ASSESSMENT OF THE PACIFIC HALIBUT STOCK IN 1999

by

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ABSTRACT

The Pacific halibut assessment is based on fitting an age- and length-structured model to data from the fishery and IPHC setline surveys. The only major change this year was a lowering of setline survey catch rates from the 1990s to account for a bait change, which reduced the population estimates by 20-30% in the eastern and central Gulf of Alaska (Areas 2 and 3A). A continuing decline in size at age also affected the estimates in Area 2C and Area 3A. Very low estimated recruitment in Area 3A in recent years implies a rapidly declining biomass in that area, but trawl surveys indicate continuing high abundance of 60-80 cm fish in that area, so this may be a false alarm. However, it does now appear that recruitment has declined from the high levels of 1985-1995. Farther west (Areas 3B and 4), biomass is estimated by extrapolating the Area 3A estimate on the basis of setline survey results. Total setline CEY (available yield at a harvest rate of 20%) is estimated to be 63 million pounds, down from almost 100 million last year. Most of the decrease in Areas 2AB and 2C is due to the bait correction, while lower weight at age and recruitment are equally influential in Area 3A.

INTRODUCTION

Each year the IPHC staff assesses the abundance and potential yield of Pacific halibut using all available data from the commercial fishery and scientific surveys (Appendix A). Exploitable biomass in each IPHC regulatory area is estimated by fitting a detailed population model to the data from that area. A biological target level for total removals is then calculated by applying a fixed harvest rate—presently 20%—to the estimate of exploitable biomass. This target level is called the “constant exploitation yield” or CEY for that area in the coming year. The corresponding target level for directed setline catches, called the setline CEY, is calculated by subtracting from the total CEY an estimate of all other removals—sport catches, bycatch of legal sized fish, wastage in the halibut fishery, and fish taken for personal use.

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

This paper reports the staff’s estimates of total abundance, recruitment trends, exploitable biomass, and total and setline CEY by area as calculated at the end of 1999 for the 2000 fishery.

THE ASSESSMENT MODEL

From 1982 through 1994, stock size was estimated by fitting an age-structured model (CAGEAN) to commercial catch-at-age and catch-per effort data. In the early 1990s it became apparent that age-specific selectivity in the commercial fishery had shifted as a result of a decline in halibut growth rates, which was more dramatic in Alaska than in Canada. An age- and length-structured model was developed and implemented in 1995 that that accounted for the change in growth. It also incorporated survey (as well as commercial) catch-at-age and catch-per effort data. The survey data contain much more information on younger fish, many of which are now smaller than the commercial size limit, and are standardized to provide a consistent index of relative abundance over time and among areas.

At first the model was fitted on the assumption that survey catchability and length-specific survey selectivity were constant, while commercial catchability and selectivity were allowed to vary over time (subject to some restraints). The resulting fits showed quite different length-specific survey selectivities in Area 2B and 3A, however, which suggested that age could still be influencing selectivity. To reflect that possibility, the new model has been fitted in two ways since 1996: by requiring constant length-specific survey selectivity (as in 1995), and by requiring constant age-specific survey selectivity. The age-specific fits generally produce lower estimates of recent recruitment and therefore present abundance, and to be conservative the staff has used those estimates to calculate CEY's.

With either fitting criterion, the abundance estimates depend strongly on the natural mortality rate M used in the population model. Until 1998 the estimate $M = 0.20$ had been used in all assessments. This estimate is quite imprecise, and an analysis done by the staff suggested that a lower working value would be appropriate. The value $M = 0.15$ was chosen and used as a standard, which lowered abundance estimates in the 1998 assessment by about 30%.

The only significant change to the assessment in 1999 was introducing an increase in setline survey catchability, beginning with the 1993 survey data, to account for a change in bait between the 1980s and the 1990s. When setline surveys resumed in 1993 (after being suspended since 1986), chum salmon was adopted as the standard bait, whereas in the 1980s the bait was herring and salmon on alternate hooks. Experiments done within the last year showed that salmon bait catches 50-150% more halibut than herring. Further experiments are planned for this summer in which mixed bait will be compared directly with salmon. In the meantime, a working value of 100% was used in the assessment. This translates to a 33% increase in overall survey catchability after the 1980s. (For every two hooks, in terms of hooks baited with salmon, the survey switched from the equivalent of 1½ hooks to 2 hooks, an increase of one third.)

Further details on the history of IPHC assessment methods and harvest strategy are given in Appendix B and in a detailed account of the 1997 assessment (Sullivan et al. 1999). Details of changes to the model made in 1998 and 1999 are given in Appendix C.

STOCK SIZE ESTIMATES IN AREAS 3B AND 4

Until 1997 the analytical model was used to estimate halibut abundance for the entire Commission area, including lightly fished regions in the western Gulf of Alaska (Area 3B) and the Bering Sea/Aleutians region (Area 4). Because there is no historical survey data for western Alaska, the assessment relied entirely on commercial data for those areas. In 1997 the Commission first did setline surveys of the entire Commission area, and they showed substantially more halibut to be available in western Alaska (relative to other areas) than the analytical model had estimated. The reason for the discrepancy is almost certainly that the analytical model, when fitted to commercial data alone, only estimates the size of the *exploited population*, and in western Alaska fishing intensity is very low or nil over large areas, so a substantial part of the stock is effectively unexploited and therefore invisible to the model but not to the surveys.

In light of the survey results, analytical estimates of stock size in Areas 3B and 4 were suspended in 1997. The procedure now is to calculate analytical estimates for Areas 2A, 2B, 2C, and 3A, and then to scale those absolute estimates by survey estimates of relative abundance in Area 3B and 4 to obtain absolute estimates for the western areas. In 1997 the sum of the abundance estimates for Areas 2A through 3A was used as the reference point. Since then the absolute estimate for Area 3A only has been used as the reference point, on the grounds that survey catch rates there are more comparable to survey catch rates farther west.

ANALYTICAL ESTIMATES OF ABUNDANCE IN 1998

Narrative account of the assessment

A stepwise summary of the 1999 assessment is shown in Table 1. The "housekeeping update" of the 1998 assessment (Step 2) consisted of a number of small items, none of which had an important effect on the estimates except as noted:

(i) Adding the 1998 survey ages, which increased the 3A estimate by about 5 M lb. and reduced the 2C estimate by 2.5 M lb.

(ii) Recomputing some of the early commercial size-at-age estimates and correcting some of the survey CPUE estimates. The latter increased the 2AB estimate by about 5 M lb.

(iii) Smoothing the commercial mean weight-at-age over ages within years rather than over years within ages, as was done in the past. The old procedure did not accurately track year-to-year changes in mean weight in the catch. The new procedure reduced the 2C estimate by about 5 M lb as a result of a drop in mean weight between 1998 and 1999 that had been ignored by the old smoother.

(iv) Slightly altering the growth equations, which raised the 3A estimate by about 5 M lb.

Increasing survey catchability by 35% in the 1990s (Step 3) to account for the bait change has the effect of reducing the apparent increase in halibut abundance since the 1980s by 25% (to 1/1.35 of the former value), but it does not reduce the estimates of 1999 biomass by the same amount because other things play a role, including commercial catch per effort. As it turned out, the 2AB and 2C estimates for 1999 decreased by about 20% and the 3A estimate by almost 30%.

The addition of the 1999 commercial data (Step 4) can affect the 1999 estimates through the commercial CPUE, the age composition of the catch, and the mean weight at age in the catch. The only sizable effect was a large decrease in the 3A estimate caused almost entirely by a decline in the mean weights. This trend has been going on for some time (Table 2). It appeared to have leveled off in the mid-1990s, but in 2C and 3A it has resumed since 1997, reducing biomass estimates in Alaska by a full 20% over the last two years.

The addition of the 1999 survey data (Step 5) had little effect in Area 2AB and a positive effect on estimated 1999 abundance in Alaska, despite the low survey catch rates. This can happen when the survey catch at age increases the estimated abundance of some year-classes.

When the estimated numbers at age are projected forward to 2000 (using the 1999 mean weights to calculate biomass), the change in the biomass estimate depends on the estimated abundance of all the year-classes in the stock, which at ages 8 to, say, 20 in 2000 will be the 1980 through 1992 year-classes. Generally the year-classes coming into the stock are now weaker than the ones passing out of it, so the projections for 2000 are lower than the 1999 estimates (Table 3). The drop is bigger in 3A (20%) than in 2AB and 2C (10%) because the assessment shows that recruitment to 3A peaked in 1980 and has been declining steeply since, to levels that are now on a par with the mid-1970s. In 2AB and 2C the 1987 and 1988 year-classes were strong, and the most recent ones appear to be mediocre but not really poor as in 3A.

