INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC–2021–SAHC–002
Last Update: 01 Oct 2021

Historical Coastwide IPHC Stock Assessments: 1988 to 1997 – *Compendium of documents*

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LIST OF DOCUMENTS FOR THE 1988 TO 1997 HISTORICAL COASTWIDE IPHC STOCK ASSESSMENTS

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Population Assessment, 1997

by

Patrick J. Sullivan and Ana M. Parma

INTRODUCTION

A new assessment procedure was introduced in 1996 which accounts for changes in individual growth that likely induce changes in fishing selectivity. In addition, IPHC setline survey data (CPUE, proportion at age, size at age) and area-specific legal-sized bycatch mortality data were added to the procedure. The new approach takes a model for growth, the additional information from surveys and bycatch observations, and brings in commercial catch-at-age and CPUE data to determine the current and historical status of the Pacific halibut population (Figure 1).

In 1997 the assessment procedure was reviewed by a panel of three external assessment scientists, as part of the ongoing process of evaluation. The panel recommended caution in implementing quotas based on the new procedure and made several other suggestions, some of which have already been incorporated into the current assessment. One such recommendation was to more fully communicate assumptions reflecting uncertainty seen in this assessment. This year we examine two assumptions concerning how survey selectivity is believed to operate.

ASSESSMENT UNCERTAINTY

The assessments discussed in this report cover three regions where both commercial catch and long term survey observations are available, namely IPHC Areas 2A-2B, 2C, and 3A. An age-size structured assessment for Area 3B (for which there are no longer-term setline survey statistics) is also provided. An alternative, survey-scaled assessment for Area 3B, and a survey-scaled assessment for Area 4, are discussed in a separate report in this document (Trumble and Hoag, 1998[Unpub]).

Uncertainty about how survey selectivity operates is particularly relevant to the 2A-2B, 2C, and 3A assessments. Surveys are designed to provide a consistent mechanism for taking observations over time so that changes in population density are reflected directly in the survey catches per skate, rather than changes due to gear configuration or targeting. However, fish behavior influences the likelihood of fish capture at different sizes and life stages. If the chances of a halibut getting caught were simply a function of size, where for example larger fish might be more likely to get hooked, then in a fishery where individual size at age is dropping one would expect the selectivity at size to remain constant while selectivity at age would drop. If, however, the chances of a halibut getting caught were more a function of age, where for example halibut gradually appeared on the grounds after reaching age eight, say, then with size at age dropping one would expect the selectivity at age to still remain constant despite the lower size of the fish.

In a commercial fishery with a minimum size limit, a decrease in selectivity at age with a decrease in size is expected. In the survey (which captures and measures all fish) we expect that selectivity reflects primarily the different vulnerability of fish of different sizes, which presumably would stay constant over time. Yet we see consistent differences in estimated selectivity between

Sullivan, P.J., Parma, A.M., 1998. Population assessment, 1997.
IPHC Rep. Assess. Res. Act. 1997., pp. 83–210.

areas (in particular between Areas 2B and 3A, see Figure 2), despite the fact that the same gear is used throughout all survey areas. These differences indicate that other factors besides size affect selectivity, such as the availability of fish of different ages on the fishing grounds for example.

Because this uncertainty cannot be resolved at present, two assessments were conducted for each of the three regulatory areas for which long term surveys were available: one assumes that survey selectivity *at age* stayed constant while size at age was decreasing, and the other assumes that survey selectivity *at length* stayed constant (Figure 3). The differences in the assessments are greatest for the most recent four to five years, and are most significant for the Area 3A assessment, where the decrease in individual size at age has been greatest. The constant-age-selectivity estimates are lower than the constant-length-selectivity estimates. The abundance of smaller, newly-recruited halibut is estimated to be much larger under the assumption of constant size-specific selectivity.

It seems likely that survey selectivity actually operates somewhere in between these two extremes. Until this issue can be resolved, we believe halibut biomass estimates are best viewed as bounded by these two sets of estimates.

STOCK ASSESSMENT

Commercial catch per unit effort increased substantially in Areas 2A, 2B, 2C, and 3B in 1997, increasing by 22%, 10%, 17%, and 13% in each area over 1996 levels. Some decline was seen in Areas 3A and 4 (-1% and -5% respectively). Coast wide this amounts to about a 10% increase, keeping steady a trend seen since 1994 (Figures 4-10). IPHC setline survey data in 1997 showed a 10% decline for the combined Area 2A-2B, a 20% increase for Area 2C, and 32% increase for Area 3A, the later rebounding from a significant drop observed in the previous year. Survey statistics tend to show more year-to-year variation as indicators, as they represent only a fraction of the annual removals. As indicated elsewhere in this report, commercial catch increased substantially this year in response to the new higher quotas set last January.

Estimated exploitable biomass of Pacific halibut remains high in all areas. This is consistent with upward trends shown in both survey and commercial CPUE indicators, which are used as inputs to the assessments. The Area 3A estimate under the constant-survey-selectivity-at-age assessment shows a sharp drop both in total biomass as well as in eight-year-old abundance. In contrast, under the constant-survey-selectivity-at-length assessment, both total biomass and eight-year-old abundance appear to remain stable. It will be several years before we will be able to recognize which of the two estimates is closest to being correct.

Inconsistencies can be noted between the relative abundance of Areas 3A and 3B as estimated in independent size-age structured assessments and those estimated using relative abundance from research surveys. The independent estimates, shown in this document, indicate that Area 3B exploitable biomass is roughly 30% of that estimated for Area 3A. IPHC setline survey and NMFS trawl survey averages conducted over the two areas, on the other hand, indicate that Area 3B exploitable biomass should be roughly 60% of that shown for Area 3A. No merging of these data has yet brought about an estimate that is consistent with all available information. However, estimates are now available (Trumble and Hoag, 1998) that use the survey relative abundances, excluding Area 3B catch at age and size data. Differences between the independent and survey-scaled assessments will continue to be examined and caution should be exercised.

The 1987 year class, shown as eight-year-olds in 1995, continues to appear strong coast-wide, while area-specific estimates indicate that the relative strength of this year class increases moving south into Area 2 (Figure 11). The reason for the difference in relative strength between areas is not known, but differential migration by a single year class to each area is one possibility. Differential survivorship of local recruits due to environmental conditions is another.

Bering Sea NMFS trawl survey data show the 1987 year class of halibut, present as ten-year-olds in the 1997 halibut fishery, to be the strongest year class in abundance in recent history. However, these halibut remain relatively small at age. Year classes subsequent to 1987 appear not to be as strong in number.

Weight at age appears to be showing an increase, especially for Areas 2C, 3A, and 3B, as shown by area specific average weight at age 12 (Figure 12). It is still not clear what may be causing the increase, but as individuals gain in weight so is there a gain in population biomass.

SETLINE CEY CALCULATION

Two constant exploitation yield (CEY) tables are presented here for use in formulating management options (Tables 1 and 2). The two tables reflect the two alternative assumptions about survey selectivity (constant selectivity at age versus constant selectivity at length) discussed in the previous sections. The format for the two tables is the same. The 1997 directed commercial setline quota and catch are presented first, with IPHC setline survey removals included in the catch. Exploitable biomass estimates are provided next. These are estimated from biomass at age multiplied by coast-wide selectivity at age as used in the harvest rate evaluation conducted last year. A 20% harvest rate is applied to this biomass to derive the total allowable CEY shown. Sport catch, wastage, subsistence, and legal-sized bycatch removals are then accounted for and removed from the total CEY values to arrive at the Setline CEY values for the directed commercial fishery.

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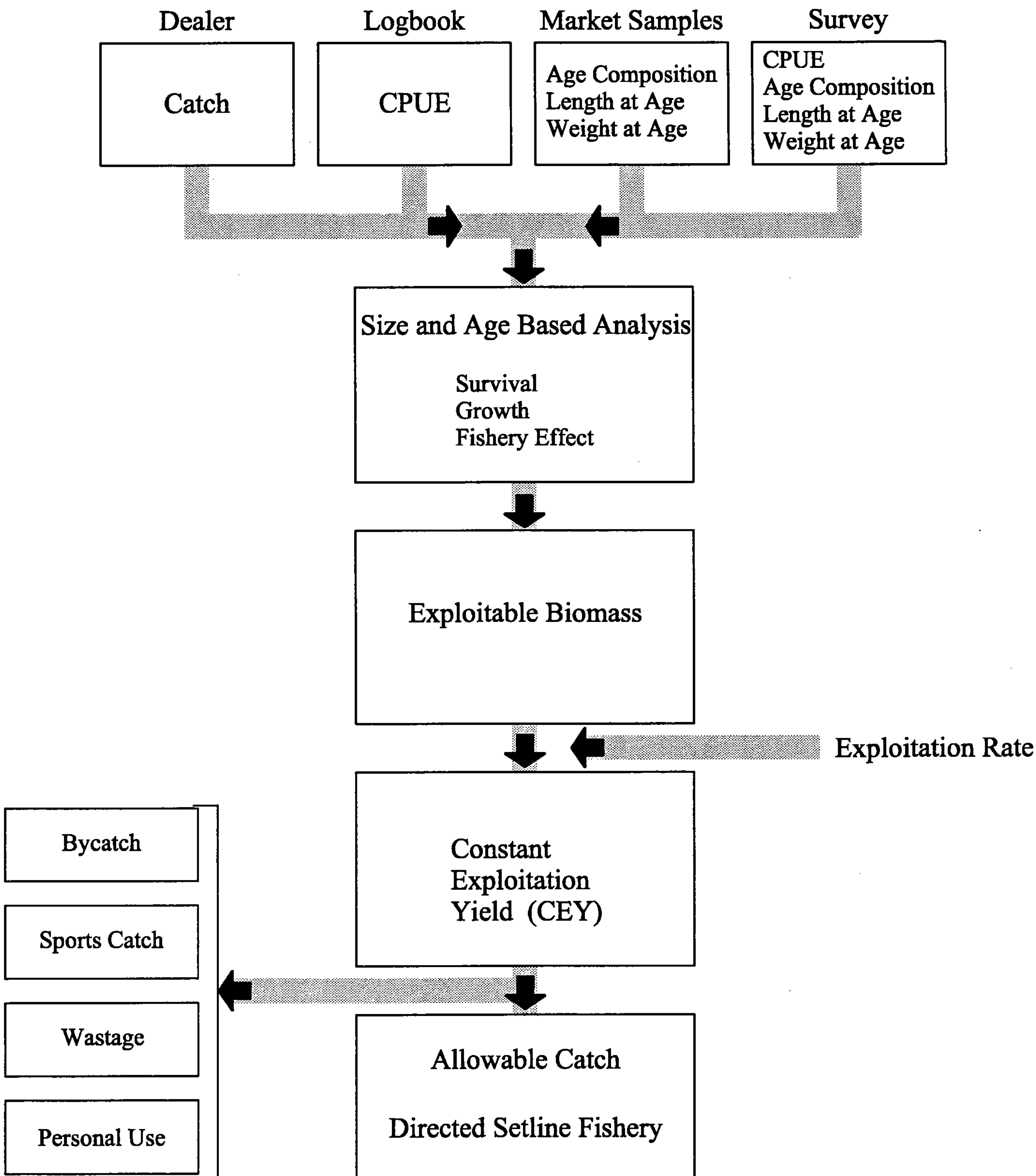

Figure 1. Overview of Pacific halibut stock assessment procedure.

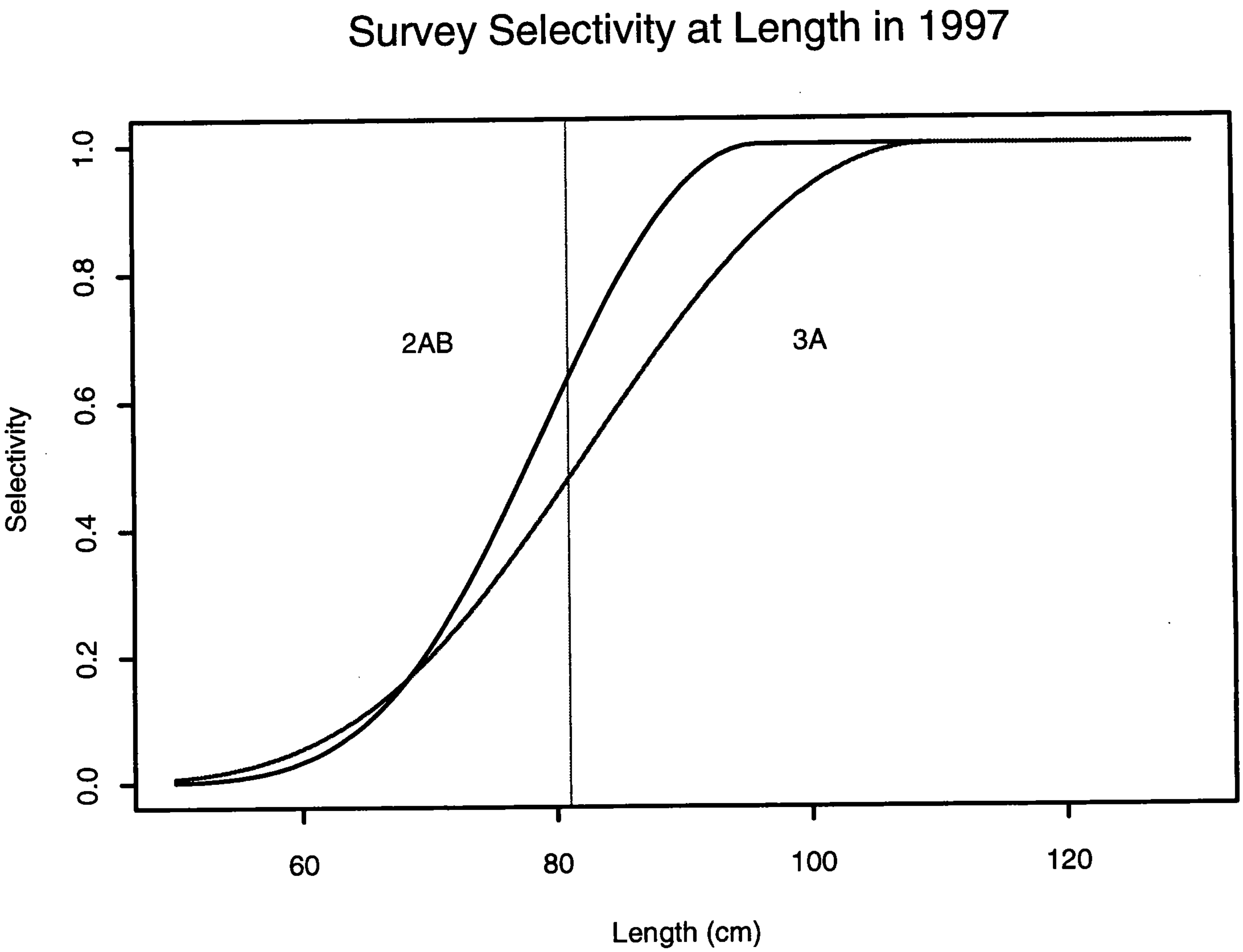

Figure 2. **Comparison of survey selectivity at length between Areas 2AB and 3A from assessments assuming constant survey selectivity at length.**

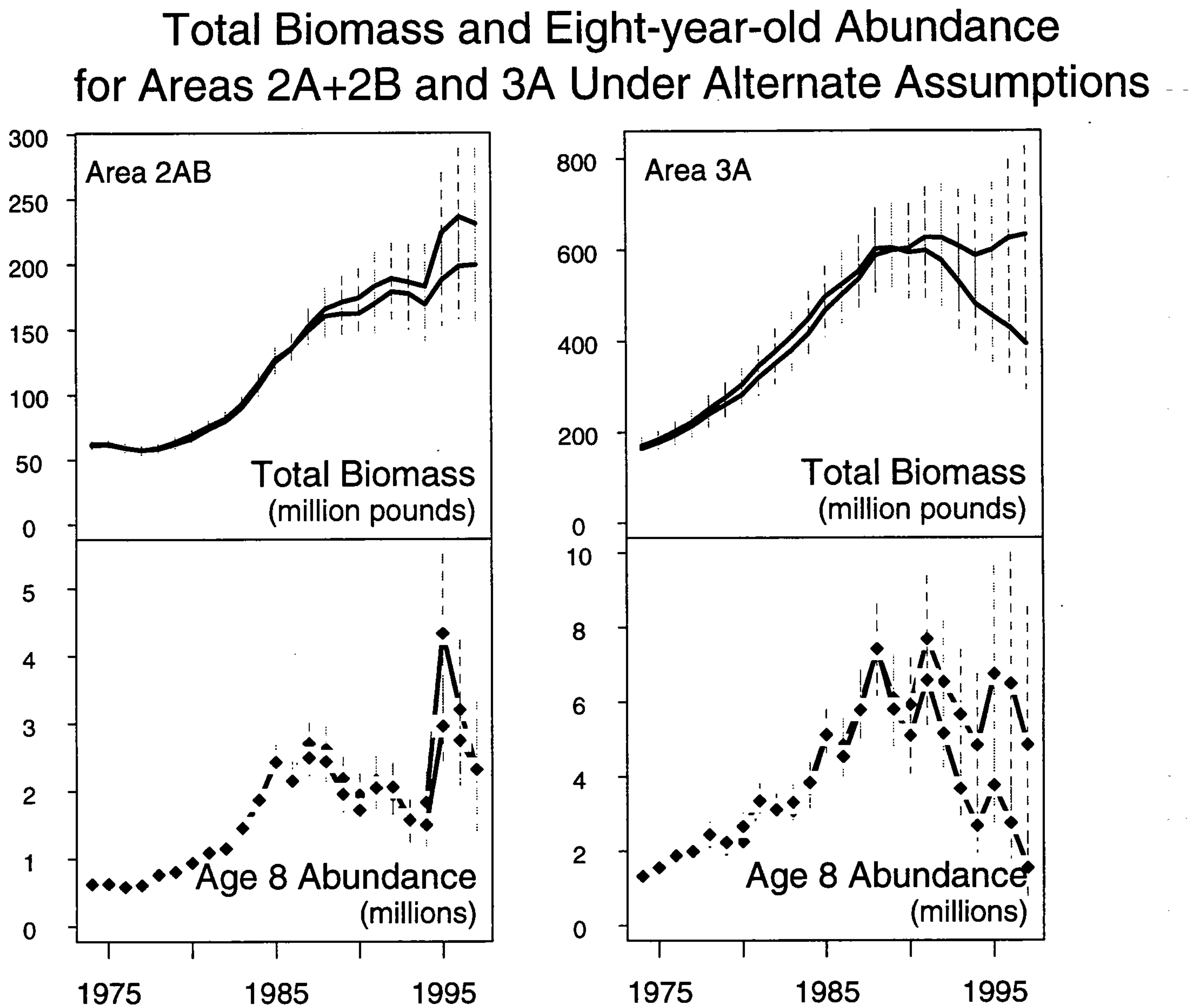

Figure 3. **Total biomass (age 8 and older) and eight-year-old abundance for Area 2A+2B and Area 3A for alternate assumptions about survey selectivity. Upper points and lines are from assessment assuming constant selectivity at length in the survey, while lower points and lines are from assessment assuming constant selectivity at age in the survey.**

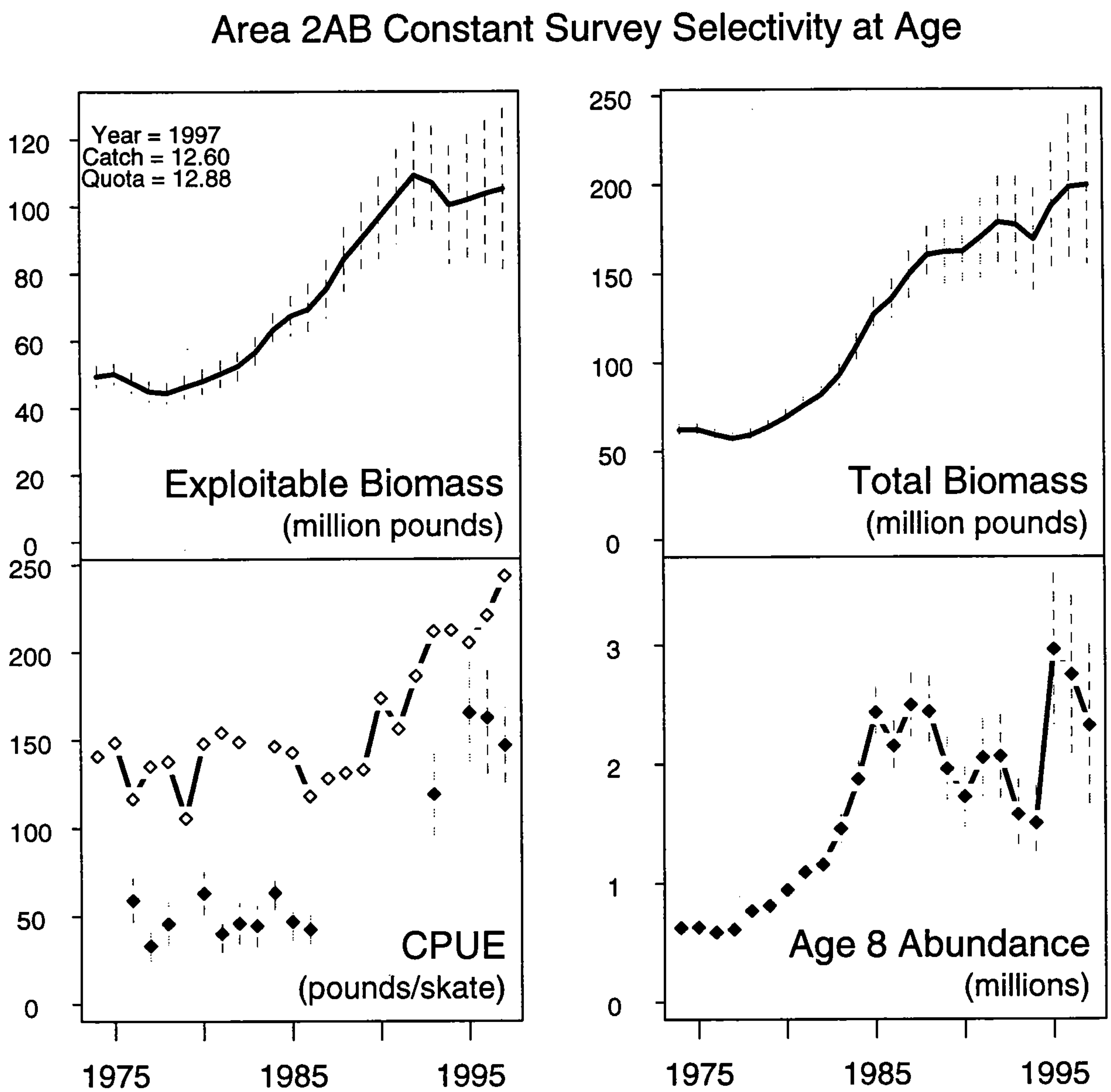

Figure 4. **Exploitable biomass, total biomass, commercial and survey CPUE, and abundance at age 8 of Pacific halibut for Area 2A and 2B combined from an age-size structured model assuming constant survey selectivity at *age.* Confidence bounds represent 95% intervals conditioned on model structure. Open CPUE diamonds are commercial and solid CPUE diamonds are survey.**

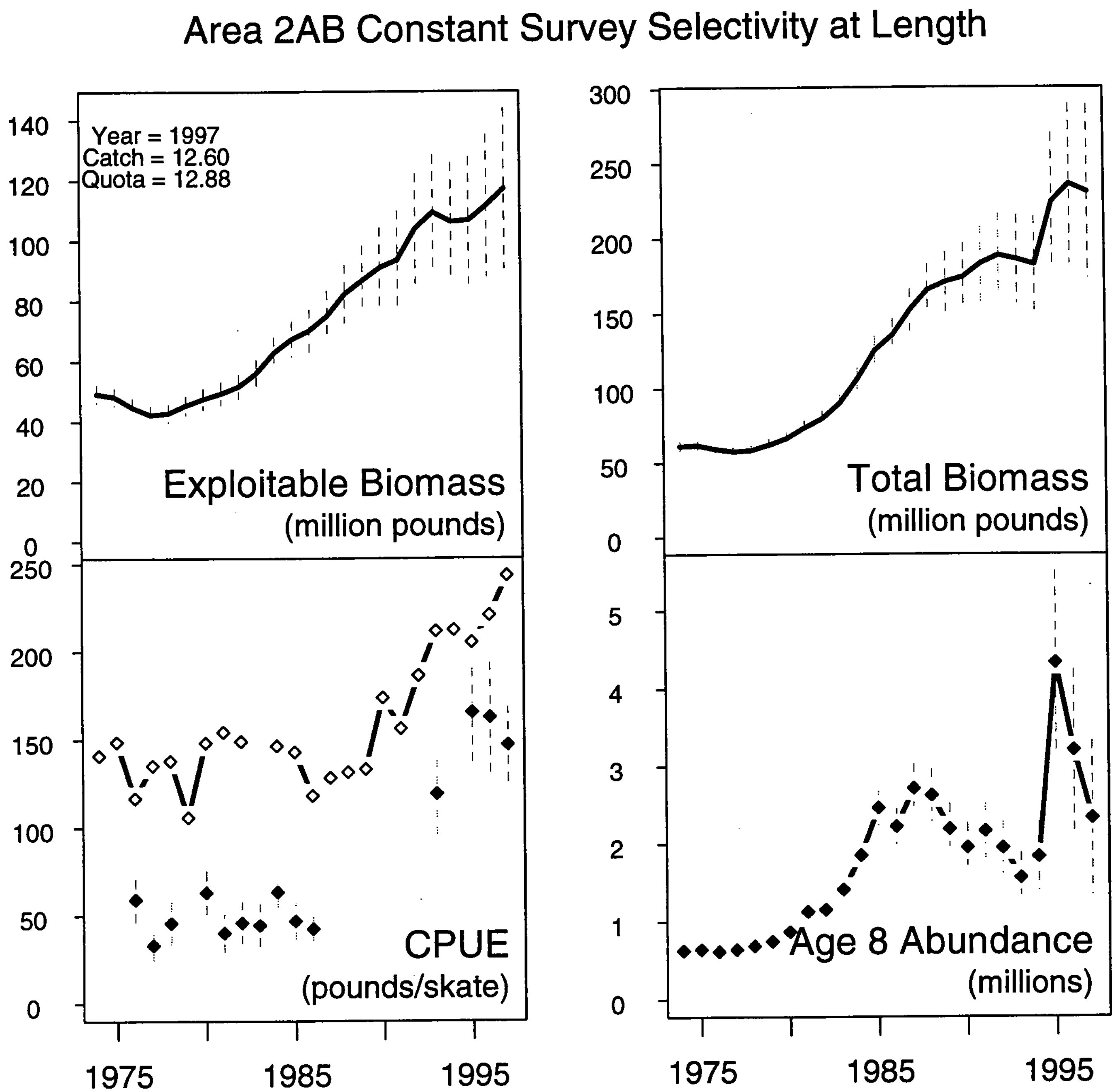

Figure 5. **Exploitable biomass, total biomass, commercial and survey CPUE, and abundance at age 8 of Pacific halibut for Area 2A and 2B combined from an age-size structured model assuming constant survey selectivity at *length*. Confidence bounds represent 95% intervals conditioned on model structure. Open CPUE diamonds are commercial and solid CPUE diamonds are survey.**

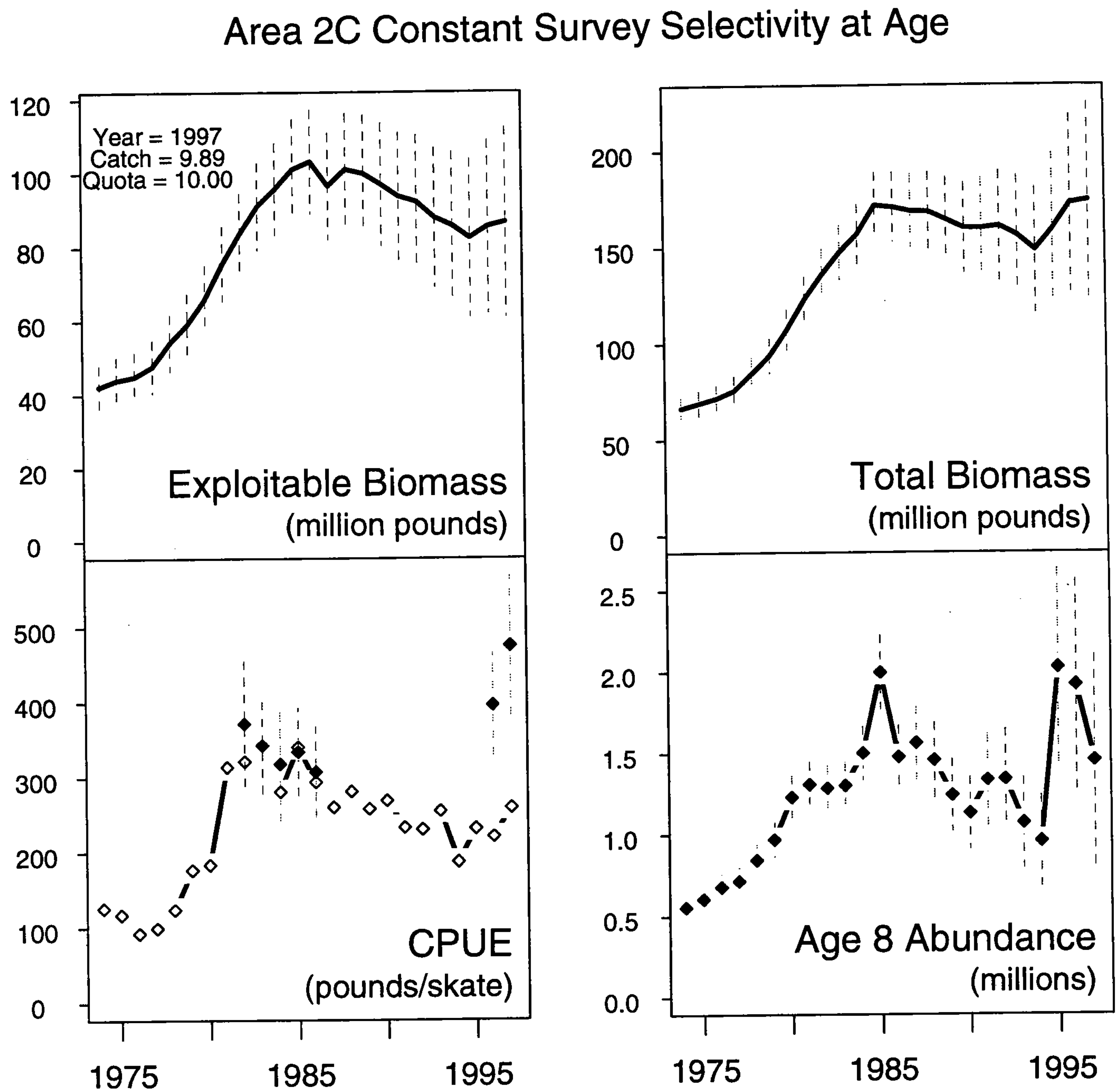

Figure 6. **Exploitable biomass, total biomass, commercial and survey CPUE, and abundance at age 8 of Pacific halibut for Area 2C from an age-size structured model assuming constant survey selectivity at *age*. Confidence bounds represent 95% intervals conditioned on model structure. Open CPUE diamonds are commercial and solid CPUE diamonds are survey.**

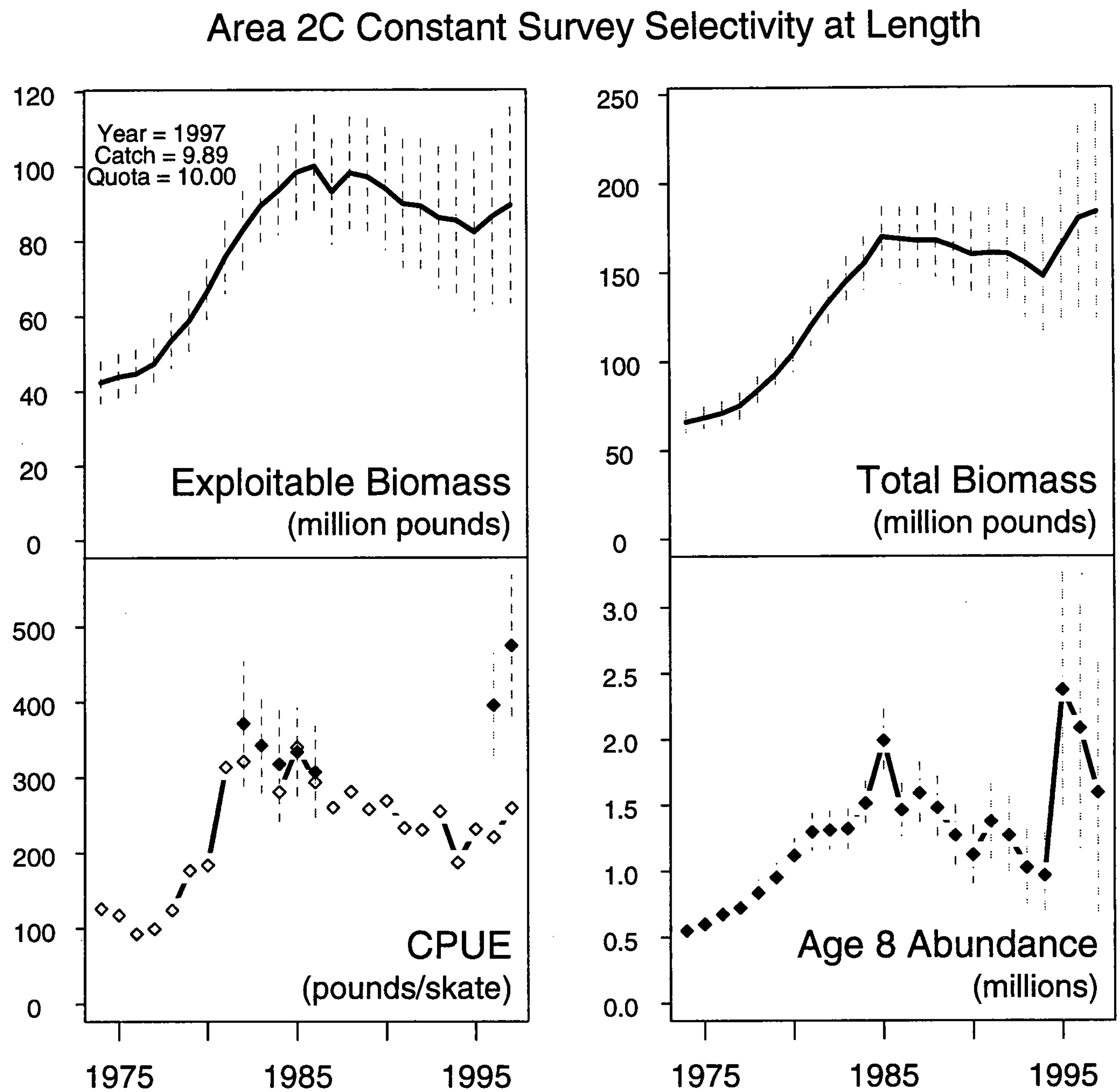

Figure 7. **Exploitable biomass, total biomass, commercial and survey CPUE, and abundance at age 8 of Pacific halibut for Area 2C from an age-size structured model assuming constant survey selectivity at *length.* Confidence bounds represent 95% intervals conditioned on model structure. Open CPUE diamonds are commercial and solid CPUE diamonds are survey.**

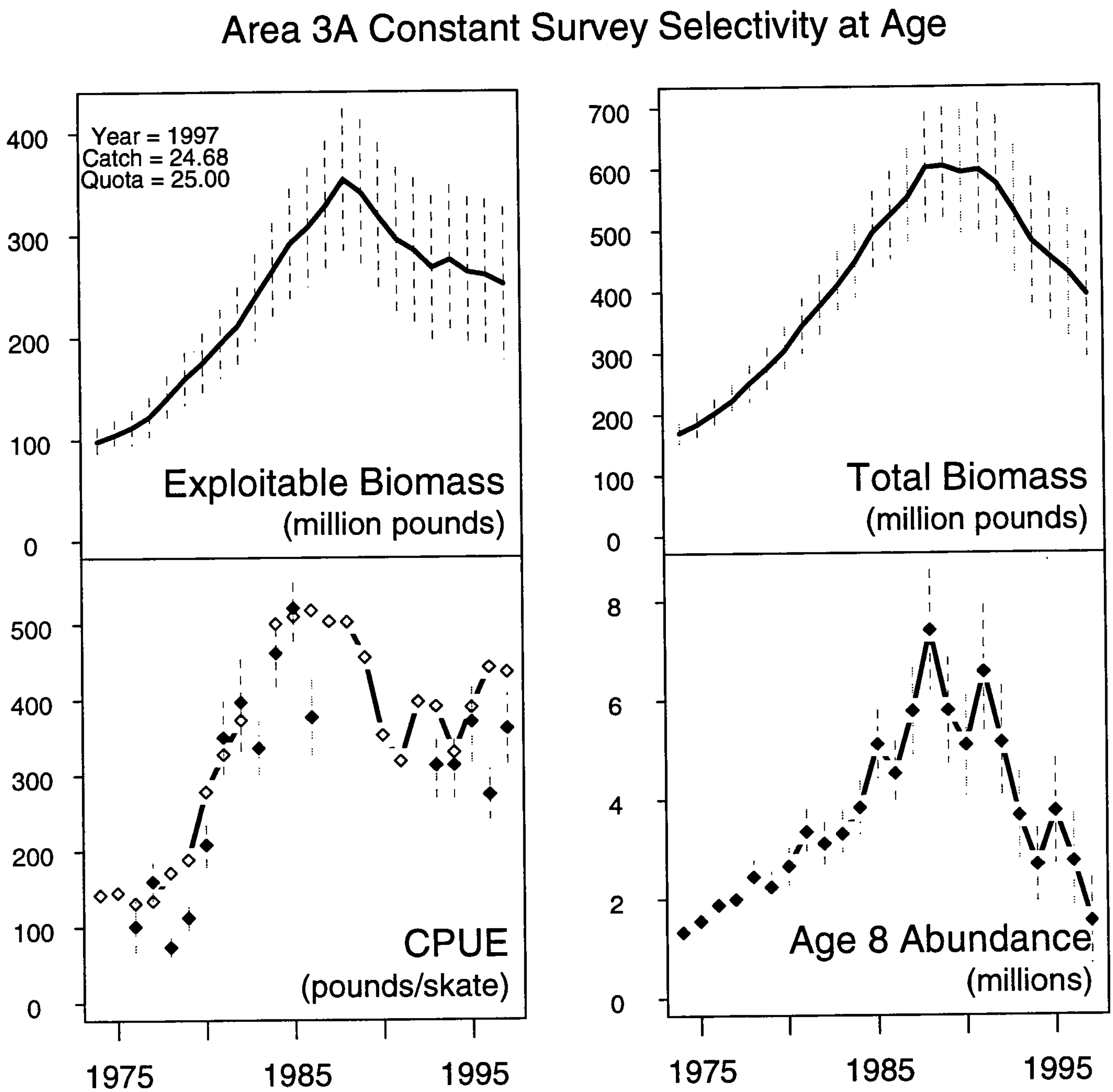

Figure 8. **Exploitable biomass, total biomass, commercial and survey CPUE, and abundance at age 8 of Pacific halibut for Area 3A from an age-size structured model assuming constant survey selectivity at *age.* Confidence bounds represent 95% intervals conditioned on model structure. Open CPUE diamonds are commercial and solid CPUE diamonds are survey.**

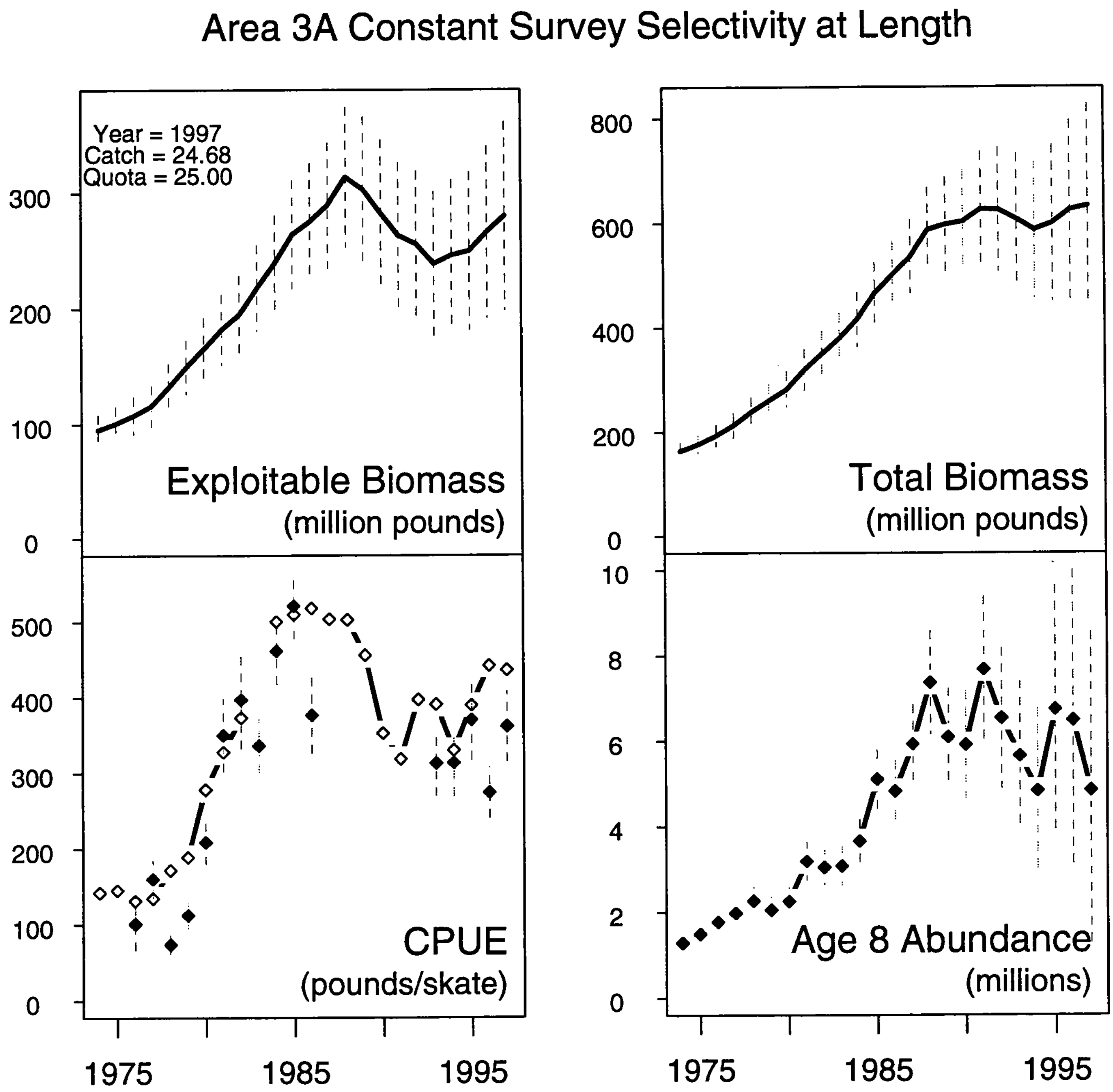

Figure 9. **Exploitable biomass, total biomass, commercial and survey CPUE, and abundance at age 8 of Pacific halibut for Area 3A from an age-size structured model assuming constant survey selectivity at *length*. Confidence bounds represent 95% intervals conditioned on model structure. Open CPUE diamonds are commercial and solid CPUE diamonds are survey.**

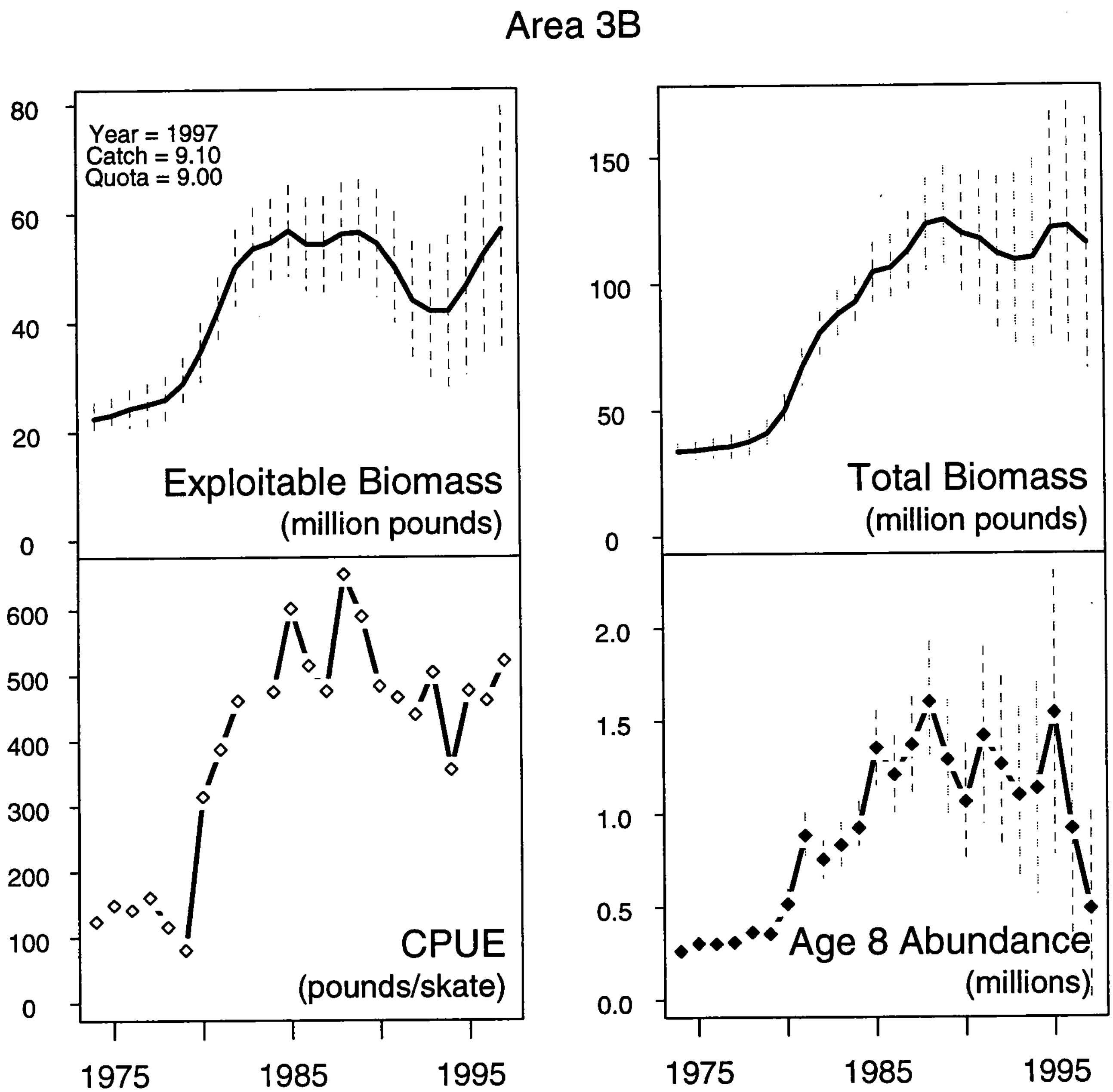

Figure 10. **Exploitable biomass, total biomass, commercial and survey CPUE, and abundance at age 8 of Pacific halibut for Area 3B from an age-size structured model. No setline survey series available. Confidence bounds represent 95% intervals conditioned on model structure.**

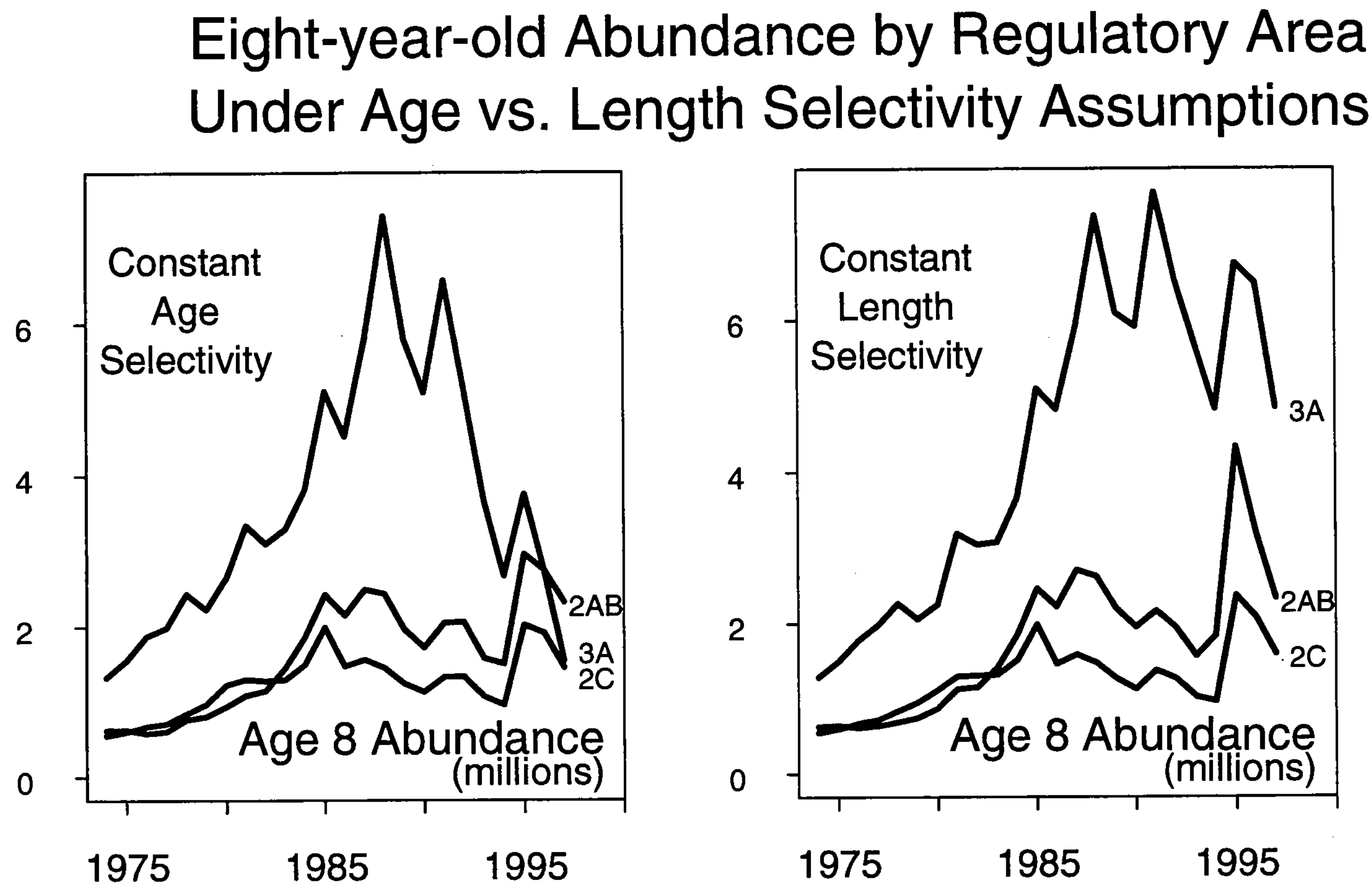

Figure 11. **Estimated abundance of eight-year-old Pacific halibut for each regulatory area for which there is long-term survey data. Estimates result from an assessment where survey selectivity at age is assumed constant and an assessment where survey selectivity at length is assumed constant.**

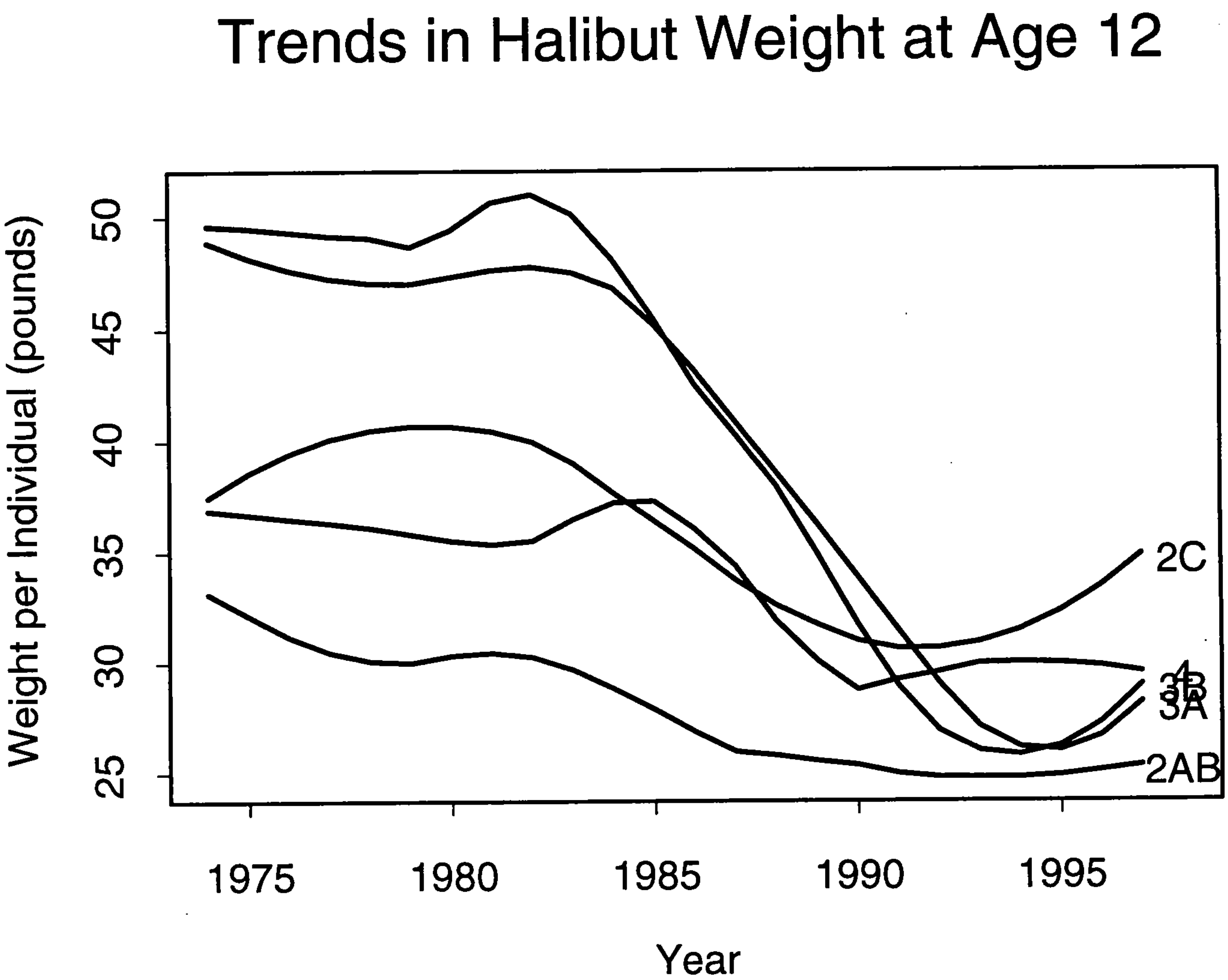

Figure 12. **Smoothed weight at age by year for twelve-year-old Pacific halibut by IPHC regulatory area.**

Table 1. **Setline CEY under constant harvest rate policy, 20% exploitation rate Constant survey selectivity at age**

	2A	2B	2C	3A	3B
1997 Quota[1]	0.70	12.50	10.00	25.00	9.00
1997 Catch[2]	0.77	12.20	9.89	24.68	9.10
Biomass	7.18	82.56	88.49	227.22	60.95
Rate	0.20	0.20	0.20	0.20	0.20
CEY	1.44	16.51	17.70	45.44	12.19
Sport	0.00	0.66	1.83	5.42	0.02
Waste	0.01	0.04	0.04	0.07	0.06
Bycatch	0.38	0.14	0.26	1.15	0.59
Subsistence	0.00	0.30	0.09	0.10	0.04
Total Removals	0.39	1.13	2.22	6.74	0.70
Setline CEY	1.05	15.38	15.48	38.71	11.49

[1] Area 2A quota includes commercial, sport, and treaty quota (including C & S).
[2] Area 2C catch includes Metlakatla catch of 88,000 pounds.
IPHC setline survey catch included in all areas.

**Table 2. Setline CEY under constant harvest rate policy, 20% exploitation rate
Constant survey selectivity at length**

	2A	2B	2C	3A
1997 Quota[1]	0.70	12.50	10.00	25.00
1997 Catch[2]	0.77	12.20	9.89	24.68
Biomass	8.44	97.08	92.58	348.25
Rate	0.20	0.20	0.20	0.20
CEY	1.69	19.42	18.52	69.65
Sport	0.00	0.66	1.83	5.42
Waste	0.01	0.04	0.04	0.07
Bycatch	0.38	0.14	0.26	1.15
Subsistence	0.00	0.30	0.09	0.10
Total Removals	0.39	1.13	2.22	6.74
Setline CEY	1.30	18.29	16.29	62.91

[1] Area 2A quota includes commercial, sport, and treaty quotas (including C & S).
[2] Area 2C catch includes Metlakatla catch of 88,000 pounds.
IPHC setline survey catch included in all areas.

Population Assessment, 1997
Technical Supplement

by

Patrick J. Sullivan and Ana M. Parma

INTRODUCTION

The discussion, figures, and tables presented here provide additional information on some technical aspects of the stock assessment. Tables 1-5 show data that are input to the assessments. Tables 6-13 show outputs from the assessments. The table number postscripts A and L correspond respectively to outputs from the constant-survey-selectivity-at-age and constant-survey-selectivity-at-length assumptions described in the Population Assessment document. Note, however, that for Area 3B, for which no time series of surveys are available, tables contain a standard size-age structured assessment while the 3B column in the L tables are left blank.

Exploitable biomass estimates are now given as a function of year-specific estimated selectivity, while the projections shown for 1998 and used in the CEY tables use an average of 2B and 3A fixed selectivities as were used in the evaluation of alternative harvest rates. Selectivity values for ages 6 and 7 were set to zero in these computations because these age classes are scarcely represented in the catches and so their estimated abundances in the last year are extremely uncertain. Total biomass represents all halibut ages 8 and older. Recruitment is now presented in terms of total abundance of eight-year-old halibut.

SMOOTHED WEIGHT AT AGE

Abundance of Pacific halibut is estimated from catch data in numbers, not weight. In order to compute biomass values (e.g. exploitable biomass, total biomass) the abundance at age estimated by the model is multiplied by weight at age. Data on weight at age are derived from annual market sample data on individual length at age, using the standard conversion to net weight (Clark, 1992).

The market sample estimates of weight vary from one year to the next in part as a result of sampling error and variability in the fishing process. Such variation, if not accounted for, would result in greater year-to-year variation in biomass estimates and associated quota recommendations than should be expected from actual changes in weight at age and abundance in the population. In order to reduce this sampling variation a smoother is typically applied to the sample weight-at-age estimates. The smoother that is used is *loess*, a type of locally-weight regression that is implemented in Splus and discussed by Chambers and Hastie (1992). This smoother has been used on halibut data since the 1994 assessment, replacing the Fortran Velleman smoother (Sullivan et al. 1995[Unpub]). The *loess* smoother uses a symmetric kernel that is robust to outliers. A span of 0.75, referring to the width of the kernel or the amount of information out of the total used for the local regression, was the default smoothing parameter.

An examination of the effect of the smoother, and the choice of the smoothing parameter indicates that weight at age may in fact be changing faster than what can be tracked by the smoother with a 0.75 span. Figure 1 shows three *loess* smoothed fits. Two use a span of 0.75 but are applied with and without the 1997 data point. Neither adequately catch the most recent upturn in weight at age because the smoother is averaging over too wide a window. Reducing the span to 0.5 provides a better fit to what appears to be the true signal on weight change. A span of 0.5 was applied to weights at age for all areas this year. For Area 3A this results in about a 7-10% increase in biomass estimates. In the future, a span that changes annually resulting in a constant number of years in the kernel might be considered. With 24 years (1974-1997) a span of 0.5 results in a symmetrically weighted smooth on 12 years worth of data. The smoother automatically adjusts for reduced data on endpoint estimates.

TRENDS IN COMMERCIAL CATCHABILITY

Background

Trends in commercial catchability are included in the assessment model by letting the log-catchability change as a random walk with constant variance equal to 0.03^2 (Parma and Sullivan, this volume). Thus relative changes in catchability from year to year are log-normally distributed with a coefficient of variation roughly equal to 0.03. While this level of variation may be sufficient to capture long-term, gradual trends in the fishery, one would expect a more abrupt change associated with the transition to individual quotas. To explore the effect of such a possibility on the biomass estimates, alternative assessment runs were done by breaking the time series of log-catchability in the year when the fishery switched to individual quotas (1992 in British Columbia and in 1996 in Alaska). This is equivalent to assuming an infinite variance for the random walk at the year of the transition. This sensitivity analysis was only conducted for the age-based survey selectivity assumption.

Results

Allowing for a break in the catchability time series resulted in biomass estimates that are somewhat lower than the baseline estimates (for constant survey selectivity at age) except in Area 3B. The change in exploitable biomass estimated for 1997 relative to the baseline value was -6% for Areas 2A-2B, -7% for Area 2C, -7% for Area 3A, and a 4% increase in Area 3B. Similar changes resulted in the estimates of total biomass. In Areas 2C and 3A a relative increase in catchability of 18% and 36%, respectively, was estimated for the year of transition to individual quotas. The analysis suggests that the recent upturn in CPUE might in part be explained as a change in catchability, and that biomasses shown in the baseline assessments might be overestimated as a result.

We plan to incorporate this break in catchability in future assessments and expect the estimates of the relative change in catchability to improve as the data series expands, especially if surveys continue to be conducted annually.

COMPARISON WITH NMFS TRAWL SURVEY DATA

Several attempts have been made to include NMFS trawl survey data into the age-size structured assessments. But analysis of results from these attempts indicate inconsistencies that have as yet to be resolved. Figure 2 compares estimates of abundance of 80-90 cm halibut derived for Area 3A from NMFS trawl survey data (Clark and Walters, 1997[Unpub]) with output from Area 3A size-age structured assessments (under both assumptions: constant setline survey selectivity at length and constant setline survey selectivity at age; see Sullivan and Parma, 1998[Unpub]). Note that while there is a general upward trend in both sets of abundance estimates, the increase is greater in the NMFS indexes. The area swept abundance estimates for the most recent years are substantially larger than those obtained from the size-age structured model (which do not include the trawl survey information) and are comparable for earlier years. If relative trends indicated by the trawl survey results are correct, then the size-age structured procedure may be greatly underestimating the strength of the incoming year classes. An upward correction of the size-age structured estimates in subsequent years might confirm this, but hypotheses as to why the two differ should still be explored.

AREA 3B SIZE-AGE STRUCTURED ESTIMATION

The Area 3B size-age structured assessment provides estimates of stock biomass which appear inconsistent with independently derived relative measures. IPHC setline surveys and NMFS trawl survey data indicate that Area 3B abundance should be roughly 60% of that estimated for Area 3A, while size-age structured analyses indicate that Area 3B is roughly 30% of that estimated for Area 3A in recent years. This inconsistency is not unique to the new assessment model, but was also present when biomass was estimated using CAGEAN. Basically the age compositions of the commercial catches in Areas 3A and 3B are similar with, if anything, a greater buildup of older fish in Area 3A (Figure 3). This, coupled with similar CPUE trends (Figure 4), would suggest that relative exploitation levels have been comparable, as indicated by the catch-at-age assessments. But this is inconsistent with surveys showing relatively more halibut in 3B.

The inconsistency between these estimates has not yet been resolved. However, several possible explanations exist. A few will be explored here. The focus tends to be on the Area 3B size-age structured estimates, since no long-term survey data exist for these, and so their uncertainty is much greater than that associated with the estimates for Area 3A. However, we cannot rule out the possibility that Area 3A might be overestimated.

One scenario is that the trends in commercial CPUE for Area 3B, the only abundance index used in the size-age structured assessment, are not representative of the true trends in biomass. Some justification for suspecting the commercial CPUE data can be found in that a shift in effort and associated catch is occurring towards areas bordering the 3A-3B regulatory area boundary (Figure 5). Such shifts were expected, and seen, in Area 2B which underwent a change to individual quotas in 1991 (Sullivan and Rebert, 1998). However, commercial CPUE indexes remain comparable between areas over years, with Area 3B currently showing moderately higher CPUE relative to Area 3A (Figure 4).

A second scenario worth exploring involves the possibility of localized depletion. Because fishing effort tends to concentrate on some portions of the area occupied by the stock, not all fish may be available to fishing. Local depletion may result in age compositions and CPUE trends that are not representative of the whole stock but only of the fraction available. If local depletion can explain why the size-age structured assessment has consistently underestimated the stock in Area 3B, then one would expect a buildup of older halibut on the grounds that are less frequented by the fleet. However, the age composition of the catch from the 1996 IPHC survey in Area 3B, which covered all the area occupied by halibut and so should reflect the age composition of the stock as a whole, is very similar to the age composition of the commercial catch in that year (Figure 3). In particular, a greater abundance of older halibut does not show up in the survey data relative to the commercial.

A final scenario to examine is that adult movement might take place between grounds whereby halibut continue to migrate from 3B to 3A as they get older. While this would not be a problem for the estimates in Area 3A, as the model allows for fish to become gradually selected (available) with age, the resulting estimates for 3B would be too low. To explore this scenario the size-age assessment model for Area 3B was modified to allow differential migration out of 3B (i.e. into Area 3A). This was done by allowing the value of the natural mortality parameter to vary with age, increasing it from the constant 0.2 assumption to a level consistent with the additional loss indicated by migration levels put forth in Table 4 of Quinn et al. (1985). The authors report a range in migration rates from 4% to 7%, with rates decreasing as age increases. This alternative assessment resulted in only about a 15% increase in exploitable biomass (Figure 6 and Table 12). Much higher migration rates (and consequent increases in 3B biomass levels) would be needed to match the relative biomass levels shown by the survey comparisons. That halibut continue to move from 3B to 3A as adults seems a likely scenario to explore further. However, the magnitude of the differences shown by the survey comparisons suggest that this may be only part of the problem. .

Data for Area 3A and 3B were combined to get an assessment that could be compared with the independent 3A and 3B assessments. The combined assessment was conducted under the constant-selectivity-at-age assumption and the output is shown in Figure 7 with estimated values given in Table 13. The combined assessment resulted in a 1997 total biomass level of 440 million pounds compared with 511 million pounds that results from summing estimates from the two independent assessments. A split of the combined assessment results, using survey proportions, would increase the biomass in 3B, but would also substantially decrease it in 3A over results from the independent assessments. Because the IPHC setline surveys that are available for the entire assessment period only cover (and not completely) Area 3A, we believe that the best assessment of Area 3A alone is the independent size-age assessment.

AN ALTERNATIVE ASSESSMENT MODEL FOR AREA 3A

Background

In the new assessment model, trends in commercial selectivities at age result from the coupling of the size distribution at age in the population with a time-varying size selectivity function. The decrease in size at age that took place over the last 15 years resulted in a reduction in the estimated selectivity of the younger age classes, which explained their poor representation in the commercial catch during the 1990s. Letting the selectivity be driven by changes in size at age thus resulted in a substantial increase in the estimated abundance of the younger age classes compared to those produced by the previous assessment model (CAGEAN) in which selectivity at age was assumed constant.

During the review of the stock assessment methods, a question was raised by the panel as to whether there was any empirical evidence for such decreases in age-selectivity that would be independent of the trends in growth. Recent changes in selectivity are difficult to estimate solely from the catch at age data because their effect on the catch age composition tends to be confounded with the effects of recent trends in recruitment. With time, the young cohorts eventually become fully selected, and then changes in abundance and selectivity can be better identified. Depending on how noisy the data and the fishing process is, unaccounted recent changes in selectivity may still show as trends in residuals along the cohort diagonals. In this case, there may still be some information to estimate recent trends in selectivity.

An alternative assessment model was developed to evaluate whether or not the catch at age data provided evidence for a decrease in selectivity, such as was estimated by the new assessment model, when no auxiliary information on size at age was incorporated. The model was applied to Area 3A because this area experienced the largest decreases in growth rate and estimated selectivity.

The Model

Abundance at age for the period 1974-1997 was estimated using an age-structured model similar to CAGEAN, except that commercial selectivity and catchability were allowed to change over time. In addition to commercial catch at age (ages 6 to 20+) and effort data, survey catch per unit of effort (*CPUE*) and age composition of survey catches were used in the estimation, as is the case in the regular assessment model.

The dynamics of abundance and the catch process were modeled using standard age-specific catch equations. Removals due to bycatch of legal halibut were ignored in this exercise. The coefficient of catchability q linking observed effort to predicted full-recruitment mortality was assumed to change according to

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

where ${}_q\varepsilon_t$ is normally distributed with zero mean and standard deviation equal to 0.03. Selectivities for ages 14 through 20+ were assumed to be constant and selectivity for the pooled age group 20+ was set to one. Changes in selectivity $s(a)$ for ages 6 to 13 were allowed by letting

$$\log(s(a)_{t+1})=\log(s(a)_t)+{}_s\varepsilon_{a,t}$$

where ${}_s\varepsilon_{a,t}$ was assumed to be normal with zero mean and standard deviation decreasing gradually with age from 0.2 At age 6 to 0.05 at age 13. Survey selectivity was assumed to be constant at age except for a brake incorporated to account for the change in hook type from J to C that took place in 1984. The survey in that year was duplicated using the two hook types in order to evaluate their relative fishing power. The C-hook was estimated to be twice as efficient as the J-hook at catching large, fully selected fish (Clark, this volume). Thus the ratio of the catchabilities of the two hooks was given a value of two in the model.

Parameters for initial abundances, full-recruitment fishing mortalities (F_t), catchabilities for years 1974-1997, commercial and survey selectivities at age and year, and survey catchabilities were estimated using the same formulation as in the regular assessment model, excluding of course all the components corresponding to growth data. Emphasis given to the different likelihood components, and the prior variance used to control the degree of variation in commercial catchability, were identical to those used for the regular assessment. An additional penalty on the curvature of the age-specific selectivity parameters for each year was included in order to smooth out changes in selectivity with age; a constant times the sum of the squared second-order differences of $\log(s(a))$ was added to the objective function.

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Exploitable biomass was computed as

$$B_t = \sum_{a=6}^{20+} N_{a,t}\ s(a)_t\ w_{a,t}$$

where $N_{a,t}$ is abundance at age and year, and $w_{a,t}$ represents smoothed average weights at age and year estimated by sampling commercial landings.

Results and Discussion

Estimated age-specific selectivity parameters show decreasing trends over the last 10 years approximately (Figure 8). Although trends are not as marked as those driven by the changes in size at age in the regular assessment, they do support the assumption that selectivity at age decreased when size at age decreased. Estimates of total and exploitable biomass should be compared with those produced by the regular assessment model under the assumption that survey selectivity is constant at age (except for the change in 1984). Trends in estimates of recruitment and biomass are similar, but absolute levels are lower in the current model, as could be expected from the smaller changes in selectivity (Figure 9). Estimated total biomass in 1997 is close 312 million pounds while the regular assessment resulted in 394 million pounds. If exploitable biomass is calculated using the coast-wide fixed selectivity schedule used to compute CEYs, the current model estimates 171 million pounds while the regular assessment model produced an estimate of 251 million pounds. Differences would be somewhat smaller if the alternative assessment model had incorporated the bycatch removals of legal-size halibut as is done in the regular assessment. Accounting for bycatch resulted in roughly a 15% increase in estimated exploitable biomass in the regular assessment.

While these results are useful in providing evidence of selectivity trends, we believe that abundance estimates provided by the regular assessment model are more reliable. Commercial selectivity is the result of a complex series of factors involving the availability of fish of different age-size classes in the fishing grounds, the efficiency of the gear, behavioral factors and fleet targeting practices. In general, it is then difficult to specify how a change in size at age might affect the catchability of different age classes. However, in the case of halibut, the existence of a legal size limit at 81 cm must undoubtedly have resulted in a substantial decrease in selectivity of the younger age groups. Selectivity and abundance parameters estimated by making use of the growth information should then be better than those that ignore the coupling between selectivity and growth.

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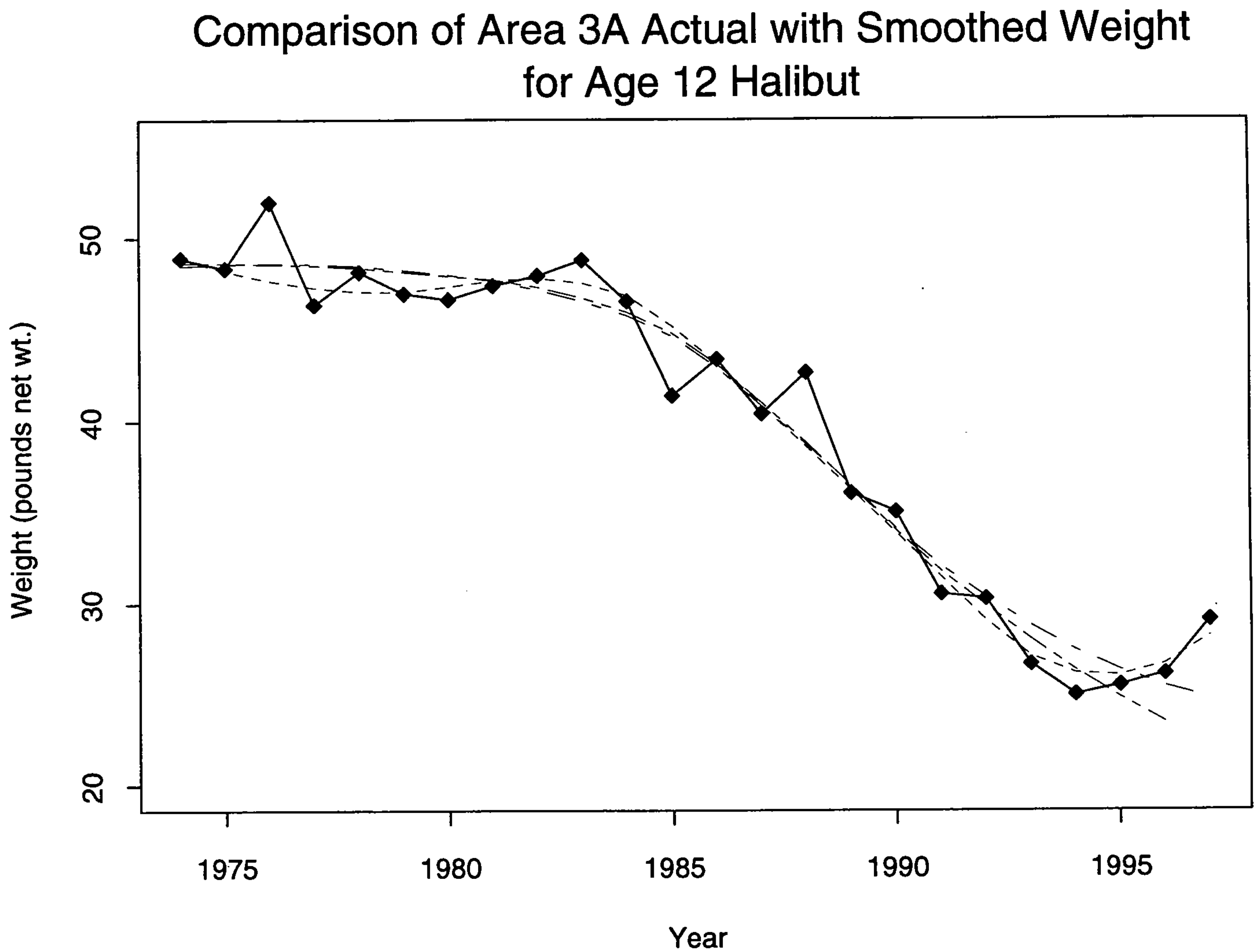

Figure 1. **Raw weight at age for Pacific halibut of age 12 sampled from Area 3A commercial landings compared with three smooth loess curves. The two curves dropping below the raw weight data are smoothed using a 0.75 span over the years 1974-1996 and 1974-1997 data respectively. The curve following the data more closely uses a 0.5 span and is applied for 1974-1997 data.**

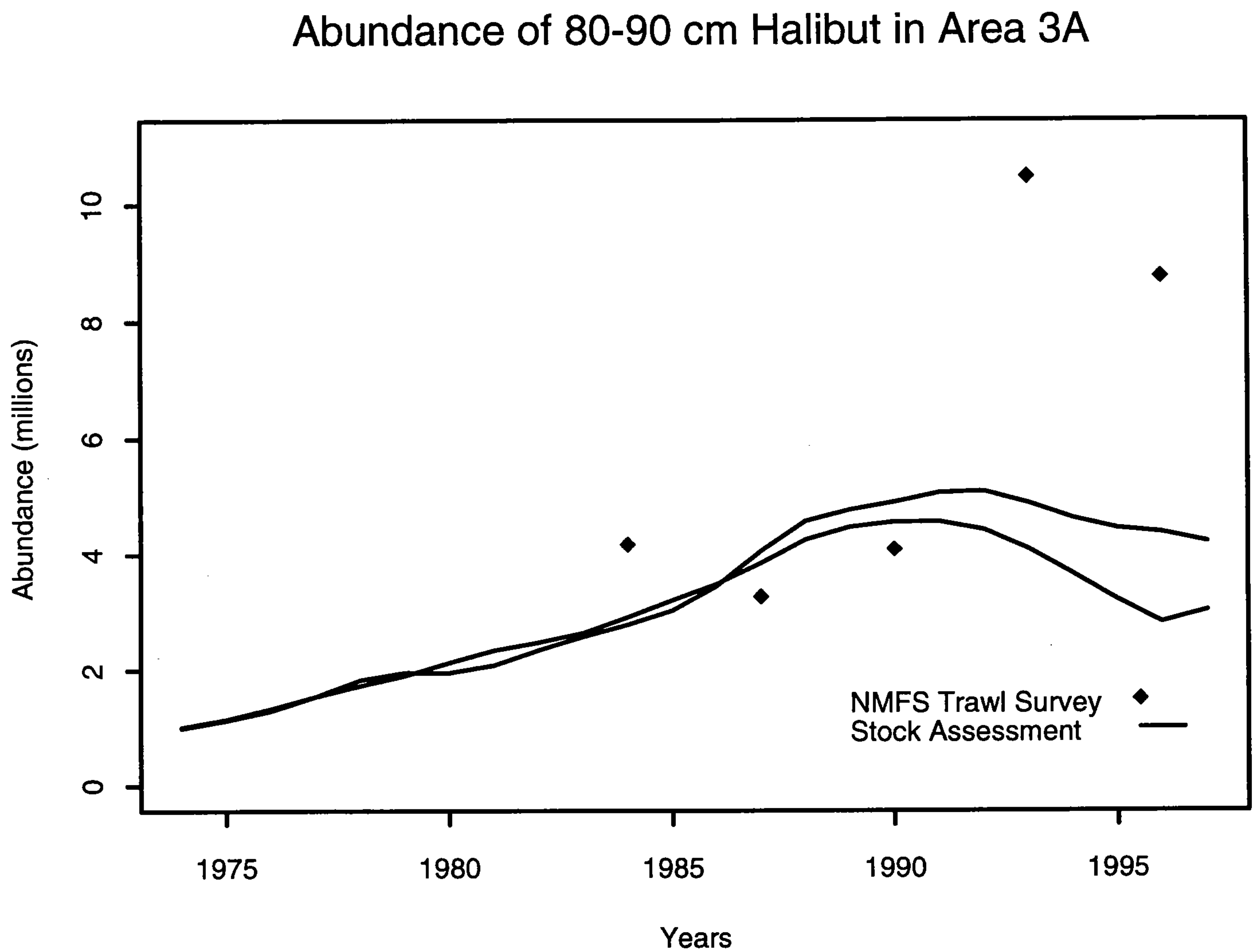

Figure 2. **Comparison of estimates of abundance of 80-90 cm Pacific halibut from NMFS trawl survey data and from size-age structured assessments for Area 3A. Stock assessments shown are for the assumptions of constant setline survey selectivity at length (upper) and constant setline survey selectivity at age (lower).**

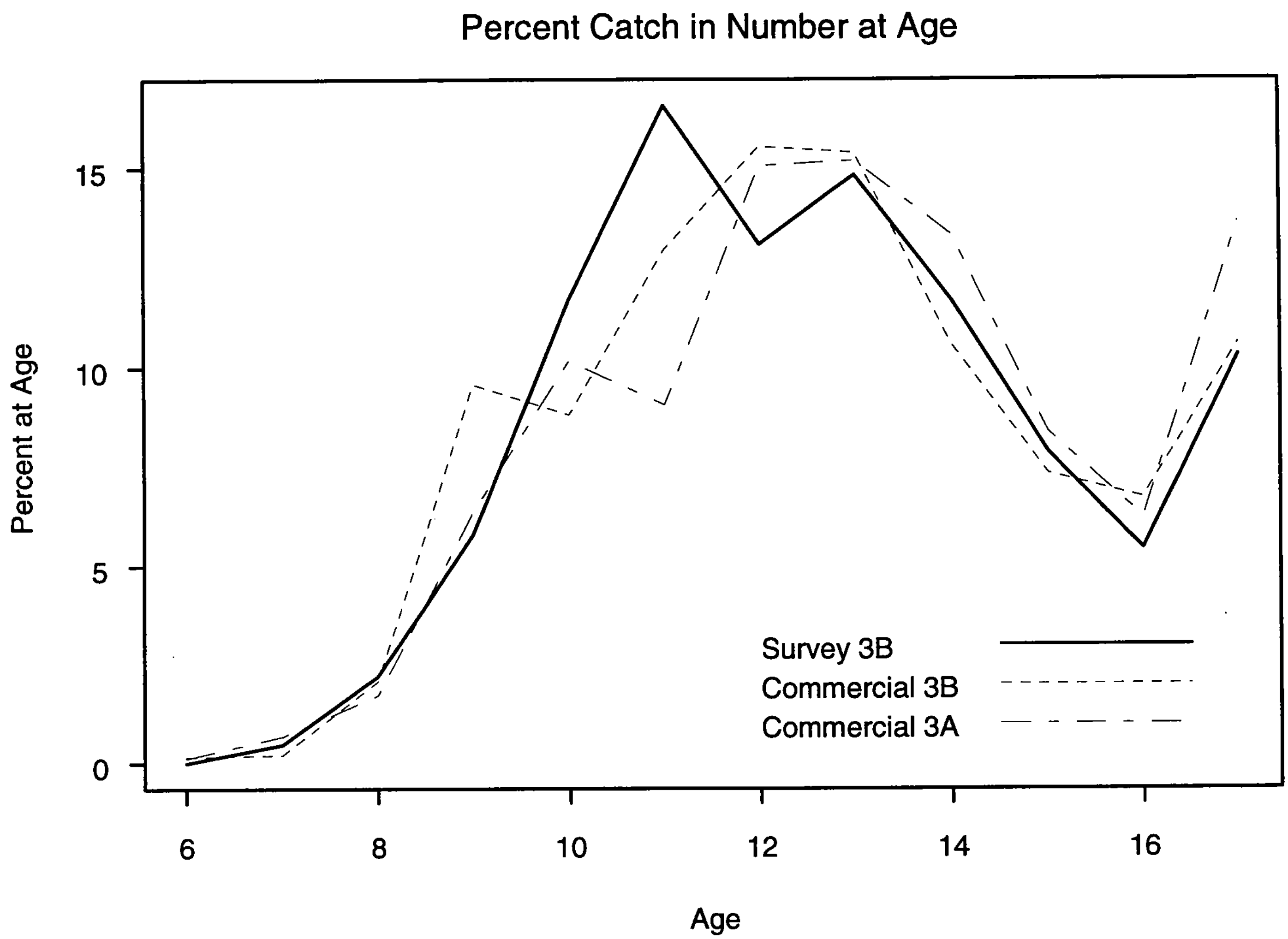

Figure 3. **Percent survey catch at age for Area 3B compared with commercial catch at age from Area 3B and Area 3A for 1997. Age 17 is a plus group, representing all halibut ages 17 and older.**

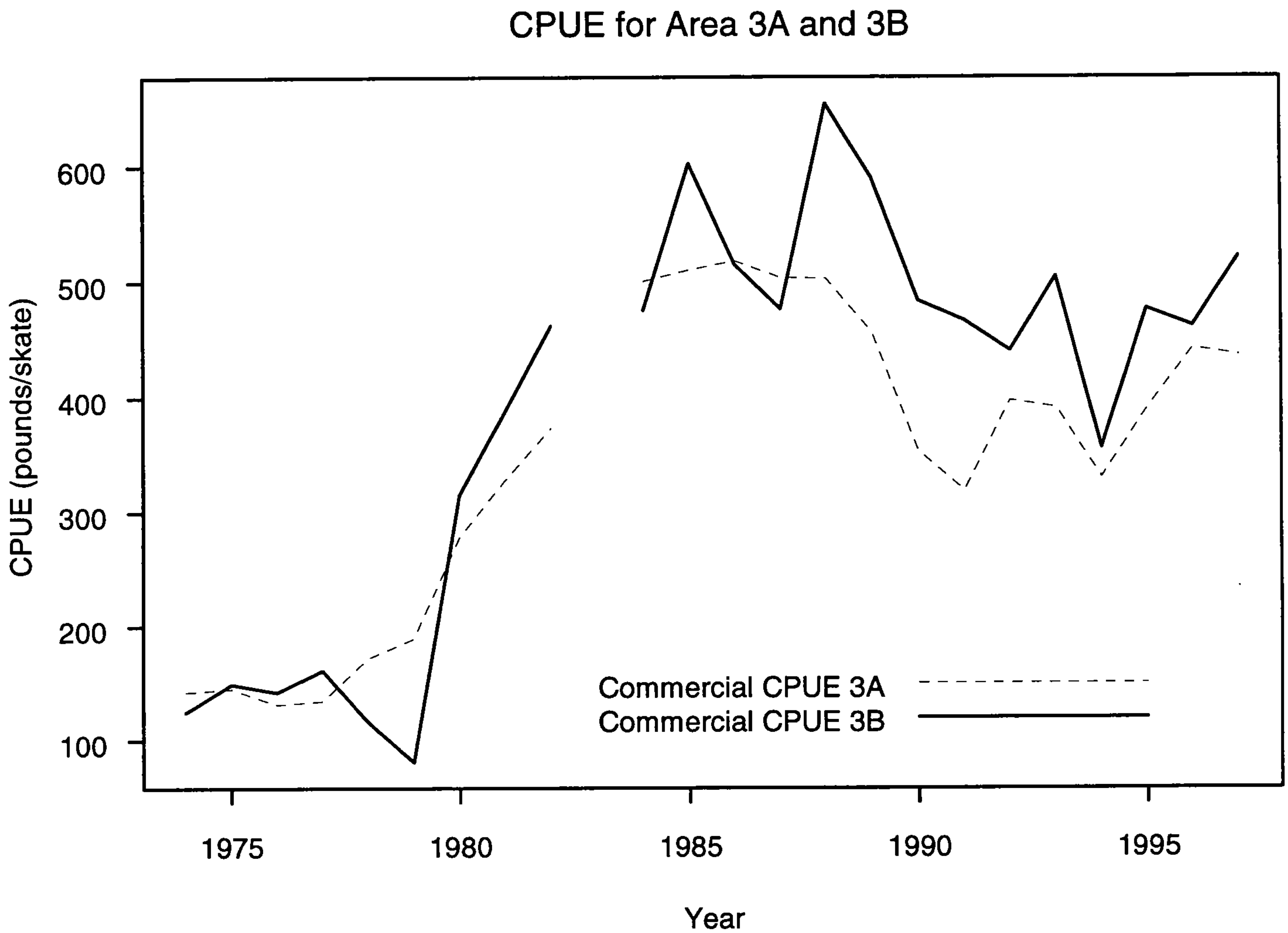

Figure 4. Comparison of commercial catch-per-unit-effort for IPHC Areas 3A and 3B.

