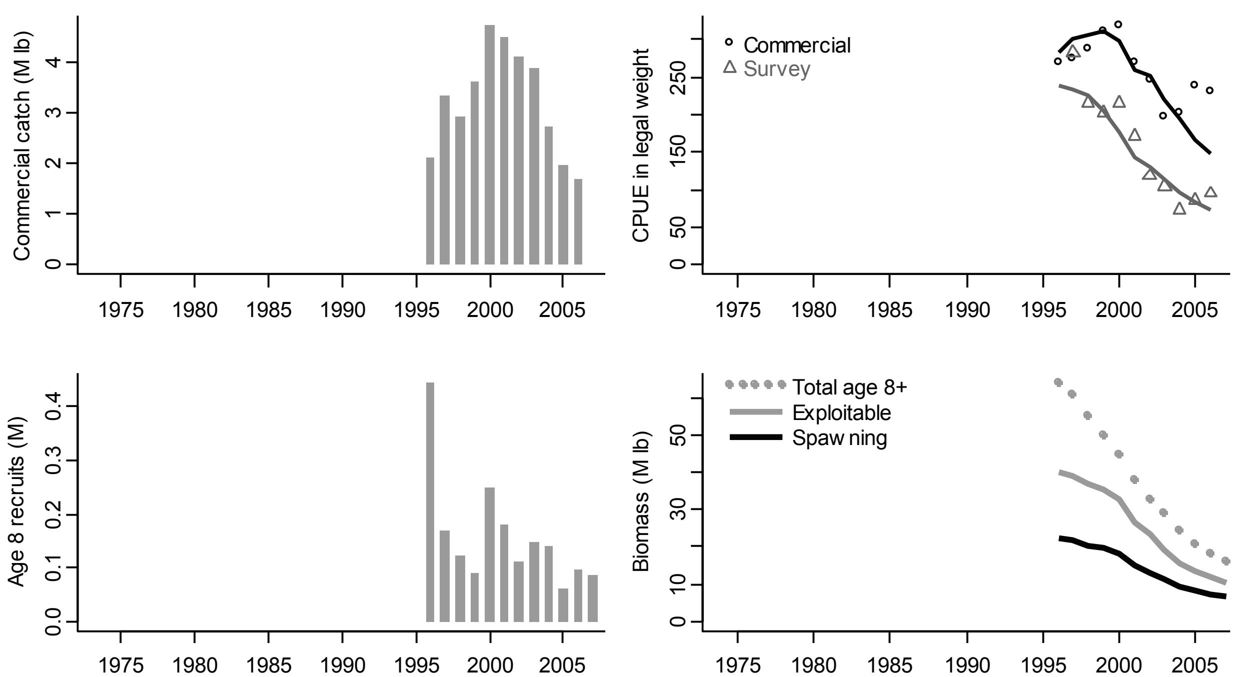

Figure 9f. Features of the 2006 closed-area assessment in Area 4B.

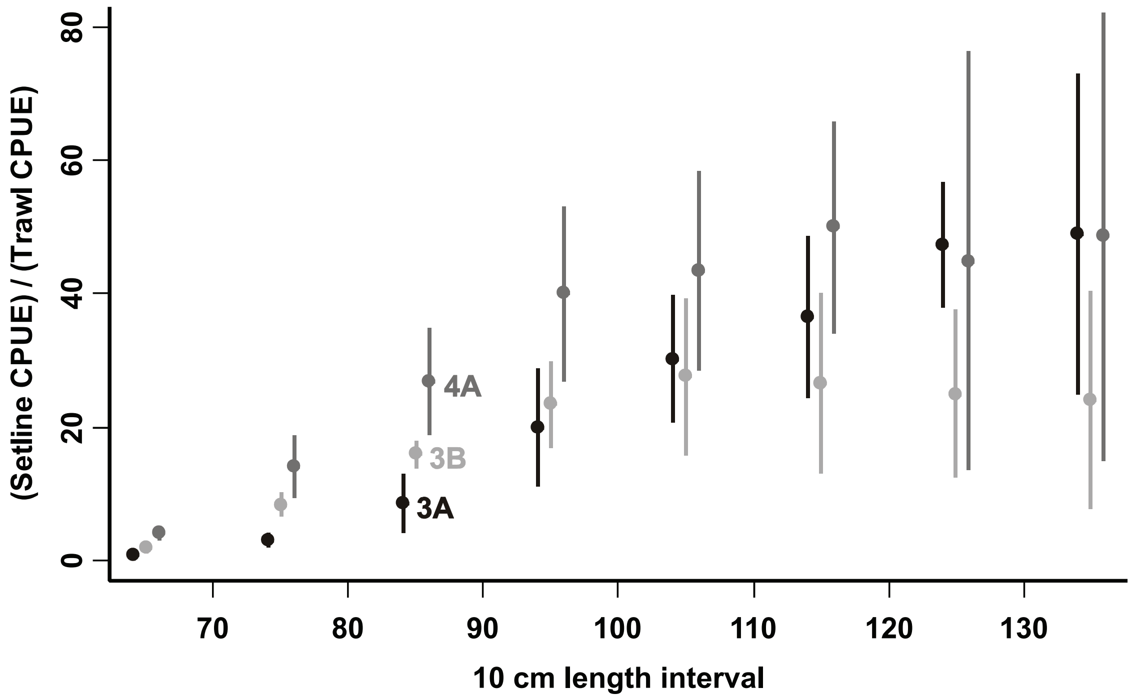

Figure 10. Ratio of setline survey catch rates at length (fish/skate) to trawl survey catch rates at length (fish/ha swept).