In summary, this year's estimates are substantially lower than last year's because of the allowance for increased survey catchability, lower mean weights at age, and recent declines in recruitment. In Alaska (2C and 3A) the cumulative effect is a 35-40% reduction; in Area 2AB about 15%.

Plots of fitted values

There is very little difference between the age- and length-specific fits in Area 2, so only the age-specific fits are illustrated for Area 2AB (Fig.1) and Area 2C (Fig.2). In Area 3A there is more of a difference, so both fits are illustrated (Figs. 3a and 3b). Most of the plotted values are tabled in Appendix D.

Except for the age-specific fit in Area 3A, all of the fits show the 1987 year-class to be strong. All of the fits show a drop in recruitment after the 1987 year-class, which in Area 3A has been steep and sustained, to the point where estimated recruitment at age 8 in 1999 is the lowest in the 1974-1999 series. As explained below, this severe decline in recruitment is likely overstated. The age- and length-specific fits in 3A show very similar recruitment trends. The length-specific estimates are slightly higher from 1980 on, with the cumulative result that the length-specific estimate of exploitable biomass in 2000 is 121.4 M lb compared with the age-specific value of 94.9.

In the plot of survey catch rates (center left panel), the broad shaded line is a data smoother that shows the general trend of the survey data points. The thin black line is the model predictions of survey catch rates. There is quite a wide scatter of the data points around the general trend, which means that the survey data are quite variable from year to year. Thus while the surveys are an essential index of the general level of stock abundance, the year-to-year changes are not very meaningful.

In the center right panel, commercial catch per effort is plotted as points and the model estimates of exploitable biomass as a dotted line. Predicted commercial CPUE is plotted as a solid line; it reflects estimated changes in commercial catchability ("q") as well as the trend in exploitable biomass. The values of exploitable biomass in this graph are calculated with the model estimates of commercial selectivity in each area in each year, and are not the same as the estimates of exploitable biomass that appear below in the calculation of setline CEY. Those are calculated with a fixed coastwide selectivity.

The estimated selectivities in the lower panels are unremarkable except for the very steep length-specific survey selectivities in recent years estimated with the age-specific model. In light of other evidence of length-specific vulnerability to hooking (from marking and video observations), these curves are probably too steep and shifted too far to the left.

ESTIMATES OF EXPLOITABLE BIOMASS AND CEY

As explained above, exploitable biomass in 3B and 4 is estimated by scaling the analytical estimate for 3A by survey estimates of relative abundance. For that purpose, average survey catch rates in 3B and 4 relative to 3A were calculated by a procedure that uses all available 1996-1999 data but places more weight on the more recent values. These relative catch rates are then scaled by relative total bottom areas (0-500 fathoms) to estimate relative total biomass levels in 3B, 4A, and 4B. There are no recent survey data for 4CDE, so last year's estimate is carried over. Estimated abundance in Area 3B and 4 relative to 3A is higher this year than last because of lower survey catch rates in 3A in 1999 and continued good catch rates farther west. The full set of exploitable biomass estimates is:

	2AB	2C	3A	3B	4A	4B	4CDE	Total
Exploitable biomass (ebio) relative to 3A	---	---	1.00	1.02	0.38	0.37	0.37	---
Ebio (M lb)	55.5	42.2	94.9	96.8	36.1	35.1	35.1	395.7

The target harvest rate of 20% was chosen on the basis of calculations of stock productivity that used a coastwide average of the estimates of commercial selectivity from the age-specific fit of the model, so the biomass estimates from the age-specific fits are used to calculate exploitable biomass and CEY (Table 4).

Some ad hoc procedures were required to estimate non-commercial removals and setline CEY by subarea within Area 4. Wastage was distributed among subareas in proportion to commercial catch. Sport catch and personal use were allocated 90% to 4A and 10% to 4CDE. Legal sized bycatch mortality was distributed in proportion to total (legal + sublegal) bycatch mortality recorded by NMFS observers. This procedure requires two assumptions. First, the distribution of observer coverage by IPHC regulatory area should be proportional to total fishing effort. Second, the size distribution within each regulatory area should be equal (since we subtracting out just the legal portion of the bycatch). It is likely that both of these assumptions are roughly met and this procedure is almost certainly more accurate than other alternatives such as distributing mortality in proportion to biomass. In 1998, observed mortality of halibut was distributed among regulatory areas as follows: 4A 16%, 4B 6%, 4CDE 24%, Closed area 54%. As the Closed Area is on the eastern Bering shelf, it is treated as part of Area 4CDE.

The distribution of exploitable biomass between Area 2A and 2B is estimated from setline survey results. Surveys in 1995 and 1997 had both shown about 8% of the total to be in Area 2A. In 1999, owing to a very low CPUE in 2B, the survey estimate was 16% with a standard deviation of 3% (meaning that a 95% confidence interval would be approximately 10-22%). A simple average of the three estimates—11%—was used as a working value to calculate exploitable biomass and CEY in Area 2A and 2B.

OUTLOOK

It now appears likely that coastwide recruitment has declined from the high levels of the 1985-1995 period, and size at age is still going down. Thus while abundance in number is still quite high relative to the levels of 1975 or 1980 (Table 3), biomass levels are not as good and the prospect is for a continuing decline as relatively strong year-classes pass out of the stock and relatively weak ones enter (and grow more slowly).

The prospect is worst in 3A, but the apparent near-failure of recruitment there may not be real. NMFS trawl surveys indicate a much higher abundance of 8-year-old halibut in Area 3A than our analytical assessment based on setline data. This is a puzzle, because for legal-sized halibut trawl and setline surveys agree reasonably well on trends in relative abundance, but since 1990 trawl survey catch rates of sublegal halibut have greatly outpaced setline survey catch rates (Fig. 4).

Another cause for suspicion is the re-emergence of a retrospective pattern in the 3A estimates (and only there), with the estimate of exploitable biomass in a given year increasing in each succeeding assessment (Table 5). This is consistent with an over-estimate of the selectivity of young fish, whose abundance is consequently underestimated initially. The estimate is then corrected in later assessments as the year-class moves through the fishery. In the past this pattern was caused by declining size at age, but size at ages 8 and below has changed very little, so some other factor must be at work.

It therefore seems very possible that exploitable biomass in 3A is underestimated and that incoming recruitment will turn out to be no worse in 3A than in 2AB and 2C. But even that would be low by recent standards.

REFERENCES

Sullivan, P.J., Parma, A.M., and Clark, W.G. 1999. Pacific halibut assessment: data and methods. Int. Pac. Halibut Comm. SCI. Rept. 97. 84 p.

Table 1. Steps in performing the 1999 assessment and corresponding estimates of exploitable biomass, by area. These estimates are from the model with fixed age-specific survey selectivity; length-specific estimates are about 10% higher in 2AB and 2C, and 25% higher in 3A.

Area 2AB

	1997	1998	1999	2000
1. 1998 assessment	71.9	70.1	**66.8**	---
2. Housekeeping update	76.1	73.3	71.8	---
3. Increase survey catchability in 1990s	80.8	74.5	57.2	---
4. Add 1999 commercial data	67.5	63.6	61.6	57.0
5. Add 1999 survey data	66.4	62.5	60.3	**55.5**

Area2C

	1997	1998	1999	2000
1. 1998 assessment	66.7	64.7	**63.9**	---
2. Housekeeping update	67.1	57.8	54.5	---
3. Increase survey catchability in 1990s	56.5	47.1	42.5	---
4. Add 1999 commercial data	56.6	47.5	41.5	37.4
5. Add 1999 survey data	61.6	52.3	46.4	**42.2**

Area 3A

	1997	1998	1999	2000
1. 1998 assessment	188.5	180.0	**158.8**	---
2. Housekeeping update	224.7	190.2	171.6	---
3. Increase survey catchability in 1990s	178.4	145.8	125.5	---
4. Add 1999 commercial data	172.8	141.0	106.5	85.2
5. Add 1999 survey data	185.4	152.9	117.5	**94.9**

Table 2. Effect of declining weight at age on exploitable biomass: what estimated ebio would be in 1999 if calculated with estimated numbers at age in 1999 and mean weights at age from previous years. This shows the full effect of smaller sizes across the whole age range, and is larger than the effect on the modal age groups (particularly in Area 2B), which is what is usually shown.