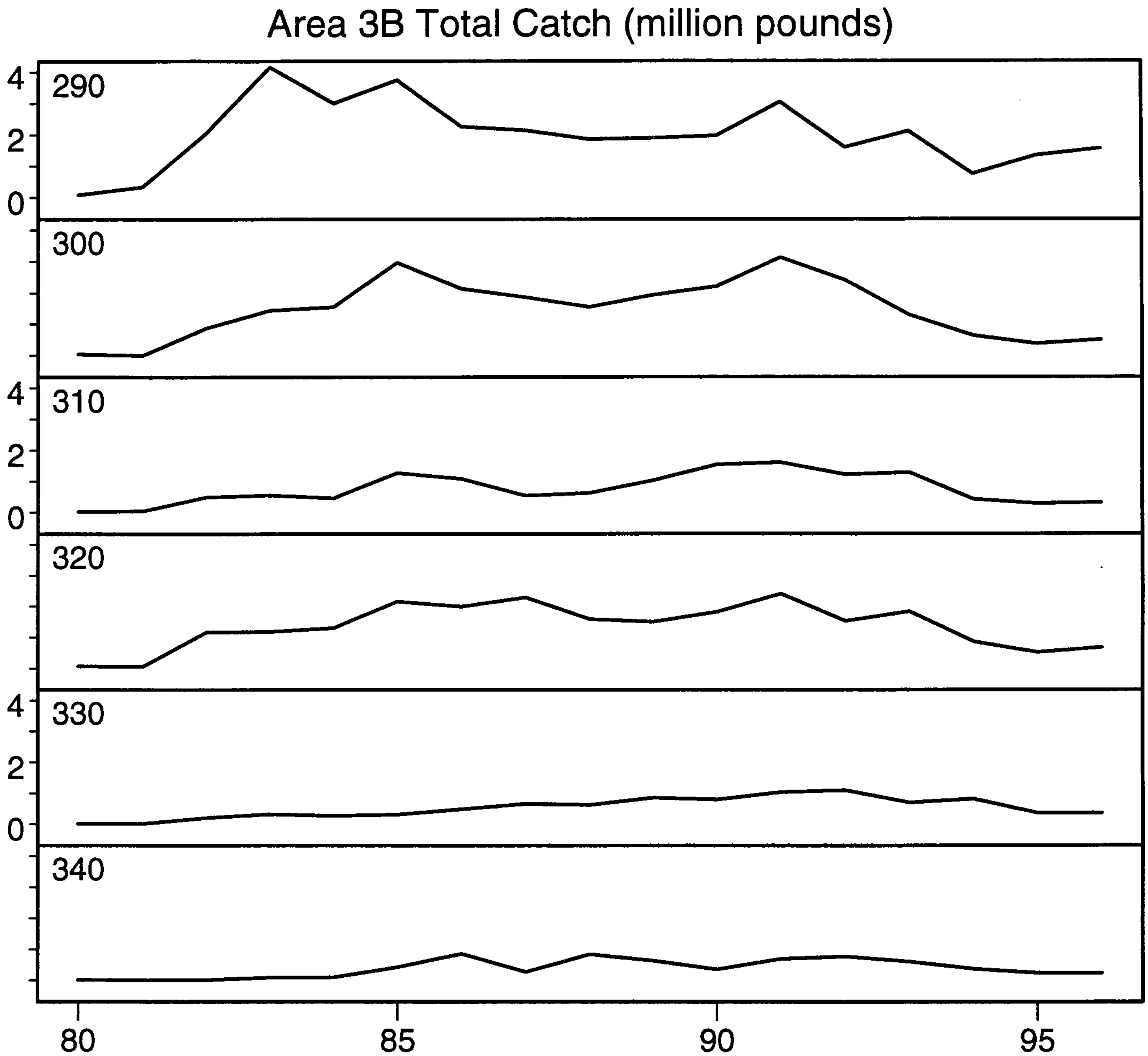

Figure 5. **Total catch in millions of pounds given by year for each Area 3B IPHC statistical area. Note the upturn in catch in recent years for stat-area 290, which is adjacent to the Area 3A-3B border near Kodiak.**

Area 3B Out-migration Model

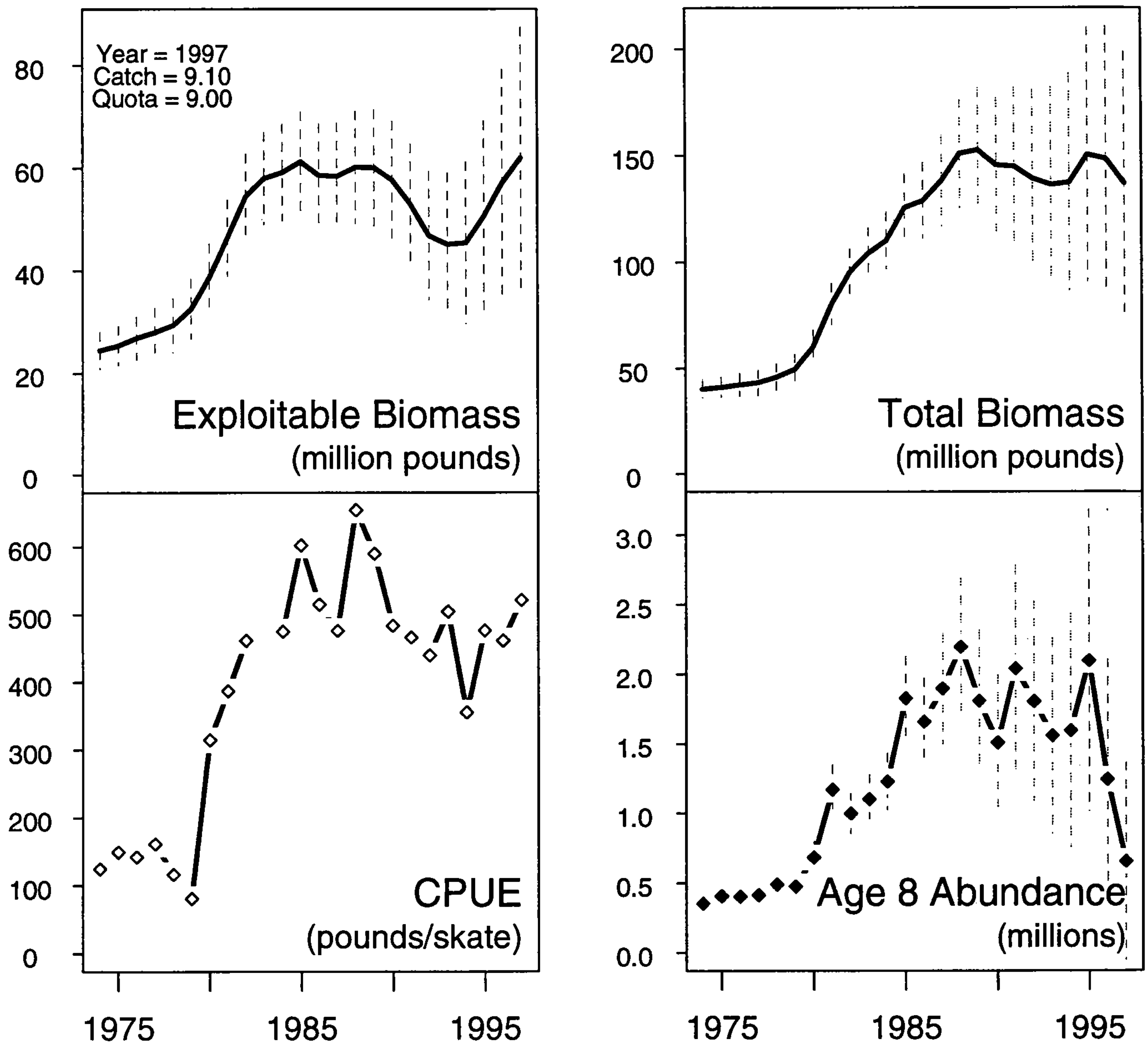

Figure 6. **Exploitable biomass, total biomass, commercial and survey CPUE, and abundance at age 8 of Pacific halibut for Area 3B from an age-size structured model with no survey information included, but assuming that out migration at age occurs based on migration rates listed in Table 4 of IPHC Scientific Report 72. Confidence bounds represent 95% intervals conditioned on model structure.**

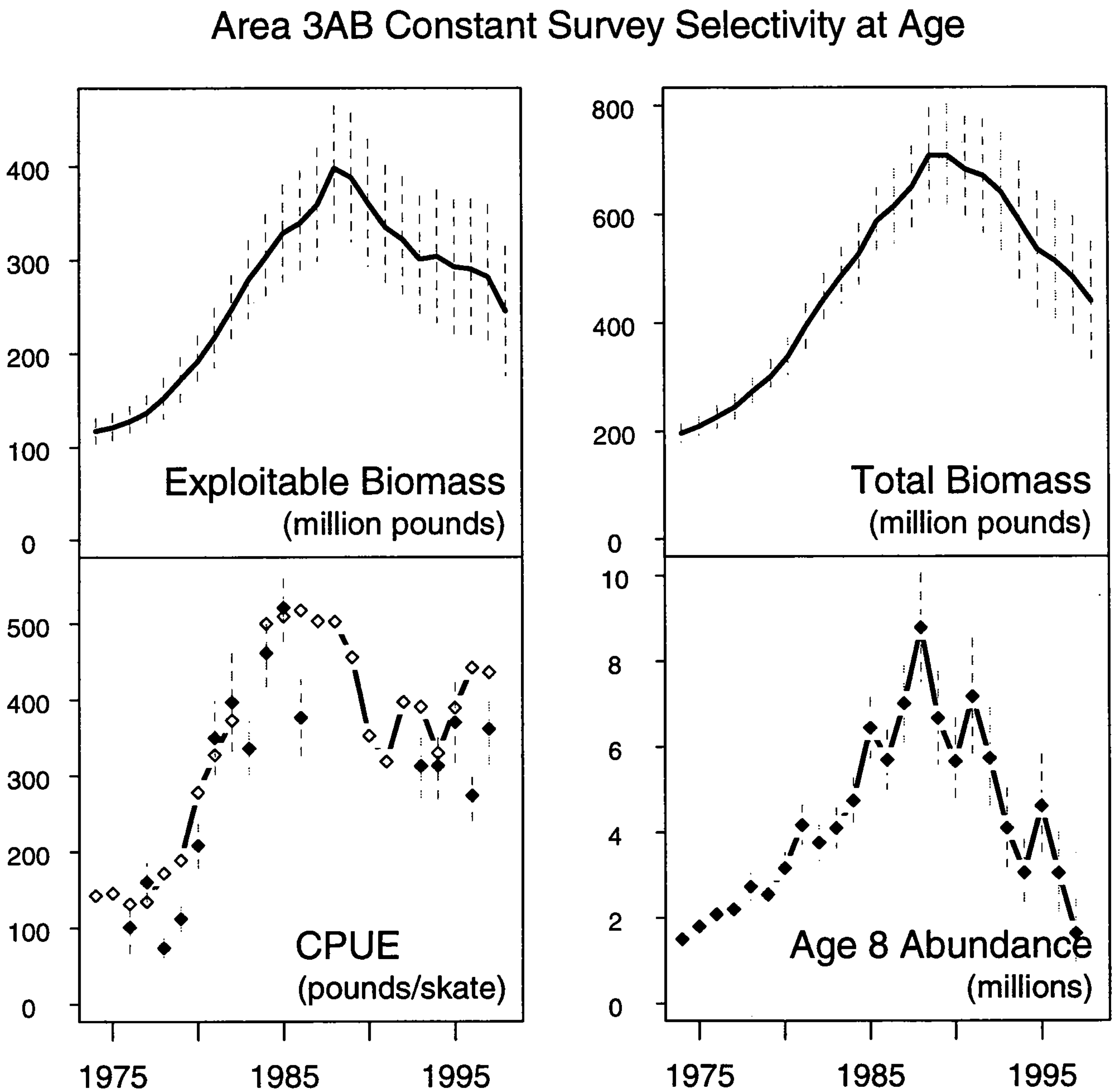

Figure 7. **Output from run where data from Area 3A and 3B were combined. Survey estimates shown are for Area 3A only.**

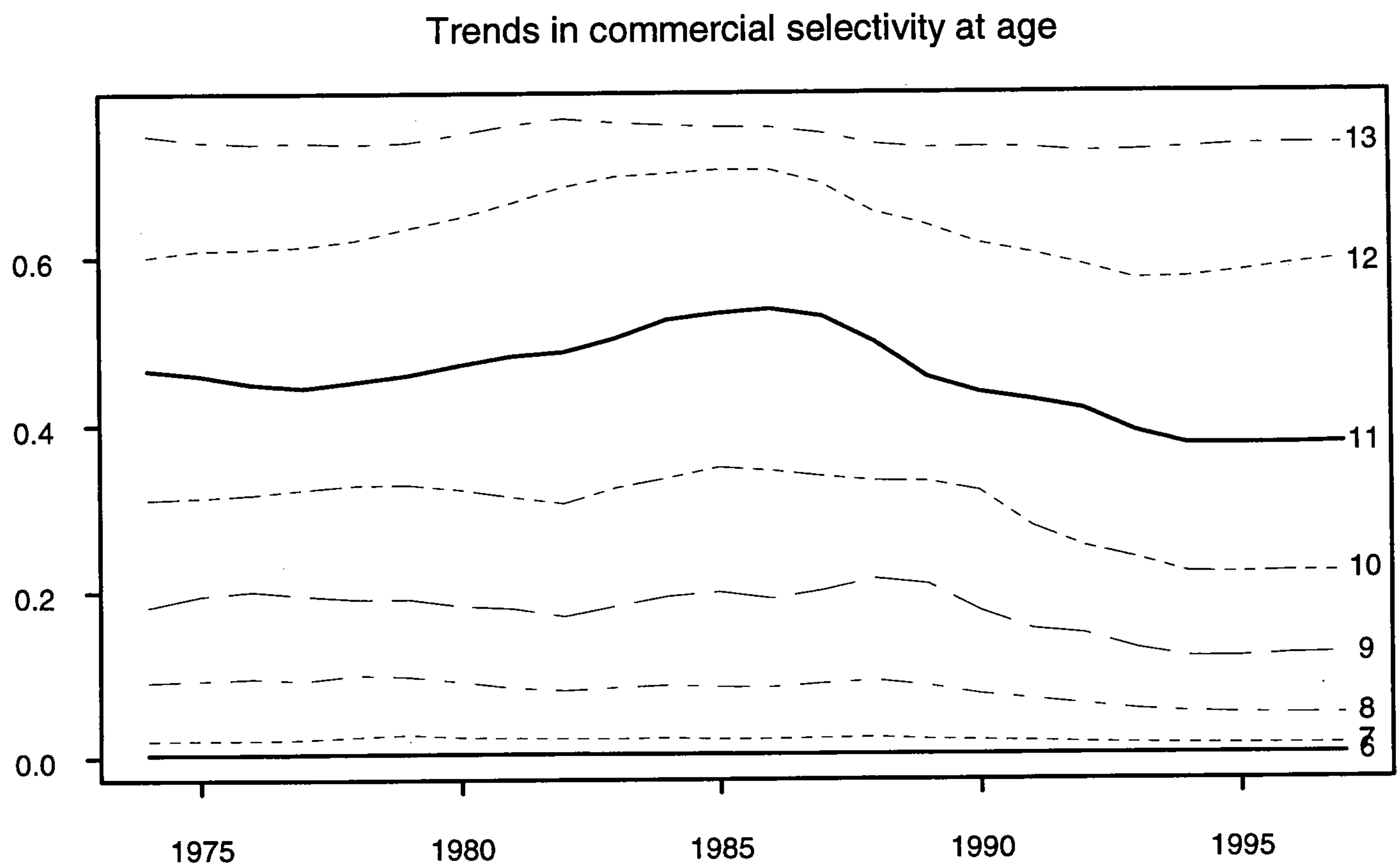

Figure 8. **Alternative model in which trends in commercial selectivity were estimated independently of growth changes for Area 3A.**

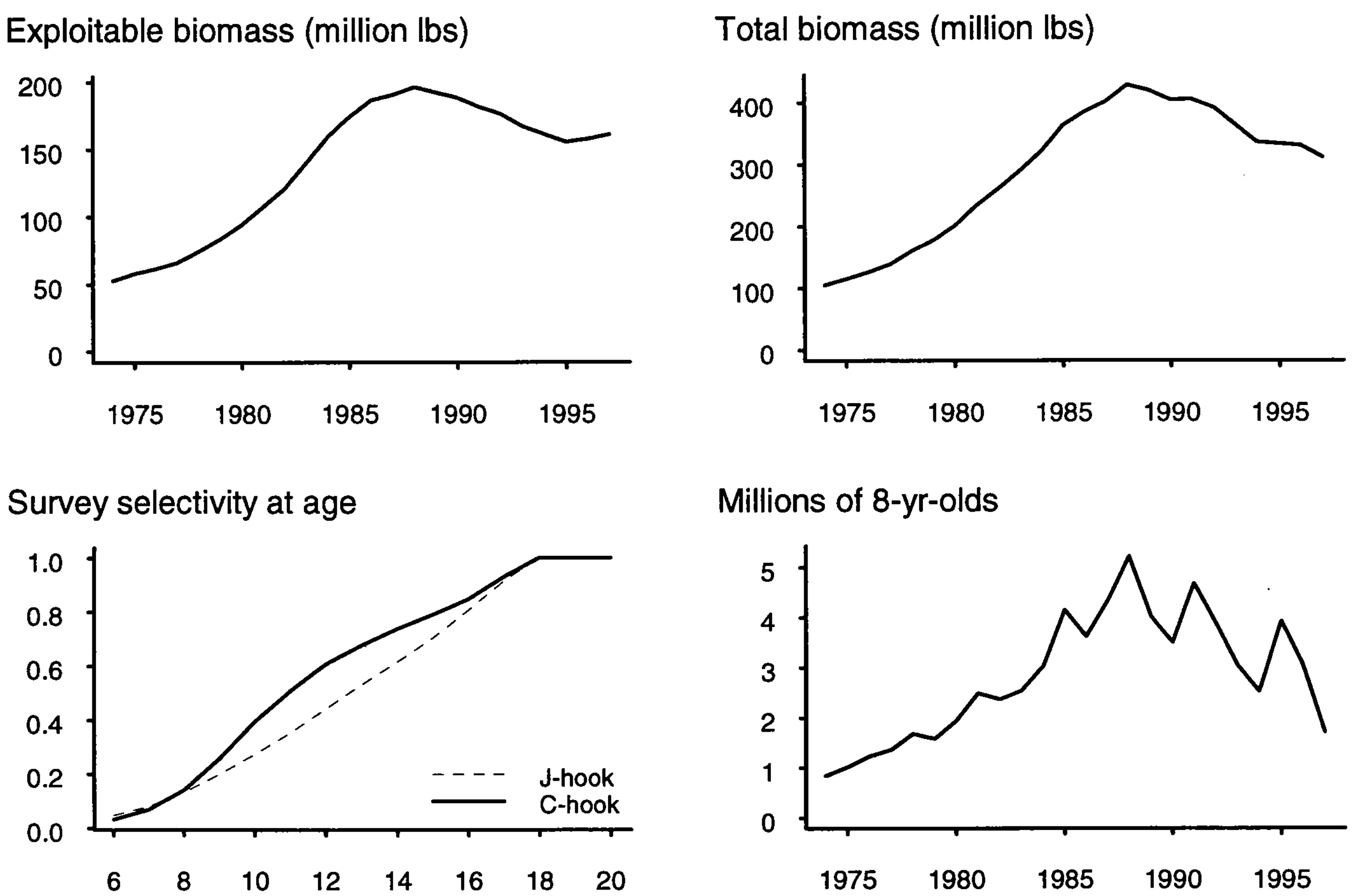

Figure 9. **Trends in Area 3A commercial selectivity estimated independently of growth changes.**

Table 1. Commercial CPUE (pounds per skate, C hook equivalent)

Year	2A	2B	2C	3A	3B	4	Total
1974	130.7	141.0	126.0	142.4	124.7	301.1	137.9
1975	130.6	148.7	117.4	145.3	149.3	210.7	139.7
1976	71.7	116.7	92.8	131.5	142.2	184.2	118.5
1977	182.2	135.3	99.4	134.6	161.3	176.2	133.1
1978	85.5	138.0	124.1	171.9	116.4	166.6	148.0
1979	110.0	105.8	176.6	189.0	80.8	146.1	154.6
1980	82.0	148.3	183.7	278.3	315.1	177.7	210.9
1981	67.7	154.3	313.7	327.7	387.2	249.9	254.6
1982	47.3	149.1	321.4	373.1	461.7	219.9	274.2
1983	NA	NA	NA	NA	NA	NA	NA
1984	69.0	146.6	280.8	500.3	475.2	235.6	288.0
1985	69.2	143.1	340.7	509.9	602.4	304.8	310.0
1986	60.9	118.2	294.0	517.9	514.8	276.5	287.7
1987	58.6	128.4	260.3	503.6	476.1	298.1	276.9
1988	171.4	131.6	281.3	502.8	654.2	296.4	309.4
1989	112.4	133.2	258.0	456.0	590.0	306.4	300.2
1990	168.4	173.9	269.1	352.9	483.6	336.2	302.0
1991	164.3	156.4	233.2	318.6	466.4	366.3	284.9
1992	113.9	186.6	230.5	397.1	440.2	312.4	304.4
1993	155.0	211.9	255.1	390.8	504.6	336.9	312.1
1994	92.4	212.5	187.5	330.2	355.9	247.1	255.5
1995	88.9	205.5	231.5	389.7	476.6	271.9	283.4
1996	154.9	221.0	221.0	442.3	461.6	339.9	311.3
1997	189.6	243.4	259.5	436.3	521.7	321.7	339.5

Table 2. Commercial Catch (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
1974	0.52	4.62	5.60	8.19	1.67	0.71	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	27.54
1977	0.21	5.43	3.19	8.64	3.19	1.22	21.88
1978	0.10	4.61	4.32	10.30	1.32	1.35	22.00
1979	0.05	4.86	4.53	11.34	0.39	1.37	22.54
1980	0.02	5.65	3.24	11.97	0.28	0.71	21.87
1981	0.20	5.65	4.01	14.22	0.45	1.19	25.72
1982	0.21	5.54	3.50	13.53	4.80	1.43	29.01
1983	0.26	5.44	6.40	14.11	7.75	4.42	38.38
1984	0.43	9.05	5.85	19.97	6.50	3.16	44.96
1985	0.49	10.39	9.21	20.85	10.89	4.28	56.11
1986	0.58	11.22	10.61	32.79	8.83	5.59	69.62
1987	0.59	12.25	10.68	31.32	7.76	6.88	69.48
1988	0.49	12.86	11.37	37.86	7.08	4.69	74.35
1989	0.47	10.43	9.53	33.73	7.84	4.93	66.93
1990	0.32	8.57	9.73	28.85	8.69	5.43	61.59
1991	0.36	7.17	8.69	22.86	11.93	5.99	57.00
1992	0.44	7.63	9.82	26.78	8.62	6.61	59.90
1993	0.52	10.63	11.29	22.74	7.86	6.25	59.28
1994	0.39	9.91	10.38	24.84	3.86	5.37	54.75
1995	0.31	9.62	7.76	18.34	3.12	4.74	43.89
1996	0.30	9.53	8.80	19.69	3.81	5.31	47.44
1997	0.40	12.20	9.89	24.68	9.10	8.79	65.05

Table 3. Total Removals Excluding Bycatch (million pounds)

Year	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	15.06	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	36.56	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	74.50
1990	0.52	9.41	11.30	33.38	8.91	5.69	69.21
1991	0.52	7.88	11.41	29.23	12.41	6.52	67.96
1992	0.70	8.36	12.10	31.81	8.83	6.89	68.69
1993	0.77	11.68	13.40	28.67	7.98	6.56	69.07
1994	0.57	10.94	12.72	30.51	3.96	5.64	64.34
1995	0.55	10.62	9.57	23.06	3.19	4.90	51.89
1996	0.53	10.52	10.38	24.79	3.89	5.55	55.65
1997	0.76	13.19	11.76	30.26	9.21	9.05	74.23

Table 4. Legal-sized Bycatch Mortality (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
1974	0.25	0.90	0.37	4.48	2.82	1.89	10.71
1975	0.25	0.90	0.45	2.61	1.66	1.10	6.98
1976	0.25	0.94	0.50	2.74	1.94	1.18	7.56
1977	0.25	0.72	0.41	3.37	1.54	1.98	8.27
1978	0.25	0.55	0.21	2.44	1.31	3.40	8.16
1979	0.25	0.69	0.64	4.49	0.69	3.44	10.20
1980	0.25	0.51	0.42	4.93	0.87	5.71	12.69
1981	0.25	0.53	0.40	3.99	1.09	4.37	10.64
1982	0.25	0.30	0.20	3.20	1.68	2.95	8.58
1983	0.25	0.29	0.20	2.08	1.22	2.47	6.51
1984	0.25	0.52	0.21	1.51	0.92	2.29	5.70
1985	0.25	0.55	0.20	0.80	0.34	2.25	4.38
1986	0.25	0.56	0.20	0.67	0.20	2.61	4.50
1987	0.25	0.79	0.20	1.59	0.40	2.67	5.90
1988	0.25	0.77	0.20	2.13	0.04	3.27	6.66
1989	0.25	0.72	0.20	1.80	0.44	1.95	5.36
1990	0.25	1.03	0.68	2.63	1.21	4.16	9.97
1991	0.25	1.22	0.55	3.13	1.03	2.92	9.10
1992	0.28	1.02	0.57	2.64	1.12	3.34	8.97
1993	0.28	0.65	0.33	1.92	0.47	2.01	5.65
1994	0.28	0.57	0.40	2.35	0.85	3.48	7.93
1995	0.38	0.71	0.24	1.57	0.90	3.31	7.11
1996	0.38	0.14	0.24	1.16	0.77	2.97	5.66
1997	0.38	0.14	0.26	1.15	0.59	2.69	5.21

Table 5. IPHC setline survey CPUE in number of halibut per effective skate and associated coefficient of variation.

	Area 2AB		Area 2C		Area 3A	
Year	CPUE	CV	CPUE	CV	CPUE	CV
1974						
1975						
1976	2.30	0.12				
1977	1.56	0.13			5.56	0.06
1978	1.84	0.12			3.66	0.06
1979					5.25	0.07
1980	2.99	0.10			6.86	0.06
1981	1.86	0.11			10.21	0.06
1982	2.31	0.12	11.28	0.09	11.53	0.06
1983	3.11	0.14	10.89	0.09	9.29	0.04
1984	4.74	0.08	13.21	0.11	13.33	0.04
1985	4.30	0.11	11.53	0.10	15.74	0.04
1986	2.70	0.10	9.44	0.09	9.58	0.06
1987						
1988						
1989						
1990						
1991						
1992						
1993	6.63	0.10			17.94	0.06
1994					19.01	0.05
1995	8.95	0.08			23.10	0.06
1996	9.20	0.09	16.89	0.09	18.54	0.07
1997	9.07	0.08	21.77	0.09	26.46	0.06

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Table 6.A Exploitable Biomass (million pounds)
Constant survey selectivity at age

Year	2A+2B	2C	3A	3B
1974	49.51	42.25	98.62	22.52
1975	50.21	44.01	104.77	23.23
1976	47.73	44.94	112.31	24.36
1977	45.05	47.69	122.68	25.15
1978	44.56	54.10	140.85	26.07
1979	46.37	59.09	159.87	28.96
1980	48.04	65.95	175.31	34.72
1981	50.23	75.51	194.29	42.23
1982	52.50	83.53	211.58	50.21
1983	56.62	91.06	239.19	53.62
1984	63.21	95.78	265.13	54.71
1985	67.42	101.20	291.76	56.90
1986	69.34	103.21	307.73	54.47
1987	75.35	96.49	328.71	54.38
1988	84.35	101.06	354.41	56.29
1989	90.31	99.91	341.87	56.57
1990	96.64	96.99	318.48	54.55
1991	102.94	93.74	295.80	50.19
1992	109.19	92.29	285.21	44.07
1993	107.01	87.94	267.94	42.13
1994	100.42	85.81	275.90	42.06
1995	101.91	82.42	263.60	46.75
1996	103.77	85.46	260.63	52.54
1997	105.18	86.67	251.86	57.06
1998	89.74	88.49	227.22	60.95

Table 6.L Exploitable Biomass (million pounds)
Constant survey selectivity at length

Year	2A+2B	2C	3A
1974	49.21	42.45	95.24
1975	48.32	44.01	100.91
1976	44.86	44.79	107.64
1977	42.30	47.34	116.06
1978	42.82	53.66	132.21
1979	45.41	58.81	149.55
1980	47.57	66.48	165.44
1981	49.36	75.80	182.04
1982	51.66	82.89	195.06
1983	56.11	89.53	217.82
1984	62.90	93.51	239.55
1985	67.37	98.35	264.28
1986	70.19	100.12	275.51
1987	75.05	93.27	289.66
1988	82.38	98.29	314.14
1989	86.81	97.23	303.68
1990	91.00	94.08	282.98
1991	93.58	90.06	263.52
1992	103.89	89.50	256.15
1993	109.32	86.36	239.07
1994	106.22	85.65	246.36
1995	106.70	82.47	250.16
1996	111.52	86.58	266.29
1997	117.18	89.65	280.42
1998	105.53	92.58	348.25

Table 7.A Total Biomass Age 8 and Older (million pounds)
Constant survey selectivity at age

Year	2A+2B	2C	3A	3B
1974	62.13	66.57	170.44	33.95
1975	62.49	69.07	184.03	34.44
1976	59.61	71.71	202.55	35.34
1977	57.39	75.77	222.11	35.98
1978	59.38	84.54	251.47	37.77
1979	63.83	93.92	276.07	41.19
1980	69.17	107.32	304.70	50.27
1981	75.73	122.97	345.32	67.16
1982	81.90	135.94	376.91	80.67
1983	92.83	147.38	410.62	88.18
1984	109.08	156.92	449.13	92.89
1985	127.17	171.87	496.96	104.73
1986	135.94	170.87	524.37	106.55
1987	149.41	168.78	553.30	113.43
1988	160.38	168.44	601.86	123.59
1989	162.27	164.26	604.14	125.41
1990	162.39	160.00	593.87	120.01
1991	170.14	159.94	598.01	117.87
1992	178.85	160.97	575.73	111.97
1993	177.36	156.30	529.94	109.37
1994	169.28	148.62	481.48	110.37
1995	188.05	159.31	455.11	121.94
1996	198.67	172.65	430.91	122.75
1997	199.68	174.45	394.76	116.06

Table 7.L Total Biomass Age 8 and Older (million pounds)
Constant survey selectivity at length

Year	2A+2B	2C	3A
1974	61.32	66.14	164.39
1975	61.92	68.52	176.92
1976	59.33	71.03	193.68
1977	57.68	75.20	213.15
1978	58.47	83.79	239.46
1979	62.09	92.94	261.00
1980	66.41	104.54	282.52
1981	73.61	120.00	319.86
1982	79.72	133.34	350.51
1983	90.14	145.14	380.52
1984	106.31	154.89	416.56
1985	125.25	169.94	466.66
1986	135.47	168.92	502.11
1987	152.35	167.75	536.42
1988	165.78	167.96	587.42
1989	171.07	164.48	598.07
1990	174.29	160.14	603.36
1991	183.39	160.86	626.79
1992	188.98	160.78	626.02
1993	186.16	155.45	608.38
1994	182.77	147.89	587.84
1995	224.32	164.77	600.75
1996	236.51	180.27	625.95
1997	231.27	184.13	633.46

Table 8.A Historical Exploitation Rates (total removals/exploitable biomass)
Constant survey selectivity at age

Year	2A+2B	2C	3A	3B
1974	0.13	0.14	0.13	0.20
1975	0.17	0.15	0.13	0.18
1976	0.18	0.13	0.12	0.19
1977	0.15	0.08	0.10	0.19
1978	0.12	0.09	0.09	0.10
1979	0.13	0.09	0.10	0.04
1980	0.13	0.06	0.10	0.03
1981	0.13	0.06	0.10	0.04
1982	0.12	0.05	0.08	0.13
1983	0.11	0.08	0.07	0.17
1984	0.17	0.07	0.08	0.14
1985	0.19	0.10	0.08	0.20
1986	0.19	0.12	0.12	0.17
1987	0.20	0.12	0.11	0.16
1988	0.18	0.13	0.13	0.13
1989	0.14	0.11	0.12	0.15
1990	0.12	0.12	0.11	0.19
1991	0.10	0.13	0.11	0.27
1992	0.09	0.14	0.12	0.23
1993	0.13	0.16	0.11	0.20
1994	0.12	0.15	0.12	0.11
1995	0.12	0.12	0.09	0.09
1996	0.11	0.12	0.10	0.09
1997	0.14	0.14	0.12	0.17

Table 8.L Historical Exploitation Rates (total removals/exploitable biomass)
Constant survey selectivity at length

Year	2A+2B	2C	3A
1974	0.13	0.14	0.13
1975	0.18	0.15	0.13
1976	0.19	0.13	0.13
1977	0.16	0.08	0.11
1978	0.13	0.09	0.10
1979	0.13	0.09	0.11
1980	0.14	0.06	0.11
1981	0.14	0.06	0.10
1982	0.12	0.05	0.09
1983	0.11	0.08	0.08
1984	0.17	0.07	0.09
1985	0.19	0.10	0.09
1986	0.19	0.12	0.14
1987	0.20	0.13	0.13
1988	0.18	0.13	0.14
1989	0.15	0.12	0.13
1990	0.12	0.13	0.13
1991	0.11	0.13	0.12
1992	0.10	0.14	0.13
1993	0.12	0.16	0.13
1994	0.12	0.15	0.13
1995	0.11	0.12	0.10
1996	0.10	0.12	0.10
1997	0.12	0.13	0.11

Table 9.A Annual Surplus Production (million pounds)
Constant survey selectivity at age

Year	2A+2B	2C	3A	3B
1974	6.99	7.73	18.82	5.20
1975	6.26	7.62	20.76	5.35
1976	6.03	8.79	24.15	5.46
1977	6.15	10.08	30.37	5.66
1978	7.34	9.60	32.05	5.51
1979	7.56	12.21	31.63	6.84
1980	8.65	13.55	36.37	8.66
1981	8.94	12.75	36.25	9.52
1982	10.54	11.72	45.06	9.89
1983	12.99	11.86	43.07	10.06
1984	14.71	12.10	49.13	9.61
1985	14.42	12.32	39.77	9.00
1986	19.53	5.25	58.20	9.35
1987	24.02	16.59	62.17	10.40
1988	21.14	11.71	32.22	7.53
1989	19.21	8.55	16.60	6.45
1990	17.52	8.74	13.33	5.76
1991	16.11	10.51	21.77	7.32
1992	8.18	8.33	17.18	8.01
1993	6.79	11.59	38.55	8.38
1994	13.85	9.73	20.56	9.49
1995	14.12	12.86	21.66	9.89
1996	12.98	11.83	17.18	9.18
1997	13.16	11.99	16.60	9.97

Table 9.L Annual Surplus Production (million pounds)
Constant survey selectivity at length

Year	2A+2B	2C	3A
1974	5.39	7.53	18.34
1975	5.28	7.47	19.94
1976	6.16	8.58	22.20
1977	7.15	9.98	28.36
1978	8.12	9.77	30.37
1979	8.04	13.02	32.09
1980	8.26	13.31	33.98
1981	8.97	11.82	31.98
1982	10.86	10.83	40.20
1983	13.20	11.13	38.87
1984	14.97	11.52	47.23
1985	15.32	12.08	35.02
1986	18.39	5.12	51.38
1987	22.36	17.05	60.95
1988	19.60	11.79	34.31
1989	17.07	8.33	19.29
1990	13.79	7.97	16.56
1991	20.17	11.40	24.99
1992	15.79	9.53	17.37
1993	10.29	13.02	37.88
1994	12.83	9.94	36.65
1995	17.09	13.92	40.76
1996	17.23	13.69	40.07
1997	18.10	14.18	42.20

Table 10.A Fishing Mortality
Constant survey selectivity at age

Year	2A+2B	2C	3A	3B
1974	0.11	0.15	0.10	0.10
1975	0.17	0.17	0.12	0.13
1976	0.18	0.15	0.11	0.14
1977	0.15	0.08	0.09	0.15
1978	0.10	0.10	0.09	0.07
1979	0.12	0.09	0.09	0.03
1980	0.13	0.06	0.09	0.01
1981	0.13	0.06	0.09	0.01
1982	0.13	0.05	0.07	0.12
1983	0.11	0.08	0.07	0.17
1984	0.20	0.08	0.10	0.14
1985	0.22	0.13	0.10	0.25
1986	0.22	0.15	0.15	0.21
1987	0.20	0.14	0.13	0.18
1988	0.21	0.16	0.15	0.16
1989	0.16	0.15	0.14	0.17
1990	0.12	0.14	0.13	0.20
1991	0.08	0.14	0.13	0.33
1992	0.09	0.16	0.13	0.26
1993	0.14	0.18	0.13	0.24
1994	0.14	0.20	0.14	0.10
1995	0.12	0.12	0.10	0.08
1996	0.13	0.15	0.12	0.09
1997	0.16	0.17	0.14	0.21

Table 10.L Fishing Mortality
Constant survey selectivity at length

Year	2A+2B	2C	3A
1974	0.11	0.15	0.10
1975	0.18	0.17	0.13
1976	0.19	0.15	0.12
1977	0.15	0.08	0.10
1978	0.11	0.10	0.10
1979	0.12	0.09	0.10
1980	0.13	0.06	0.09
1981	0.14	0.06	0.10
1982	0.13	0.05	0.08
1983	0.11	0.09	0.08
1984	0.20	0.08	0.11
1985	0.22	0.13	0.11
1986	0.21	0.15	0.17
1987	0.20	0.15	0.15
1988	0.22	0.16	0.17
1989	0.17	0.15	0.15
1990	0.13	0.14	0.15
1991	0.09	0.14	0.14
1992	0.09	0.16	0.15
1993	0.14	0.18	0.15
1994	0.13	0.20	0.16
1995	0.12	0.12	0.11
1996	0.12	0.15	0.11
1997	0.14	0.16	0.13

Table 11.A Total Abundance of Eight-year-old Halibut (millions)
Constant survey selectivity at age

Year	2A+2B	2C	3A	3B
1974	0.63	0.56	1.33	0.26
1975	0.63	0.61	1.56	0.30
1976	0.59	0.68	1.88	0.30
1977	0.61	0.71	1.99	0.31
1978	0.77	0.84	2.45	0.36
1979	0.81	0.97	2.23	0.36
1980	0.94	1.23	2.66	0.52
1981	1.09	1.31	3.35	0.88
1982	1.16	1.29	3.11	0.75
1983	1.46	1.30	3.30	0.83
1984	1.87	1.50	3.83	0.93
1985	2.43	2.00	5.11	1.36
1986	2.15	1.48	4.52	1.21
1987	2.50	1.56	5.78	1.37
1988	2.44	1.46	7.41	1.60
1989	1.96	1.24	5.80	1.29
1990	1.73	1.13	5.09	1.07
1991	2.05	1.33	6.57	1.42
1992	2.07	1.34	5.15	1.27
1993	1.58	1.07	3.67	1.10
1994	1.50	0.96	2.68	1.14
1995	2.96	2.03	3.76	1.54
1996	2.75	1.92	2.74	0.92
1997	2.32	1.45	1.54	0.49

Table 11.L Total Abundance of Eight-year-old Halibut (millions)
Constant survey selectivity at length

Year	2A+2B	2C	3A
1974	0.63	0.55	1.29
1975	0.64	0.60	1.49
1976	0.62	0.67	1.77
1977	0.64	0.72	1.98
1978	0.69	0.83	2.26
1979	0.75	0.95	2.05
1980	0.87	1.12	2.25
1981	1.13	1.30	3.19
1982	1.15	1.31	3.05
1983	1.41	1.32	3.08
1984	1.85	1.51	3.66
1985	2.46	1.99	5.10
1986	2.22	1.46	4.83
1987	2.71	1.59	5.93
1988	2.62	1.48	7.37
1989	2.19	1.27	6.09
1990	1.95	1.12	5.92
1991	2.17	1.38	7.68
1992	1.95	1.27	6.53
1993	1.56	1.03	5.65
1994	1.84	0.97	4.83
1995	4.33	2.37	6.74
1996	3.21	2.08	6.48
1997	2.33	1.59	4.85

Table 12. Summary of Outputs from Area 3B Out-Migration Run

Year	Exploitable Biomass Estimated Selectivity	Total Biomass (millions of pounds)	Historical Exploitation Rate	Abundance of Eight-year-old Halibut (millions)
1974	24.44	40.23	0.18	0.35
1975	25.42	41.04	0.17	0.41
1976	26.86	42.18	0.17	0.40
1977	28.06	43.18	0.17	0.41
1978	29.38	45.70	0.09	0.49
1979	32.59	49.54	0.03	0.48
1980	38.69	60.00	0.03	0.68
1981	46.44	80.25	0.03	1.17
1982	54.50	95.32	0.12	1.00
1983	58.01	104.20	0.15	1.10
1984	59.15	110.14	0.13	1.23
1985	61.23	125.51	0.19	1.83
1986	58.64	128.85	0.16	1.66
1987	58.40	138.22	0.15	1.90
1988	60.17	151.00	0.12	2.20
1989	60.10	152.69	0.14	1.81
1990	57.68	145.56	0.18	1.51
1991	53.00	144.86	0.25	2.04
1992	46.85	139.24	0.21	1.80
1993	45.15	136.26	0.19	1.56
1994	45.44	137.33	0.11	1.59
1995	50.65	150.46	0.08	2.10
1996	57.10	148.43	0.08	1.24
1997	62.01	137.08	0.16	0.65
1998	69.86			

Table 13. Summary of Outputs from Combined Area 3AB Run Constant survey selectivity at age assumption

Year	Exploitable Biomass Estimated Selectivity	Total Biomass	Historical Exploitation Rate	Abundance of Eight-year-old Halibut
1974	117.35	196.66	0.15	1.50
1975	121.44	209.37	0.14	1.80
1976	127.98	226.63	0.14	2.08
1977	137.10	245.04	0.12	2.20
1978	152.73	273.89	0.10	2.73
1979	172.09	301.06	0.10	2.54
1980	191.74	338.14	0.10	3.16
1981	217.23	394.01	0.09	4.17
1982	247.04	443.93	0.10	3.76
1983	279.27	487.42	0.09	4.10
1984	303.12	527.13	0.10	4.74
1985	328.85	587.33	0.11	6.44
1986	339.72	615.36	0.14	5.69
1987	359.31	650.13	0.13	7.01
1988	398.20	708.14	0.13	8.79
1989	388.31	707.34	0.12	6.67
1990	361.01	682.43	0.13	5.65
1991	335.29	670.73	0.14	7.18
1992	322.23	640.33	0.14	5.73
1993	301.05	587.87	0.13	4.10
1994	304.06	534.94	0.12	3.05
1995	293.06	513.51	0.10	4.61
1996	290.61	484.24	0.11	3.04
1997	282.21	440.20	0.15	1.63
1998	245.65			

Stock Assessment Methodology: Model Documentation

by

Ana M. Parma and Patrick J. Sullivan

ABSTRACT

A size and age-structured model was developed recently to assess halibut stocks. The main difference between this model and CAGEAN, the model used in the annual assessments until 1994, is that the selectivity of the different age-classes is no longer assumed to be constant. Rather, age-specific selectivity is modeled as a function of the size distribution at age and a size-specific selectivity function, both of which may change over time. This document describes the model formulation and the data used in the estimation.

BACKGROUND

Pacific halibut have undergone a rapid reduction in body growth in recent years, with average weight-at-age now half of what it was 20 years ago. This has a number of consequences for halibut stock assessment and management. Stock assessments conducted in the late 1980s and early 1990s used a catch-age model (CAGEAN -- Deriso, Quinn, and Neal 1985) which assumes that fishing mortality can be partitioned into a constant age-specific selectivity component, and a time-dependent full-selection fishing mortality component. This assumption can work well even though fishing gear may be size-selective when fish maintain roughly a constant size-at-age, and when other factors such as type of gear used and targeting practices remain stable. Given the recent changes observed in halibut growth, however, the assumption was considered to be problematic and to severely bias the assessments (Parma and Sullivan 1996[Unpub]). Due to the constant-selectivity assumption, a low representation of the younger age classes in the landings resulted in drastically declining recruitment estimates in the early 1990s. Initial estimates were later adjusted upwards in successive assessments as fish grew and became vulnerable to the setline gear. As a result, stock assessments showed a strong retrospective pattern, in which estimates of exploitable biomass for past years were consistently adjusted upwards in every successive assessment and, while stock levels appeared to be declining rather steeply, quotas remained stable. To address these problems, we developed an alternative assessment model which accounts for possible changes in selectivity with age that result from changes in size-at-age.

Here we describe the model and specify the data used for parameter estimation. An outline of the model relative to the dynamics of the age classes represented in the exploited stock is presented first. This component is similar structurally to previous age-structured models used on halibut and so its development should be familiar. This is followed by a reformulation of the selectivity at age as a dynamic function of the size distribution of each age class in the population coupled with a size-based selectivity function. The effect of the minimum size limit on the catch age composition is modeled explicitly; other parameters controlling the size-based selectivity are allowed to change gradually over time. Finally, a model of how the size-distribution at age changes with time and

Sullivan, P.J., Parma, A.M., 1998. Population assessment, 1997.
IPHC Rep. Assess. Res. Act. 1997., pp. 83–210.

through the effect of size-selective mortality is developed. Size-selective mortality couples growth and fishing mortality into a size-age dynamic model for each cohort.

MODEL DEVELOPMENT

Abundance Dynamics

The population abundance N of a cohort at age a+1 in year t+1 is related to the cohort's abundance at the previous age a and year t by:

$$N_{a+1,t+1} = N_{a,t}\,\mathrm{e}^{-M}\left(1-{}_{\mathrm{b}}H_{a,t}\right)\left(1-{}_{\mathrm{c}}S_{a,t}\left(1-\mathrm{e}^{-F_t}\right)\right) \qquad \text{for} \quad a=6,\cdots,18 \qquad (1)$$

where M is the instantaneous rate of natural mortality, ${}_{c}S_{a,t}$ is selectivity for fish of age a at time t, F_t is the instantaneous commercial fishing mortality at time t for fully-selected fish, and ${}_{b}H_{a,t}$ is the finite rate of bycatch mortality at age a and time t, which results from fisheries targeting on other species. Age classes from age 6 to 20 are considered, where age 20 is actually a "plus" age-group which accumulates all fish of age 20 and older. The notation used in this and subsequent equations is summarized in Appendix 1.

The survivorship component representing the commercial fishery differs from the more familiar Baranoff equation in that fishing is assumed to take place in a short period in the middle of the year, and selectivity at age is modeled as the *fraction* of each age class that is recruited to the exploitable stock and suffers and instantaneous fishing mortality equal to F_t. In other words, we equate selectivity with availability (Ricker 1975) and assume that all available fish are fully vulnerable. In the more familiar formulation selectivity is equated with vulnerability, which affects the instantaneous rate of fishing mortality of different sizes of ages, and differences in availability of different stock components are ignored. Either formulation should be adequate in practice to explain differences in age composition between the population and the catches. The formulation above is computationally straightforward for use in determining effects on survivorship and size-at-age as we shall see later, and it is consistent with the definition of exploitable biomass used to compute recommended catch levels. Note that the selectivity component ${}_{c}S_{a,t}$ is a function of both age and time, unlike standard separable age-structured models which assume that selectivity is a function of age alone and is constant over time.

Assuming in addition that bycatch mortality takes place prior to the fishing season, the catch associated with the directed commercial fishery ${}_{c}C$ follows:

$$ {}_{\mathrm{c}}C_{a,t} = N_{a,t}\,\mathrm{e}^{\frac{-M}{2}}\left(1-{}_{\mathrm{b}}H_{a,t}\right){}_{\mathrm{c}}S_{a,t}\left(1-\mathrm{e}^{-F_t}\right) \qquad (2)$$

Age composition of the survey catches is given by

$$ {}_{\mathrm{s}}P_{a,t} = \frac{{}_{\mathrm{s}}S_{a,t}\,N_{a,t}}{\sum_i {}_{\mathrm{s}}S_{i,t}\,N_{i,t}}$$

where ${}_{s}S_{a,t}$ is survey selectivity at age and time, parameterized as described below. Predicted ${}_{c}C_{a,t}$'s and ${}_{s}P_{a,t}$'s are fitted to the observed catches for parameter estimation. Observations on halibut bycatch are available only by size-category, and so a size-based formulation is used to fit the model to those observations. Details are provided in Appendix 2.

Two abundance are used in the estimation: commercial *CPUE* (or effort) and survey *CPUE*. Strict proportionality between biomass and commercial *CPUE* was not assumed, as the catchability of the commercial fleet was allowed to vary according to a random walk model so that:

$$\ln(Q_{t+1}) = \ln(Q_t) + {}_q\varepsilon_t \tag{3}$$

where ${}_q\varepsilon_t \sim N(0, {}_q\sigma^2)$. The parameter ${}_q\sigma^2$ is used to control the amount of year-to-year variation allowed in Q_t. Similar random-walk formulations are used for other model parameters as well, whenever time-series trends are considered likely. The effective commercial effort can be predicted by assuming that mortality F_t for fully-vulnerable fish is related to fishing effort according to:

$${}_cE_t = \frac{F_t}{{}_cQ_t} \tag{4}$$

The survey catch in numbers per unit effort is predicted as

$${}_sCPUE_t = {}_sQ \; e^{\frac{-M}{2}} \sum_a {}_sS_{a,t} N_{a,t} \tag{5}$$

where ${}_sQ$ is the catchability coefficient for the surveys, which is assumed to be constant except for an adjustment factor incorporated to account for a change in hook type as explained below .

Selectivity

Selectivity, the relative catchability of fish of different ages and sizes, is usually modeled as a function solely of age. In the so-called separable models (e.g. CAGEAN) age-specific selectivity is assumed to be time-invariant. Such an assumption results in a considerable reduction in the number of parameters that need to be estimated in catch-age analysis. The assumption is valid when capture is an age-dependent process as, for example, when organisms recruit to the fishery at a certain life stage and when the size-at-age is relatively stable with time. The distribution of size at age of Pacific halibut has changed over time, with fish being about 20% smaller (in length) at age now than they were in the early 1980s. By not accounting for this change and by assuming that selectivity is constant at age, erroneous time trends can be introduced into the estimation procedure.

There are several ways of addressing this issue. The approach we have chosen attempts to model the change in selectivity at age by tracking how size at age changes in the population and assuming that selectivity at size can change slowly through time. In this manner, we can explicitly incorporate the effect of the minimum size limit on the age composition of the catches, and at the same time allow for trends in size-selectivity that may occur particularly when size-at-age changes. Given the distribution of size at age a at time t, here represented by log-length X, and a selectivity at size ${}_c s_t(X)$, we can compute expected selectivity at age and time by integration over the size distribution of fish at age a at time t:

$$ {}_c S_{a,t} = \int_{-\infty}^{\infty} {}_c s_t(X) \varphi\left(X | \mu_{a,t}, \sigma^2_{a,t}\right) \mathrm{d}X \, \exp\left\{ {}_{\text{sel}} \varepsilon_{a,t} \right\} \tag{6} $$

where the function $\varphi(X|\mu_{a,t},\sigma^2_{a,t})$ represents the probability that a fish of age a at time t is of log-length X, assumed to be Gaussian with mean $\mu_{a,t}$ and variance $\sigma^2_{a,t}$. We allow for small random deviations in selectivity at age by assuming that ${}_{\text{sel}}\varepsilon_{a,t} \sim N\left(0, {}_{\text{sel}}\sigma_t^2\right)$ for ages 6-10; selectivities of age classes older than 10 are as predicted from their size-distribution coupled with the size-based selectivity (i.e. ${}_{\text{sel}}\varepsilon_{a,t}=0$ for $a > 10$). Selectivity at size for the commercial fishery at time t can be represented in terms of the legal size (81 cm) and two parameters (X_t^{full} and ν_t):

$$ {}_c s_t(X) = \begin{cases} 0, & \text{for} \quad X < \ln(81) \\ \exp\left\{ \dfrac{-\left(X - X_t^{\text{full}}\right)^2}{2\nu_t} \right\} & \text{for} \quad \ln(81) \le X \le X_t^{\text{full}} \\ 1, & \text{for} \quad X > X_t^{\text{full}} \end{cases} \tag{7} $$

Selectivity is zero for fish smaller than the legal size, increases according to a half Gaussian curve scaled to reach a maximum of one at $X = X_t^{\text{full}}$, the size (log-length) at full selectivity, and equals one beyond X_t^{full}. Equations (1), (6), and (7) imply that discarded sublegal fish are assumed to survive with probability equal to one. The parameters X_t^{full} and ν_t are allowed to change over time assuming a random walk model with constraints in the variances of the year-to-year deviations.

$$ \begin{aligned} X_{t+1}^{\text{full}} &= X_t^{\text{full}} + {}_{X\text{full}}\varepsilon_t \qquad \text{where } {}_{X\text{full}}\varepsilon_t \sim N\left(0, {}_{X\text{full}}\sigma_t^2\right) \\ \ln(\nu_{t+1}) &= \ln(\nu_t) + {}_{\nu}\varepsilon_t \qquad \text{where } {}_{\nu}\varepsilon_t \sim N\left(0, {}_{\nu}\sigma_t^2\right) \end{aligned} \tag{8} $$

The formulation is similar to that used for $\ln(Q_t)$ except that the variances for the normal deviations are year-specific. This was done so as to allow selectivity to change more when growth rates are changing rapidly; very little change was allowed during periods of relatively stable size at age.

The size-selectivity of the longline survey is assumed to have the same functional form except for the discontinuity at the legal size limit which does not apply to the surveys. In 1984, the hook type used in the surveys was changed from J-hook to the more efficient circle hook (C-hook) used by the commercial fleet. In order to estimate the relative efficiency of the two hook types, two parallel sets were fished on each survey station in 1984, one with each hook type. The ratio of catches by 10-cm size category showed that the C-hook selected fish of smaller sizes than the J-hook (Clark, this volume). The C-hook was estimated to be twice as effective as the J-hook at catching large, fully selected fish. In order to account for these experimental results, the ratio of the catchabilities of the hooks is assumed known and equal to two, and selectivity parameters are estimated separately for the two time periods with an overlap in 1984. The size-specific ratios of catches obtained by the two hook types in 1984 are predicted from the ratios of expected catches, computed by summing across ages. Predicted catch ratios, ratio_l, were fitted to the observed ratios, ratio_l^{obs}.

Two model formulations are considered: (a) selectivity at length is constant over time except for the change in 1984 associated with the change in hook type, and (b) selectivity at length changes over time so that the coupling of changing size at age and changing survey size-selectivity results in constant age-specific selectivities (except for the change in hook). In the first formulation surveys conducted using the same hook are assumed to index population abundance by size-category. This formulation would be more appropriate if survey selectivity reflected mostly the properties of the fishing gear as it interacts with fish of different sizes. The second would be preferred if the availability of fish of different age classes on the surveyed grounds were the dominant factor in determining survey selectivity.

Growth Dynamics

The selectivity and size distribution in the catch of fish of a given age-class depend on their size distribution in the population. Thus, the growth dynamics must be modeled as well. In the absence of size-selective mortality, the median length-at-age $m_{a,t} = \exp(\mu_{a,t})$ is assumed to propagate according to

$$m_{a+1,t+1} = \alpha_t + \beta\, m_{a,t} \qquad \text{for } a = 6,7,\cdots \tag{9}$$

with time-varying initial size $m_{6,t}$ and intercept α_t. When the growth coefficient β is less than one, this representation corresponds to a von Bertalanffy model (applied to median length at age) with a time trend in the parameter corresponding to the asymptotic length $L_\infty = \alpha_t/(1-\beta)$, and a time trend in size at age 6 (the age of recruitment). When $\beta = 1$, growth is linear with time-varying slope and initial size. The time-series trend in the mean log-length at recruitment $\mu_{6,t}$ is modeled as a random walk

$$\mu_{6,t+1} = \mu_{6,t} + {}_{\mu}\varepsilon_t \tag{10}$$

where ${}_{\mu}\varepsilon_t \sim N(0, {}_{\mu}\sigma^2)$. The growth intercept α_t is modeled as a cubic polynomial function of t.

The variance in log-length at age $\sigma^2_{a,t}$ is linked to the mean $\mu_{a,t}$ by

$$\sigma^2_{a,t} = \left[c + d\mu_{a,t}\right]^2 \tag{11}$$

If d is set to zero, $\sigma_{a,t}$ is constant and equal to c, so that the coefficient of variation of length-at-age is constant and equal to $CV[L] = \sqrt{\exp(c^2) - 1} \cong c$. The variance relationship is assumed to hold even when $\mu_{a,t}$ changes due to size-selective mortality.

The effect of size-selective mortality on the size distribution at age is incorporated by adjusting the mean log-length at age, from $\mu_{a,t}$ (the mean prior to the fishing season) to $\mu^{+}_{a,t}$ (the mean at a time immediately following fishing). Realistically, the nature of the distribution should also be affected, but we assume that a Gaussian function is still an adequate approximation of the distribution of log-length after the fishery. We let the variance follow again as the square of a linear function of the mean as stated above. If the means change as a result of changes either in the environment or due to size selection, the variances will change as well in a corresponding manner.

Because larger fish are selectively removed by the fishery, $\mu^{+}_{a,t}$ is smaller than $\mu_{a,t}$. The mean log-length in the population after fishing has taken place is given by:

$$\mu^{+}_{a,t} = \frac{\int_{-\infty}^{\infty} X\left(1-{}_{c}s_t(X)\,{}_{c}H_t\right)\varphi\left(X\,|\,\mu_{a,t},\sigma^2_{a,t}\right)\mathrm{d}X}{\int_{-\infty}^{\infty}\left(1-{}_{c}s_t(X)\,{}_{c}H_t\right)\varphi\left(X\,|\,\mu_{a,t},\sigma^2_{a,t}\right)\mathrm{d}X} \tag{12}$$

where $(1-{}_{c}s_t(X)\,{}_{c}H_t)$ represents the survivorship from fishing with ${}_{c}H_t = (1 - \exp(-F_t))$ representing the harvest fraction and $\varphi(X|\mu_{a,t},\sigma^2_{a,t})$ the probability density function of log-length X as a function of the prior mean $\mu_{a,t}$ and variance $\sigma^2_{a,t}$. The denominator of the equation above corresponds to the fraction of fish of age a that survive after the fishing season.

The median length at age $a+1$, prior to the next fishing season, is predicted based on $m^{+}_{a,t} = \exp(\mu^{+}_{a,t})$ as:

$$m_{a+1,t+1} = \alpha_t + \beta\, m^{+}_{a,t}. \tag{13}$$

The corresponding mean of log-length prior to the next fishing is $\mu_{a+1,t+1}=\ln(m_{a+1,t+1})$, which is used to calculate $\sigma^2_{a+1,t+1}$ as in equation (11). The two parameters that specify the pdf of X prior to the fishing season at time $t+1$ are thus obtained and a new recursive cycle can be applied.

Given that the pdf of the log-length-at-age for a cohort is represented by $\varphi(X|\mu_{a,t},\sigma^2_{a,t})$, the mean and variance of the log-length-at-age in the catch can be predicted as the first and adjusted second moments normalized by the average selectivity at age:

$$
\begin{aligned}
{}_{c}\mu_{a,t} &= \frac{\int_{\ln(81)}^{\infty} X\;{}_{c}s_t(X)\,\varphi\left(X|\mu_{a,t},\sigma^2_{a,t}\right)\mathrm{d}X}{\int_{\ln(81)}^{\infty} {}_{c}s_t(X)\,\varphi\left(X|\mu_{a,t},\sigma^2_{a,t}\right)\mathrm{d}X}\\
{}_{c}\sigma^2_{a,t} &= \frac{\int_{\ln(81)}^{\infty} X^2\;{}_{c}s_t(X)\,\varphi\left(X|\mu_{a,t},\sigma^2_{a,t}\right)\mathrm{d}X}{\int_{\ln(81)}^{\infty} {}_{c}s_t(X)\,\varphi\left(X|\mu_{a,t},\sigma^2_{a,t}\right)\mathrm{d}X} - {}_{c}\mu^2_{a,t}
\end{aligned}
\tag{14}
$$

Note that the integration is done across all sizes above the legal size limit (ln(81)). Similar equations are used to predict the mean log-length at age ${}_{s}\mu_{a,t}$ and the variance of log-length at age ${}_{s}\sigma^2_{a,t}$ for survey catches; but because survey selectivity is not restricted by the legal size limit, the lower limit of integration is set to $-\infty$. The specific assumptions made about the pdf of X and the shape of

$s_t(X)$ lead to a numerically efficient algorithm, as selectivities at age $S_{a,t}$, and the moments of the distribution of X in the catch and among the survivors can be expressed as a function of standard Gaussian cumulative distributions.

ESTIMATION

Objective Function

Model predictions are fitted to three types of observations: catch at age, *CPUE* (or effort), and the mean and variance of log-length at age in the catches. This information is collected from the sampled commercial fishery for all areas, and for the longline surveys which are available only for some areas and years. Information on halibut bycatch is available for all areas and years as total bycatch in numbers by size category. The size composition of the current year's bycatch is not available for the assessment and so the previous year's sizes are used. Bycatch data are treated as being free of error and bycatch numbers are subtracted out from each cohort based on the predicted age composition at size (see Appendix 2). Thus the bycatch process is not parameterized and the observations are not "fitted" by the model.

Parameters in Table 1 are estimated separately for each area by maximizing the likelihood of the available observations while penalizing the variability of some of the stochastic variables modeled by specifying their variances *a priori*. Log-normal errors are assumed throughout and the weighted residual sum of squares *RSS* is computed by summing the following components:

Catch-at-age equations:

$$RSS_{\text{c:c}} = \lambda_{\text{c:c}} \sum_a \sum_t \left[\frac{\ln({}_{\text{c}}C^{\text{obs}}{}_{a,t}) - \ln({}_{\text{c}}C_{a,t})}{\text{sd}\left(\ln({}_{\text{c}}C^{\text{obs}}{}_{a,t})\right)} \right]^2$$

$$RSS_{\text{s:c}} = \lambda_{\text{s:c}} \sum_a \sum_t \left[\frac{\ln({}_{\text{s}}P^{\text{obs}}{}_{a,t}) - \ln({}_{\text{s}}P_{a,t})}{\text{sd}\left(\ln({}_{\text{s}}P^{\text{obs}}{}_{a,t})\right)} \right]^2$$

Effort equations:

$$RSS_{\text{c:e}} = \lambda_{\text{c:e}} \sum_t \left[\ln(E^{\text{obs}}{}_t) - \ln(E_t)\right]^2$$

$$RSS_{\text{s:e}} = \lambda_{\text{s:e}} \sum_t \left[\frac{\ln({}_{\text{s}}CPUE^{\text{obs}}{}_t) - \ln({}_{\text{s}}CPUE_t)}{\text{sd}\left(\ln({}_{\text{s}}CPUE^{\text{obs}}{}_t)\right)} \right]^2$$

Length equations:

$$RSS_{\text{c:}\mu} = \lambda_{\text{c:}\mu} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\text{c}}\mu^{\text{obs}}{}_{a,t}) - \ln({}_{\text{c}}\mu_{a,t})}{\text{sd}\left(\ln({}_{\text{c}}\mu^{\text{obs}}{}_{a,t})\right)} \right]^2$$

$$RSS_{\text{c:}\sigma} = \lambda_{\text{c:}\sigma} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\text{c}}\sigma^2{}_{a,t}{}^{\text{obs}}) - \ln({}_{\text{c}}\sigma^2{}_{a,t})}{\text{sd}\left(\ln({}_{\text{c}}\sigma^2{}_{a,t}{}^{\text{obs}})\right)} \right]^2$$

$$RSS_{\text{s:}\mu} = \lambda_{\text{s:}\mu} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\text{s}}\mu^{\text{obs}}{}_{a,t}) - \ln({}_{\text{s}}\mu_{a,t})}{\text{sd}\left(\ln({}_{\text{s}}\mu^{\text{obs}}{}_{a,t})\right)} \right]^2$$

$$RSS_{\text{s:}\sigma} = \lambda_{\text{s:}\sigma} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\text{s}}\sigma^2{}_{a,t}{}^{\text{obs}}) - \ln({}_{\text{s}}\sigma^2{}_{a,t})}{\text{sd}\left(\ln({}_{\text{s}}\sigma^2{}_{a,t}{}^{\text{obs}})\right)} \right]^2$$

C-J-hook-conversion equations:

$$RSS_{\text{c-j}} = \lambda_{\text{c-j}} \sum_l \left[\frac{(\text{ratio}^{\text{obs}}{}_l - \text{ratio}_l)}{\text{sd}\left(\text{ratio}^{\text{obs}}{}_l\right)} \right]^2$$

Thus the total sum of squares is given as

$$RSS = RSS_{\text{c:c}} + RSS_{\text{s:c}} + RSS_{\text{c:e}} + RSS_{\text{s:e}} + RSS_{\text{c:}\mu} + RSS_{\text{s:}\mu} + RSS_{\text{c:}\sigma} + RSS_{\text{s:}\sigma} + RSS_{\text{c-j}}$$

The negative log-likelihood of the observations, up to additive constants, is

$$L = 0.5\, n_{\text{obs}} \log(RSS)$$

where n_{obs} is the total number of observations. Parameter estimates are obtained by minimizing the objective function

$$f = L + \text{penalties}$$

where the penalties correspond to prior assumptions made about some of the stochastic processes involved, namely, time-series trends in catchability (equation (3))

$$PSS_q = 0.5 \sum_t \frac{{}_q\varepsilon_t^2}{{}_q\sigma^2}$$

time-series trends in mean log-length at age 6 (equation (10)),

$$PSS_{\mu} = 0.5 \sum_{t} \frac{{}_{\mu}\varepsilon_t^2}{{}_{\mu}\sigma^2}$$

time-series trends in the parameters of the size-selectivity function $s_t(X)$ for the commercial fishery and the survey when appropriate (equation (8)),

$$PSS_{\text{Xfull}} = 0.5 \sum_{t} \frac{{}_{\text{Xfull}}\varepsilon_t^2}{{}_{\text{Xfull}}\sigma_t^2} \quad \text{and} \quad PSS_{v} = 0.5 \sum_{t} \frac{{}_{v}\varepsilon_t^2}{{}_{v}\sigma_t^2}$$

and random deviations in selectivity at age affecting the youngest age classes (equation (6)),

$$PSS_{\text{sel}} = 0.5 \sum_{a,t} \frac{{}_{\text{sel}}\varepsilon_{a,t}^2}{{}_{\text{sel}}\sigma^2} \quad \text{for} \quad a = 6, \cdots, 10$$

The penalties term in the objective function is thus

$$\text{penalties} = PSS_q + PSS_{\mu} + PSS_{\text{Xfull}} + PSS_v + PSS_{\text{sel}}$$

The model was implemented using AD Model Builder (Otter Research Ltd. 1994) which uses automatic differentiation to minimize the objective function. The minimization is conducted in steps or phases of increasing complexity as specified by the user.

Weighting Criteria

Relative weights are used to control the emphasis that the different *RSS* components receive in the estimation. Weights should correspond to the level of information present in the data. Two methods are used for setting those weights:

First, a relative weighting of observations of the same type (e.g. within catch, or length) is incorporated on an observation-by-observation basis. We use empirically-computed coefficients of variation of the statistics whenever possible. Because errors are assumed to be log-normally distributed, the coefficients of variation of the observations approximate the standard deviations of the corresponding log-transformed variables. Catch-at-age observations are weighted based on the coefficient of variation of the age proportions in the market sample data. Residuals corresponding to the mean and variance of log-length in the commercial catch are weighted using the coefficient of variation of the estimated moments determined from bootstrap; those from the survey catch are weighted using coefficients of variation determined from standard equations based on simple random sampling. Coefficient of variations for age proportions and *CPUE* in the surveys are estimated assuming simple random sampling.

Second, a differential weighting of data of different types is effected through the *l*'s, as in previous model formulations (Table 2). Sampling-based measures of uncertainty do not normally capture all the variability present in the process, so *l*'s lower than one are used in most cases to increase the variance assigned to the different components in an *ad hoc* manner. The *l* associated with effort is greater than one because its variance cannot be estimated empirically and the residual sum of squares alone is not fully indicative of the effort variation relative to the catch component.

A greater emphasis is also placed on the C-hook/J-hook observed catch ratios by setting $l_{c\text{-}j}$ to five. All weights affecting the *RSS* are relative, as an overall residual variance is estimated.

In addition to the relative weights affecting the observations' *RSS*, variances for the four random walk components are set *a priori.* As described earlier these represent trends in commercial catchability, initial size at age, and the two selectivity parameters. The drift in the walk is controlled by the assumed distribution on the random variables e. Here the variables are assumed to be Gaussian distributed with zero mean and variance s^2. In contrast to the variances of the observations, variances of these process are assumed known, which effectively creates a prior for the amount of random deviation. The random walk for the log-catchability is assumed to have a variance equal to 0.03^2. The variance of the log-length at recruitment was set at 0.1^2. and the square root of the variances of the random walks for the two selectivity parameters range between 0.01 and 0.03.

Number of Observations

The availability of survey information varies depending on the regulatory area: areas 2B and 3A were surveyed more often from 1974 through 1986, and since 1993, while other areas were surveyed more sporadically; no longline surveys were conducted from 1987 to 1992. Observations for the commercial fishery are available for all years and age groups modeled, except for effort data for year 1983, when the commercial fleet was in the process of switching from using J hooks to using the more efficient circle hooks. If there are A age groups and T years, there typically will be $A'T$ observations on commercial catch, $A'T$ observations on log-length at age, $A'T$ observations on variance of log-length at age, and T-1 observations on fishing effort. For the surveys, there will be a maximum of $A'(T\text{-}7)$ observations on each the catch-at-age, and the mean and variance of log-length at age, and T-6 *CPUE* observations. Aging of survey samples collected in the current year is not completed at the time of the assessment, only survey *CPUE* is available. Under this scenario there are $(6\ 'A\ 'T) - (A'7'3) + 2\ 'T - 7$ observations. This amounts to 1886 observations for data covering 1974 through 1997.

Fundamental Model Parameters

In order to define a set of estimable parameters and to make sure that the estimates have reasonable values, certain parameters are fixed while others are estimated under a specified set of constraints. The natural mortality parameter is one such parameter which is typically fixed. We set it here to $M = 0.2$ and assume it to be constant over all time periods and age-classes modeled. We plan to relax this assumption in the future and estimate M jointly using prior information.

The initial conditions for size at age in the population at the start, $m_{a,1}$, aÎ{6,…,20+}, are constrained to follow a three parameter von Bertalanffy model. The growth coefficient b is constrained to be between 0.5 and one, the log-length at full selectivity X_t^{full} in year t=1 is constrained to be less than ln(130),), and a quadratic penalty is added to the objective function so as to force the predicted commercial and survey selectivities for the 20+ age group to be equal to one. The variance of log-length at age is assumed to be constant by setting d=0 in equation (11). Estimated parameters are shown in Table 1, although the actual minimization is conducted over a different parameter space. Re-parameterizations are used to reduce the correlation among estimated parameters, and transformations are used in some cases to constrain parameter values; the latter is done automatically by AD Model Builder when bounded parameters are specified.

Derived Parameters

Derived parameters of management interest are the exploitable biomass

$$B_t = \sum_a {}_cS_{a,t}\, w_{a,t}\, N_{a,t}$$

where $w_{a,t}$ are smoothed weights at age in the commercial catch, and the exploitable biomass at the beginning of the year following the assessment, which is predicted as

$$B_{T+1} = \sum_{a=6}^{19} {}_cS_{a+1,t}\, w_{a+1,t}\, N_{a,t}\, e^{-M} \left(1 - {}_bH_{a,t}\right)\left(1 - {}_cS_{a,t}\ {}_cH_t\right) +$$
$$ {}_cS_{20,t}\, w_{20,t}\, N_{20,t}\, e^{-M} \left(1 - {}_bH_{20,t}\right)\left(1 - {}_cS_{20,t}\ {}_cH_t\right) + {}_cS_{6,t}\, w_{6,t}\, \overline{N}_{6,\cdot}$$

where $\overline{N}_{6,\cdot}$ is the average of the age-6 abundance estimates for the T years covered by the assessment. This last term has no effect on projected exploitable biomass because ${}_cS_{6,t}$ is close to zero.

Uncertainty of Parameter Estimates

AD Model Builder provides standard deviations of estimated and derived model parameters as specified by the user. The covariance matrix of the parameter estimates is estimated by inverting the Hessian matrix and using the Delta method in the case of derived parameters, such as predicted exploitable biomass. We are currently evaluating the use of Markov Chain Monte Carlo methods, which have been recently implemented in AD Model Builder, to express uncertainty and conduct simulations for policy evaluation.

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Table 1. Estimated model parameters

Parameters		Number
$N_{6,t}$	recruitment	T
$N_{a,1}$	initial abundance	A-1
F_t	fishing mortality	T
${}_cQ_t$	commercial catchability	T
${}_sQ$	survey catchability	1
X_t^{full} and ν_t	size-selectivity	$2\times T + 2 \times$ number of surveys (or 2 if surveys have constant size-selectivity)
${}_{sel}\varepsilon_{a,t}$	deviations in selectivity at age	$(10\text{-}5)\times T$
$\mu_{6,t}$	mean log-length at age 6	T
α_0 and β_0	initial log-length at age	2
α_t	intercept of growth equation	3
β	slope of growth equation	1
c	coefficient of variation of size at age	1

Table 2. Lambda and associated ISD ($1/\sqrt{Lambda}$), with rational for information content. ISD represents lambda's information weighting in units of standard deviation.

Component	Lambda	ISD	Rational
Catch	0.25	2	Twice sample CV
Effort	50.00	$\sqrt{2}/10$	Twice variance of catch Includes measurement error
Commercial Length μ	0.04	5	Less emphasis than catch on fit
Commercial Length σ	0.50	$\sqrt{2}$	Twice sample variance
Survey Proportion	0.25	2	Twice sample CV
Survey Effort	0.25	2	Twice sample CV
Survey Length μ	0.04	5	Less emphasis than catch on fit
Survey Length σ	0.50	$\sqrt{2}$	Twice sample variance
C/J hook ratio	0.50	$\sqrt{2}$	Twice sample variance

APPENDIX 1: NOTATION

Prescripts:

b	Bycatch
c	Commercial
s	Survey

Subscripts:

a	Age
t	Time
l	Length category

Superscripts:

obs	Observation variable
+	Time immediately after fishing

Catch and Abundance:

${}_{c}C_{a,t}$	Commercial catch at age and time
${}_{c}C^{obs}_{a,t}$	Observed commercial catch at age and time
${}_{c}P_{a,t}$	Age composition in survey catches at time t
${}_{c}P^{obs}_{a,t}$	Observed age composition in survey catches at time t
${}_{b}C^{obs}_{l,t}$	Observed bycatch at size category and time
${}_{s}CPUE_{t}$	CPUE at time for survey
${}_{s}CPUE^{obs}_{t}$	Observed CPUE at time for survey
${}_{c}E_{t}$	Fishing effort at time for commercial fishery
${}_{c}E^{obs}_{t}$	Observed fishing effort at time for commercial fishery
F_{t}	Instantaneous fishing mortality at time
${}_{b}H_{a,t}$	Finite rate of bycatch mortality at age and time
${}_{b}H_{l,t}$	Finite rate of bycatch mortality at size category and time
${}_{c}H_{t}$	Harvest fraction of fully selected fish $=1-\exp(-F_t)$
$N_{a,t}$	Population numbers at age and time
M	Instantaneous natural mortality
${}_{c}Q_{t}$	Catchability for commercial fishery
${}_{s}Q$	Catchability for survey
${}_{c}s_{t}(X)$	Selectivity of fish of log-length X in the commercial fishery in year t
${}_{s}s_{t}(X)$	Selectivity of fish of log-length X in the survey in year t
${}_{c}S_{a,t}$	Selectivity of fish of age a in the commercial fishery in year t
${}_{s}S_{a,t}$	Selectivity of fish of age a in the survey in year t
ν_{t}	Variance-like parameter of size-selectivity $s_t(X)$
X^{full}_{t}	Log-length beyond which fish are fully-selected

Size and Growth:

α_t	Intercept of the recursive growth equation
β	Slope of the recursive growth equation
c	Intercept of standard deviation relative to mean log-length at age
d	Slope of standard deviation relative to mean log-length at age
$m_{a,t}$	Median length at age in the population in year $t = \exp(\mu_{a,t})$
$m^+_{a,t,}$	Median length of fish of age a surviving the fishing season in year t
$\mu_{a,t}$	Mean log-length at age in the population in year t
$\mu^+_{a,t}$	Mean log-length of fish of age a surviving the fishing season in year t
${}_c\mu_{a,t}$	Mean log-length at age in the commercial catch in year t
${}_s\mu_{a,t}$	Mean log-length at age in the survey catch in year t
${}_c\mu^{obs}_{a,t}$	Observed mean log-length at age and time in the commercial catch
${}_s\mu^{obs}_{a,t,}$	Observed mean log-length at age and time in the survey catch
$\varphi(X\|\mu,\sigma^2)$	Gaussian pdf with mean μ and variance σ^2
$\sigma^2_{a,t}$	Variance of log-length at age in the population in year t
${}_c\sigma^2_{a,t}$	Variance of log-length at age in the commercial catch in year t
${}_s\sigma^2_{a,t}$	Variance of log-length at age in the survey catch in year t
${}_c\sigma^{2\ obs}_{a,t}$	Observed variance of log-length at age and time in the commercial catch
${}_s\sigma^{2\ obs}_{a,t}$	Observed variance of log-length at age and time in the survey catch
X	Log-length

Weighting Factors and variances of random components:

$\lambda_{c:c}$	Weight for commercial log-catch-at-age residuals
$\lambda_{e:c}$	Weight for commercial effort residuals
$\lambda_{c:\mu}$	Weight for commercial mean log-length residuals
$\lambda_{c:\sigma}$	Weight for commercial variance of log-length residuals
$\lambda_{s:c}$	Weight for survey log-catch-at-age residuals
$\lambda_{s:e}$	Weight for survey *CPUE* residuals
$\lambda_{s:\mu}$	Weight for survey mean log-length residuals
$\lambda_{s:\sigma}$	Weight for survey variance of log-length residuals
$\lambda_{c:j}$	Weight for C-J catch ratios
${}_\mu\sigma^2$	Variance of ${}_\mu\varepsilon_t$, the time-series deviations affecting $\mu_{6,t}$
${}_q\sigma^2$	Variance of ${}_q\varepsilon_t$, the time-series deviations of log-catchability
${}_{sel}\sigma^2_a$	Variance of selectivity deviations ${}_{sel}\varepsilon_{a,t}$
${}_\nu\sigma^2_t$	Variance of ${}_\nu\varepsilon_t$, the time-series deviations affecting selectivity parameter ν_t
${}_{Xfull}\sigma^2_t$	Variance of ${}_{Xfull}\varepsilon_t$ the deviations affecting selectivity parameter X^{full}_t

APPENDIX 2: BYCATCH FORMULATION

Bycatch data are only available by size category and so a size-based formulation is used to account for the mortality of halibut of legal size induced by bycatch. Total abundance by 10-cm size category present prior to the fishing season is first computed for each year t by summing across age classes. Assuming that bycatch data are observed without error, and that bycatch mortality occurs just prior to commercial fishing, the finite rate of mortality induced by bycatch on a given size category l, denoted as ${}_bH_{l,t}$, is given by

$$ {}_{\mathrm{b}}H_{l,t} = \frac{{}_{\mathrm{b}}C_{l,t}^{\mathrm{obs}}}{\sum_a N_{a,t}\, e^{\frac{-M}{2}} \int_{X \in l} \varphi\left(X \mid \mu_{a,t}, \sigma_{a,t}^2\right) dX} $$

where the fraction of each age class that corresponds to each size category is obtained by integrating $\varphi(X|\mu,\sigma^2)$. The finite rate of bycatch mortality for each age class a in year t is computed by apportioning the observed bycatch at size, ${}_{\mathrm{b}}C_{l,t}^{\mathrm{obs}}$, to the different age classes in proportion to their abundance, and summing across size categories. Equivalently,

$$ {}_{\mathrm{b}}H_{a,t} = \sum_l {}_{\mathrm{b}}H_{l,t} \int_{X \in l} \varphi\left(X \mid \mu_{a,t}, \sigma_{a,t}^2\right) dX $$

Analysis

Relative Fishing Power of C-Hooks and J-Hooks

by

William G. Clark

ABSTRACT

In the early 1980s both the commercial fishery and the IPHC setline surveys changed from J-hooks to C-hooks. Sets with both hook types at the same stations in 1984 showed that C-hooks caught 2.2 times as much as J-hooks in weight of legal sized halibut. That factor has been used ever since to adjust early J-hook catch rates to the present C-hook standard. The 1984 data were re-analyzed this year because the stock assessment now uses survey catch rates in number rather than weight. The re-analysis showed that the conversion factor in number is higher, and it varies with fish size.

BACKGROUND

In the early 1980s both the commercial halibut fishery and the IPHC setline surveys changed from the traditional J-shaped hook ("J-hook") to a circle-shaped hook ("C-hook"), because catch rates were substantially higher with C-hooks. In 1984 the Commission surveyed Areas 2B and 3A twice, fishing the same stations with both hook types. In the aggregate, C-hooks caught 2.2 times as much in weight of legal sized halibut as J-hooks. This factor has been used ever since to convert commercial and survey J-hook catch rates in early data to the present C-hook standard. For example, commercial J-hook catch per effort in the late 1970s is multiplied by 2.2 to make it comparable with present C-hook data, and survey catch rates likewise.

This conversion factor clearly has a large effect on estimates of trends in relative abundance. Its importance was recognized by the scientists who conducted the peer review of the IPHC stock assessment in September 1997. As a result of their questions, the staff realized that we should have calculated a different conversion factor when we began to fit the assessment model to survey catch rates in number rather than in weight. In the 1984 surveys, C-hooks caught 2.4 times as much as J-hooks in number of legal sized halibut, and 2.6 times as much in total numbers.

After the review, the staff re-analyzed the 1984 data to develop a more appropriate conversion. This paper summarizes the results.

THE 1984 SURVEY DATA

In 1984 a total of 174 fixed survey stations in Area 2B (northern British Columbia) and Area 3A (Kodiak) were fished twice, once with J-hooks and once with C-hooks. In fact a slightly larger number of stations were fished with both hook types, but at a few stations the number of hooks fished differed between hook types. There were some other stations that were fished only with J-hooks or only with C-hooks in 1984, so the data have to be compiled carefully to allow for a straightforward comparison of catch rates.

Sullivan, P.J., Parma, A.M., 1998. Population assessment, 1997.
IPHC Rep. Assess. Res. Act. 1997., pp. 83–210.

COMPARISON OF LENGTH FREQUENCIES

In both Area 2B and Area 3A, C-hooks caught a significantly higher proportion of small fish than J-hooks (Fig. 1). This indicates that the relative fishing power of C-hooks is not the same for all sizes of fish. But the differences in length frequencies between the two hook types are the same in Area 2B and Area 3A, which means that the data can be pooled for purposes of analysis and a single conversion procedure can be used for all areas.

RELATIVE FISHING POWER AS A FUNCTION OF LENGTH

The absolute length frequencies of halibut caught at the same stations show clearly that C-hooks were far more effective than J-hooks for all sizes of fish (Fig. 1a). The ratio of C-hook to J-hook catches, smoothed by running a data smoother through the length frequencies, suggests that the relative power of C-hooks increases from about 2 among the smallest fish in the catch (50-60 cm) to over 3 among fish near legal size (60-90 cm) and then decreases gradually back to about 2 among the largest fish (over 120 cm; Fig 2a). These are ratios of catches in number, so the estimates of relative power refer to catch in number rather than weight.

These estimates of relative fishing power are of course subject to sampling error. The variance of the sample ratios was estimated by bootstrapping the survey data. Each bootstrap trial consisted of drawing a sample of 174 stations with replacement from the 174 stations in the dataset and calculating the relative fishing power of C-hooks relative to J-hooks for each 10-cm length interval (Fig. 3). The variance of the bootstrap sample ratios is an estimate of the variance of the point estimate calculated directly from the whole dataset. Both the point estimates (not the bootstrap means) and the bootstrap standard deviations are shown in Table 1. The ratios are quite variable for the smallest and largest fish, but for intermediate sizes the standard deviation is about 0.2, which indicates (as did the Kolmogorov-Smirnov test in Fig. 1) that the decrease from over 3 among near-legal-sized fish to about 2 among large fish is significant.

DISCUSSION

The relative fishing power of C-hooks and J-hooks is not a simple matter. Evidently it depends on size, the superiority of C-hooks being greatest among fish near the legal size limit (81 cm) and somewhat less among the smallest and largest fish. The reasons for this variation are not known, but presumably result from the different ways in which fish of different sizes are hooked by the two hook types. It is known, for example, that C-hooks almost always hook fish around the mouth, while J-hooks are sometimes swallowed. J-hooks often snag large fish; C-hooks do not.

Fortunately, the differences between C-hooks and J-hooks were the same in Area 2B and Area 3A in 1984, and presumably are the same now as well. There has been a large decline in size at age in Area 3A since 1984, with the result that fish in Area 3A are now about the same size at age as fish in 2B. It seems reasonable to suppose that the effect of hook type has not been influenced by the change in growth since 1984 because it was not influenced by the difference in growth in 1984.

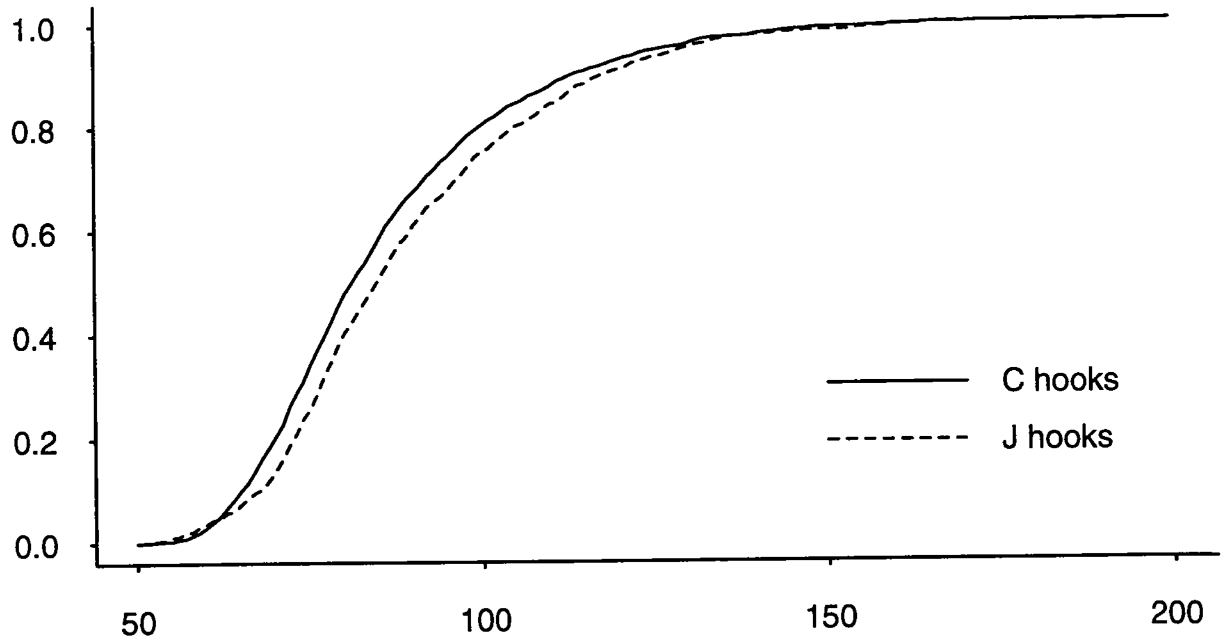

Figure 1a. Cumulative length frequencies of catches in Area 2B in 1984.
Kolmogorov-Smirnov statistic = 0.085; 95% point = 0.055.

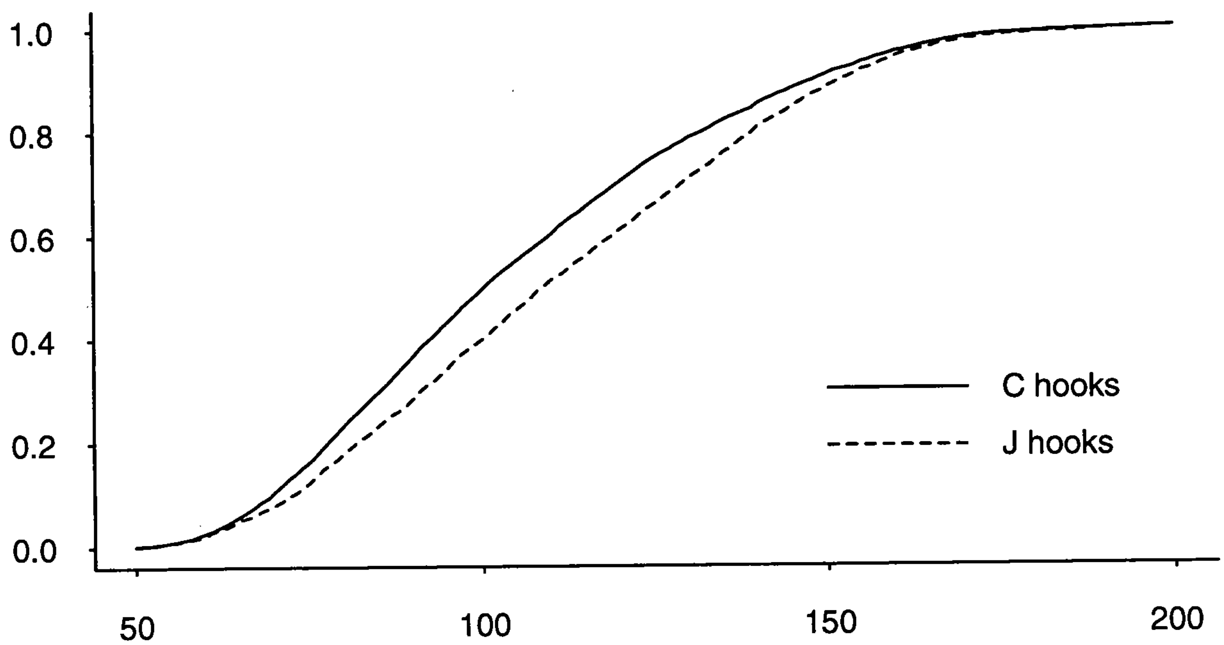

Figure 1b. Cumulative length frequencies of catches in Area 3A in 1984.
Kolmogorov-Smirnov statistic = 0.100; 95% point = 0.027.

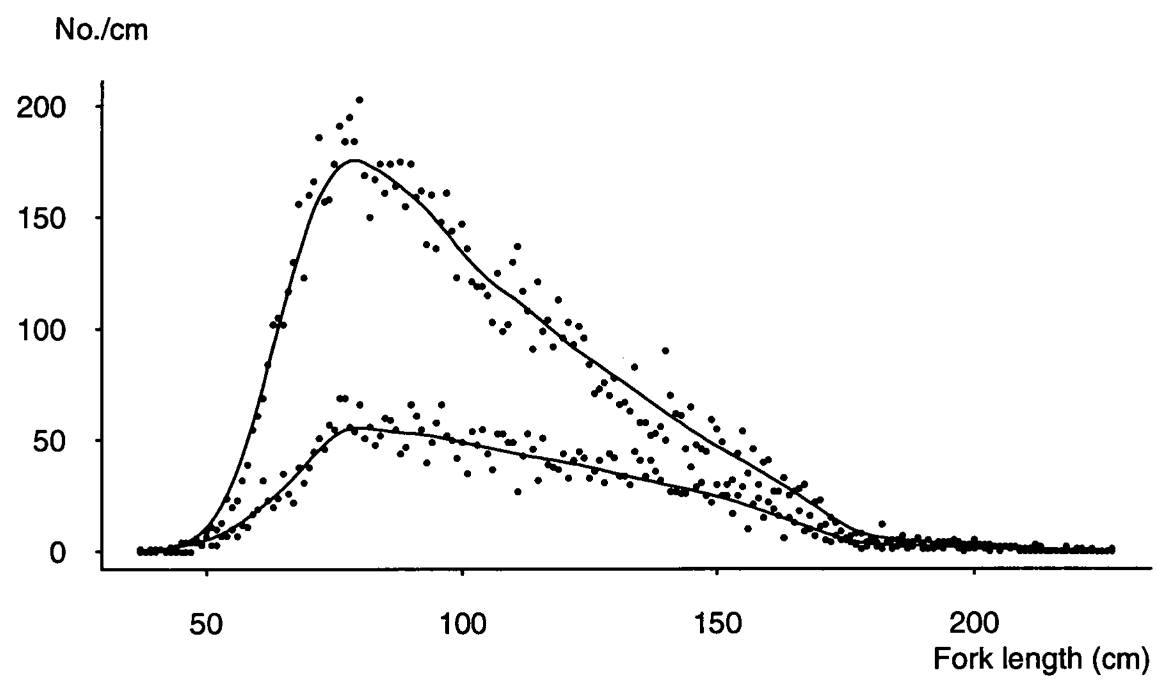

Figure 2a. Length frequencies of C-hook (upper) and J-hook (lower) catches at the same stations in 1984. (Lines are data smoothers.)

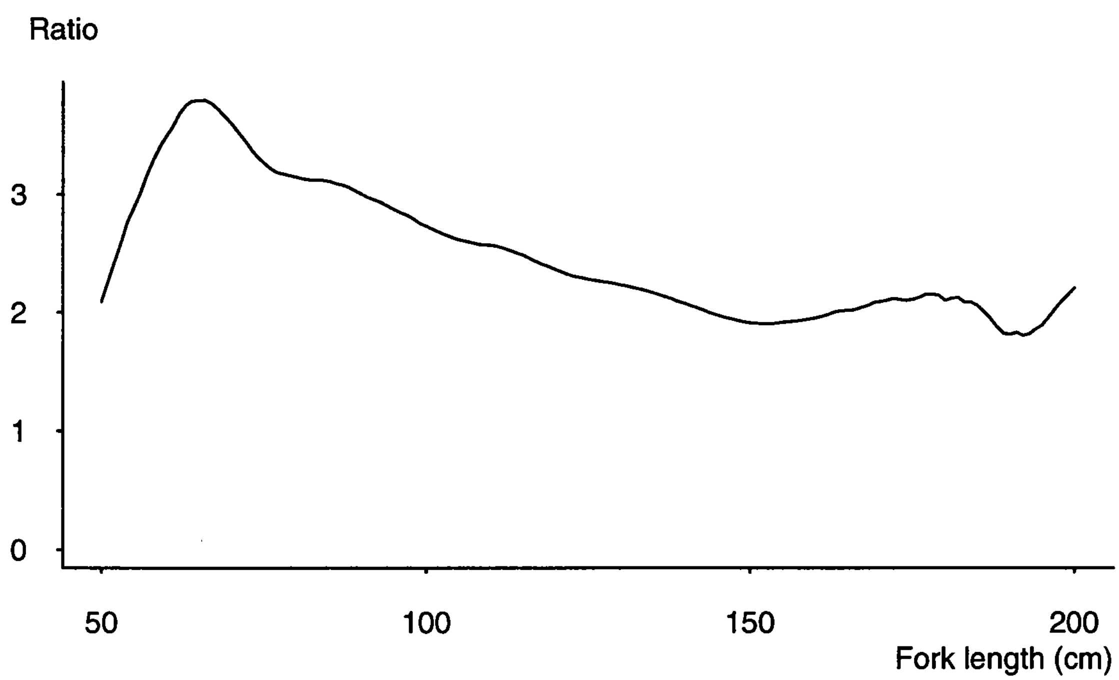

Figure 2b. Fishing power of C hooks relative to J hooks as a function of length. (Ratio of smoothed length frequencies in Fig. 2a.)

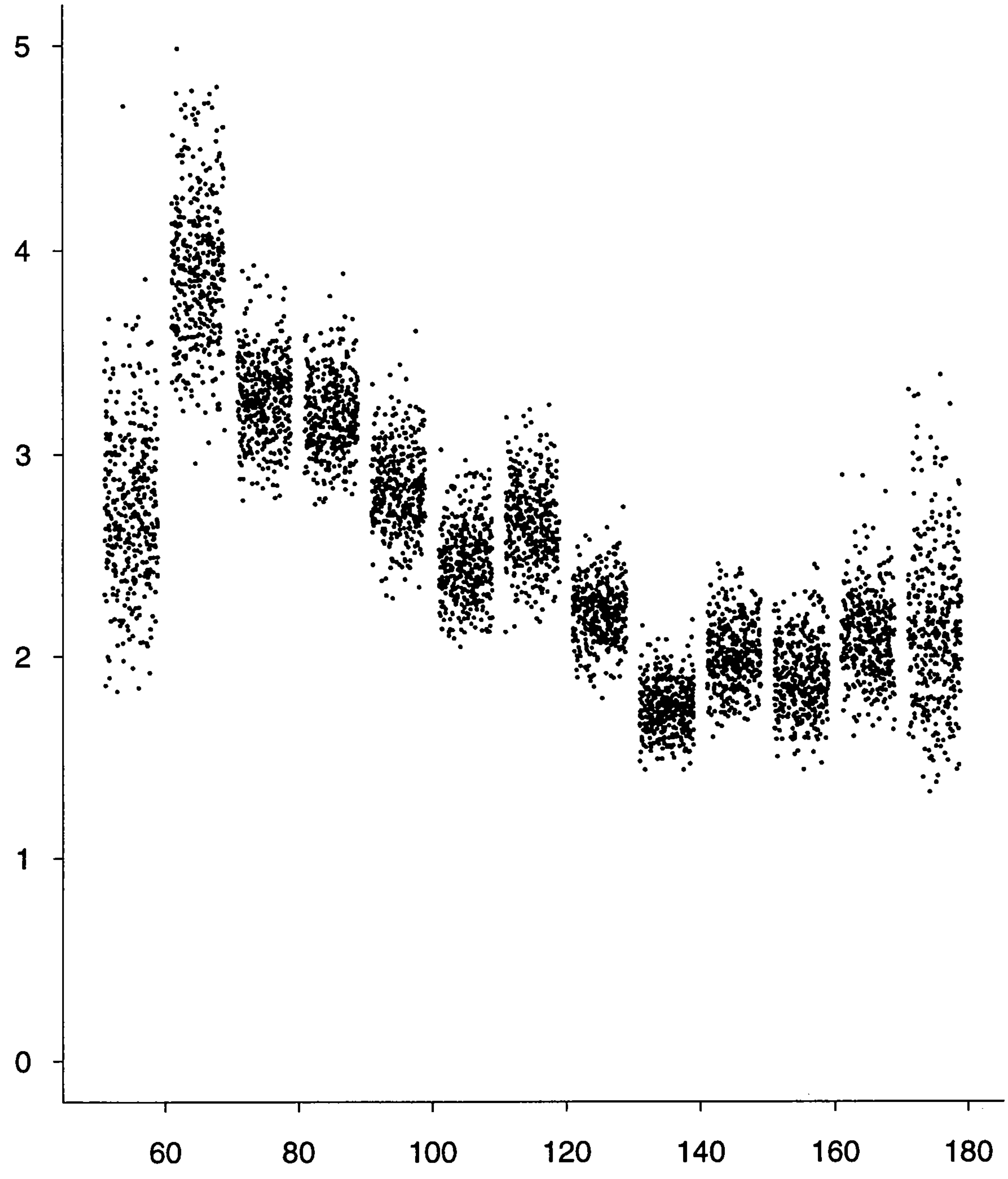

Figure 3. Distribution of bootstrap estimates of C-hook relative to J-hook fishing power, by 10 cm length interval. (Each estimate calculated by sampling the 174 stations with replacement; points jittered.)