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	0.80	12.33	10.63	26.03	13.17		3.40	1.98	0.53	2.58	0.37	71.82
2006	0.82	11.78	10.47	25.38	11.03		3.31	1.60	0.50	2.40	0.36	67.64

Table A2. 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	Total
J-hook CPUE:											
1974	59	64	57	65	57	---	---	---	---	---	---
1975	59	68	53	66	68	---	---	---	---	---	---
1976	33	53	42	60	65	---	---	---	---	---	---
1977	83	61	45	61	73	---	---	---	---	---	---
1978	39	63	56	78	53	---	---	---	---	---	---
1979	50	48	80	86	37	---	---	---	---	---	---
1980	37	65	79	118	113	---	---	---	---	---	---
1981	33	67	145	142	160	158	99	110	---	---	---
1982	22	68	167	170	217	103	---	91	---	---	---
1983	---	---	---	---	---	---	---	---	---	---	---
C-hook CPUE:											
1984	63	148	314	524	475	366	161	---	197	---	367
1985	62	147	370	537	602	333	234	---	330	---	407
1986	60	120	302	522	515	265	---	427	239	---	365
1987	57	131	260	504	476	341	220	384	---	---	357
1988	134	137	281	503	655	453	224	---	201	---	405
1989	124	134	258	455	590	409	268	331	384	---	381
1990	168	175	269	353	484	434	209	288	381	---	335
1991	158	148	233	319	466	471	329	223	398	---	330
1992	115	171	230	397	440	372	278	249	412	---	337
1993	147	208	256	393	514	463	218	257	851	---	376
1994	93	215	207	353	377	463	198	167	480	---	321
1995	116	219	234	416	476	349	189	---	475	---	348
1996	159	226	238	473	556	515	269	---	---	---	411
1997	226	241	246	458	562	483	275	335	671	---	412
1998	194	232	236	451	611	525	287	287	627	---	421
1999	---	213	199	437	538	500	310	270	535	---	393
2000	263	229	186	443	577	547	318	223	556	---	411
2001	169	226	196	469	431	474	270	203	511	---	377
2002	181	222	244	507	399	402	245	148	503	---	376
2003	184	231	233	487	364	355	196	105	389	---	350
2004	145	212	240	485	328	315	202	120	444	---	338
2005	155	197	203	446	293	301	238	91	379	---	313
2006	131	202	174	407	299	257	231	71	294	NA	292

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

Figures refer to all stations fished. For years when only the northern portion of Area 2B was fished, the CPUE is multiplied by 0.89 to reflect the relationship between overall CPUE and northern CPUE in years when the whole area was 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. *No hook corrections* are applied; J-hook values are raw J-hook catch rates. Area 4EBS is the eastern Bering Sea shelf, first surveyed in 2006. The Total column is affected by a constructed series of eastern Bering Sea values (not shown).

	2A	2B	2C	3A	3B	4A	4B	4C	4D	4EBS	Total
J-hook surveys:											
1974	---	---	---	---	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---	---	---	---	---
1976	---	---	---	---	---	---	---	---	---	---	---
1977	---	13	---	73	---	---	---	---	---	---	---
1978	---	18	---	34	---	---	---	---	---	---	---
1979	---	NA	---	51	---	---	---	---	---	---	---
1980	---	25	---	95	---	---	---	---	---	---	---
1981	---	16	---	162	---	---	---	---	---	---	---
1982	---	21	145	180	---	---	---	---	---	---	---
1983	---	18	142	147	---	---	---	---	---	---	---
1984	---	25	---	217	---	---	---	---	---	---	---
C-hook surveys:											
1984	---	57	260	446	---	---	---	---	---	---	---
1985	---	42	260	466	---	---	---	---	---	---	---
1986	---	38	283	377	---	---	---	---	---	---	---
1987	---	NA	---	---	---	---	---	---	---	---	---
1988	---	NA	---	---	---	---	---	---	---	---	---
1989	---	NA	---	---	---	---	---	---	---	---	---
1990	---	NA	---	---	---	---	---	---	---	---	---
1991	---	NA	---	---	---	---	---	---	---	---	---
1992	---	NA	---	---	---	---	---	---	---	---	---
1993	---	93	---	323	---	---	---	---	---	---	---
1994	---	NA	---	313	---	---	---	---	---	---	---
1995	29	148	---	370	---	---	---	---	---	---	---
1996	---	156	306	317	352	---	---	---	---	---	---
1997	35	139	411	331	415	237	282	71	111	---	160
1998	---	82	232	281	435	310	216	---	---	---	149
1999	37	85	204	241	438	382	203	---	---	---	139
2000	---	93	233	272	373	286	216	---	213	---	136
2001	41	105	237	256	357	207	171	---	197	---	126
2002	33	95	261	299	297	174	119	---	257	---	120
2003	22	75	223	229	262	159	104	---	195	---	102
2004	27	88	173	270	236	142	73	---	132	---	102
2005	28	67	171	276	211	111	86	---	69	---	96
2006	16	55	144	232	181	88	95	---	63	18	83

Appendix B. Evolution of IPHC assessment methods, 1982-2005

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 was the same as the 2004 assessment. The only important change in procedure was the use of the NMFS trawl survey to estimate biomass in Area 4CDE where an analytical assessment was not done.

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