	Area 2AB	**Area 2C**	**Area 3A**
Ebio with 1999 nos. and weights from:			
1974	105.4	70.9	278.3
1975	103.6	71.4	283.2
1976	101.6	71.5	286.7
1977	98.7	71.4	288.8
1978	95.0	70.7	289.9
1979	91.8	70.4	289.5
1980	89.4	70.3	288.2
1981	86.8	70.1	286.1
1982	84.7	69.5	283.0
1983	82.8	68.4	278.7
1984	81.4	66.6	273.9
1985	79.7	64.1	267.8
1986	78.0	61.8	261.9
1987	76.3	59.7	254.3
1988	74.5	58.1	245.0
1989	72.6	57.1	233.1
1990	70.7	56.7	218.8
1991	72.4	57.8	180.6
1992	69.8	54.7	179.7
1993	63.6	55.2	157.3
1994	59.9	51.5	141.0
1995	64.0	65.9	144.8
1996	61.1	57.2	144.7
1997	62.3	56.5	149.2
1998	59.3	48.4	133.1
1999	60.3	46.4	117.5

Table 3. Estimated abundance at age in 2000 as a proportion of estimated abundance at the same age in selected earlier years. (E.g., in the table below for Area 2AB, the value 6.06 at age 13 in 1975 means that estimated abundance at age 13 in 2000 is 6.06 times the estimated abundance at age 13 in 1975.)

Area 2AB. Total estimated age10+ abundance in 2000 = 91% of 1999 level.

Age	8	9	10	11	12	13	14	15	16	17	18	19	20+
1975	1.06	1.74	2.50	2.70	4.41	6.06	2.34	5.19	4.93	3.79	3.23	4.32	4.40
1980	0.67	1.29	2.20	2.98	4.76	5.41	2.72	2.55	3.04	3.23	3.20	2.78	4.45
1985	0.28	0.59	1.06	1.43	2.30	2.98	1.85	2.16	3.33	3.56	2.98	3.39	3.33
1990	0.42	0.58	0.68	0.72	1.27	1.37	0.98	1.30	2.13	2.40	2.39	3.47	4.89
1995	0.23	0.71	1.00	0.84	1.21	1.59	0.68	0.54	0.67	0.79	0.64	1.05	2.05
1999	0.64	0.68	0.93	0.66	0.84	1.89	0.93	0.75	0.92	1.07	0.79	0.73	1.00
2000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Area2C. Total estimated age10+ abundance in 2000 = 86% of 1999 level.

Age	8	9	10	11	12	13	14	15	16	17	18	19	20+
1975	1.41	1.31	1.57	2.13	3.29	3.84	1.23	2.23	1.93	1.68	1.51	2.20	3.05
1980	0.68	0.72	0.87	1.33	2.28	3.00	1.52	1.71	2.07	1.84	1.48	1.08	1.79
1985	0.44	0.49	0.61	0.75	1.07	1.24	0.68	0.75	1.01	0.99	0.89	1.03	1.15
1990	0.74	0.57	0.53	0.62	1.10	0.95	0.60	0.72	0.83	0.71	0.58	0.75	1.04
1995	0.43	0.74	0.74	0.77	1.26	1.73	0.73	0.64	0.71	0.75	0.46	0.68	0.93
1999	1.18	0.91	0.78	0.59	0.82	1.98	0.86	0.76	0.91	1.07	0.79	0.72	0.86
2000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Area 3A. Total estimated age 10+ abundance in 2000 = 79% of 1999 level.

Age	8	9	10	11	12	13	14	15	16	17	18	19	20+
1975	0.65	0.62	1.34	1.38	2.71	3.67	1.95	5.09	5.88	5.35	6.23	8.96	12.46
1980	0.38	0.37	0.64	0.84	1.72	2.79	2.29	3.29	3.83	4.40	3.07	2.42	3.54
1985	0.19	0.21	0.46	0.53	0.91	1.55	1.28	1.47	2.17	2.60	2.17	2.63	1.85
1990	0.20	0.14	0.21	0.29	0.72	0.91	0.87	1.37	1.84	1.93	1.73	2.15	1.59
1995	0.23	0.26	0.36	0.29	0.45	0.81	0.51	0.55	0.95	1.50	1.05	1.57	1.57
1999	1.29	0.53	0.91	0.50	0.68	1.35	0.69	0.69	0.73	1.15	0.80	0.71	1.04
2000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4. Exploitable biomass estimates and catch limit recommendations.

Area	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
1999 exploitable biomass (from the 1998 assessment)	5.36	61.64	64.00	159.00	138.33	46.11	34.98	58.83	568.25
1999 Setline CEY (from the 19998 assessment)	0.69	11.21	10.49	24.67	26.83	8.42	6.71	9.80	98.82
1999 quota	0.76	12.10	10.49	24.67	13.37	4.24	3.98	4.45	74.06
2000 exploitable biomass (from the 1999 assessment)	6.11	49.40	42.20	94.90	96.80	36.10	35.10	35.10	395.70
Total CEY at 20%	1.22	9.88	8.44	18.98	19.36	7.22	7.02	7.02	79.14
Non-commercial removals									
Bycatch	0.38	0.11	0.23	1.60	0.88	0.58	0.22	2.83	6.83
Sport catch	0.34	1.58	1.83	5.24	0.02	0.10	0.00	0.01	9.12
Personal use	0.00	0.30	0.00	0.10	0.04	0.08	0.00	0.01	0.53
Wastage	0.01	0.04	0.07	0.10	0.07	0.04	0.04	0.04	0.39
2000 Setline CEY	0.83	7.85	6.31	11.94	18.36	6.42	6.77	4.13	62.65
2000/1999 total CEY	1.14	0.80	0.66	0.60	0.70	0.78	1.00	0.60	0.70
2000/1999 setline CEY	1.20	0.70	0.60	0.48	0.68	0.76	1.01	0.42	0.63

Table 5. An apparent retrospective pattern in the estimates of exploitable biomass in Area 3A.

Year estimated:	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Last data year:									
1995	173	182	163	148	146				
1996	179	190	172	158	157	154			
1997	185	199	182	170	173	173	172		
1998	185	199	184	172	176	177	178	146	
1999	188	203	187	176	180	183	185	153	118