Table 1. **Point estimates and bootstrap standard deviations of the fishing power of C-hooks relative to J-hooks, by 10-cm length interval.**

Length interval (cm)	Point estimate	Standard deviation
50-60	2.81	0.39
60-70	3.92	0.35
70-80	3.27	0.22
80-90	3.18	0.19
90-100	2.83	0.18
100-110	2.47	0.17
110-120	2.67	0.19
120-130	2.21	0.14
130-140	1.75	0.14
140-150	2.00	0.17
150-160	1.92	0.16
160-170	2.10	0.20
170-180	2.19	0.39

Coastwide Distribution of Exploitable Biomass According to 1997 Setline Surveys

by

William G. Clark

ABSTRACT

In 1997 IPHC surveyed the entire Commission area (except for the eastern Bering Sea shelf) for the first time. The results provide an estimate of relative abundance coastwide. In agreement with earlier estimates based partly on trawl surveys, setline surveys show about 25% of the biomass in Area 4, 55% in Area 3, and 20% in Area 2. The 1997 survey showed that Area 2A had 8% of the combined 2B/2A biomass.

INTRODUCTION

IPHC has conducted systematic setline surveys off and on since 1963, the great majority of them in northern British Columbia (northern Area 2B) and around Kodiak (western Area 3A). In 1997 all regulatory areas were surveyed in their entirety except for the large eastern Bering Sea shelf in Area 4 (Fig. 1 and 2). No stations were fished in Area 4E, and in Area 4D only the shelf edge was fished. Survey operations are reported in detail in a separate paper in this volume.

COASTWIDE BIOMASS DISTRIBUTION

Average survey catch per effort is an index of fish density in each regulatory area. Multiplied by the bottom area in each regulatory area, it provides an index of total exploitable biomass that can be compared among regulatory areas to estimate the distribution of biomass among regulatory areas (Table 1). In order to estimate what the average setline survey catch per effort would have been on the eastern Bering Sea shelf, NMFS trawl survey catch rates were compared from the entire shelf and from Area 4C, where both setline and trawl surveys were conducted. Trawl survey catch rates of legal sized halibut on the shelf as a whole were a little more than half the rate in 4C, so it was estimated conservatively that the setline survey catch rate would have been about half the 4C value.

The survey estimates of relative abundance agree well with the standard stock assessment in Areas 2A, 2B, 2C, and 3A. The surveys indicate relatively more fish in Area 3B and Area 4 than the stock assessment, perhaps because these areas are fished less intensively. The stock assessment works by reconstructing historical stock sizes from known removals (and natural mortality), so it will tend to miss fish in areas that are unexploited or lightly exploited.

These figures should not be treated as precise. The mean setline survey catch per effort typically has a coefficient of variation of 10%, so a 95% confidence interval on any of the cpue values in Table 1 would be ±20%. The survey results are therefore consistent with a range of values, but they nonetheless give a good general idea of where the fish are.

DISTRIBUTION OF BIOMASS BETWEEN AREA 2A AND AREA 2B

Stratified random surveys were conducted in Area 2A and the southern part of Area 2B (along with the standard grid survey in northern 2B) in 1995 and 1997. Stations were allocated among subareas so as to provide estimates of relative abundance in Area 2B-1 (northern British Columbia), 2B-2 (west coast of Vancouver Island), 2A-1 (the Boldt case area off Washington), and 2A-2 (the remainder of 2A). Average catch per effort (net pounds of legal sized fish per standard skate) by subarea was:

	2A-2	2A-1	2B-2	2B-1
1995	32	23	66	166
1997	35	34	74	182

The point estimates of the percentage distribution of exploitable biomass among subareas in each year, calculated from catch per effort and bottom area in the same way as the coastwide percentages, were:

	2A-2	2A-1	2B-2	2B-1
1995	6.2	1.5	8.0	84.3
1997	6.0	2.1	8.0	83.9

The point estimate of the proportion of the combined 2A/2B biomass lying in 2A, along with one standard deviation of the estimate, was:

1995: 0.077 ± 0.046
1997: 0.080 ± 0.032
Both: 0.079 ± 0.028

Owing to the patchy distribution of fish at the south end of the range, these estimates are quite variable. In both years, they indicate that about 8% of the combined 2A/2B biomass was in Area 2A (text table below), but the standard deviation of that proportion was 3-4% in both years, so the close agreement of the two point estimates is mostly luck. Still, the surveys do provide a direct estimate of the apportionment. Averaging the two results to reduce the variance gives a round estimate of 8% as the 2A share of the total.

ABUNDANCE IN AREA 3B AND AREA 4 RELATIVE TO OTHER AREAS

The analytical stock assessment shows abundance in Area 3B to be only about 30% of abundance in Area 3A, while a variety of survey data indicate 60-70% as much fish in 3B as 3A. The stock assessment for Area 4 also tends to underestimate abundance there relative to survey results, and in addition is highly variable owing to short and noisy data series. Because of these problems, the staff is considering abundance estimates for Area 3B and Area 4 calculated by scaling the analytical estimates of biomass in Area 2 and Area 3A, where we have confidence in the assessment, by the survey estimates of relative biomass.

For this purpose, we use Area 2 and Area 3A combined as a reference area. Table 1 shows that this reference area in 1997 contains 54% of the coastwide exploitable biomass. Area 3B is estimated to have 21% of the total or 21/54=39% of the biomass in the reference area. Similarly, Area 4 in total has 25% of the total or 25/54=46% of the reference region. If the estimated abundance on the Bering Sea shelf (except Area 4C) is excluded, then Area 4 has 31% of the reference area abundance.

All of these proportions are based on survey mean catch rates that have a standard error of 5-7%. The resulting standard deviation of the estimated proportions is about 3.5%, so an approximate 95% confidence interval would be the point estimate ± 7%.

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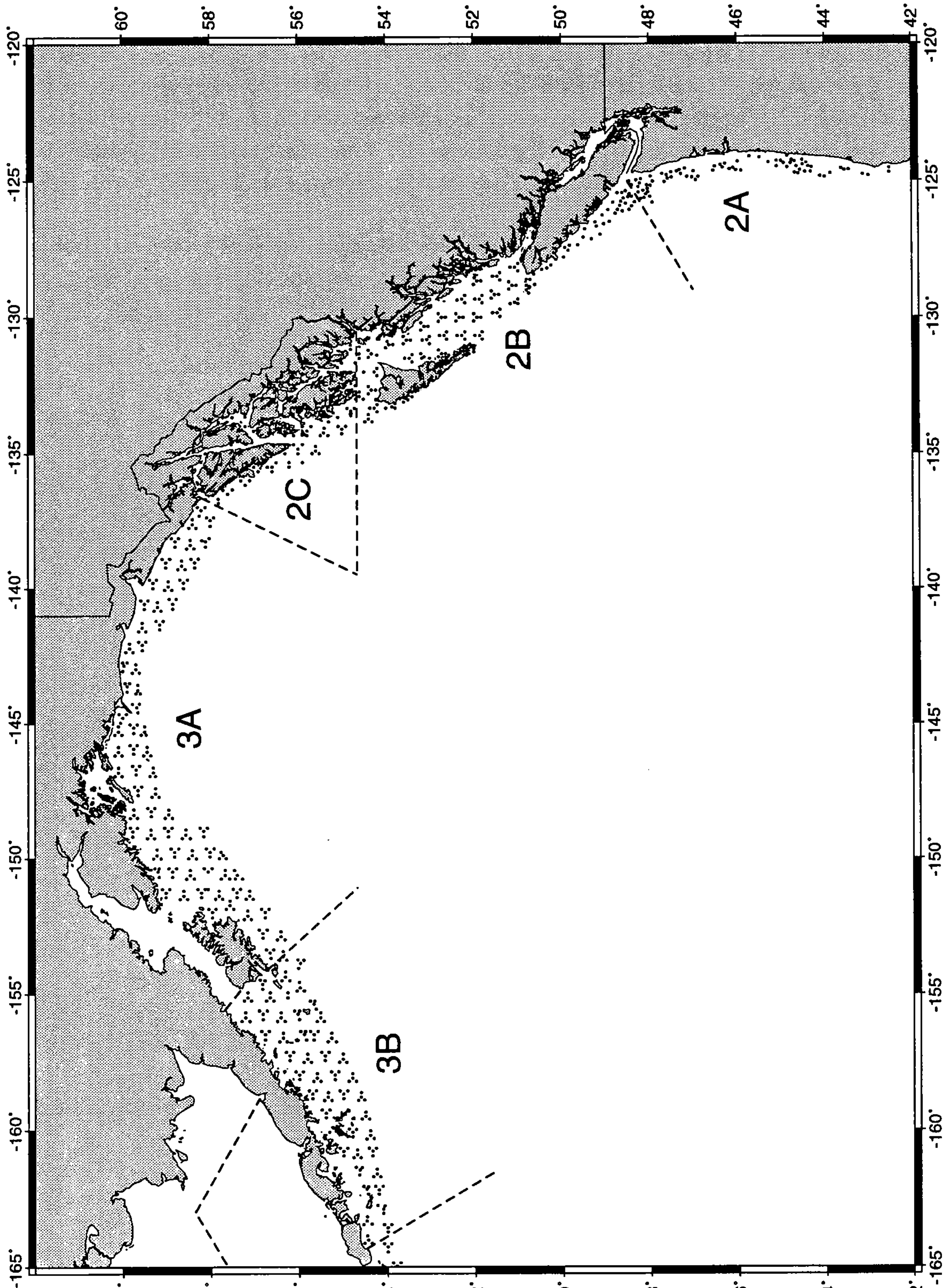

Figure 1. Setline survey stations fished in the Gulf of Alaska in 1997.

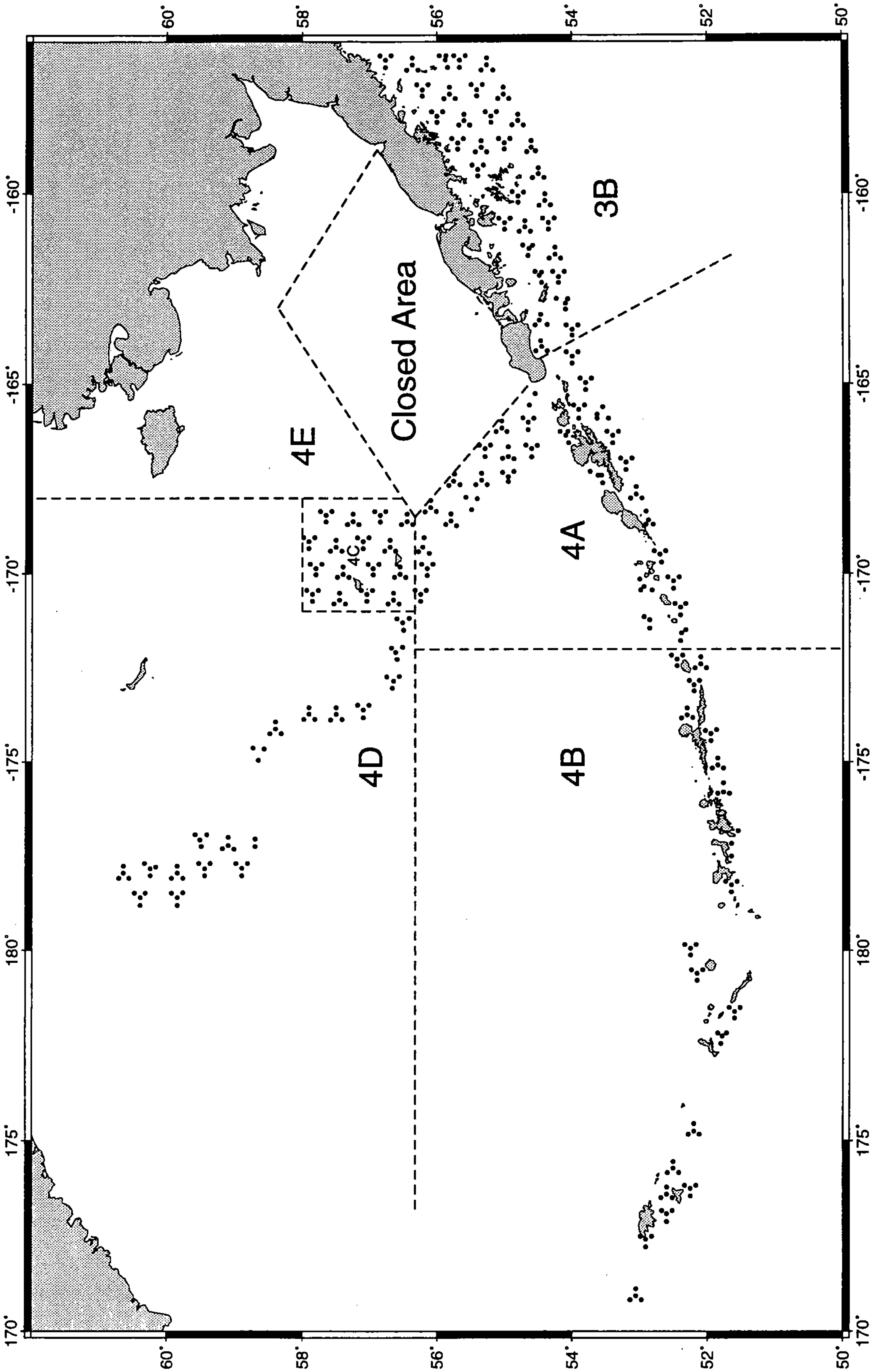

Figure 2. Setline survey stations fished in western Alaska in 1997.

Table 1. **Distribution of exploitable biomass according to 1997 setline survey results.**

	Area (K nm^2)	Raw cpue	Adjusted cpue	% of total biomass
2A	11.1	35	35	0.7
2B	26.2	161	161	8.3
2C	13.9	407	371	10.0
3A	48.2	318	371	34.7
3B	29.5	412	371	21.3
4A	15.8	245	245	7.5
4B	12.8	281	281	7.0
4C	9.6	57	57	1.1
4D edge	4.5	111	111	1.0
Bering shelf	145.0	---	30	8.4

Notes

1. Areas are total bottom area within 200 fm except for the 4D edge, which is bottom between 100 and 200 fm plus shallower grounds shown in Technical Report 36, and the eastern Bering Sea shelf, which is approximately the area up to St. Matthew Is.

2. A single cpue is used for the northern Gulf (2C-3A-3B).

3. The entire Bering shelf is assumed to have half the density of 4C because the NMFS trawl survey catch rate of legal sized fish there averaged a little more than half the 4C rate for the 1990-96 surveys combined.

Re-evaluation of the 32-inch Commercial Size Limit

by

Ana M. Parma

ABSTRACT

The effects of the commercial size limit on expected yield per recruit and female spawning biomass per recruit were evaluated. Intrinsic growth parameters for female and male halibut, and size-specific selectivity of the commercial fishery were estimated independently for Areas 2B and 3A by fitting a sex-specific, age-structured population model to data from the setline surveys and the commercial fishery for the period 1974-1996. Area-specific schedules of female maturity at age were estimated using information collected in the summer research surveys of 1995 and 1996. Yield per recruit and spawning biomass per recruit for Area 3A were little affected when the commercial legal size was dropped from 81 cm (approximately the current value) to 60 cm, and commercial selectivity at length was fixed at the values estimated for 1996. In Area 2B, a decrease in the legal size would result in a small increase in yield per recruit and a small decrease in spawning biomass per recruit. Lowering the size limit would bring about a substantial reduction in spawning biomass per recruit in both areas if such a drop were followed by a shift in commercial selectivity towards smaller fish sizes. The current size limit of 32 inches is thus considered to be appropriate as the potential gains derived from lowering it are small compared to the associated potential reproductive losses.

BACKGROUND

A commercial size limit of 32 inches was adopted by the Commission in 1973 in order to increase substainable yields (Myhre 1974) when halibut growth rates were at high record levels. The size limit was re-evaluated in 1991 (Clark and Parma 1995), after a substantial decline in halibut growth rates had taken place, and found to be adequate based on yield per recruit and spawning biomass per recruit considerations. That conclusion was supported by analysis and modeling of size-at-age and age composition data collected in 1989 and 1990, and maturity data collected in 1980-1986, before the setline surveys were discontinued. The schedule of age-specific commercial selectivities estimated by Cagean, the assessment model used at the time, was also used in the fit so that the selectivity at length estimated by the model was consistent with the selectivity estimated in the assessment.

Since then, major changes in halibut life history parameters and assessment methodology have taken place which required a re-evaluation of the size limit:

1. Size at age continued to decrease abruptly, especially in the Gulf of Alaska, and has stabilized in the most recent years. This is evidenced by trends in size at age in both the commercial catch and the setline surveys, which were resumed in 1993.
2. A major shift in the female maturity schedule to smaller sizes paralleled the changes in growth, while age-specific maturity remained relatively stable.

3. The assessment model was modified to account for changes in size at age and their effects on commercial selectivity. The assumption made by Cagean that commercial selectivity at age had stayed constant since 1974 is now considered inappropriate, and was abandoned in favor of a time-varying selectivity at length.

The slower growth and smaller size of maturation suggested that lowering the commercial size limit might bring about substantial yield increases. The purpose of this study was to evaluate potential gains in yield per recruit and effects on female spawning biomass per recruit associated with lowering the size limit to 60 cm. Because the size limit may provide some level of protection to the stock that is robust to assessment errors (Myers 1996), the risks associated with dropping the size limit would need to be evaluated if the yield per recruit analysis, conducted assuming that fishing mortalities can be perfectly controlled, indicated substantial potential gains in yield. The results presented below show that only small increases in yield could be expected from a reduction in the size limit.

ESTIMATION OF GROWTH AND SELECTIVITY PARAMETERS

Methods

A sex and age-structured model was used to estimate growth and selectivity parameters in Areas 2B and 3A. The model is an extension of the model used for the annual assessment of the stocks. The main difference is that here the dynamics of growth and abundance are modeled separately for males and females. Commercial selectivity at age and year for each sex results from the coupling of the sex-specific size distribution at age with a time-varying size-specific selectivity function. The effect of the legal size limit on the age and size composition of the commercial catch is explicitly modeled by setting the selectivity of fish smaller than the size limit to zero. Mean log-length at age for each sex propagates according to a recursive Ford-Walford equation with stochastic intercept and initial size. Trends in growth rate are allowed by letting the size at recruitment and the growth intercept change over time in a constrained manner following a random walk. In addition, the size distribution at age and sex in the modeled population is affected by the fishery which selectively removes the largest fish.

Parameter estimation is done similarly to the assessment model. The model is fitted to data on commercial catch at age for the period 1974-1996, mean and variance of log-length at age in the commercial catches, mean and variance of log-length at age and sex in the survey catches, age-sex composition of the survey catches, commercial effort data, and survey catch per unit of effort. Because the sex ratio in the commercial catch is unknown, two simplifying assumptions were made in order to extend the assessment model to make it sex-specific: (1) sex ratio at age six, the first age-class modeled, was set to one, and (2) survey and commercial selectivity at size were the same for males and females. Detalis about the model and estimation method are provided in Appendix 1.

Results and discussion

The model was able to match well the trends in size at age in the commercial and survey catches (Figures 1-3 and 7-9) and the commercial catch at age (Figures 4 and 10) in both areas. The fit of the age and sex composition of the surveys was not as good and exhibited strong trends in the residuals (Figures 5-6 and 11-12). This is similar to what occurs with the assessment model, independently of whether the survey selectivity is assumed to be a constant function of fish size or age. While samples taken for ageing from the surveys used to be generally smaller than those from the commercial catches, similar sample sizes (about 2000 fish per area) have been used in recent years. Certainly the assumptions made about the fishing process are more restricted in the case of the survey than for the commercial fishery. While survey selectivity was assumed to be constant (except to account for the change in hook type in 1984), commercial selectivity was allowed to vary from year to year which should result in better fits.

Estimated trends in growth indicated that both the initial size at recruitment and the growth intercept decreased in the 1980s and stabilized or increased in recent years (Figure 13). The decrease in growth was more pronounced in Area 3A than in Area 2B. Estimated commercial selectivity indicates that fish tend to be selected when they are smaller and younger in Area 2B than in Area 3A (Figure 14). In Area 3A, commercial selectivity tended to shift to smaller sizes while size at age decreased.

ESTIMATION OF FEMALE MATURITY

Methods

Female maturity schedules for Areas 2B and 3A were estimated using data collected during the standardized setline summer surveys of 1995 and 1996. Maturity proportions at age and length estimated from setline surveys in 1980-1986 are also shown for comparison. Maturity status was determined on board by visual examination of the gonads. Maturity proportions at age were used in this study to compute spawning biomass per recruit. Females that were maturing, and presumably would spawn in the following winter, were classified as mature. Accordingly, ages determined from the otoliths were increased by one so that they corresponded to the ages at the time of spawning the following winter. Maturity status was determined for a total of 2369 female halibut of known age (between six and 20) in Area 2B and 2550 in Area 3A. A Generalized Linear Model was fitted to the maturity proportions using the function implemented in S+. The expected probability that a female of length a is mature, $p(a)$, was assumed to be a linear function of age, on the logit scale, so that

$$\ln\left(\frac{p(a)}{1-p(a)}\right) = m + n\,a.$$

The error was assumed to be binomially distributed. The age at which 50% of the females are mature is given by

$$A_{0.50} = \frac{-m}{n}.$$

A similar model was also fitted as a function of length instead of age to estimate the length at 50% maturity ($L_{0.50}$).

Results

Maturity schedules observed in 1995 and 1996 are markedly different from those observed in the 1980s (Figures 15 and 16). Length at 50% maturity in Area 2B decreased from about 110 cm to about 100 cm. A shift of close to 35 cm took place in Area 3A, from $L_{0.50}$=124.53

in the 1980s to $L_{0.50}$ =90.55 cm in recent years. The maturity schedules at age were remarkably stable, showing no change in Area 2B (from $A_{0.50}$ = 11.98 to $A_{0.50}$ = 11.73), and a drop of about one year (from $A_{0.50}$ = 12.58 to $A_{0.50}$ = 11.22) in Area 3A.

EFFECT OF THE SIZE LIMIT ON YIELD PER RECRUIT AND SPAWNING BIOMASS PER RECRUIT

Methods

The same age- and sex-structured population model used for parameter estimation was used to compute expected yield per recruit and spawning biomass per recruit. Assumptions about growth and fishing mortality were identical to those made in the estimation model, except that growth parameters were fixed at the values estimated for 1996. The range of ages was extended from 6-20 to 6-25, and the last age group corresponded to actual age 25, instead of being a pool of ages as in the estimation model. Age distribution was truncated at age 25 to avoid extrapolating growth patterns too far beyond the age range used in the estimation.

Commercial selectivity was assumed to increase with fish size according to a half-normal function and be equal one for fish larger than the length of full selectivity. In contrast to the estimation model, fish smaller than the size limit were assumed to be caught and discarded with an associated mortality of 16%. Because it is difficult to predict how commercial selectivity would be affected if the current legal size limit were dropped, two extreme alternative assumptions were made (Figure 17). In the first, selectivity remained constant at the values estimated for 1996 in spite of the change in the size limit. In the second, a drop in the size limit resulted in a shift of the selectivity towards smaller fish sizes. In the latter case, parameters of the normal curve were chosen so that the length at 50% selectivity equaled 60 cm. The variance parameter was fixed at the value estimated for Area 2B, the steepest of the two estimated curves. A range of harvest rates from zero to 0.40 was used in combination with size limits of 81 cm and 60 cm.

Spawning biomass per recruit was computed as

$$SB/R = \frac{\sum_{a=6}^{25} p(a)\, w(a)\, N_a^f}{N_6^f}$$

where $p(a)$ is the schedule of female maturity at age estimated for 1995-1996, $w(a)$ is female weight at age and N_a^f is female abundance at age predicted using the same formulations used in the estimation model, except for the addition of the discard mortality. The term "recruit" here refers to a 6-yr-old fish at the start of the year. The standard length-weight relationship was used to predict weight from length (Clark 1992). Numerical integration was used to compute the average weight at age for males and females in the commercial catch as a function of the size distribution in the population, the size selectivity and the legal size limit. Parameter values used in the computations are shown in Table 1.

Results and discussion

Estimated commercial selectivity for fish smaller than 81 cm is very small in Area 3A. As a result yield per recruit and spawning biomass per recruit were little affected when the commercial size limit was dropped from 81 cm to 60 cm, and selectivity was fixed at the values estimated for 1996 (Figure 18). Only if fish became selected when they are smaller would the size limit significantly affect the age and size of capture, and in turn the yield. Indeed, lowering the size limit resulted in a moderate increase in yield when selectivity was assumed to shift towards smaller sizes in response to the change in regulation (Figure 18). Gains in yield per recruit were however accompanied by major losses in spawning biomass per recruit, as summarized in Table 2 for a 20% harvest rate. The assumption made here that the size of 50% selectivity would match a new size limit of 60 cm should be viewed as rather extreme, as fish would have to be selected at much smaller sizes than they are currently selected even in the surveys. Results are however useful to illustrate trade-offs between maximum potential yield gains and associated reproductive losses.

Results for Area 2B are slightly different due to the steeper commercial selectivity in that area. A decrease in the size limit resulted in some increase in yield per recruit and a small decrease in spawning biomass per recruit (Figure 19, Table 3). As in Area 3A, dropping the legal size could result in substantial decreases in spawning biomass per recruit if such a drop were followed by a shift in commercial selectivity towards smaller fish sizes.

One alternative that could be considered to capitalize potential gains in yield and at the same time maintain the reproductive potential of the stock would be to drop the legal size but adjust harvest rates down to compensate for resulting reproductive losses. A drawback of such a strategy is that if selectivities did shift to smaller sizes in response to a drop in the size limit, protection of the spawning biomass would have to rely much more heavily on our ability to control harvest rates than is the case at present. The strategy would thus be less robust to errors in the stock assessment. The black dots in Figures 18 and 19 show harvest rates and associated yields that resulted in the same spawning biomass per recruit as in the *status quo* conditions (i.e. harvest rate =0.20, fixed selectivity and size limit = 81 cm). When such a constraint is imposed, yield gains are very small and do not guarantee a change in strategy and regulation. The current size limit of 32 inches is thus considered to be appropriate as the potential gains derived from lowering it are small compared to the associated potential reproductive losses.

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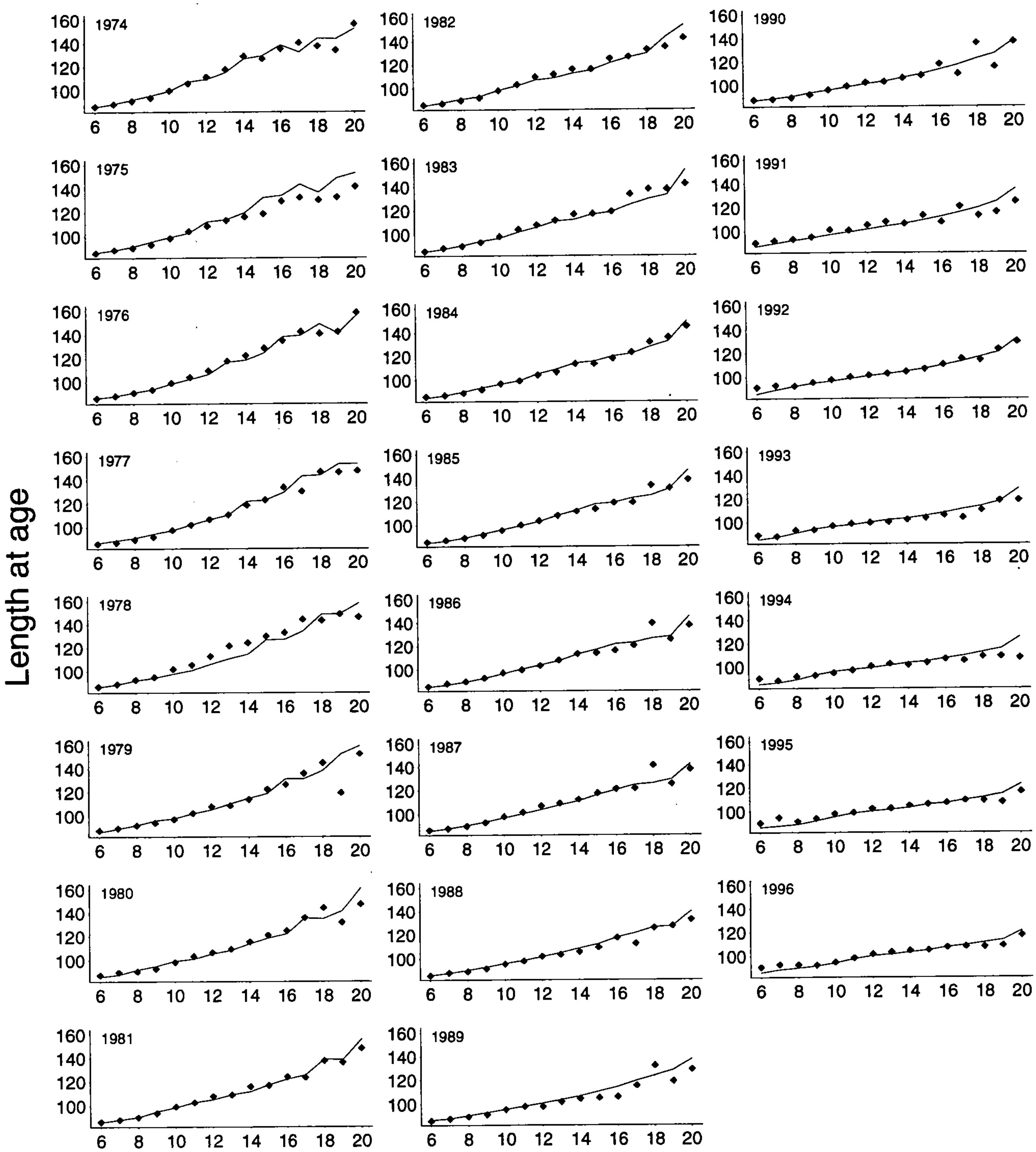


Figure 1. Area 2B mean lengths at age in the commercial catch for the period 1974-1996

Sullivan, P.J., Parma, A.M., 1998. Population assessment, 1997.
IPHC Rep. Assess. Res. Act. 1997., pp. 83–210.

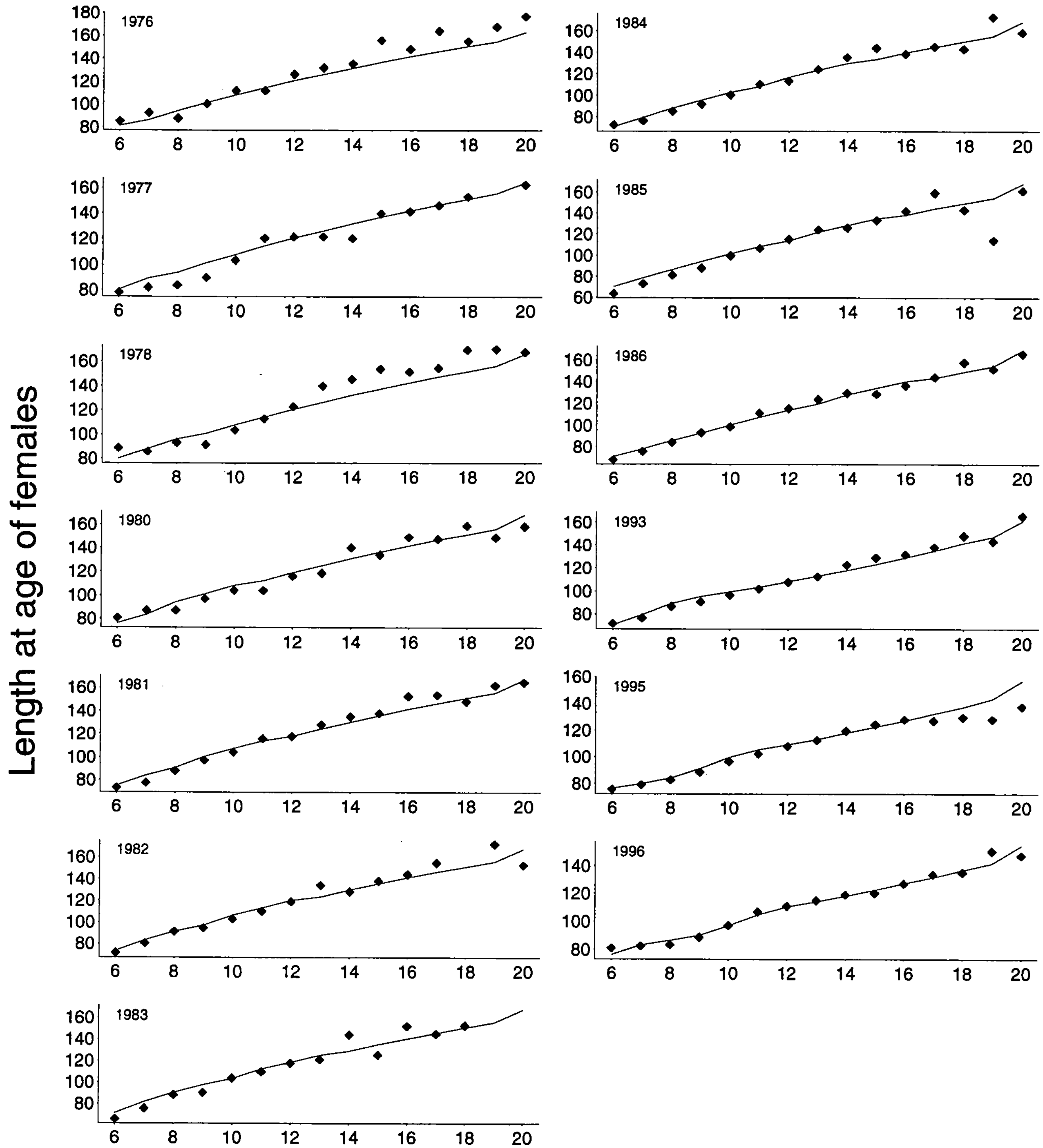


Figure 2. Mean length at age of female halibut caught in setline surveys in Area 2B.

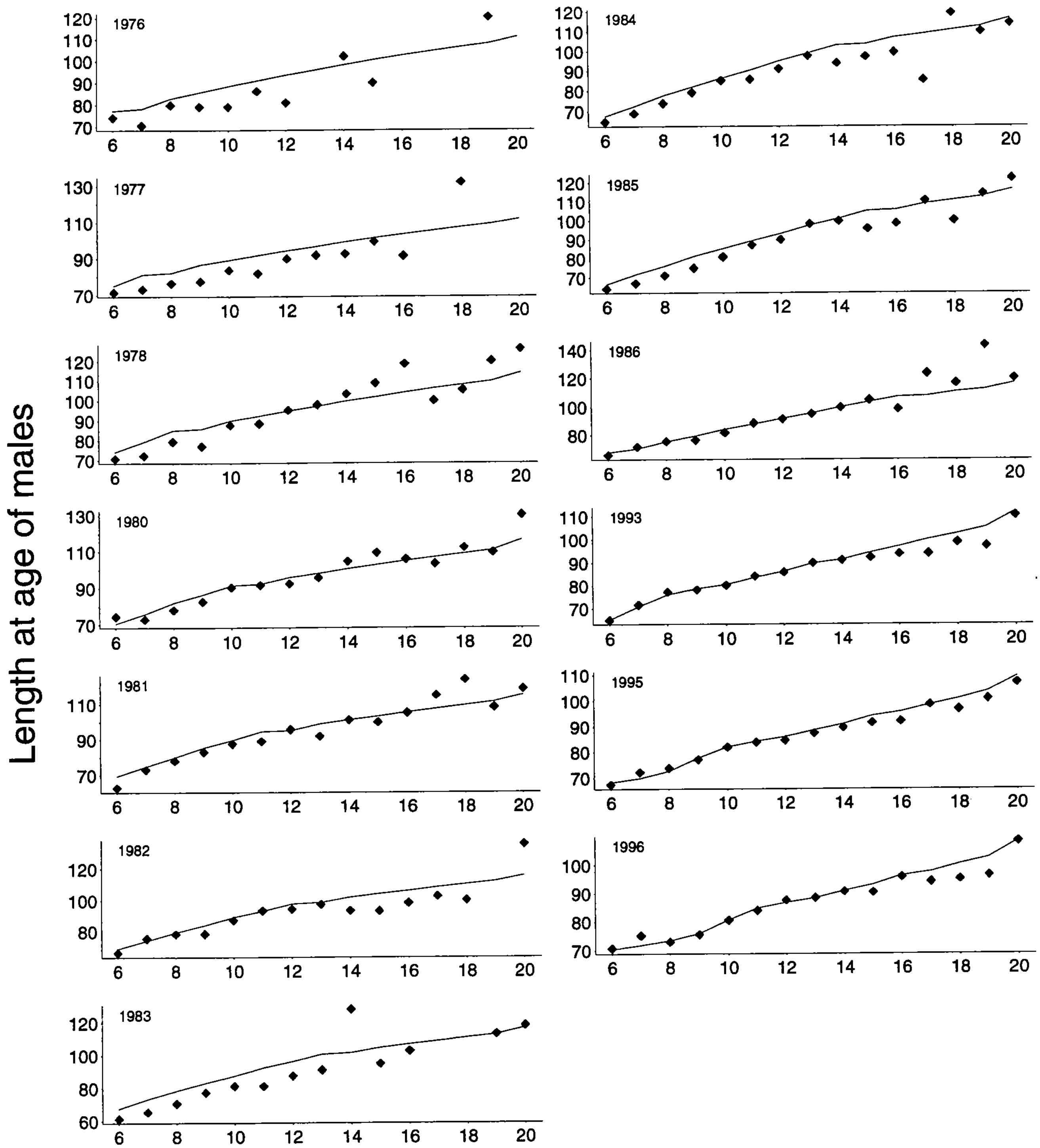


Figure 3. Mean length at age of male halibut caught in setline surveys in Area 2B

Sullivan, P.J., Parma, A.M., 1998. Population assessment, 1997. IPHC Rep. Assess. Res. Act. 1997., pp. 83–210.

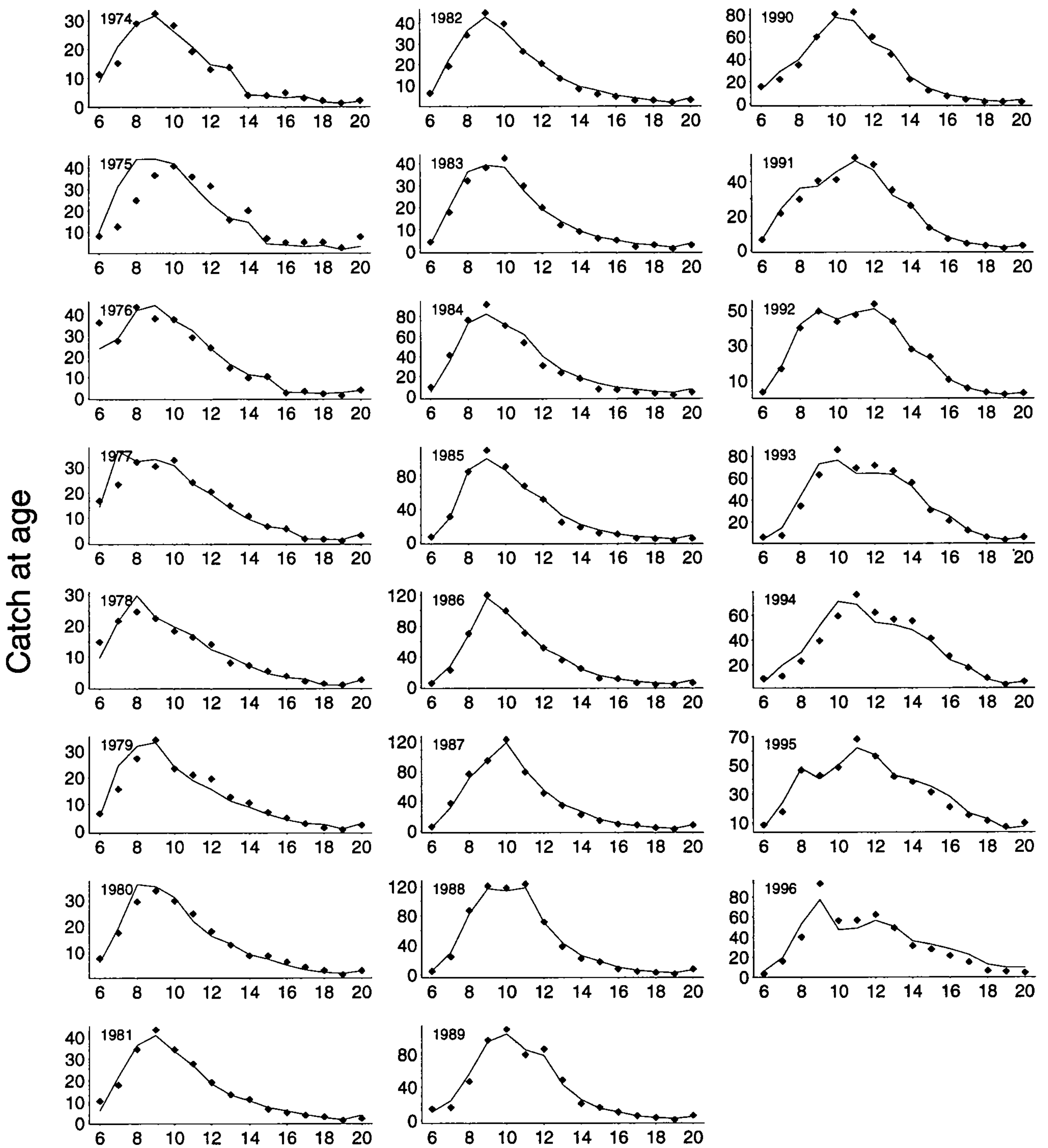


Figure 4. Commercial catch at age (thousands) in Area 2B for the period 1974-1996.

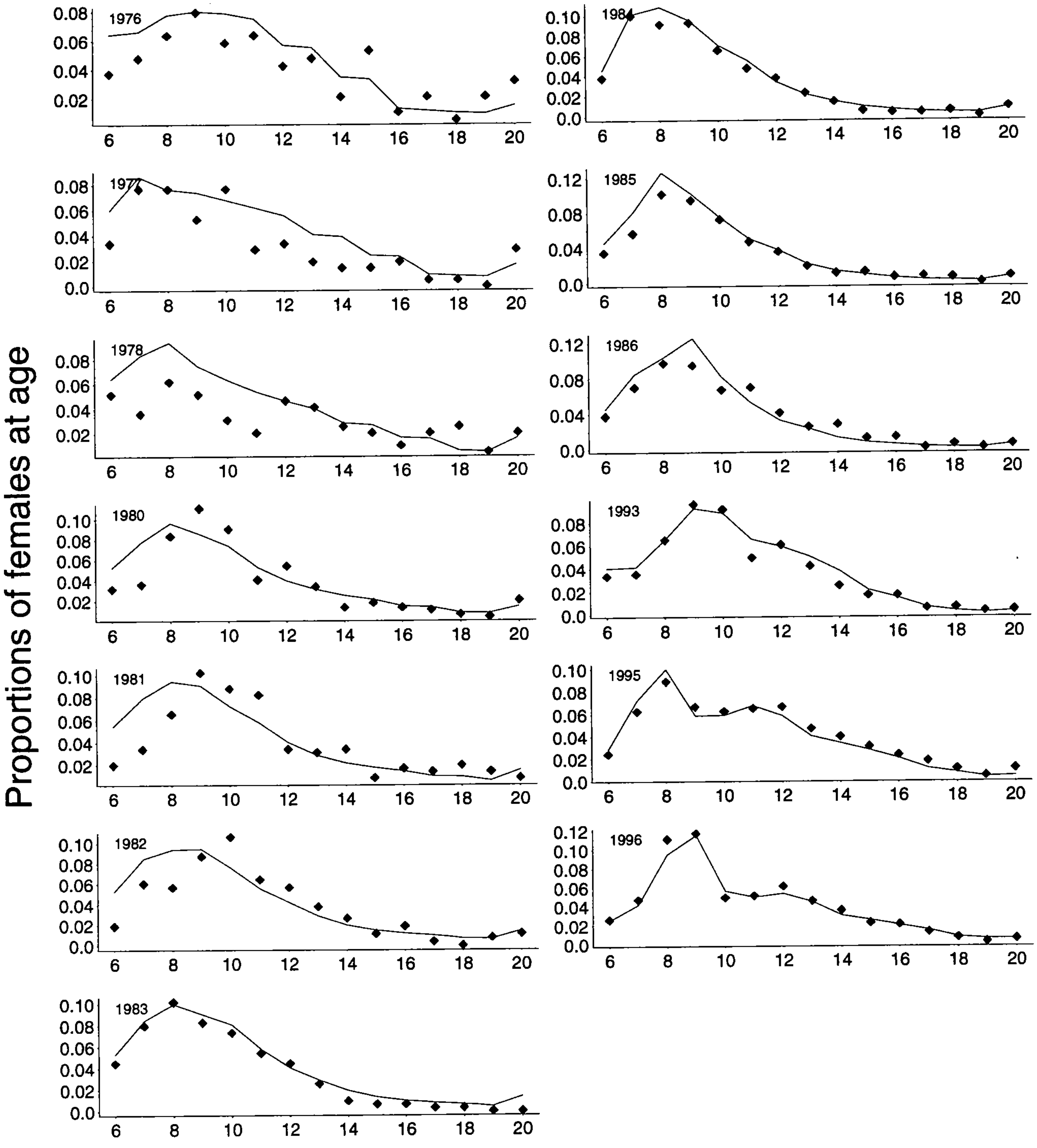


Figure 5. Proportions of female halibut at age in setline survey catches in Area 2B

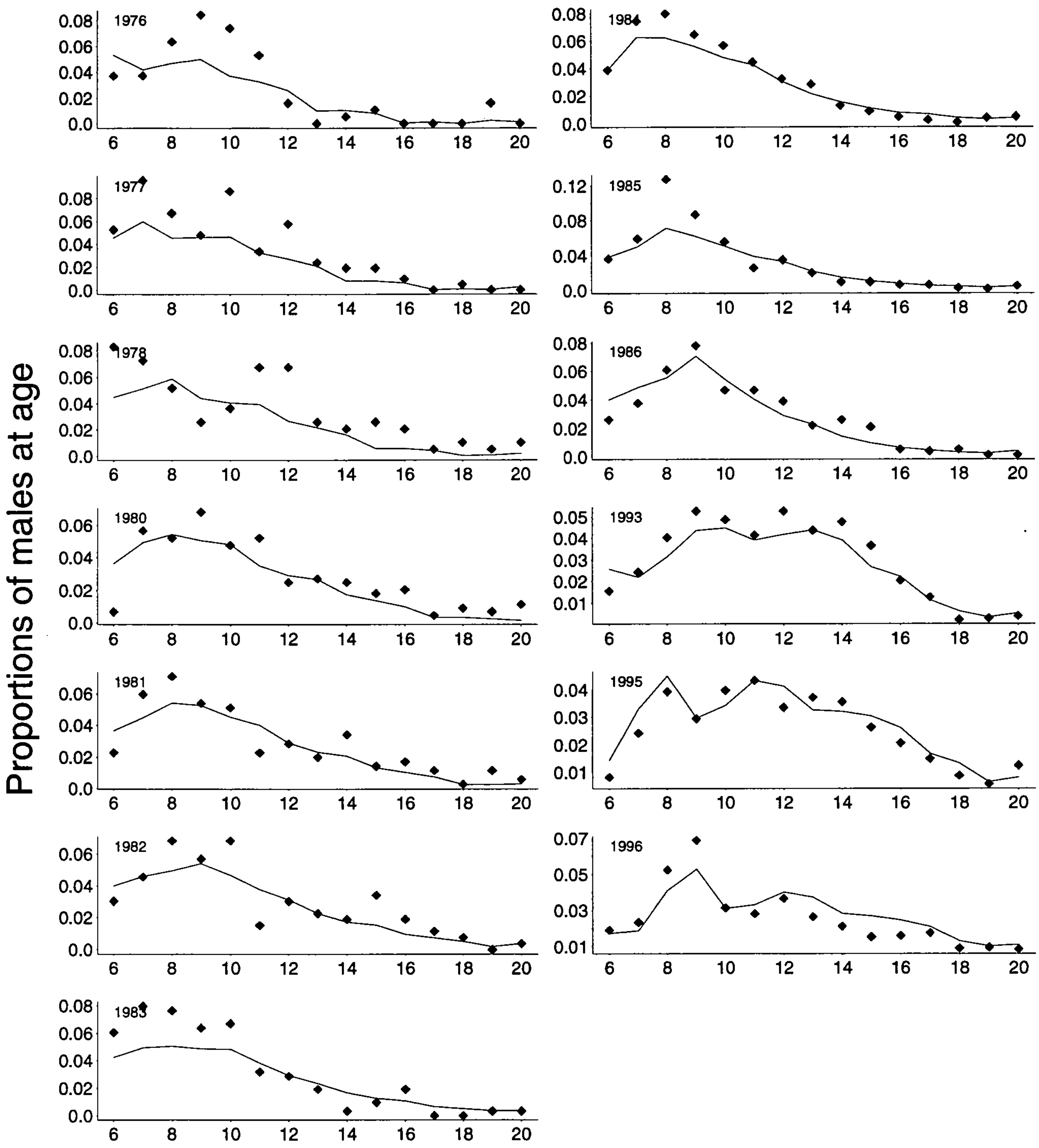


Figure 6. Proportions of male halibut at age in setline survey catches in Area 2B.

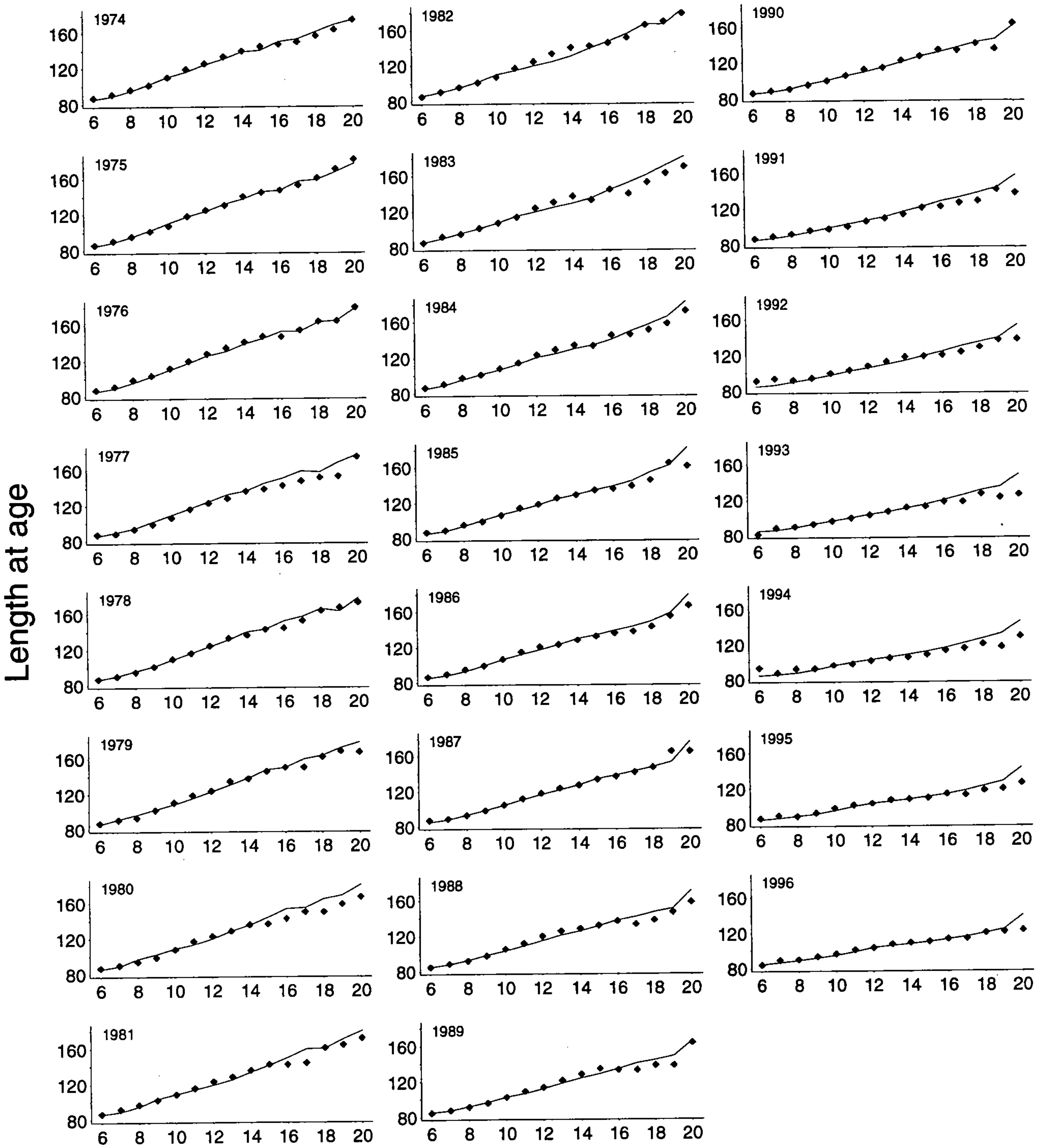


Figure 7. Area 3A mean lengths at age in the commercial catch for the period 1974-1996

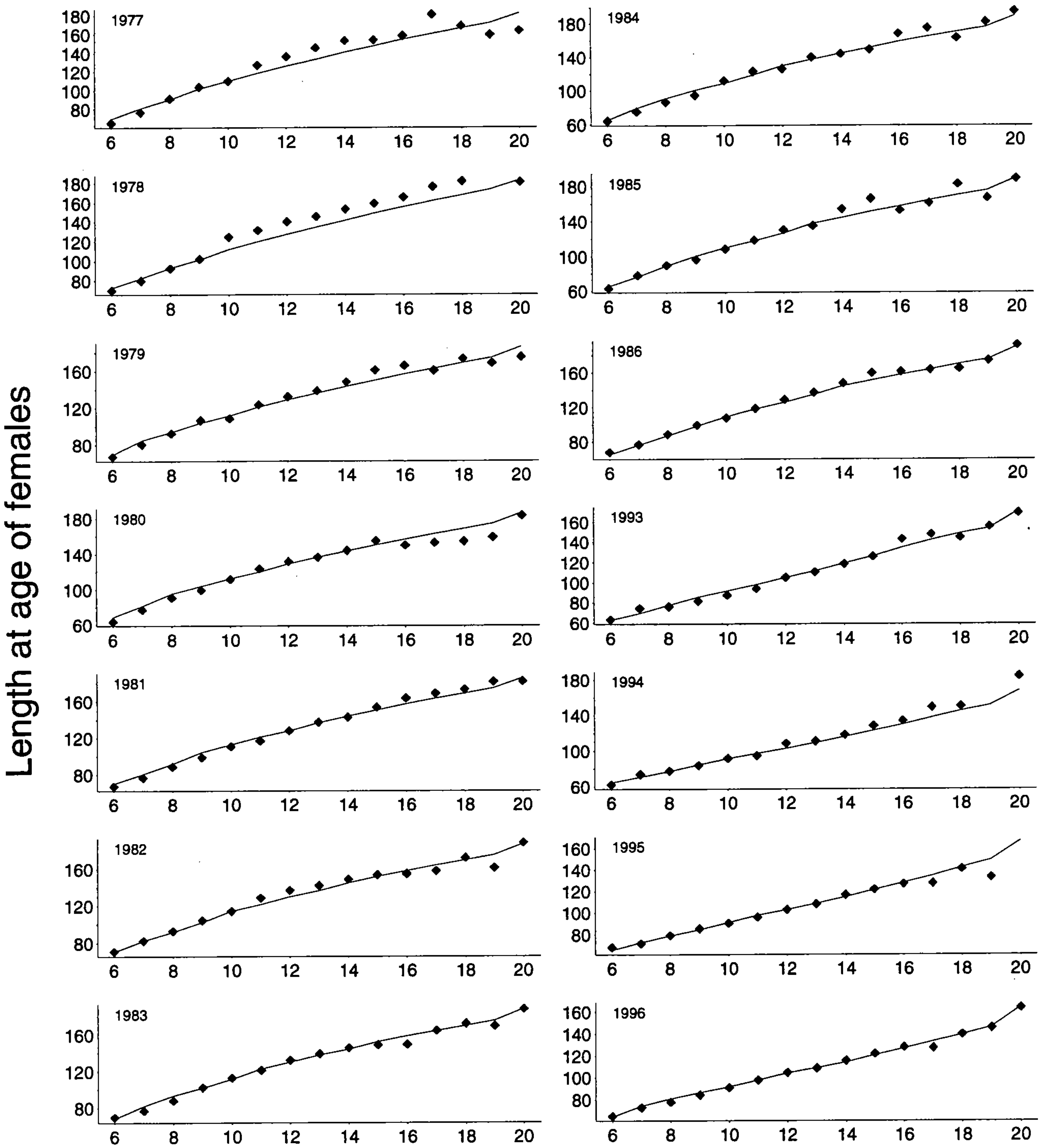


Figure 8. Mean length at age of female halibut caught in setline surveys in Area 3A.

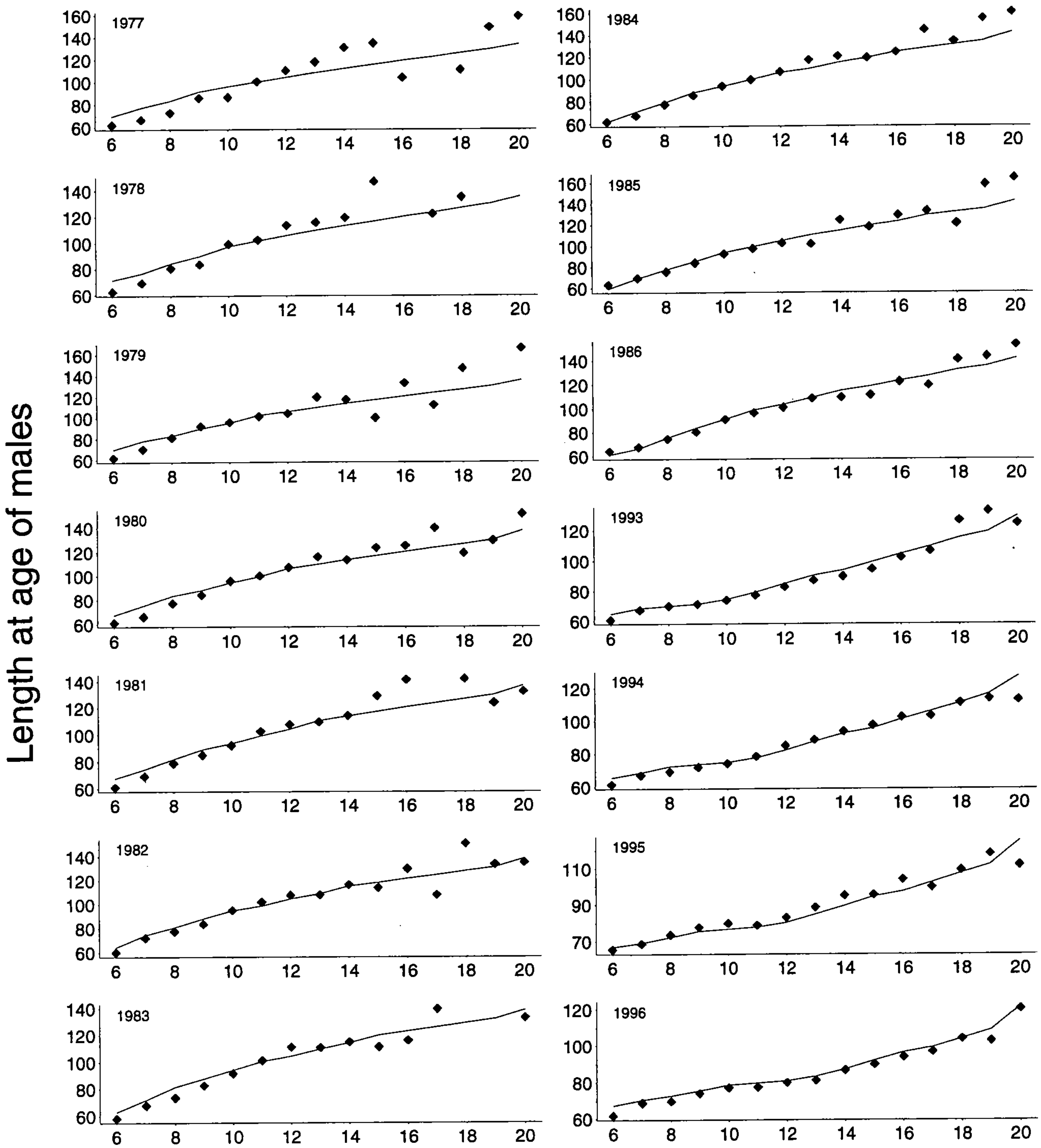


Figure 9. Mean length at age of male halibut caught in setline surveys in Area 3A

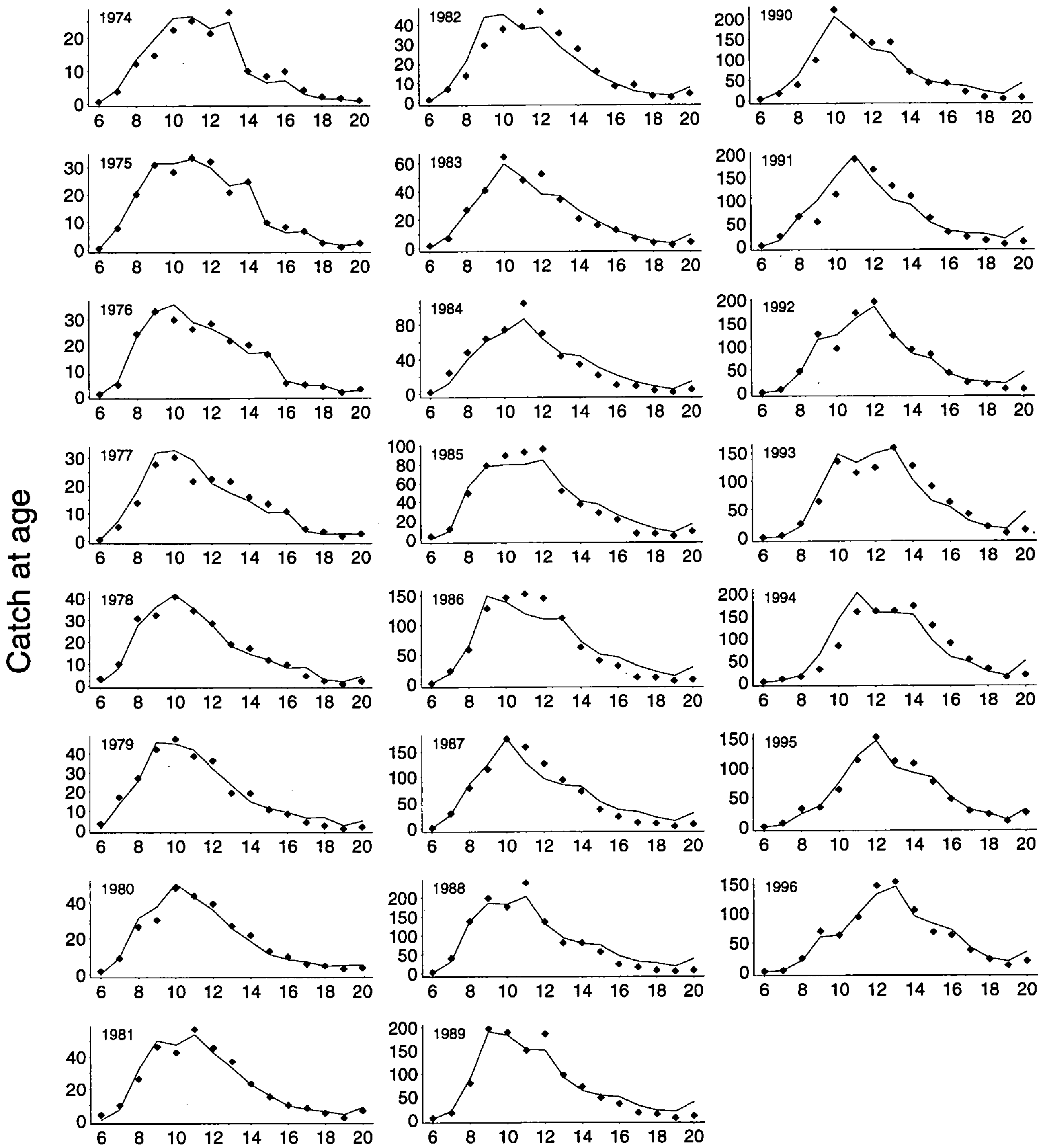


Figure 10. Commercial catch at age (thousands) in Area 3A for the period 1974-1996.

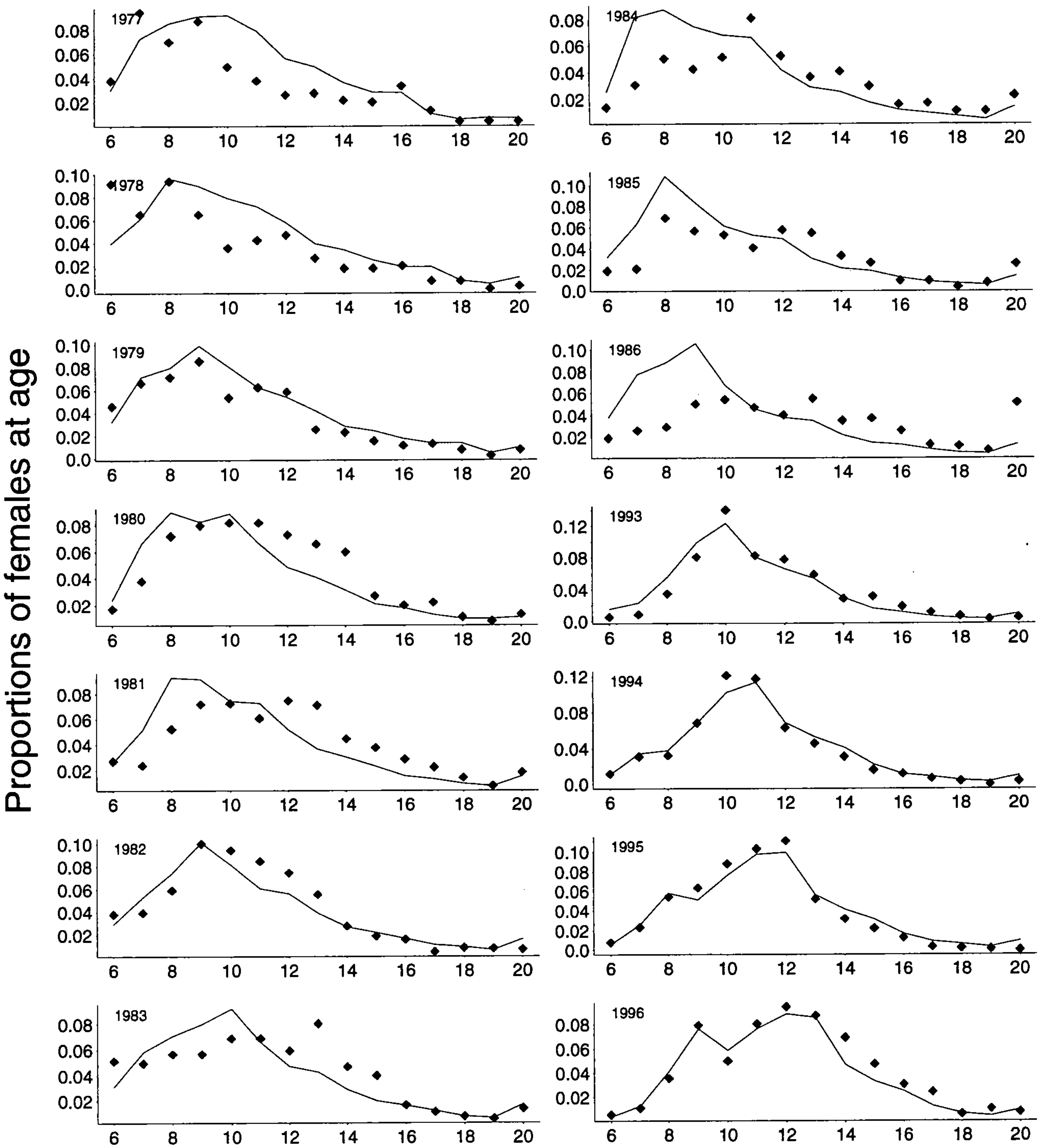


Figure 11. Proportions of female halibut at age in setline survey catches in Area 3A.

Sullivan, P.J., Parma, A.M., 1998. Population assessment, 1997.
IPHC Rep. Assess. Res. Act. 1997., pp. 83–210.

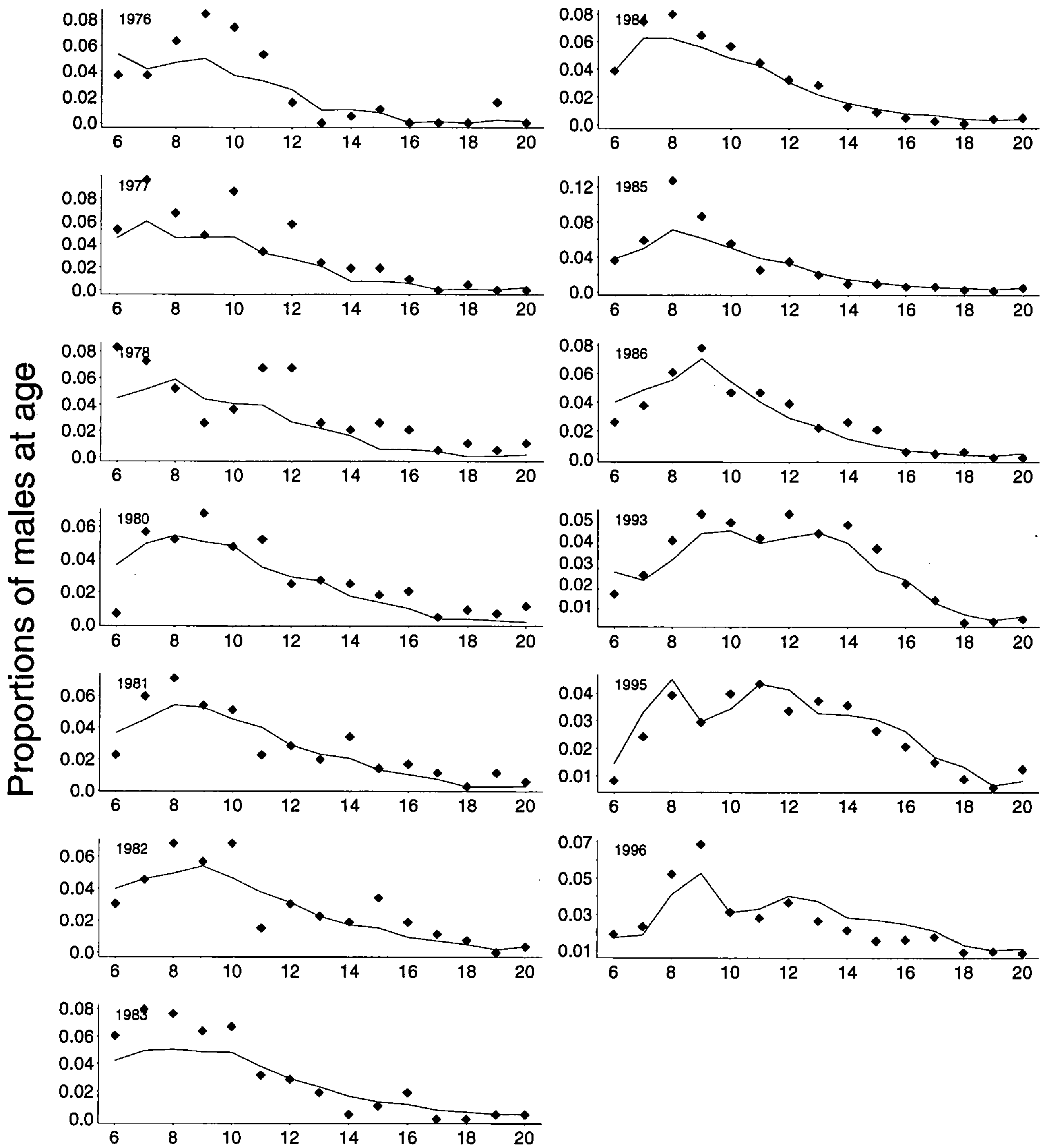


Figure 12. Proportions of male halibut at age in setline survey catches in Area 3A.

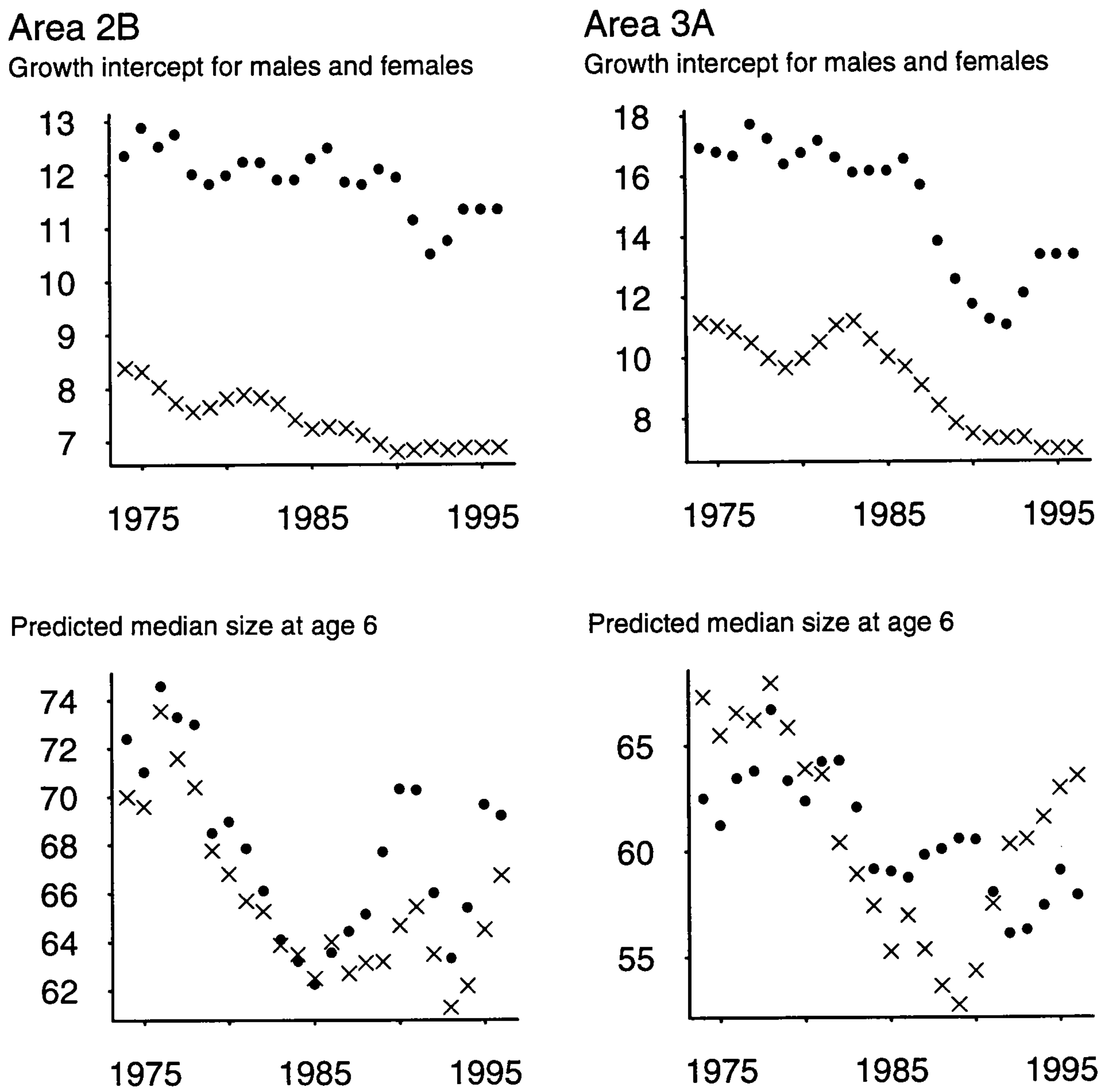
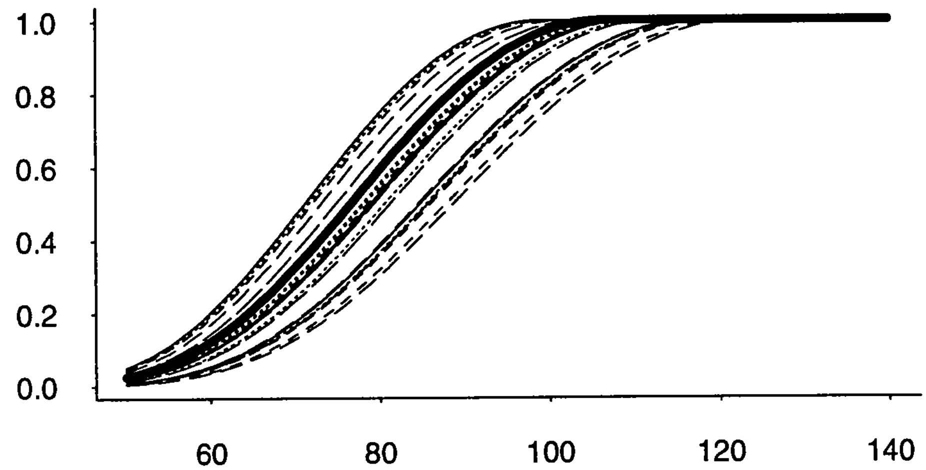


Figure 13. Estimated trends in median size at recruitment and growth intercept for male (crosses) and female (points) halibut in Areas 2B and 3A.

Commercial selectivity at length



Commercial selectivity at length

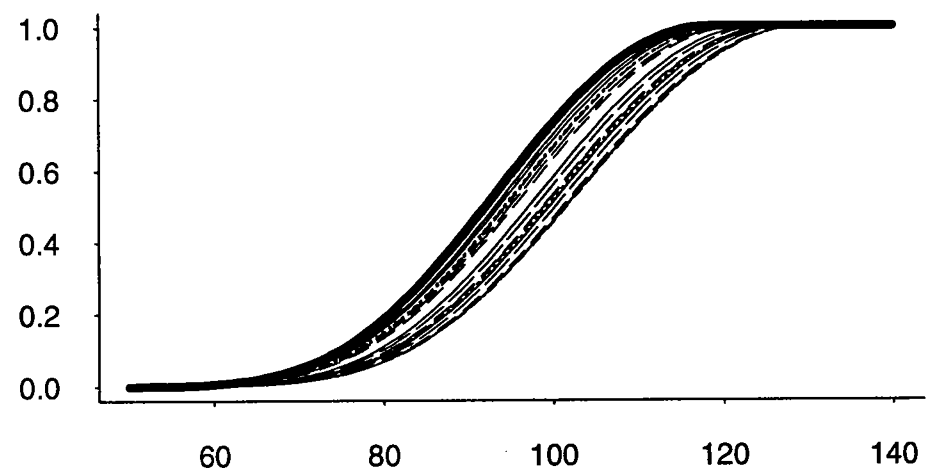


Figure 14. Commercial selectivity in Areas 2B and 3A. Thick solid line corresponds to the function estimated for 1996

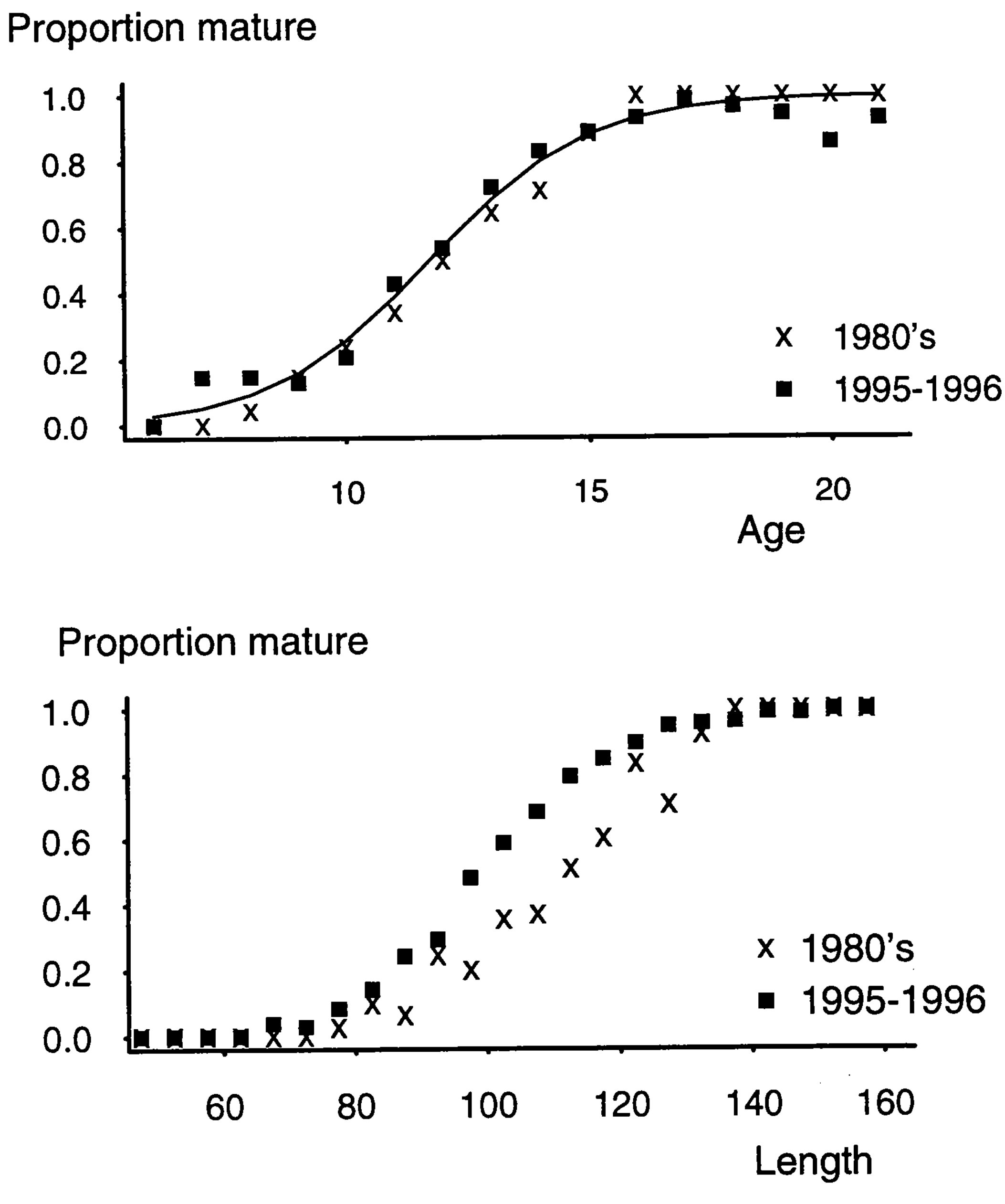


Figure 15. Female maturity schedules in Area 2B. Solid line is a logistic model fitted to the 1995-1996 data.

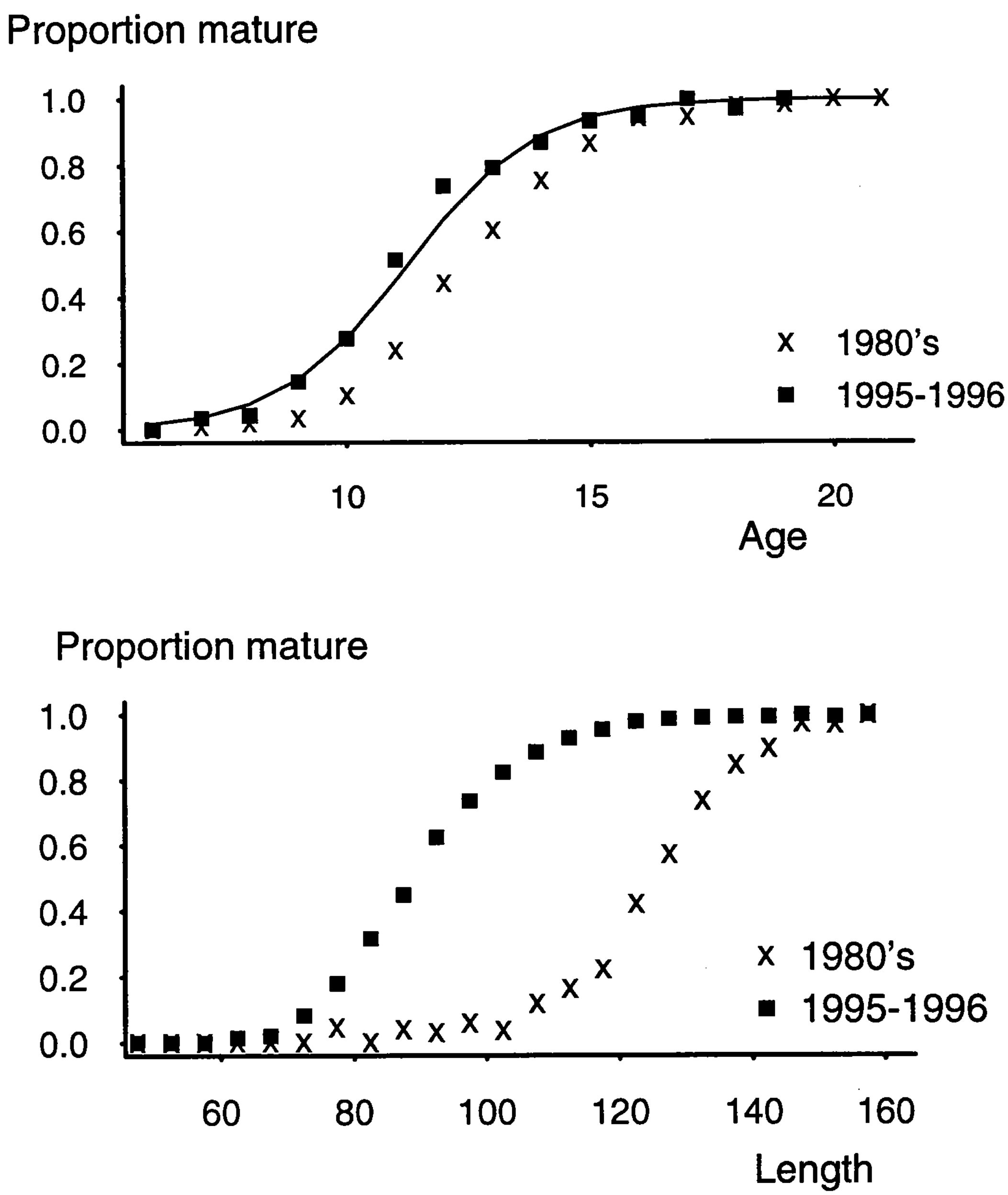


Figure 16. Female maturity schedules in Area 3A. Solid line is a logistic model fitted to the 1995-1996 data.

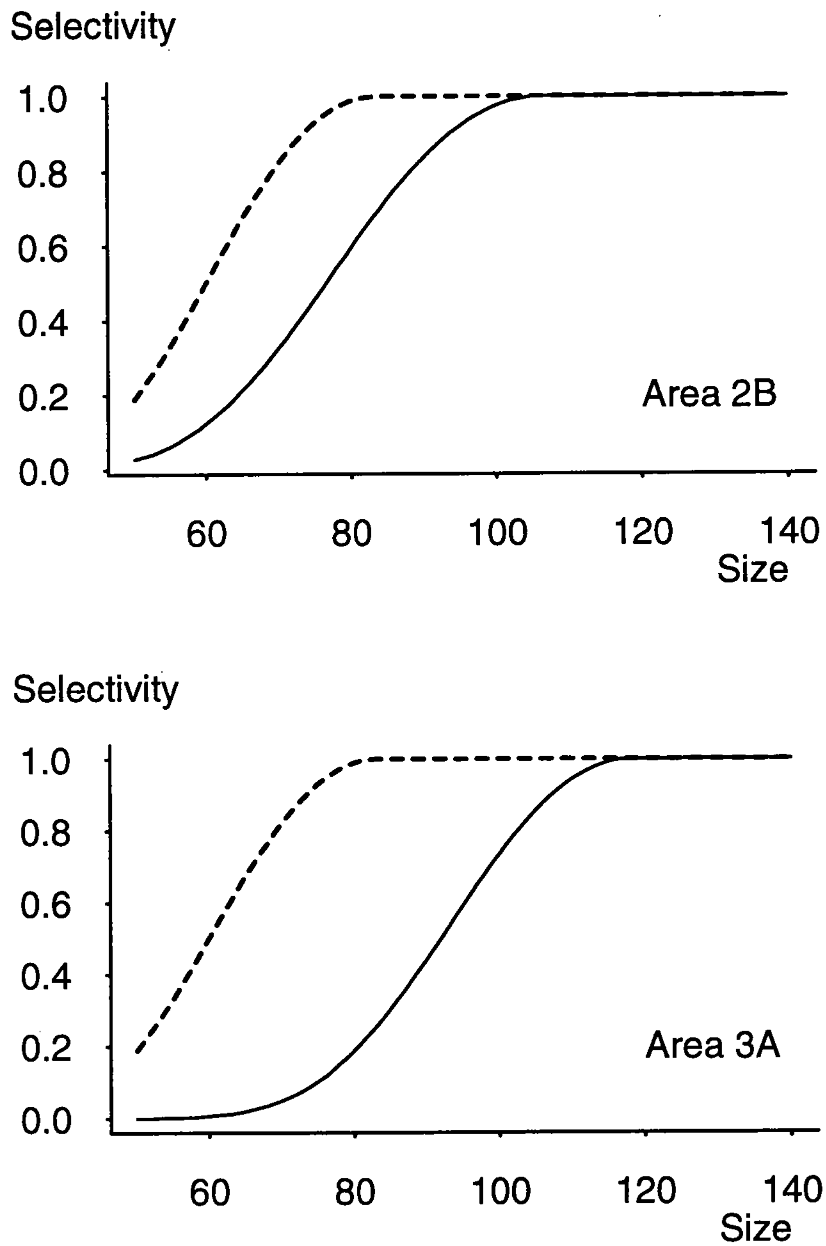


Figure 17. Setline selectivities for areas 2B and 3A estimated for the commercial catch in 1996 (solid line) and shifted to the left so that the size at 50% selectivity equals 60 cm.