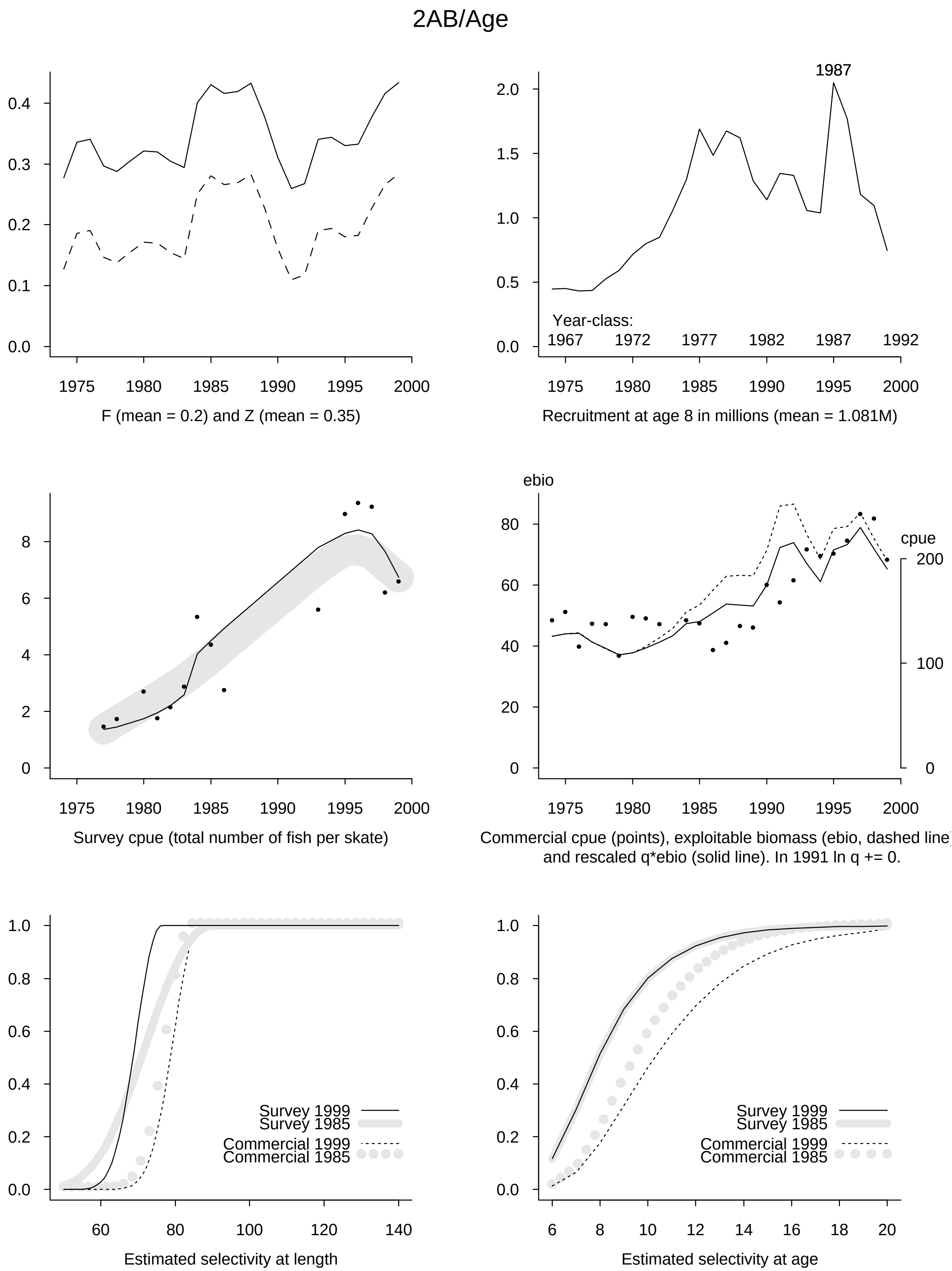

Figure 1. Features of the age-specific model fit in Area 2AB.

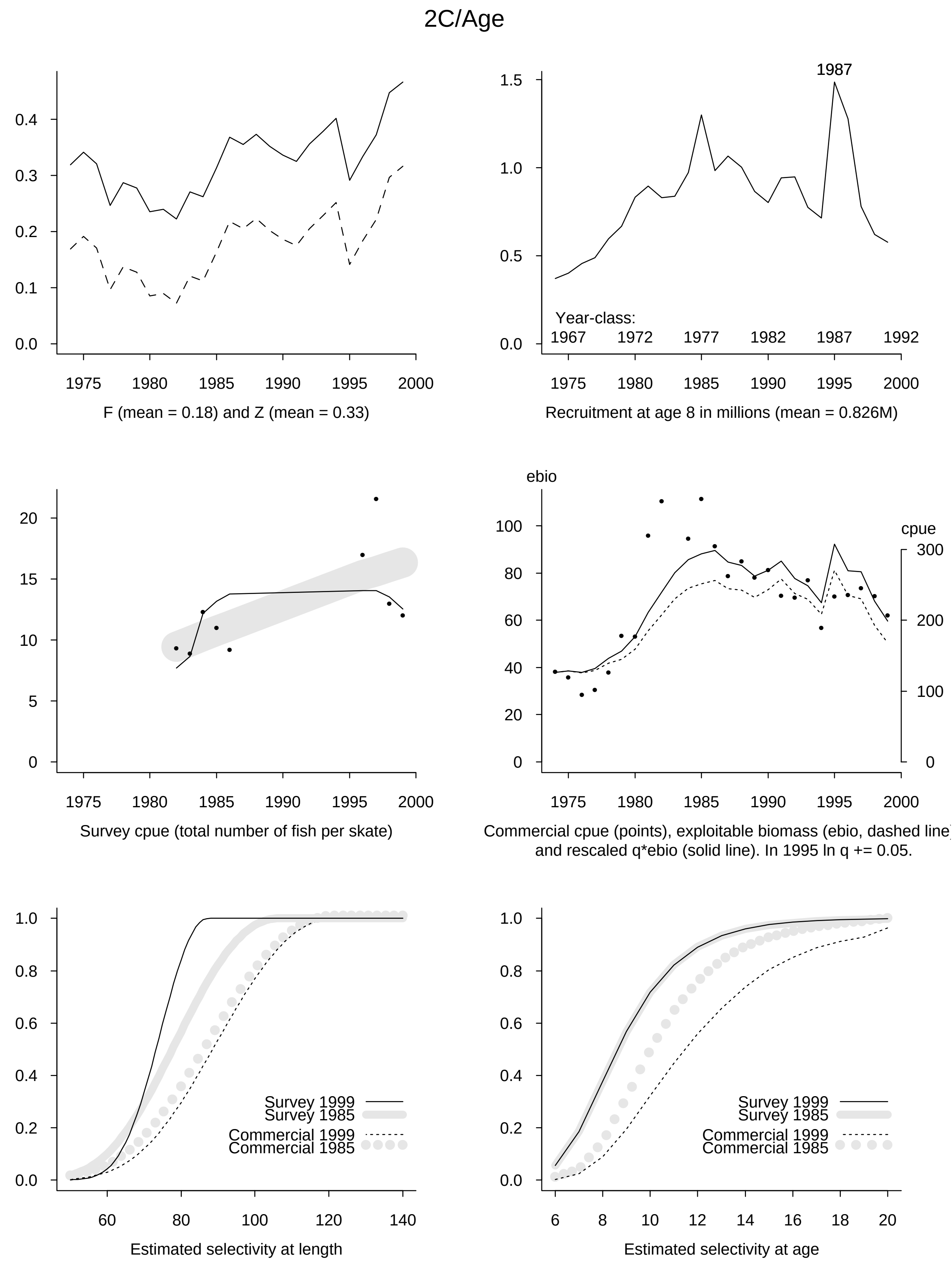

Figure 2. Features of the age-specific model fit in Area 2C.

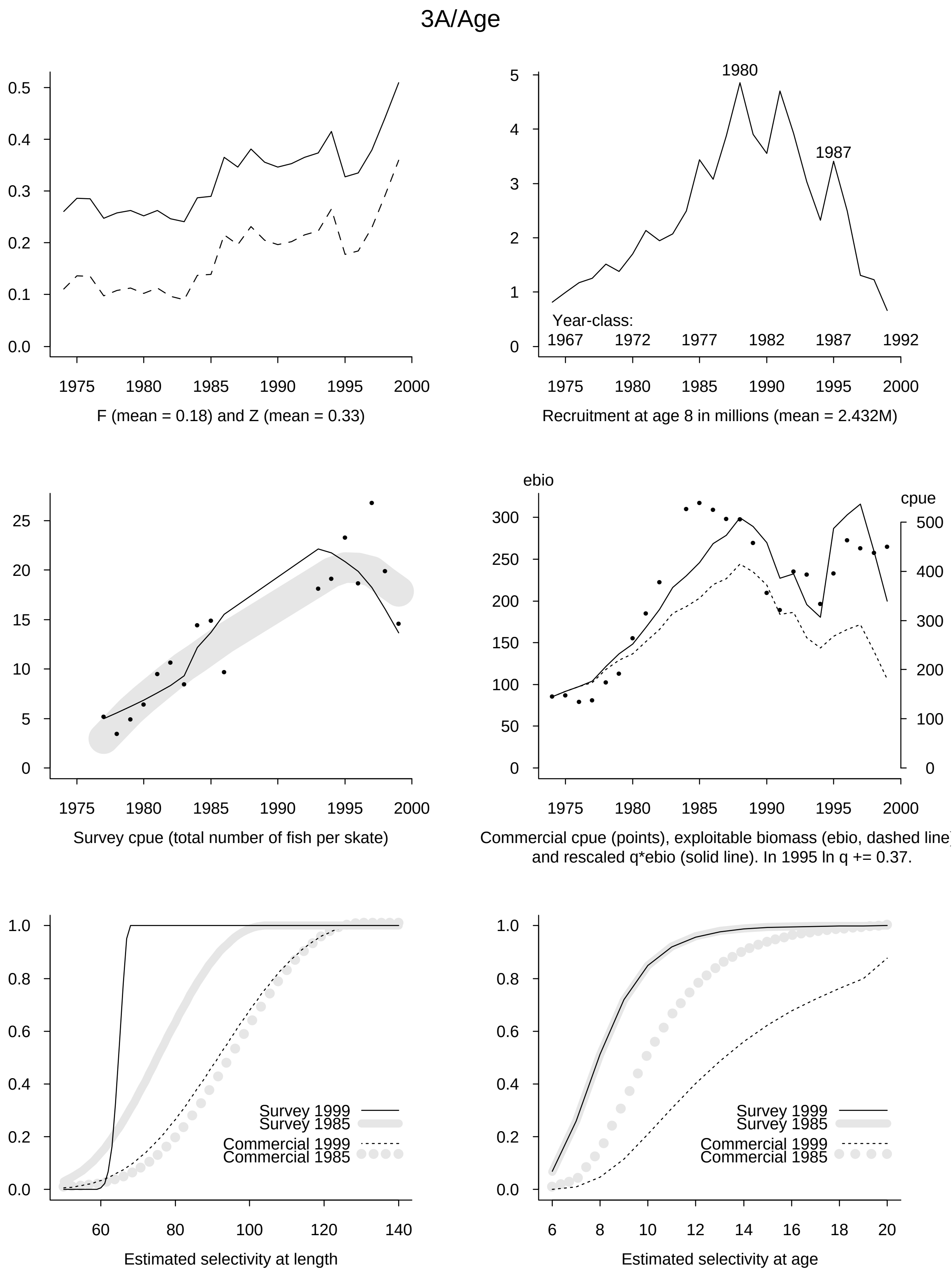

Figure 3a. Features of the age-specific model fit in Area 3A.

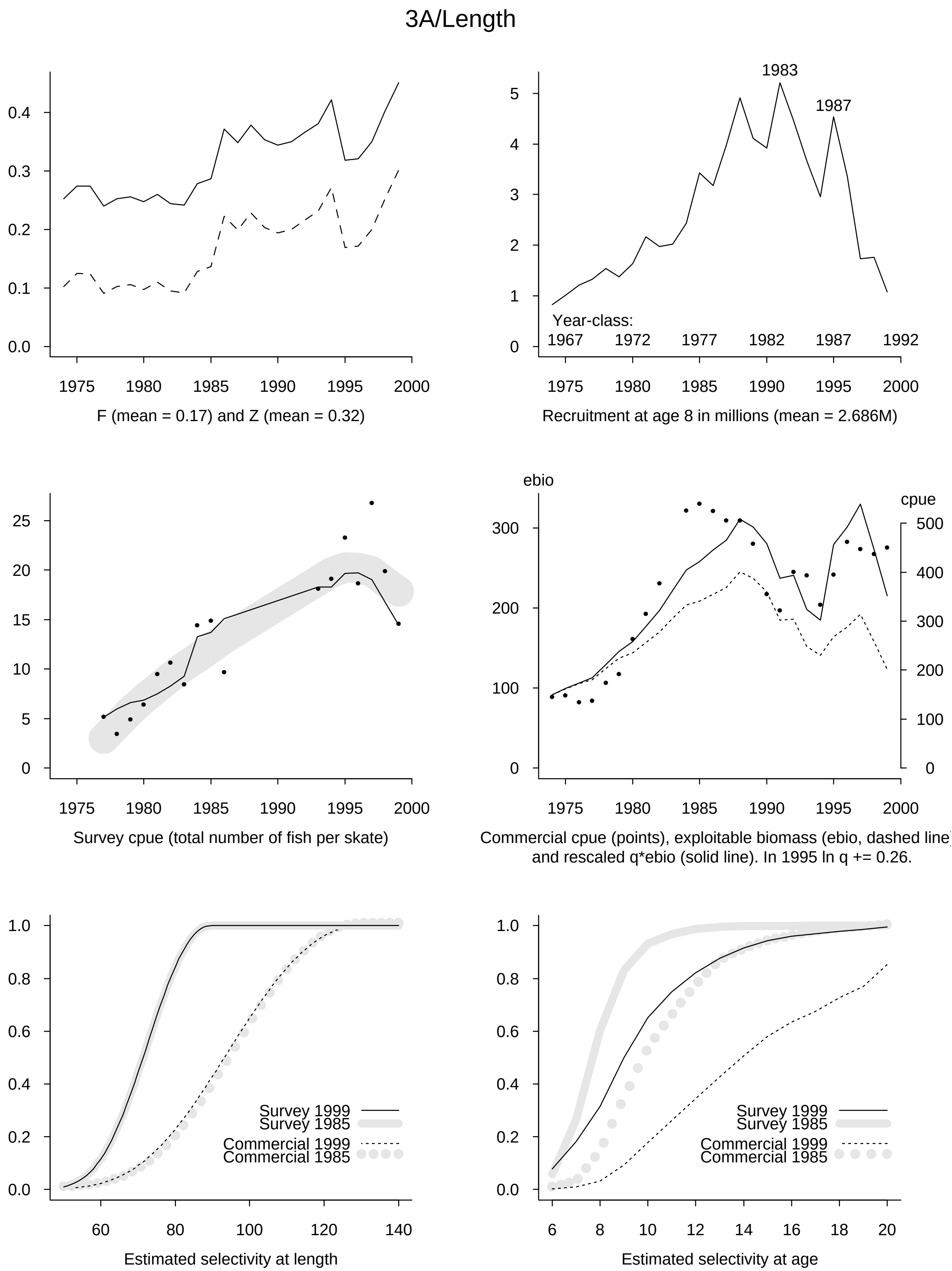

Figure 3b. Features of the length-specific model fit in Area 3A.

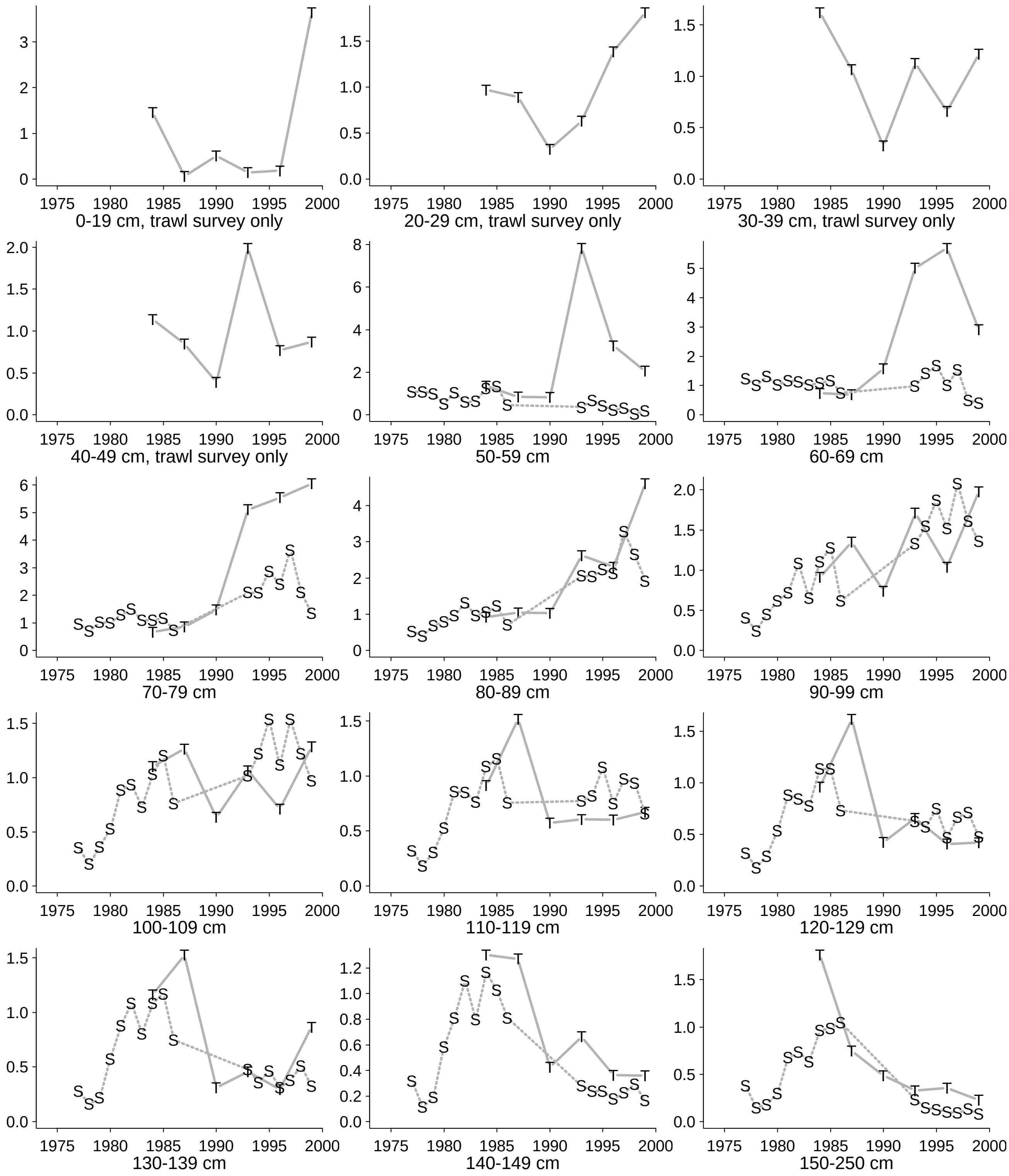

Figure 4. IPHC setline survey (S) and NMFS trawl survey (T) catch rates at length in Area 3A. In each graph, both series are scaled to average 1.0 over the years 1984-1990. Setline catch rates are adjusted for estimated catchability and selectivity.