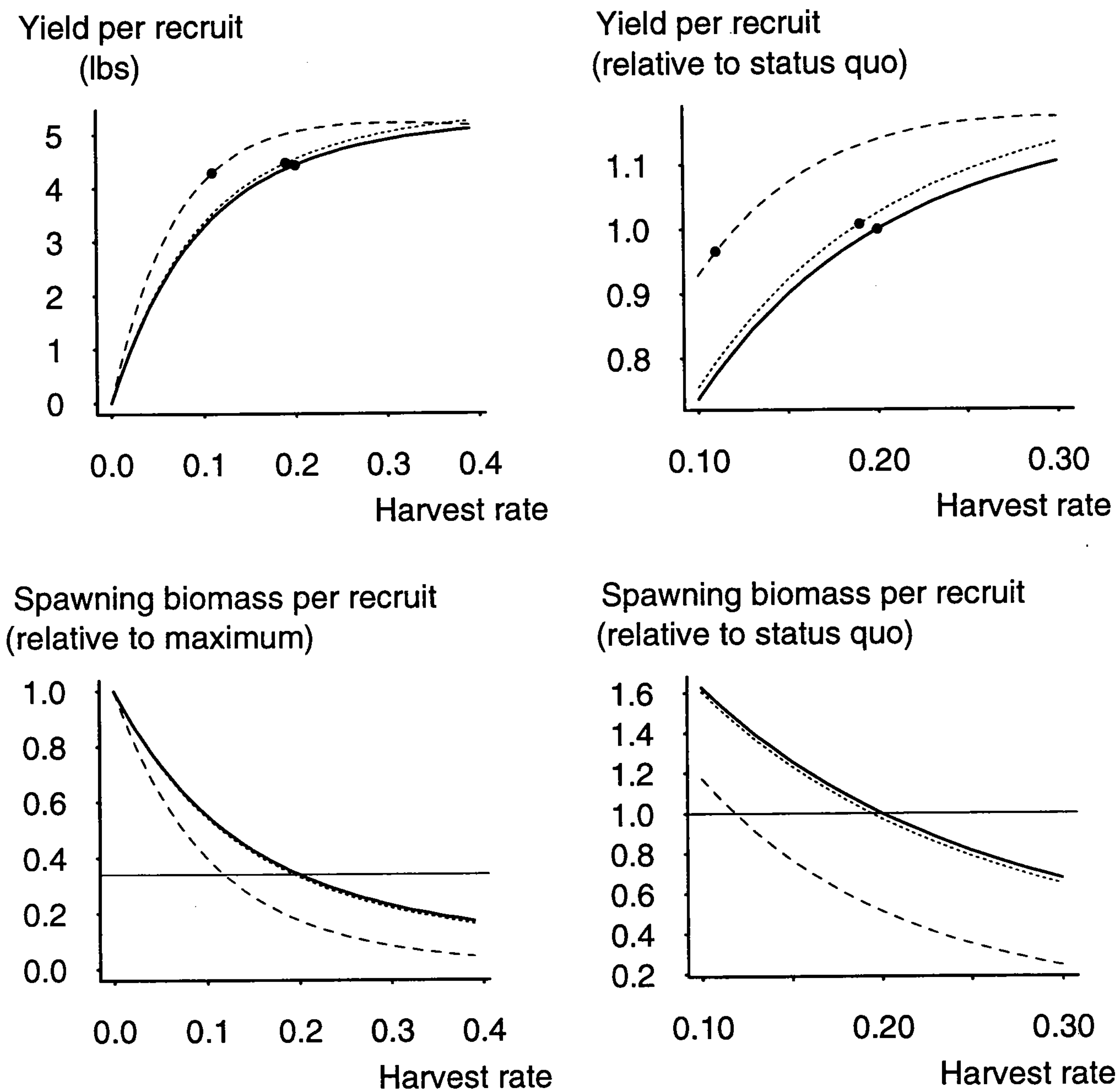


Figure 18. Area 3A female + male yield per recruit (Y/R) and spawning biomass per recruit (SB/R). Solid lines represent status quo (size limit = 81 cm and selectivity as estimated for 1996); dotted and dashed lines are both for a size limit = 60 cm, but selectivities are, respectively, as in 1996 or shifted left. Points of SB/R = status quo value are marked on the Y/R plots.

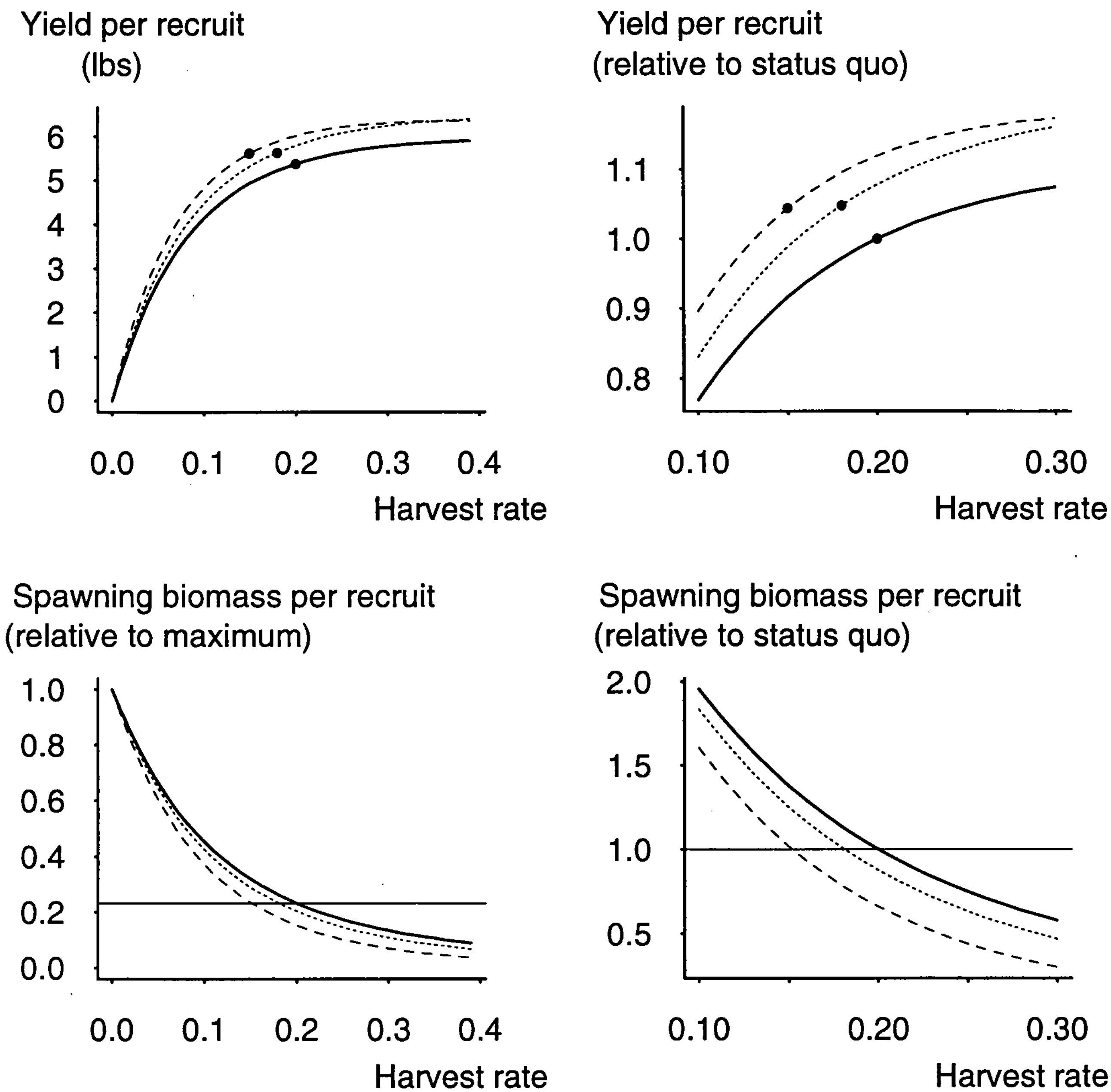


Figure 19. Area 2B female + male yield per recruit (Y/R) and spawning biomass per recruit (SB/R). Solid lines represent status quo (size limit = 81 cm and selectivity as estimated for 1996); dotted and dashed lines are both for a size limit = 60 cm, but selectivities are, respectively, as in 1996 or shifted left. Points of SB/R = status quo value are marked on the Y/R plots.

Table 1. **Growth, maturity and selectivity parameters used to compute yield per recruit and spawning biomass per recruit for Areas 2B and 3A.**

	Area 2B		Area 3A	
Process	Males	Females	Males	Females
Growth:				
initial log-length (μ_6)	4.20	4.24	4.151	4.059
growth intercept (α)	6.89	11.34	6.979	13.391
growth slope (β)	0.952	0.949	0.949	0.936
CV of length at age	0.085	0.124	0.093	0.121
Maturity:				
age at 50% maturity		11.726		11.22
b parameter		0.6126		0.759
Fixed selectivity:				
length at full selectivity	107 cm		119 cm	
length at 50% selectivity	77 cm		92 cm	
Shifted selectivity:				
length at full selectivity	83 cm		83 cm	
length at 50% selectivity	60 cm		60 cm	

Table 2. Area 3A yield per recruit and spawning biomass per recruit under status quo (i.e. size limit = 81 cm, setline selectivity as estimated for 1996 and harvest rate = 0.20), and with a size limit = 60 cm and setline selectivity either fixed at the 1996 value or shifted to achieve a selectivity equal to 0.50 at 60 cm.

	Yield per recruit		**Spawning biomass per recruit**	
	pounds	relative to status quo	relative to maximum	relative to status quo
Size limit = 81 cm 1996 selectivity harvest rate = 0.20	4.44	1.00	0.34	1.00
Size limit = 60 cm 1996 selectivity harvest rate = 0.20	4.55	1.03	0.33	0.97
Size limit = 60 cm shifted selectivity harvest rate = 0.20	5.05	1.14	0.17	0.51

Table 3. Area 2B yield per recruit and spawning biomass per recruit under status quo (i.e. size limit = 81 cm, setline selectivity as estimated for 1996 and harvest rate = 0.20), and with a size limit = 60 cm and setline selectivity either fixed at the 1996 value or shifted to achieve a selectivity equal to 0.50 at 60 cm.

	Yield per recruit		Spawning biomass per recruit	
	pounds	relative to status quo	relative to maximum	relative to status quo
Size limit = 81 cm 1996 selectivity harvest rate = 0.20	5.38	1.00	0.23	1.00
Size limit = 60 cm 1996 selectivity harvest rate = 0.20	5.80	1.08	0.20	0.87
Size limit = 60 cm shifted selectivity harvest rate = 0.20	6.02	1.12	0.15	0.66

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APPENDIX 1. ESTIMATION MODEL

Abundance Dynamics

An age- and sex-structured model was used to estimate growth and selectivity parameters. For each sex s, abundance N^s at age $a+1$ in year $t+1$ was predicted from the abundance in the previous year as:

$$N^{s}_{a+1,t+1} = N^{s}_{a,t}\, e^{-M} \left(1 - {}_{c}S^{s}_{a,t}\, H_t\right) \qquad \text{for} \quad a = 6,\cdots,18 \qquad (1)$$

where M is the coefficient of natural mortality, ${}_{c}S^{s}_{a,t}$ is selectivity for fish of age a and sex s at time t, and H_t is the harvest fraction in year t for fully-selected fish. Age classes from age six to 20+ were considered, where age 20+ corresponds to ages 20 and older. Sex-ratio was assumed to be equal to one at age six. The notation used in this and subsequent equations is summarized in Appendix 2.

Fishing was assumed to take place in a short period in the middle of the year, and age-selectivity was modeled as the *fraction* of each age class recruited to the exploitable stock which suffered a harvest rate equal to H_t. Commercial catch ${}_{c}C$ at age was predicted by:

$$_{c}C_{a,t} = H_t\, e^{\frac{-M}{2}} \left(N^{f}_{a,t}\ {}_{c}S^{f}_{a,t} + N^{m}_{a,t}\ {}_{c}S^{m}_{a,t}\right) \qquad (2)$$

The catchability of the commercial fleet was allowed to vary according to a random walk model of the form:

$$\ln(Q_{t+1}) = \ln(Q_t) + {}_{q}\varepsilon_t \qquad (3)$$

where ${}_{q}\varepsilon_t \sim N(0, {}_{q}\sigma^2)$. The parameter ${}_{q}\sigma^2$ controls the amount of year-to-year variation allowed in Q_t. Similar random-walk formulations were used for other model parameters as well, whenever time-series trends were considered likely. The effective commercial effort was predicted by :

$$E_t = \frac{-\ln(1 - H_t)}{{}_{c}Q_t} \qquad (4)$$

The survey catch per unit effort (in numbers) was predicted as

$$_{s}CPUE_t = {}_{s}Q\ e^{\frac{-M}{2}} \sum_{a} \left({}_{s}S^{f}_{a,t}\, N^{f}_{a,t} + {}_{s}S^{m}_{a,t}\, N^{m}_{a,t}\right) \qquad (5)$$

where ${}_{s}S^{s}_{a,t}$ is sex-specific survey selectivity at age and time, and ${}_{s}Q$ is the catchability coefficient. Survey catchability was assumed to be constant except for an adjustment factor incorporated to account for a change in hook type as explained below. Age-sex composition of the survey catches was given by

$$_{s}P^{s}_{a,t} = \frac{_{s}S^{s}_{a,t}\, N^{s}_{a,t}}{\sum_{i} ({_{s}S^{f}_{i,t}}\, N^{f}_{i,t} + {_{s}S^{m}_{i,t}}\, N^{m}_{i,t})}$$

Selectivity

Commercial selectivity was assumed to be a function of size with time-dependent parameters X_t^{full} and ν_t. If X represents log-length, the size-selectivity function in year t, assumed to be the same for males and females, was given by

$$_{c}s_t(X) = \begin{cases} 0, & \text{for} \quad X < \ln(81) \\ \exp\left\{\dfrac{-\left(X - X_t^{\text{full}}\right)^2}{2\nu_t}\right\} & \text{for} \quad \ln(81) \le X \le X_t^{\text{full}} \\ 1, & \text{for} \quad X > X_t^{\text{full}} \end{cases} \tag{6}$$

where 81 cm corresponds to the legal size limit below which selectivity was assumed to be zero.. Selectivity at age and year was predicted separately for each sex by integrating the size selectivity over the sex-specific distributions of size at age in each year as:

$$_{c}S^{s}_{a,t} = \int_{-\infty}^{\infty} {_{c}s_t}(X)\varphi\left(X|\mu^{s}_{a,t}, {_{x}\sigma^{2s}}\right)\mathrm{d}X \tag{7}$$

where $\varphi(X|\mu^{s}_{a,t}, {_x\sigma^{2s}})$ represents the distribution of log-length at age a and sex s in year t, assumed to be Gaussian with mean $\mu^{s}_{a,t}$ and constant variance $_{x}\sigma^{2s}$. The equations (1), (6) and (7) imply that mortality of discarded sublegal fish was ignored. The parameters X_t^{full} and ν_t were allowed to change over time according to a random walk model with constraints in the variances of the year-to-year deviations:

$$\begin{aligned} X_{t+1}^{\text{full}} &= X_t^{\text{full}} + {_{X\text{full}}\varepsilon_t} \qquad \text{where } {_{X\text{full}}\varepsilon_t} \sim N\left(0, {_{X\text{full}}\sigma_t^2}\right) \\ \ln(\nu_{t+1}) &= \ln(\nu_t) + {_{\nu}\varepsilon_t} \qquad \text{where } {_{\nu}\varepsilon_t} \sim N\left(0, {_{\nu}\sigma_t^2}\right) \end{aligned} \tag{8}$$

The formulation is similar to that used for $\ln(Q_t)$ except that the variances for the normal deviations were adjusted so that selectivity was allowed to change more when growth rates were changing rapidly, and very little when size at age was relatively stable.

The selectivity of the setline survey was assumed to have the same functional form as the commercial selectivity (equation (6)) except for the legal size limit which does not apply to the surveys. In 1984, the hook type used in the surveys was changed from J-hook to the more efficient circle hook (C-hook) used by the commercial fleet. In order to estimate the relative efficiency of the two hook types, two parallel sets were fished on each survey station in 1984, one with each hook type. The ratio of catches by 10-cm size category showed that the C-hook selected fish of smaller sizes than the J-hook (Clark, this volume). The C-hook was estimated to be twice as effective as the J-hook at catching large, fully selected fish. In order to account for these experimental results, the ratio of the catchabilities of the hooks was assumed known and equal to two, and selectivity parameters were estimated separately for the two time periods with an overlap in 1984. The size-specific ratios of catches obtained by the two hook types in 1984 were predicted by summing the expected size-specific catches across ages and sexes. Predicted catch ratios for each size category l, ratio_l, were fitted to the observed ratios, ratio_l^{obs}.

Growth Dynamics

Female halibut grow faster than male halibut and so growth parameters were made sex-specific. For simplicity, however, sex superscripts have been dropped from the notation in this section. In the absence of size-selective mortality, the median length-at-age for each sex $(= \exp(\mu_{a,t}))$ was assumed to propagate according to

$$m_{a+1,t+1} = \alpha_t + \beta\, m_{a,t} \qquad \text{for } a = 6,7,\cdots \tag{9}$$

with time-varying initial size $m_{6,t}$ and intercept α_t. When $\beta < 1$, this equation corresponds to a von Bertalanffy model (applied to median length at age) with a time trend in the parameter corresponding to the asymptotic length $L_\infty = \alpha_t/(1-\beta)$, and a time trend in size at age 6. Trends in the mean log-length at recruitment $\mu_{6,t}$ and in $\ln(\alpha_t)$ were modeled as random walks:

$$\begin{aligned} \mu_{6,t+1} &= \mu_{6,t} + {}_{\mu}\varepsilon_t \\ \ln(\alpha_{t+1}) &= \ln(\alpha_t) + {}_{\alpha}\varepsilon \end{aligned} \tag{10}$$

where ${}_{\mu}\varepsilon_t \sim N(0, {}_{\mu}\sigma^2)$ and ${}_{\alpha}\varepsilon_t \sim N(0, {}_{\alpha}\sigma^2)$. The variance of log-length at age was assumed to be constant and equal to ${}_{x}\sigma^2$, so that the coefficient of variation of length-at-age was constant and equal to $CV[L] = \sqrt{\exp({}_{x}\sigma^2) - 1} \cong {}_{x}\sigma$.

The effect of size-selective mortality on the size distribution at age was incorporated by adjusting the mean log-length at age, from $\mu_{a,t}$ (the mean prior to the fishing season) to $\mu^{+}_{a,t}$ (the mean at a time immediately after fishing). Realistically, the nature of the distribution should also be affected, but we assumed that a Gaussian function was still adequate to approximate the distribution of log-length prior to the next fishery. The mean log-length in the population after fishing has taken place is given by:

$$\mu^{+}_{a,t} = \frac{\int_{-\infty}^{\infty} X\left(1 - {}_{c}s_t(X) H_t\right) \varphi\left(X \mid \mu_{a,t}, {}_{x}\sigma^2\right) dX}{\int_{-\infty}^{\infty} \left(1 - {}_{c}s_t(X) H_t\right) \varphi\left(X \mid \mu_{a,t}, {}_{x}\sigma^2\right) dX} \tag{11}$$

where $(1 - {}_{c}s_t(X)\, H_t)$ represents the survivorship from fishing and $\varphi(X|\mu_{a,t}, {}_{x}\sigma^2)$ the distribution of log-length X as a function of the prior mean $\mu_{a,t}$ and variance ${}_{x}\sigma^2$. The denominator of the equation above corresponds to the fraction of fish of age a that survived after the fishing season. Because larger fish are selectively removed by the fishery, $\mu^{+}_{a,t}$ is smaller than $\mu_{a,t}$.

The median length at age $a+1$, prior to the next fishing season, was predicted based on $m^{+}_{a,t} = \exp(\mu^{+}_{a,t})$ as:

$$m_{a+1,t+1} = \alpha_t + \beta m^{+}_{a,t} \tag{12}$$

from which $\mu_{a+1,t+1}$ was computed as $\ln(m_{a+1,t+1})$. The mean and variance of the log-length-at-age in the catch were predicted as:

$${}_{c}\mu_{a,t} = \frac{\int_{\ln(81)}^{\infty} X\ {}_{c}s_t(X)\left(\varphi\left(X|\mu^{f}{}_{a,t},{}_{x}\sigma^{2^{f}}\right)N^{f}_{a,t} + \varphi\left(X|\mu^{m}{}_{a,t},{}_{x}\sigma^{2^{m}}\right)N^{m}_{a,t}\right)\mathrm{d}X}{\int_{\ln(81)}^{\infty} {}_{c}s_t(X)\left(\varphi\left(X|\mu^{f}{}_{a,t},{}_{x}\sigma^{2^{f}}\right)N^{f}_{a,t} + \varphi\left(X|\mu^{m}{}_{a,t},{}_{x}\sigma^{2^{m}}\right)N^{m}_{a,t}\right)\mathrm{d}X}$$

$${}_{c}\sigma^{2}_{a,t} = \frac{\int_{\ln(81)}^{\infty} X^{2}\ {}_{c}s_t(X)\left(\varphi\left(X|\mu^{f}{}_{a,t},{}_{x}\sigma^{2^{f}}\right)N^{f}_{a,t} + \varphi\left(X|\mu^{m}{}_{a,t},{}_{x}\sigma^{2^{m}}\right)N^{m}_{a,t}\right)\mathrm{d}X}{\int_{\ln(81)}^{\infty} {}_{c}s_t(X)\left(\varphi\left(X|\mu^{f}{}_{a,t},{}_{x}\sigma^{2^{f}}\right)N^{f}_{a,t} + \varphi\left(X|\mu^{m}{}_{a,t},{}_{x}\sigma^{2^{m}}\right)N^{m}_{a,t}\right)\mathrm{d}X} - {}_{c}\mu^{2}_{a,t} \tag{13}$$

Note that the integration was done across all sizes above the legal size limit (ln(81)). Similar equations were used to predict the sex-specific means and variances of log-length at age for survey catches, respectively ${}_{s}\mu^{s}_{a,t}$ and ${}_{s}\sigma^{2s}_{a,t}$, but the lower limit of integration was set to $-\infty$. The assumptions made about the pdf of X and the functional form of $s_t(X)$ lead to a numerically efficient algorithm, as selectivities at age $S_{a,t}$, and the moments of the distribution of X in the catch and among the survivors could be expressed as a function of standard Gaussian cumulative distributions.

Estimation

The model was fitted to data for the period 1974-1996. Data from the commercial fishery included effort, catch at age, and mean and variance of log-length at age. Data from the setline surveys included *CPUE*, age-sex proportions, and mean and variance of log-length at age for males and females. Parameters in Table 1 were estimated separately for areas 2B and 3A by maximizing the likelihood of the observations while penalizing the variability of some of the stochastic variables for which *a priori* variances were specified. Log-normal errors were assumed throughout and the weighted residual sum of squares *RSS* was computed by summing the following components:

Catch-at-age equations:

$$RSS_{\mathrm{c:c}} = \lambda_{\mathrm{c:c}} \Sigma_a \ \Sigma_t \left[\frac{\ln({}_{\mathrm{c}}C^{\mathrm{obs}}{}_{a,t}) - \ln({}_{\mathrm{c}}C_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{c}}C^{\mathrm{obs}}{}_{a,t})\right)} \right]^2$$

$$RSS_{\mathrm{s:c}} = \lambda_{\mathrm{s:c}} \Sigma_s \ \Sigma_a \ \Sigma_t \left[\frac{\ln({}_{\mathrm{s}}P^{\mathrm{obs}}{}_{a,t}{}^{s}) - \ln({}_{\mathrm{s}}P^{s}{}_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{s}}P^{\mathrm{obs}}{}_{a,t}{}^{s})\right)} \right]^2$$

Effort equations:

$$RSS_{\mathrm{c:e}} = \lambda_{\mathrm{c:e}} \sum_t \left[\ln(E^{\mathrm{obs}}{}_t) - \ln(E_t)\right]^2$$

$$RSS_{\mathrm{s:e}} = \lambda_{\mathrm{s:e}} \sum_t \left[\frac{\ln({}_{\mathrm{s}}CPUE^{\mathrm{obs}}{}_t) - \ln({}_{\mathrm{s}}CPUE_t)}{\mathrm{sd}\left(\ln({}_{\mathrm{s}}CPUE^{\mathrm{obs}}{}_t)\right)} \right]^2$$

Length equations:

$$RSS_{\mathrm{c}:\mu} = \lambda_{\mathrm{c}:\mu} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\mathrm{c}}\mu^{\mathrm{obs}}{}_{a,t}) - \ln({}_{\mathrm{c}}\mu_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{c}}\mu^{\mathrm{obs}}{}_{a,t})\right)} \right]^2$$

$$RSS_{\mathrm{c}:\sigma} = \lambda_{\mathrm{c}:\sigma} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\mathrm{c}}\sigma^2{}_{a,t}{}^{\mathrm{obs}}) - \ln({}_{\mathrm{c}}\sigma^2{}_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{c}}\sigma^2{}_{a,t}{}^{\mathrm{obs}})\right)} \right]^2$$

$$RSS_{\mathrm{s}:\mu} = \lambda_{\mathrm{s}:\mu} \Sigma_s \ \Sigma_a \Sigma_t \left[\frac{\ln({}_{\mathrm{s}}\mu^{\mathrm{obs}^s}{}_{a,t}) - \ln({}_{\mathrm{s}}\mu^{s}{}_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{s}}\mu^{\mathrm{obs}^s}{}_{a,t})\right)} \right]^2$$

$$RSS_{\mathrm{s}:\sigma} = \lambda_{\mathrm{s}:\sigma} \Sigma_s \ \Sigma_a \Sigma_t \left[\frac{\ln({}_{\mathrm{s}}\sigma^{2^s}{}_{a,t}{}^{\mathrm{obs}}) - \ln({}_{\mathrm{s}}\sigma^{2^s}{}_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{s}}\sigma^{2^s}{}_{a,t}{}^{\mathrm{obs}})\right)} \right]^2$$

C-J-hook-conversion equations:

$$RSS_{\mathrm{c\text{-}j}} = \lambda_{\mathrm{c\text{-}j}} \sum_l \left[\frac{\ln(\mathrm{ratio}^{\mathrm{obs}}{}_l) - \ln(\mathrm{ratio}_l)}{\mathrm{sd}\left(\ln(\mathrm{ratio}^{\mathrm{obs}}{}_l)\right)} \right]^2$$

Thus the total sum of squares was given as

$$RSS = RSS_{c:c} + RSS_{s:c} + RSS_{c:e} + RSS_{s:e} + RSS_{c:\mu} + RSS_{s:\mu} + RSS_{c:\sigma} + RSS_{s:\sigma} + RSS_{c\text{-}j}$$

The negative log-likelihood of the observations, up to additive constants, is

$$L = 0.5\, n_{obs} \log(RSS)$$

where n_{obs} is the total number of observations. Parameter estimates are obtained by minimizing the objective function

$$f = L + \text{penalties}$$

where the penalties correspond to prior assumptions made about some of the stochastic processes involved, namely, trends in catchability (equation (3))

$$PSS_q = 0.5 \sum_t \frac{{}_q\varepsilon_t^2}{{}_q\sigma^2}$$

trends in the mean log-length at age 6 and growth intercept (equation (10))

$$PSS_\mu = 0.5 \sum_s \sum_t \frac{{}_\mu\varepsilon_t^{s\,2}}{{}_\mu\sigma^2} \quad \text{and} \quad PSS_\alpha = 0.5 \sum_s \sum_t \frac{{}_\alpha\varepsilon_t^{s\,2}}{{}_\alpha\sigma^2}$$

and variability in the parameters of the size-selectivity function $s_t(X)$ for the commercial fishery (equation (8)),

$$PSS_{Xfull} = 0.5 \sum_t \frac{{}_{Xfull}\varepsilon_t^2}{{}_{Xfull}\sigma_t^2} \quad \text{and} \quad PSS_v = 0.5 \sum_t \frac{{}_v\varepsilon_t^2}{{}_v\sigma_t^2}\,.$$

The penalties term in the objective function is thus

$$\text{penalties} = PSS_q + PSS_\mu + PSS_\alpha + PSS_{Xfull} + PSS_v$$

The model was implemented using AD Model Builder (Otter Research Ltd. 1994) which uses automatic differentiation to minimize the objective function. The minimization is conducted in steps or phases of increasing complexity as specified by the user.

The emphasis given to different data types in the estimation was controlled in two ways. First, empirically-computed coefficients of variation of the observed statistics were used in all cases except for the commercial effort. Because errors were assumed to be log-normally distributed, the coefficients of variation of the observations approximate the standard deviations of the corresponding log-transformed variables. Catch-at-age observations were weighted based on the coefficient of variation of the age proportions in the market sample data. Residuals corresponding to the mean and variance of log-length in the commercial catch were weighted using the coefficient of variation of the estimated moments determined from bootstrap calculations; those from the survey catch were weighted using coefficients of variation determined from standard equations based on simple random sampling. Coefficient of variations for age proportions and *CPUE* in the surveys were estimated assuming simple random sampling. Second, an *ad hoc* differential weighting of data of different types was effected through the λ's. Sampling-based measures of uncertainty do not normally capture all the variability present in the process, so in most cases λ's were chosen so as to increase the empirically-based standard deviations by a factor of two (i.e., λ=0.25). The likelihood component corresponding to the age and sex compositions of survey catches was assigned a λ equal to one because that was the only source of information on sex-specific abundance. A greater emphasis was also placed on the C-hook/J-hook observed catch ratios by setting $\lambda_{c\text{-}j}$ to five. Values for the variances of the stochastic processes are given below:

Prior Variances	
${}_{\alpha}\sigma^2 =$	0.07^2
${}_{\mu}\sigma^2 =$	0.10^2
${}_{q}\sigma^2 =$	0.03^2
${}_{X\mathrm{full}}\sigma_t^2 =$	0.01^2 for t<1984
	0.03^2 for t≥1984
${}_{v}\sigma^2_t =$	0.01^2 for t<1984
	0.03^2 for t≥1984

Model Parameters

Certain model parameters were fixed while bounds were specified for others. Natural mortality was set to $M = 0.2$. The initial conditions for size at age of males and females in the population in year one, $m_{a,1}$, $a \in \{6,\ldots,20+\}$, were constrained to follow a von Bertalanffy model with sex-specific parameters. The growth coefficients β were constrained to be between 0.5 and one, the log-length at full selectivity X_t^{full} in year t=1 was constrained to be less than ln(130), and a quadratic penalty was added to the objective function so as to force the predicted commercial and survey selectivities for female halibut in the 20+ age group to be equal to one. Estimated parameters are shown in the table below, although the actual minimization was conducted over a different parameter space. Re-parameterizations were used to reduce the correlation among estimated parameters, and transformations were used in some cases to constrain parameter values; the latter is done automatically by AD Model Builder when bounded parameters are specified.

Parameters		Number
$N_{6,t}$	recruitment	T
$N^s_{a,1}$	initial abundance	$2\times(A\text{-}1)$
H_t	fishing mortality	T
${}_{c}Q_t$	commercial catchability	T
${}_{s}Q$	survey catchability	1
X_t^{full} and ν_t	size-selectivity	$2\times T + 4$
$\mu^s_{6,t}$	mean log-length at age 6	$2\times T$
α^s_0 and β^s_0	initial log-length at age	4
α^s_t	intercept of growth equation	$2\times(T\text{-}1)$
β^s	slope of growth equation	2
${}_{x}\sigma^{2s}$	variance of log-length at age	2

APPENDIX 2: NOTATION

Prescripts:	c	Commercial
	s	Survey
Subscripts:	a	Age
	t	Time
	l	Length category
Superscripts:	obs	Observation variable
	+	Time immediately after fishing
	s	Sex

Catch and Abundance (s superscripts dropped):

${}_cC_{a,t}$	Commercial catch at age and time
${}_cC^{obs}_{a,t}$	Observed commercial catch at age and time
${}_cP_{a,t}$	Age composition in survey catches at time t
${}_cP^{obs}_{a,t}$	Observed age composition in survey catches at time t
${}_sCPUE_t$	CPUE at time for survey
${}_sCPUE^{obs}_t$	Observed CPUE at time for survey
E_t	Fishing effort at time for commercial fishery
E^{obs}_t	Observed fishing effort at time for commercial fishery
H_t	Harvest fraction of fully selected fish
$N_{a,t}$	Population numbers at age and time
M	Instantaneous natural mortality
${}_cQ_t$	Catchability for commercial fishery
${}_sQ$	Catchability for survey
${}_cs_t(X)$	Selectivity of fish of log-length X in the commercial fishery in year t
${}_ss_t(X)$	Selectivity of fish of log-length X in the survey in year t
${}_cS_{a,t}$	Selectivity of fish of age a in the commercial fishery in year t
${}_sS_{a,t}$	Selectivity of fish of age a in the survey in year t
v_t	Variance-like parameter of size-selectivity $s_t(X)$
X^{full}_t	Log-length beyond which fish are fully-selected

Size and Growth (s superscripts dropped):

α_t	Intercept of the recursive growth equation
β	Slope of the recursive growth equation
$m_{a,t}$	Median length at age in the population in year $t = \exp(\mu_{a,t})$
$m^+_{a,t}$	Median length of fish of age a surviving the fishing season in year t
$\mu_{a,t}$	Mean log-length at age in the population in year t
$\mu^+_{a,t}$	Mean log-length of fish of age a surviving the fishing season in year t
${}_c\mu_{a,t}$	Mean log-length at age in the commercial catch in year t
${}_s\mu_{a,t}$	Mean log-length at age in the survey catch in year t
${}_c\mu^{obs}_{a,t}$	Observed mean log-length at age and time in the commercial catch
${}_s\mu^{obs}_{a,t}$	Observed mean log-length at age and time in the survey catch
$\varphi(X\|\mu,\sigma^2)$	Gaussian pdf with mean μ and variance σ^2
${}_x\sigma^2$	Variance of log-length at age in the population in year t
${}_c\sigma^2_{a,t}$	Variance of log-length at age in the commercial catch in year t

${}_{s}\sigma^2_{a,t}$	Variance of log-length at age in the survey catch in year t
${}_{c}\sigma^{2\ obs}_{a,t}$	Observed variance of log-length at age and time in the commercial catch
${}_{s}\sigma^{2\ obs}_{a,t}$	Observed variance of log-length at age and time in the survey catch

Weighting Factors and variances of random components:

$\lambda_{c:c}$	Weight for commercial log-catch-at-age residuals
$\lambda_{e:c}$	Weight for commercial effort residuals
$\lambda_{c:\mu}$	Weight for commercial mean log-length residuals
$\lambda_{c:\sigma}$	Weight for commercial variance of log-length residuals
$\lambda_{s:c}$	Weight for survey log-catch-at-age residuals
$\lambda_{s:e}$	Weight for survey *CPUE* residuals
$\lambda_{s:\mu}$	Weight for survey mean log-length residuals
$\lambda_{s:\sigma}$	Weight for survey variance of log-length residuals
${}_{\mu}\sigma^2$	Variance of ${}_{\mu}\varepsilon_t$, the time-series deviations affecting $\mu_{6,t}$
${}_{\alpha}\sigma^2$	Variance of ${}_{\alpha}\varepsilon_t$, the time-series deviations of $\ln(\alpha_t)$
${}_{q}\sigma^2$	Variance of ${}_{q}\varepsilon_t$, the time-series deviations of log-catchability
${}_{\nu}\sigma^2_t$	Variance of ${}_{\nu}\varepsilon_t$, the time-series deviations affecting selectivity parameter ν_t
${}_{Xfull}\sigma^2_t$	Variance of ${}_{Xfull}\varepsilon_t$, the deviations affecting selectivity parameter X^{full}_t

A Proposed Method for Setting Area 4 and Area 3B Catch Limits

by

Robert J. Trumble and Stephen H. Hoag

INTRODUCTION

IPHC's management policy is to set catch limits that are proportional to biomass for each IPHC regulatory area (Figure 1). However, acceptable estimates of biomass have not been available for Areas 3B and Area 4 subareas. This report reviews past procedures and presents a new method for setting catch limits in Area 4A, 4B, 4CDE, and Area 3B.

Area 4

IPHC regulatory Area 4 has one of the weakest of the data sets used to manage Pacific halibut, so biomass estimates there are among the most uncertain. Yet, the area contains a significant portion of the total halibut resource. To overcome the data limitations in the past, the IPHC stock assessment has used data pooled over the subareas, or pooled with adjacent areas. Through 1989, data pooled for Areas 3B and 4 formed the basis for stock assessment, because the Area 4 data times series was too short to provide reliable estimates. Calculation of exploitable biomass for 3B and 4 occurred by partitioning the total exploitable biomass with relative CPUE values. From the 1990 through 1997 fishing seasons, separate estimates occurred for Areas 3B and 4. However, insufficient data still left large concerns for the quality of the Area 4 biomass estimate, and prevented a biologically-based estimate of exploitable biomass in the subareas 4A, 4B, 4C, 4D, and 4E. In the absence of biological data, catch limits for the subareas were based on maintaining historical catch proportions.

In 1995, the IPHC developed a biologically-based procedure for subdividing biomass in Area 4, and announced plans to use the procedure for setting catch limits for Areas 4A, 4B, 4C, 4D, and 4E in 1996. The NPFMC asked the IPHC to postpone the procedure pending further review, and adopted a Catch Sharing Plan that specified historical catch proportions the 4C, 4D, and 4D. The initial procedure for setting biologically-based biomass estimates in Area 4 involved combining the area of fishing grounds (mapped and measured by IPHC) with commercial CPUE in each of the subareas to calculate relative biomass. At the time, this was the best information available. This procedure was not entirely satisfactory because it did not address the fundamental issue of the overall quality of the Area 4 exploitable biomass estimate.

During the following year, the IPHC summarized biological data important to the discussion. Legal-sized halibut generally spawn in winter along the upper continental slope in water from 150 to 300 fm. Fish in the Bering Sea move up on to the outer continental shelf in spring, and disperse onto the Bering Sea flats in summer. Most commercial halibut fishing in the Bering Sea occurs during July and August after the halibut fully migrated out of the deep water and had time to redistribute across the shelf. The largest removals occur during the summer from a small region of Area 4D along the edge of the continental shelf. Areas such as Area 4C, for example, appear to be in a migratory pathway of fish moving from the edge to the flats. For other areas on the Bering Sea flats where local fisheries occurred, halibut are available for only short periods of time, depending on the migratory pattern. Thus, fish caught in any of subareas 4C, 4D, or 4E could likely have been caught in the other areas at a different time of year. The large-scale mixing suggests that halibut in the eastern Bering Sea are a single biological unit, and that local depletion is not likely at the current scale of fishing.

In 1996, the IPHC decided that no biological basis existed to justify maintaining the separate subareas in the eastern Bering Sea, and announced at the 1997 Annual Meeting that it would combine 4C, 4D and 4E for the 1998 season. The NPFMC modified the Catch Sharing Plan to comply with IPHC biologically-based catch limit for Area 4CDE, so that it could set allocative catch limits for the separate subareas.

Area 3B

In contrast to Area 4, the data series in Area 3B is fairly extensive. Logbook data for calculating CPUE and biological data for size and age distributions are satisfactory. Area 3B does, however, lack a long sequence of longline surveys. For unknown reasons, the stock assessment model has estimated biomass for Area 3B that is inconsistent with other biological information. For example, the fishing grounds and the CPUE in Area 3B are nearly as large as in Area 3A. The 1995 and 1997 IPHC longline surveys showed estimated relative biomass about two-thirds as large as in Area 3A. National Marine Fisheries Service trawl surveys swept-area estimates showed a similar relationship. Yet the stock assessment model estimates Area 3A biomass at about four times larger than 3B biomass. The mixed signals from the biological data and from the model show that something happens in Areas 3A and 3B that we don't understand.

PROPOSED PROCEDURE

In 1997, the IPHC began a five year program of longline surveys of the halibut areas from the California-Oregon border into the Bering Sea and the Aleutian Islands. Station locations are placed systematically for even coverage of the bottom area from 20 fm to 250 fm. Results of the survey give us an opportunity to use fishery-independent data to assess the abundance of exploitable biomass in Areas 4 and 3B relative to other areas, and the relative biomass within Area 4. Because we have good estimates of absolute biomass in other areas, we can convert the relative biomass to absolute biomass in Areas 4 and 3B.

The surveys provide estimates of catch per unit effort (CPUE) for each of the IPHC regulatory areas. CPUE is proportional to density of halibut in each area. We previously mapped bottom area in each IPHC Area. Therefore, we can estimate relative biomass in each Area by multiplying CPUE times bottom area (Table 1). For example, CPUE in Area 3A is 371 pounds per skate and bottom area is 48.2 thousand square nmi, or 17,882 biomass units. Area 4A has 245 pounds per skate and a bottom area of 15.8 thousand square nmi, or 3,871 biomass units. Area 4A biomass divided by Area 3A biomass is

$$3{,}871/17{,}882 = 0.21.$$

Thus, the biomass in 3A is about five times higher than in 4A. To calculate the absolute biomass in Area 4A, we can multiply 0.21 times the biomass in Area 3A derived from the stock assessment model. Multiplying the estimated exploitable biomass by a harvest rate of 20% produces the Constant Exploitation Yield (CEY) that is the starting point for catch limit determination. Subtracting other removals (bycatch, sport, wastage, and personal use) from the total CEY produces the setline CEY.

CALCULATION OF CEY

In the example above, we used Area 3A as the reference area to calculate biomass in Area 4A. A standard area for actual calculations of Area 4 and 3B biomass should be an area for which we have a long data series and for which we have confidence in absolute biomass. We used the sum of biomass in Areas 2A, 2B, 2C, and 3A as the standard. To estimate the exploitable biomass in Areas 3B and 4, we determined the ratio of relative biomass (from CPUE and bottom area) in the unknown areas to the standard area, and multiplied the ratio times the standard exploitable biomass. Then we multiplied the exploitable biomass by 0.2 to calculate total CEY, then subtracted other removals to calculate the setline CEY.

Calculation of setline CEY for the subareas of Area 4 and for Area 3B requires estimated biomass for Areas 2A-3A, the proportion each area is of the standard biomass, and other removals for Area 4 and 3B. Table 2 contains two biomass estimates for Areas 2A-3A, resulting from two different assumptions in the stock assessment model.

The fishery in Area 4CDE occurs mostly on the Bering Sea edge in Areas 4C and 4D, which is characterized by small fishing areas with relatively high density. The rest of the Bering Sea flats are characterized by low density and very large area. Bycatch occurs mainly on the flats where little halibut fishing occurs, while much less bycatch occurs along the edge. Given the two biomass estimates for the standard area, mixing among the halibut on the edge and on the flats, the location of halibut fishing, how do we deal with bycatch and setting catch limits in our calculations?

The data in Tables 1 and 2 permit calculation of the exploitable biomass in Areas 3B and 4 (Table 3). The calculations involve a range of values and assumptions, which result in a range of options. First, we have estimates based on the two biomass estimates for the standard area. Then we have two approaches for estimating biomass for Area 4CDE. One approach treats the Bering Sea edge as the only area that we will consider for biomass calculations, because that is the area where most harvest occurs. The other approach considers the entire region, which consists of the remainder of Area 4D, 4E and the IPHC closed area. From the exploitable biomass, we calculate total CEY and setline CEY (Table 4).

Under the proposed procedure, Area 3B values vary from biomass levels of 158.13 to 213.08 millions pounds and setline CEY values of 30.83 to 41.82 million pounds. These results show a much larger biomass and CEY than is shown by the assessment model. The assessment model appears to underestimate the size of the Area 3B stock for unknown reasons. Area 4A biomass values range from 56.76 to 76.49 million pounds; setline CEY values range from 11.05 to 15.00 million pounds. Area 4B biomass values range from 52.71 to 71.03 million pounds; setline CEY values range 10.15 to 13.82 million pounds. In Area 4CDE, we have two sets of estimates. If we considered only the edge, where most of the fishing occurs, the biomass values range from 16.22 to 21.85 million pounds; CEY values range from 1.03 to 2.16 million pounds. Including the remainder of Area 4D, 4E and the closed area in the Area 4CDE estimates increase biomass and CEY values substantially: biomass ranges from 77.04 to 103.81 and CEY ranges from 13.20 to 18.55. Aggregated Area 4 CEY values using the new procedure limited to the Bering Sea edge, ranging from 22 to 30 million pounds, are comparable to the CEY estimate of 25 million pounds proposed last year from the stock assessment model. However, the aggregate Area 4 CEY values for the entire Bering Sea, which range from 35 to 50 million pounds, are substantially higher than the Area 4 CEY from the assessment model last year.

SUMMARY

The IPHC staff developed new methods of estimating exploitable biomass for Areas 3B and 4. The stock assessment model produced results for 3B that were inconsistent with other fishery and biological data. The data set in Area 4 is considered inadequate to estimate biomass for Areas 4A, 4B, and 4CDE. The new method used results of halibut setline surveys that extended from the Oregon-California border into the Bering Sea and along the Aleutian Islands. The surveys provided estimates of relative biomass derived from survey CPUE and the bottom area in the survey area. The ratio of exploitable biomass in 3B or the subareas of Area 4 to a standard area multiplied by the biomass in the standard area gives a value for biomass for the unknown areas. The stock assessment model provided a range of two biomass values in the standard area (2A, 2B, 2C, and 3A), because of two different assumptions used in the model. We further provided a range of two estimates in Area 4CDE, depending on whether all or a portion of the Bering Sea continental shelf was included in the estimates. The new procedure generally gave estimates higher than estimates provided by the stock assessment model. The procedure is new and is based on a single year of surveys. We believe that the general pattern of exploitable biomass provided by the new procedure is better than used previously. However, we recommend caution in applying the values for setting catch limits while more surveys and more evaluation occur.

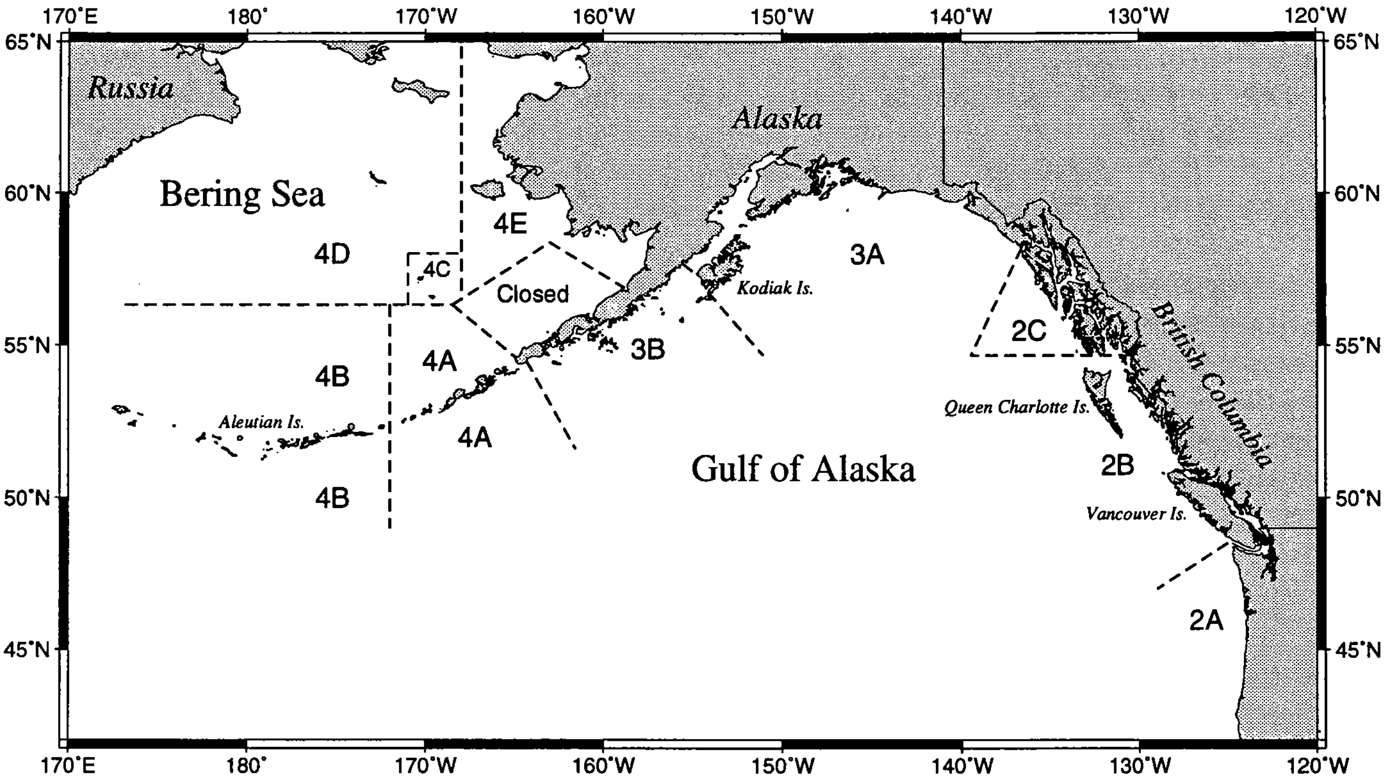

Figure 1. **IPHC regulatory areas for 1997.**

Table 1. **Distribution of exploitable biomass according to 1997 setline survey results (From Bill Clark).**

	Area (K nmi^2)	Raw cpue	Adjusted cpue	% of total biomass
2A	11.1	35	35	0.7
2B	26.2	161	161	8.3
2C	13.9	407	371	10.0
3A	48.2	318	371	34.7
3B	29.5	412	371	21.3
4A	15.8	245	245	7.5
4B	12.8	281	281	7.0
4C	9.6	57	57	1.1
4D edge	4.5	111	111	1.0
Bering shelf	145.0	---	30	8.4

Notes

1. Areas are total bottom area within 200 fm except for the 4D edge, which is bottom between 100 and 200 fm plus shallower grounds shown in IPHC Technical Report 36, and the eastern Bering Sea shelf, which incorporates the remainder of Area 4D and 4E approximately up to St. Matthew Island and the IPHC closed area.

2. A single cpue is used for the northern Gulf (2C-3A-3B).

3. The Bering shelf (the portions of 4D < 100 fm, 4E and the IPHC closed area) is assumed to have half the density of 4C because the NMFS trawl survey catch rate of legal sized fish there averaged a little more than half the 4C rate for the 1990-96 surveys combined.

Table 2. **Standard Exploitable Biomass (millions of pounds) used for calculating biomass in Areas 3B and 4.**

Area	Biomass Age-Based	Biomass Length-Based
2A	7.18	8.44
2B	82.56	97.08
2C	88.49	92.58
3A	227.22	348.25
Total	405.45	546.35

Table 3. **Exploitable biomass (millions of pounds) in Areas 3B and 4, relative to exploitable biomass in Areas 2A-3A.**

		Biomass relative to 2A-3A	
Area	% Std Biomass	Age Selectivity	Length Selectivity
3B	39	158.13	213.08
4A	14	56.76	76.49
4B	13	52.71	71.03
4CDE Edge	4	16.22	21.85
4CDE Total	19	77.04	103.81

Table 4. Total CEY and Setline CEY (millions of pounds) for Areas 3B and 4, calculated from Table 3.

	Total CEY			Set Line CEY	
Area	Age Selectivity	Length Selectivity	Other Removals	Age Selectivity	Length Selectivity
3B	31.63	42.62	0.8	30.83	41.82
4A	11.35	15.30	0.30	11.05	15.00
4B	10.54	14.21	0.39	10.15	13.82
4CDE Edge	3.24	4.37	2.21	1.03	2.16
4CDE Total	15.41	20.76	2.21	13.20	18.55

Population Assessment, 1996

by

Patrick J. Sullivan and Ana M. Parma

INTRODUCTION

Over the last several years IPHC staff have noted and discussed changes taking place in the halibut fishery that would likely lead to changes in interpretations and assumptions associated with the Pacific halibut stock assessment. In particular, we indicated that Pacific halibut have undergone a rapid reduction in individual growth in recent years, with average length at age now being 20-25% lower than what it was 10-15 years ago. We also noted that changes in the fishery, prompted by initiation of individual-quota programs, would likely have an effect as well. Last year we proposed a new approach that accounts for changes in individual size at age and its likely effect on the catchability of halibut. The approach, presented in preliminary form at last year's IPHC Annual Meeting, indicated that both stock biomass and recruitment might be higher than that estimated under previous stock assessment procedures. This year was spent confirming these preliminary results, while continuing to incorporate other important sources of information into the assessment. The new assessment procedure not only takes into account commercial age-composition, catch, and CPUE as it has in the past, it also includes size at age of the commercial catch, and catch, CPUE, age-composition, and size at age of IPHC standardized setline surveys. In addition, it now accounts for the mortality of legal-sized halibut associated with bycatch in non-directed fisheries (Figure 1). These features of the new assessment procedure aid in adjusting for changes in growth, in accounting for changes in the fishery, and in better tracking the influence of bycatch mortality on the stock.

Exploitable biomass estimates have increased under the new stock assessment. The increase in the estimates can be broken down into three major components. (1) Halibut size at age is now better represented in the assessment model. We recognize that halibut size at age has been decreasing in recent years as a result of slower growth. This reduction in size has reduced the catchability of younger age groups by setline gear through fish behavior and thresholds imposed under the legal size limit. The "poor recruitment" of age 8 halibut into the fishery was interpreted as low abundance in earlier assessments rather than as poor catchability due to smaller size. This lower catchability can now be estimated, and the estimated abundance of both younger and older age groups has increased accordingly. (2) Bycatch mortality of legal-sized halibut is now included as removals directly in the assessment along with other removals (commercial and sport catches, wastage, and personal use). The estimated biomass must increase to account for the increased level of removals. The magnitude of the increase depends on the amount of legal-sized bycatch mortality relative to total stock biomass in each area. (3) Information from IPHC setline surveys can now be explicitly incorporated. Survey CPUE trends support trends seen in commercial fishery CPUE, lending greater weight to the belief that abundance has increased since the 1980s, while helping to point out changes that have taken place in halibut catch statistics under the recently implemented individual-quota programs.

Sullivan, P.J., Parma, A.M., 1997. Population assessment, 1996.
IPHC Rep. Assess. Res. Act. 1996., pp. 81–130.

STOCK ASSESSMENT

The Pacific halibut stock assessment continues to show a slight downward trend in coastwide stock biomass over the last five years (Figure 2). This trend, however, is not as severe as that reported under previous assessments. In contrast, some IPHC regulatory areas show a leveling off (Areas 2A, 2B), or an increase (Areas 3B, 4), after accounting for the effects of slower growth and bycatch mortality (Figures 3-8). IPHC systematic survey catch per unit effort (CPUE), now incorporated in the assessment, can be compared with commercial setline CPUE (in number of halibut per skate) in Areas 2B, 2C, and 3A (Figure 9). Survey CPUE, while generally lower than commercial CPUE in Area 2B, shows a greater relative increase between observations taken in the 1990s and those taken in the 1970s to 1980s. Area 2C surveys also show an increase in contrast to the decline shown by commercial CPUE. Area 3A survey and commercial CPUEs both are quite consistent in indicating an increase since the 1980s, with similarly high levels occurring currently. The sublegal-sized component of the fishery is making up a greater proportion of the survey catch in recent years (Figure 9) again indicating the influence of smaller individual size on observed measures of abundance. The assessment now follows changing trends in growth, and takes account of changes in gear selectivity which are likely to occur simultaneously. In areas where this change in growth is great (e.g. Areas 3A and 3B), the result is generally a greater increase in the estimated level of abundance. Apparent poor recruitment to the fishery by more recent cohorts shown in earlier assessments actually resulted from a reduced vulnerability to the fishery, rather than a diminished abundance.

Commercial CPUE (in pounds per skate) is stable or on the upturn this year, with a coastwide increase of 10% from 283 pounds per skate (lbs/sk) in 1995 to 311 lbs/ks in 1996 (Figure 2). CPUE on an area-by-area basis increased 74% to 155 lbs/sk in 2A and 8% to 221 lbs/sk in 2B, decreased 5% to 221 lbs/sk in 2C, increased 13% to 442 lbs/sk in 3A, decreased 3% to 462 lbs/sk in 3B, and increased 25% lbs/sk in Area 4 (Figures 3-8).

Change continues to be observed in the average weight at age of individual halibut. Figure 10 shows the trend in the weight of age-12 halibut for each regulatory area. Dramatic decreases can be seen in the average weight of fish landed in the central regulatory areas Area 3A and Area 3B. Decreasing, though less dramatic, trends can be seen in Area 2AB and Area 4, while some increase can now be seen in the weight of halibut caught in Area 2C. Halibut younger than age 12 (not shown) have begun to exhibit an upturn in weight for all areas except Area 3A. The implications of these continually changing weights for determining the status and production levels of future stock biomass is complex and will continue to be monitored.

The incorporation of growth into the assessment has had a major effect on our estimates of year-class strength and trends in recruitment. The stock assessment figures show total biomass of 8-year-old halibut labeled as recruitment (Figures 2-8). This statistic represents the relative year-class strength in biomass of potential recruits rather than a reflection of their level of entry into the fishable portion of the stock. Under previous assessment methods the trends in these recruitment estimates were in severe decline. Some decline can still be seen on average coastwide and in most areas. However, the decline is not severe and the strength of more recent cohorts is better represented. The 1987 year class in particular, indicated as being strong in abundance in National Marine Fisheries Service trawl surveys (Clark and Walters, 1995), continues to show its strength as it enters into the fishery. These recruiting halibut (shown as a peak in eight-year-old recruitment biomass in 1995 in Figures 2-8) will be ten years of age during the 1997 season. Of these fish, approximately one third are estimated to be available to the fishery. The presence of this year-class appears to be greatest in Area 4; however, great uncertainty is associated with the Area 4 estimate. Recruitment biomass estimates in this and other areas are highly imprecise in the most recent years, when cohorts have been observed only once or twice in the fishery. Furthermore, given the generally smaller size of these fish, the percentage available for harvest is estimated to be very low, which in turn implies that the estimates themselves may be quite unreliable as only a very small fraction is observed in the catch. An additional consequence of the reduced size-at-age is that the overall contribution to exploitable biomass of these year classes is likely to be smaller in the long term than the strong year classes of larger individuals observed in the mid-1980s. The strength of the 1987 year class, never-the-less, is a positive sign for the fishery.

As can be noted in the accompanying figures, each area's assessment demonstrates its own unique representation of stock trends and recruitment levels. The total quantity of information available for each area's assessment is not the same however. Areas 2A-2B, 2C, and 3A, for example, all have long term IPHC setline survey data that provide information on trends in total abundance and year-class strength. Area 3B and Area 4 lack such systematic and longer term survey information. The resulting estimates are considerably less precise with one half to one third the level of confidence of the estimates given in the other areas.

In Area 3B, inconsistencies can be noted in relative abundance as estimated in independent assessments conducted on Areas 3A and 3B. The independent estimates, shown in this document, indicate that Area 3B exploitable biomass is roughly 30% of that estimated for Area 3A. The 1996 IPHC setline survey and NMFS trawl survey averages conducted over the two areas, on the other hand, indicate that Area 3B exploitable biomass should be roughly 60% of that shown for Area 3A (Clark 1996). No merging of these data has yet brought about an estimate that is consistent with all available information. Unfortunately, long-term setline survey information is lacking in Area 3B. Such information would be invaluable in addressing observed differences in estimates of relative abundance. Commission staff will continue to follow closely trends and statistics collected in Area 3B relative to the neighboring Area 3A.

In Area 4, low harvests in the 1970s have reduced the level of information available from the commercial catch for this area. Furthermore, there is sparse commercial coverage of all grounds known to contain halibut in Area 4. The lack of complete data coverage over time and area is a serious concern in the assessment of the Area 4 stock. As noted by the measures of relative uncertainty shown in the stock biomass and recruitment figures, greater risk is associated with managing the stock in these areas under the current management protocols. Commission staff will consider alternative assessment and management strategies for Area 4

SETLINE CEY CALCULATION

Given the changes occurring in the biology of the stock, and the associated change in the assessment, exploitation rates used in calculating the constant exploitation yield (CEY) must be reevaluated. How different exploitation rates perform hinges on the relationship between adult biomass levels and future levels of recruitment, as well as the average reproductive contribution of recruits. In conformance with a change in method of bycatch accounting, the choice of harvest rate now reflects the loss due to pre-recruitment bycatch mortality. The analysis of alternative harvest rates conducted using a definition of exploitable biomass that is consistent with current estimates of selectivity indicates that harvest rates in the range 0.20-0.25 may achieve close to maximum

Sullivan, P.J., Parma, A.M., 1997. Population assessment, 1996. IPHC Rep. Assess. Res. Act. 1996., pp. 81–130.

yields under a variety of possible future recruitment scenarios with a high likelihood that the stock is maintained within the range of historically observed levels. These and other issues are discussed more fully in a separate document. Setline CEYs computed using a harvest rate of 0.20 are shown in Table 1.

In computing the setline CEY from the total CEY under a 0.20 harvest rate, a new method of accounting for bycatch has been implemented. In past reports, total bycatch mortality was reported in Table 1 and a pound-for-pound adult reproductive compensation poundage was computed as a reduction in each IPHC area in proportion to the biomass in that area. This year, we instead incorporated legal-sized bycatch mortality into the calculation of stock abundance as removal. This contributed to raising the estimated stock levels. Legal-sized bycatch mortality is now the only component removed in the CEY calculation, with the sublegal-sized bycatch component resulting in a reduction of the recommended range of harvest rates. The legal-sized bycatch mortality reduction represents the current year's losses, and the CEY is reduced in each area by the level of legal-sized bycatch mortality that has taken place in that area.

We believe that these estimates better reflect the stock biomass and harvest levels on which management should be based, especially in areas where the assessment is supported by fishery-independent data. However, we recognize that the assessment method is new and will continue to evolve as we incorporate new data and further evaluate sensitivity to differences in model assumptions. The uncertainty demonstrated for the estimates given in Area 3B and especially Area 4, areas with little or no fishery-independent data, must be considered in setting catch limits for the upcoming season.

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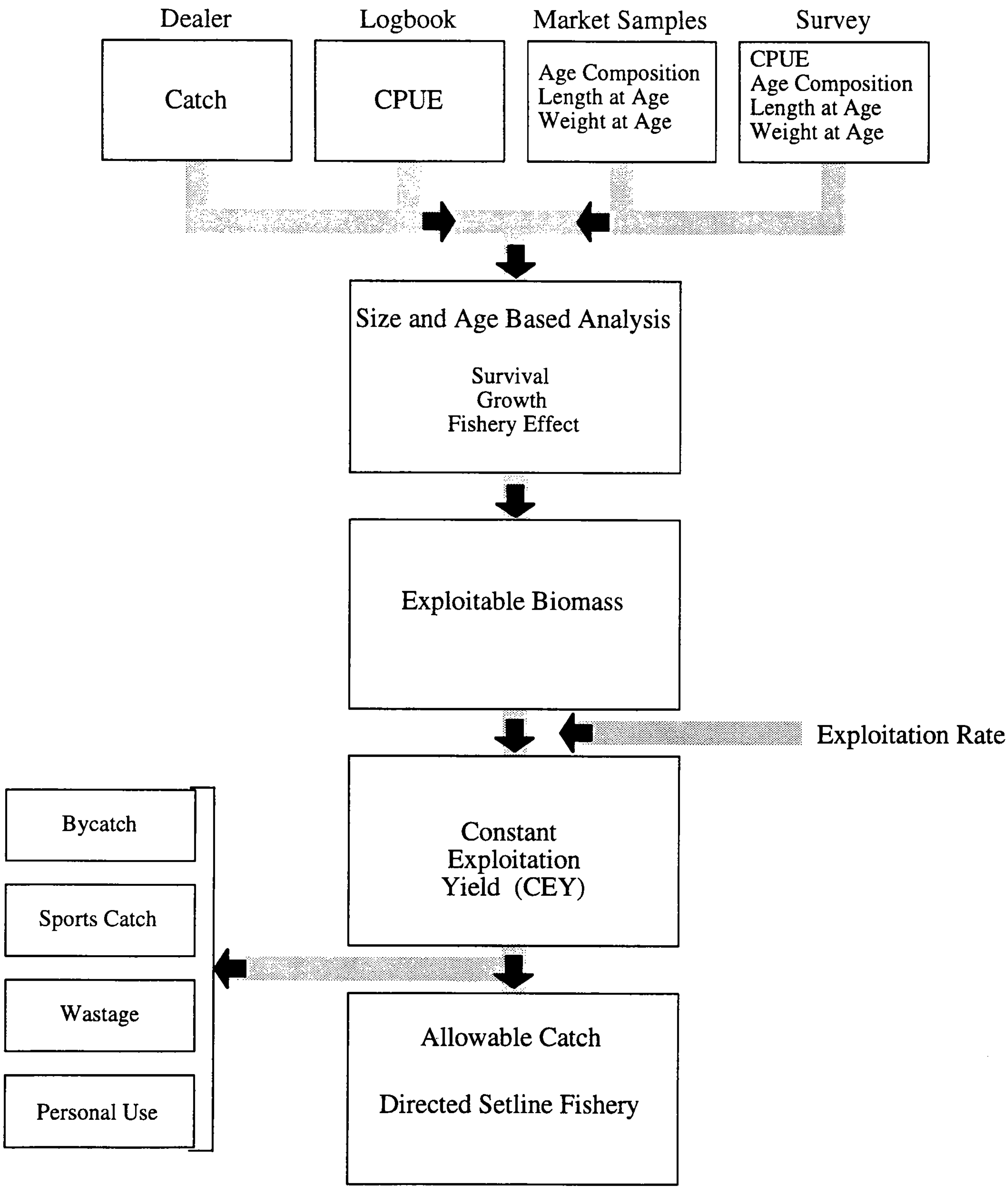

Figure 1. Overview of Pacific halibut stock assessment procedure.

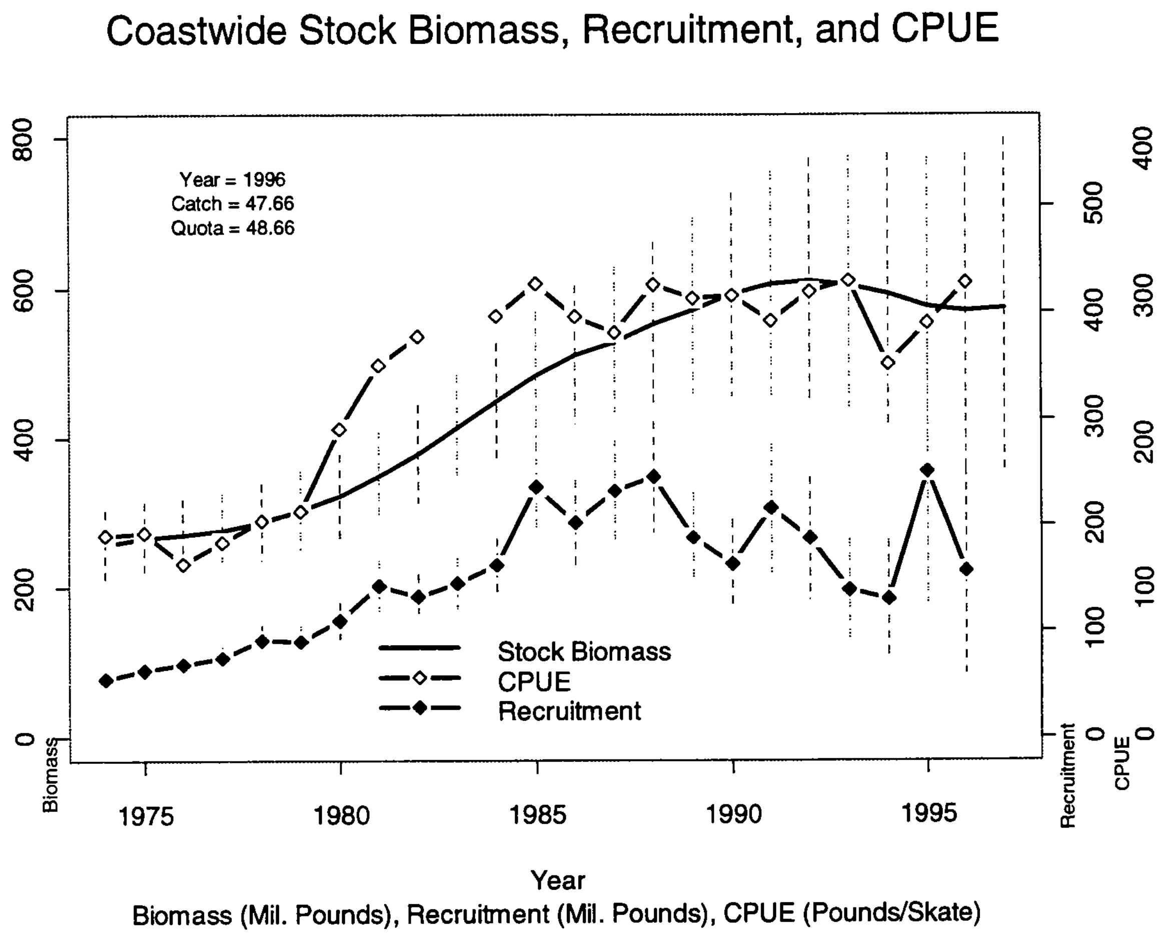

Figure 2. Coastwide size-age based estimates of exploitable stock biomass, commercial CPUE, and total biomass of eight-year-old halibut as an indicator of recruitment. Vertical lines represent confidence measures (plus or minus two standard deviations) on the biomass estimates.

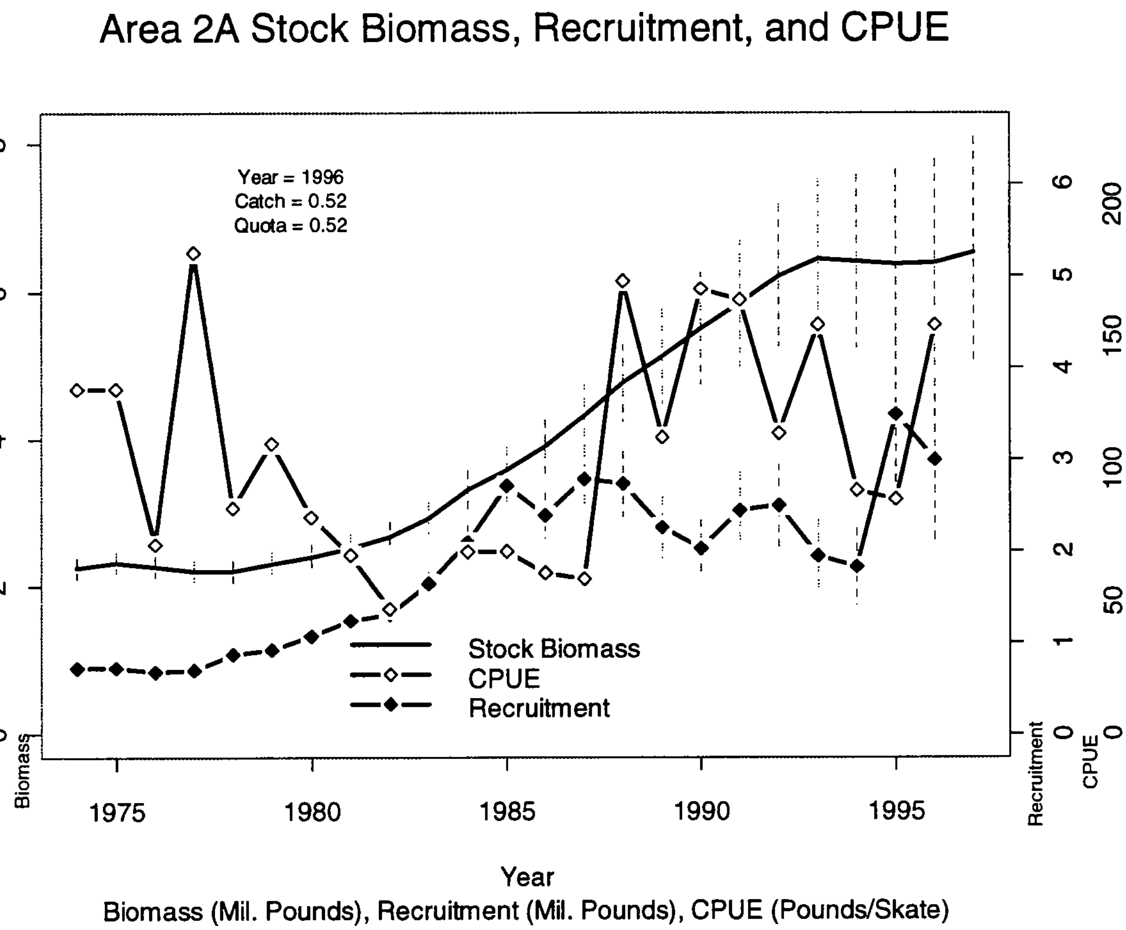

Figure 3. Area 2A size-age based estimates of exploitable stock biomass, commercial CPUE, and total biomass of eight-year-old halibut as an indicator of recruitment. Vertical lines represent confidence measures (plus or minus two standard deviations) on the biomass estimates. Area 2A biomass estimates represent 7% of the Area 2A-2B combined estimate.

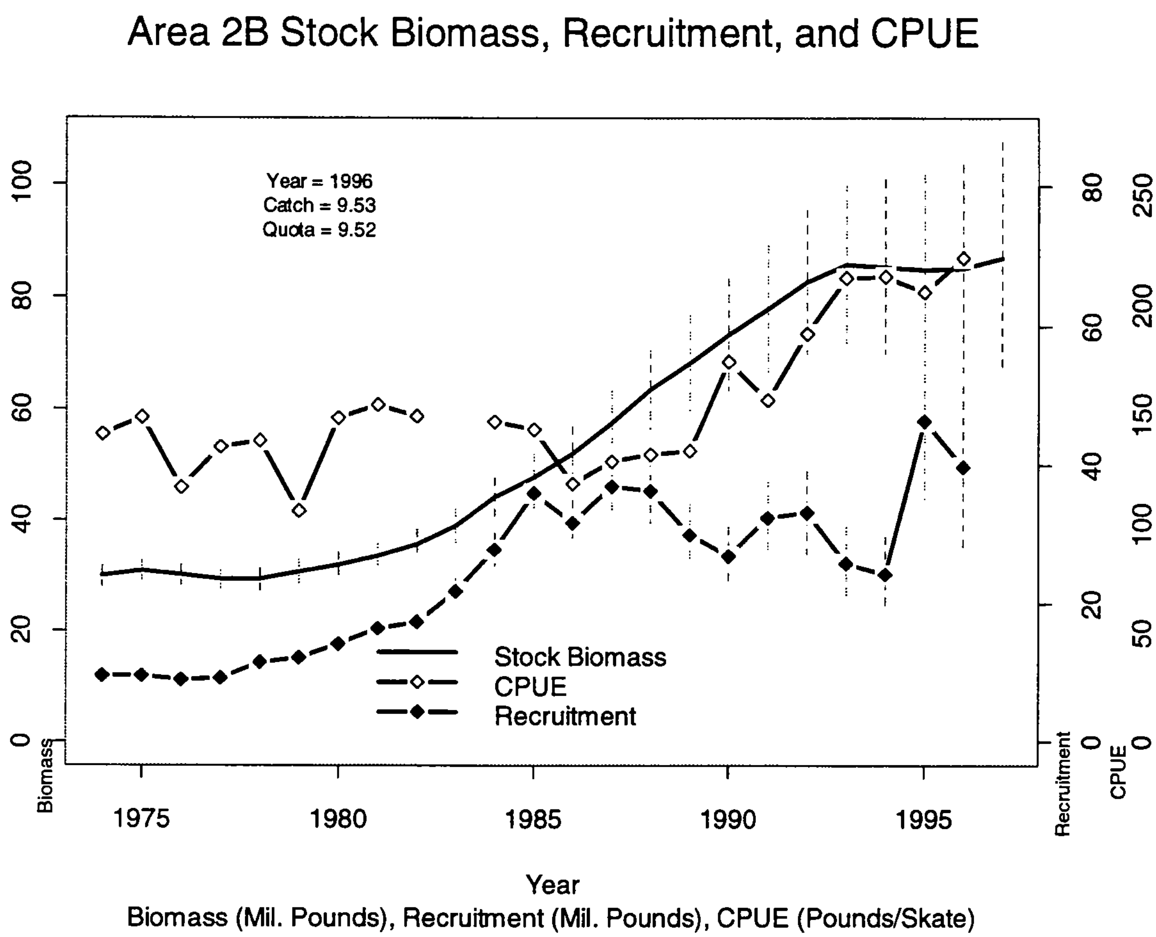

Figure 4. Area 2B size-age based estimates of exploitable stock biomass, commercial CPUE, and total biomass of eight-year-old halibut as an indicator of recruitment. Vertical lies represent confidence measures (plus or minus two standard deviations) on the biomass estimates. Area 2B biomass estimates represent 93% of the Area 2A-2B combined estimate.

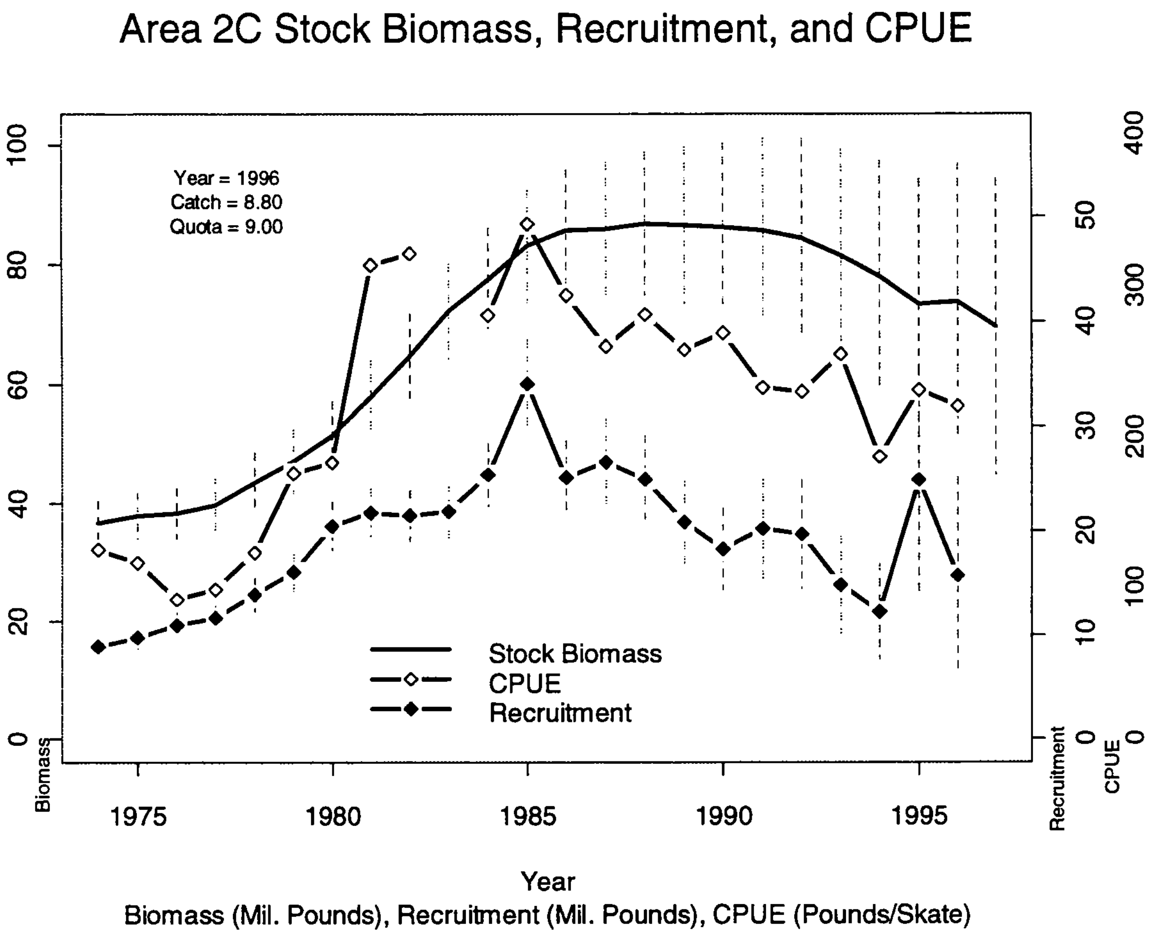

Figure 5. Area 2C size-age based estimates of exploitable stock biomass, commercial CPUE, and total biomass of eight-year-old halibut as an indicator of recruitment. Vertical lines represent confidence measures (plus or minus two standard deviations) on the biomass estimates.

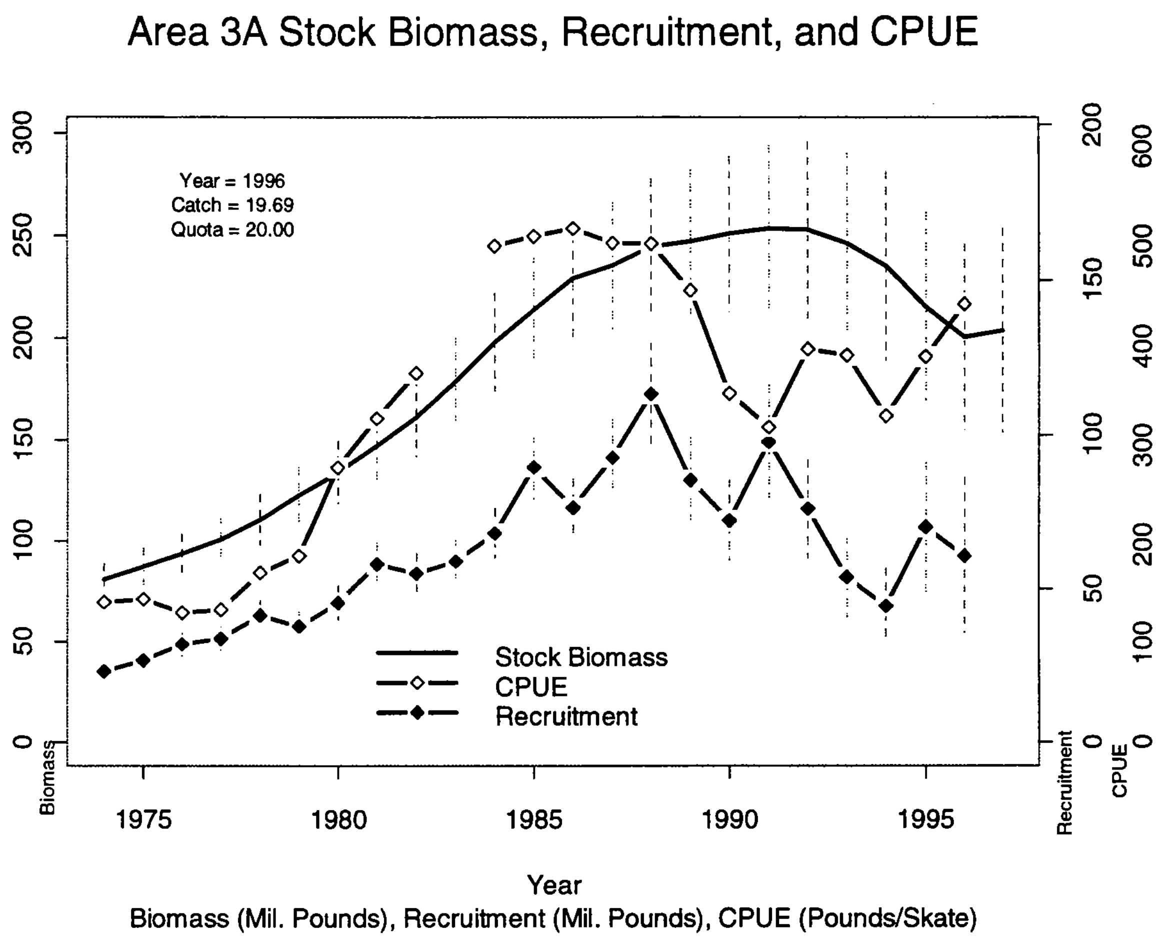

Figure 6. Area 3A size-age based estimates of exploitable stock biomass, commercial CPUE, and total biomass of eight-year-old halibut as an indicator of recruitment. Vertical lines represent confidence measures (plus or minus two standard deviations) on the biomass estimates.

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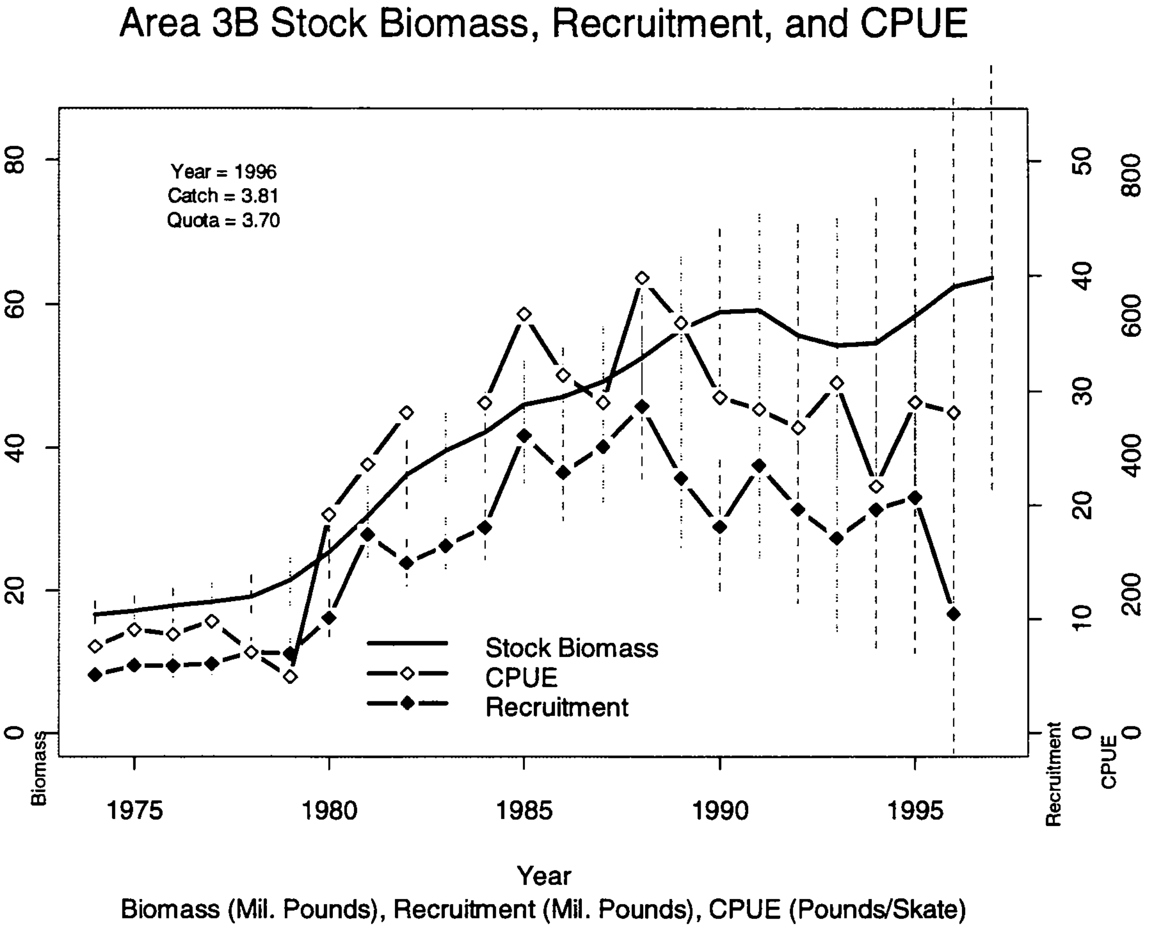

Figure 7. Area 3B size-age based estimates of exploitable stock biomass, commercial CPUE, and total biomass of eight-year-old halibut as an indicator of recruitment. Vertical lines represent confidence measures (plus or minus two standard deviations) on the biomass estimates.

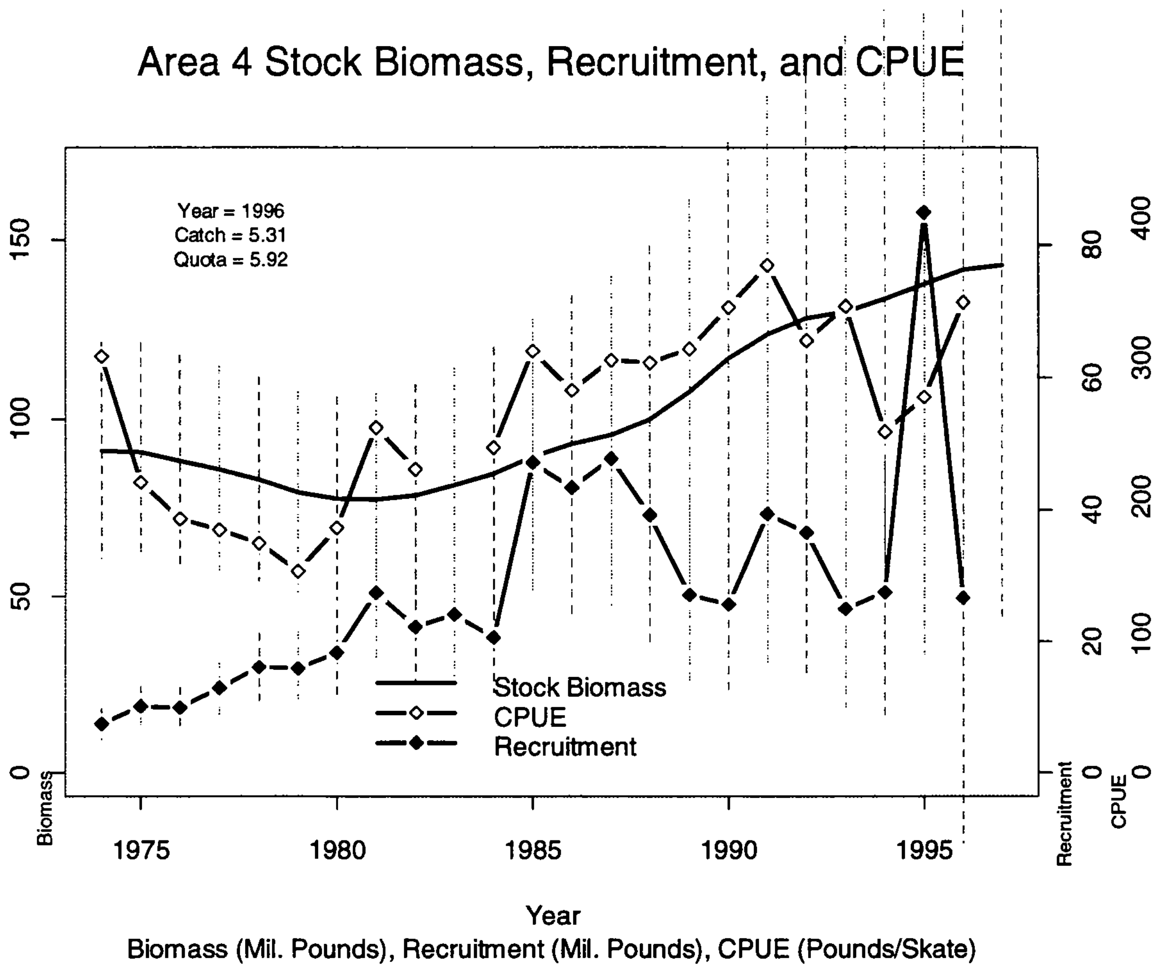

Figure 8. Area 4 size-age based estimates of exploitable stock biomass, commercial CPUE, and total biomass of eight-year-old halibut as an indicator of recruitment. Vertical lines represent confidence measures (plus or minus two standard deviations) on the biomass estimates.

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Commercial CPUE Contrasted with IPHC Setline Survey CPUE

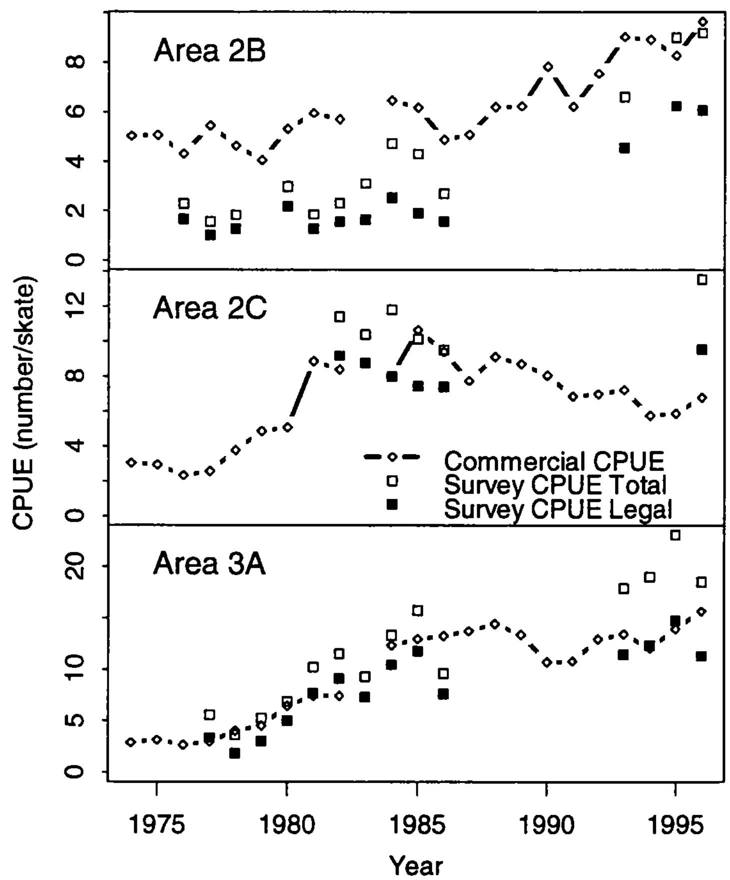

Figure 9. Commercial setline catch per unit effort (CPUE) in number of halibut per skate contrasted with IPHC setline survey CPUE in total number of halibut per skate and number of legal-sized halibut per skate.

Sullivan, P.J., Parma, A.M., 1997. Population assessment, 1996. IPHC Rep. Assess. Res. Act. 1996., pp. 81–130.