APPENDIX A. SELECTED FISHERY AND SURVEY DATA SUMMARIES

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

	2A	2B	2C	3A	3B	4	Total
1974	0.52	4.62	5.60	8.19	1.67	0.71	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	27.54
1977	0.21	5.43	3.19	8.64	3.19	1.22	21.88
1978	0.10	4.61	4.32	10.30	1.32	1.35	22.00
1979	0.05	4.86	4.53	11.34	0.39	1.37	22.54
1980	0.02	5.65	3.24	11.97	0.28	0.71	21.87
1981	0.20	5.65	4.01	14.22	0.45	1.19	25.72
1982	0.21	5.54	3.50	13.53	4.80	1.43	29.01
1983	0.26	5.44	6.40	14.11	7.75	4.42	38.38
1984	0.43	9.05	5.85	19.97	6.50	3.16	44.96
1985	0.49	10.39	9.21	20.85	10.89	4.28	56.11
1986	0.58	11.22	10.61	32.79	8.83	5.59	69.62
1987	0.59	12.25	10.68	31.32	7.76	6.88	69.48
1988	0.49	12.86	11.37	37.86	7.08	4.69	74.35
1989	0.47	10.43	9.53	33.73	7.84	4.93	66.93
1990	0.32	8.57	9.73	28.85	8.69	5.43	61.59
1991	0.36	7.17	8.69	22.86	11.93	5.99	57.00
1992	0.44	7.63	9.82	26.78	8.62	6.61	59.90
1993	0.52	10.63	11.29	22.74	7.86	6.25	59.28
1994	0.37	9.91	10.38	24.84	3.86	5.37	54.73
1995	0.30	9.62	7.76	18.34	3.12	4.74	43.88
1996	0.30	9.56	8.86	19.70	3.66	5.31	47.38
1997	0.41	12.42	9.92	24.63	9.07	8.79	65.24
1998	0.46	13.15	10.19	25.70	11.16	9.07	69.74
1999	0.45	12.73	10.20	25.29	13.87	11.88	74.42

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

	2A	2B	2C	3A	3B	4	Total
1974	0.25	0.90	0.37	4.48	2.82	1.90	10.71
1975	0.25	0.90	0.45	2.61	1.66	1.10	6.98
1976	0.25	0.94	0.50	2.74	1.94	1.18	7.56
1977	0.25	0.72	0.41	3.37	1.54	1.98	8.27
1978	0.25	0.55	0.21	2.44	1.31	3.40	8.16
1979	0.25	0.69	0.64	4.49	0.69	3.45	10.21
1980	0.25	0.51	0.42	4.93	0.87	5.71	12.69
1981	0.25	0.53	0.40	3.99	1.09	4.37	10.64
1982	0.25	0.30	0.20	3.20	1.68	2.95	8.58
1983	0.25	0.29	0.20	2.08	1.22	2.47	6.51
1984	0.25	0.52	0.21	1.51	0.92	2.29	5.70
1985	0.25	0.55	0.20	0.80	0.34	2.25	4.38
1986	0.25	0.56	0.20	0.67	0.20	2.62	4.50
1987	0.25	0.79	0.20	1.59	0.40	2.68	5.91
1988	0.25	0.77	0.20	2.13	0.04	3.27	6.66
1989	0.25	0.72	0.20	1.80	0.44	1.95	5.37
1990	0.25	1.03	0.67	2.63	1.21	4.16	9.96
1991	0.25	1.22	0.55	3.12	1.03	2.91	9.09
1992	0.28	1.02	0.57	2.65	1.12	3.34	8.97
1993	0.28	0.65	0.33	1.92	0.47	2.01	5.65
1994	0.28	0.57	0.40	2.35	0.85	3.48	7.93
1995	0.38	0.70	0.22	1.46	0.83	3.21	6.81
1996	0.38	0.17	0.23	1.43	0.97	3.58	6.76
1997	0.38	0.11	0.24	1.55	0.73	3.80	6.81
1998	0.38	0.12	0.24	1.47	0.73	3.63	6.56
1999	0.38	0.11	0.23	1.60	0.88	3.46	6.65

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

	2A	2B	2C	3A	3B	4	Total
1974	0.52	4.62	5.60	8.19	1.67	0.71	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	27.54
1977	0.22	5.45	3.26	8.84	3.19	1.22	22.18
1978	0.11	4.62	4.40	10.58	1.32	1.35	22.38
1979	0.06	4.88	4.70	11.70	0.39	1.37	23.11
1980	0.04	5.66	3.57	12.46	0.28	0.71	22.72
1981	0.22	5.67	4.33	14.97	0.45	1.20	26.84
1982	0.26	5.61	3.99	14.25	4.80	1.44	30.34
1983	0.32	5.54	6.95	15.05	7.75	4.42	40.05
1984	0.55	9.17	6.47	21.00	6.50	3.17	46.86
1985	0.68	11.02	10.11	22.99	11.09	4.44	60.33
1986	0.92	11.80	11.77	36.55	9.23	5.91	76.18
1987	1.04	12.95	11.83	34.89	8.10	7.17	75.97
1988	0.74	13.41	12.65	42.63	7.20	4.80	81.43
1989	0.80	11.11	11.28	38.19	8.03	5.08	74.51
1990	0.52	9.41	11.30	33.38	8.91	5.69	69.21
1991	0.52	7.88	11.41	29.23	12.42	6.57	68.03
1992	0.70	8.36	12.10	31.81	8.86	6.89	68.72
1993	0.77	11.68	13.40	28.67	8.00	6.54	69.07
1994	0.56	10.94	12.72	30.51	3.98	5.63	64.33
1995	0.54	11.55	9.57	23.05	3.19	4.91	52.81
1996	0.52	11.47	10.44	24.79	3.74	5.55	56.52
1997	0.77	14.34	11.67	30.44	9.19	9.03	75.45
1998	0.85	15.09	12.95	31.12	11.28	9.32	80.61
1999	0.79	14.67	12.08	30.78	13.99	12.13	84.43

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

Values before 1984 are multiplied by the J-C hook correction for catch in weight of legal-sized fish (2.2). 1983 is excluded because it consists of a mixture of J- and C-hook data.

	2A	2B	2C	3A	3B	4
1974	131	141	126	142	125	301
1975	131	149	117	145	149	211
1976	72	117	93	131	142	184
1977	182	135	99	135	161	176
1978	86	138	124	172	116	167
1979	110	106	177	189	81	146
1980	82	144	175	261	249	124
1981	82	146	318	311	353	242
1982	47	149	366	375	479	220
1983	---	---	---	---	---	---
1984	69	149	314	524	475	236
1985	69	146	370	537	602	305
1986	61	119	302	522	515	276
1987	59	129	260	504	476	298
1988	171	133	281	503	655	296
1989	124	133	258	455	590	306
1990	168	174	269	353	484	339
1991	164	156	233	319	466	366
1992	114	187	230	397	440	312
1993	155	212	255	391	505	337
1994	97	213	187	331	369	247
1995	131	209	232	393	476	272
1996	161	219	233	460	543	355
1997	216	243	243	445	569	364
1998	224	238	232	434	595	394
1999	127	203	205	448	542	421

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

Series refer to standard survey areas: all of 2A, 2B north of Vancouver Is., outside stations in 2C, 3A west of 147ºW, all of 3B, the Aleutian portion of 4A, all of 4B.

Values before 1984 are multiplied by a J-C hook correction for legal-sized catch in weight (2.2), although this does not fully account for the difference in selectivity between hook types. Values before 1992 are multiplied by a bait correction (1.35) to account for the switch from mixed bait to all salmon in the 1990s. Mean catch rates have coefficients of variation of 5-10%.