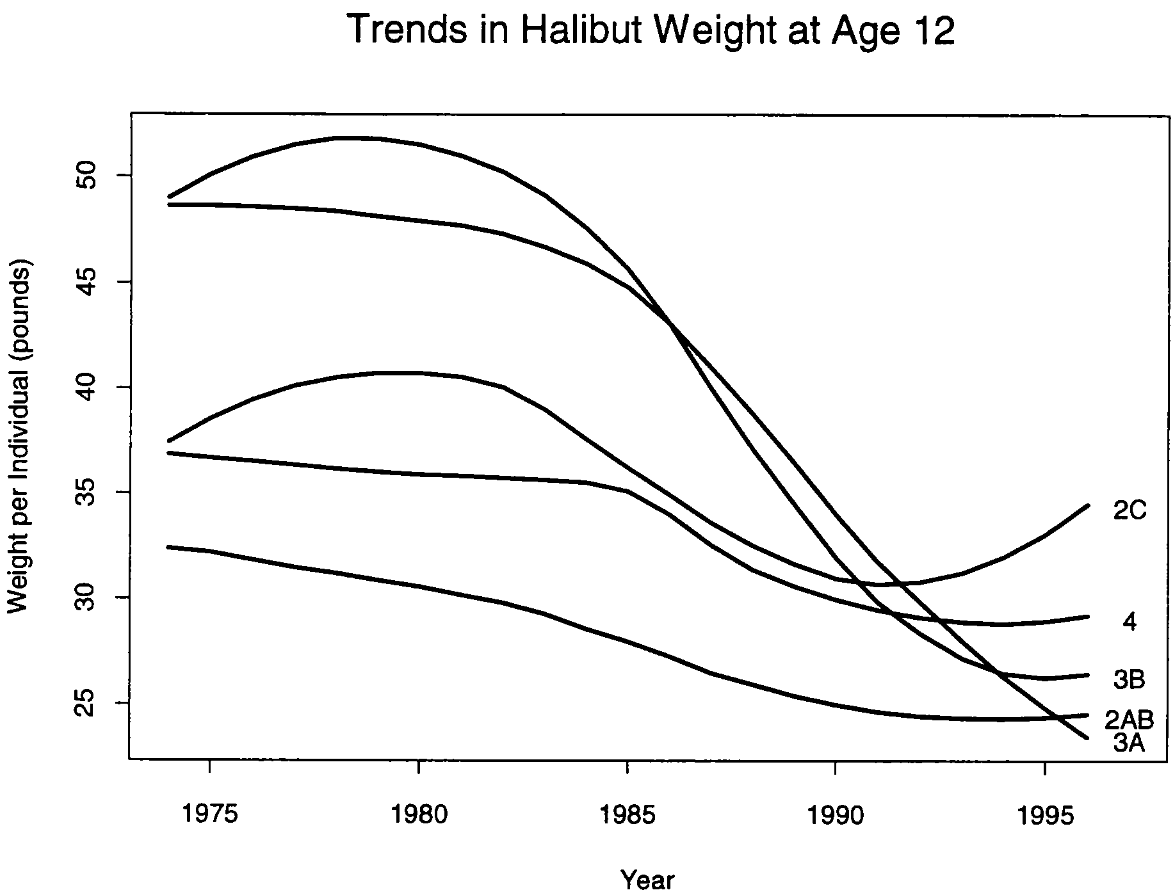

Figure 10. Trends in average individual weight at age for age 12 halibut in each IPHC regulatory area. Weight given in pounds net weight.

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Table 1. **Setline CEY under constant harvest rate policy, 20% exploitation rate.**

	2A	2B	2C	3A	3B	4	Total
Quota	0.52	9.52	9.00	20.00	3.70	5.92	48.66
Catch	0.52	9.53	8.80	19.69	3.81	5.31	47.66
Biomass	6.54	86.90	69.58	203.31	63.69	142.91	572.93
Rate	0.20	0.20	0.20	0.20	0.20	0.20	0.20
CEY	1.31	17.38	13.92	40.66	12.74	28.58	114.59
Sport	0.00	0.66	1.91	4.87	0.02	0.04	7.50
Waste	0.00	0.24	0.18	0.63	0.11	0.14	1.31
Bycatch	0.37	0.19	0.28	1.52	1.08	3.02	6.46
Subsistence	0.00	0.30	0.13	0.10	0.04	0.09	0.66
Total Removals	0.38	1.39	2.50	7.11	1.25	3.29	15.92
Setline CEY	0.93	15.99	11.41	33.55	11.49	25.29	98.67

Table A.1 Commercial CPUE (pounds per skate, C hook equivalent)

Year	2A	2B	2C	3A	3B	4	Total
1974	130.7	141.0	126.0	142.4	124.7	301.1	137.9
1975	130.6	148.7	117.4	145.3	149.3	210.7	139.7
1976	71.7	116.7	92.8	131.5	142.2	184.2	118.5
1977	182.2	135.3	99.4	134.6	161.3	176.2	133.1
1978	85.5	138.0	124.1	171.9	116.4	166.6	148.0
1979	110.0	105.8	176.6	189.0	80.8	146.1	154.6
1980	82.0	148.3	183.7	278.3	315.1	177.7	210.8
1981	67.7	154.3	313.7	327.7	387.2	249.9	254.6
1982	47.3	149.1	321.4	373.1	461.7	219.9	274.2
1983	NA	NA	NA	NA	NA	NA	NA
1984	69.0	146.6	280.8	500.3	475.2	235.6	288.0
1985	69.2	143.1	340.7	509.9	602.4	304.8	310.0
1986	60.9	118.2	294.0	517.9	514.8	276.5	287.7
1987	58.6	128.4	260.3	503.6	476.1	298.1	276.9
1988	171.4	131.6	281.3	502.8	654.2	296.4	309.4
1989	112.4	133.2	258.0	456.0	590.0	306.4	300.2
1990	168.4	173.9	269.1	352.9	483.6	336.2	302.0
1991	164.3	156.4	233.2	318.6	466.4	366.3	284.9
1992	113.9	186.6	230.5	397.1	440.2	312.4	304.4
1993	155.0	211.9	255.1	390.8	504.6	336.9	312.1
1994	92.4	212.5	187.5	330.2	355.9	247.1	255.5
1995	88.9	205.5	231.5	389.7	476.6	271.9	283.4
1996	154.9	221.0	221.0	442.3	461.6	339.9	310.6

Table A.2 Commercial Catch (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
1974	0.52	4.62	5.60	8.19	1.67	0.71	21.31
1975	0.46	7.13	6.24	10.60	2.56	0.63	27.62
1976	0.24	7.28	5.53	11.04	2.73	0.72	27.54
1977	0.21	5.43	3.19	8.64	3.19	1.22	21.88
1978	0.10	4.61	4.32	10.30	1.32	1.35	22.00
1979	0.05	4.86	4.53	11.34	0.39	1.37	22.54
1980	0.02	5.65	3.24	11.97	0.28	0.71	21.87
1981	0.20	5.65	4.01	14.22	0.45	1.19	25.72
1982	0.21	5.54	3.50	13.53	4.80	1.43	29.01
1983	0.26	5.44	6.40	14.11	7.75	4.42	38.38
1984	0.43	9.05	5.85	19.97	6.50	3.16	44.96
1985	0.49	10.39	9.21	20.85	10.89	4.28	56.11
1986	0.58	11.22	10.61	32.79	8.83	5.59	69.62
1987	0.59	12.25	10.68	31.32	7.76	6.88	69.48
1988	0.49	12.86	11.37	37.86	7.08	4.69	74.35
1989	0.47	10.43	9.53	33.73	7.84	4.93	66.93
1990	0.32	8.57	9.73	28.85	8.69	5.43	61.59
1991	0.36	7.17	8.69	22.86	11.93	5.99	57.00
1992	0.44	7.63	9.82	26.78	8.62	6.61	59.90
1993	0.52	10.63	11.29	22.74	7.86	6.25	59.28
1994	0.39	9.91	10.38	24.84	3.86	5.37	54.75
1995	0.31	9.62	7.76	18.34	3.12	4.74	43.89
1996	0.30	9.53	8.80	19.69	3.81	5.31	47.44

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Table A.3 Total Removals (million pounds excluding bycatch)

Year	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	12.45	0.28	0.71	22.71
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	15.06	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	36.56	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	74.50
1990	0.52	9.41	11.30	33.38	8.91	5.69	69.21
1991	0.52	7.88	11.41	29.23	12.41	6.52	67.96
1992	0.70	8.36	12.10	31.81	8.83	6.89	68.69
1993	0.77	11.68	13.40	28.67	7.98	6.56	69.07
1994	0.57	10.94	12.72	30.51	3.96	5.64	64.34
1995	0.55	10.62	9.57	23.06	3.18	4.89	51.88
1996	0.52	10.52	10.76	24.88	3.88	5.54	56.10

Sullivan, P.J., Parma, A.M., 1997. Population assessment, 1996. IPHC Rep. Assess. Res. Act. 1996., pp. 81–130.

Table A.4 Legal-sized Bycatch Mortality (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
1974	0.39	0.90	0.37	4.48	2.82	1.89	10.85
1975	0.39	0.90	0.45	2.61	1.66	1.10	7.11
1976	0.39	0.94	0.50	2.74	1.94	1.18	7.70
1977	0.39	0.72	0.41	3.36	1.54	1.98	8.41
1978	0.39	0.55	0.21	2.44	1.31	3.40	8.30
1979	0.39	0.69	0.64	4.49	0.69	3.44	10.34
1980	0.39	0.51	0.42	4.93	0.87	5.71	12.83
1981	0.39	0.53	0.40	3.99	1.10	4.37	10.78
1982	0.39	0.30	0.20	3.20	1.68	2.94	8.71
1983	0.39	0.29	0.20	2.08	1.22	2.47	6.65
1984	0.39	0.52	0.21	1.51	0.92	2.29	5.84
1985	0.39	0.55	0.20	0.80	0.34	2.24	4.52
1986	0.39	0.56	0.20	0.67	0.20	2.61	4.64
1987	0.39	0.79	0.20	1.59	0.40	2.67	6.04
1988	0.39	0.77	0.20	2.13	0.04	3.27	6.80
1989	0.39	0.72	0.20	1.80	0.44	1.95	5.50
1990	0.41	1.03	0.68	2.63	1.22	4.16	10.12
1991	0.41	1.22	0.55	3.13	1.03	2.92	9.26
1992	0.37	1.02	0.57	2.64	1.12	3.34	9.06
1993	0.37	0.65	0.33	1.92	0.47	2.01	5.75
1994	0.37	0.57	0.70	2.68	0.91	3.56	8.79
1995	0.37	0.71	0.60	2.33	1.19	3.28	8.48
1996	0.37	0.19	0.28	1.52	1.08	3.02	6.46

Sullivan, P.J., Parma, A.M., 1997. Population assessment, 1996. IPHC Rep. Assess. Res. Act. 1996., pp. 81–130.

Table A.5 Exploitable Biomass (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
1974	2.25	29.91	36.66	80.85	16.64	91.06	257.37
1975	2.32	30.83	37.82	87.24	17.14	90.75	266.09
1976	2.27	30.21	38.26	93.41	17.90	88.19	270.25
1977	2.21	29.35	39.69	100.56	18.45	85.87	276.13
1978	2.21	29.36	43.45	110.46	19.14	82.98	287.60
1979	2.31	30.70	46.99	122.21	21.43	79.41	303.05
1980	2.40	31.94	51.29	133.66	25.40	77.48	322.18
1981	2.53	33.55	57.79	146.85	30.41	77.32	348.45
1982	2.68	35.65	64.71	160.82	36.24	78.51	378.60
1983	2.93	38.93	72.23	178.50	39.62	81.23	413.45
1984	3.32	44.06	77.57	197.70	42.16	84.50	449.30
1985	3.59	47.70	83.19	213.41	46.03	89.31	483.21
1986	3.91	51.94	85.71	228.98	47.12	92.95	510.62
1987	4.32	57.40	85.98	235.32	49.25	95.50	527.77
1988	4.78	63.45	86.81	244.58	52.56	99.75	551.92
1989	5.13	68.17	86.63	246.94	56.47	107.56	570.91
1990	5.51	73.19	86.34	250.80	58.92	116.95	591.72
1991	5.86	77.82	85.79	253.39	59.17	123.60	605.65
1992	6.22	82.66	84.45	252.73	55.68	128.12	609.86
1993	6.45	85.68	81.49	245.95	54.31	129.92	603.80
1994	6.42	85.28	78.06	235.10	54.66	133.68	593.19
1995	6.38	84.79	73.43	214.92	58.40	137.72	575.64
1996	6.40	85.03	73.87	200.30	62.39	141.78	569.77
1997	6.54	86.90	69.58	203.31	63.69	142.91	572.93

Table A.6 Historical Exploitation Rates (total removals/exploitable biomass)

Year	2A	2B	2C	3A	3B	4	Total
1974	0.40	0.18	0.16	0.16	0.27	0.03	0.12
1975	0.37	0.26	0.18	0.15	0.25	0.02	0.13
1976	0.28	0.27	0.16	0.15	0.26	0.02	0.13
1977	0.28	0.21	0.09	0.12	0.26	0.04	0.11
1978	0.23	0.18	0.11	0.12	0.14	0.06	0.11
1979	0.20	0.18	0.11	0.13	0.05	0.06	0.11
1980	0.18	0.19	0.08	0.13	0.05	0.08	0.11
1981	0.24	0.18	0.08	0.13	0.05	0.07	0.11
1982	0.24	0.17	0.06	0.11	0.18	0.06	0.10
1983	0.24	0.15	0.10	0.10	0.23	0.08	0.11
1984	0.28	0.22	0.09	0.11	0.18	0.06	0.12
1985	0.30	0.24	0.12	0.11	0.25	0.07	0.13
1986	0.33	0.24	0.14	0.16	0.20	0.09	0.16
1987	0.33	0.24	0.14	0.16	0.17	0.10	0.16
1988	0.24	0.22	0.15	0.18	0.14	0.08	0.16
1989	0.23	0.17	0.13	0.16	0.15	0.07	0.14
1990	0.17	0.14	0.14	0.14	0.17	0.08	0.13
1991	0.16	0.12	0.14	0.13	0.23	0.08	0.13
1992	0.17	0.11	0.15	0.14	0.18	0.08	0.13
1993	0.18	0.14	0.17	0.12	0.16	0.07	0.12
1994	0.15	0.13	0.17	0.14	0.09	0.07	0.12
1995	0.14	0.13	0.14	0.12	0.07	0.06	0.10
1996	0.14	0.13	0.15	0.13	0.08	0.06	0.11

Table A.7 Annual Surplus Production (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
1974	0.98	6.44	7.13	19.05	4.98	2.29	40.87
1975	0.80	7.42	7.14	19.38	4.98	-0.83	38.89
1976	0.57	7.36	7.46	20.93	5.22	-0.42	41.12
1977	0.62	6.18	7.42	22.11	5.42	0.31	42.06
1978	0.60	6.51	8.16	24.77	4.92	1.18	46.14
1979	0.55	6.82	9.65	27.64	5.05	2.88	52.58
1980	0.55	7.78	10.49	30.57	6.16	6.26	61.81
1981	0.77	8.31	11.64	32.93	7.37	6.76	67.78
1982	0.90	9.19	11.71	35.13	9.86	7.10	73.90
1983	1.10	10.96	12.49	36.33	11.51	10.16	82.55
1984	1.21	13.33	12.30	38.22	11.29	10.27	86.62
1985	1.39	15.81	12.83	39.36	12.53	10.33	92.25
1986	1.72	17.81	12.25	43.57	11.55	11.07	97.97
1987	1.88	19.79	12.86	45.74	11.80	14.09	106.17
1988	1.49	18.91	12.67	47.12	11.16	15.87	107.22
1989	1.57	16.85	11.20	43.86	10.92	16.42	100.82
1990	1.28	15.07	11.43	38.60	10.38	16.50	93.26
1991	1.29	13.94	10.62	31.69	9.95	13.95	81.43
1992	1.30	12.40	9.72	27.68	8.58	12.02	71.69
1993	1.11	11.93	10.30	19.74	8.80	12.33	64.21
1994	0.91	11.02	8.78	13.00	8.61	13.24	55.57
1995	0.94	11.57	10.61	10.77	8.36	12.23	54.49
1996	0.94	11.61	10.68	10.03	8.94	12.59	53.93

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Table A.8 Fishing Mortality

Year	2A-2B	2C	3A	3B	4
1974	0.11	0.16	0.10	0.10	0.01
1975	0.16	0.17	0.13	0.14	0.01
1976	0.17	0.15	0.12	0.14	0.01
1977	0.14	0.08	0.10	0.15	0.02
1978	0.10	0.11	0.11	0.07	0.02
1979	0.11	0.09	0.11	0.03	0.02
1980	0.12	0.06	0.10	0.01	0.01
1981	0.13	0.07	0.11	0.01	0.01
1982	0.12	0.05	0.09	0.12	0.02
1983	0.11	0.09	0.09	0.17	0.05
1984	0.20	0.08	0.12	0.14	0.03
1985	0.22	0.13	0.12	0.24	0.05
1986	0.21	0.15	0.19	0.21	0.05
1987	0.19	0.15	0.16	0.18	0.06
1988	0.20	0.16	0.19	0.16	0.04
1989	0.15	0.15	0.17	0.17	0.04
1990	0.11	0.14	0.17	0.20	0.04
1991	0.08	0.14	0.17	0.34	0.05
1992	0.08	0.16	0.18	0.26	0.05
1993	0.13	0.19	0.18	0.23	0.04
1994	0.12	0.21	0.22	0.10	0.04
1995	0.12	0.13	0.14	0.08	0.03
1996	0.13	0.17	0.15	0.08	0.04

Table A.9 Recruitment Biomass (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
1974	0.72	9.53	8.90	23.03	5.10	7.43	54.71
1975	0.72	9.57	9.75	26.66	5.94	10.12	62.77
1976	0.67	8.96	10.95	31.93	5.91	9.88	68.30
1977	0.69	9.21	11.65	33.71	6.07	12.91	74.25
1978	0.87	11.55	13.88	41.39	7.13	16.11	90.93
1979	0.92	12.17	16.08	37.85	6.98	15.91	89.91
1980	1.07	14.15	20.46	45.52	10.13	18.28	109.60
1981	1.23	16.39	21.75	58.10	17.44	27.44	142.36
1982	1.31	17.35	21.46	55.03	14.95	22.20	132.31
1983	1.64	21.80	21.85	58.96	16.45	24.13	144.83
1984	2.10	27.84	25.39	68.12	18.07	20.64	162.16
1985	2.71	36.01	34.04	89.56	26.09	47.20	235.62
1986	2.39	31.70	25.10	76.44	22.86	43.39	201.88
1987	2.78	36.95	26.59	92.66	25.14	47.79	231.93
1988	2.73	36.32	24.90	113.26	28.67	39.23	245.11
1989	2.26	29.97	20.83	85.30	22.40	27.10	187.85
1990	2.02	26.89	18.25	72.21	18.14	25.66	163.19
1991	2.44	32.43	20.20	97.67	23.51	39.42	215.66
1992	2.50	33.18	19.68	76.02	19.66	36.56	187.60
1993	1.95	25.85	14.80	53.86	17.14	24.97	138.56
1994	1.82	24.25	12.24	44.42	19.65	27.51	129.89
1995	3.49	46.39	24.89	70.09	20.71	84.88	250.44
1996	3.00	39.80	15.69	60.68	10.49	26.68	156.33

Table A.10 Exploitable Biomass Estimates with Measures of Variation.

	2A	2B	2C	3A	3B	4
Biomass	6.54	86.90	69.58	203.31	63.69	142.91
2 Standard Dev.	1.55	20.62	24.88	50.01	29.46	98.74
Coef. Of Var.	11.8	11.8	17.9	12.3	23.1	34.5

Sullivan, P.J., Parma, A.M., 1997. Population assessment, 1996. IPHC Rep. Assess. Res. Act. 1996., pp. 81–130.

Population Assessment, 1996
Technical Supplement

by

Patrick J. Sullivan and Ana M. Parma

INTRODUCTION

The discussion, figures, and tables presented here provide additional information on more technical aspects of the stock assessment.

CPUE AND EFFECTIVE SKATE CALCULATION

The staff are working through updates of historical estimates of CPUE (Figure 1). This involves checking historical records as they occur in the database for internal consistency and consistency with published reports. CPUE is calculated using algorithms that get updated as the level of resolution of the data increases and as assumptions get changed. Effective skates as currently computed is in units of circle-hook, adjusted to 18 ft spacing or the equivalent of 100 hooks per skate, and adjusted for hook type (Table 1).

$$N_{EffectiveSkates} = N_{Skates} \cdot 1.52 \cdot (1.0 - \exp(-0.06 \cdot H_{Spacing})) \cdot \frac{Length_{Skate}}{100 \cdot H_{Spacing}} \cdot H_{Adjustment} + 0.5$$

The hook spacing adjustment follows Hamley and Skud (1978) as subsequently checked by Sullivan (1991). The hook adjustment is based on the work of Quinn et al. (1985).

For Area 2A, gear with spacing less than 4 feet is included with the spacing indicator (*Hspacing*) set at 4 feet as documented in Sullivan (1994). In all other areas, gear with spacing at less than 4 feet is excluded. CPUE (fixed-hook and snap-hook) has been recomputed back to 1980 using verified data. Subtle differences can be seen between newly computed and historic CPUEs for years not previously recomputed (1980-1983). The 1983 estimates (the J-C transition year) appear as outliers in all series and will be treated as a missing values in subsequent assessments. The fixed-hook and snap-hook time series are remarkably similar. In the past, CPUE for Area 2A-2B was computed by an effort weighted combintation of fixed-hook catch and effort with snap-hook catch an effort where the snap-hook catch and effort were for statistical areas 80 and south as noted by Sullivan et al. (1992). This year Area 2A-2B CPUE has been recomputed using a 50:50 combination of fixed-hook and hooktype adjusted snap-hook CPUE trends. This combination of gear-type CPUE should better represent trends in abundance while accounting for shifts in effort between gear-types. Snap-hook gear currently makes up close to 85% of the catch landed in Area 2B (Figure 1). Catch and effort from fixed-hook gear only is being using to compute CPUE in the remaining IPHC regulatory areas.

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EFFECT OF LEGAL-SIZED BYCATCH MORTALITY

In order to examine how the inclusion of legal-sized bycatch mortality influenced estimates of exploitable biomass, model runs were conducted with bycatch mortality excluded and with all other inputs to the model remaining the same. Figure 2 shows that, except for Area 4, the effect of bycatch inclusion into the model was a 10-20% increase in the estimated exploitable biomass. In Area 4, the effect was an 83% increase in estimated exploitable biomass in the most recent year, with increases ranging between 50% and 80% in earlier years. Note that in Area 4 legal-sized bycatch mortality currently represents about 35% of total legal-sized removals in that area, while in other areas bycatch mortality averages around 6% of total legal-sized removals.

PRIOR WEIGHTING FACTORS

Each piece of information included in the assessment is given a prior weighting to reflect the level of information that is contained in it. This is done in two ways. The first is through the measurement error associated with each observation (e.g. the standard error in the estimated mean length of age-eight halibut in the catch). So each data point that is included reflects both a measure and its standard error. The second is a weighting that takes into account other types of stochasticity including variation in the natural process as well has more subjective beliefs about the information available in each component. This often included prior weightings (or penalties) on the nature of the stochastic process, where size-at-age, for example, might be constrained to be autoregressive of order one with interannual variation (sigma) specified. The factors representing this second level of information and used in this year's stock assessment are given in Table 2. These are the multidimensional analog to the single effort-lambda weighting used previously with CAGEAN. Exploitable biomass estimates were explored for sensitivity to differences in values of effort lambda. In reducing effort lambda from a value of 50 (used in the current assessment) to a value of 25 exploitable biomass increased by 1% in Area 2AB and 2% in Area 2C, while decreasing 4% in Areas 3A and 3B.

CONSTANT SIZE-BASED VS. CONSTANT AGE-BASED SURVEY SELECTIVITY

A change in size at age observed in the Pacific halibut fishery provided strong motivation for developing a new approach to assessing halibut abundance. Modeled changes in growth were used to modifying how changes in selectivity likely occurred over time in the fishery. However, changes in selectivity associated with changes in size at age alone cannot explain everything that is observed. The likelihood of catching halibut of different sizes and ages still appears to differ by fishery and geographic region. Our initial approach to modeling selectivity assumed that survey selectivity would remain constant with length or size, and differences in selecitivity at age among regions would reflect differences in size at age. However, differences in selectivity by region, especially between Areas 2AB and 3A, cannot be explained by size-selectivity of the gear alone. The 82 cm size-limit in the commercial fishery undoubtedly results in a selectivity that is more consistently size-based than age-based. When that limit is removed, as occurs in the IPHC setline surveys, it is not so clear which is the more appropriate assumption. Similarly, to what can be seen in landings from the commercial fishery, surveys indicate that smaller, younger fish appear to be more vulnerable to capture in the southern range of Pacific halibut (e.g. Area 2B) than they are in the northern

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range (Area 3A). Since gear-types are similar between areas, and identical for IPHC setline surveys, the differences observed in the estimated size-based selectivities must be associated with something else, such as differential recruitment of year-classes to the fishing grounds.

To explore the effect of these assumptions model runs were conducted on data from Areas 2AB and 3A by first letting survey selectivity at *age* remain constant and then letting survey selectivity at *length* remain constant. The resulting exploitable biomass trends and estimated commercial and survey selectivities at age and length are shown in Figure 3. Selectivity graphs containing multiple curves represent selectivity schedules that change with time. Generally the selectivity-at-age curves shift left to right with time; as fish get smaller their likelihood of capture is less at age. Selectivity at length is not so neatly characterized within the commercial fishery. Area 2AB commercial selectivity-at-length curves go from left to right, while they go from right to left in Area 3A. Survey selectivity at length goes from right to left, as fish have to become selected at smaller sizes if age-based selectivity is to remain constant in spite of the decrease in growth. Naturally, only a single curve is present for survey selectivity when it is assumed to be constant age-based or constant length-based with time. Gaps in the series of survey selectivity curves, as seen in Area 3A figures in particular, represent the 1987 to 1992 gap in IPHC setline surveys.

Note how much more shifted to the left survey selectivity curves for Area 2AB appear to be as previously discussed. This suggests that the assumption of constant survey selectivity at age may be the more appropriate option to choose. This aspect of the assessment will have to be explored further in the future.

RETROSPECTIVE ANALYSES

A retrospective analysis was conducted on data for Areas 2AB, 2C, 3A, and 3B to gauge the degree of change estimates now go through when data for recent years are removed. Despite the variability that still remains, resulting patterns (Figure 4) are a significant improvement over those observed when commercial selectivity at age was assumed constant (Parma and Sullivan, 1996). Unfortunately, lacking a continuous series of survey CPUE precludes conducting a true retrospective analysis. In fact, much of the variability between successive retrospective runs shows the effect of new survey information being added. Survey CPUE in number of halibut per effective skate is given in Table 3.

CAGEAN RUNS

Tables 4 and 5 provide CEY estimates as they occur using 1996 data under the CAGEAN model with previously held assumptions. Tables 4 and 5 show respectively the results under 20% and 30% harvest rates. CAGEAN does not contain any of the growth modeling contained in the the size-age-based model. Nor do these estimates reflect the inclusion of legal-sized bycatch mortality, nor have they been fitted in any way to IPHC setline survey data. Exploitable biomass as shown is based on the 1986 fixed selectivity estimates, which are much higher than estimated selectivities currently in use. The computation of the CEY is similar to that presented for the current assessment with one major exception. In Tables 4 and 5, bycatch is dealt with as it was under the old bycatch compensation methodology. Total bycatch (both legal- and sublegal-sized) mortality is included in these tables and is distributed by area in proportion to the estimated exploitable biomass in that area.

Sullivan, P.J., Parma, A.M., 1997. Population assessment, 1996. IPHC Rep. Assess. Res. Act. 1996., pp. 81–130.

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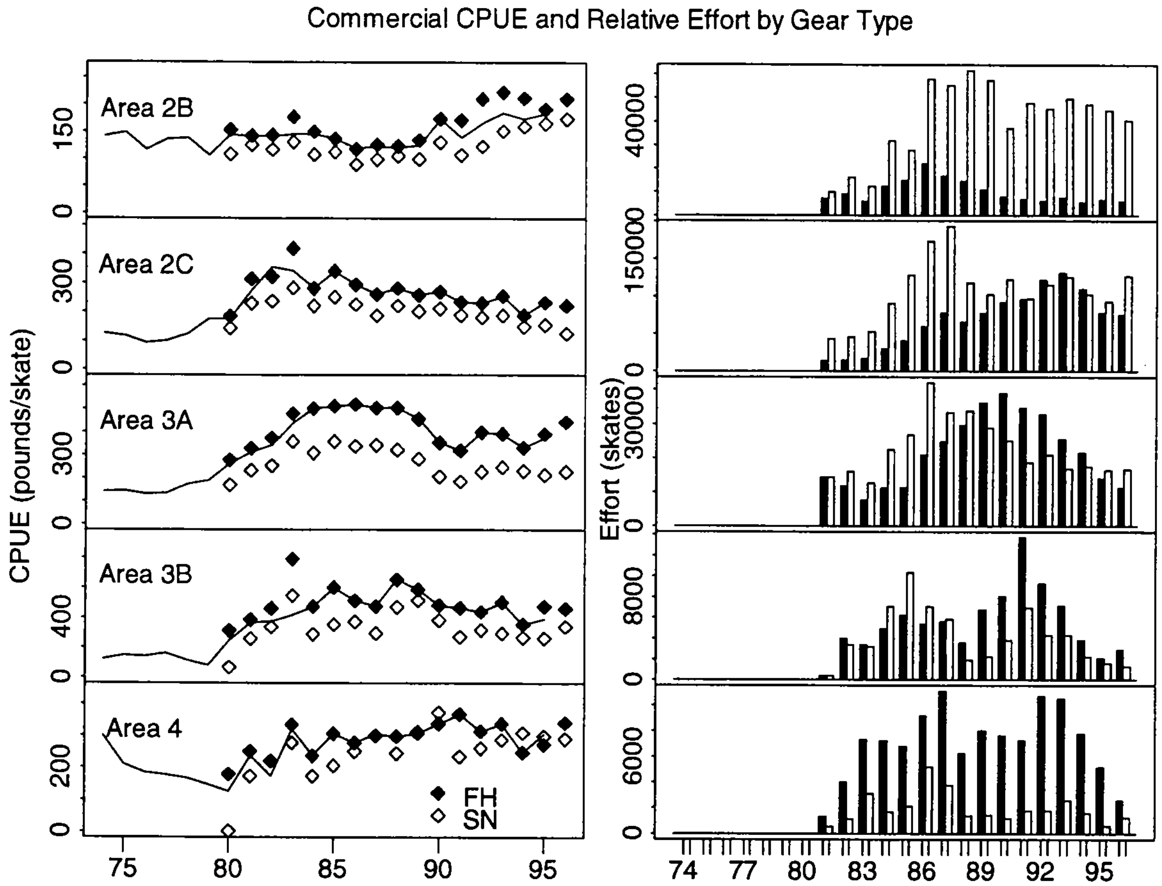

Figure 1. Estimate fixed-hook and snap-hook CPUE (shown on the left respectively as filled and unfilled diamonds) compared with historically used estimates (shown as a solid line) for each IPHC area. Total recorded effort in effective skates for fixed-hook and snap-hook (shown on the right respectively as filled and unfilled bars).

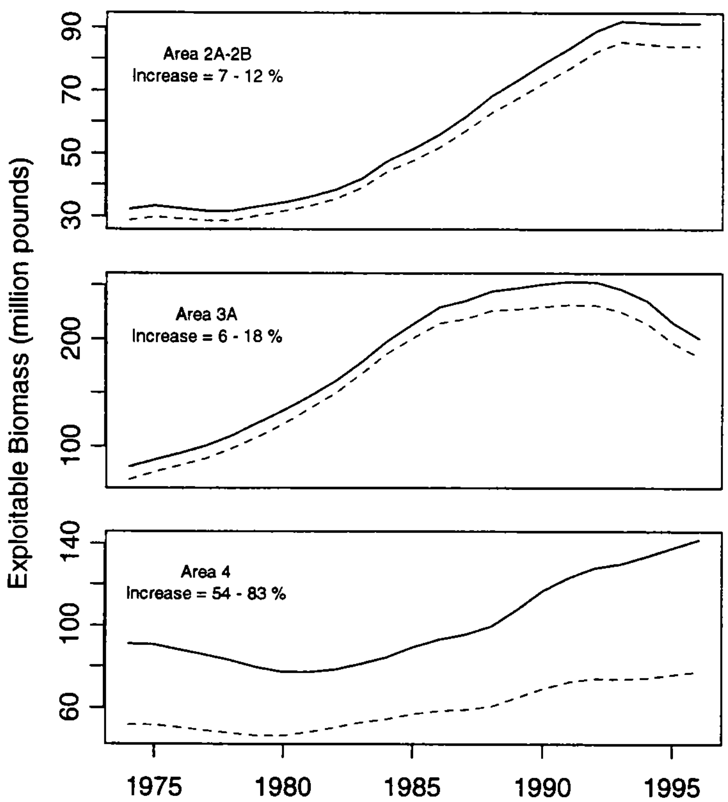

Figure 2. Estimated exploitable biomass with (solid line) and without (dashed line) legal-sized bycatch mortality added to total removals. Difference is greatest when bycatch mortality levels are high.

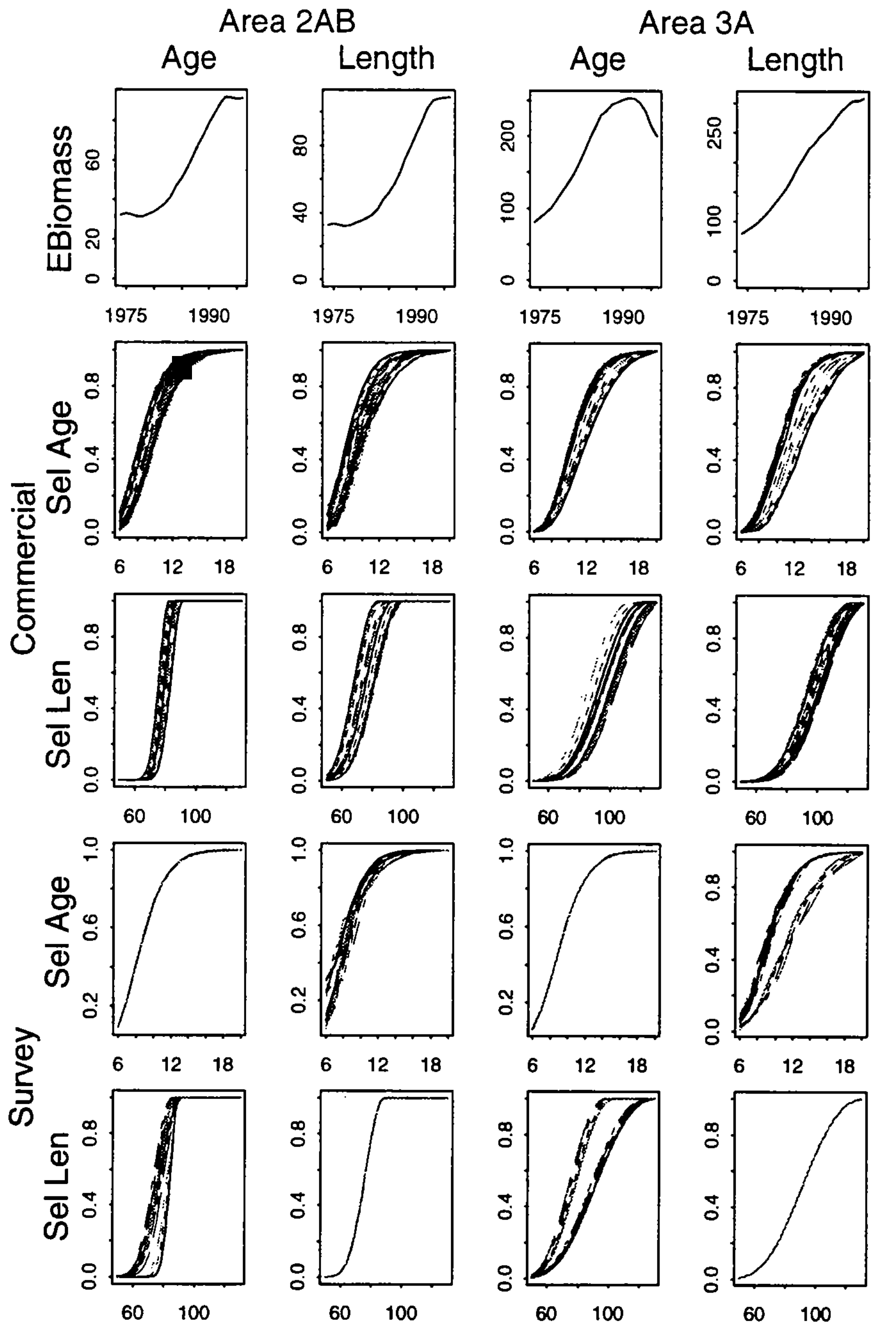

Figure 3. Comparison of exploitable biomass and selectivity estimates in Area 2AB and Area 3A under different model assumptions about survey selectivity. The first and third columns of graphs represent runs where selectivity at age is assumed to be constant in the survey. The second and fourth columns of graphs represent runs where selectivity at length is assumed to be constant in the survey.

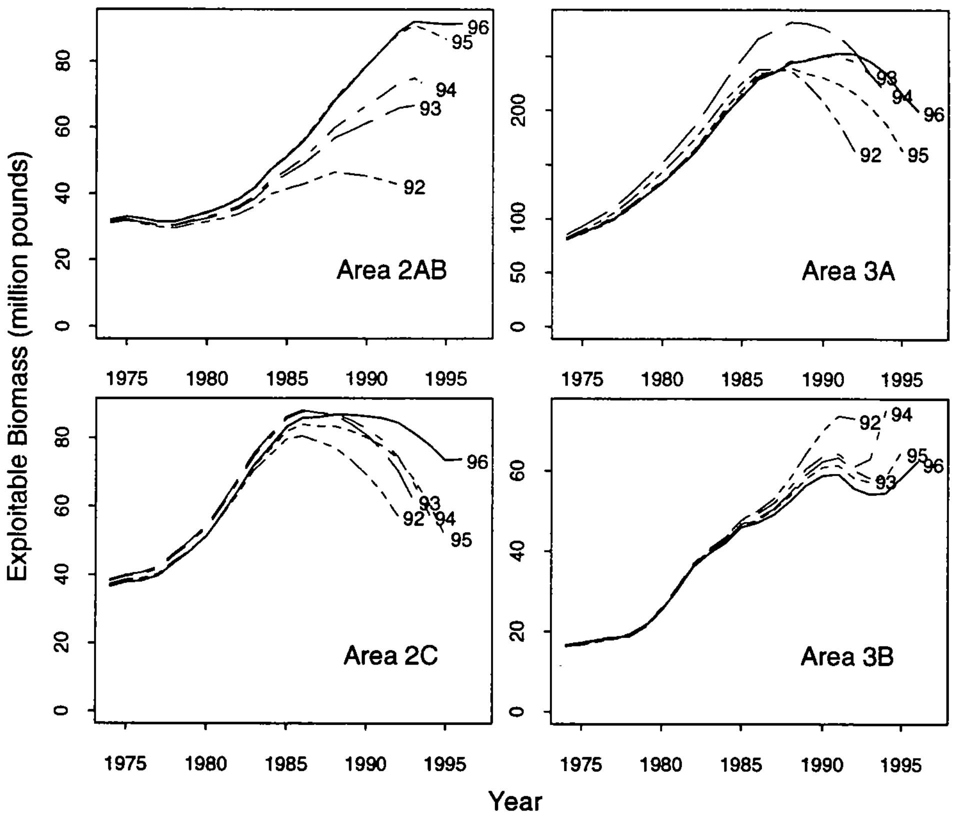

Figure 4. Retrospective plots of exploitable biomass under the constant age-based survey selectivity model. Year shown for each curve indicates the final year of data used for the estimate.

Table 1. Conversion factor for adjusting to circle hook units.

Hook Type	Description	Hook Adjustment
C	Circle Hook	1.000
J	J Hook	0.450
M	Mixed Circle and J Hooks	0.730

Table 2. Weighting factors and variances of random components as defined in Parma and Sullivan (1996).

Weighting Factor	Area 2A-2B	Area 2C	Area 3A	Area 3B	Area 4
$\lambda_{c:c}$	0.25	0.25	0.25	0.25	0.25
$\lambda_{e:c}$	50.00	50.00	50.00	50.00	50.00
$\lambda_{c:\mu}$	0.04	0.04	0.04	0.04	0.04
$\lambda_{c:\sigma}$	0.50	0.50	0.50	0.50	0.50
$\lambda_{s:c}$	0.25	0.25	0.25	0.0	0.0
$\lambda_{s:e}$	0.25	0.25	0.25	0.0	0.0
$\lambda_{s:\mu}$	0.04	0.04	0.04	0.0	0.0
$\lambda_{s:\sigma}$	0.50	0.50	0.50	0.0	0.0
${}_{\mu}\sigma^2$	0.01	0.01	0.01	0.01	0.01
${}_{q}\sigma^2$	0.001	0.001	0.001	0.001	0.001
${}_{sel}\sigma^2_a$	0.0002	0.0002	0.0002	0.0002	0.0002
${}_{v}\sigma^2_t$	0.01–0.03	0.01–0.03	0.01–0.03	0.01–0.03	0.01–0.03
${}_{\chi_{full}}\sigma^2_t$	0.01–0.03	0.01–0.03	0.01–0.03	0.01–0.03	0.01–0.03

Table 3. **IPHC setline survey CPUE in number of halibut per effective skate and associated coefficient of variation.**

	Area 2AB		Area 2C		Area 3A	
Year	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**
1974						
1975						
1976	2.30	0.115				
1977	1.56	0.134			5.56	0.058
1978	1.84	0.121			3.66	0.060
1979					5.25	0.070
1980	2.99	0.100			6.86	0.056
1981	1.86	0.110			10.21	0.061
1982	2.31	0.120	11.28	0.093	11.53	0.063
1983	3.11	0.138	10.89	0.086	9.29	0.039
1984	4.74	0.082	13.21	0.113	13.33	0.038
1985	4.30	0.114	11.53	0.103	15.74	0.035
1986	2.70	0.099	9.44	0.092	9.58	0.065
1987						
1988						
1989						
1990						
1991						
1992						
1993	6.63	0.098			17.94	0.057
1994					19.01	0.052
1995	9.02	0.079			23.10	0.055
1996	9.20	0.090	16.89	0.089	18.54	0.066

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Table 4. **Setline CEY under constant harvest rate policy, 20% exploitation rate, using CAGEAN estimates of exploitable biomass under 1986 CAGEAN estimated fixed selectivities and total (legal-sized and sublegal-sized) bycatch distributed by area in proportion to estimated exploitable biomass.**

	2A	2B	2C	3A	3B	4	Total
Quota	0.52	9.52	9.00	20.00	3.70	5.92	48.66
Catch	0.52	9.53	8.80	19.69	3.81	5.31	47.66
Biomass	3.37	44.81	53.00	77.29	14.21	49.39	242.07
Rate	0.20	0.20	0.20	0.20	0.20	0.20	0.20
CEY	0.67	8.96	10.60	15.46	2.84	9.88	48.41
Sport	0.00	0.66	1.91	4.87	0.02	0.04	7.50
Waste	0.00	0.24	0.18	0.63	0.11	0.14	1.31
Bycatch	0.37	0.19	0.28	1.52	1.08	3.02	6.46
Subsistence	0.00	0.30	0.13	0.10	0.04	0.09	0.66
Total Removals	0.38	1.39	2.50	7.11	1.25	3.29	15.92
Setline CEY	0.30	7.57	8.10	8.35	1.59	6.58	32.49

Table 5. **Setline CEY under constant harvest rate policy, 30% exploitation rate, using CAGEAN estimates of exploitable biomass under 1986 CAGEAN estimated fixed selectivities and total (legal-sized and sublegal-sized) bycatch distributed by area in proportion to estimated exploitable biomass.**

	2A	2B	2C	3A	3B	4	Total
Quota	0.52	9.52	9.00	20.00	3.70	5.92	48.66
Catch	0.52	9.53	8.80	19.69	3.81	5.31	47.66
Biomass	3.37	44.81	53.00	77.29	14.21	49.39	242.07
Rate	0.30	0.30	0.30	0.30	0.30	0.30	0.30
CEY	1.01	13.44	15.90	23.19	4.26	14.82	72.62
Sport	0.00	0.66	1.91	4.87	0.02	0.04	7.50
Waste	0.00	0.24	0.18	0.63	0.11	0.14	1.31
Bycatch	0.19	2.49	2.95	4.30	0.79	2.75	13.46
Subsistence	0.00	0.30	0.13	0.10	0.04	0.09	0.66
Total Removals	0.19	3.69	5.17	9.89	0.96	3.02	22.93
Setline CEY	0.82	9.75	10.73	13.29	3.31	11.79	49.69

Changes to Stock Assessment Methodology: Model Documentation

by

Ana M. Parma and Patrick J. Sullivan

ABSTRACT

A new model for the analysis of halibut catch-at-age and catch-at-length data has been developed to assess halibut stocks. The main difference between this model and CAGEAN, the model used in the annual assessments until 1994, is that the selectivity of the different age-classes is no longer assumed to be constant. Rather, age-specific selectivity is modeled as a function of the size distribution at age and a size-specific selectivity function, both of which may change over time. This document describes the model formulation and the data used in the estimation.

BACKGROUND

Pacific halibut have undergone a rapid reduction in body growth in recent years, with average weight-at-age now half of what it was 20 years ago. This has a number of consequences for halibut stock assessment and management. Stock assessments conducted in the late 1980s and early 1990s used a catch-age model (CAGEAN -- Deriso, Quinn, and Neal 1985) which assumes that fishing mortality can be partitioned into a constant age-specific selectivity component, and a time-dependent full-selection fishing mortality component. This assumption can work well even though fishing gear may be size-selective when fish maintain roughly a constant size-at-age, and when other factors such as type of gear used and targeting practices remain stable. Given the recent changes observed in halibut growth, however, the assumption was considered to be problematic and to severely bias the assessments (Parma and Sullivan 1996). Due to the constant-selectivity assumption, the reduced representation of the younger age classes in the landings of recent years resulted in drastically declining recruitment estimates. Abundance estimates of the corresponding year classes were later adjusted upwards in successive assessments as fish became vulnerable and recruited to the exploitable stock. As a result, stock assessments showed a strong retrospective pattern, in which estimates of exploitable biomass for past years were consistently adjusted upwards in every successive assessment, and while stock levels appeared to be declining rather steeply quotas remained stable. To address these problems, we developed an alternative assessment model which accounts for possible changes in selectivity with age that result from changes in size-at-age.

Here we describe the model and specify the data used for parameter estimation. An outline of the model relative to the dynamics of the age classes represented in the exploited stock is presented first. This component is similar structurally to previous age-structured models used on halibut and so its development should be familiar. This is followed by a reformulation of the selectivity at age as a dynamic function of the underlying size distribution of each age class coupled with a size-based selectivity function. The effect of the legal size on the representation of the different age classes in the catch is modeled explicitly; other parameters controlling the size-based selectivity are allowed to change gradually over time. Finally, a model of how the size-distribution at age changes with time and through the effect of size-selective mortality is developed. Size-selective mortality couples growth and fishing mortality into a size-age dynamic model for each cohort.

MODEL DEVELOPMENT

Abundance Dynamics

The population abundance N of a cohort at age a+1 in year t+1 is related to the cohort's abundance at the previous age a and year t by:

$$N_{a+1,t+1} = N_{a,t}\, e^{-M} \left(1 - {}_{b}H_{a,t}\right)\left(1 - {}_{c}S_{a,t}\left(1 - e^{-F_t}\right)\right) \qquad \text{for} \quad a = 6,\cdots,18 \tag{1}$$

where M is the instantaneous rate of natural mortality, ${}_{c}S_{a,t}$ is selectivity for fish of age a at time t, F_t is the instantaneous commercial fishing mortality at time t for fully-selected fish, and ${}_{b}H_{a,t}$ is the finite rate of bycatch mortality at age a and time t, which results from fisheries targeting on other species. Age classes from age 6 to 20 are considered, where age 20 is actually a "plus" age-group which accumulates all fish of age 20 and older. The notation used in this and subsequent equations is summarized in Appendix 1.

The survivorship component representing the commercial fishery differs from the more familiar Baranoff equation in that fishing is assumed to take place in a short period in the middle of the year, and selectivity at age is modeled as the *fraction* of each age class that is recruited to the exploitable stock and suffers and instantaneous fishing mortality equal to F_t. In other words, we equate selectivity with availability (Ricker 1975) and assume that all available fish are fully vulnerable. In the more familiar formulation selectivity is equated with vulnerability, which affects the instantaneous rate of fishing mortality of different sizes of ages, and differences in availability of different stock components are ignored. Either formulation should be adequate in practice to explain differences in age composition between the population and the catches. The formulation above is computationally straightforward for use in determining effects on survivorship and size-at-age as we shall see later, and it is consistent with the definition of exploitable biomass used to compute recommended catch levels. Note that the selectivity component ${}_{c}S_{a,t}$ is a function of both age and time, unlike standard separable age-structured models which assume that selectivity is a function of age alone and is constant over time.

Assuming in addition that bycatch mortality takes place prior to the fishing season, the catch associated with the directed commercial fishery ${}_{c}C$ follows:

$${}_{c}C_{a,t} = N_{a,t}\, e^{\frac{-M}{2}} \left(1 - {}_{b}H_{a,t}\right) {}_{c}S_{a,t} \left(1 - e^{-F_t}\right) \tag{2}$$

Age composition of the survey catches is given by

$${}_{s}P_{a,t} = \frac{{}_{s}S_{a,t}\, N_{a,t}}{\sum_{i} {}_{s}S_{i,t}\, N_{i,t}}$$

where ${}_{s}S_{a,t}$ is survey selectivity at age and time, parameterized as described below. The arrays of predicted ${}_{c}C_{a,t}$'s and ${}_{s}P_{a,t}$'s are fitted to the observed catches for parameter estimation. Observations on halibut bycatch are available only by size-category, and so a size-based formulation is used to fit the model to those observations. Details are provided in Appendix 2.

Two abundance indices can be used in the estimation: commercial *CPUE* (or fishing effort) and survey *CPUE*. Strict proportionality between biomass and commercial *CPUE* was not assumed, as the catchability of the commercial fleet was allowed to vary according to a random walk model of the form:

$$\ln(Q_{t+1}) = \ln(Q_t) + {}_{q}\varepsilon_t \tag{3}$$

where ${}_{q}\varepsilon_t \sim N(0, {}_{q}\sigma^2)$. The parameter ${}_{q}\sigma^2$ is used to control the amount of year-to-year variation allowed in Q_t. Similar random-walk formulations are used for other model parameters as well, whenever time-series trends are considered likely, but change is expected to be slow. The effective commercial effort can be predicted by assuming that mortality F_t for fully-vulnerable fish is related to fishing effort according to:

$${}_{c}E_t = \frac{F_t}{{}_{c}Q_t} \tag{4}$$

The survey catch in numbers per unit effort can be predicted as

$${}_{s}CPUE_t = {}_{s}Q\ e^{\frac{-M}{2}} \sum_{a} {}_{s}S_{a,t} N_{a,t} \tag{5}$$

where ${}_{s}Q$ is the catchability coefficient for the surveys assumed to be constant.

Selectivity

Selectivity, the relative catchability of fish of different ages and sizes, is usually modeled as a function solely of age. In the so-called separable models (e.g. CAGEAN) age-specific selectivity is assumed to be time-invariant. Such an assumption results in a considerable reduction in the number of parameters that need to be estimated in catch-age analysis. The assumption is valid when capture is an age-dependent process as, for example, when organisms recruit to the fishery at a certain life stage and when the size-at-age is relatively stable with time. The distribution of size at age of Pacific halibut has changed over time, with fish being about 20% smaller (in length) at age now than they were 20 years ago. By not accounting for this change and by assuming that selectivity is constant at age, erroneous time trends can be introduced into the estimation procedure.

There are several ways of addressing this issue. The approach we have chosen attempts to model the change in selectivity at age by tracking how size at age changes in the population and assuming that selectivity at size can change slowly through time. In this manner, we can explicitly incorporate the effect of the minimum size limit on the age composition of the catches, and at the same time allow for trends in size-selectivity that may occur particularly when size-at-age changes.

Given the distribution of size at age a at time t, here represented by log-length X, and a selectivity at size ${}_{c}s_t(X)$, we can compute expected selectivity at age and time by integration over the size distribution of fish at age a at time t:

$$ {}_{c}S_{a,t} = \int_{-\infty}^{\infty} {}_{c}s_t(X)\varphi\left(X \mid \mu_{a,t}, \sigma^2_{a,t}\right)\mathrm{d}X \exp\left\{{}_{\mathrm{sel}}\varepsilon_{a,t}\right\} \tag{6} $$

where the function $\varphi(X|\mu_{a,t},\sigma^2_{a,t})$ represents the probability that a fish of age a at time t is of log-length X, assumed to be Gaussian with mean $\mu_{a,t}$ and variance $\sigma^2_{a,t}$. We allow for small random deviations in selectivity at age by assuming that ${}_{\mathrm{sel}}\varepsilon_{a,t} \sim N\left(0, {}_{\mathrm{sel}}\sigma_t^2\right)$ for ages 6-10; selectivities of age classes older than 10 are as predicted from their size-distribution coupled with the size-based selectivity (i.e. ${}_{\mathrm{sel}}\varepsilon_{a,t}=0$ for $a > 10$). Selectivity at size for the commercial fishery at time t can be represented in terms of the legal size (81 cm) and two parameters (X_t^{full} and ν_t):

$$ {}_{c}s_t(X) = \begin{cases} 0, & \text{for} \quad X < \ln(81) \\ \exp\left\{\dfrac{-\left(X - X_t^{\mathrm{full}}\right)^2}{2\nu_t}\right\} & \text{for} \quad \ln(81) \le X \le X_t^{\mathrm{full}} \\ 1, & \text{for} \quad X > X_t^{\mathrm{full}} \end{cases} \tag{7} $$

Selectivity is zero for fish smaller than the legal size, increases according to a half Gaussian curve scaled to reach a maximum of one at $X = X_t^{\mathrm{full}}$, the size (log-length) at full selectivity, and equals one beyond X_t^{full}. Equations (1), (6), and (7) imply that discarded sublegal fish are assumed to survive with probability equal to one. The parameters X_t^{full} and ν_t are allowed to change over time assuming a random walk model with constraints in the variances of the year-to-year deviations.

$$ \begin{aligned} X_{t+1}^{\mathrm{full}} &= X_t^{\mathrm{full}} + {}_{X\mathrm{full}}\varepsilon_t \qquad \text{where } {}_{X\mathrm{full}}\varepsilon_t \sim N\left(0, {}_{X\mathrm{full}}\sigma_t^2\right) \\ \ln(\nu_{t+1}) &= \ln(\nu_t) + {}_{\nu}\varepsilon_t \qquad \text{where } {}_{\nu}\varepsilon_t \sim N\left(0, {}_{\nu}\sigma_t^2\right) \end{aligned} \tag{8} $$

The formulation is similar to that used for $\ln(Q_t)$ except that the variances for the normal deviations are year-specific. This was done so as to allow selectivity to change more when growth rates are changing rapidly; very little change was allowed during periods of relatively stable size at age.

The size-selectivity of the longline survey is assumed to have the same functional form except for the discontinuity at the legal size limit which does not apply to the surveys. Two model formulations were considered: (a) selectivity parameters are constant over time and so surveys are assumed to index population abundance by size-category; (b) size-selectivity parameters change over time so that the coupling of changing size at age and changing survey size-selectivity results in constant age-specific selectivities (i.e., ${}_{s}S_{a,t} = {}_{s}S_a$). The first formulation would be more appropriate if survey selectivity reflected mostly the properties of the fishing gear as it interacts with fish of different sizes. The second would be preferred if the availability of fish of different age classes on the surveyed grounds were the dominant factor in determining survey selectivity.

Growth Dynamics

The selectivity and size distribution in the catch of fish of a given age-class depend on their size distribution in the population. Thus, the growth dynamics must be modeled as well. In the absence of size-selective mortality, the median length-at-age $m_{a,t} = \exp(\mu_{a,t})$ is assumed to propagate according to

$$m_{a+1,t+1} = \alpha_t + \beta\, m_{a,t} \qquad \text{for } a = 6,7,\cdots \tag{9}$$

with time-varying initial size $m_{6,t}$ and intercept α_t. When the growth coefficient β is less than one, this representation corresponds to a von Bertalanffy model (applied to median length at age) with a time trend in the parameter corresponding to the asymptotic length $L_\infty = \alpha_t/(1-\beta)$, and a time trend in size at age 6 (the age of recruitment). When $\beta = 1$, growth is linear with time-varying slope and initial size. The time-series trend in the mean log-length at recruitment $\mu_{6,t}$ is modeled as a random walk

$$\mu_{6,t+1} = \mu_{6,t} + {}_{\mu}\varepsilon_t \tag{10}$$

where ${}_{\mu}\varepsilon_t \sim N(0, {}_{\mu}\sigma^2)$. The growth intercept α_t is modeled as a cubic polynomial function of t.

The variance in log-length at age $\sigma^2_{a,t}$ is linked to the mean $\mu_{a,t}$ by

$$\sigma^2_{a,t} = \left[c + d\mu_{a,t}\right]^2 \tag{11}$$

If d is set to zero, $\sigma_{a,t}$ is constant and equal to c, so that the coefficient of variation of length-at-age is constant and equal to $CV[L] = \sqrt{\exp(c^2) - 1} \cong c$. The variance relationship is assumed to hold even when $\mu_{a,t}$ changes due to size-selective mortality.

The effect of size-selective mortality on the size distribution at age is incorporated by adjusting the mean log-length at age, from $\mu_{a,t}$ (the mean prior to the fishing season) to $\mu^+_{a,t}$ (the mean at a time immediately following fishing). Realistically, the nature of the distribution should also be affected, but we assume that a Gaussian function is still an adequate approximation of the distribution of log-length after the fishery. We let the variance follow again as the square of a linear function of the mean as stated above. If the means change as a result of changes either in the environment or due to size selection, the variances will change as well in a corresponding manner.

Because larger fish are selectively removed by the fishery, $\mu^+_{a,t}$ is smaller than $\mu_{a,t}$. The mean log-length in the population after fishing has taken place is given by:

$$\mu^+_{a,t} = \frac{\int_{-\infty}^{\infty} X\left(1 - {}_c s_t(X)\, {}_c H_t\right)\varphi\left(X \mid \mu_{a,t}, \sigma^2_{a,t}\right)\mathrm{d}X}{\int_{-\infty}^{\infty} \left(1 - {}_c s_t(X)\, {}_c H_t\right)\varphi\left(X \mid \mu_{a,t}, \sigma^2_{a,t}\right)\mathrm{d}X} \tag{12}$$

Sullivan, P.J., Parma, A.M., 1997. Population assessment, 1996. IPHC Rep. Assess. Res. Act. 1996., pp. 81–130.

where $(1-{}_cs_t(X)\,{}_cH_t)$ represents the survivorship from fishing with ${}_cH_t = (1 - \exp(-F_t))$ representing the harvest fraction and $\varphi(X|\mu_{a,t},\sigma^2_{a,t})$ the probability density function of log-length X as a function of the prior mean $\mu_{a,t}$ and variance $\sigma^2_{a,t}$. The denominator of the equation above corresponds to the fraction of fish of age a that survive after the fishing season.

The median length at age $a+1$, prior to the next fishing season, is predicted based on $m^+_{a,t} = \exp(\mu^+_{a,t})$ as:

$$m_{a+1,t+1} = \alpha_t + \beta\, m^+_{a,t}. \tag{13}$$

The corresponding mean of log-length prior to the next fishing is $\mu_{a+1,t+1}=\ln(m_{a+1,t+1})$, which is used to calculate $\sigma^2_{a+1,t+1}$ as in equation (11). The two parameters that specify the pdf of X prior to the fishing season at time $t+1$ are thus obtained and a new recursive cycle can be applied.

Given that the pdf of the log-length-at-age for a cohort is represented by $\varphi(X|\mu_{a,t},\sigma^2_{a,t})$, the mean and variance of the log-length-at-age in the catch can be predicted as the first and adjusted second moments normalized by the average selectivity at age:

$$
\begin{aligned}
{}_c\mu_{a,t} &= \frac{\int_{\ln(81)}^{\infty} X\ {}_cs_t(X)\varphi\left(X|\mu_{a,t},\sigma^2_{a,t}\right)\mathrm{d}X}{\int_{\ln(81)}^{\infty} {}_cs_t(X)\varphi\left(X|\mu_{a,t},\sigma^2_{a,t}\right)\mathrm{d}X}\\
{}_c\sigma^2_{a,t} &= \frac{\int_{\ln(81)}^{\infty} X^2\ {}_cs_t(X)\varphi\left(X|\mu_{a,t},\sigma^2_{a,t}\right)\mathrm{d}X}{\int_{\ln(81)}^{\infty} {}_cs_t(X)\varphi\left(X|\mu_{a,t},\sigma^2_{a,t}\right)\mathrm{d}X} - {}_c\mu^2_{a,t}
\end{aligned}
\tag{14}$$

Note that the integration is done across all sizes above the legal size limit (ln(81)). Similar equations were used to predict the mean log-length at age ${}_s\mu_{a,t}$ and the variance of log-length at age ${}_s\sigma^2_{a,t}$ for survey catches; but because survey selectivity is not restricted by the legal size limit, the lower limit of integration is set to $-\infty$. The specific assumptions made about the pdf of X and the shape of $s_t(X)$ lead to a numerically efficient algorithm, as selectivities at age $S_{a,t}$, and the moments of the distribution of X in the catch and among the survivors can be expressed as a function of standard Gaussian cumulative distributions.

ESTIMATION

Objective Function

Model predictions may be compared to three types of observations: catch at age and time in the catches, commercial effort at time or *CPUE*, and the mean and variance of log-length at age and time in the catches. This information is collected from the sampled commercial fishery for all areas, and for the longline surveys which are available only for some areas and years. Information on halibut bycatch is available for all areas and years as total bycatch in numbers by size category. The size composition of the current year's bycatch is not available for the assessment and so the previous year's sizes are used. Bycatch data are treated as being free of error and bycatch numbers are subtracted out from each cohort based on the predicted age composition at size (see Appendix 2). Thus the bycatch process is not parameterized and the observations are not "fitted" by the model.

Parameters in Table 1 are estimated separately for each area by maximizing the likelihood of the available observations while penalizing the variability of some of the stochastic variables modeled by specifying their variances *a priori*. Log-normal errors are assumed throughout and the weighted residual sum of squares *RSS* is computed by summing the following components:

Catch-at-age equations:

$$RSS_{\mathrm{c:c}} = \lambda_{\mathrm{c:c}} \Sigma_a \ \Sigma_t \left[\frac{\ln({}_{\mathrm{c}}C^{\mathrm{obs}}{}_{a,t}) - \ln({}_{\mathrm{c}}C_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{c}}C^{\mathrm{obs}}{}_{a,t})\right)} \right]^2$$

$$RSS_{\mathrm{s:c}} = \lambda_{\mathrm{s:c}} \Sigma_a \ \Sigma_t \left[\frac{\ln({}_{\mathrm{s}}P^{\mathrm{obs}}{}_{a,t}) - \ln({}_{\mathrm{s}}P_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{s}}P^{\mathrm{obs}}{}_{a,t})\right)} \right]^2$$

Effort equations:

$$RSS_{\mathrm{c:e}} = \lambda_{\mathrm{c:e}} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\mathrm{c}}E^{\mathrm{obs}}{}_{t}) - \ln({}_{\mathrm{c}}E_{t})}{\mathrm{sd}\left(\ln({}_{\mathrm{c}}E^{\mathrm{obs}}{}_{t})\right)} \right]^2$$

$$RSS_{\mathrm{s:e}} = \lambda_{\mathrm{s:e}} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\mathrm{s}}CPUE^{\mathrm{obs}}{}_{t}) - \ln({}_{\mathrm{s}}CPUE_{t})}{\mathrm{sd}\left(\ln({}_{\mathrm{s}}CPUE^{\mathrm{obs}}{}_{t})\right)} \right]^2$$

Length equations:

$$RSS_{\mathrm{c:\mu}} = \lambda_{\mathrm{c:\mu}} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\mathrm{c}}\mu^{\mathrm{obs}}{}_{a,t}) - \ln({}_{\mathrm{c}}\mu_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{c}}\mu^{\mathrm{obs}}{}_{a,t})\right)} \right]^2$$

$$RSS_{\mathrm{c:\sigma}} = \lambda_{\mathrm{c:\sigma}} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\mathrm{c}}\sigma^2{}_{a,t}{}^{\mathrm{obs}}) - \ln({}_{\mathrm{c}}\sigma^2{}_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{c}}\sigma^2{}_{a,t}{}^{\mathrm{obs}})\right)} \right]^2$$

$$RSS_{\mathrm{s:\mu}} = \lambda_{\mathrm{s:\mu}} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\mathrm{s}}\mu^{\mathrm{obs}}{}_{a,t}) - \ln({}_{\mathrm{s}}\mu_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{s}}\mu^{\mathrm{obs}}{}_{a,t})\right)} \right]^2$$

$$RSS_{\mathrm{s:\sigma}} = \lambda_{\mathrm{s:\sigma}} \Sigma_a \Sigma_t \left[\frac{\ln({}_{\mathrm{s}}\sigma^2{}_{a,t}{}^{\mathrm{obs}}) - \ln({}_{\mathrm{s}}\sigma^2{}_{a,t})}{\mathrm{sd}\left(\ln({}_{\mathrm{s}}\sigma^2{}_{a,t}{}^{\mathrm{obs}})\right)} \right]^2$$

Thus the total sum of squares is given as

$$RSS = RSS_{c:c} + RSS_{s:c} + RSS_{c:e} + RSS_{s:e} + RSS_{c:\mu} + RSS_{s:\mu} + RSS_{c:\sigma} + RSS_{s:\sigma}$$

The negative log-likelihood of the observations, up to additive constants, is

$$L = 0.5\, n_{\text{obs}} \log(RSS)$$

where n_{obs} is the total number of observations. Parameter estimates are obtained by minimizing the objective function

$$f = L + \text{penalties}$$

where the penalties correspond to prior assumptions made about some of the stochastic processes involved, namely, time-series trends in catchability (equation (3))

$$PSS_q = 0.5 \sum_t \frac{{}_q\varepsilon_t^2}{{}_q\sigma^2}$$

time-series trends in mean log-length at age 6 (equation (10)),

$$PSS_\mu = 0.5 \sum_t \frac{{}_\mu\varepsilon_t^2}{{}_\mu\sigma^2}$$

time-series trends in the parameters of the size-selectivity function $s_t(X)$ for the commercial fishery and the survey when appropriate (equation (8)),

$$PSS_{X\text{full}} = 0.5 \sum_t \frac{{}_{X\text{full}}\varepsilon_t^2}{{}_{X\text{full}}\sigma_t^2} \quad \text{and} \quad PSS_\nu = 0.5 \sum_t \frac{{}_\nu\varepsilon_t^2}{{}_\nu\sigma_t^2}$$

and random deviations in selectivity at age affecting the youngest age classes (equation (6)),

$$PSS_{\text{sel}} = 0.5 \sum_{a,t} \frac{{}_{\text{sel}}\varepsilon_{a,t}^2}{{}_{\text{sel}}\sigma^2} \quad \text{for} \quad a = 6, \cdots, 10$$

The penalties term in the objective function is thus

$$\text{penalties} = PSS_q + PSS_\mu + PSS_{X\text{full}} + PSS_\nu + PSS_{\text{sel}}$$

The model was implemented using AD Model Builder (Otter Research Ltd. 1994) which uses automatic differentiation to minimize the objective function. The minimization is conducted in steps or phases of increasing complexity as specified by the user.

Weighting Criteria

Relative weights are used to control the level of influence of the different *RSS* components and penalties on the model fit. Weights affecting residual sum of squares (components of *RSS*) should correspond to the level of information present in the data. It should be noted that two methods for controlling the emphasis that the data receive in the estimation are available. First, a relative weighting of observations of the same type (e.g. within catch, effort, or length) is incorporated on an observation-by-observation basis. We used empirically-computed coefficients of variation of the statistics whenever possible. Because errors are assumed to be log-normally distributed, the coefficients of variation of the observations approximate the standard deviations of the corresponding log-transformed variables. Catch-at-age observations were weighted based on the coefficient of variation of the age proportions in the market sample data. Residuals corresponding to the mean and variance of log-length in the commercial catch were weighted using the coefficient of variation of the estimated moments determined from bootstrap calculations; those from the survey catch were weighted using coefficients of variation determined from standard equations based on simple random sampling. Coefficient of variations for age proportions and *CPUE* in the surveys were estimated assuming simple random sampling. Second, a differential weighting of data of different types can be effected through the λ's, as in previous model formulations. Sampling-based measures of uncertainty do not normally capture all the sources of variability present in the process, so λ's lower than one were used in all cases to increase the variance assigned to the different components in an *ad hoc* manner.

Number of Observations

The availability of survey information varies depending on the regulatory area: areas 2B and 3A were surveyed more often from 1974 through 1986, and since 1993, while other areas were surveyed more sporadically; no longline surveys were conducted from 1987 to 1992. Observations for the commercial fishery are available for all years and age groups modeled, except for effort data for year 1983, when the commercial fleet was in the process of switching from using J hooks to using the more efficient circle hooks. If there are A age groups and T years, there typically will be $A \times T$ observations on commercial catch, $A \times T$ observations on log-length at age, $A \times T$ observations on variance of log-length at age, and T-1 observations on fishing effort. For the surveys, there will be a maximum of $A \times (T-7)$ observations on each the catch-at-age, and the mean and variance of log-length at age, and T-6 *CPUE* observations. Ageing of survey samples collected in the current year is not completed at the time of the assessment, only survey *CPUE* is available. Under this scenario there are $(6 \times A \times T) - (A \times 7 \times 3) + 2 \times T - 7$ observations. This amounts to 1774 observations for data covering 1974 through 1996.

Fundamental Model Parameters

In order to define a set of estimable parameters and to make sure that the estimates have reasonable values, certain parameters must be fixed while others must be estimated under a specified set of constraints. The natural mortality parameter is one such parameter which is typically fixed. We set it here to $M = 0.2$ and assume it to be constant over all time periods and age-classes modeled. We plan to relax this assumption in the future and estimate M jointly using prior information.

The initial conditions for size at age in the population at the start, $m_{a,1}$, $a \in \{6,\ldots,20+\}$, are constrained to follow a three parameter von Bertalanffy model. The growth coefficient β is constrained to be between 0.5 and one, the log-length at full selectivity X_t^{full} in year t=1 is constrained to be less than ln(130). The variance of log-length at age is assumed to be constant by setting d=0 in equation (11). Estimated parameters are shown in Table 1, although the actual minimization is conducted over a different parameter space. Re-parameterizations are used to reduce the correlation among estimated parameters, and transformations are used in some cases to constrain parameter values; the latter is done automatically by AD Model Builder when bounded parameters are specified.

Table 1. Estimated model parameters

Parameters		Number
$N_{6,t}$	recruitment	T
$N_{a,1}$	initial abundance	A-1
F_t	fishing mortality	T
${}_cQ_t$	commercial catchability	T
${}_sQ$	survey catchability	1
X_t^{full} and v_t	size-selectivity	$2 \times T + 2 \times$ number of surveys (or 2 if surveys have constant size-selectivity)
${}_{\text{sel}}\varepsilon_{a,t}$	deviations in selectivity at age	$(10\text{-}5) \times T$
$\mu_{6,t}$	mean log-length at age 6	T
α_0 and β_0	initial log-length at age	2
α_t	intercept of growth equation	T-1
β	slope of growth equation	1
c	coefficient of variation of size at age	1

Derived Parameters

Derived parameters of management interest are the exploitable biomass

$$B_t = \sum_a {}_cS_{a,t}\, w_{a,t}\, N_{a,t}$$

where $w_{a,t}$ are smoothed weights at age in the commercial catch, and the exploitable biomass at the beginning of the year following the assessment, which is predicted as

$$B_{T+1} = \sum_{a=6}^{19} {}_cS_{a+1,t}\, w_{a+1,t}\, N_{a,t}\, e^{-M} \left(1 - {}_bH_{a,t}\right)\left(1 - {}_cS_{a,t}\ {}_cH_t\right) +$$

$${}_cS_{20,t}\, w_{20,t}\, N_{20,t}\, e^{-M} \left(1 - {}_bH_{20,t}\right)\left(1 - {}_cS_{20,t}\ {}_cH_t\right) + {}_cS_{6,t}\, w_{6,t}\, \overline{N}_{6,\cdot}.$$

where $\overline{N}_{6,\cdot}$ is the average of the age-6 abundance estimates for the T years covered by the assessment. This last term has no effect on projected exploitable biomass because ${}_cS_{6,t}$ is close to zero.

Uncertainty of Parameter Estimates

AD Model Builder provides standard deviations of estimated and derived model parameters as specified by the user. The covariance matrix of the parameter estimates is estimated by inverting the Hessian matrix and using the Delta method in the case of derived parameters, such as predicted exploitable biomass. AD Model Builder can also compute likelihood profiles for selected parameters of interest.

Future Developments

The main aspects that will be explored during 1997 are:

the effects of using robust likelihood formulations.
the estimation of M using informative priors.
the use of likelihood profiles and other representations of the uncertainty of parameter estimates.

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APPENDIX 1: NOTATION

Prescripts:	
b	Bycatch
c	Commercial
s	Survey
Subscripts:	
a	Age
t	Time
l	Length category
Superscripts:	
obs	Observation variable
+	Time immediately after fishing
Catch and Abundance:	
${}_{c}C_{a,t}$	Commercial catch at age and time
${}_{c}C^{obs}_{a,t}$	Observed commercial catch at age and time
${}_{c}P_{a,t}$	Age composition in survey catches at time t
${}_{c}P^{obs}_{a,t}$	Observed age composition in survey catches at time t
${}_{b}C^{obs}_{l,t}$	Observed bycatch at size category and time
${}_{s}CPUE_{t}$	CPUE at time for survey
${}_{s}CPUE^{obs}_{t}$	Observed CPUE at time for survey
${}_{c}E_{t}$	Fishing effort at time for commercial fishery
${}_{c}E^{obs}_{t}$	Observed fishing effort at time for commercial fishery
F_{t}	Instantaneous fishing mortality at time
${}_{b}H_{a,t}$	Finite rate of bycatch mortality at age and time
${}_{b}H_{l,t}$	Finite rate of bycatch mortality at size category and time
${}_{c}H_{t}$	Harvest fraction of fully selected fish $=1-\exp(-F_t)$
$N_{a,t}$	Population numbers at age and time
M	Instantaneous natural mortality
${}_{c}Q_{t}$	Catchability for commercial fishery
${}_{s}Q$	Catchability for survey
${}_{c}s_{t}(X)$	Selectivity of fish of log-length X in the commercial fishery in year t
${}_{s}s_{t}(X)$	Selectivity of fish of log-length X in the survey in year t
${}_{c}S_{a,t}$	Selectivity of fish of age a in the commercial fishery in year t
${}_{s}S_{a,t}$	Selectivity of fish of age a in the survey in year t
v_{t}	Variance-like parameter of size-selectivity $s_t(X)$
X^{full}_{t}	Log-length beyond which fish are fully-selected
Size and Growth:	
a_{t}	Intercept of the recursive growth equation
b	Slope of the recursive growth equation
c	Intercept of standard deviation relative to mean log-length at age
d	Slope of standard deviation relative to mean log-length at age
$m_{a,t}$	Median length at age in the population in year $t = \exp(\mu_{a,t})$

$m^{-}_{a,t,}$	Median length of fish of age *a* surviving the fishing season in year *t*
$\mu_{a,t}$	Mean log-length at age in the population in year *t*
$\mu^{+}_{a,t}$	Mean log-length of fish of age *a* surviving the fishing season in year *t*
${}_{c}\mu_{a,t}$	Mean log-length at age in the commercial catch in year *t*
${}_{s}\mu_{a,t}$	Mean log-length at age in the survey catch in year *t*
${}_{c}\mu^{obs}_{a,t}$	Observed mean log-length at age and time in the commercial catch
${}_{s}\mu^{obs}_{a,t.}$	Observed mean log-length at age and time in the survey catch
$\varphi(X\|\mu,\sigma^2)$	Gaussian pdf with mean μ and variance σ^2
$\sigma^2_{a,t}$	Variance of log-length at age in the population in year *t*
${}_{c}\sigma^2_{a,t}$	Variance of log-length at age in the commercial catch in year *t*
${}_{s}\sigma^2_{a,t}$	Variance of log-length at age in the survey catch in year *t*
${}_{c}\sigma^{2\ obs}_{a,t}$	Observed variance of log-length at age and time in the commercial catch
${}_{s}\sigma^{2\ obs}_{a,t}$	Observed variance of log-length at age and time in the survey catch
X	Log-length

Weighting Factors and variances of random components:

$\lambda_{c:c}$	Weight for commercial log-catch-at-age residuals
$\lambda_{e:c}$	Weight for commercial effort residuals
$\lambda_{c:\mu}$	Weight for commercial mean log-length residuals
$\lambda_{c:\sigma}$	Weight for commercial variance of log-length residuals
$\lambda_{s:c}$	Weight for survey log-catch-at-age residuals
$\lambda_{s:e}$	Weight for survey *CPUE* residuals
$\lambda_{s:\mu}$	Weight for survey mean log-length residuals
$\lambda_{s:\sigma}$	Weight for survey variance of log-length residuals
${}_{\mu}\sigma^2$	Variance of ${}_{\mu}\varepsilon_t$, the time-series deviations affecting $\mu_{6,t}$
${}_{q}\sigma^2$	Variance of ${}_{q}\varepsilon_t$, the time-series deviations of log-catchability
${}_{sel}\sigma^2_a$	Variance of selectivity deviations ${}_{sel}\varepsilon_{a,t}$
${}_{\nu}\sigma^2_t$	Variance of ${}_{\nu}\varepsilon_t$, the time-series deviations affecting selectivity parameter ν_t
	Variance of the deviations affecting selectivity parameter X^{full}_t

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APPENDIX 2: BYCATCH FORMULATION

Bycatch data are only available by size category and so a size-based formulation is used to account for the mortality of halibut of legal size induced by bycatch. Total abundance by 10-cm size category present prior to the fishing season is first computed for each year t by summing across age classes. Assuming that bycatch data are observed without error, and that bycatch mortality occurs just prior to commercial fishing, the finite rate of mortality induced by bycatch on a given size category l, denoted as ${}_{b}H_{l,t}$ is given by

$$ {}_{b}H_{l,t} = \frac{{}_{b}C^{\text{obs}}_{l,t}}{\sum\limits_{a} N_{a,t}\, e^{\frac{-M}{2}} \int\limits_{X\in l} \varphi\left(X|\mu_{a,t},\sigma^{2}_{a,t}\right)dX} $$

where the fraction of each age class that corresponds to each size category is obtained by integrating $\varphi(X|\mu,\sigma^2)$. The finite rate of bycatch mortality for each age class a in year t is computed by apportioning the observed bycatch at size, ${}_{b}C^{\text{obs}}_{l,t}$, to the different age classes in proportion to their abundance, and summing across size categories. Equivalently,

$$ {}_{b}H_{a,t} = \sum_{l} {}_{b}H_{l,t} \int\limits_{X\in l} \varphi\left(X|\mu_{a,t},\sigma^{2}_{a,t}\right)dX $$

POPULATION ASSESSMENT, 1995

by

Patrick J. Sullivan and Ana M. Parma

INTRODUCTION

IPHC staff annually provide an assessment of stock status on Pacific halibut. Last year, we noted that certain trends in the biology of the halibut stock and in the prosecution of the fishery would force us to re-evaluate some assumptions made in the assessment. Since that time, modifications to the assessment model were made to address some of these issues. The Pacific halibut stock assessment procedure now incorporates growth as well as directed harvest mortality and recruitment (Parma and Sullivan, 1995). The procedure utilizes catch at age, length at age, and weight at age from both commercial and IPHC survey landings (Figure 1). These data were re-estimated this year for all areas and years (Clark, personal communication). The stock assessment procedure also includes, as it has in the past, commercial catch per unit effort recorded from IPHC logbook data. The newly developed procedure is useful in interpreting some trends that potentially bias assessments, although certain aspects of the procedure need to be more thoroughly explored and other components need further development. It is in this context that this year's assessment is given. Results from the new procedure are examined with reference to the previous procedure, general trends are noted in catch statistics and assessment results, and developments slated for the upcoming year are outlined.

STOCK ASSESSMENT

The Pacific halibut stock assessment (under both current and previous methods) continues to show a downward trend in stock biomass (Figures 2-8). Both procedures reflect trends caused by strong year classes passing through the fishery, followed by poorer year classes resulting from poorer recruitment. The current method follows changing trends in growth, and takes account of changes in gear selectivity which are likely to occur concurrently. In areas where this change in size is great (e.g. Areas 3A and 3B), the result is generally an increase in the current absolute level of abundance as the assumption made in previous assessments likely underestimated stock size as was indicated in last year's assessment. Unfortunately, it is this *absolute* level of abundance for which greater caution in interpreting results must be exercised, as these estimates are more sensitive to assumptions made in the procedures. For this reason, and to provide some perspective on the differences between estimates, time trends, and other aspects of this change in methodology, both the assessment under the previous model and the assessment under the current model are given. First, however, we shall examine commercial and survey catch statistics.

Sullivan, P.J., Parma, A.M., 1996. Population assessment, 1995. IPHC Rep. Assess. Res. Act. 1995., pp. 79–107.

Commercial catch per unit effort (CPUE) trends are on the upturn this year, with a coast-wide increase of 12% from 244.2 pounds per skate in 1994 to 282.7 pounds per skate in 1995. Last year's coast-wide values were the lowest since the early 1980's when the stock was believed to have first begun rebuilding. CPUE on an area-by-area basis increased 23% in 2A, 5% in 2B, 25% in 2C, 13% in 3A, 11% in 3B and 23% in 4. IPHC systematic survey CPUE has also shown an upturn in recent years with a 40% increase in Area 2B from 119 pounds per skate in 1993 to 167 pounds per skate in 1995, and with an 18% increase in Area 3A from 313 pounds per skate in 1994 to 370 pounds per skate in 1995. Survey CPUE in Area 2B has more than doubled since the mid-1980s averaging 57 pounds per skate in 1985-1986 compared with the 143 pounds per skate average for the two most recent surveys. On the other hand, survey CPUE in Area 3A has dropped on average over that same time period averaging 439 pounds per skate over the years 1984-1986 while averaging 332 pounds per skate during 1993-1995. Survey and commercial CPUE estimates are shown in Figures 9 and 10 with stock estimates from the current size-age based procedure for Areas 2B and 3A. Note the consistency between the survey and the commercial CPUE indexes for the two areas. This suggests that in a broad sense both are tracking the same pattern in the fishery.

Trends in halibut size at age may be examined using the 1994 to 1995 change in weight-at-age of twelve-year-old fish in the catch: 23.4 to 26.0 pounds in 2A, 23.5 to 25.5 pounds in 2B, 27.2 to 40.3 pounds in 2C, 25.0 to 25.5 pounds in 3A, 31.4 to 25.6 pounds in 3B, and 34.2 to 28.4 pounds in 4. Figures 11 and 12 show general trends in size at age in the commercial catch for Area 2B and Area 3A. Note that statistics given on an age-specific basis are generally more variable than stock-wide statistics. Nevertheless, it appears that weight-at-age may be leveling off or reversing in trend in some areas and in particular among younger age classes.

Exploitable stock biomass trends and total recruitment biomass can be examined relative to commercial catch-per-unit-effort trends coast-wide and area by area in Figures 2-8. The current size-age based estimates (shown in black) can be contrasted with previous CAGEAN estimates (shown in gray). The size-age based estimates better represent the changing trends in the halibut fishery (Parma and Sullivan, 1995). However, further development of this approach must take place before it can accurately be used in setting absolute harvest limits. Biomass trends, however, can continue to be monitored using this approach. Exploitable biomass trends continue to show a downward trend coast-wide and in all areas except Gulf of Alaska, where in Areas 3A and 3B strong recruitment trends indicate the beginning of an upturn. Estimates under the current size-age based procedure generally indicate a historical decline that is not nearly as steep as that shown by estimates calculated using previous methods.

The 1987 year class, indicated as a strong year class in abundance as pre-recruits in National Marine Fisheries Service trawl surveys, appears now to be entering the fishery. The presence of this year-class is most apparent in IPHC Areas 3A and 3B although some indication of it can be seen in other areas. Recruitment biomass estimates, it must be noted, are highly variable in the most recent years, when cohorts have been observed only once or twice in the fishery. Furthermore, given the generally smaller size of these fish, the percentage available for harvest is estimated to be very low, which in turn implies that the estimates themselves may be quite unreliable as only a very small fraction is observed in the catch. Recruitment estimates for the most recent year were constrained to remain below maximum levels of estimated recruitment abundance obtained for earlier years. An additional consequence of the reduced size-at-age is that the overall contribution to exploitable biomass of these year classes is likely to be smaller in

Sullivan, P.J., Parma, A.M., 1996. Population assessment, 1995. IPHC Rep. Assess. Res. Act. 1995., pp. 79–107.

the long term than the strong year classes of larger individuals observed in the mid-1980s. Figure 13 highlights this contrast between the biomass of 8-year-old halibut estimated to be in the population and the portion of that biomass available to fishing (exploitable biomass). The upturn in recruitment, such as it is, is a positive sign for the fishery.

In last year's assessment, a contrast in signals was noted in the assessment for Area 2B. Changes in catchability were cited as a likely cause for the increase in CPUE observed in the fleet relative to the decline in biomass estimated for the stock. Subsequent analysis and additional IPHC scientific setline survey data now suggest that whatever changes did result from the implementation of the IVQ management system their influence on IPHC statistics is not broadly apparent. Figure 14 compares CPUE from the commercial fleet with and without adjusting for changes in fleet dynamics that occurred before and after initiation of the halibut individual vessel quota in British Columbia. While vessel movement by area and over season as represented in the analysis was noticeable and significant, the net effect was not sufficient to explain away an increasing trend observed in CPUE. Recent survey CPUE data also indicate that this change occurred independent of fleet dynamics. Inspection of catch-at-age data from the area for the years 1993-1994 now suggests several year-classes may be stronger (as 11-15 year-old fish) than what earlier estimates of recruitment may have indicated. One explanation for this is that halibut recruited later to the fishery. Another is that targeting on small fish may have shifted over that period. Still another is that halibut, over that time period were actually too small to be represented as recruits. Such scenarios, while still only hypotheses, would likely explain the conflict seen in the fit to the data and possibly raise estimated biomass levels for that area. Some of these possibilities will be explored in the upcoming year.

Estimated exploitable biomass levels have increased in Area 4 this year under both assessment procedures, thus reflecting information in the data used by both. A significant upturn in the Area 4 CPUE index, as indicated in the 1995 value, accounts for about half the overall increase, while updates to the age-composition data made while re-evaluating and re-estimating the base-line market sample data for the size-age based estimation procedure accounts for the rest. A retrospective analysis of Area 4 exploitable biomass estimates (Figure 15) indicates greater variability in the estimate for the most recent year and the performance of the procedure (as indicated by various fitting criteria) is the poorest of any IPHC area. This may in part be due to the current lack of survey information available for that Area. It is likely that lower exploitation levels in the late 1970s and early 1980s may also contribute to the lack of stability in these estimates as less information is available on the early cohorts.

Further development of the size-age based approach is planned for the upcoming year. Anticipated extensions include a model of the change in growth rate, inclusion of scientific survey CPUE, and inclusion of bycatch removals as a source of legal-sized halibut mortality. Current implementations indicate that such modifications are likely to result in biomass estimates that are generally higher than those now estimated. But, as noted in the discussion on recruitment, the current definition of exploitable biomass must be re-evaluated in conjunction with a re-evaluation of the constant harvest rate policy given the new estimates.

Sullivan, P.J., Parma, A.M., 1996. Population assessment, 1995. IPHC Rep. Assess. Res. Act. 1995., pp. 79–107.

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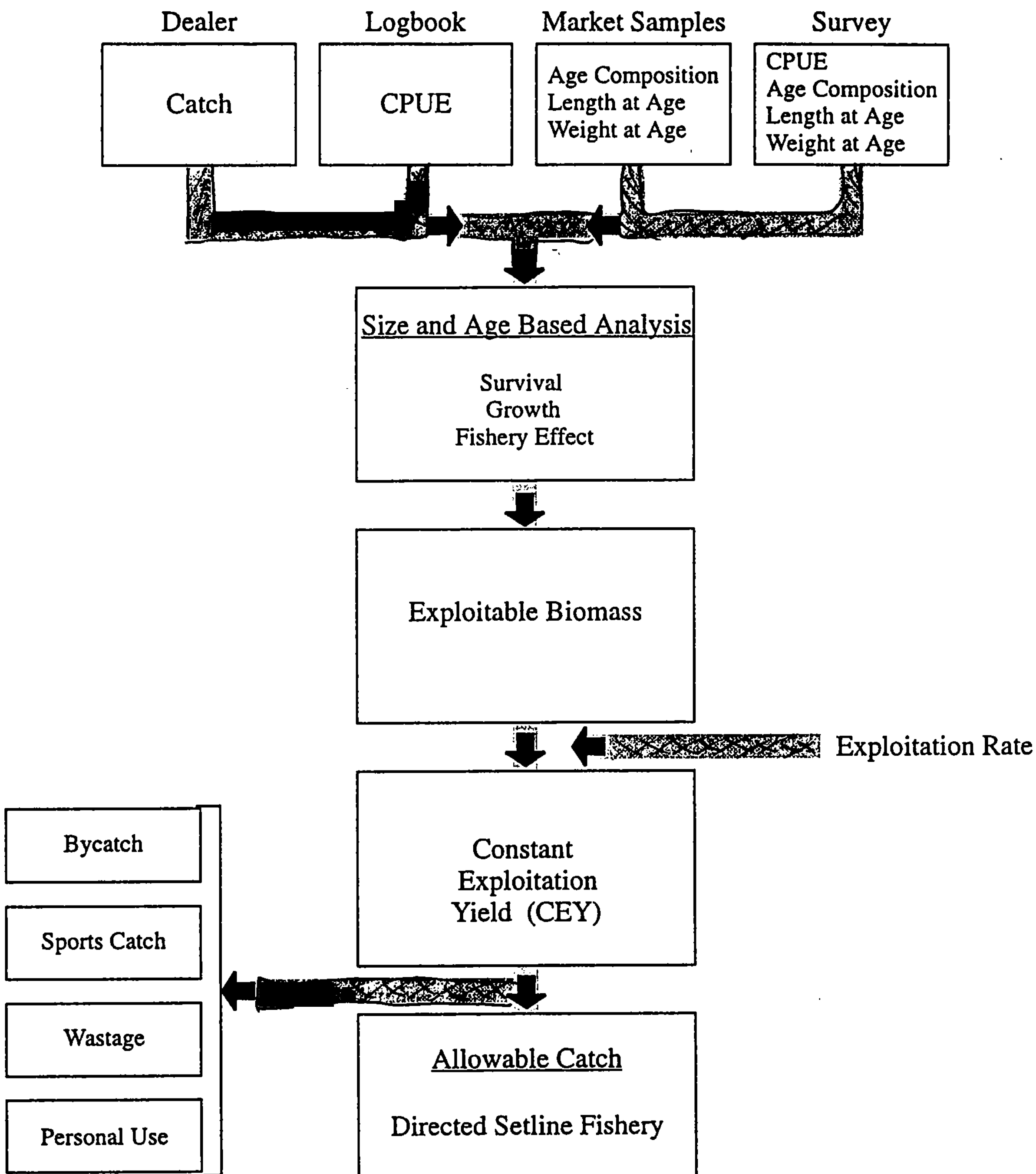

Figure 1. Overview of Pacific halibut stock assessment procedure.