	2A	2B	2C	3A	3B	4A	4B
1974	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---
1976	---	---	---	---	---	---	---
1977	---	45	---	217	---	---	---
1978	---	62	---	101	---	---	---
1979	---	---	---	151	---	---	---
1980	---	83	---	282	---	---	---
1981	---	53	---	481	---	---	---
1982	---	62	481	535	---	---	---
1983	---	59	416	437	---	---	---
1984	---	86	406	602	---	---	---
1985	---	63	437	629	---	---	---
1986	---	57	404	509	---	---	---
1987	---	---	---	---	---	---	---
1988	---	---	---	---	---	---	---
1989	---	---	---	---	---	---	---
1990	---	---	---	---	---	---	---
1991	---	---	---	---	---	---	---
1992	---	---	---	---	---	---	---
1993	---	105	---	323	---	---	---
1994	---	---	---	313	---	---	---
1995	---	166	---	370	---	---	---
1996	---	175	387	273	352	---	---
1997	---	156	492	366	415	237	282
1998	---	92	272	346	436	304	216
1999	37	95	260	251	441	367	204

Table A6. IPHC setline survey CPUE of all fish (incl. sublegals) in number (per skate).

Series refer to standard survey areas: all of 2A, 2B north of Vancouver Is., outside stations in 2C, 3A west of 147ºW, all of 3B, the Aleutian portion of 4A, all of 4B.

Values before 1984 are multiplied by a J-C hook correction for total catch in number (2.6), although this does not fully account for the difference in selectivity between hook types. Values before 1992 are multiplied by a bait correction (1.35) to account for the switch from mixed bait to all salmon in the 1990s. Mean catch rates have coefficients of variation of 5-10%.

	2A	2B	2C	3A	3B	4A	4B
1974	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---
1976	---	---	---	---	---	---	---
1977	---	2.5	---	8.8	---	---	---
1978	---	2.9	---	5.8	---	---	---
1979	---	---	---	8.4	---	---	---
1980	---	4.7	---	11.0	---	---	---
1981	---	3.0	---	16.5	---	---	---
1982	---	3.7	16.1	18.4	---	---	---
1983	---	4.9	15.4	14.6	---	---	---
1984	---	7.1	16.5	19.3	---	---	---
1985	---	5.8	14.7	19.9	---	---	---
1986	---	3.6	12.3	12.9	---	---	---
1987	---	---	---	---	---	---	---
1988	---	---	---	---	---	---	---
1989	---	---	---	---	---	---	---
1990	---	---	---	---	---	---	---
1991	---	---	---	---	---	---	---
1992	---	---	---	---	---	---	---
1993	---	5.5	---	18.0	---	---	---
1994	---	---	---	19.0	---	---	---
1995	---	8.9	---	23.2	---	---	---
1996	---	9.3	16.8	18.5	20.8	---	---
1997	---	9.2	21.5	26.7	27.2	13.3	12.2
1998	---	6.2	12.9	19.8	26.3	16.4	10.6
1999	2.0	6.6	11.9	14.5	26.6	19.3	9.7

APPENDIX B. RECENT CHANGES IN IPHC ASSESSMENT METHODS AND HARVEST POLICY

1982-1994: stock size was estimated with CAGEAN, a strictly age-structured model fitted to commercial catch-at-age and catch-per-effort data. Because of a decrease in growth rates between the late 1970s and early 1990s, there were persistent underestimates of incoming recruitment and total stock size in the assessments done in the early 1990s.

Until 1985, allowable removals were calculated as a proportion of estimated annual surplus production (ASP), the remaining production being allocated to stock rebuilding. In 1985 the Commission adopted a constant harvest rate policy, meaning that allowable removals are determined by applying a fixed harvest rate to estimated exploitable biomass. This harvest level is called the Constant Exploitation Yield, or CEY. The fixed harvest rate was set at 28% in 1985, increased to 35% in 1987, and lowered to 30% in 1993.

1995: a new age- and length-structured model was implemented that accounted for the change in growth and was fitted to survey as well as commercial catch-at-age and catch-per-effort data. The new model produced substantially higher biomass estimates. In Area 3A this resulted from accounting for the change in growth schedule. In Area 2B, where the change in growth had been much less than in Alaska, it resulted from fitting the model to survey catch-per-effort, which showed a larger stock increase since the mid-1980s than commercial catch-per-effort. Quotas were held at the 1995 level to allow time for a complete study of the new model and results,

1996: differences in estimated selectivity between British Columbia and Alaska led to the consideration of two alternatives for fitting the model, one in which survey selectivity was a fixed function of age and the other in which it was a function of length. Spawner-recruit estimates from the new model resulted in a lowering of the target harvest rate to 20%. Quotas were increased somewhat, but not to the level indicated by the new biomass estimates.

1997: setline surveys of the entire Commission area indicated substantially more halibut in western Alaska (IPHC Areas 3B and 4) than the analytical assessment. Biomass in those areas was estimated by scaling the analytical estimates of absolute abundance in Areas 2 and 3A by the survey estimate of relative abundance in western Alaska. CEY estimates increased again, and quotas were increased again, but still to a level well below the CEY's.

1998: the working value of natural mortality was lowered from 0.20 to 0.15, reducing analytical estimates of biomass in Areas 2 and 3A by about 30%. At the same time setline survey estimates of abundance in Areas 3B and 4 relative to Areas 2 and 3A increased, so biomass estimates in the western area decreased by a smaller amount.

1999: setline survey catch rates in the 1990s were adjusted downward to account for the effect of changing to all-salmon bait when the surveys resumed in 1993. This reduced biomass estimates by 20-30%.

Appendix C. Changes made to the assessment model since 1997

The 1997 assessment fully documented in IPHC Scientific Report No. 79. This appendix lists changes made since then.

CHANGES MADE IN 1998

The only major change was a reduction of the natural mortality rate from 0.20 to 0.15, which had the effect, other things being equal, of lowering abundance estimates by about 30%. A number of other changes, listed below, were made in order to make the model more realistic or more fittable, but on balance they did not change any of the abundance estimates by more than 5%.

1. Working value of natural mortality lowered from 0.20 to 0.15.

Analysis done during the year by the staff showed that in the short term an overestimate of natural mortality could lead to a substantial overestimate of stock size when past fishing mortality rates were low, as they have been for Pacific halibut. On the other side, the consequences of an underestimate of natural mortality are less serious. (See the abstract by Clark in this volume.)

The true value of natural mortality is not known. Analysis of catch curves and tagging data in the early 1960's produced a wide range of estimates with a center of 0.15-0.20. Age compositions of commercial catches of fish aged 20-30 in the western Aleutians (Area 4B) in the mid-1990s show an apparent total mortality of 0.24. A small part of this is fishing mortality, and about 0.05 results from an increasing trend in year-class strength among these particular year-classes (spawned during the late 1960's and early 1970's). The remainder is natural mortality, which is therefore something less than 0.20 and perhaps less than 0.15, but probably not much less than 0.15.

2. Break in commercial catchability allowed in the first year of IQ management.

When the model is fitted, commercial catchability is allowed to change from year to year but a prior distribution for the changes is specified and used to calculate a penalty function that is added to the objective function. This serves to prevent large year-to-year changes which would be unrealistic in the absence of a major change in the conduct of the fishery. The implementation of individual quota (IQ) schemes in Canada (1991) and Alaska (1995) was such a major change, so for in those years commercial catchability was allowed to jump with no penalty.

3. Size-at-age data screened and weighted more heavily.

In previous years all available size-at-age data was used but it was down-weighted relative to other data types because some of the estimates of means and variances were based on very small samples and were clearly wild. This year outliers were removed from the data, and the estimates for a given age group in a given year were used only if the sample size was at least 15 (in both the commercial and survey data). In addition, an error that had been present in the calculation of the estimated variance of the estimated variance [*sic*] of length at age in commercial landings, was corrected. Finally, commercial size-at-age data for ages 6-8 were not used in the fit. A large fraction of fish in those age groups are now below the minimum size limit so the mean and variance of the lengths of the few fish of those ages in the commercial catch do not contain much information about the corresponding population parameters. With the size-at-age data cleaned up, there was no reason to down-weight it, so the ISD was reduced from 5 to 2, the same as most other data types.

3. Requirement of full recruitment at age 20 dropped.

In previous years a large penalty was charged if age-specific selectivity at age 20 was less than one, which effectively forced the oldest fish to be fully recruited. An examination of length distributions at age 20 (actually 20+) this year showed a substantial proportion of fish in the 100-120 cm range where recruitment is not complete, so the penalty was dropped. This resulted in a much better fit to recent size-at-age data. The model had been overestimating size at age to meet the full-recruitment requirement.

4. Some parameters not estimated.

In Area 2B, fish appear to be almost fully recruited at the minimum size limit. As a result the two parameters of the commercial selectivity function are poorly defined and attempts to estimate changes over time led to numerical difficulties. To cure those, the slope parameter was fixed (i.e., estimated as a constant).

In Areas 2C and 3A the length at full recruitment to the commercial fishery tended to drift to unrealistically large values, even with a penalty. In order to constrain that parameter, it was estimated as a fixed parameter and bounded.

Changes made in 1999

1. Setline survey catchability increased as of 1993.

It became apparent late in 1999 that setline survey catchability had increased when the survey adopted all-salmon bait when the surveys were resumed in 1993. Preliminary data indicated that catchability might have increased by 25-50%. Model-based estimates of the change averaged 35% (with one of three area-by-area estimates hitting the upper constraint of 50%). That average was used as a fixed value in all areas, implemented as an addition of 0.3 to the log of survey catchability in 1993.

2. Growth equations slightly modified.

The α parameter of the equation for annual growth in median length was modeled as a random walk rather than as a cubic polynomial of time, mainly to improve computational stability.

APPENDIX D. SELECTED ESTIMATES FROM THE 1999 ASSESSMENT

The following tables show trends in recruitment, stock size, and exploitation rate estimated with the model used in 1999. Except for the catches, all of these estimates are liable to change in later years, sometimes dramatically, as new data and methods are used in the assessment.

The columns in the tables are:

R = age 8 recruits (millions)
N = total abundance of age 8+ fish (millions)
C = total catch in number of age 8+ fish (million net lb)
C/N = exploitation rate in number of age 8+ fish
B = total biomass of age 8+ fish (million net lb)
Y = total catch in weight of age 8+ fish (million net lb)
Y/B = exploitation rate in weight

The “catches” are actually total removals except for bycatch. Total biomass is calculated using estimated mean size at age in the sea rather than in the catch, and is not directly comparable with estimates of exploitable biomass.

Area 2AB

	R	N	C	C/N	B	Y	Y/B
1974	0.45	1.71	0.14	0.08	44.55	4.81	0.11
1975	0.45	1.75	0.21	0.12	45.14	7.28	0.16
1976	0.43	1.70	0.21	0.12	49.10	6.69	0.14
1977	0.44	1.66	0.16	0.10	45.84	5.15	0.11
1978	0.52	1.77	0.14	0.08	43.02	4.20	0.10
1979	0.59	1.94	0.16	0.08	39.99	4.66	0.12
1980	0.72	2.20	0.19	0.08	41.96	5.35	0.13
1981	0.80	2.48	0.21	0.08	45.86	5.52	0.12
1982	0.85	2.75	0.22	0.08	49.98	5.51	0.11
1983	1.06	3.20	0.22	0.07	53.73	5.54	0.10
1984	1.29	3.82	0.39	0.10	60.84	9.05	0.15
1985	1.69	4.57	0.48	0.10	65.77	11.20	0.17
1986	1.49	4.92	0.52	0.11	74.18	12.32	0.17
1987	1.67	5.38	0.56	0.10	80.91	13.34	0.16
1988	1.62	5.66	0.60	0.11	78.08	13.75	0.18
1989	1.29	5.55	0.49	0.09	76.01	11.58	0.15
1990	1.14	5.41	0.40	0.07	84.25	9.47	0.11
1991	1.35	5.57	0.30	0.05	98.70	7.98	0.08
1992	1.33	5.77	0.34	0.06	102.94	8.73	0.08
1993	1.06	5.64	0.51	0.09	95.70	12.27	0.13
1994	1.04	5.38	0.47	0.09	88.02	11.22	0.13
1995	2.05	6.21	0.46	0.07	98.86	11.65	0.12
1996	1.77	6.62	0.50	0.08	104.08	11.66	0.11
1997	1.18	6.38	0.63	0.10	104.36	14.49	0.14
1998	1.09	5.95	0.69	0.12	95.85	15.60	0.16
1999	0.74	5.20	0.64	0.12	83.70	15.26	0.18

Area 2C

	R	N	C	C/N	B	Y	Y/B
1974	0.37	1.55	0.13	0.09	44.15	5.51	0.12
1975	0.40	1.59	0.15	0.10	45.54	6.13	0.13
1976	0.45	1.66	0.13	0.08	45.00	5.45	0.12
1977	0.49	1.77	0.08	0.05	47.26	3.17	0.07
1978	0.59	2.03	0.12	0.06	51.29	4.22	0.08
1979	0.66	2.28	0.13	0.06	52.91	4.58	0.09
1980	0.83	2.65	0.10	0.04	58.98	3.49	0.06
1981	0.89	3.07	0.13	0.04	68.89	4.25	0.06
1982	0.82	3.33	0.11	0.03	76.29	3.91	0.05
1983	0.83	3.58	0.19	0.05	82.87	6.83	0.08
1984	0.96	3.85	0.19	0.05	89.08	6.32	0.07
1985	1.27	4.39	0.29	0.07	93.65	10.03	0.11
1986	0.96	4.46	0.37	0.08	97.25	11.63	0.12
1987	1.03	4.49	0.35	0.08	93.66	11.75	0.13
1988	0.97	4.48	0.39	0.09	92.72	12.49	0.13
1989	0.83	4.31	0.34	0.08	87.15	11.15	0.13
1990	0.76	4.13	0.33	0.08	90.20	11.19	0.12
1991	0.88	4.10	0.31	0.07	92.79	11.16	0.12
1992	0.88	4.07	0.35	0.09	88.58	12.00	0.14
1993	0.70	3.85	0.37	0.10	83.00	13.33	0.16
1994	0.64	3.59	0.38	0.10	79.68	12.58	0.16
1995	1.31	4.02	0.23	0.06	85.26	9.47	0.11
1996	1.11	4.33	0.30	0.07	84.01	10.35	0.12
1997	0.67	4.09	0.35	0.09	79.39	11.58	0.15
1998	0.52	3.69	0.44	0.12	71.58	12.86	0.18
1999	0.47	3.22	0.42	0.13	61.07	11.95	0.20

Area 3A

	R	N	C	C/N	B	Y	Y/B
1974	0.82	3.32	0.17	0.05	103.58	8.10	0.08
1975	1.00	3.59	0.22	0.06	112.10	10.43	0.09
1976	1.18	3.99	0.23	0.06	120.81	10.92	0.09
1977	1.26	4.39	0.18	0.04	127.98	8.73	0.07
1978	1.52	5.03	0.24	0.05	152.50	10.35	0.07
1979	1.38	5.40	0.27	0.05	167.46	11.34	0.07
1980	1.70	5.95	0.27	0.05	175.63	12.28	0.07
1981	2.12	6.85	0.33	0.05	197.50	14.76	0.07
1982	1.92	7.37	0.30	0.04	218.68	14.10	0.06
1983	2.03	7.97	0.35	0.04	246.48	14.91	0.06
1984	2.43	8.90	0.51	0.06	251.25	20.56	0.08
1985	3.33	10.44	0.57	0.05	266.25	22.77	0.09
1986	2.95	11.37	0.92	0.08	288.71	36.21	0.13
1987	3.67	12.53	0.93	0.07	303.76	34.42	0.11
1988	4.54	14.38	1.22	0.09	338.05	41.93	0.12
1989	3.58	14.69	1.11	0.08	323.82	37.88	0.12
1990	3.19	14.71	0.98	0.07	298.26	33.09	0.11
1991	4.15	15.75	0.94	0.06	279.12	28.87	0.10
1992	3.39	15.88	1.02	0.06	267.55	31.70	0.12
1993	2.57	15.16	0.97	0.06	238.86	28.62	0.12
1994	1.93	13.98	1.08	0.08	224.63	30.38	0.14
1995	2.78	13.67	0.81	0.06	226.79	22.95	0.10
1996	1.99	12.91	0.87	0.07	224.29	24.74	0.11
1997	1.02	11.25	1.02	0.09	208.17	30.34	0.15
1998	0.94	9.59	1.13	0.12	175.50	31.07	0.18
1999	0.50	7.63	1.22	0.16	139.00	30.75	0.22