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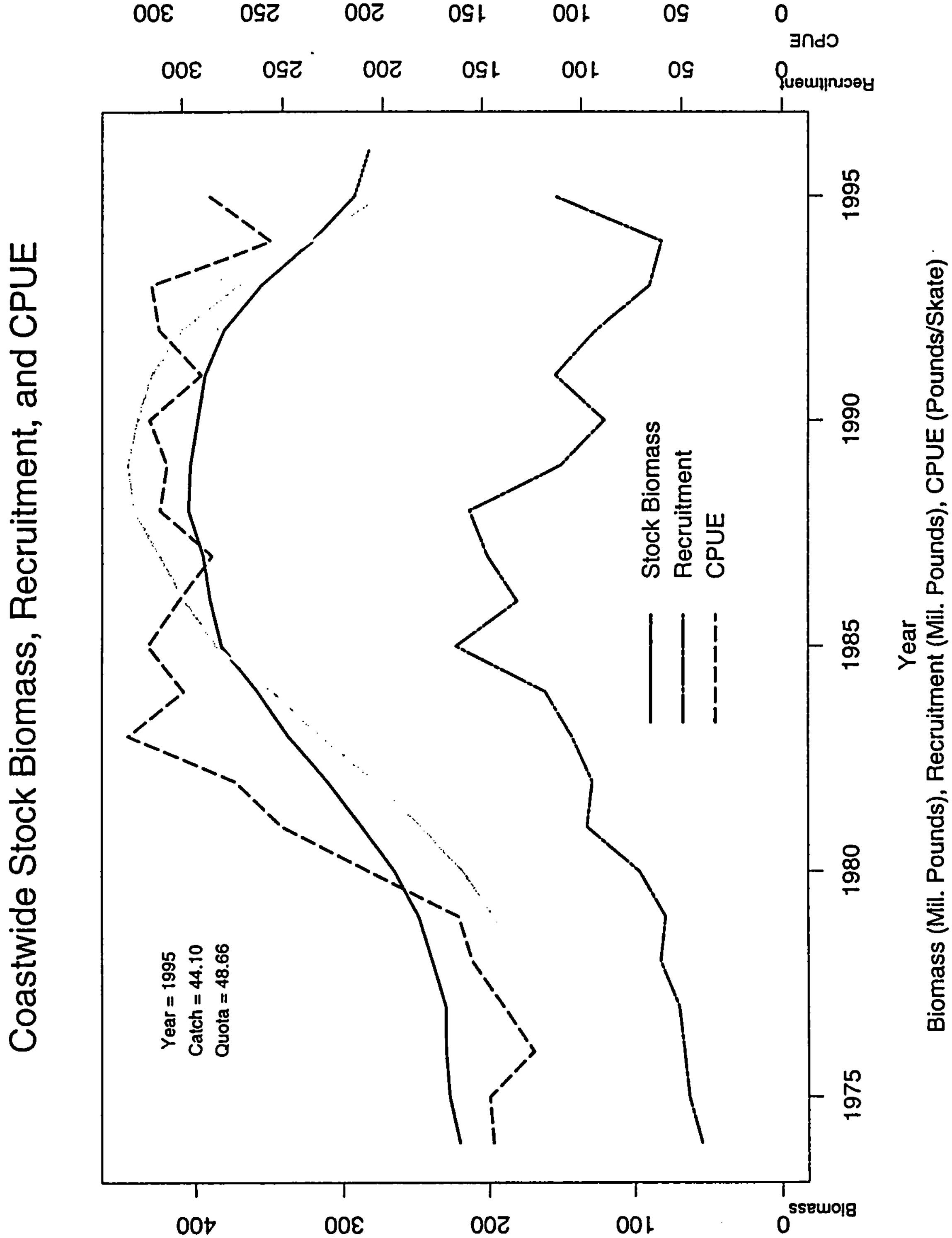

Figure 2. **Coastwide size-age based estimates of exploitable stock biomass and recruitment contrasted with CPUE and exploitable biomass estimates from catch-age analysis.**

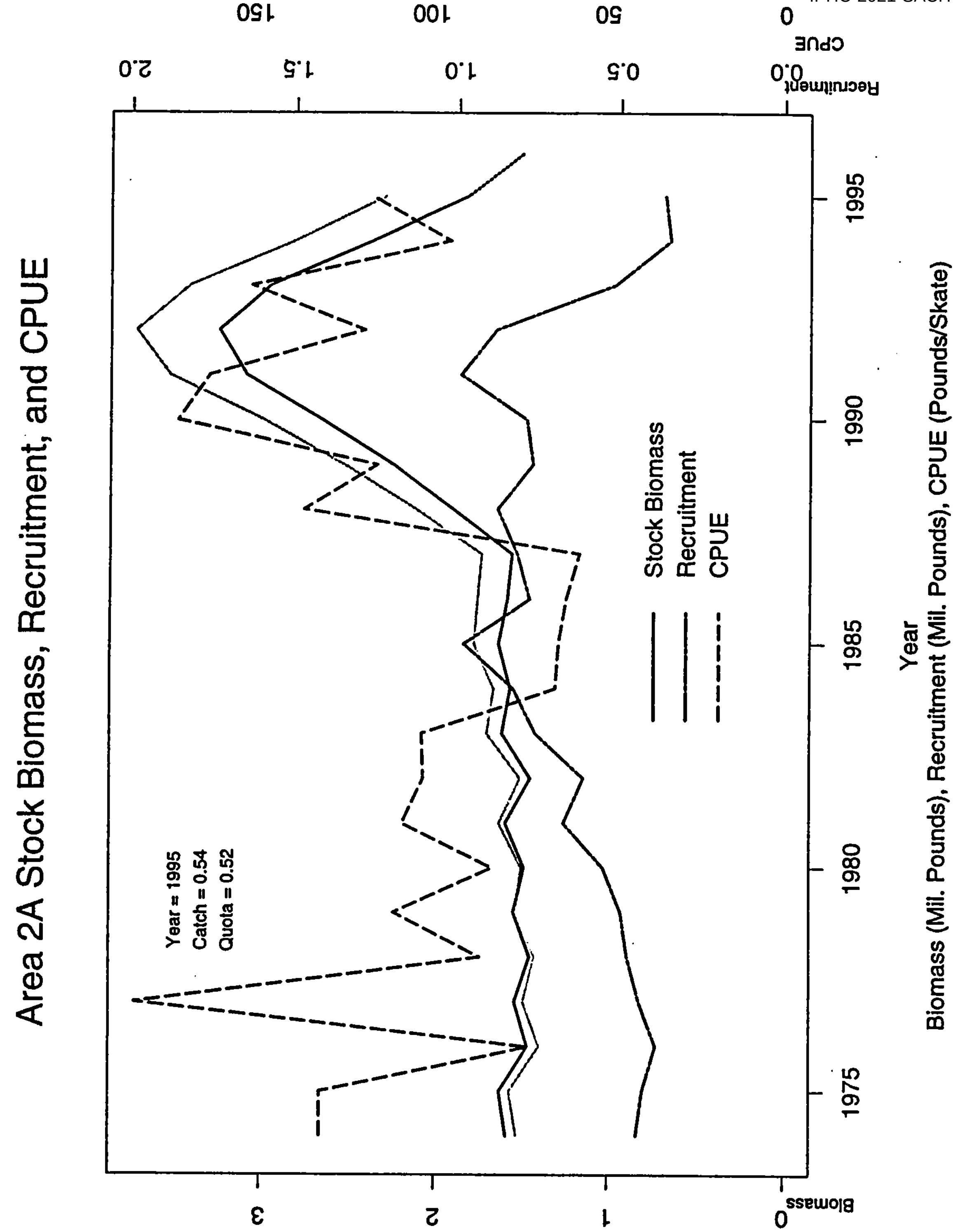

Figure 3. **Area 2A size-age based estimates of exploitable stock biomass and recruitment contrasted with CPUE and exploitable biomass estimates from catch-age analysis.**

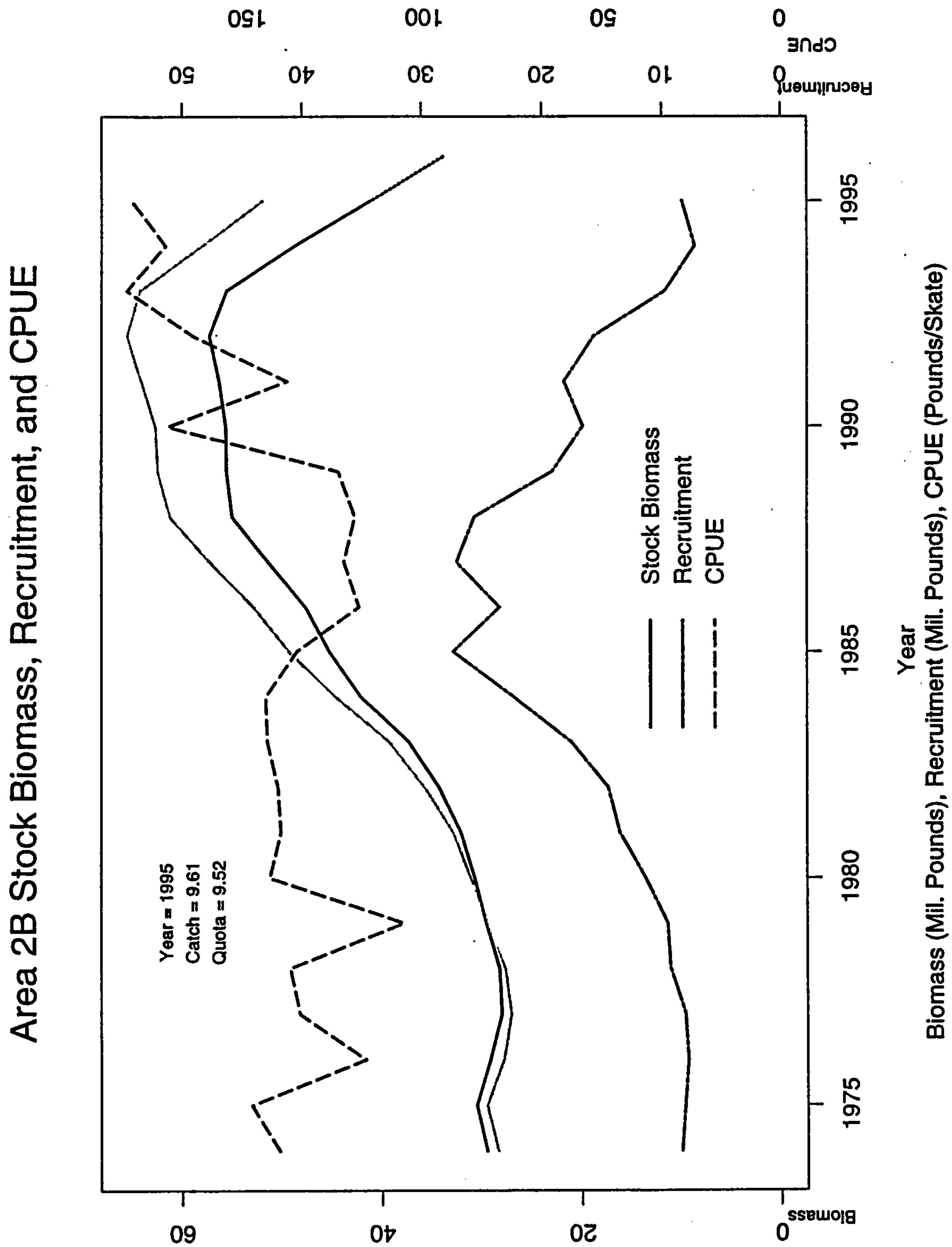

Figure 4. **Area 2B size-age based estimates of exploitable stock biomass and recruitment contrasted with CPUE and exploitable biomass estimates from catch-age analysis.**

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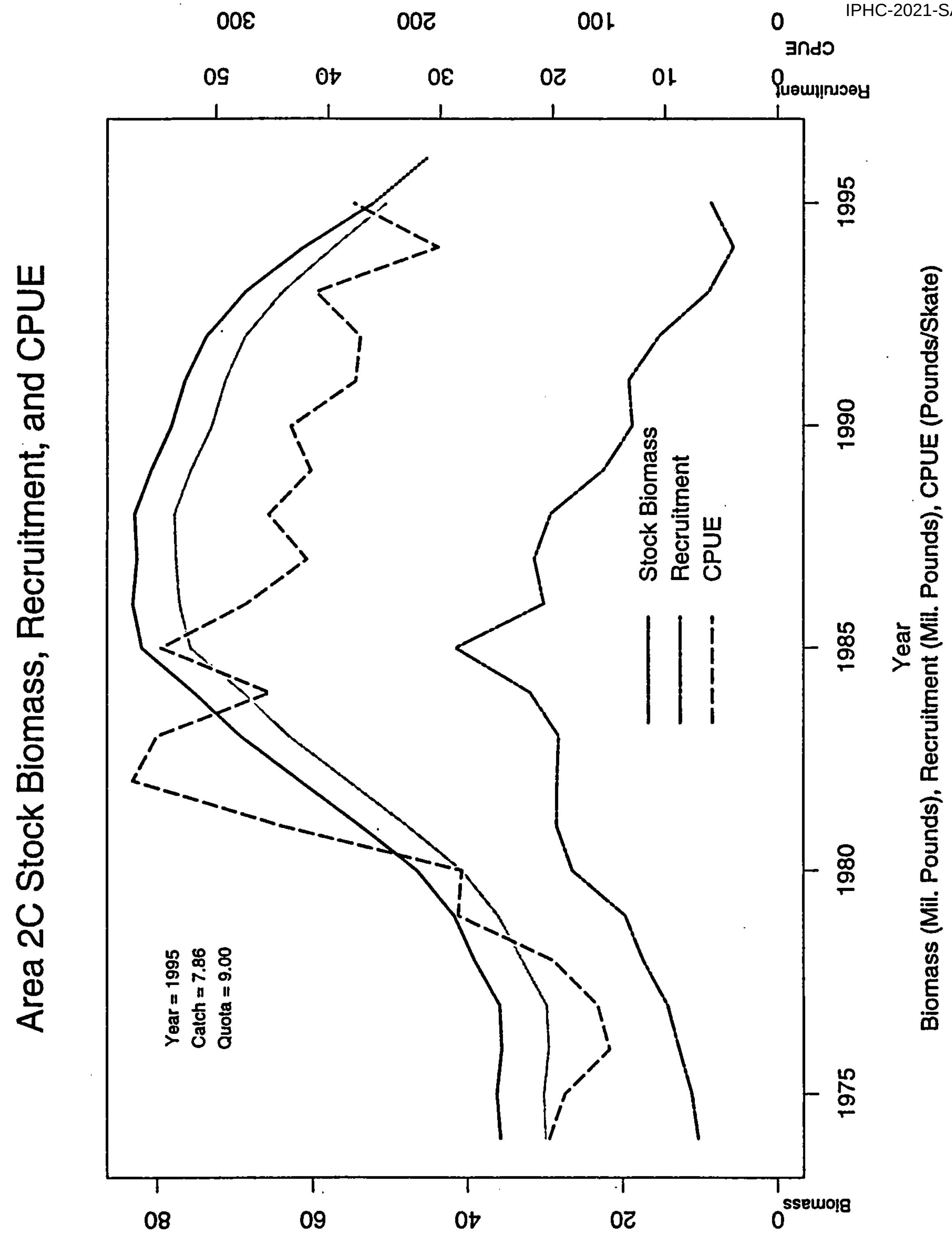

Figure 5. **Area 2C size-age based estimates of exploitable stock biomass and recruitment contrasted with CPUE and exploitable biomass estimates from catch-age analysis.**

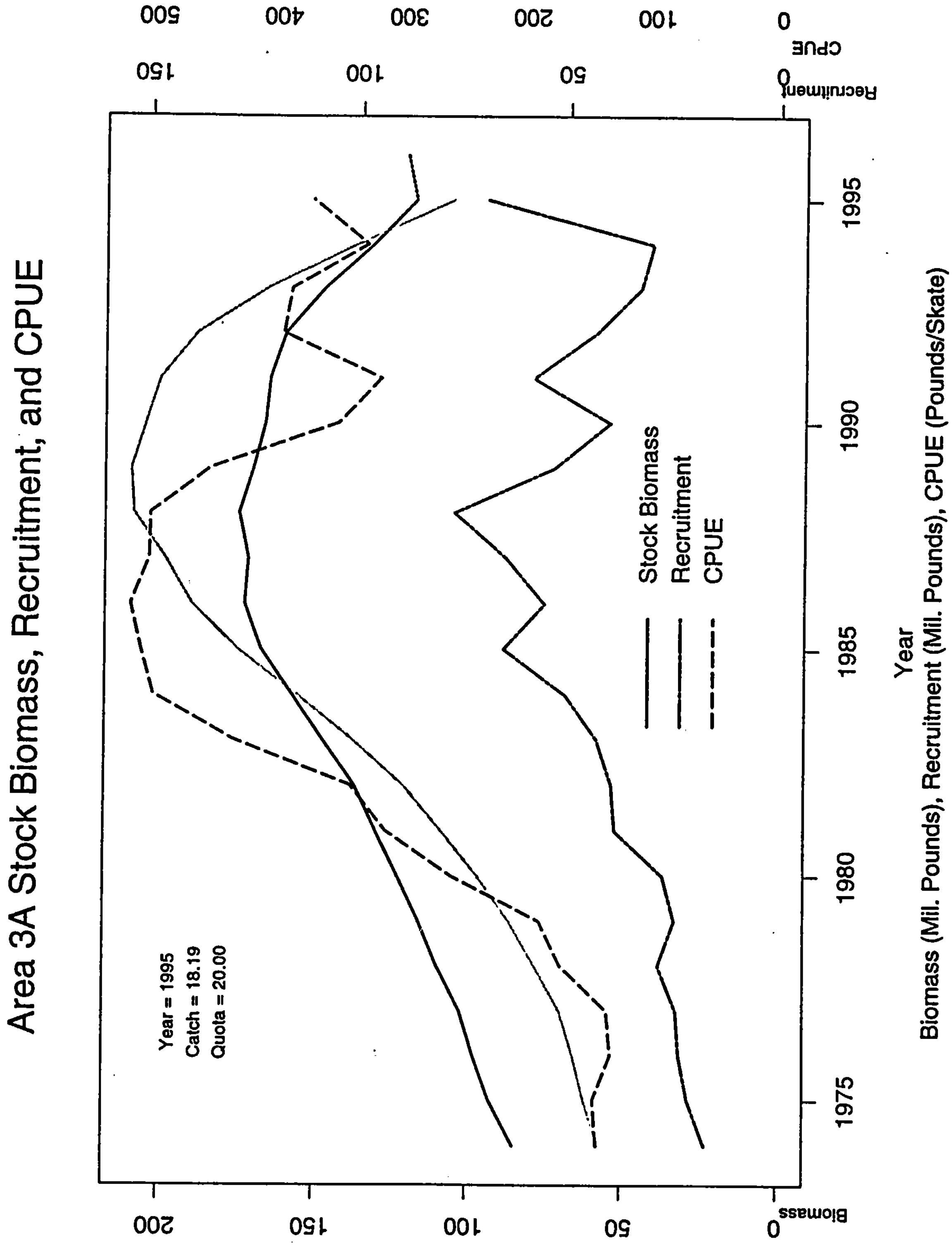

Figure 6. Area 3A size-age based estimates of exploitable stock biomass and recruitment contrasted with CPUE and exploitable biomass estimates from catch-age analysis.

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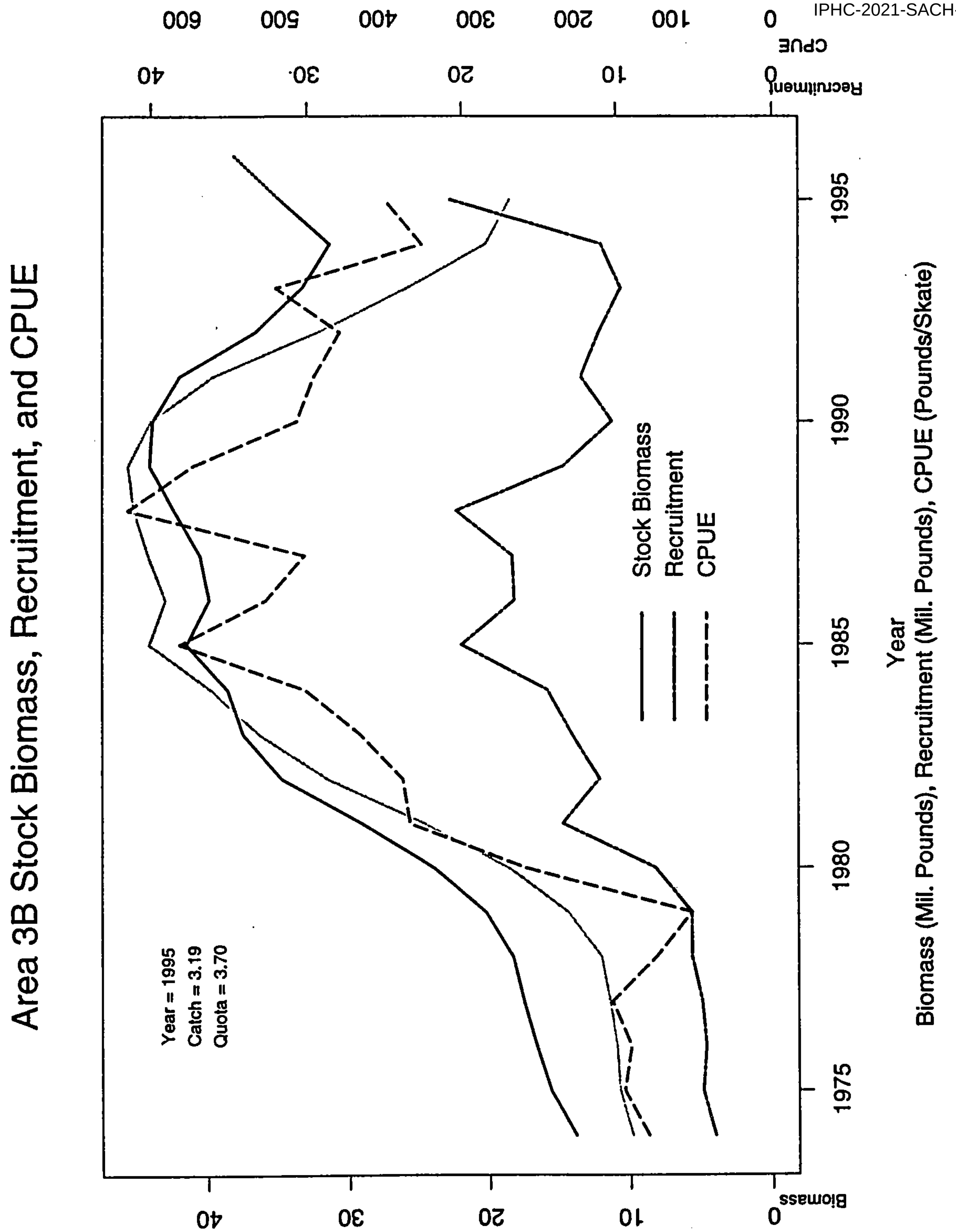

Figure 7. Area 3B size-age based estimates of exploitable stock biomass and recruitment contrasted with CPUE and exploitable biomass estimates from catch-age analysis.

Sullivan, P.J., Parma, A.M., 1996. Population assessment, 1995. IPHC Rep. Assess. Res. Act. 1995., pp. 79–107.

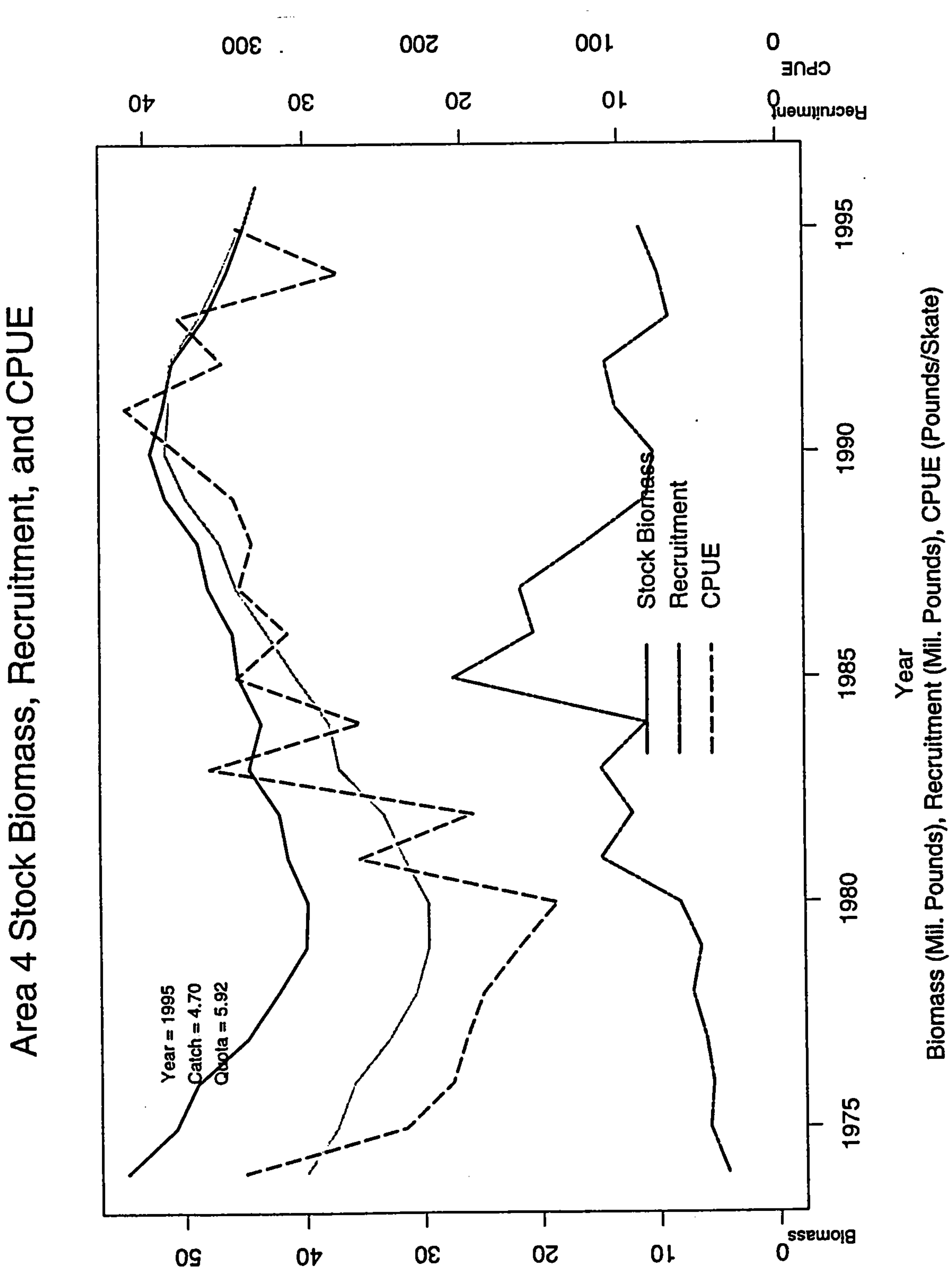

Figure 8. Area 4 size-age based estimates of exploitable stock biomass and recruitment contrasted with CPUE and exploitable biomass estimates from catch-age analysis.

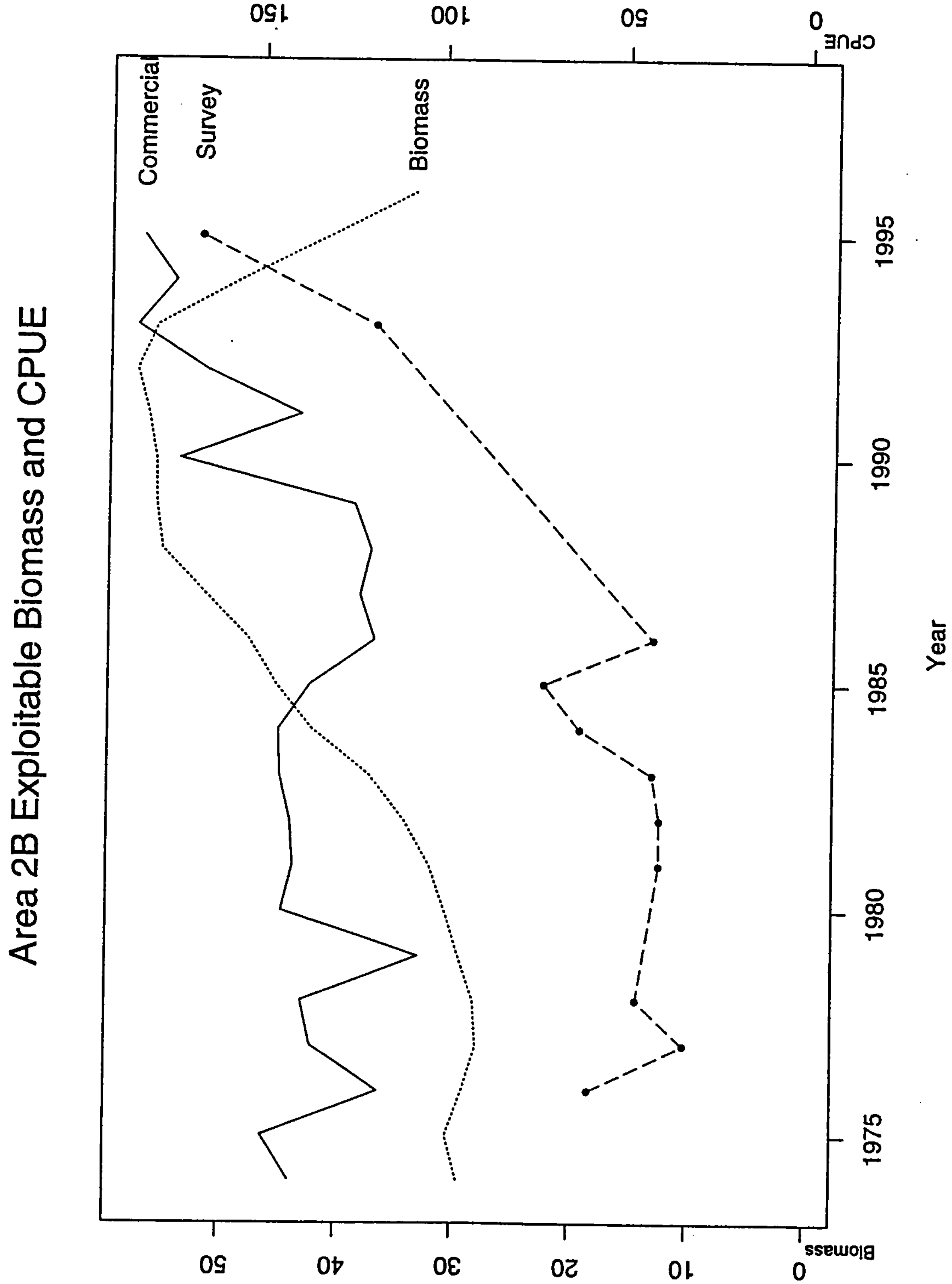

Figure 9. Area 2B exploitable biomass estimates compared with commercial and IPHC systematic survey CPUE estimates.

Sullivan, P.J., Parma, A.M., 1996. Population assessment, 1995. IPHC Rep. Assess. Res. Act. 1995., pp. 79–107.

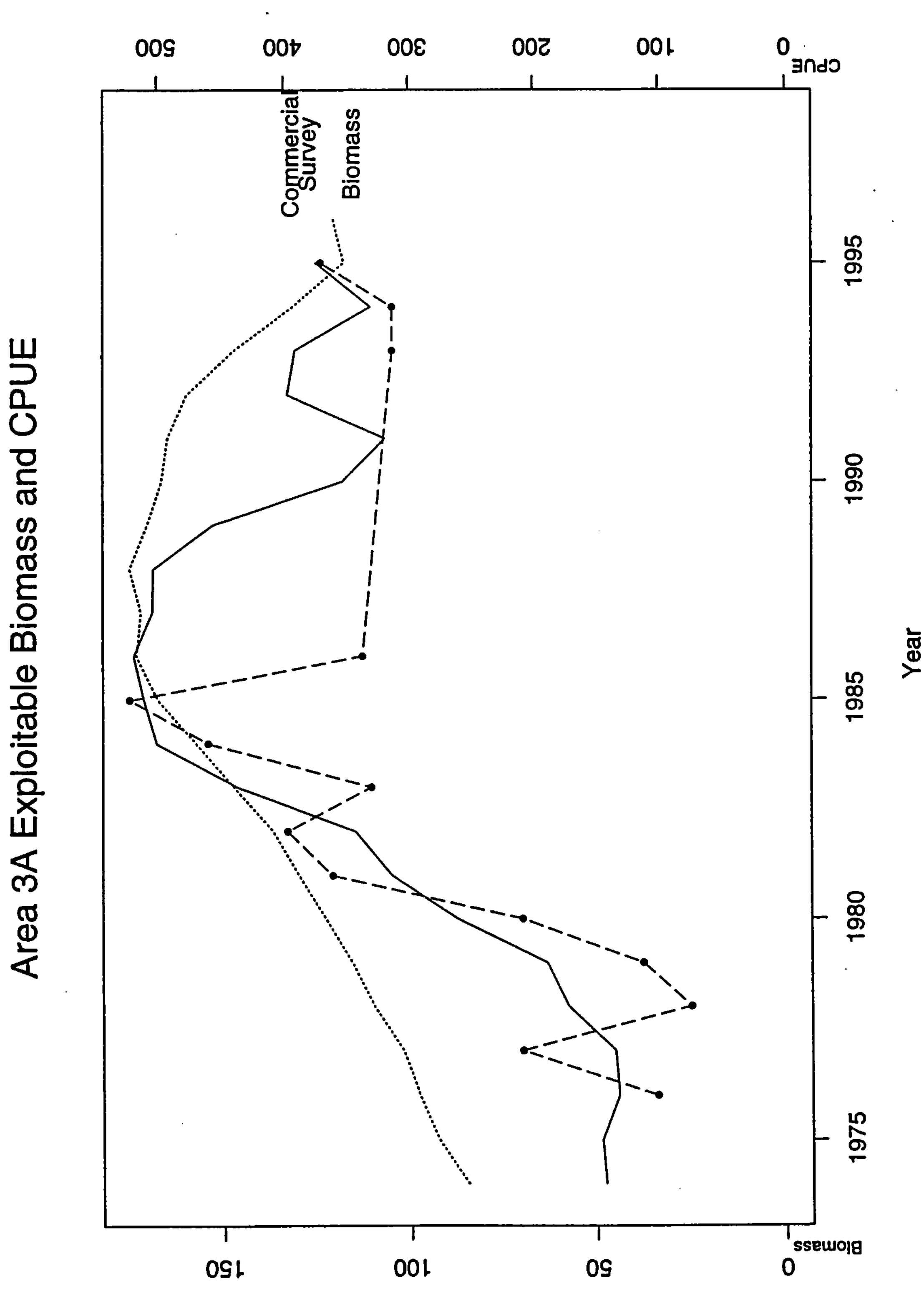

Figure 10. Area 3A exploitable biomass estimates compared with commercial and IPHC systematic survey CPUE estimates.

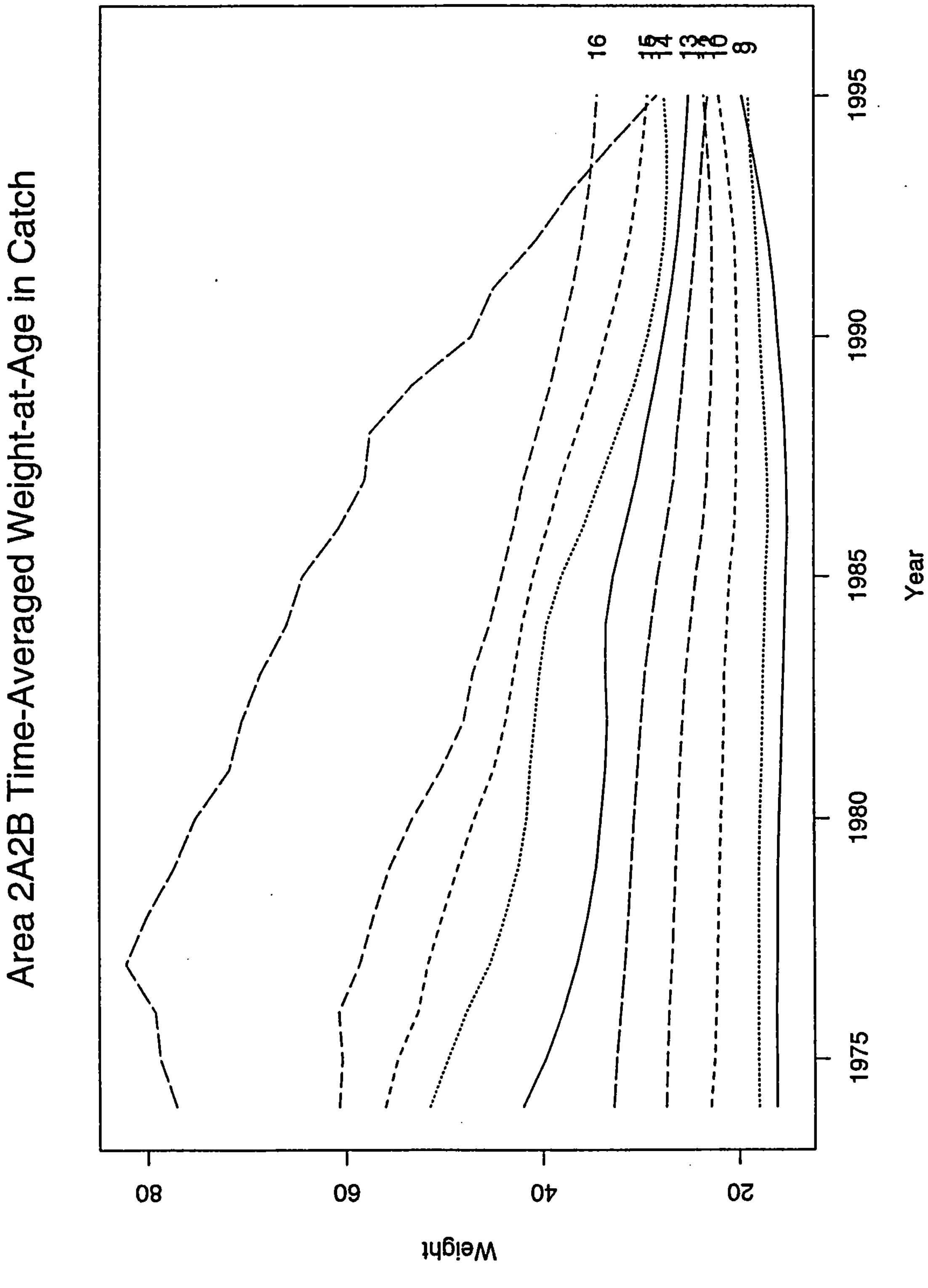

Figure 11. Area 2A-2B time-averaged weight-at-age in the catch by age-class.

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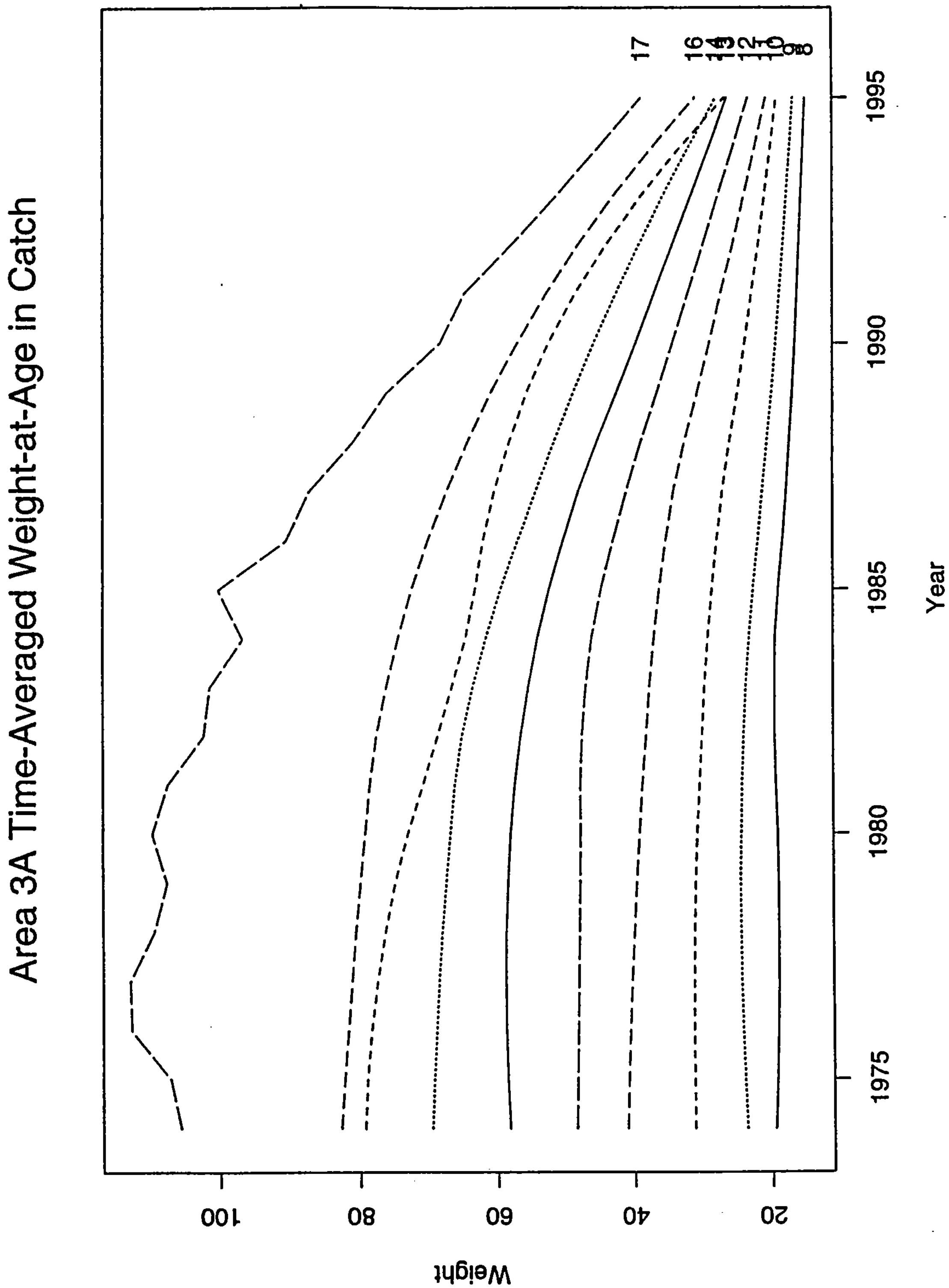

Figure 12. Area 3A time-averaged weight-at-age in the catch by age-class.

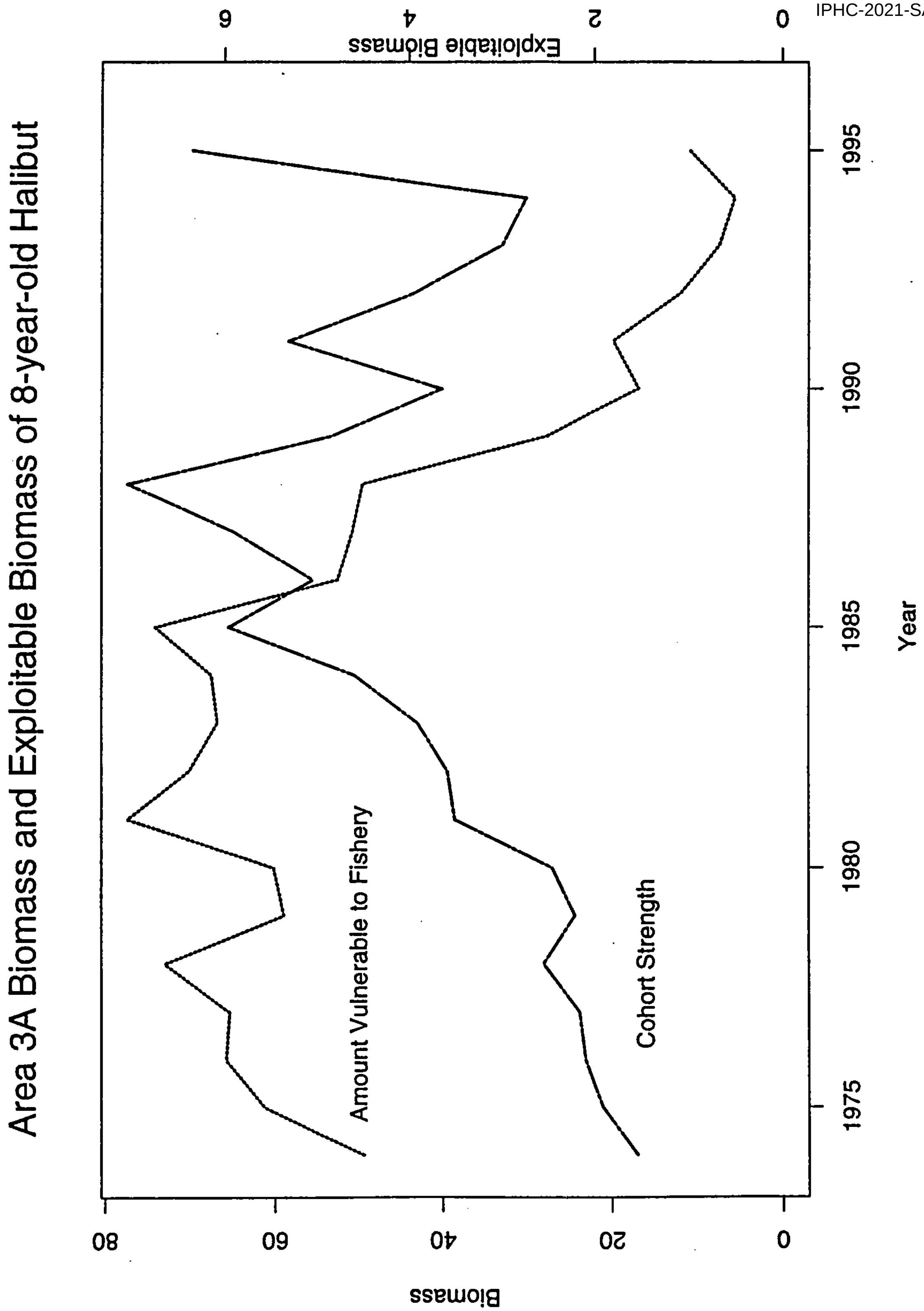

Figure 13. Area 3A cohort strength of 8-year-old halibut (recruits) shown in biomass contrasted with the biomass of those vulnerable to the fishery (exploitable biomass).

Sullivan, P.J., Parma, A.M., 1996. Population assessment, 1995. IPHC Rep. Assess. Res. Act. 1995., pp. 79–107.

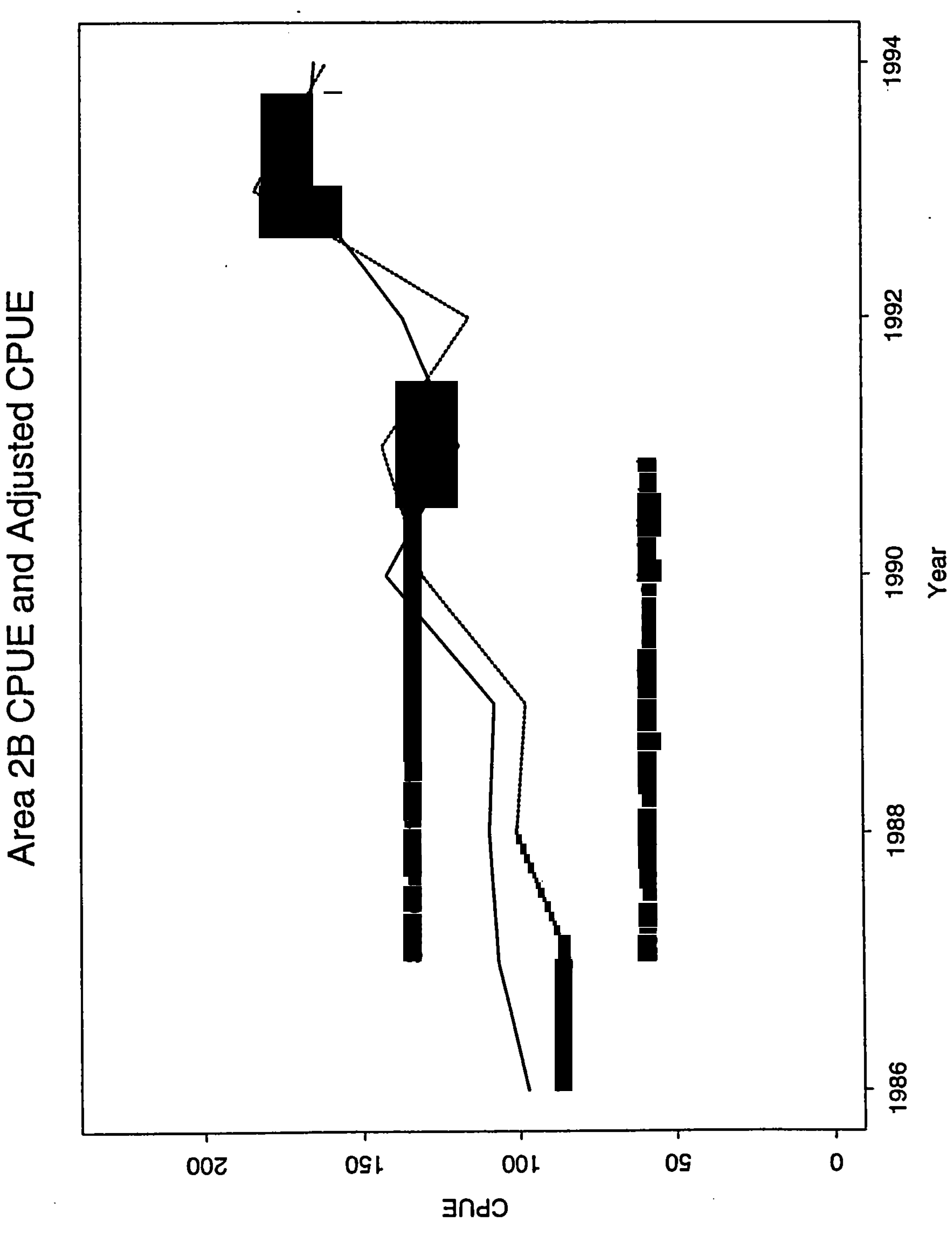

Figure 14. Area 2B CPUE as a standard estimate compared with an estimate that is area-weighted and seasonally adjusted.

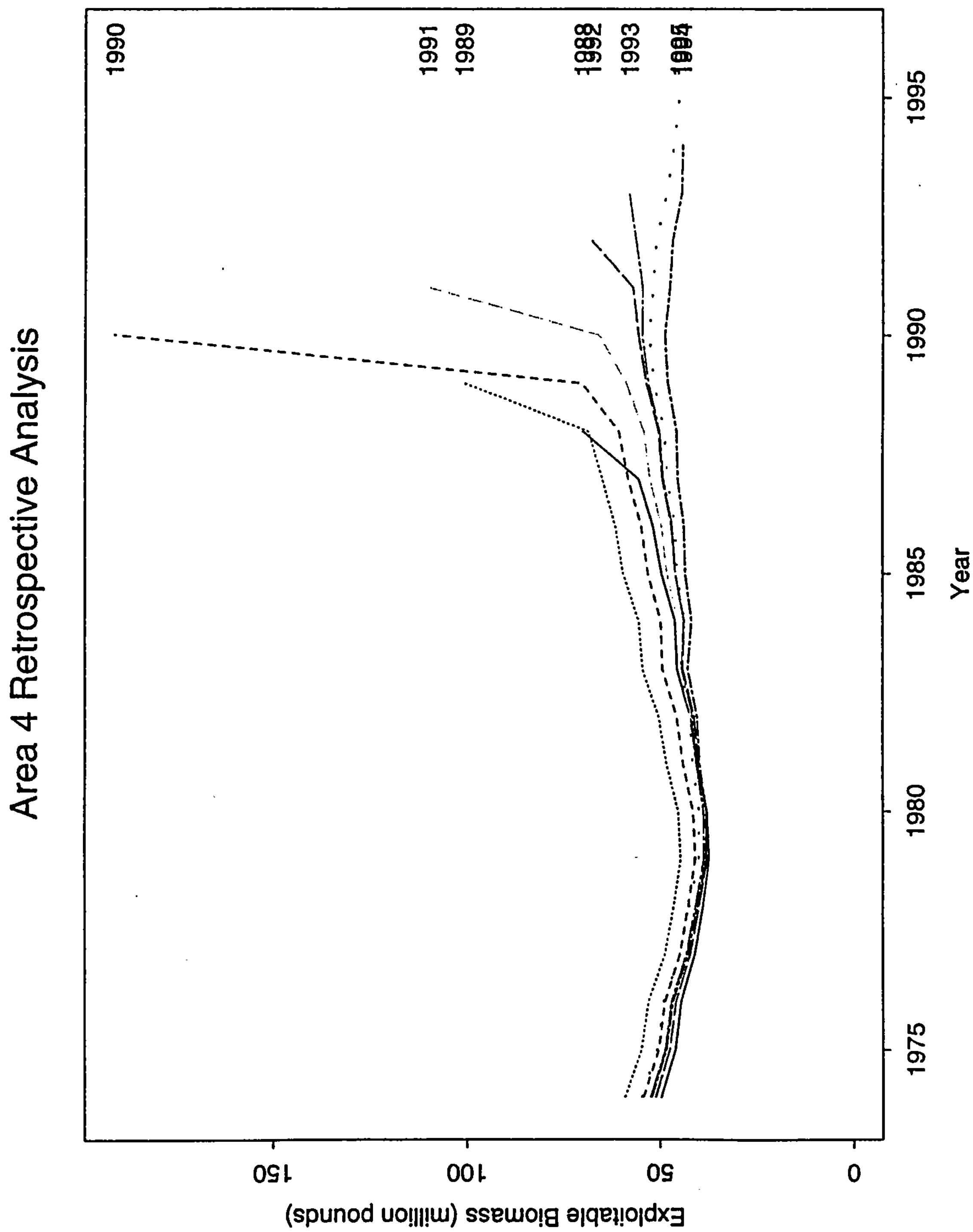

Figure 15. Area 4 retrospective analysis progressively removing the influence of the latest year's data point.

APPENDIX (TABLES)

Table A.1 Commercial CPUE (pounds per skate, C hook equivalent)

Year	2A	2B	2C	3A	3B	4	Total
1974	130.7	141.0	126.0	142.4	124.7	301.1	137.9
1975	130.6	148.7	117.4	145.3	149.3	210.7	139.7
1976	71.7	116.7	92.8	131.5	142.2	184.2	118.5
1977	182.2	135.3	99.4	134.6	161.3	176.2	133.1
1978	85.5	138.0	124.1	171.9	116.4	166.6	148.0
1979	110.0	105.8	176.6	189.0	80.8	146.1	154.6
1980	82.0	143.7	174.7	260.6	249.5	124.2	197.6
1981	107.6	140.6	273.6	313.5	368.3	236.8	239.1
1982	101.6	141.4	355.9	342.6	375.8	172.5	261.3
1983	102.1	144.4	342.8	437.0	419.4	320.0	311.4
1984	64.1	144.8	280.8	500.3	475.2	235.6	285.6
1985	63.2	136.1	340.7	509.9	602.4	304.8	302.4
1986	61.0	118.6	294.0	517.9	514.8	276.5	288.1
1987	57.3	122.8	260.3	503.6	476.1	303.6	272.4
1988	135.3	119.8	281.3	502.8	654.2	296.4	296.8
1989	114.8	124.5	258.0	456.0	590.0	306.4	293.4
1990	170.7	172.4	269.1	352.9	483.6	336.2	301.5
1991	161.9	138.9	233.2	318.6	466.4	366.3	277.4
1992	118.4	165.1	230.5	397.1	440.2	312.4	297.0
1993	150.3	183.8	255.1	390.8	504.6	336.9	300.5
1994	94.1	173.1	187.5	330.2	355.9	247.1	244.2
1995	116.1	182.6	233.9	374.0	394.1	304.2	273.6

Sullivan, P.J., Parma, A.M., 1996. Population assessment, 1995. IPHC Rep. Assess. Res. Act. 1995., pp. 79–107.

Table A.2 Commercial Catch (million pounds)

Year	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	0.50	10.63	11.29	22.74	7.86	6.25	59.27
1994	0.39	9.91	10.38	24.84	3.86	5.37	54.75
1995	0.31	9.61	7.86	18.19	3.19	4.70	43.86

Sullivan, P.J., Parma, A.M., 1996. Population assessment, 1995. IPHC Rep. Assess. Res. Act. 1995., pp. 79–107.

Table A.3 Total Removals (million pounds excluding bycatch)

Year	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	15.06	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	36.56	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	74.50
1990	0.52	9.41	11.30	33.38	8.91	5.69	69.21
1991	0.52	7.88	11.41	29.20	12.41	6.52	67.93
1992	0.70	8.36	12.10	31.81	8.83	6.89	68.69
1993	0.76	11.68	13.40	28.67	7.98	6.56	69.05
1994	0.57	10.94	12.72	30.51	3.96	5.64	64.34
1995	0.55	10.62	9.93	23.19	3.26	4.91	52.46

Sullivan, P.J., Parma, A.M., 1996. Population assessment, 1995. IPHC Rep. Assess. Res. Act. 1995., pp. 79–107.

Table A.4 Exploitable Biomass (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
1974	1.58	29.43	35.78	84.55	13.82	54.83	220.00
1975	1.62	30.45	36.23	92.32	15.61	50.80	227.03
1976	1.46	29.07	35.64	97.52	16.63	49.00	229.32
1977	1.53	27.92	35.90	101.93	17.52	44.86	229.67
1978	1.45	28.19	39.11	109.58	18.30	42.28	238.90
1979	1.54	29.48	41.73	115.54	20.21	39.93	248.42
1980	1.48	30.65	46.47	122.53	23.89	39.81	264.84
1981	1.59	31.98	53.78	129.69	29.03	41.44	287.51
1982	1.44	34.19	61.54	136.72	34.73	42.14	310.75
1983	1.61	37.24	69.30	147.14	37.46	44.63	337.38
1984	1.56	42.10	75.35	156.97	38.55	43.64	358.18
1985	1.63	45.28	81.90	167.02	41.44	45.49	382.77
1986	1.58	47.62	83.05	172.39	39.84	45.98	390.45
1987	1.56	51.37	82.53	171.33	40.50	48.00	395.27
1988	1.90	55.01	82.83	174.27	42.33	48.81	405.15
1989	2.24	55.55	80.76	169.71	44.02	51.52	403.79
1990	2.65	55.63	78.19	166.01	43.83	52.75	399.05
1991	3.08	56.29	76.47	164.40	41.91	51.70	393.85
1992	3.24	57.29	73.67	159.39	36.59	50.89	381.07
1993	2.95	55.58	68.59	147.02	33.27	48.18	355.58
1994	2.36	48.75	61.18	131.26	31.34	46.34	321.24
1995	1.82	41.14	52.19	117.52	34.84	45.00	292.51
1996	1.49	33.71	45.25	120.35	38.12	43.83	282.74

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Table A.4 - Addendum CAGEAN Exploitable Biomass (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
1974	1.52	28.30	29.90	56.73	9.81	39.98	166.25
1975	1.57	29.40	30.15	61.66	10.71	37.40	170.88
1976	1.39	27.75	29.49	65.14	10.93	35.95	170.65
1977	1.48	27.01	29.75	69.48	11.41	32.97	172.10
1978	1.42	27.63	33.00	77.62	12.00	30.65	182.31
1979	1.53	29.32	36.10	86.04	14.34	29.57	196.90
1980	1.50	31.00	40.67	96.47	18.57	29.57	217.77
1981	1.63	32.76	47.73	108.38	24.54	31.60	246.65
1982	1.50	35.61	55.35	120.86	31.48	33.41	278.21
1983	1.70	39.26	63.03	137.52	36.32	37.14	314.96
1984	1.66	44.65	68.94	155.24	39.70	37.93	348.12
1985	1.78	49.30	75.74	174.66	44.06	40.67	386.20
1986	1.76	52.83	77.18	189.56	42.94	43.13	407.39
1987	1.73	57.18	77.64	198.13	44.13	45.68	424.49
1988	2.11	61.18	77.83	208.01	45.11	47.04	441.28
1989	2.52	62.48	75.73	208.93	45.52	49.81	444.99
1990	2.98	62.71	73.01	204.52	43.94	51.51	438.68
1991	3.51	64.10	71.29	199.92	39.56	51.20	429.58
1992	3.70	65.52	68.66	188.12	32.15	51.10	409.26
1993	3.40	64.21	63.85	165.50	25.85	48.65	371.46
1994	2.81	57.96	57.33	136.54	20.23	46.86	321.73
1995	2.29	51.91	50.48	105.31	18.52	45.24	273.75
1996	2.08	47.14	46.09	92.00	17.07	43.56	247.95

Table A.5 Historical Exploitation Rates (total removals / exploitable biomass)

Year	2A	2B	2C	3A	3B	4	Total	+Bycatch
1974	0.33	0.16	0.16	0.10	0.12	0.01	0.10	0.18
1975	0.28	0.23	0.17	0.11	0.16	0.01	0.12	0.17
1976	0.16	0.25	0.16	0.11	0.16	0.01	0.12	0.18
1977	0.15	0.20	0.09	0.09	0.18	0.03	0.10	0.15
1978	0.08	0.16	0.11	0.10	0.07	0.03	0.09	0.14
1979	0.04	0.17	0.11	0.10	0.02	0.03	0.09	0.15
1980	0.03	0.18	0.08	0.10	0.01	0.02	0.09	0.15
1981	0.14	0.18	0.08	0.12	0.02	0.03	0.09	0.14
1982	0.18	0.16	0.06	0.10	0.14	0.03	0.10	0.14
1983	0.20	0.15	0.10	0.10	0.21	0.10	0.12	0.15
1984	0.35	0.22	0.09	0.13	0.17	0.07	0.13	0.16
1985	0.42	0.24	0.12	0.14	0.27	0.10	0.16	0.18
1986	0.58	0.25	0.14	0.21	0.23	0.13	0.20	0.22
1987	0.67	0.25	0.14	0.20	0.20	0.15	0.19	0.22
1988	0.39	0.24	0.15	0.24	0.17	0.10	0.20	0.24
1989	0.36	0.20	0.14	0.23	0.18	0.10	0.18	0.22
1990	0.20	0.17	0.14	0.20	0.20	0.11	0.17	0.22
1991	0.17	0.14	0.15	0.18	0.30	0.13	0.17	0.21
1992	0.22	0.15	0.16	0.20	0.24	0.14	0.18	0.22
1993	0.26	0.21	0.20	0.20	0.24	0.14	0.19	0.24
1994	0.24	0.22	0.21	0.23	0.13	0.12	0.20	0.25
1995	0.30	0.26	0.19	0.20	0.09	0.11	0.18	0.23

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Table A.6 Annual Surplus Production

Year	2A	2B	2C	3A	3B	4	Total
1974	0.56	5.64	6.05	15.96	3.45	-3.31	28.35
1975	0.30	5.75	5.65	15.80	3.58	-1.18	29.90
1976	0.32	6.13	5.79	15.44	3.63	-3.42	27.89
1977	0.14	5.72	6.47	16.49	3.96	-1.36	31.41
1978	0.20	5.91	7.02	16.55	3.24	-1.00	31.91
1979	0.00	6.05	9.45	18.69	4.07	1.25	39.52
1980	0.15	6.99	10.88	19.62	5.41	2.35	45.39
1981	0.07	7.88	12.09	22.00	6.15	1.90	50.09
1982	0.43	8.66	11.74	24.67	7.53	3.93	56.97
1983	0.28	10.41	13.01	24.88	8.85	3.43	60.85
1984	0.61	12.35	13.02	31.05	9.38	5.03	71.45
1985	0.64	13.35	11.25	28.36	9.49	4.93	68.01
1986	0.89	15.54	11.25	35.49	9.90	7.93	81.00
1987	1.38	16.59	12.13	37.84	9.93	7.98	85.85
1988	1.08	13.96	10.58	38.06	8.89	7.50	80.07
1989	1.21	11.19	8.72	34.50	7.84	6.32	69.77
1990	0.96	10.07	9.58	31.78	6.99	4.64	64.01
1991	0.67	8.88	8.61	24.18	7.08	5.71	55.14
1992	0.41	6.65	7.02	19.45	5.52	4.17	43.21
1993	0.18	4.85	6.00	12.92	6.05	4.72	34.71
1994	0.03	3.33	3.73	16.76	7.46	4.30	35.61
1995	0.02	2.81	3.18	15.01	8.30	4.17	32.42

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Table A.7 Fishing Mortality

Year	2A-2B	2C	3A	3B	4
1974	0.13	0.17	0.09	0.11	0.01
1975	0.21	0.20	0.12	0.15	0.01
1976	0.21	0.19	0.12	0.16	0.02
1977	0.17	0.10	0.10	0.18	0.03
1978	0.11	0.14	0.11	0.08	0.04
1979	0.15	0.13	0.12	0.03	0.04
1980	0.15	0.08	0.12	0.01	0.02
1981	0.16	0.09	0.13	0.01	0.03
1982	0.15	0.06	0.11	0.15	0.05
1983	0.13	0.10	0.13	0.26	0.14
1984	0.24	0.10	0.19	0.21	0.10
1985	0.27	0.16	0.21	0.40	0.15
1986	0.26	0.19	0.35	0.37	0.16
1987	0.26	0.18	0.36	0.32	0.19
1988	0.29	0.20	0.48	0.29	0.12
1989	0.24	0.19	0.46	0.31	0.14
1990	0.18	0.18	0.44	0.38	0.15
1991	0.13	0.18	0.42	0.66	0.17
1992	0.14	0.21	0.47	0.56	0.18
1993	0.23	0.25	0.48	0.54	0.17
1994	0.24	0.31	0.62	0.23	0.16
1995	0.25	0.22	0.48	0.19	0.15

Table A.8 Recruitment Biomass (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
1974	0.45	8.29	7.03	16.95	3.67	3.22	39.61
1975	0.43	8.03	7.58	21.01	4.44	4.37	45.86
1976	0.39	7.74	8.72	23.05	4.24	4.16	48.29
1977	0.44	8.00	9.73	23.79	4.50	4.58	51.04
1978	0.47	9.24	11.92	28.05	5.13	5.42	60.23
1979	0.50	9.47	13.53	24.30	5.14	4.88	57.82
1980	0.55	11.37	18.23	27.06	7.46	6.21	70.87
1981	0.67	13.49	19.64	38.58	13.41	11.15	96.95
1982	0.61	14.44	19.61	39.45	11.03	9.18	94.31
1983	0.76	17.55	19.47	42.99	12.81	11.17	104.75
1984	0.83	22.31	22.01	50.49	14.42	8.29	118.35
1985	0.98	27.27	28.63	65.41	19.95	20.59	162.84
1986	0.78	23.42	20.79	55.39	16.56	15.43	132.37
1987	0.82	27.00	21.65	64.83	16.70	16.29	147.28
1988	0.88	25.49	20.17	77.33	20.29	12.05	156.21
1989	0.77	19.06	15.44	53.29	13.39	8.25	110.20
1990	0.79	16.56	12.90	40.08	10.22	7.80	88.35
1991	0.99	18.11	13.19	58.37	12.21	10.19	113.06
1992	0.88	15.64	10.45	43.45	11.08	10.82	92.34
1993	0.51	9.70	6.03	32.99	9.67	6.79	65.69
1994	0.35	7.17	3.89	30.12	10.95	7.49	59.98
1995	0.36	8.25	5.84	69.71	20.72	8.65	113.52

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Table A9. IPHC halibut setline survey CPUE.

Year	2B	3A
1974		
1975		
1976	59	101
1977	33	209
1978	46	74
1979		112
1980		209
1981	40	361
1982	40	397
1983	42	330
1984	62	460
1985	72	521
1986	42	337
1987		
1988		
1989		
1990		
1991		
1992		
1993	119	313
1994		313
1995	167	370

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REPORT OF ASSESSMENT AND RESEARCH ACTIVITIES 1994

POPULATION ASSESSMENT, 1994

by

Patrick J. Sullivan and Ana M. Parma

INTRODUCTION

The Pacific halibut stock assessment for 1994 combines catch at age with catch per unit of effort in order to estimate stock abundance and determine stock trends. The analysis is conducted by area and applied to data from Areas 2A-2B, 2C, 3A, 3B, and 4. This year, as has been done every year since the inception of the Commission, information is collected on all aspects of the fishery. Total catch was tallied using tickets from the plants at which halibut is landed. Catch per unit effort (CPUE) was developed from 3300 logbooks covering 70-80% of the 55 million pounds of landed catch. Seven thousand licenses were issued forming an information base which the staff used to update logbook data and validate ticket data. Thirteen thousand halibut were lengthed and sampled for otoliths. The otoliths were later microscopically aged and used in combination with the individual length measurements to determine the age composition and average weight at age of individuals in the stock. And two hundred and seventy tags were collected from twenty-nine different ports to add to the information used in monitoring mortality and migration. These data is used in the stock assessment to determine the exploitable biomass, which is the stock biomass available for harvest.

The constant exploitation yield (CEY) is determined by applying a 0.30 harvest rate to the estimated exploitable biomass. This year we are proposing that this rate be applied to estimated biomass levels for the start of the upcoming year (1995) rather than to estimated biomass levels derived for the start of the previous year (1994) as has been done in the past. The yield resulting from the application of this rate represents 30% of the estimated exploitable biomass for 1995. Given the CEY, the recommended allowable catch is determined by accounting for removals from other sources (sport catch, wastage, bycatch, and personal use). The overall procedure involved in collecting data, conducting the assessment, and determining the CEY is outlined in Figure 1.

STOCK ASSESSMENT

Each year the stock assessment data are examined for signals indicating the trends in abundance. We shall first present the results from the standard stock assessment to note general trends in the halibut stock. After this discussion, the results for Regulatory Areas 2B and 3A will be examined more closely to highlight other features of the data.

The total exploitable biomass of Pacific halibut was determined to be 282.6 million pounds at the beginning of 1994 and 242.7 million pounds at the start of the 1995 season. This

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represents an overall decline in biomass of 18% between 1993 and 1994, and indicates a decline of 14% between 1994 and 1995. These rates are high relative to the 5-15% declines observed in previous years. Figure 2 shows the trends in exploitable biomass, recruitment, and CPUE for the total stock. Figures 3 through 8 give the area-by-area trends. These trends indicate a decrease in exploitable biomass from 1993 to 1994 of 20% in Area 2A, 13% in Area 2B, 12% in Area 2C, 23% in Area 3A, 27% in Area 3B, and 9% in Area 4.

Recruitment of 8-year-old halibut appears again to have dropped off in all areas. This year's recruitment again represents the lowest recruitment of 8-year-olds observed in nearly two decades. The low recruitment of recent years indicates that the stock will continue its decline at a rate of about 10-15% per year over the next several years. This trend is apparent in all of the assessments despite the relatively high levels of CPUE observed in recent years.

Sometimes the signals that come from a particular fishery are mixed and the degree of inconsistency in the signals will indicate the degree of caution that must be exercised in determining catch quotas. Last year's standard stock assessment was contrasted with an alternative assessment that discounted the upturn in CPUE observed over the last few years in order to highlight this disparity. In Area 2B in particular, the higher level of CPUE that has been observed since the implementation of the IVQ program appears to run counter to what one would expect in stock trends based on catch-at-age information (Figure 4). These trends should reflect the diminishment of several strong year-classes and the subsequent period of poor recruitment. The situation is much the same this year. Catch-per-unit-effort in the post IVQ fishery is 20% higher than the long term average even though age composition data show a decline in stock abundance. If these CPUE values are reduced by twenty percent, the corresponding estimated exploitable biomasses are reduced by the same amount, and the resulting quota reduced by a third (Figure 9). We must exercise caution in this area.

In Area 3A, stock biomasses appear to be dropping dramatically. This drop is in part due to the continued low levels of recruitment, but is also due in part to a declining weight at age of individuals observed in the catch (Figure 10). The average weight at age of eleven year old halibut has dropped in half since the late 1970s (a time of historically high weights at age). This decline in weight is observed in other areas of the Gulf as well and if these trends in recruitment and weight at age continue coast-wide lows in exploitable biomasses will be observed.

In addition to estimating the current year's stock levels, stock levels for previous years are re-estimated using updated information and methods. Changes in the level of bycatch, waste, and sport catch coupled with the inherent variability observed in the stock dynamics and the measurement process results in adjustments to abundance estimates made in previous years. This can cause the allowable catch to be higher than expected in some areas where stock abundance indicates more of a decline. This pattern, where the initial estimates are lower than the current corresponding estimates, has occurred over the last several years with halibut. Similar patterns in the stock biomass estimates have occurred for other stocks and the IPHC staff and fishery scientists from other agencies have been working toward a solution to this problem. Unfortunately, there is no guarantee that a solution will be forthcoming, and it is unlikely that the estimates will continue to adjust upward.

CONSTANT EXPLOITATION YIELD

Results from the 1994 stock assessments are used in determining the total and setline constant exploitation yields. This year a modification to the procedure for determining CEY is proposed that is more conservative to the stock during stock declines. This procedure uses some additional assumptions to project estimates of stock abundance to the beginning of 1995, rather than use the results of the standard assessment which give estimates at the start of the 1994 season (prior to fishing). Table 1 shows the yields for the suggested method for determining CEY based on the estimated 1995 exploitable biomasses along with the 1994 catch and quota. Table 2 shows the yields under the previous method for determining CEY based on the 1994 exploitable biomasses. The overall CEY is obtained by multiplying the area specific exploitable biomass by the constant exploitation yield rate of 0.30. Once the exploitation rate has been applied equally to all areas, the biomass removal from other sources is subtracted out to determine the allowable setline catch. The setline constant exploitation yields provide guidance as to the harvest that should be taken by the setline commercial fishery in order to maintain optimal yields and viability of the stock. We have discussed disparities and trends in the data that might not be evident in examining the CEYs alone. This information suggests that a more conservative approach be taken in some areas like Area 2B where the CEYs from the standard assessment may be artificially inflated due to spurious trends in CPUE.

BYCATCH

Adjustments to the allowable catch for bycatch shown in Table 1 and Table 2 represent compensation to the stock for losses in the stock's reproductive potential due to losses from bycatch. The allowable catch is reduced in line 1.4 of Table 1 and Table 2 by one pound for every pound of bycatch removed. The bycatch reduction in each area is made in proportion to the estimated exploitable biomass in that area.

BERING SEA CONSTANT EXPLOITATION YIELD

Information has recently become available that allows subarea specific quota recommendations for the Bering Sea to be developed using the same methodology that has been used in determining area specific CEYs from the combined 2A-2B assessment. The method uses historical fishing grounds as a measure of area and CPUE as a measure of density to partition total abundance for the area into separate abundances for each subarea to which the constant exploitation rate may be applied. Table 3 shows the Bering Sea subareas, the estimated habitat determined from historical fishing grounds, an average CPUE from data gathered over the last five years, the percent of the stock exploitable biomass associated with each subarea, and the subarea CEY resulting from the application of the 0.30 constant harvest rate. These subarea specific CEYs should be used in determining harvests that are proportional to biomass.

Table 1. 1994 Assessment of Yield – Rate = .30
Based on projected 1995 exploitable biomass.

		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1994 Quota	0.55*	10.00	11.00	26.00	4.00	5.40	56.95
	1994 Catch	0.58*	9.90	10.25	25.05	3.95	5.33	55.06
1.2	CEY	0.68*	13.82	13.94	31.16	4.96	8.08	72.63
1.3	OTHER CATCHES							
	Sport	— *	0.66	1.80	5.28	0.00	0.09	7.83
	Waste	0.01	0.30	0.41	1.82	0.14	0.17	2.85
	Bycatch	0.15	3.04	3.07	6.87	1.09	1.78	16.00
	Personal Use	0.00	0.30	0.11	0.33	0.06	0.12	0.92
	TOTAL	0.16	4.30	5.39	14.30	1.29	2.16	27.60
1.4	SETLINE CEY	0.52*	9.52	8.54	16.87	3.66	5.92	45.03

Estimates in million pounds by subarea.

* Sport catch included for area 2A.

Table 2. 1994 Assessment of Yield – Rate = .30
Based on 1994 exploitable biomass estimates.

		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1994 Quota	0.55*	10.00	11.00	26.00	4.00	5.40	56.95
	1994 Catch	0.58*	9.90	10.25	25.05	3.95	5.33	55.06
1.2	CEY	0.76*	15.69	16.79	37.03	5.52	8.97	84.78
1.3	OTHER CATCHES							
	Sport	— *	0.66	1.80	5.28	0.00	0.09	7.83
	Waste	0.01	0.30	0.41	1.82	0.14	0.17	2.85
	Bycatch	0.14	2.96	3.17	6.99	1.04	1.69	16.00
	Personal Use	0.00	0.30	0.11	0.33	0.06	0.12	0.92
	TOTAL	0.15	4.22	5.49	14.42	1.24	2.07	27.60
1.4	SETLINE CEY	0.61*	11.47	11.30	22.61	4.28	6.90	57.18

Estimates in million pounds by subarea.

* Sport catch included for area 2A.

Table 3. Area 4 Biomass Distribution

Area Name	Habitat Area	CPUE	Percent Biomass	Area CEY
4A	8183	386.85	41.3	2.44
4B	6118	246.24	19.6	1.16
4C	561	225.25	1.6	0.09
4DS	5019	422.31	27.6	1.63
4DN	586	436.13	3.3	0.20
4E	4910	100.50	6.4	0.38
Total	25,377	224.50	100.0	5.92

IPHC Stock Assessment

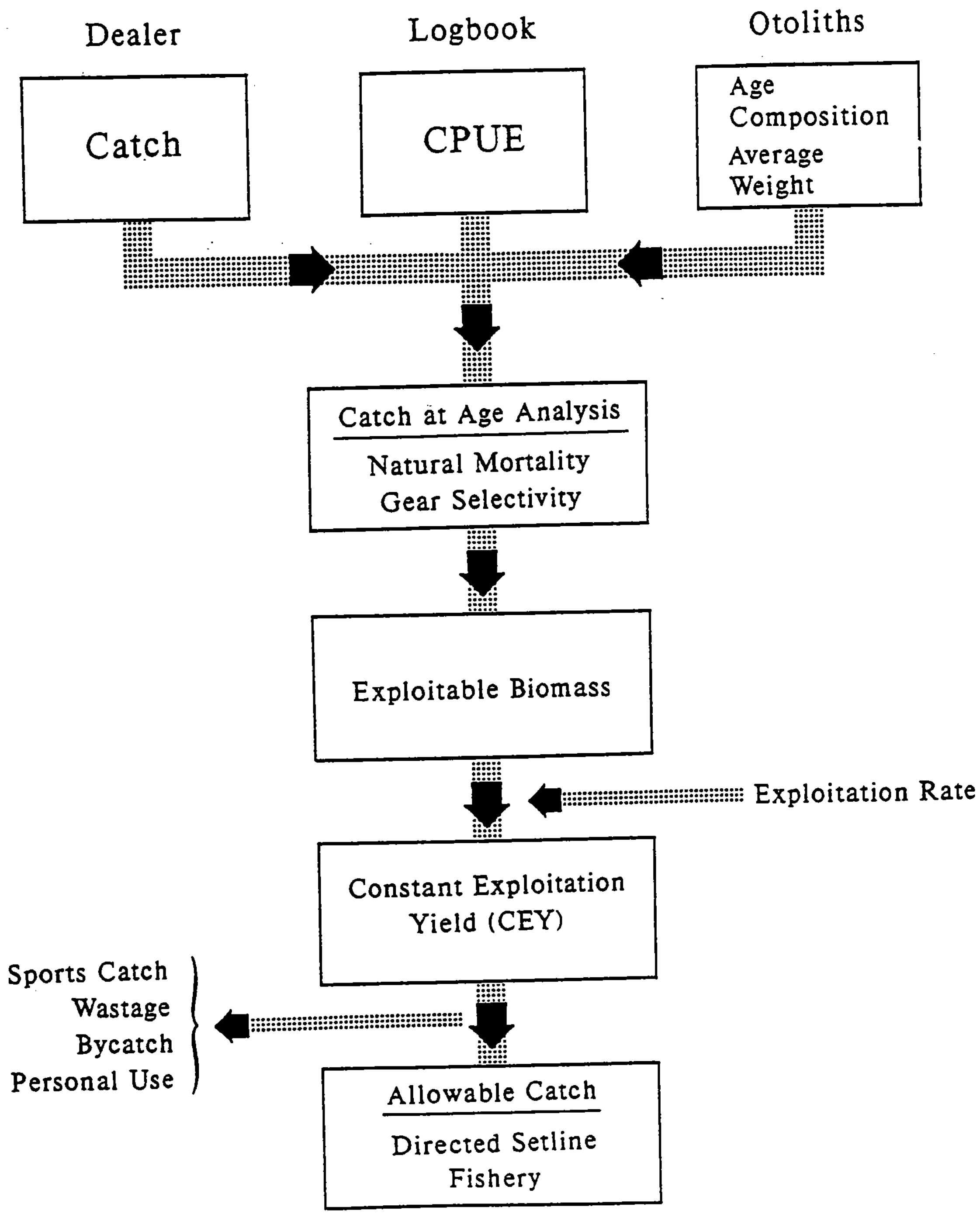


Figure 1

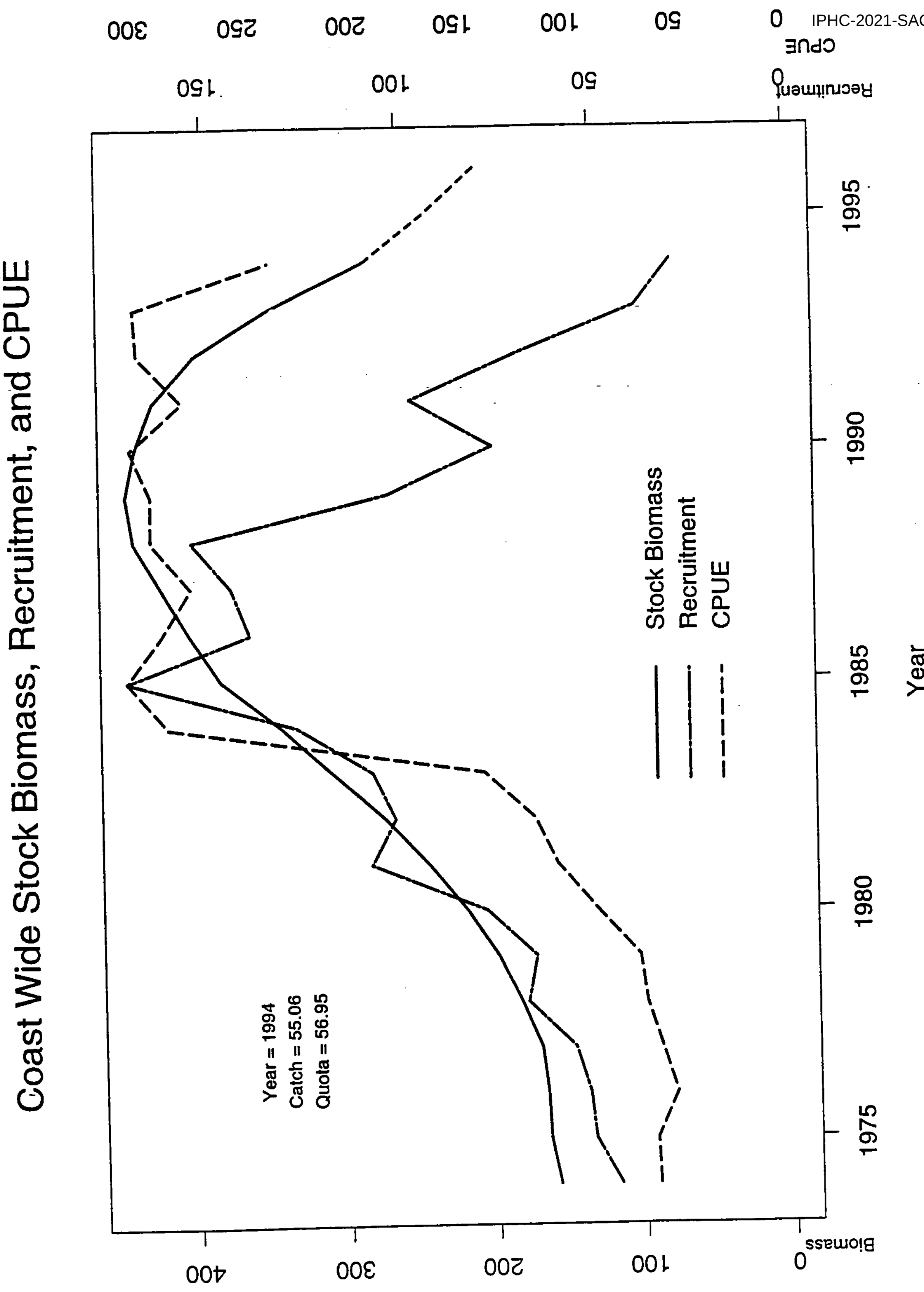


Figure 2. Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

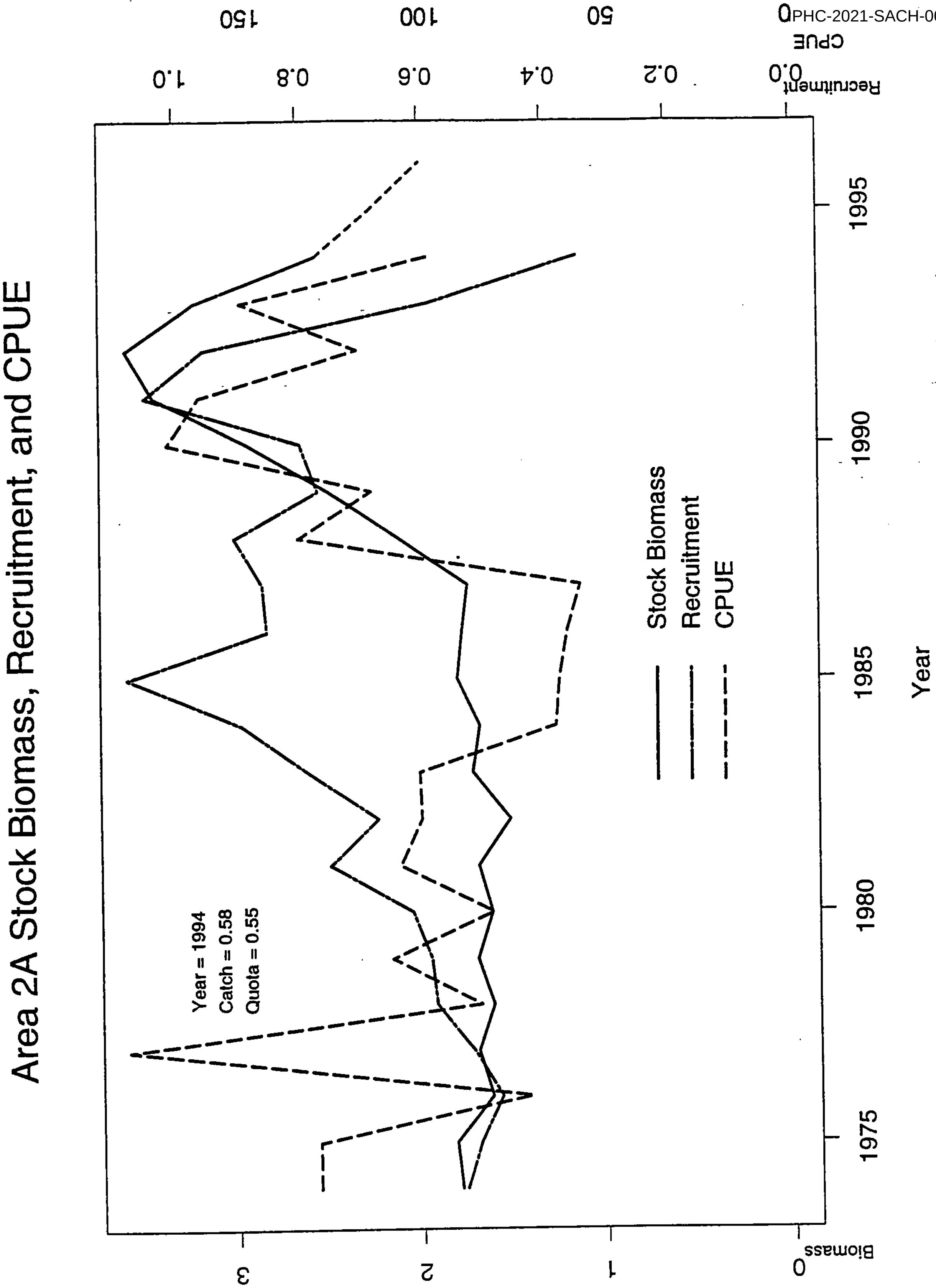


Figure 3. Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

Area 2B Stock Biomass, Recruitment, and CPUE

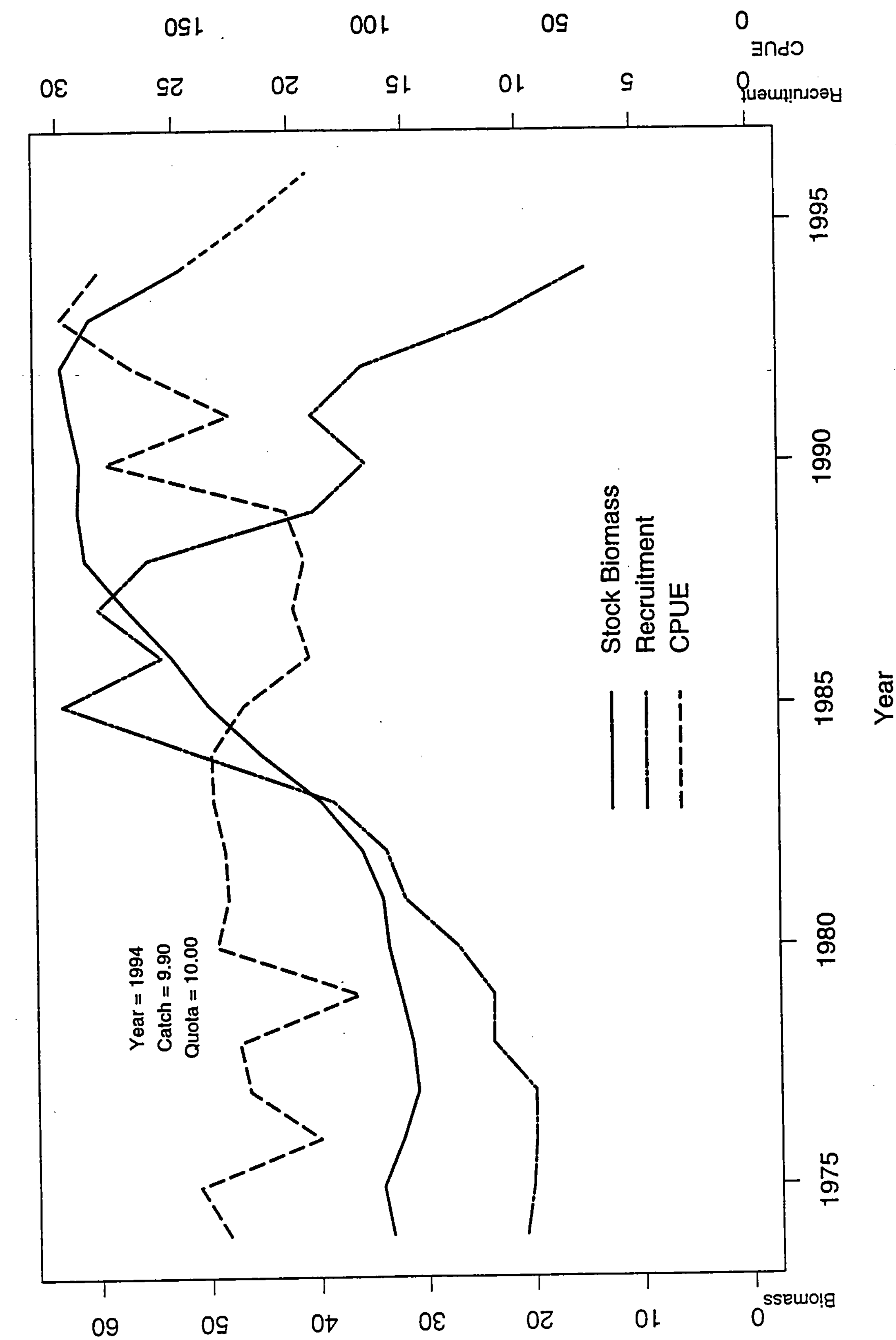


Figure 4. Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

68

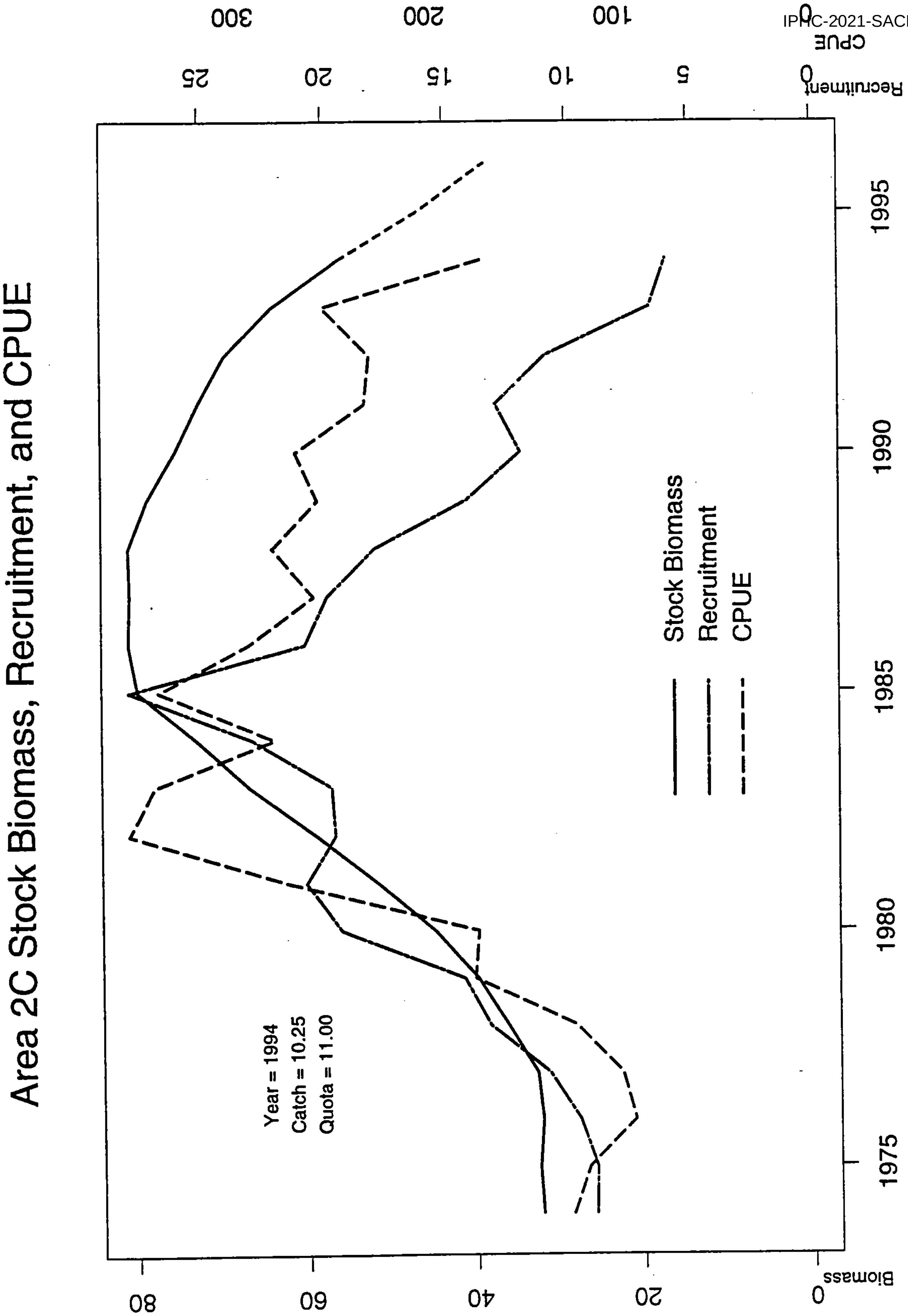


Figure 5. Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

69

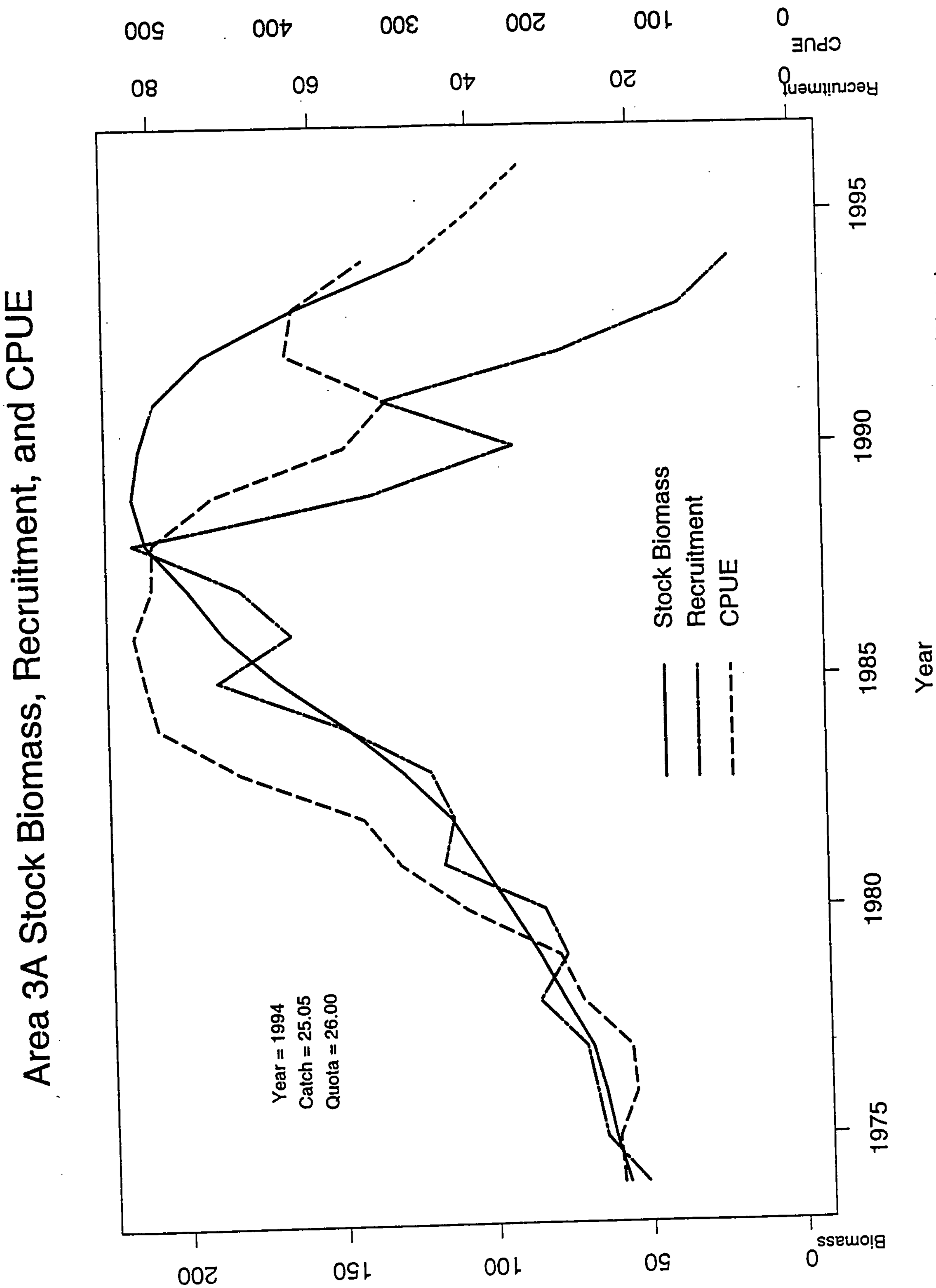


Figure 6. Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

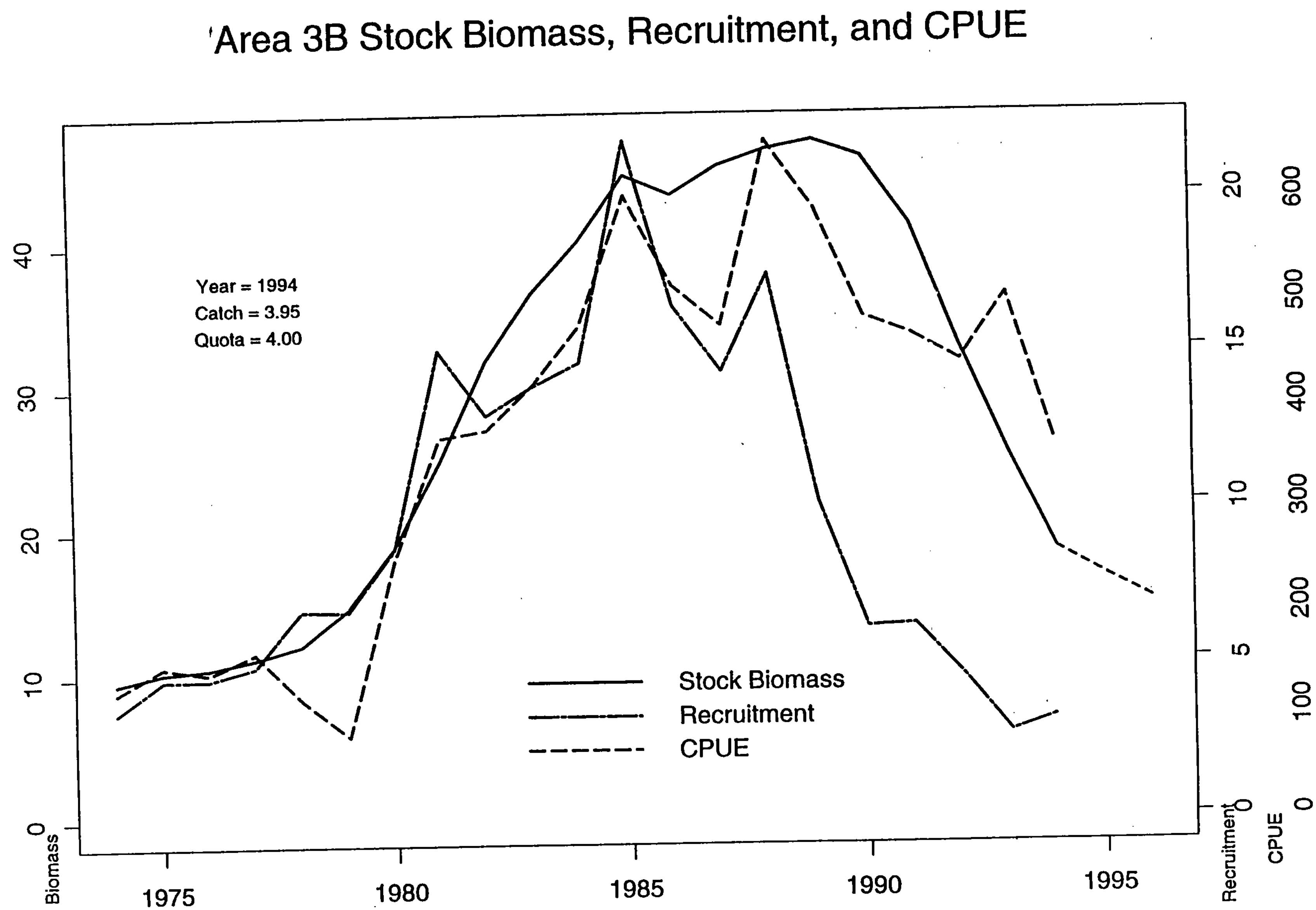


Figure 7. Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

Area 4 Stock Biomass, Recruitment, and CPUE

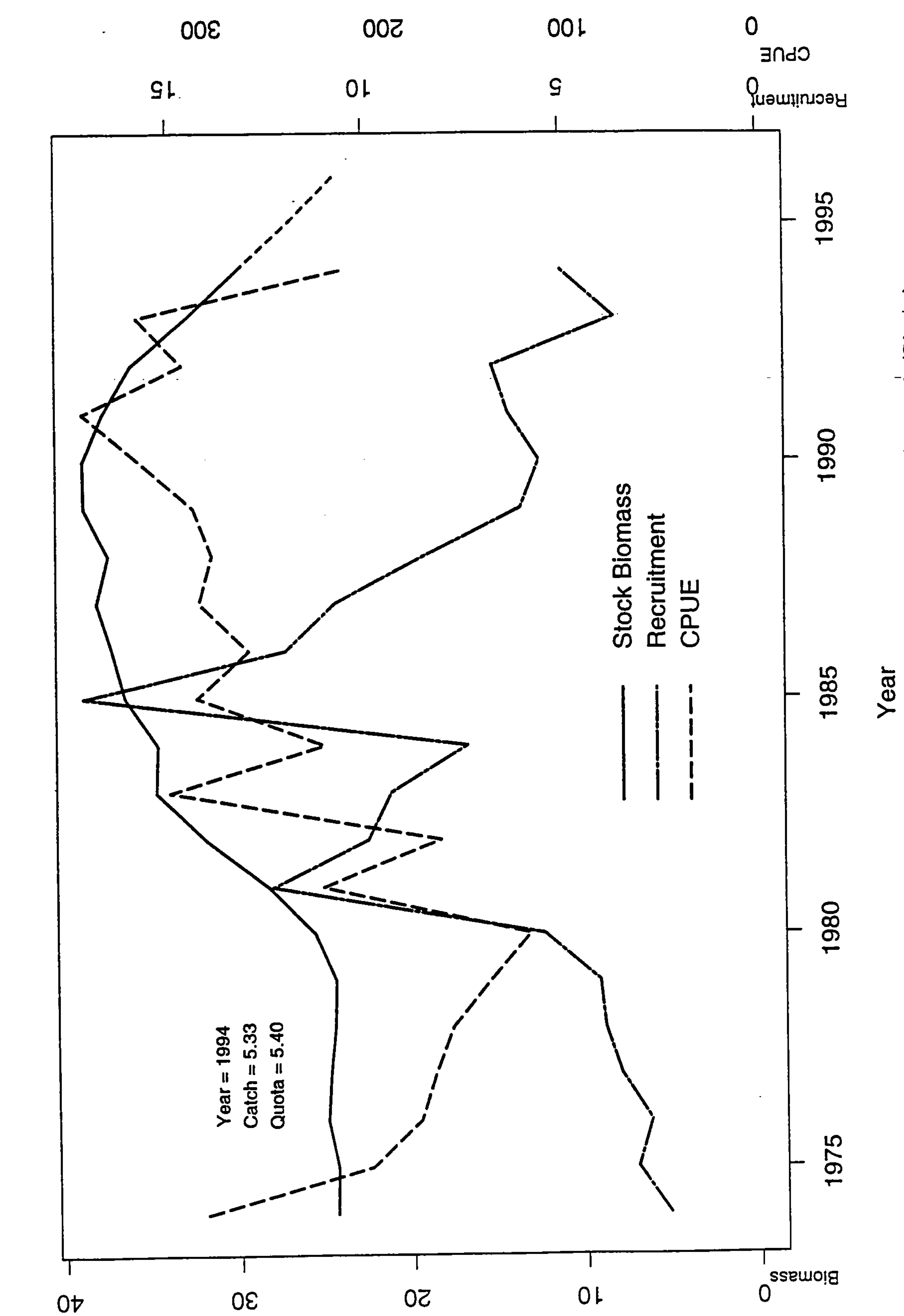


Figure 8. Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

72

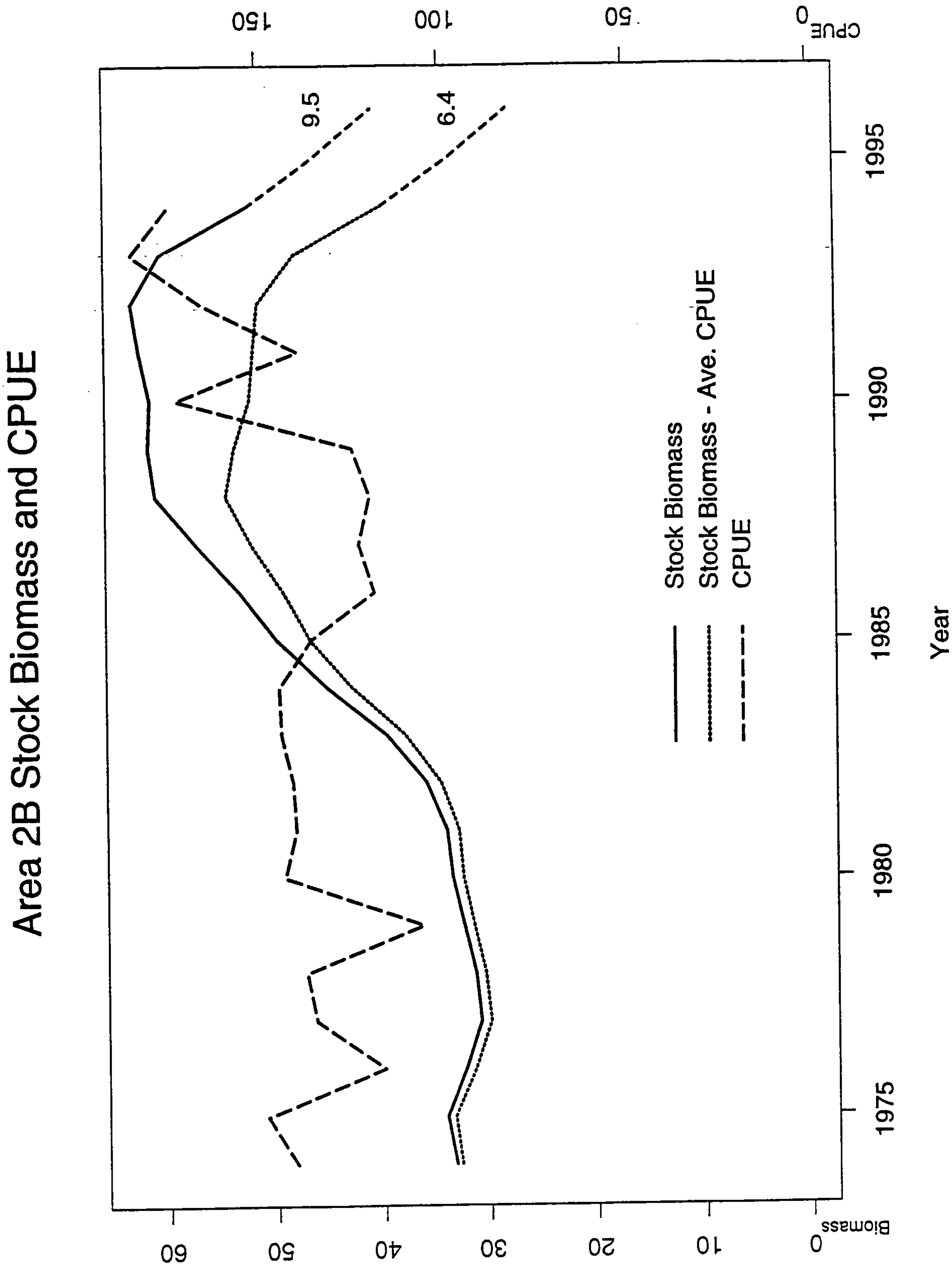


Figure 9. Biomass (Mil. Pounds), CPUE (Pounds/Skate)

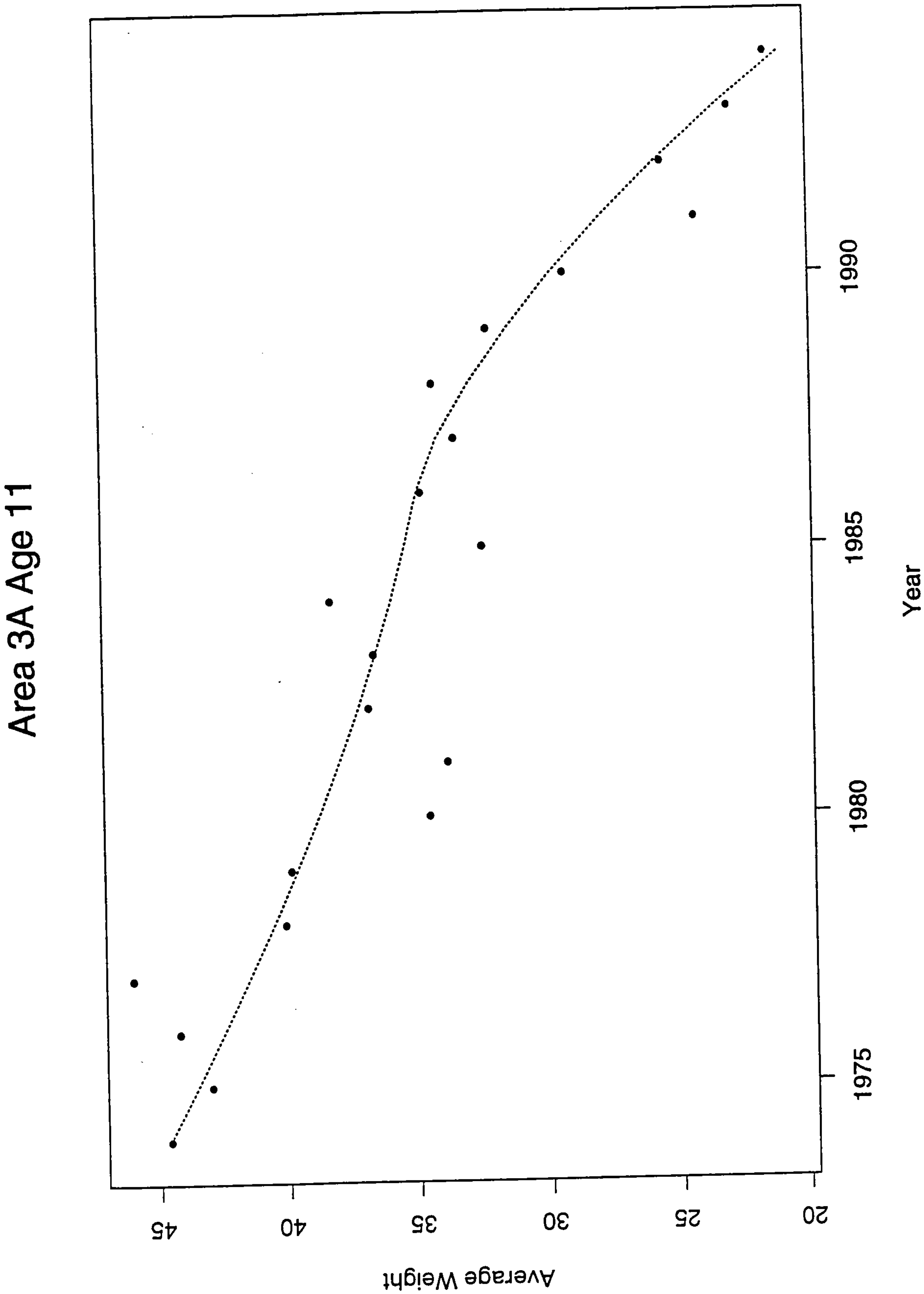

Area 3A Age 11
Average Weight
45
40
35
30
25
20
Year
1975
1980
1985
1990

Figure 10

POPULATION ASSESSMENT, 1994 TECHNICAL SUPPLEMENT

by

Patrick J. Sullivan, Ana M. Parma, and Richard C. Leickly

The tables and figures to follow provide more detail on the 1994 stock assessment.

Table A.1 shows commercial CPUE estimates adjusted to Circle hook standardized equivalence.
Table A.2 shows commercial catch of fish ages eight and older, pounds net weight, by area and year.
Table A.3 shows total removals, this represents the commercial catch with sport catch, and mortality from gear lost added.
Table A.4 shows the estimated exploitable biomass by area and year for the standard assessment and the projected 1995 values.
Table A.5 gives the estimated historical exploitation rate calculated as total removals divided by exploitable biomass.
Table A.6 shows the annual surplus production (ASP), provided for historical comparisons.
Table A.7 shows the estimated total instantaneous fishing mortality rates.
Table A.8 provides estimates of 8-year-old recruitment in millions of pounds.

Because the total catch values used in the stock assessment include sport catch and wastage the exploitation rates given in Tables A.5 and A.10 and the mortality rates shown in Tables A.7 and A.12 are slightly higher than the rates resulting from commercial fishing alone. The values shown in Tables A.5, A.7, A.10, and A.12 can be used to examine the relative harvest rate in each area under the historical harvest time series. Tables A.4 through A.8 are estimates from the CAGEAN routine under the standard assessment. The entries throughout these tables will change each year as updated and more recent information become available.

Figures A.1 through A.6 show the fit of the model to the observed data under the standard assessment. The heights of the blocks represent the observed values while the heights of the lines represent the estimated values. Figure A.1 shows the observed versus estimated efforts for each closed area run. Figures A.2 through A.6 show the observed versus estimated catches for Areas 2A-2B, 2C, 3A, 3B, and 4 respectively. The figures are to scale across both age and time.

A new version of CAGEAN, called CageanS, has been implemented this year and its development is documented in the report entitled "Catch-at-age Analysis Using CageanS: An Object-Oriented Implementation of CAGEAN" by Leickly and Sullivan. The new S based estimation procedure derives the same estimates as the old VMS fortran version, but it has all the functionality of the object oriented programming language in the statistical environment provided using Splus.

Sullivan, P.J., Parma, A.M., 1995. Population assessment, 1994. IPHC Rep. Assess. Res. Act. 1994., pp. 59–84.

A new data preprocessing procedure was also implemented to take raw data from the IPHC Ingres database and compile object data files for use by CageanS in Splus. The new preprocesser replaces the series of fortran programs described in the 1991 RARA report "Assessment Methods" by Sullivan, Parma, and Vienneau. The resulting data objects for use in CageanS are the same as those used in CAGEAN except that a loess smoother now replaces the Velleman smoother that was applied to the average weights at age. Smoothers are applied to weight at age across years to stabilize the biomass estimates, which are based on the abundance at age estimates. The loess smoother with a 15 year running bandwidth and a symmetric weighting distribution was found to be more robust on the tail points and better at tracking trends than the median based Velleman procedure. Figure A.7 contrasts the fit between results from the two smoothing approaches.

Briefly, the preprocesser performs the following tasks: 1) Reads in the Ingres data from external ASCII files; 2) Modifies the catch-at-age and catch-per-unit-effort data from the commercial database to reflect total removals (i.e. commercial plus sportcatch and wastage); 3) Truncates the age composition data at age 8 and pools information on age groups that are 20 and older for smoothing; 4) Smooths weights at age for age classes 8 through 20+ using the loess smoother; 5) Pools information for ages 17 and older; (Pooling to 20 before smoothing and to 17 after smoothing makes the best use of the information available for the older cohorts so that changes in weight at age in the pooled groups can follow the changes brought about by a cohort passing through.) 6) Combines data for Areas 2A and 2B for a joint assessment; 7) Creates Splus data objects for analysis and input into CageanS.

A Splus function was developed to project the stock biomass ahead one year to the start of the current season by taking the terminal biomass estimate, removing the catch, adjusting for growth, and adding in an estimate of recruitment. The calculations take place in a standard way by using the abundance at age estimates and passing them through the estimated mortality, adding a year to the age identifier, and applying the terminal weight-at-age to calculate biomass. Recruitment of 8-year-olds for the upcoming year is based on an average of the estimated recruitment of the previous five years.

Table A.1 Commercial CPUE* (pounds per skate)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	130.7	141.0	126.0	142.4	124.7	301.1	137.9
1975	130.6	148.7	117.4	145.3	149.3	210.7	139.7
1976	71.7	116.7	92.8	131.5	142.2	184.2	118.5
1977	182.2	135.3	99.4	134.6	161.3	176.2	133.1
1978	85.5	138.0	124.1	171.9	116.4	166.6	148.0
1979	110.0	105.8	176.6	189.0	80.8	146.1	154.6
1980	82.0	143.7	174.7	260.6	249.5	124.2	197.6
1981	107.6	140.6	273.6	313.5	368.3	236.8	239.1
1982	101.6	141.4	355.9	342.6	375.8	172.5	261.3
1983	102.1	144.4	342.8	437.0	419.4	320.0	311.4
1984	64.3	144.8	280.8	500.3	475.2	235.6	285.7
1985	63.3	136.1	340.7	509.9	602.4	304.8	302.4
1986	61.1	118.6	294.0	517.9	514.8	276.5	288.1
1987	57.4	122.8	260.3	503.6	476.1	303.6	272.4
1988	135.4	119.8	281.3	502.8	654.2	296.4	296.8
1989	115.1	124.5	258.0	456.0	590.0	306.4	293.4
1990	171.2	172.4	269.1	352.9	483.6	336.2	301.5
1991	162.6	139.3	233.2	318.6	466.4	366.3	277.5
1992	118.9	165.6	230.5	397.1	440.2	312.4	297.5
1993	151.0	184.2	255.1	390.8	504.6	336.9	301.1
1994	98.5	173.9	170.6	335.8	359.4	224.5	240.1

* Standardized C hook equivalence.

Table A.2 Commercial Catch (million pounds)

	AREA						
Year	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	0.50	10.63	11.29	22.74	7.86	6.25	59.27
1994	0.38	9.90	10.25	25.05	3.95	5.33	54.85

Estimates in million pounds by subarea.

Table A.3 Total Removals (million pounds)

Year	AREA 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	15.06	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	36.56	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	74.50
1990	0.52	9.41	11.30	33.38	8.91	5.69	69.21
1991	0.52	7.83	10.69	28.24	12.35	6.31	65.93
1992	0.70	8.26	11.73	31.32	8.80	6.78	67.59
1993	0.76	11.38	13.29	28.34	7.92	6.44	68.13
1994	0.56	10.63	12.31	31.33	3.99	5.52	64.35

Estimates in million pounds by subarea.

Sullivan, P.J., Parma, A.M., 1995. Population assessment, 1994. IPHC Rep. Assess. Res. Act. 1994., pp. 59–84.

Table A.4 Exploitable Biomass (Closed Subarea)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	1.79	33.27	32.32	57.26	9.56	24.43	158.64
1975	1.82	34.12	32.66	61.55	10.29	24.38	164.82
1976	1.62	32.30	32.24	64.46	10.55	24.95	166.11
1977	1.69	30.82	32.85	68.43	11.21	24.78	169.79
1978	1.61	31.33	36.30	76.95	12.10	24.49	182.77
1979	1.69	32.38	39.76	84.97	14.58	24.41	197.79
1980	1.61	33.43	44.86	93.99	18.79	25.62	218.31
1981	1.69	33.94	51.60	103.36	24.78	28.27	243.65
1982	1.51	35.84	58.95	113.19	31.74	31.86	273.10
1983	1.71	39.62	66.70	128.96	36.49	34.71	308.18
1984	1.68	45.11	72.86	147.65	40.02	34.61	341.92
1985	1.79	49.79	79.76	169.35	44.63	36.48	381.81
1986	1.77	53.13	80.81	186.18	43.28	37.19	402.35
1987	1.74	57.22	80.70	197.79	45.24	38.08	420.76
1988	2.11	61.01	80.82	211.09	46.32	37.41	438.76
1989	2.49	61.64	78.65	215.17	46.93	38.79	443.67
1990	2.93	61.46	75.35	212.78	45.81	38.84	437.17
1991	3.43	62.41	72.55	207.82	41.17	37.69	425.06
1992	3.57	63.10	69.44	191.98	32.56	36.07	396.71
1993	3.21	60.45	63.91	161.56	25.17	32.85	347.15
1994	2.55	52.30	55.97	123.45	18.41	29.90	282.59
1995	2.25	46.07	46.45	103.88	16.52	26.92	242.09

Estimates in million pounds by subarea.

Table A.5 Historical Exploitation Rates (Closed Subarea)

	AREA							
Year	2A	2B	2C	3A	3B	4	Total	+Bycatch
1974	0.29	0.14	0.17	0.14	0.17	0.03	0.13	0.25
1975	0.25	0.21	0.19	0.17	0.25	0.03	0.17	0.24
1976	0.15	0.23	0.17	0.17	0.26	0.03	0.17	0.25
1977	0.13	0.18	0.10	0.13	0.28	0.05	0.13	0.20
1978	0.07	0.15	0.12	0.14	0.11	0.06	0.12	0.19
1979	0.04	0.15	0.12	0.14	0.03	0.06	0.12	0.19
1980	0.02	0.17	0.08	0.13	0.01	0.03	0.10	0.19
1981	0.13	0.17	0.08	0.14	0.02	0.04	0.11	0.17
1982	0.17	0.16	0.07	0.13	0.15	0.05	0.11	0.15
1983	0.19	0.14	0.10	0.12	0.21	0.13	0.13	0.16
1984	0.33	0.20	0.09	0.14	0.16	0.09	0.14	0.17
1985	0.38	0.22	0.13	0.14	0.25	0.12	0.16	0.18
1986	0.52	0.22	0.15	0.20	0.21	0.16	0.19	0.21
1987	0.60	0.23	0.15	0.18	0.18	0.19	0.18	0.21
1988	0.35	0.22	0.16	0.20	0.16	0.13	0.19	0.22
1989	0.32	0.18	0.14	0.18	0.17	0.13	0.17	0.20
1990	0.18	0.15	0.15	0.16	0.19	0.15	0.16	0.20
1991	0.15	0.13	0.15	0.14	0.30	0.17	0.16	0.19
1992	0.20	0.13	0.17	0.16	0.27	0.19	0.17	0.21
1993	0.24	0.19	0.21	0.18	0.31	0.20	0.20	0.24
1994	0.22	0.20	0.22	0.25	0.22	0.18	0.23	0.28

Estimates in million pounds by subarea.

Sullivan, P.J., Parma, A.M., 1995. Population assessment, 1994. IPHC Rep. Assess. Res. Act. 1994., pp. 59–84.

Table A.6 Annual Surplus Production (Closed Subarea)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	0.55	5.47	5.94	12.47	2.40	0.66	27.5
1975	0.26	5.30	5.82	13.51	2.81	1.19	28.91
1976	0.31	5.81	6.14	15.01	3.39	0.55	31.22
1977	0.14	5.95	6.71	17.36	4.07	0.93	35.16
1978	0.19	5.67	7.86	18.61	3.80	1.27	37.4
1979	-0.01	5.93	9.81	20.72	4.61	2.59	43.64
1980	0.11	6.17	10.31	21.84	6.26	3.36	48.05
1981	0.05	7.57	11.67	24.80	7.41	4.79	56.29
1982	0.46	9.38	11.74	30.01	9.55	4.29	65.43
1983	0.29	11.04	13.11	33.75	11.28	4.33	73.79
1984	0.67	13.85	13.38	42.69	11.12	5.04	86.75
1985	0.66	14.36	11.15	39.83	9.73	5.15	80.87
1986	0.89	15.89	11.66	48.16	11.19	6.81	94.59
1987	1.41	16.74	11.96	48.18	9.19	6.49	93.97
1988	1.12	14.04	10.47	46.72	7.81	6.18	86.35
1989	1.24	10.93	7.99	35.80	6.91	5.13	68.01
1990	1.02	10.36	8.51	28.42	4.27	4.53	57.1
1991	0.66	8.52	7.57	12.40	3.73	4.69	37.58
1992	0.34	5.61	6.20	0.91	1.42	3.55	18.03
1993	0.10	3.23	5.35	-9.76	1.16	3.49	3.58
1994	0.08	2.79	4.69	-7.46	0.85	3.18	2.91

Estimates in million pounds by subarea.

Table A.7 Fishing Mortality (Closed Subarea)

Year	AREA				
	2A+2B	2C	3A	3B	4
1974	0.14	0.21	0.19	0.21	0.03
1975	0.23	0.24	0.25	0.30	0.03
1976	0.21	0.21	0.23	0.27	0.03
1977	0.16	0.12	0.17	0.31	0.06
1978	0.13	0.14	0.19	0.13	0.05
1979	0.14	0.13	0.18	0.03	0.05
1980	0.17	0.11	0.21	0.02	0.02
1981	0.17	0.10	0.21	0.02	0.05
1982	0.14	0.07	0.16	0.16	0.04
1983	0.13	0.11	0.15	0.22	0.15
1984	0.18	0.10	0.17	0.17	0.12
1985	0.21	0.16	0.20	0.34	0.14
1986	0.21	0.17	0.27	0.23	0.17
1987	0.21	0.17	0.24	0.21	0.21
1988	0.22	0.19	0.28	0.17	0.13
1989	0.19	0.18	0.24	0.18	0.15
1990	0.14	0.17	0.21	0.23	0.15
1991	0.10	0.16	0.20	0.38	0.17
1992	0.12	0.20	0.23	0.35	0.21
1993	0.18	0.24	0.25	0.41	0.21
1994	0.20	0.30	0.32	0.22	0.21

Sullivan, P.J., Parma, A.M., 1995. Population assessment, 1994. IPHC Rep. Assess. Res. Act. 1994., pp. 59–84.

Table A.8 Recruitment Biomass (Closed Subarea)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	0.5	9.9	8.9	19.8	3.5	2.3	44.9
1975	0.5	9.6	8.9	24.8	4.5	3.1	51.4
1976	0.5	9.4	9.6	25.9	4.5	2.8	52.7
1977	0.5	9.4	10.8	27.1	4.9	3.5	56.3
1978	0.6	11.3	13.2	32.8	6.7	3.9	68.4
1979	0.6	11.2	14.3	29.3	6.6	4.1	66.1
1980	0.6	12.8	19.3	31.9	8.6	5.5	78.7
1981	0.8	15.1	20.7	44.5	15.1	12.4	108.5
1982	0.7	15.9	19.5	43.2	13.0	9.9	102.2
1983	0.8	18.2	19.7	46.1	13.9	9.3	107.9
1984	0.9	24.1	22.9	57.3	14.6	7.4	127.1
1985	1.1	29.9	27.9	72.5	21.7	17.2	170.2
1986	0.9	25.6	20.8	63.4	16.4	12.0	139.0
1987	0.9	28.3	19.8	69.7	14.3	10.7	143.7
1988	0.9	26.2	17.9	82.8	17.4	8.4	153.6
1989	0.8	19.0	14.1	53.0	10.1	6.0	103.0
1990	0.8	16.7	11.9	34.9	6.1	5.5	75.9
1991	1.0	19.1	12.9	51.4	6.1	6.3	96.9
1992	1.0	16.8	10.8	29.1	4.5	6.7	69.0
1993	0.6	11.0	6.5	14.1	2.7	3.6	38.5
1994	0.3	7.0	5.9	7.8	3.2	5.0	29.2

Estimates in million pounds by subarea.

Effort

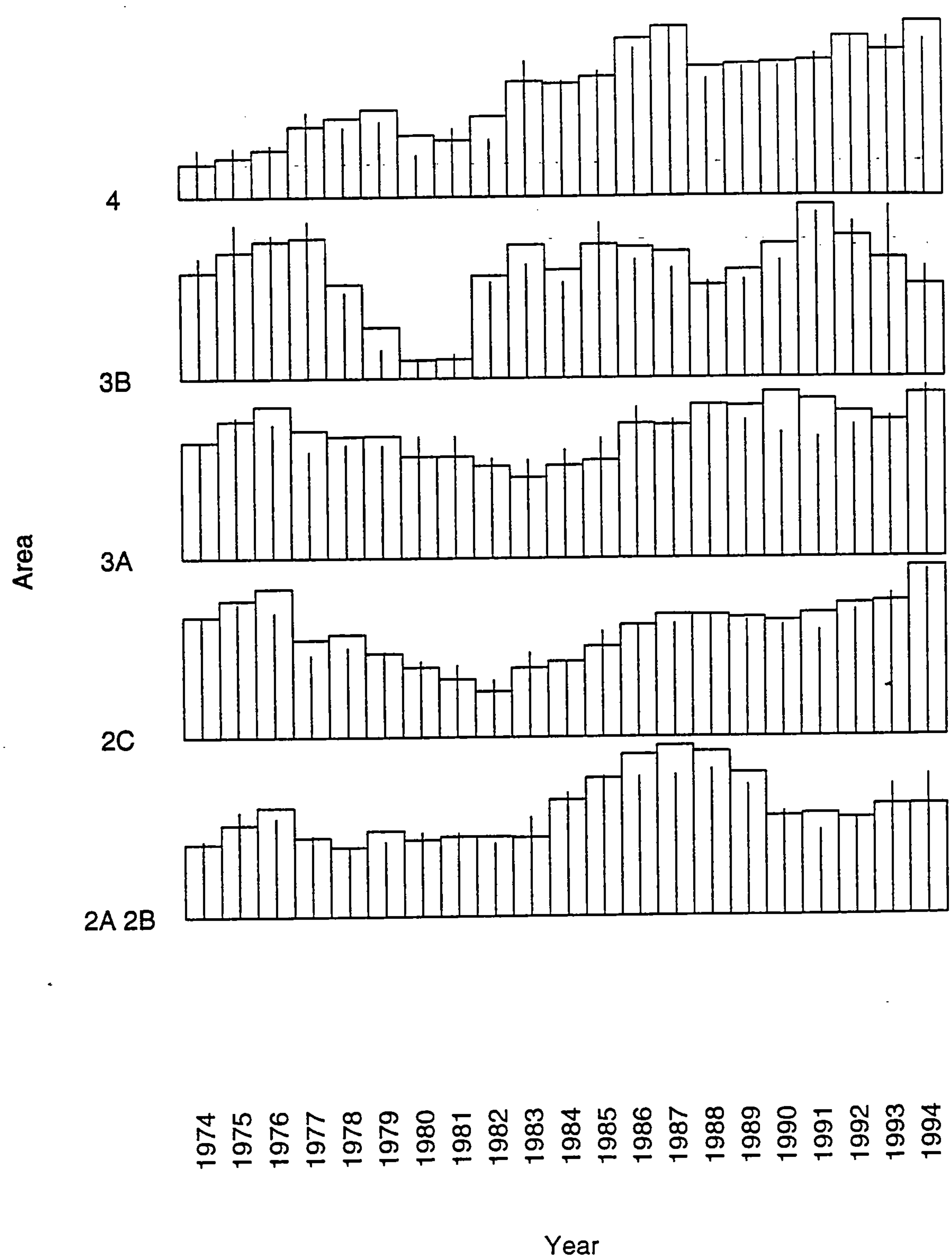


Figure A.1

Area 2A-2B Age Composition

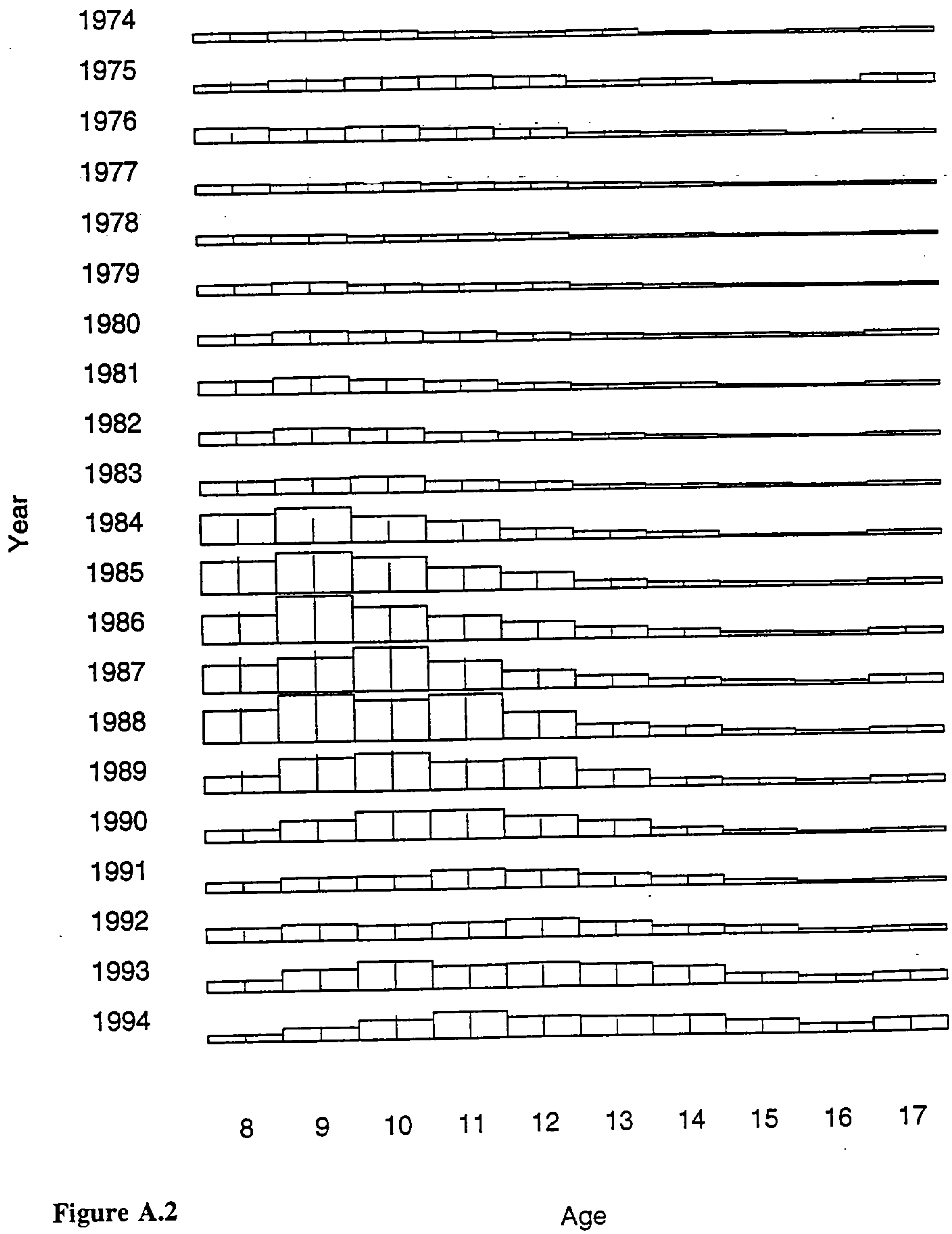


Figure A.2

Area 2C Age Composition

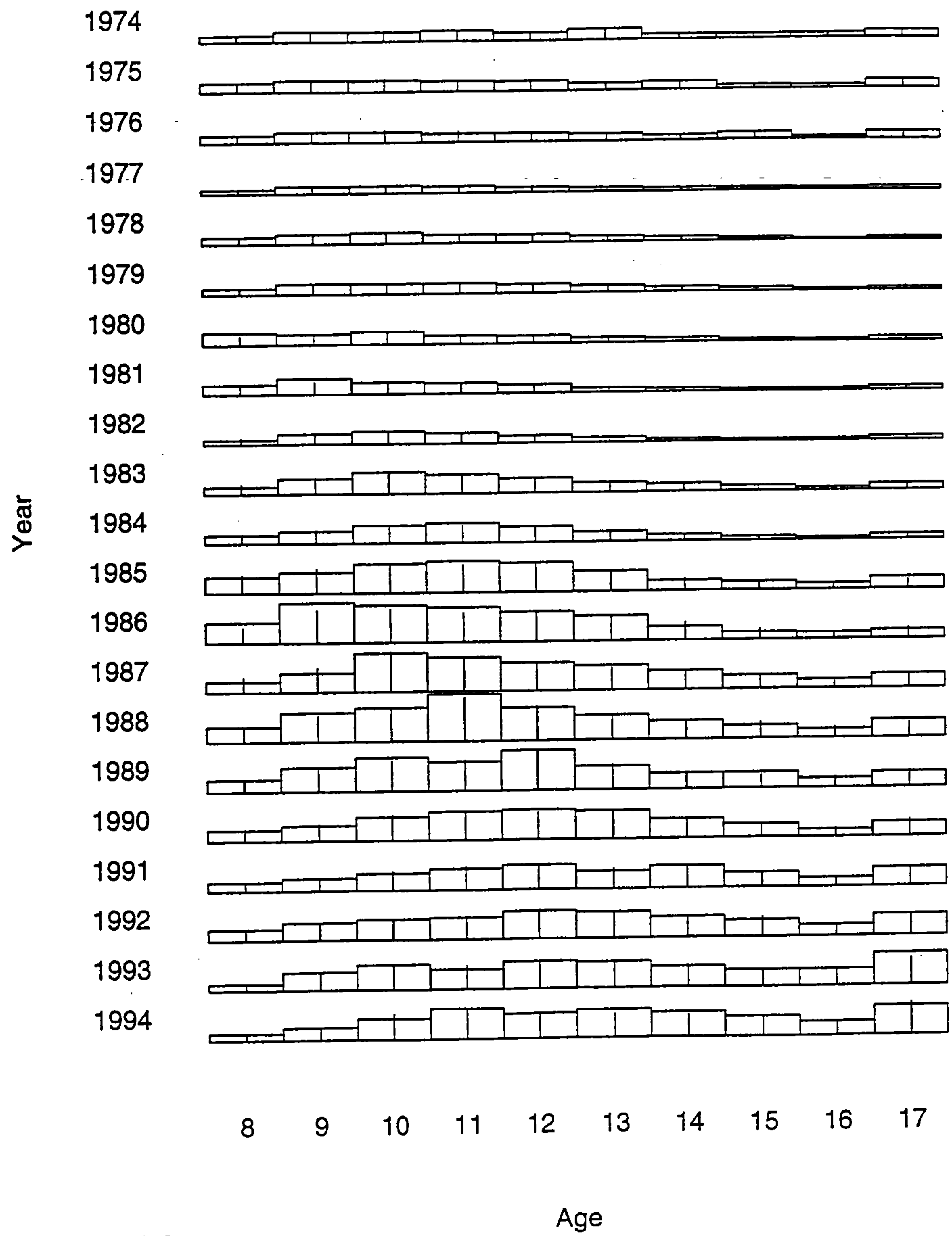


Figure A.3

Sullivan, P.J., Parma, A.M., 1995. Population assessment, 1994. IPHC Rep. Assess. Res. Act. 1994., pp. 59–84.

Area 3A Age Composition

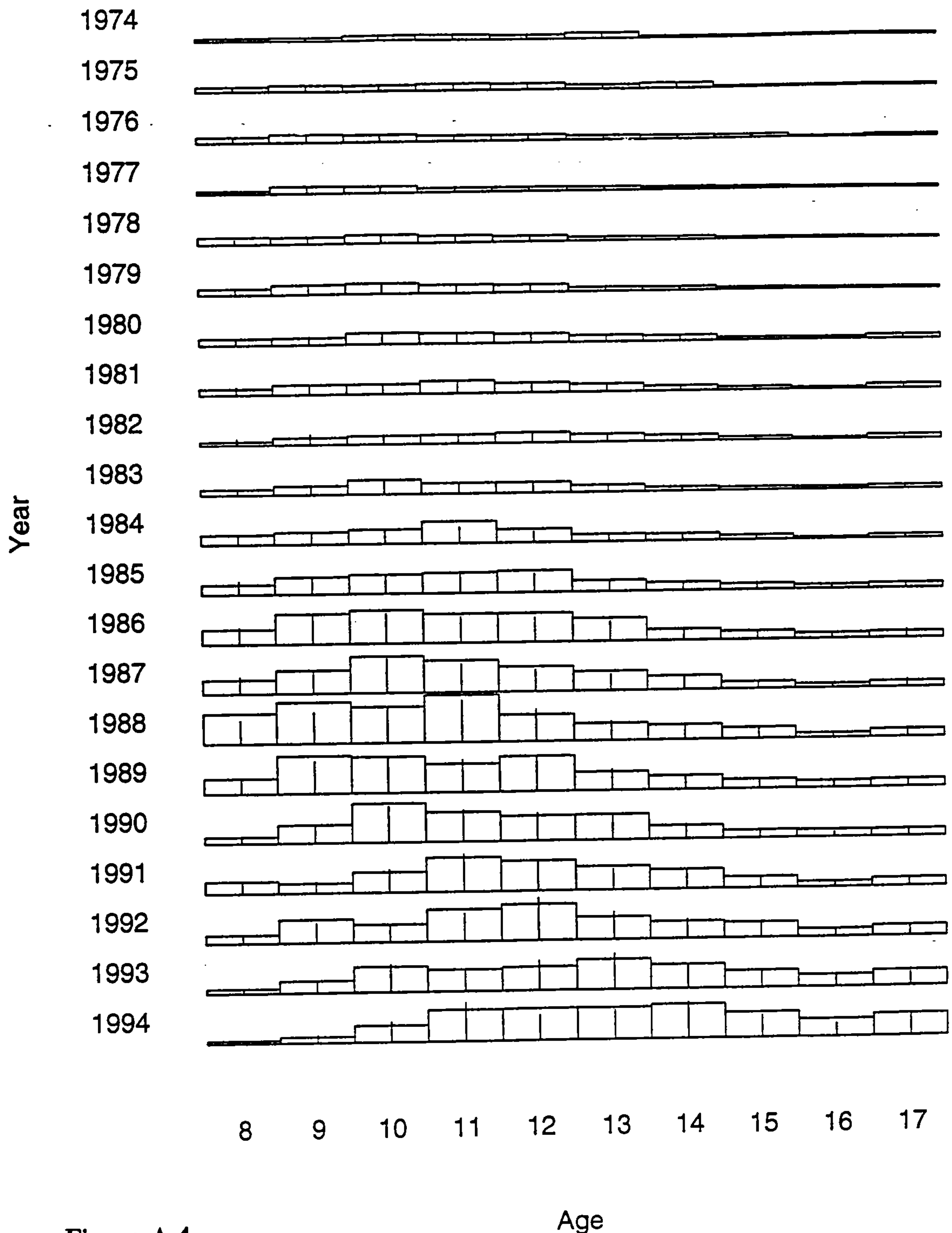
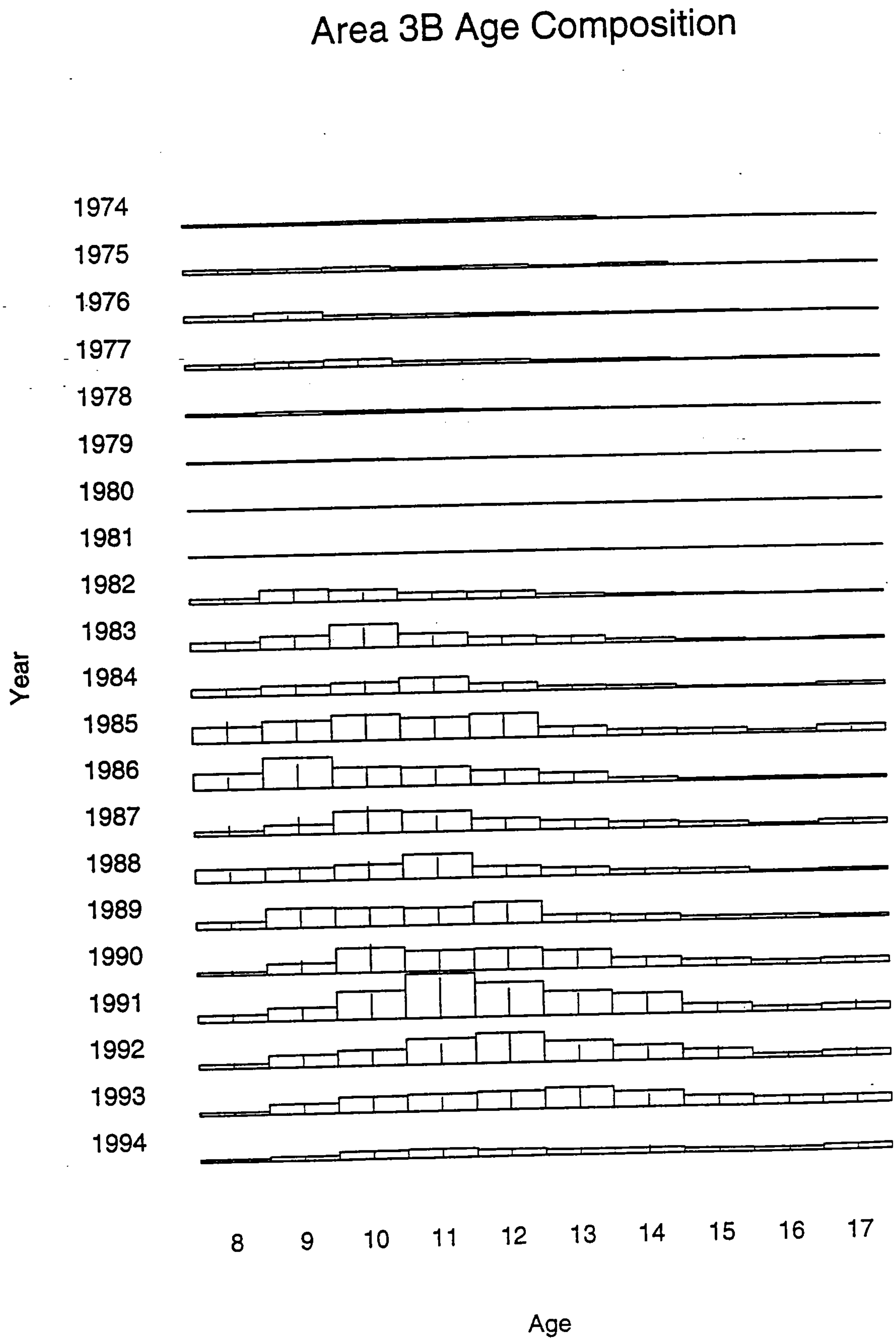


Figure A.4



Area 3B Age Composition
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
Year
8
9
10
11
12
13
14
15
16
17
Age

Figure A.5

Area 4 Age Composition

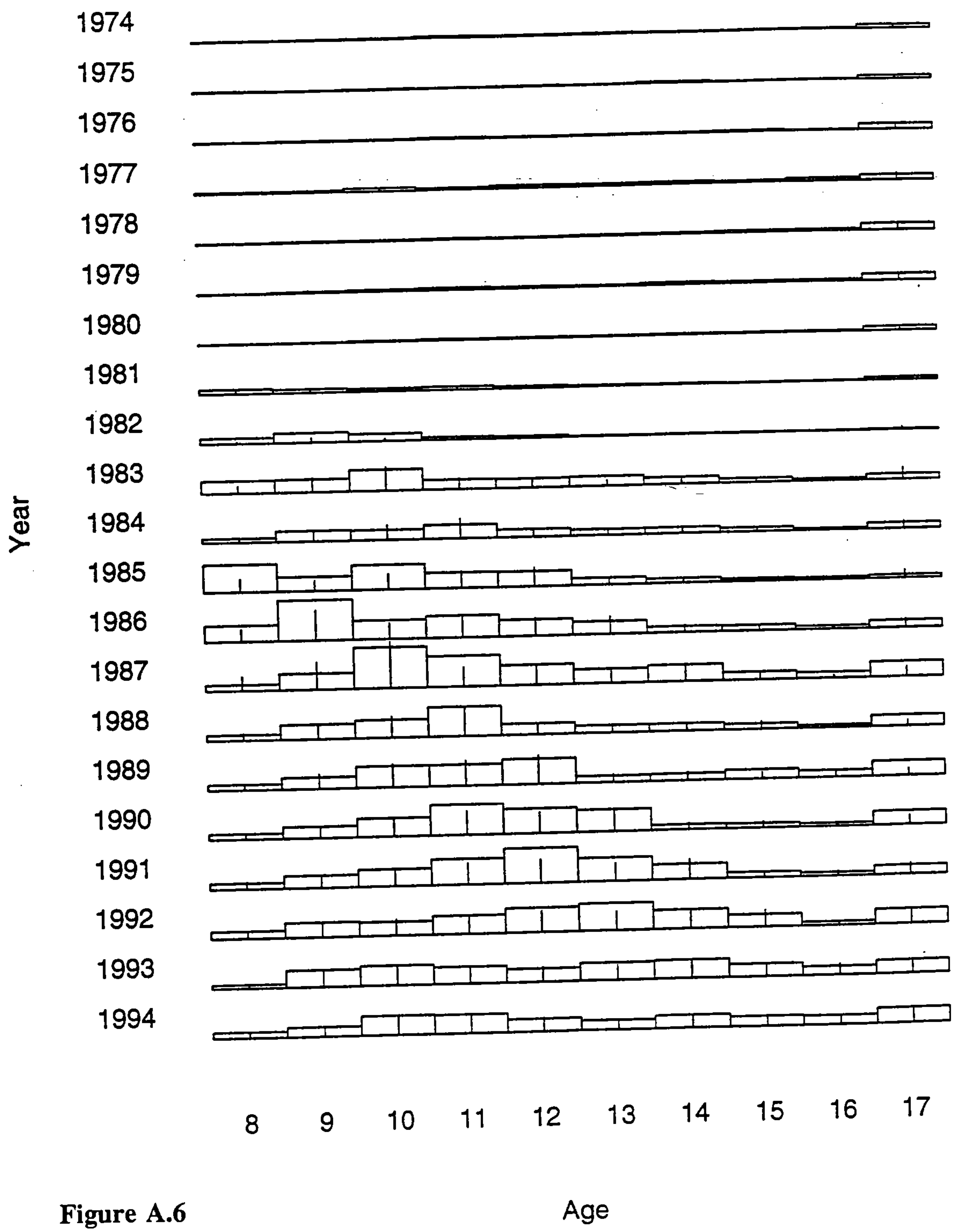
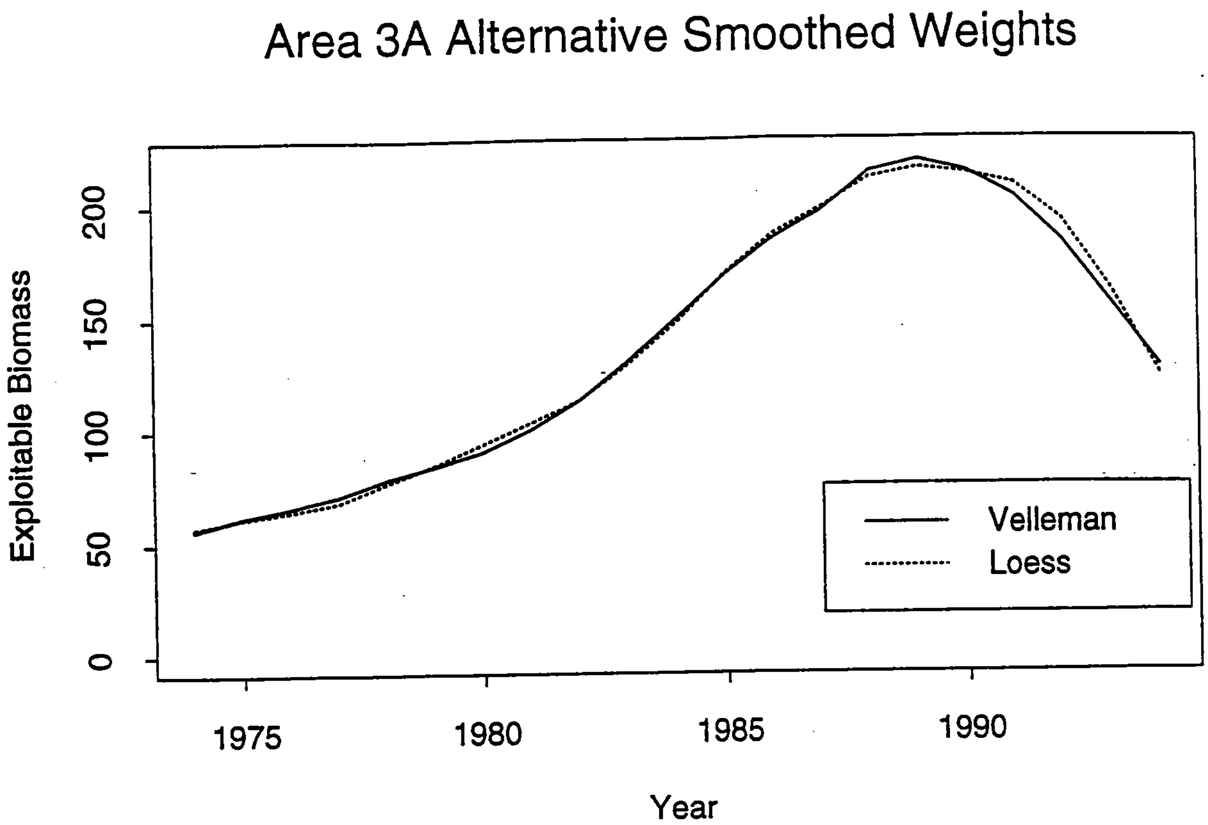


Figure A.6


Area 3A Alternative Smoothed Weights
Exploitable Biomass
0
50
100
150
200
1975
1980
1985
1990
Year
Velleman
Loess

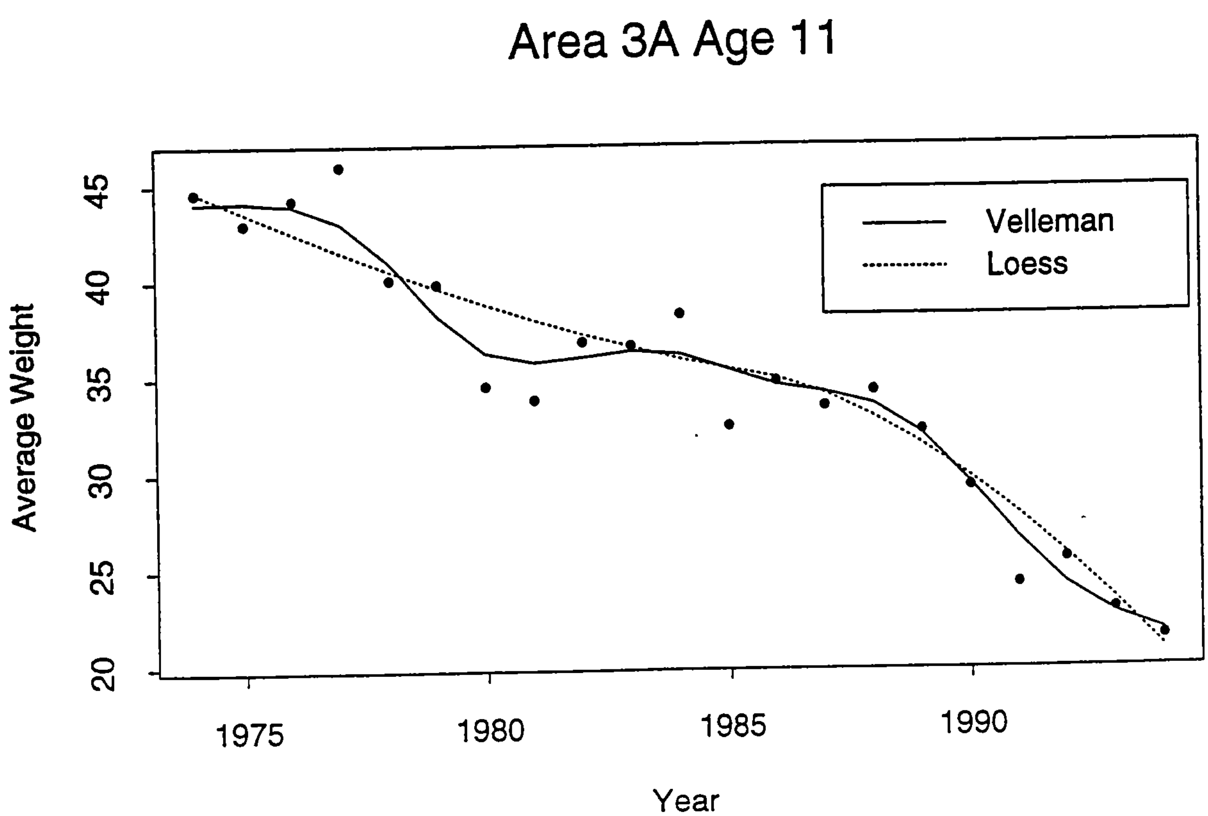

Area 3A Age 11
Average Weight
20
25
30
35
40
45
1975
1980
1985
1990
Year
Velleman
Loess

Figure A.7

POPULATION ASSESSMENT, 1993

by

Patrick J. Sullivan

INTRODUCTION

The 1993 assessment of Pacific halibut contrasts catch at age with catch per unit of effort in order to estimate stock abundance and examine stock trends. The analysis is conducted by area and applied to data from Areas 2A-2B, 2C, 3A, 3B, and 4. Information is collected annually on catch, catch per unit effort (CPUE), age composition, and average weight at age. This data is used to determine the exploitable biomass -- the stock biomass available for harvest. The constant exploitation yield (CEY) is determined by applying a 0.30 harvest rate factor to the estimated exploitable biomass. The yield resulting from the application of this rate represents a little less than a third of the exploitable biomass. Given the CEY, the recommended allowable catch is determined by accounting for removals from other sources (sport catch, wastage, bycatch, and personal use). The procedure is outlined in Figure 1.

STOCK ASSESSMENT

Each year the standard stock assessment is explored for inconsistencies that might result from disparate signals received from the stock through catch at age and CPUE. Sometimes the signals are mixed and the degree of consistency in the signals will indicate the degree of caution that must be exercised in determining catch quotas. This year's standard stock assessment is contrasted with an alternative assessment that discounts the upturn in CPUE observed over the last few years. The upturn in CPUE appears to run counter to what one would expect in stock trends based on catch-at-age information. These trends should reflect the diminishment of several strong year-classes and the subsequent period of poor recruitment. The upturn in CPUE appears to have been a coast-wide phenomenon, but the degree to which this upturn has affected the assessment appears to be area specific. The total exploitable biomass of Pacific halibut in 1993 was determined to be 300.4 million pounds in the standard assessment and 249.8 million pounds in the alternative assessment which discounts the effect of CPUE for the years 1992 and 1993. This represents an overall decline in biomass of 12% and 15% respectively this year. These rates are higher than the 5-10% declines observed in previous years. Figure 2 shows the trends in exploitable biomass, recruitment, and CPUE for the total stock. Figures 3 through 8 give the area-by-area trends. The upper edge of the shaded region depicting stock biomass represents the standard assessment and the lower edge represents the alternative assessment. The trends in the estimated exploitable biomass indicate a decrease of 13-20% Area 2A, 6-13% Area 2B, 10% Area 2C, 12-13% Area 3A, 24-41% Area 3B, and 11-24% Area 4 with respect to the

Sullivan, P.J., 1994. Population assessment, 1993. IPHC
Rep. Assess. Res. Act. 1993., pp. 63–131.

corresponding estimated 1992 biomass levels.

Recruitment of 8-year-old halibut appears again to have dropped off in all areas. This year's recruitment represents the lowest recruitment of 8-year-olds observed in nearly two decades. In addition, this year's sixteen-year-old age class (the 1977 year-class), which recruited strongly as eight-year-olds in 1985 (Figures 2 through 8), is contributing much less now to the fishery in terms of yield. The low recruitment of recent years indicates that the stock will continue its decline at a rate of about 10-15% per year over the next several years. This trend is apparent in both the standard and the alternative assessment despite the recent upturn in CPUE.

In addition to estimating the current year's stock levels, stock levels for previous years are re-estimated using updated formation. Changes in the level of bycatch, waste, and sport catch coupled with the inherent variability observed in the stock dynamics and the measurement process results in adjustments to previous abundance estimates. This can cause the allowable catch to be higher than expected in some areas where stock abundance indicates more of a decline.

CONSTANT EXPLOITATION YIELD

Results from the 1993 stock assessments are used in determining the total and setline constant exploitation yields. Table 1 shows the yields for the standard assessment along with the 1993 catch and quota. Table 2 shows the yields under the alternative assessment. The overall CEY is obtained by multiplying the area specific exploitable biomass by the constant exploitation yield rate of 0.30. Once the exploitation rate has been applied equally to all areas, the biomass removal from other sources is subtracted out to determine the allowable setline catch. The setline constant exploitation yields provide guidance as to the harvest that should be taken by the setline commercial fishery in order to maintain optimal yields and viability of the stock.

The magnitude of the range in the biomass estimates and the associated CEYs reflects the degree of caution that must be exercised in determining the quota. As a guideline Table 3 summarizes the features of the quota recommendations from this and the previous assessment. Listed are the 1992 setline CEY, the 1993 quotas and catch, the 1993 setline CEY under the standard and alternative assessments, and the average of the two 1993 setline CEY estimates. The magnitude of the difference between the standard and the alternative setline CEY estimates for Areas 2A, 2B, 3B, and 4 reflects the strong downward signal coming through the catch-at-age information in contrast to the upward signal reflected in the CPUE. This suggests that a more conservative quota should be considered for these Areas. In addition, changes in fleet behavior in Area 2B under the recently implemented individual vessel quota management system, may further affect the interpretation of CPUE for that area. Discounting the Area 2B CPUE for those years could result in biomass estimates that are even lower than those provided by the alternative assessment discussed above. An area-by-area harvest that is at or below the averaged 1993 setline CEY levels would be consistent with previous quota recommendations, consistent with projected biomass trends, and diminish the disparity in exploitation rates between Areas.

BYCATCH

Adjustments to the allowable catch for bycatch shown in Table 1 and Table 2 represent compensation to the stock for losses in the stock's reproductive potential due to losses from bycatch. The allowable catch is reduced in line 1.4 of Table 1 and Table 2 by one pound for every pound of bycatch removed. The bycatch reduction in each area is made in proportion to the estimated exploitable biomass in that area.

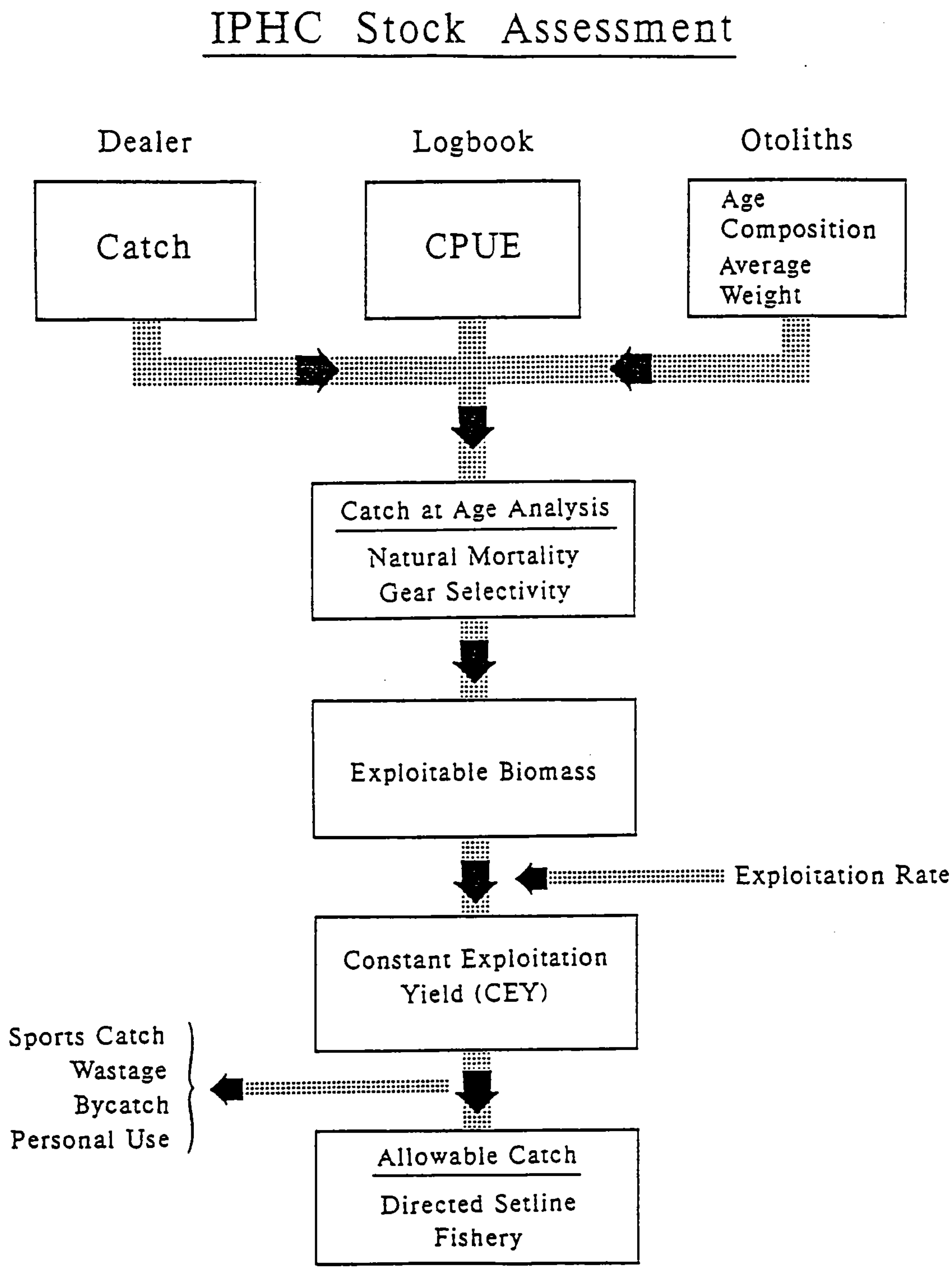


Figure 1. **IPHC Stock Assessment**

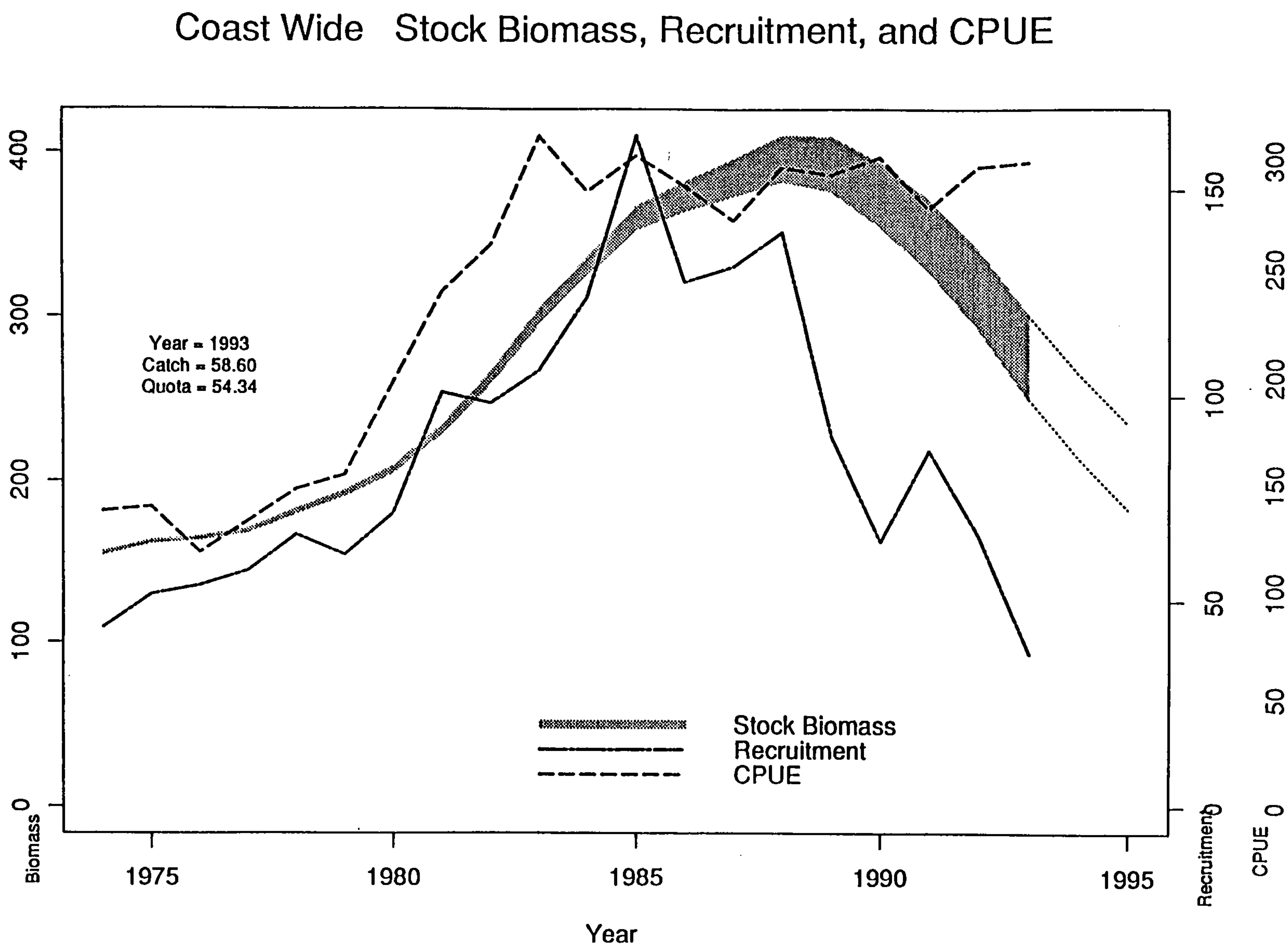


Figure 2. **Coastwide stock biomass (million pounds), recruitment (million pounds), and CPUE (pounds/skate).**

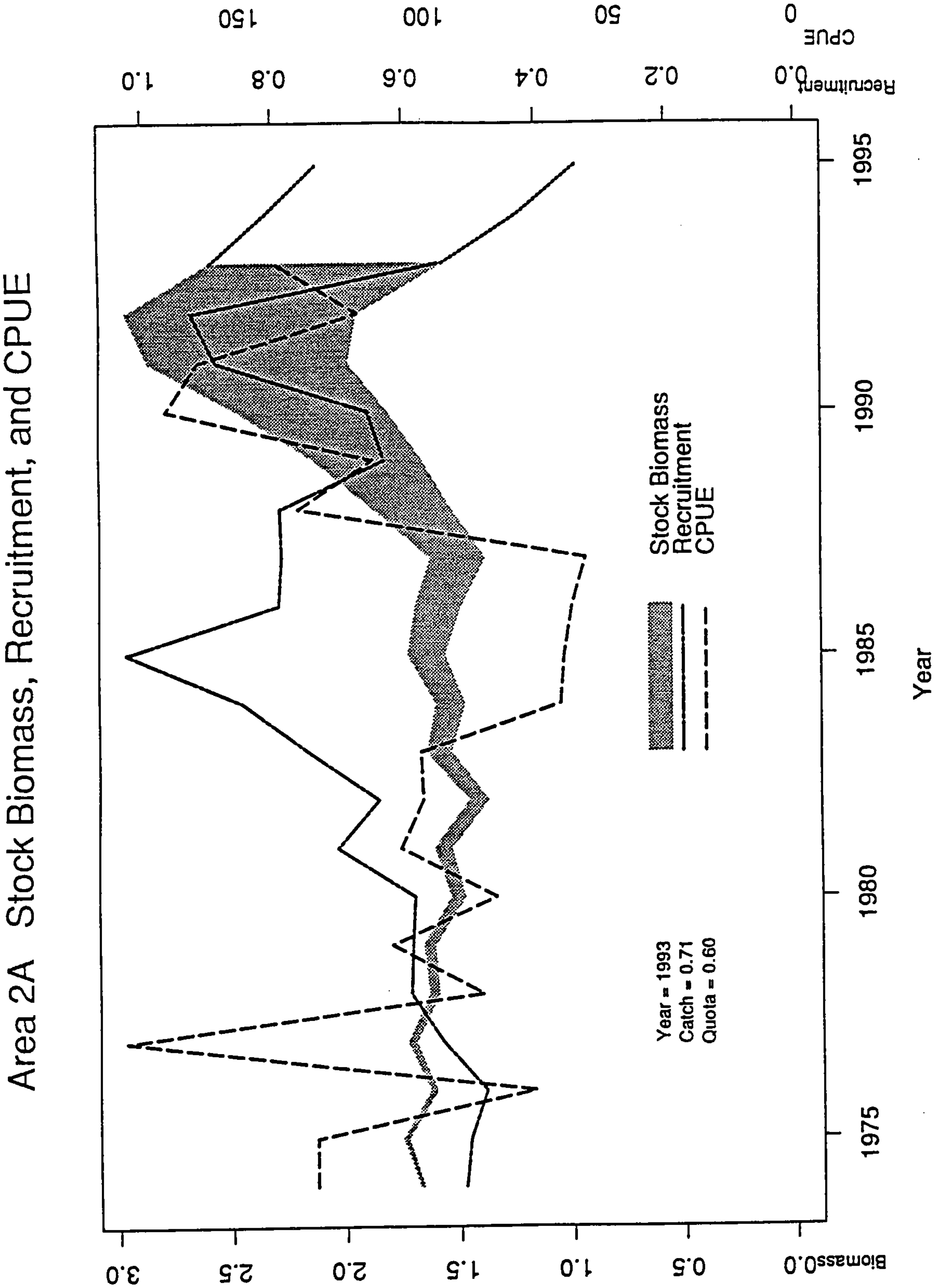


Figure 3. **Area 2A stock biomass (million pounds), recruitment (million pounds), and CPUE (pounds/skate).**

Area 2B   Stock Biomass, Recruitment, and CPUE

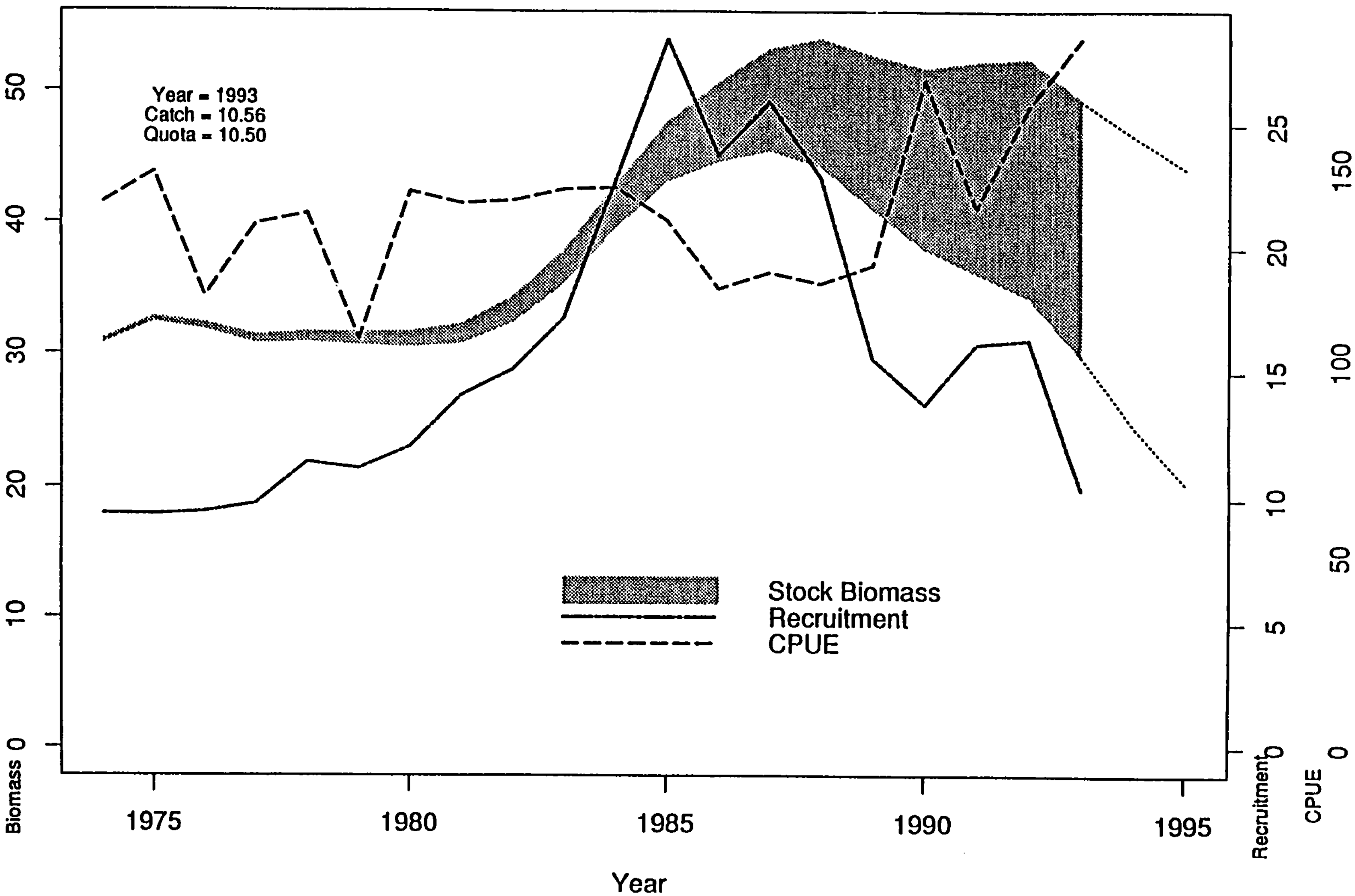


Figure 4. **Area 2B stock biomass (million pounds, recruitment (million pounds), and CPUE (pounds/skate).**

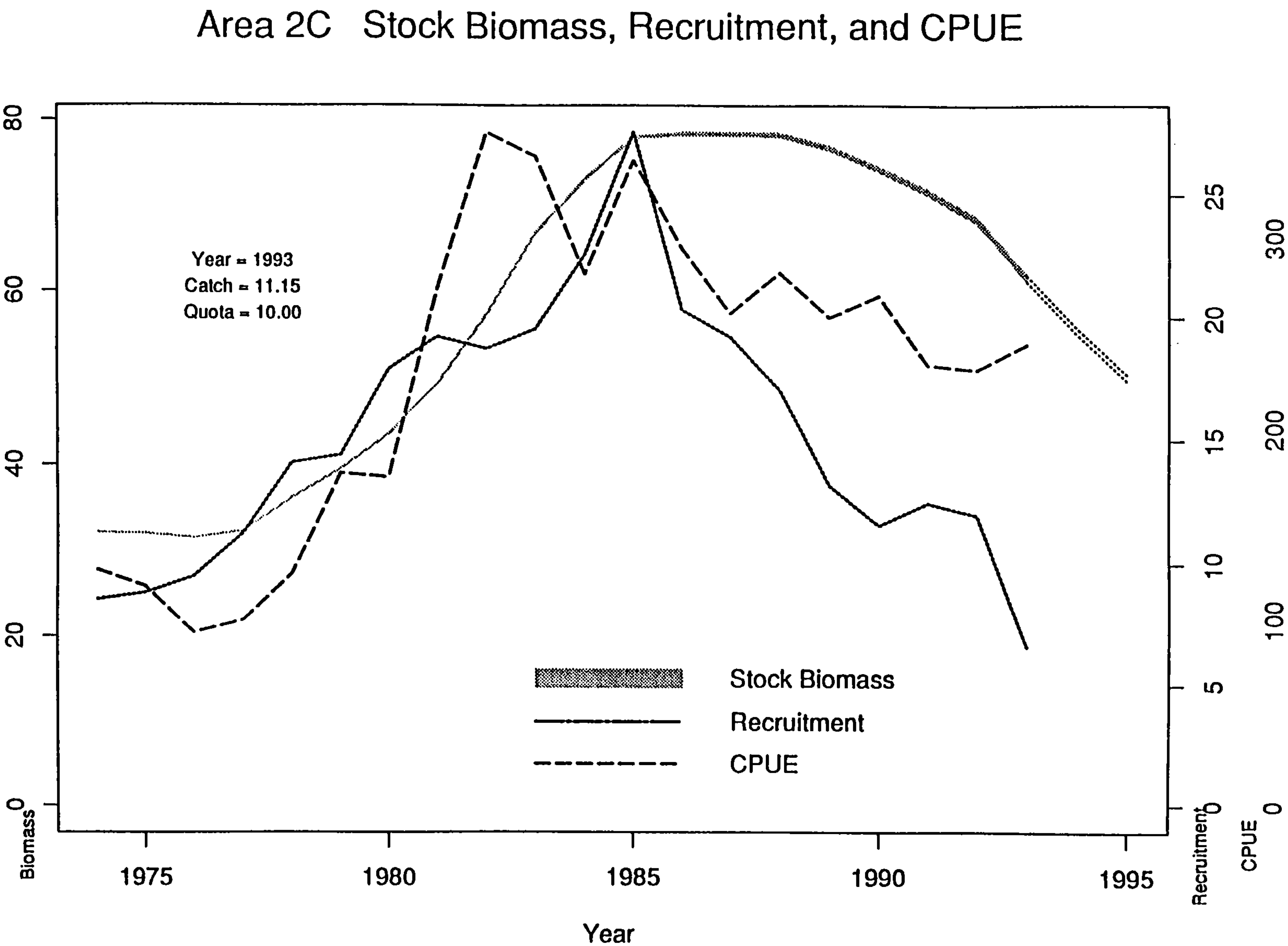


Figure 5. **Area 2C stock biomass (million pounds, recruitment (million pounds), and CPUE (pounds/skate).**

Table 2. **1993 Assessment of Yield - Rate = .30**
Discounting 1993 and 1992 CPUE

		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1993 Quota	0.60*	10.50	10.00	20.70	6.50	6.04	54.34
	1993 Catch	0.71*	10.56	11.15	22.85	7.10	6.23	58.60
1.2	CEY	0.47*	8.92	18.33	39.63	3.11	4.47	74.94
1.3	OTHER CATCHES							
	Sport	--- *	0.75	1.84	4.36	0.00	0.06	7.01
	Waste	0.02	0.34	0.40	1.13	0.24	0.20	2.33
	Bycatch	0.10	1.81	3.72	8.04	0.63	0.91	15.20
	Personal Use	0.00	0.30	0.11	0.33	0.06	0.12	0.92
	TOTAL	0.12	3.20	6.07	13.86	0.93	1.29	25.46
1.4	SETLINE CEY	0.35*	5.72	12.26	25.77	2.18	3.18	49.48

Estimates in million pounds by subarea.

* Sport catch included for area 2A.

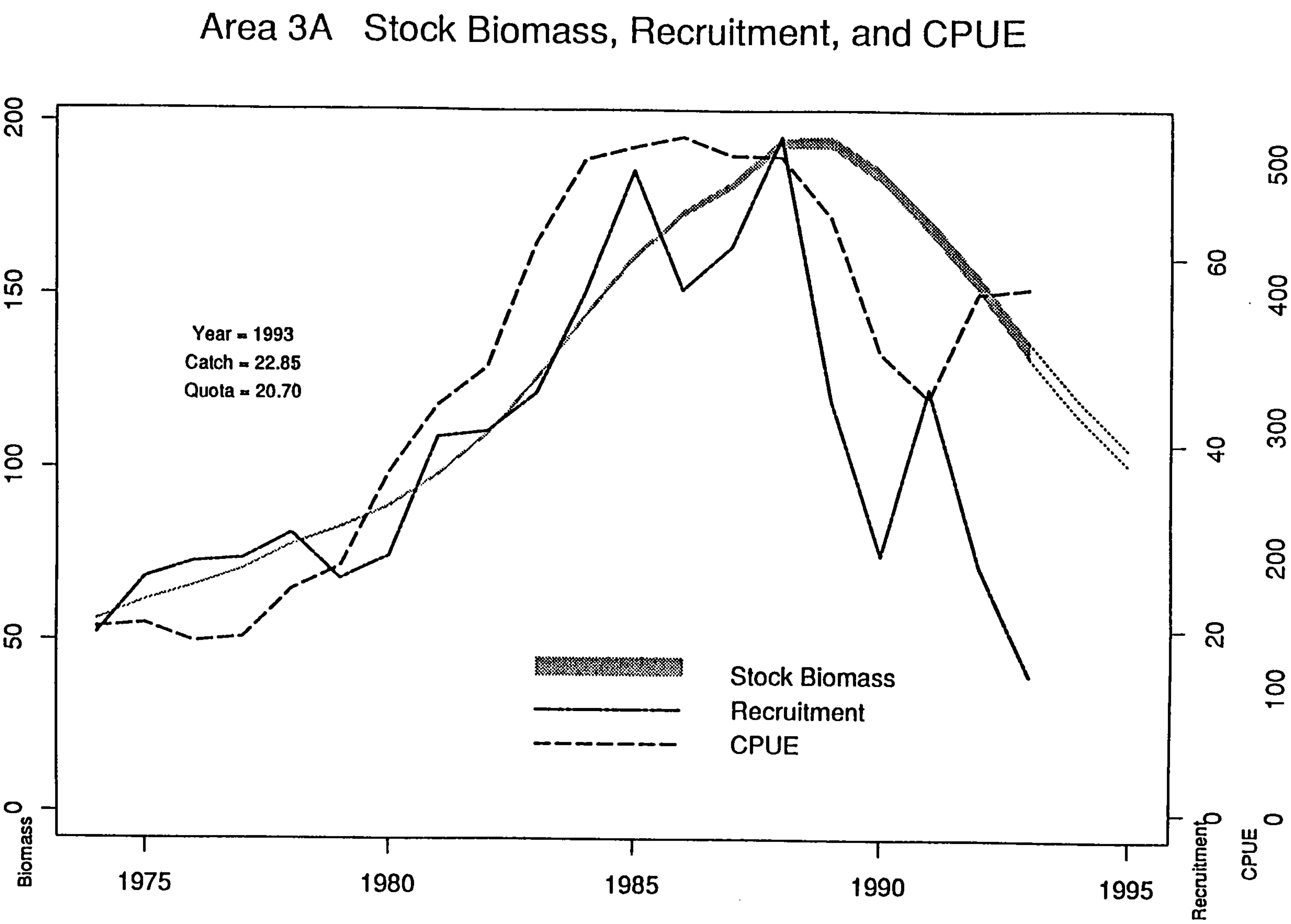


Figure 6. **Area 3A stock biomass (million pounds, recruitment (million pounds), and CPUE (pounds/skate).**

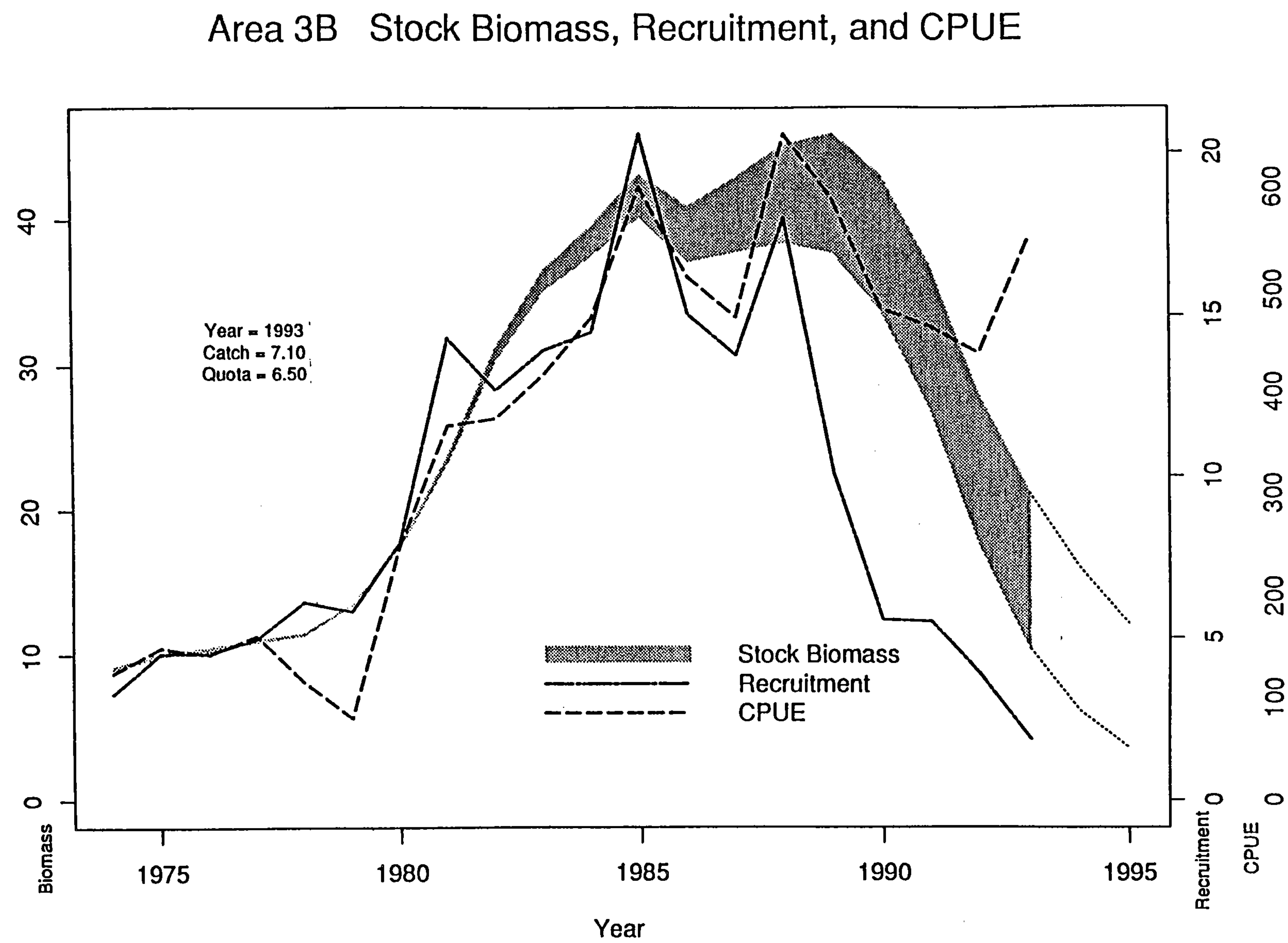


Figure 7. **Area 3B stock biomass (million pounds, recruitment (million pounds), and CPUE (pounds/skate).**

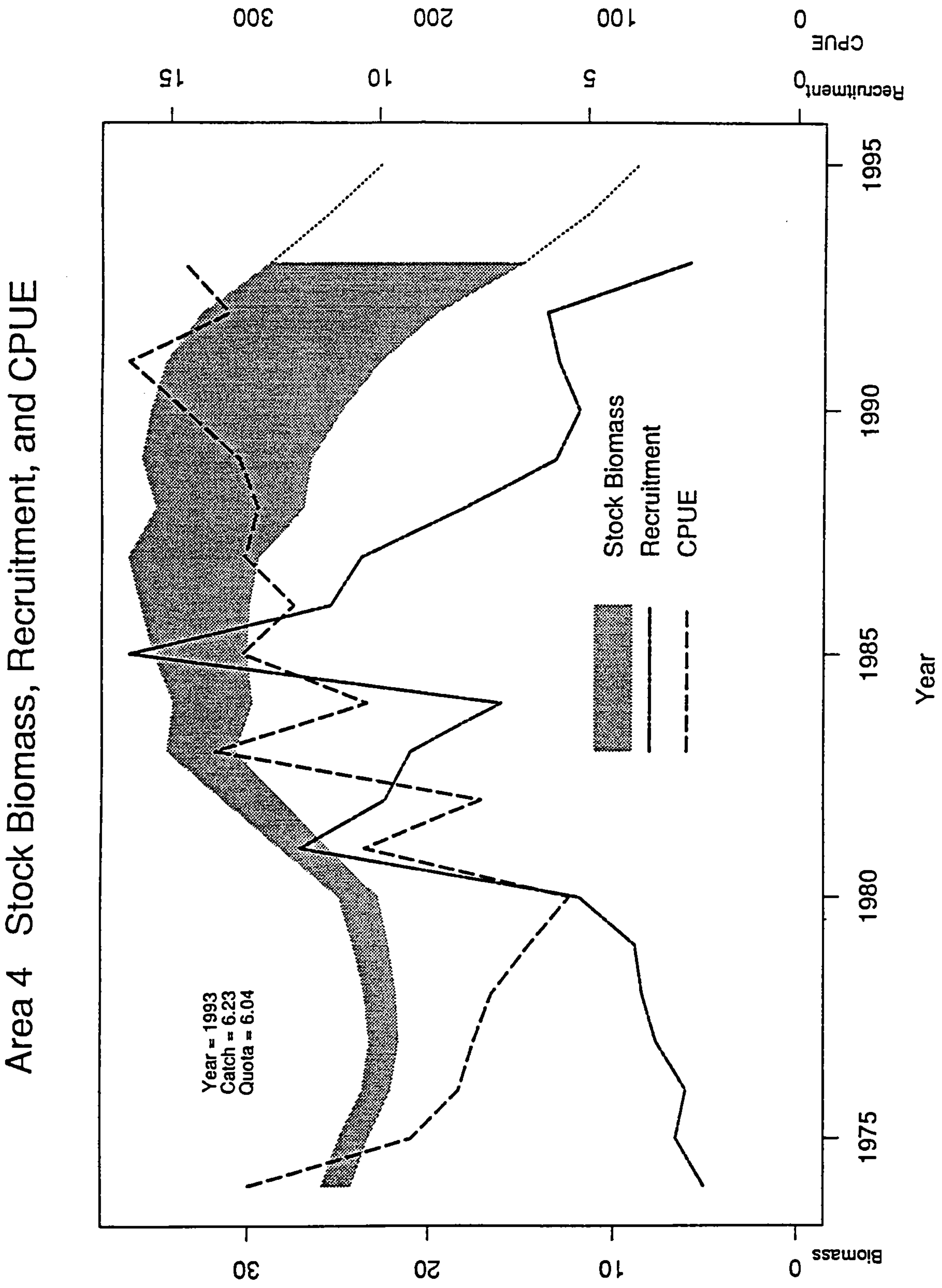


Figure 8. **Area 4 stock biomass (million pounds), recruitment (million pounds), and CPUE (pounds/skate).**

Table 1. 1993 Assessment of Yield - Rate = .30

		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1993 Quota	0.60*	10.50	10.00	20.70	6.50	6.04	54.34
	1993 Catch	0.71*	10.56	11.15	22.85	7.10	6.23	58.60
1.2	CEY	0.78*	14.79	18.55	41.00	6.34	8.65	90.11
1.3	OTHER							
	Sport	--- *	0.75	1.84	4.36	0.00	0.06	7.01
	Waste	0.02	0.34	0.40	1.13	0.24	0.20	2.33
	Bycatch	0.13	2.49	3.13	6.92	1.07	1.46	15.20
	Personal Use	0.00	0.30	0.11	0.33	0.06	0.12	0.92
	TOTAL	0.15	3.88	5.48	12.74	1.37	1.84	25.46
1.4	SETLINE CEY	0.63*	10.91	13.07	28.27	4.97	6.81	64.65

Estimates in million pounds by subarea.

* Sport catch included for area 2A.

Table 2. **1993 Assessment of Yield - Rate = .30**
Discounting 1993 and 1992 CPUE

		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1993 Quota	0.60*	10.50	10.00	20.70	6.50	6.04	54.34
	1993 Catch	0.71*	10.56	11.15	22.85	7.10	6.23	58.60
1.2	CEY	0.47*	8.92	18.33	39.63	3.11	4.47	74.94
1.3	OTHER CATCHES							
	Sport	--- *	0.75	1.84	4.36	0.00	0.06	7.01
	Waste	0.02	0.34	0.40	1.13	0.24	0.20	2.33
	Bycatch	0.10	1.81	3.72	8.04	0.63	0.91	15.20
	Personal Use	0.00	0.30	0.11	0.33	0.06	0.12	0.92
	TOTAL	0.12	3.20	6.07	13.86	0.93	1.29	25.46
1.4	SETLINE CEY	0.35*	5.72	12.26	25.77	2.18	3.18	49.48

Estimates in million pounds by subarea.

* Sport catch included for area 2A.

Table 3. 1993 Setline Exploitation Yield Summary

	AREA						
	2A	2B	2C	3A	3B	4	TOTAL
1992 SETLINE CEY	0.46*	9.81	10.41	23.13	4.07	5.59	53.47
1993 QUOTA	0.60*	10.50	10.00	20.70	6.50	6.04	54.34
1993 CATCH	0.71*	10.56	11.15	22.85	7.10	6.23	58.60
1993 SETLINE CEY							
Standard	0.63*	10.91	13.07	28.27	4.97	6.81	64.65
Alternative	0.35*	5.72	12.26	25.77	2.18	3.18	49.48
Average	0.49*	8.32	12.66	27.02	3.58	5.00	57.07

Estimates in million pounds by subarea.

* Sport catch included for area 2A.

REPORT OF ASSESSMENT AND RESEARCH ACTIVITIES

POPULATION ASSESSMENT, 1993 TECHNICAL SUPPLEMENT

by

Patrick J. Sullivan and Ana M. Parma

The tables and figures to follow provide more detail on the 1993 stock assessment.

Table A.1 shows commercial CPUE estimates adjusted to Circle hook standardized equivalence.
Table A.2 shows commercial catch millions of pounds net weight by area and year.
Table A.3 shows total removals, this represents the commercial catch with sport catch, and mortality from gear lost added.
Table A.4 shows the estimated exploitable biomass by area and year for the standard assessment.
Table A.5 gives the estimated historical exploitation rate calculated as total removals divided by exploitable biomass for the standard assessment.
Table A.6 shows the annual surplus production (ASP), provided for historical comparisons for the standard assessment.
Table A.7 shows the estimated total instantaneous fishing mortality rates for the standard assessment.
Table A.8 provides estimates of 8-year-old recruitment millions of pounds for the standard assessment.
Table A.9 shows the estimated exploitable biomass by area and year for the alternative assessment.
Table A.10 gives the estimated historical exploitation rate calculated as total removals divided by exploitable biomass for the alternative assessment.
Table A.11 shows the annual surplus production (ASP), provided for historical comparisons for the alternative assessment.
Table A.12 shows the estimated total instantaneous fishing mortality rates for the alternative assessment.
Table A.13 provides estimates of 8-year-old recruitment millions of pounds for the alternative assessment.

Because the total catch values used in the stock assessment include sport catch and wastage the exploitation rates given in Tables A.5 and A.10 and the mortality rates shown in Tables A.7 and A.12 are slightly higher than the rates resulting from commercial fishing alone. The values shown in Tables A.5, A.7, A.10, and A.12 can be used to examine the relative harvest rate in each area under the historical harvest time series. Tables A.4 through A.8 are estimates from the CAGEAN routine for the standard assessment while Tables A.9 through A.12 are the corresponding estimates for the alternative assessment with 1992 and 1993 CPUE discounted. The entries throughout these tables will change each year as updated and more recent information

Sullivan, P.J., 1994. Population assessment, 1993. IPHC Rep. Assess. Res. Act. 1993., pp. 63–131.

become available.

Figures A.1 through A.6 show the fit of the model to the observed data under the standard assessment. Figures A.7 through A.12 show the fit under the alternative assessment with CPUE discounted. The heights of the blocks represent the observed values while the heights of the lines represent the estimated values. Figures A.1 and A.7 show the observed versus estimated efforts for each closed area run for the standard and alternative assessments respectively. Figures A.2 through A.6 and Figures A.8 through A.12 show the observed versus estimated catches for Areas 2A-2B, 2C, 3A, 3B, and 4 for the standard and alternative assessments respectively. The figures are to scale across both age and time.

CPUE was re-estimated this year for all years by gear-type back to 1984. Figure A.13 shows the previous estimates (solid line) compared with the revised estimates for fixed-hook gear (dotted line) and snap-hook gear (dashed line). Currently only fixed-hook CPUE is used for stock assessment in Areas 2C, 3A, 3B, and 4, while both gear-types are used in Area 2A, and CPUE from snap-hook gear for statistical areas south of the northern end of Vancouver Is. is combined with CPUE from fixed-hook gear for all areas in 2B. The revised estimates represent an updating of information now stored in a relational database using updated data handling algorithms. This arrangement facilitates the use of logbook information that was previously unavailable, such as total log landings which occur on a mixture of gears where the dividual landing records on the log are recorded by gear-type. Note that the difference between the previous and the revised CPUE estimates is slight, and that snap-gear and fixed-gear trends are similar, although the average CPUE by gear-type can significantly differ depending on Area.

CPUE from gear with hook-spacing which is less than 4 feet is now being included in the 2A CPUE calculations. This modification is discussed in the Area 2A Assessment Supplement.

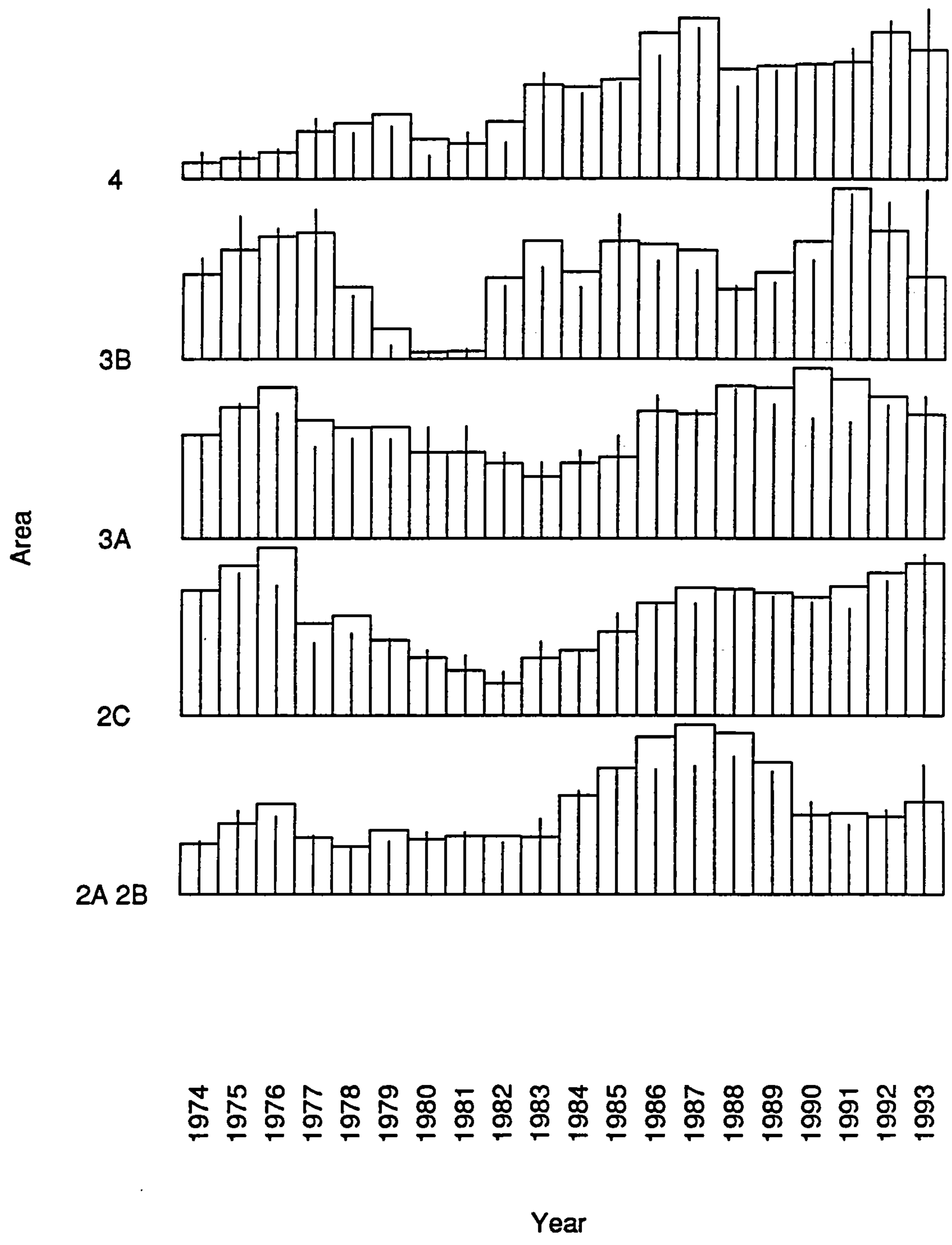


Figure A.1 Effort

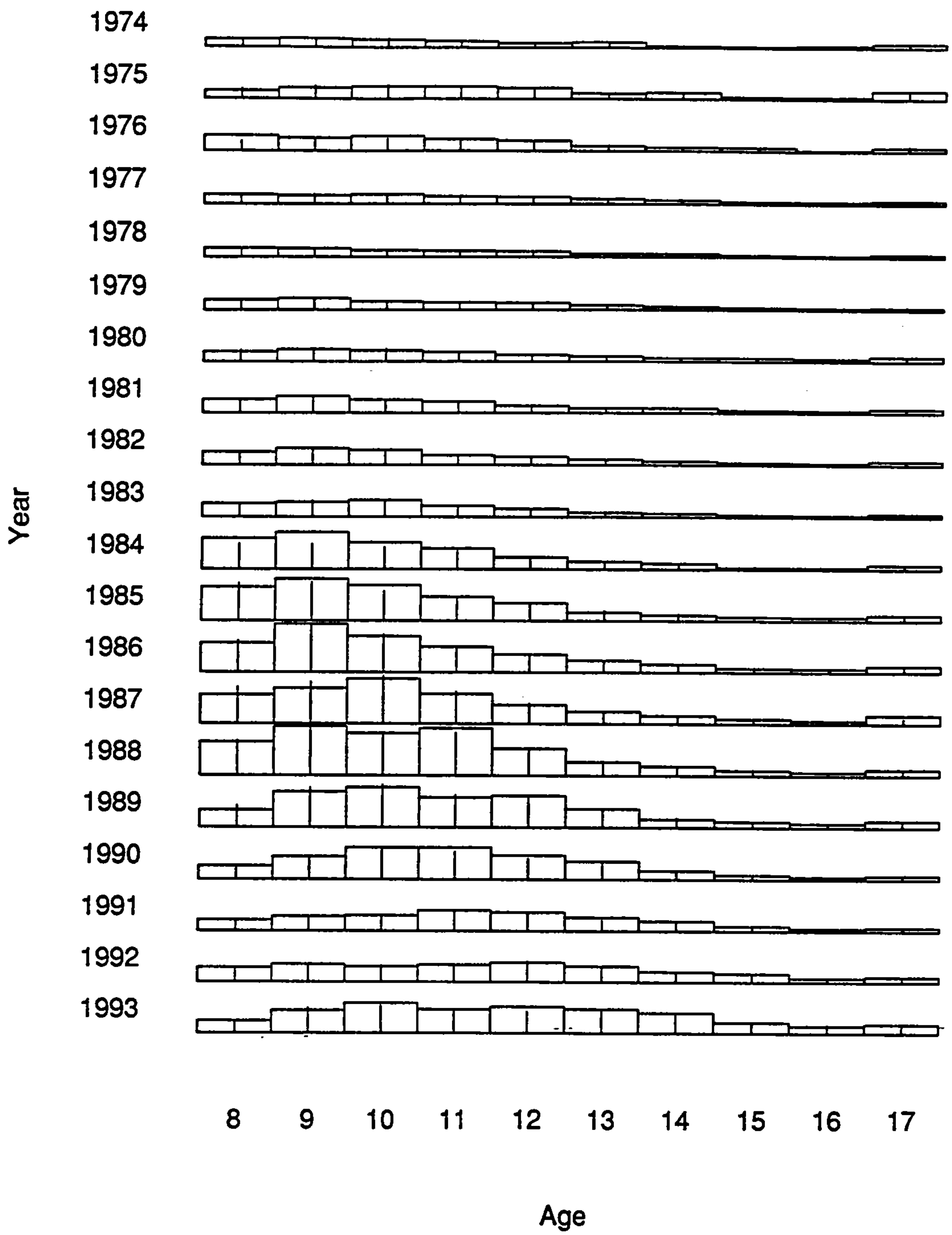


Figure A.2 2A/2B Age Composition

Sullivan, P.J., 1994. Population assessment, 1993. IPHC
Rep. Assess. Res. Act. 1993., pp. 63–131.

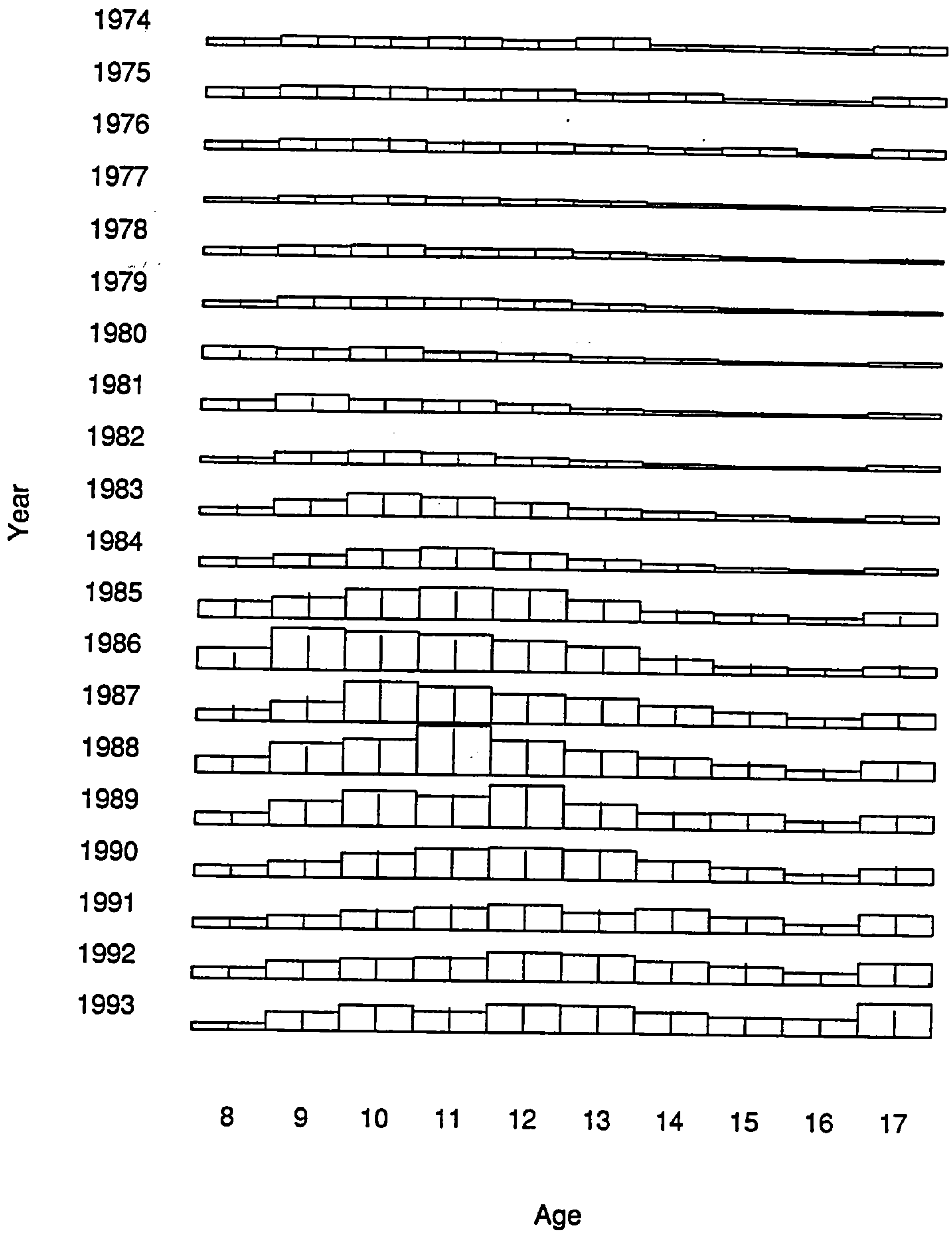


Figure A.3 2C Age Composition

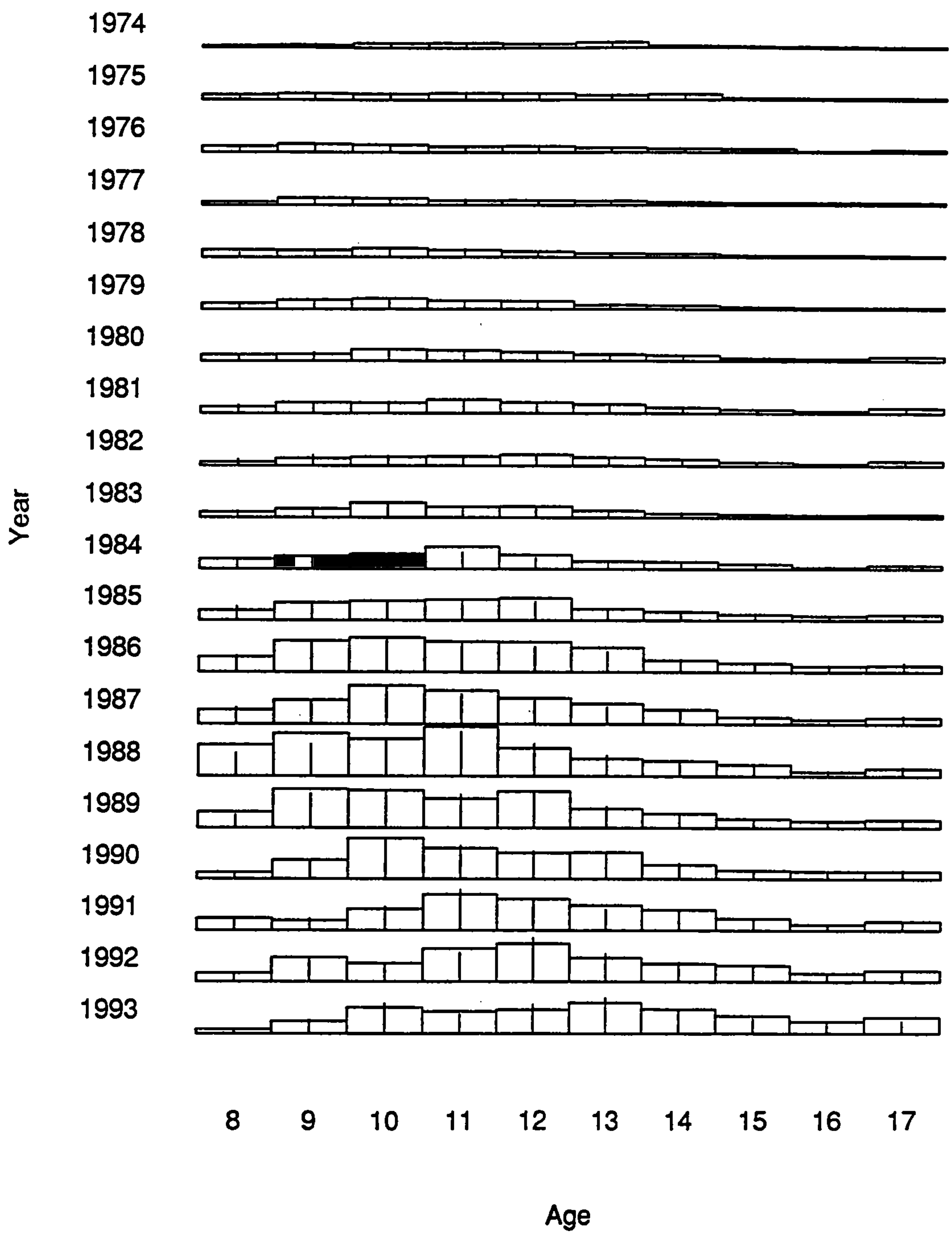


Figure A.4 3A Age Composition

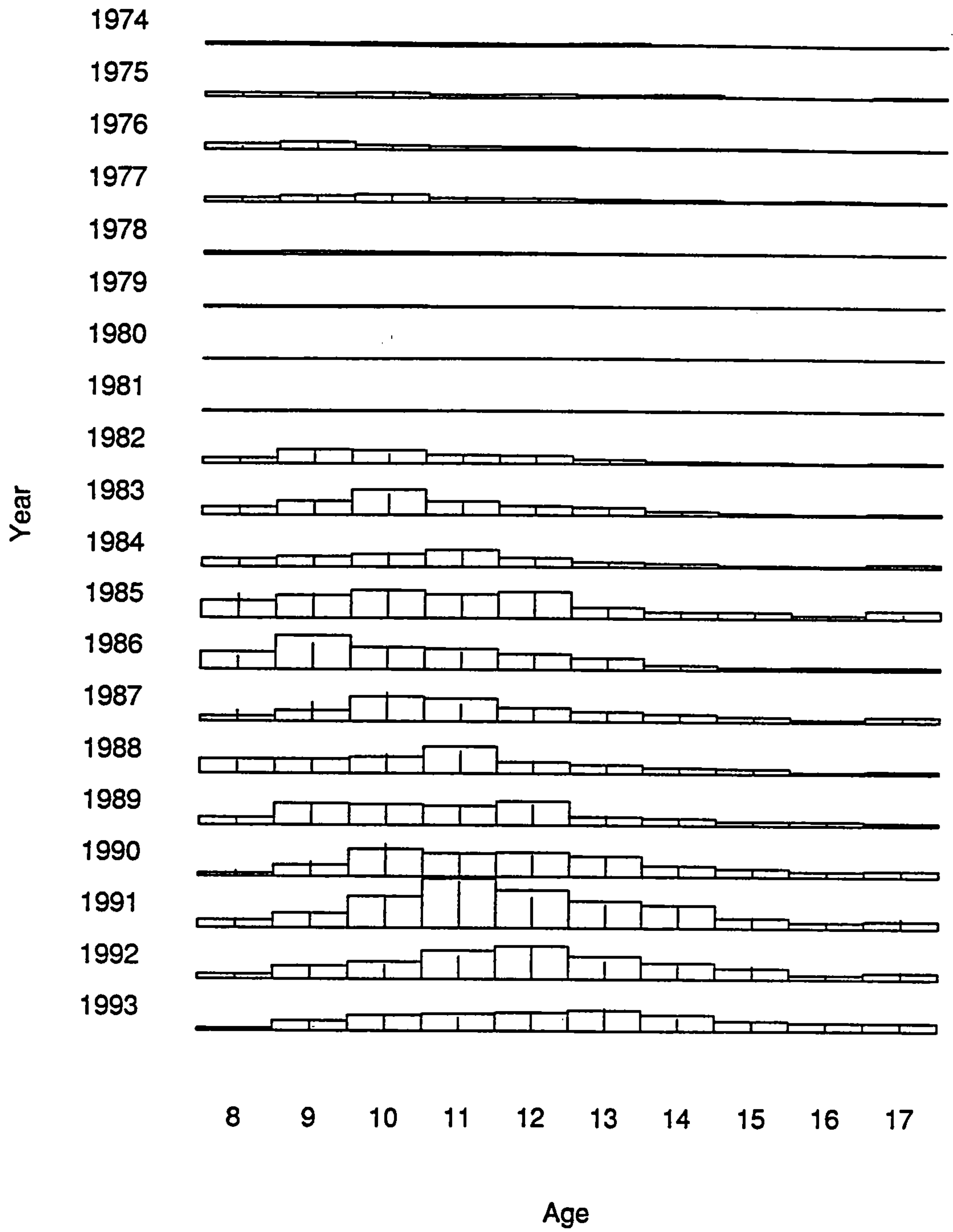


Figure A.5 3B Age Composition

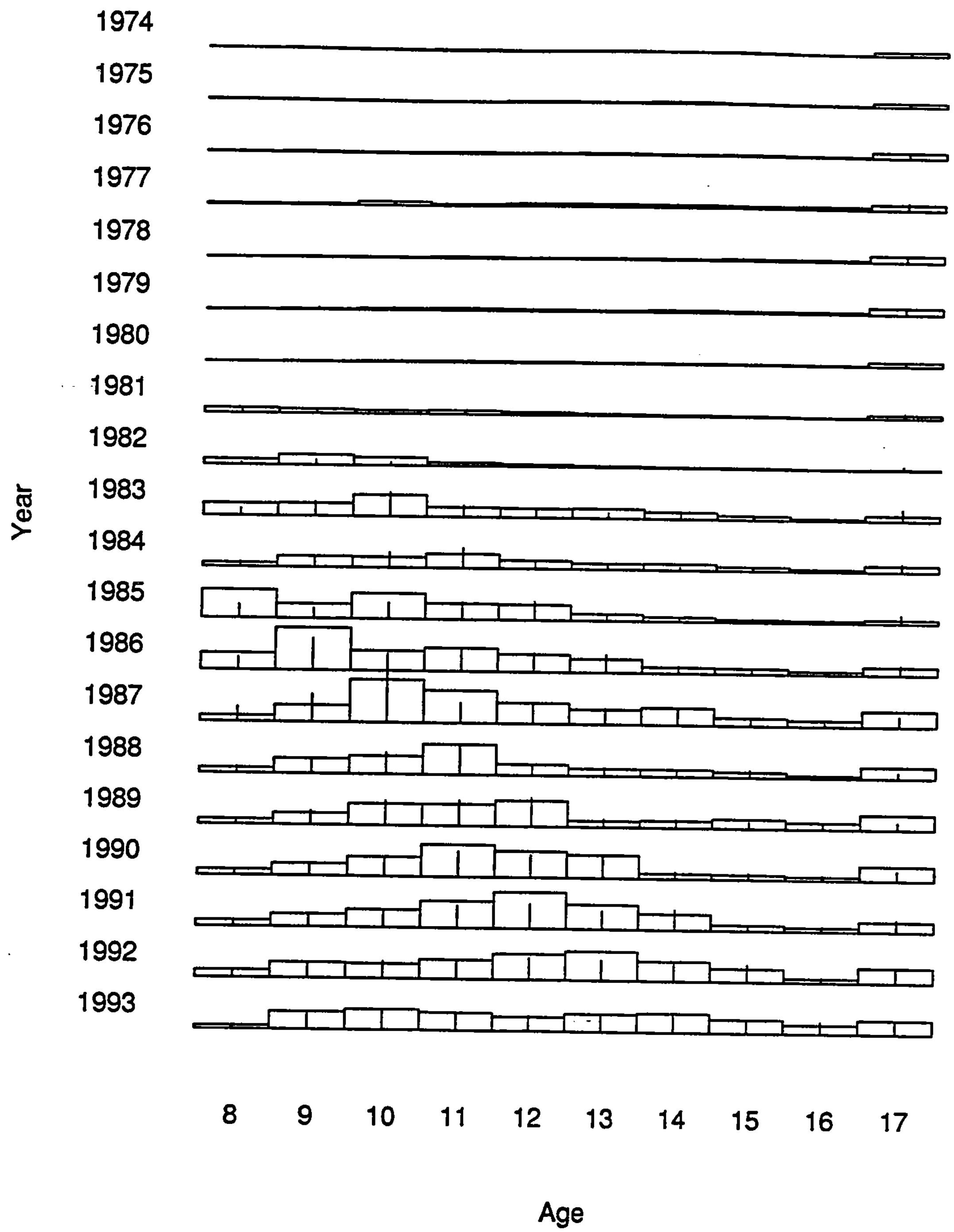


Figure A.6 4 Age Composition

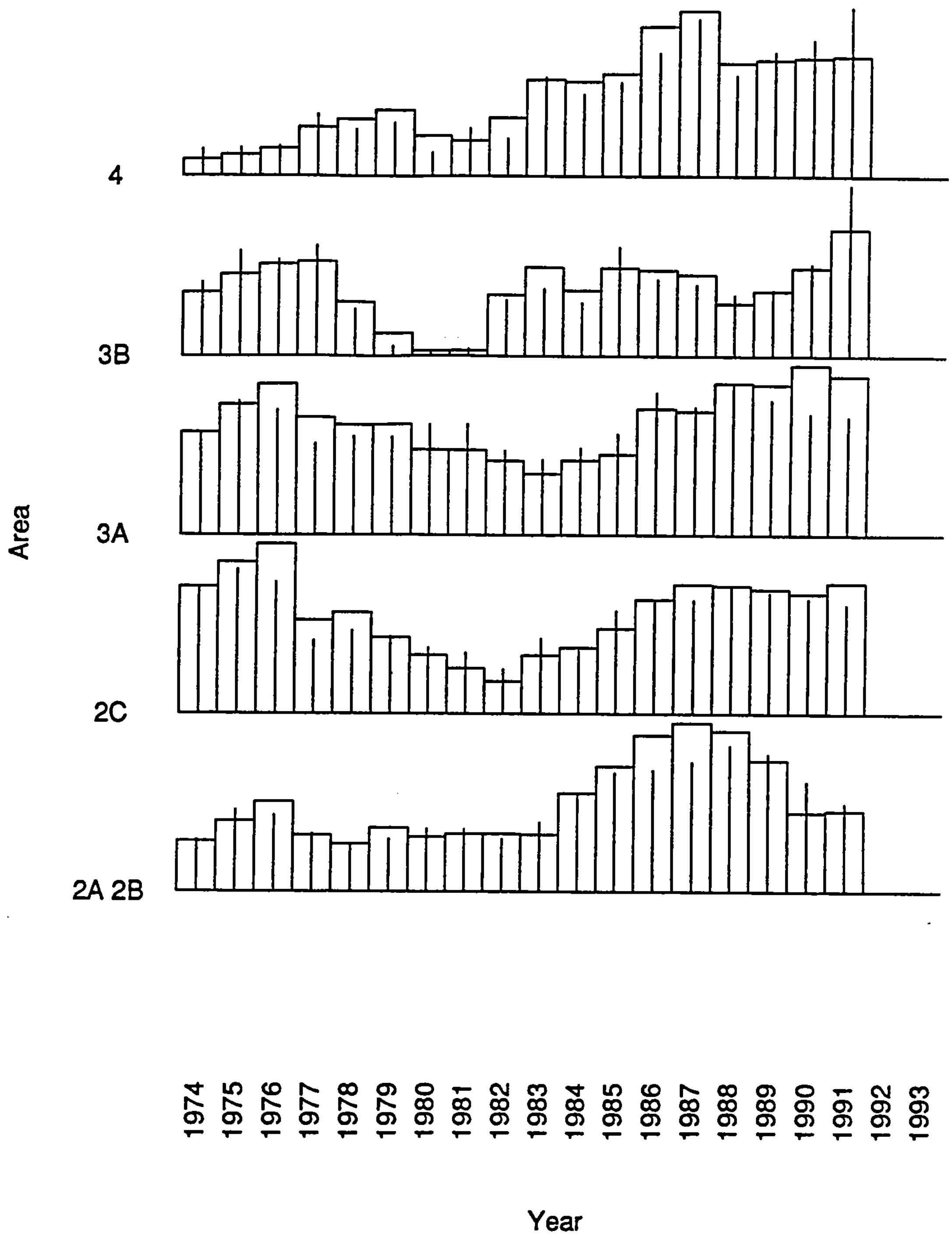


Figure A.7 Effort

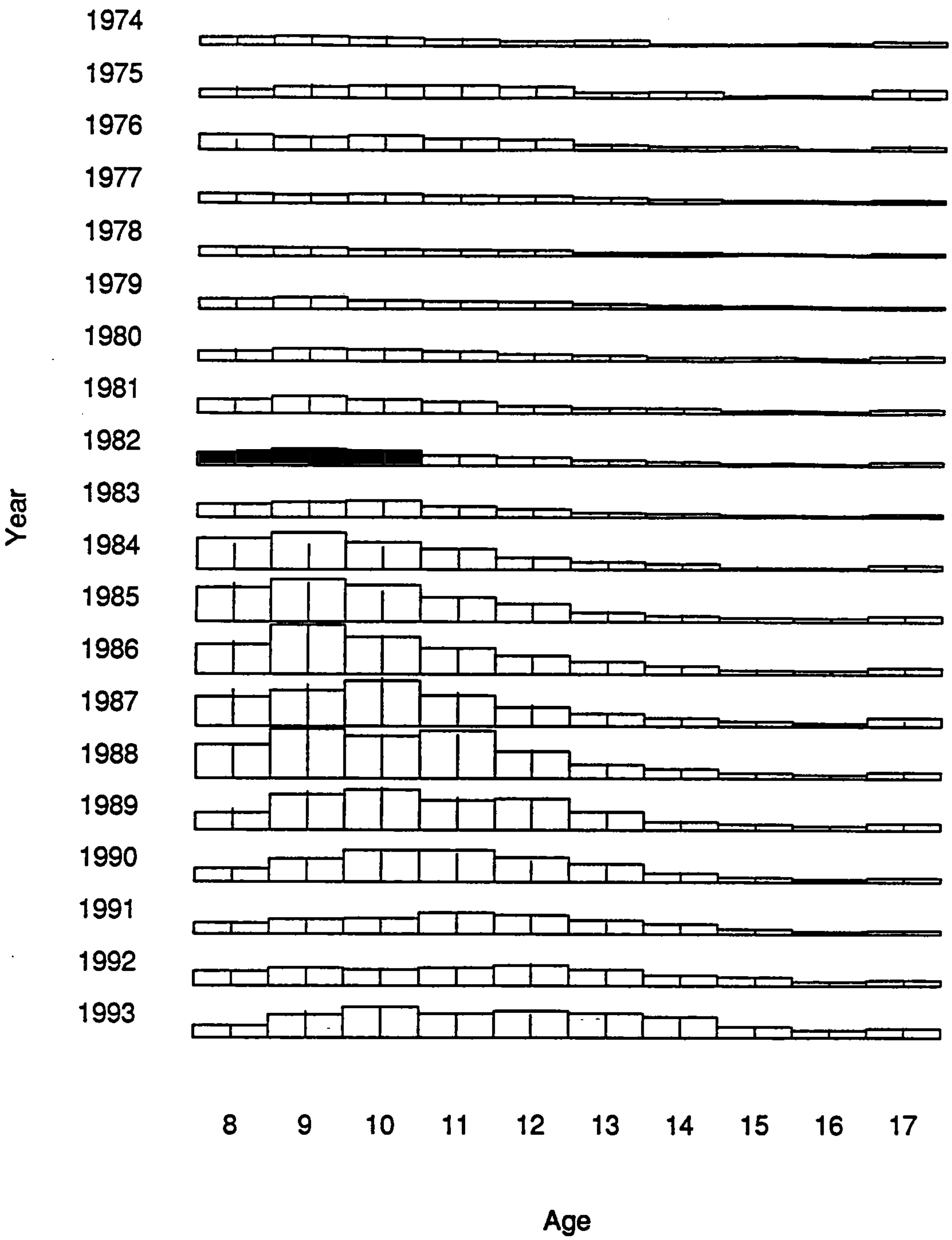


Figure A.8 2A/2B Age Composition

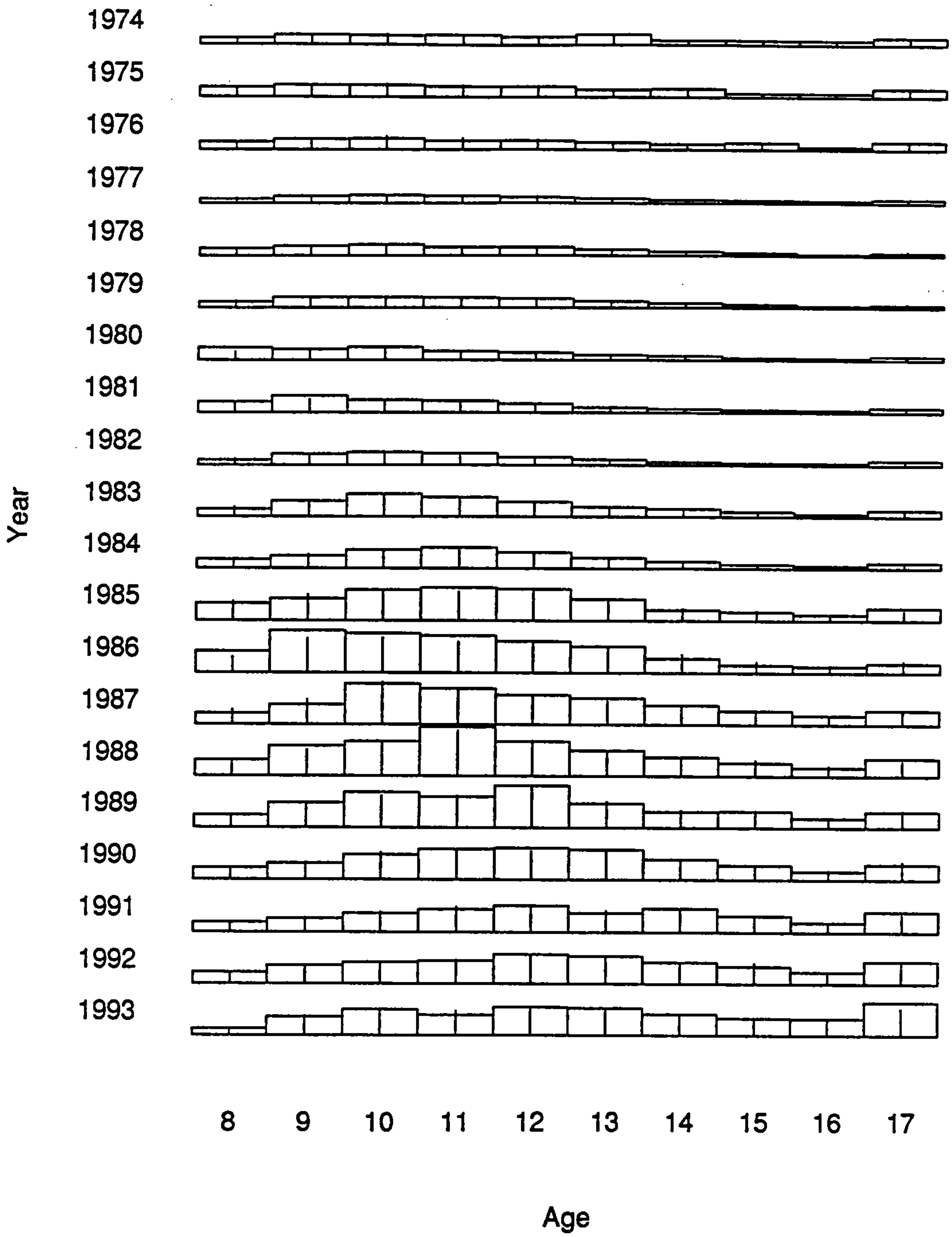


Figure A.9 2C Age Composition

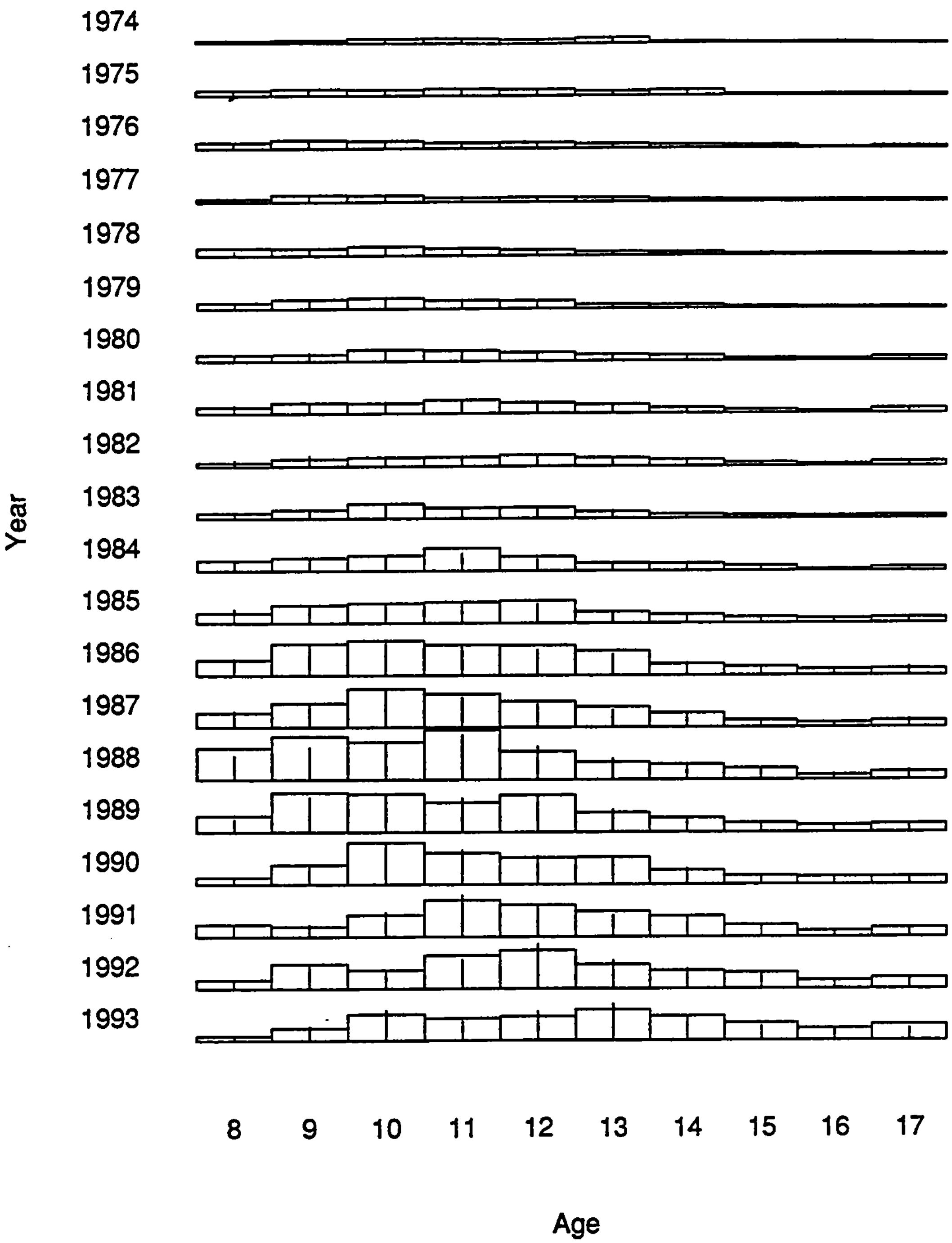


Figure A.10 **3A Age Composition**

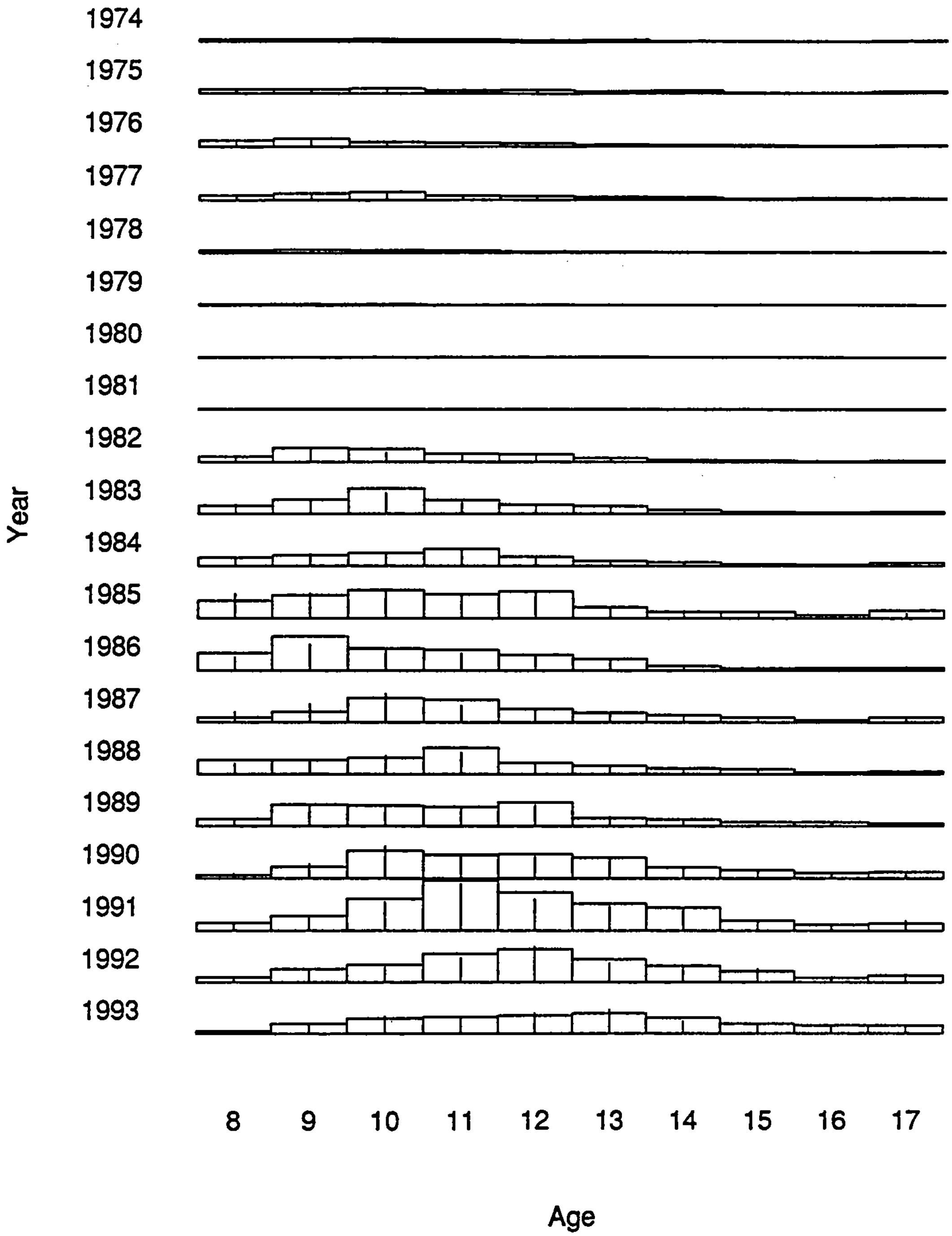


Figure A.11 **3B Age Composition**

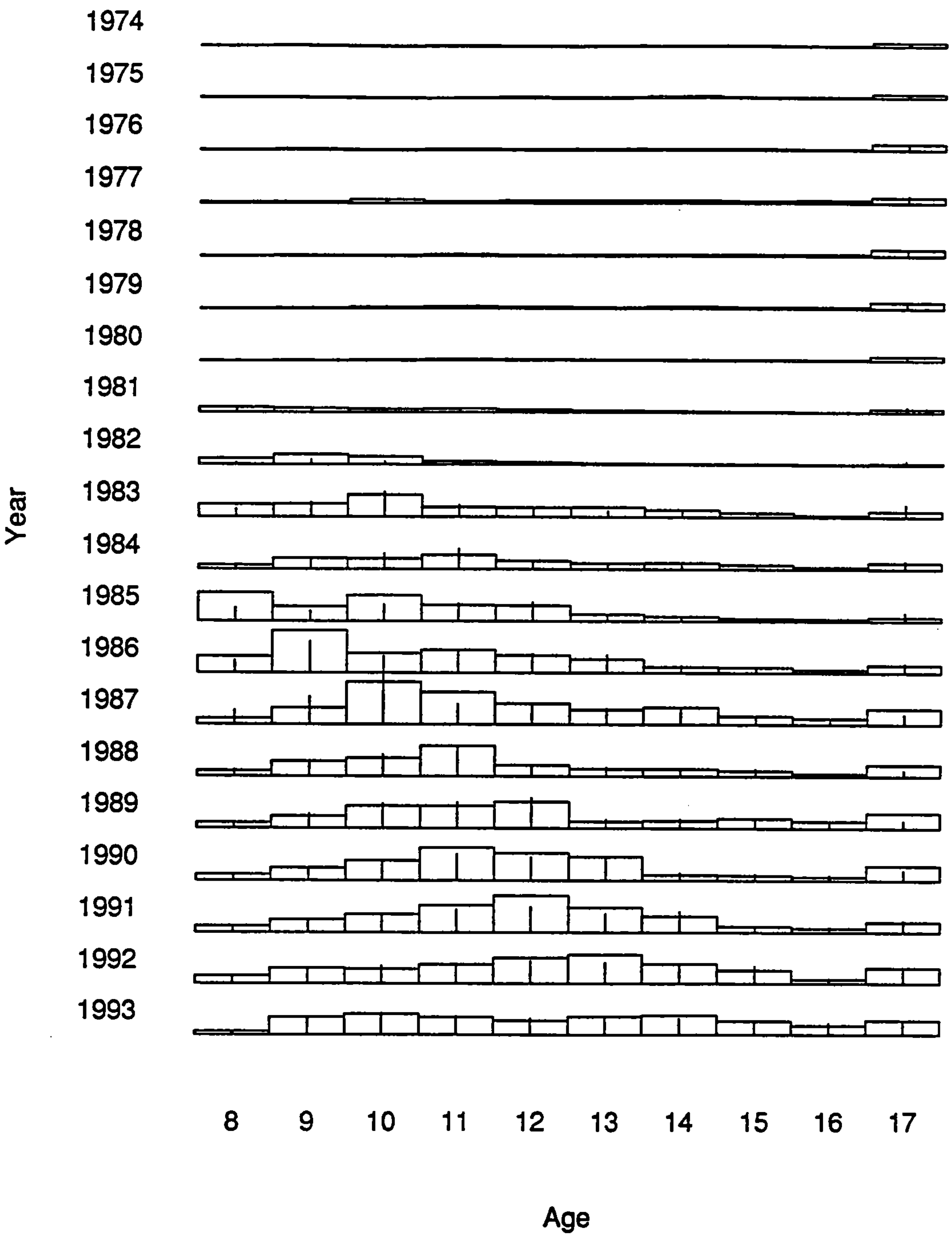


Figure A.12 **4 Age Composition**

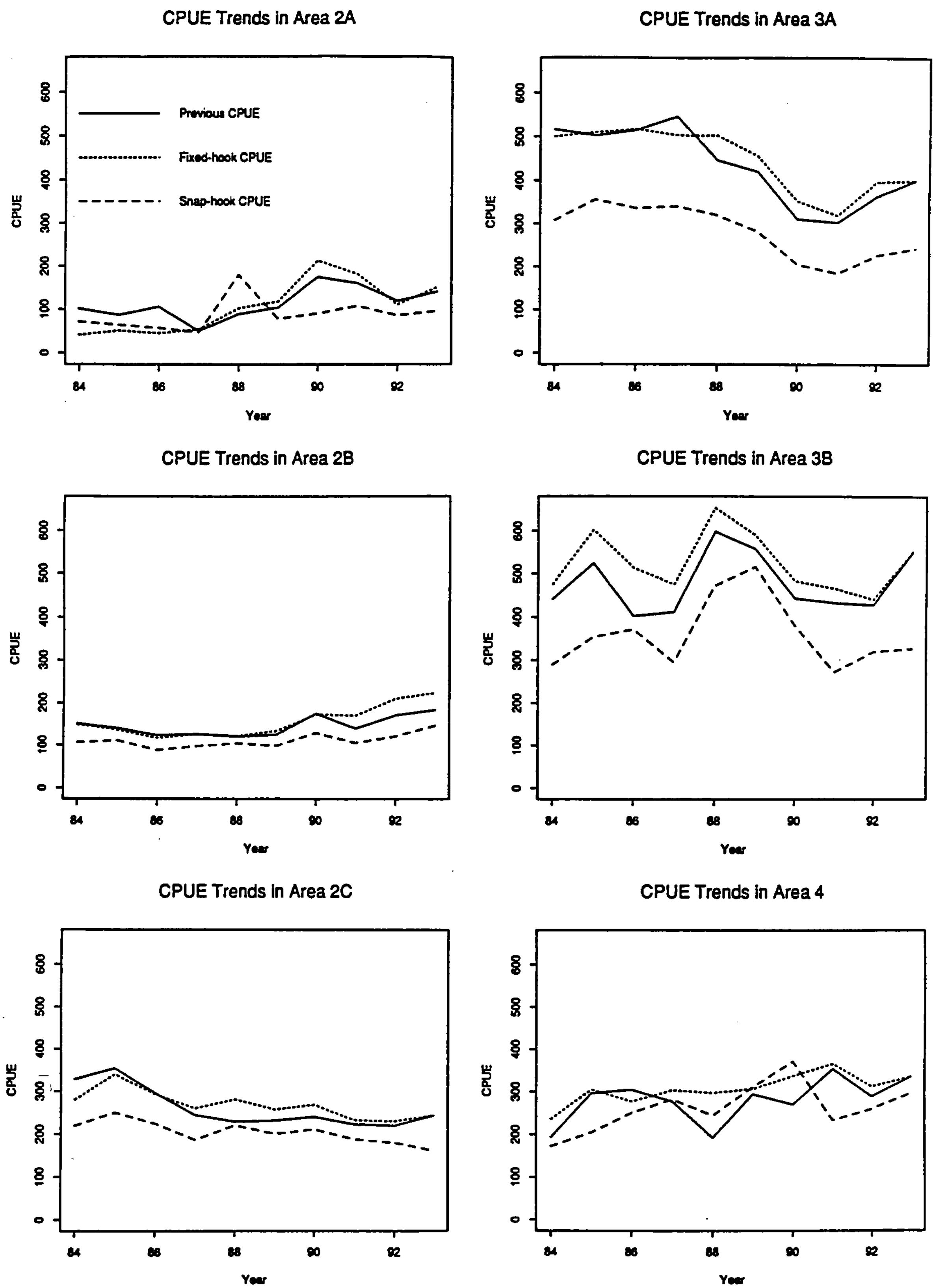


Figure A.13 **CPUE trends**

Table A.1 Commercial CPUE (pounds per skate)

Year	AREA						Total
	2A	2B	2C	3A	3B	4	
1974	130.7	141.0	126.0	142.4	124.7	301.1	137.9
1975	130.6	148.7	117.4	145.3	149.3	210.7	139.7
1976	71.7	116.7	92.8	131.5	142.2	184.2	118.5
1977	182.2	135.3	99.4	134.6	161.3	176.2	133.2
1978	85.5	138.0	124.1	171.9	116.4	166.6	147.9
1979	110.0	105.8	176.6	189.0	80.8	146.1	154.1
1980	82.0	143.7	174.7	260.6	249.5	124.2	197.2
1981	107.6	140.6	273.6	313.5	368.3	236.8	237.4
1982	101.6	141.4	355.9	342.6	375.8	172.5	259.8
1983	102.1	144.4	342.8	437.0	419.4	320.0	310.8
1984	64.3	144.8	280.8	500.3	475.2	235.6	286.3
1985	63.3	136.1	340.7	509.9	602.4	304.8	304.7
1986	61.1	118.6	294.0	517.9	514.8	276.5	289.0
1987	57.4	122.8	260.3	503.6	476.1	303.6	275.5
1988	135.4	119.8	281.3	502.8	654.2	296.4	293.5
1989	115.1	124.5	258.0	456.0	590.0	306.4	293.4
1990	171.2	172.4	269.1	352.9	483.6	336.2	302.5
1991	162.6	139.3	233.2	318.6	466.4	366.3	278.6
1992	118.9	165.6	230.5	397.1	440.2	312.4	298.7
1993	141.2	183.2	243.8	400.9	551.8	336.8	299.3

* Standardized C hook equivalence.

Sullivan, P.J., 1994. Population assessment, 1993. IPHC
Rep. Assess. Res. Act. 1993., pp. 63–131.

Table A.2 Commericial Catch (million pounds)

Year	AREA						Total
	2A	2B	2C	3A	3B	4	
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	21.87
1978	0.10	4.61	4.32	10.30	1.32	1.35	21.99
1979	0.05	4.86	4.53	11.34	0.39	1.37	22.53
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	25.73
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	44.97
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	69.63
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	66.94
1990	0.32	8.57	9.73	28.85	8.69	5.43	61.61
1991	0.36	7.17	8.69	22.86	11.93	5.99	56.99
1992	0.44	7.63	9.82	26.78	8.62	6.61	59.89
1993	0.45	10.56	11.15	22.85	7.10	6.23	58.34

Sullivan, P.J., 1994. Population assessment, 1993. IPHC
Rep. Assess. Res. Act. 1993., pp. 63–131.

Table A.3 Total Removals (million pounds)

Year	AREA 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	5.44	3.26	8.84	3.19	1.22	22.17
1978	0.11	4.62	4.40	10.58	1.32	1.35	22.37
1979	0.06	4.88	4.70	11.70	0.39	1.37	23.10
1980	0.04	5.66	3.57	12.45	0.28	0.71	22.72
1981	0.22	5.68	4.33	14.98	0.45	1.20	26.86
1982	0.26	5.60	3.99	14.25	4.80	1.44	30.34
1983	0.33	5.54	6.95	15.06	7.75	4.42	40.05
1984	0.55	9.18	6.47	21.00	6.50	3.18	46.87
1985	0.69	11.02	10.10	22.99	11.09	4.44	60.33
1986	0.92	11.80	11.77	36.56	9.23	5.92	76.19
1987	1.04	12.95	11.83	34.88	8.10	7.17	75.98
1988	0.74	13.41	12.65	42.63	7.20	4.80	81.43
1989	0.80	11.11	11.28	38.20	8.04	5.09	74.52
1990	0.53	9.41	11.31	33.38	8.91	5.69	69.23
1991	0.52	7.82	10.69	28.24	12.35	6.31	65.92
1992	0.69	8.39	11.73	31.32	8.80	6.77	67.72
1993	0.70	11.42	13.22	27.60	7.16	6.41	66.51

Table A.4 Exploitable Biomass (Closed Subarea)

Year	AREA						Total
	2A	2B	2C	3A	3B	4	
1974	1.67	31.06	32.23	56.07	9.01	25.90	155.93
1975	1.75	32.78	32.10	61.69	9.88	24.95	163.14
1976	1.62	32.31	31.59	65.87	10.27	23.65	165.30
1977	1.72	31.34	32.39	70.68	10.85	23.25	170.23
1978	1.63	31.64	36.16	77.87	11.37	23.55	182.21
1979	1.65	31.57	39.49	82.91	13.51	24.16	193.30
1980	1.53	31.62	43.45	89.02	17.55	24.97	208.13
1981	1.60	32.19	49.33	98.26	23.68	28.21	233.26
1982	1.45	34.26	57.32	110.18	31.20	31.35	265.76
1983	1.63	37.75	66.78	126.45	36.51	34.40	303.52
1984	1.59	42.80	73.01	144.25	39.50	34.02	335.17
1985	1.72	47.61	78.05	161.06	43.00	35.07	366.50
1986	1.68	50.60	78.47	174.09	40.84	35.78	381.46
1987	1.61	53.21	78.51	182.56	42.78	36.43	395.11
1988	1.86	53.97	78.44	195.34	45.05	34.93	409.59
1989	2.13	52.65	76.88	195.68	45.82	35.69	408.85
1990	2.46	51.66	74.42	186.43	42.89	35.20	393.07
1991	2.86	52.15	71.77	172.49	36.77	34.43	370.47
1992	2.97	52.38	68.55	155.80	27.85	32.51	340.06
1993	2.59	49.30	61.84	136.68	21.12	28.83	300.37

Estimates in million pounds by subarea.

Table A.5 Historical Exploitation Rates (Closed Subarea)

	AREA							
Year	2A	2B	2C	3A	3B	4	Total	+Bycatch
1974	0.31	0.15	0.17	0.15	0.19	0.03	0.14	0.26
1975	0.26	0.22	0.19	0.17	0.26	0.03	0.17	0.24
1976	0.15	0.23	0.17	0.17	0.27	0.03	0.17	0.25
1977	0.13	0.17	0.10	0.13	0.29	0.05	0.13	0.20
1978	0.07	0.15	0.12	0.14	0.12	0.06	0.12	0.19
1979	0.04	0.15	0.12	0.14	0.03	0.06	0.12	0.20
1980	0.03	0.18	0.08	0.14	0.02	0.03	0.11	0.20
1981	0.14	0.18	0.09	0.15	0.02	0.04	0.12	0.18
1982	0.18	0.16	0.07	0.13	0.15	0.05	0.11	0.16
1983	0.20	0.15	0.10	0.12	0.21	0.13	0.13	0.17
1984	0.34	0.21	0.09	0.15	0.16	0.09	0.14	0.17
1985	0.40	0.23	0.13	0.14	0.26	0.13	0.16	0.18
1986	0.55	0.23	0.15	0.21	0.23	0.17	0.20	0.22
1987	0.64	0.24	0.15	0.19	0.19	0.20	0.19	0.22
1988	0.40	0.25	0.16	0.22	0.16	0.14	0.20	0.23
1989	0.38	0.21	0.15	0.20	0.18	0.14	0.18	0.21
1990	0.21	0.18	0.15	0.18	0.21	0.16	0.18	0.22
1991	0.18	0.15	0.15	0.16	0.34	0.18	0.18	0.22
1992	0.23	0.16	0.17	0.20	0.32	0.21	0.20	0.25
1993	0.27	0.23	0.21	0.20	0.34	0.22	0.22	0.27

Estimates in million pounds by subarea.

Table A.6 Annual Surplus Production (Closed Subarea)

Year	AREA						Total
	2A	2B	2C	3A	3B	4	
1974	0.60	6.34	5.47	13.81	2.54	-0.24	28.52
1975	0.33	6.66	5.73	14.78	2.95	-0.67	29.78
1976	0.34	6.31	6.33	15.85	3.31	0.32	32.46
1977	0.13	5.74	7.03	16.03	3.71	1.52	34.16
1978	0.13	4.55	7.73	15.62	3.46	1.96	33.45
1979	-0.06	4.93	8.66	17.81	4.43	2.18	37.95
1980	0.11	6.23	9.45	21.69	6.41	3.95	47.84
1981	0.07	7.75	12.32	26.90	7.97	4.34	59.35
1982	0.44	9.09	13.45	30.52	10.11	4.49	68.10
1983	0.29	10.59	13.18	32.86	10.74	4.04	71.70
1984	0.68	13.99	11.51	37.81	10.00	4.23	78.22
1985	0.65	14.01	10.52	36.02	8.93	5.15	75.28
1986	0.85	14.41	11.81	45.03	11.17	6.57	89.84
1987	1.29	13.71	11.76	47.66	10.37	5.67	90.46
1988	1.01	12.09	11.09	42.97	7.97	5.56	80.69
1989	1.13	10.12	8.82	28.95	5.11	4.60	58.73
1990	0.93	9.90	8.66	19.44	2.79	4.92	46.64
1991	0.63	8.05	7.47	11.55	3.43	4.39	35.52
1992	0.31	5.31	5.02	12.20	2.07	3.09	28.00
1993	0.27	5.00	4.53	10.70	1.57	2.74	24.73

Estimates in million pounds by subarea.

Sullivan, P.J., 1994. Population assessment, 1993. IPHC
Rep. Assess. Res. Act. 1993., pp. 63–131.

Table A.7 Fishing Mortalities (Closed Subarea)

Year	AREA				
	2A-2B	2C	3A	3B	4
1974	0.15	0.21	0.19	0.24	0.03
1975	0.24	0.24	0.25	0.33	0.03
1976	0.22	0.22	0.23	0.30	0.03
1977	0.17	0.12	0.17	0.35	0.07
1978	0.13	0.14	0.19	0.15	0.05
1979	0.15	0.13	0.18	0.03	0.06
1980	0.18	0.11	0.21	0.02	0.02
1981	0.17	0.10	0.21	0.02	0.05
1982	0.15	0.07	0.16	0.17	0.04
1983	0.14	0.12	0.15	0.24	0.15
1984	0.19	0.10	0.18	0.19	0.12
1985	0.23	0.16	0.21	0.37	0.14
1986	0.23	0.17	0.29	0.25	0.18
1987	0.24	0.18	0.26	0.23	0.22
1988	0.25	0.20	0.30	0.19	0.14
1989	0.23	0.19	0.27	0.20	0.16
1990	0.17	0.18	0.24	0.25	0.17
1991	0.13	0.17	0.24	0.42	0.19
1992	0.16	0.21	0.27	0.40	0.23
1993	0.24	0.25	0.29	0.43	0.25

Sullivan, P.J., 1994. Population assessment, 1993. IPHC
Rep. Assess. Res. Act. 1993., pp. 63–131.

Table A.8 Recruitment (Closed Subarea)

Year	AREA						Total
	2A	2B	2C	3A	3B	4	
1974	0.5	9.5	8.6	19.5	3.3	2.2	43.6
1975	0.5	9.4	8.8	25.6	4.5	2.9	51.7
1976	0.5	9.5	9.5	27.2	4.5	2.7	53.9
1977	0.5	9.9	11.3	27.6	5.0	3.3	57.6
1978	0.6	11.5	14.1	30.3	6.2	3.7	66.4
1979	0.6	11.3	14.4	25.4	5.9	3.9	61.4
1980	0.6	12.1	17.9	27.9	8.0	5.2	71.7
1981	0.7	14.1	19.3	40.8	14.3	11.9	101.1
1982	0.6	15.1	18.8	41.4	12.7	9.8	98.5
1983	0.7	17.3	19.6	45.7	14.0	9.2	106.4
1984	0.8	22.8	22.6	56.2	14.5	7.1	124.0
1985	1.0	28.5	27.6	69.5	20.6	16.0	163.2
1986	0.8	23.8	20.3	56.6	15.1	11.2	127.7
1987	0.8	26.0	19.2	61.2	13.8	10.4	131.5
1988	0.8	22.9	17.1	73.2	18.0	7.9	139.9
1989	0.6	15.6	13.2	44.9	10.1	5.7	90.1
1990	0.7	13.7	11.6	27.9	5.6	5.2	64.7
1991	0.9	16.2	12.5	46.0	5.5	5.7	86.8
1992	0.9	16.3	12.0	26.9	3.9	6.0	65.9
1993	0.5	10.4	6.6	15.0	1.9	2.6	37.0

Estimates in million pounds by subarea.

Table A.9 Exploitable Biomass (Closed Subarea)
Discounting 1993 and 1992 CPUE

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	1.66	30.83	32.21	55.97	9.18	24.32	154.17
1975	1.73	32.46	32.08	61.56	10.07	23.37	161.27
1976	1.60	31.88	31.56	65.71	10.45	22.10	163.29
1977	1.69	30.78	32.35	70.49	11.00	21.65	167.96
1978	1.59	30.91	36.11	77.63	11.47	21.80	179.51
1979	1.60	30.67	39.42	82.64	13.52	22.25	190.11
1980	1.47	30.51	43.36	88.69	17.41	22.83	204.27
1981	1.53	30.79	49.21	97.85	23.26	25.63	228.28
1982	1.37	32.44	57.18	109.67	30.37	28.24	259.27
1983	1.53	35.37	66.59	125.80	35.17	30.74	295.20
1984	1.47	39.59	72.78	143.41	37.51	29.81	324.57
1985	1.56	43.18	77.77	159.97	40.19	30.10	352.76
1986	1.49	44.71	78.14	172.69	37.10	29.96	364.08
1987	1.38	45.52	78.13	180.74	37.80	29.48	373.04
1988	1.53	44.32	77.99	192.92	38.44	26.95	382.16
1989	1.66	41.02	76.37	192.60	37.70	26.55	375.90
1990	1.81	37.91	73.84	182.85	33.75	24.87	355.02
1991	1.98	36.09	71.12	168.49	26.98	22.78	327.44
1992	1.94	34.28	67.84	151.49	17.52	19.58	292.63
1993	1.56	29.75	61.11	132.11	10.36	14.90	249.78

Estimates in million pounds by subarea.

Sullivan, P.J., 1994. Population assessment, 1993. IPHC Rep. Assess. Res. Act. 1993., pp. 63–131.

Table A.10 Historical Exploitation Rates (Closed Subarea)
Discounting 1993 and 1992 CPUE

Year	AREA						Total	+Bycatch
	2A	2B	2C	3A	3B	4		
1974	0.31	0.15	0.17	0.15	0.18	0.03	0.14	0.26
1975	0.27	0.22	0.19	0.17	0.25	0.03	0.17	0.24
1976	0.15	0.23	0.18	0.17	0.26	0.03	0.17	0.25
1977	0.13	0.18	0.10	0.13	0.29	0.06	0.13	0.20
1978	0.07	0.15	0.12	0.14	0.12	0.06	0.12	0.19
1979	0.04	0.16	0.12	0.14	0.03	0.06	0.12	0.20
1980	0.03	0.19	0.08	0.14	0.02	0.03	0.11	0.20
1981	0.14	0.18	0.09	0.15	0.02	0.05	0.12	0.18
1982	0.19	0.17	0.07	0.13	0.16	0.05	0.12	0.16
1983	0.21	0.16	0.10	0.12	0.22	0.14	0.14	0.17
1984	0.37	0.23	0.09	0.15	0.17	0.11	0.14	0.17
1985	0.44	0.26	0.13	0.14	0.28	0.15	0.17	0.19
1986	0.62	0.26	0.15	0.21	0.25	0.20	0.21	0.23
1987	0.75	0.28	0.15	0.19	0.21	0.24	0.20	0.23
1988	0.48	0.30	0.16	0.22	0.19	0.18	0.21	0.25
1989	0.48	0.27	0.15	0.20	0.21	0.19	0.20	0.23
1990	0.29	0.25	0.15	0.18	0.26	0.23	0.19	0.24
1991	0.26	0.22	0.15	0.17	0.46	0.28	0.20	0.25
1992	0.36	0.24	0.17	0.21	0.50	0.35	0.23	0.29
1993	0.45	0.38	0.22	0.21	0.69	0.43	0.27	0.33

Estimates in million pounds by subarea.

Table A.11 Annual Surplus Production (Closed Subarea)
Discounting 1993 and 1992 CPUE

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	0.59	6.25	5.47	13.78	2.56	-0.24	28.41
1975	0.33	6.55	5.72	14.75	2.94	-0.64	29.65
1976	0.33	6.18	6.32	15.82	3.28	0.27	32.20
1977	0.12	5.57	7.02	15.98	3.66	1.37	33.72
1978	0.12	4.38	7.71	15.59	3.37	1.80	32.97
1979	-0.07	4.72	8.64	17.75	4.28	1.95	37.27
1980	0.10	5.94	9.42	21.61	6.13	3.51	46.71
1981	0.06	7.33	12.30	26.80	7.56	3.81	57.86
1982	0.42	8.53	13.40	30.38	9.60	3.94	66.27
1983	0.27	9.76	13.14	32.67	10.09	3.49	69.42
1984	0.64	12.77	11.46	37.56	9.18	3.47	75.08
1985	0.62	12.55	10.47	35.71	8.00	4.30	71.65
1986	0.81	12.61	11.76	44.61	9.93	5.44	85.16
1987	1.19	11.75	11.69	47.06	8.74	4.64	85.07
1988	0.87	10.11	11.03	42.31	6.46	4.40	75.18
1989	0.95	8.00	8.75	28.45	4.09	3.41	53.65
1990	0.70	7.59	8.59	19.02	2.14	3.60	41.64
1991	0.48	6.01	7.41	11.24	2.89	3.11	31.14
1992	0.31	3.86	5.00	11.94	1.64	2.09	24.84
1993	0.25	3.35	4.50	10.41	0.97	1.59	21.20

Estimates in million pounds by subarea.

Table A.12 Fishing Mortalities (Closed Subarea)
Discounting 1993 and 1992 CPUE

	AREA				
Year	2A-2B	2C	3A	3B	4
1974	0.15	0.21	0.19	0.22	0.03
1975	0.24	0.24	0.25	0.31	0.03
1976	0.22	0.22	0.23	0.28	0.03
1977	0.17	0.12	0.17	0.33	0.07
1978	0.14	0.14	0.19	0.14	0.05
1979	0.15	0.13	0.19	0.03	0.06
1980	0.18	0.11	0.21	0.02	0.03
1981	0.18	0.10	0.21	0.02	0.05
1982	0.15	0.07	0.16	0.17	0.04
1983	0.15	0.12	0.15	0.24	0.17
1984	0.21	0.10	0.18	0.19	0.14
1985	0.25	0.16	0.21	0.38	0.16
1986	0.26	0.18	0.29	0.27	0.22
1987	0.28	0.18	0.26	0.25	0.28
1988	0.31	0.20	0.31	0.21	0.18
1989	0.29	0.19	0.28	0.23	0.22
1990	0.23	0.18	0.25	0.32	0.24
1991	0.19	0.17	0.24	0.59	0.30
1992	0.25	0.21	0.28	0.70	0.42
1993	0.43	0.26	0.30	1.11	0.54

Sullivan, P.J., 1994. Population assessment, 1993. IPHC
Rep. Assess. Res. Act. 1993., pp. 63–131.

Table A.13 Recruitment (Closed Subarea)
Discounting 1993 and 1992 CPUE

Year	AREA						Total
	2A	2B	2C	3A	3B	4	
1974	0.5	9.3	8.6	19.5	3.3	2.0	43.2
1975	0.5	9.2	8.8	25.5	4.5	2.7	51.2
1976	0.5	9.3	9.5	27.1	4.5	2.4	53.3
1977	0.5	9.5	11.3	27.5	4.9	3.0	56.8
1978	0.6	11.1	14.1	30.2	6.0	3.3	65.3
1979	0.6	10.8	14.4	25.4	5.7	3.5	60.2
1980	0.6	11.5	17.9	27.8	7.6	4.6	70.0
1981	0.7	13.3	19.2	40.6	13.6	10.5	97.9
1982	0.6	14.1	18.7	41.2	11.9	8.6	95.1
1983	0.7	15.8	19.5	45.4	12.9	7.9	102.2
1984	0.8	20.4	22.5	55.8	13.1	5.9	118.5
1985	0.9	24.8	27.5	68.8	18.2	13.0	153.2
1986	0.7	20.0	20.2	55.8	12.8	8.7	118.2
1987	0.6	20.9	19.1	60.2	11.1	7.8	119.8
1988	0.6	17.5	16.9	71.7	13.8	5.6	126.2
1989	0.5	11.3	13.1	43.8	7.2	3.8	79.6
1990	0.4	9.3	11.5	27.1	3.6	3.2	55.2
1991	0.6	10.3	12.3	44.5	3.1	3.2	74.1
1992	0.6	9.7	11.8	25.8	1.8	3.0	52.8
1993	0.3	5.7	6.5	14.3	0.7	1.2	28.5

Estimates in million pounds by subarea.

AREA 2A ASSESSMENT SUPPLEMENT

by

Patrick J. Sullivan

INTRODUCTION

The Pacific halibut stock is assessed on an annual basis coast wide. This year's assessment is presented in the sections of this report entitled Population Assessment, 1993 (Sullivan 1994a) and in Population Assessment, 1993: Technical Supplement (Sullivan 1994b). The Population Assessment section provides estimates of the exploitable biomass, shows population trends, makes quota recommendations based on a constant exploitation rate, and generally outlines the information that goes into the assessment. The Technical Supplement section provides further information, including area specific tables of commercial CPUE, commercial catch, total removals, exploitable biomass, historical exploitation rates, annual surplus production, and total instantaneous fishing mortality estimates. The Technical Supplement section also documents changes or modifications to the methodology that have been initiated in the present year. This Area 2A Supplement summarizes and expands on the Area 2A assessment and indicates where in the literature such supplemental information may usually be found. A brief overview of the assessment methodology is given first, followed by a biological assessment of the Area 2A stock. CPUE and CPUE partitioning methodology are also presented for determining quota recommendations.

AREA 2A ASSESSMENT METHODOLOGY

Area 2A encompasses Pacific halibut grounds off the coasts of Washington, Oregon, and California. Roughly 1% of the halibut exploitable biomass resides in this area and there are a number of recent reports that address the assessment and management of halibut in that area (Deriso and Price 1987, Trumble and Williams 1988, Clark 1989, Trumble 1990, Clark 1992, Clark and Wilkins 1992, St. Pierre 1992, Blood 1992) including two recent IPHC Scientific Reports (Trumble et al. 1991, Sullivan et al. 1993).

Pacific halibut stock assessments are conducted on an area by area basis. Due to its relatively low level of stock biomass the Area 2A assessment is conducted jointly with the assessment for Area 2B (British Columbia) thus providing a more stable annual estimate. A catch-age procedure (Deriso et al. 1985) is used in the analysis with modifications as discussed in (Sullivan et al. 1992, Sullivan 1994a,b). As indicated in the Population Assessment section of the annual (variously named) report to the Commissioners total catch, catch-per-unit-effort (CPUE), age composition, and average weight are incorporated into the analysis along with assumptions about natural mortality and selectivity. Analysis of model sensitivity to these assumptions for the Area 2A assessment are discussed elsewhere by Clark (Trumble et al. 1991). Generally, trends from the Area 2A-2B combined assessment mainly reflect the Area 2B stock dynamics because 95% of the catch, and therefore 95% of the available information, comes from that area. Relative trends not withstanding, the total catch contribution from Area 2A does effect the absolute levels of estimated abundance.

Area 2A commercial catch is given in the annual Technical Supplement sections and includes non-treaty commercial and treaty landings, while total removals include, in addition, sport harvest and wastage. Historical distribution of the catch, and other catch statistics, are given by fleet and by various area specifications (e.g. statistical area, state) in recent IPHC Scientific Reports (Trumble et al. 1991). Catch by Area 2A statistical areas is reviewed in Figure 1. Note that there has been a significant increase in the harvest over the time period considered in the analysis. Low catches observed in the years 1978, 1979, and 1980 were due to early closure of the season in Area 2 when most of the catch was being taken in what is now known as Area 2C.

Conversion factors used to standardize effort are applied annually on a coast-wide basis (Sullivan et al. 1992). Snap-gear effort is currently multiplied by a factor of 0.71 and, for statistical areas 81 and south, is computed in with fixed gear effort in determining the area-wide CPUEs. Snap-gear data are currently being evaluated for coast-wide use. Adjustments are made to standardize effort for the effect of variations in hook-spacing (Hamley and Skud 1978, Sullivan 1991), and in recent assessments gear with spacing less than four feet has been excluded because this short a spacing falls outside the range of the data used to derive the standardization algorithm. However, the shorter spacing (commonly used for black-cod fishing) makes up a significant portion of the poundage for which logbook information is available in Area 2A. Figure 2 shows recent trends in CPUE for gear with spacing greater than four feet, less than four feet, and combined. The resulting change in mean CPUE between estimates that include or exclude gear with spacing less than four feet was not significant although the annual variance in the estimate was reduced. This suggests that gear with hook-spacing less than four feet can reasonably be included in the estimates. Catch and effort statistics for gear of this type will now be included (in Area 2A only) by uniformly applying the adjustment estimated for gear with four foot spacing to gear with hook spacing less than four feet. This results in roughly a 46% upward adjustment to CPUE for gear of this type as shown in Figure 2.

Table 1 gives the percent of landed poundage for which useable effort information is available for the years 1986-1992 for Area 2A and for Area 3A for comparison. Logbook information is taken only from commercial (treaty and non-treaty) catch, but because sport catch makes up a greater portion of the overall landings in Area 2A the percentages are also provided with sport catch included for contrast. The percent coverage is adequate for providing consistent estimates of biomass.

Auxiliary estimates of halibut abundance from trawl survey data have been considered for inclusion into the Area 2A assessment (Clark and Wilkins 1992), but there is a puzzling unexplained difference in trends between the trawl survey data and the commercial CPUE data. Trawl survey estimates appear to be relatively low in 1977 and 1980. It is likely that Area 2A would have been closed to fishing had these estimates been used as a measure of stock abundance. In contrast, a significant catch with fairly stable commercial CPUE was taken over this time period. Incorporating this auxiliary information now could impart spurious trends to the estimates. Joint research between IPHC and NMFS continues in this area.

Age and length-at-age information is gathered through the standard port sampling procedures applied coast-wide (Clark 1990). The only difference is that Area 2A ages and lengths are sampled at 10 times the rate (pounds sampled per pounds landed) of Area 2B in order to increase precision in this area. (The actual sample size target is 1000 otolith samples in Area 2A and 2000 in Area 2B).

AREA 2A BIOLOGICAL ASSESSMENT

Coast-wide assessments indicate that the Pacific halibut stock has been declining at a rate of about 5-10% per year since the mid-1980s (Sullivan 1994a,b). Recent analysis of NMFS Bering Sea trawl survey data indicates a strong 1987 year class on the horizon that should enter the fishery at age 8 in 1995 (Clark and Walters 1993) which will hopefully stem stock decline. Area 2A recruitment measures (biomass of fish at age 8 as estimated jointly with Area 2B) show trends in biomass and recruitment that are similar to those observed coast-wide.

Biomass and recruitment trends are based on the standard catch-age analysis and combine a number of measures of stock dynamics in a unified and systematic manner. However, examining biological indicators for the Area 2A stock that are not linked to any specific model may also be enlightening. Figure 3, for example, shows the smoothed catch at age by cohort from the time it first enters the fishery till the time it leaves. The smoother averages over time and over the different cohorts represented, and only those cohorts present in the fishery from age 8 till age 17 were used (i.e. cohorts that were age 8 recruits the years 1974 through 1983). The contrast between the three relative catches per year in the fishery indicates that, on average, halibut were, over those years, harvested more heavily earlier in their life history in Areas 2A and 2B than they were in Area 3A. This is consistent with model based estimates (Figure 4) which indicate that the harvest rate was 10% higher on average in 2A than in 3A in those years and that the harvest rate in 2B was 10% higher than that in 2A over the same period. This area specific contrast is also marked the relative abundance of halibut at age the 1992 catch (Figure 5), pointing to a standing stock with significantly smaller and younger halibut relative to northern portions of the population. In 1992, the average age of halibut the catch in Area 2A was 10.7 years in contrast to an average age of 11.5 years in Area 2B, 12.7 years in 2C, and 12.1-12.7 years in Areas 3 and 4. A smaller weight at age and a negligible number of fish age 18 and older are also observed (Blood 1993). These effects are not likely due to changes in the characteristics of the fleet (Table 2) or sampling procedure (Clark 1992), and may reflect poorer or less available habitat, poorer recruitment (Figure 6), and higher ploitation rates relative to Areas north (Figure 4). The combined commercial, treaty, and sport exploitation has, since 1974, averaged at a rate of 0.25 pound removed per pound of exploitable biomass contrast to the 0.20 rate observed for Area 2B and the 0.18 rate observed for Area 3A as based on 1992 stock assessment estimates.

CPUE AND CPUE PARTITIONING

Catch-per-unit-effort for halibut represents the poundage of legal size fish (length greater than 81 cm) landed per standard skate (1800 foot length of line with 18 foot hook spacing). As mentioned above, and discussed elsewhere (Sullivan et al. 1992), adjustments are made to account for variation in hook-type, hook-spacing, and gear-type. A comparison across IPHC regulatory Areas indicates that CPUE has remained low in the southern most Areas 2A and 2B (Figure 7).

Individual vessel quota management, initiated for Pacific halibut 1991 in Area 2B, has brought about changes in fleet behavior that area. Initial indications are that these changes have not affected IPHC catch statistics (Sullivan 1993) although research this area continues.

A combined assessment is conducted for Area 2A and 2B and then relative measures of CPUE and habitat are used to partition the biomass between the two areas. The principles behind the method of CPUE partitioning are discussed in IPHC Scientific Report No. 72 (Quinn et al. 1985) and elsewhere (Sullivan et al. 1992). The partitioning works in this way: CPUE provides a measure of halibut density, this estimate when multiplied by area (habitat) results in an estimate of relative abundance. The estimates are generally derived by averaging, in some manner, the relevant statistics over time. There are various approaches to taking these averages for both CPUE and habitat although the results are fairly consistent between methods (Quinn et al. 1985).

In 1992, IPHC staff used a 4.5% to 95.5% partition between Area 2A and Area 2B. This partition reflected a compromise between the value of 4.3% under a 10 year running average and 4.9% under a 5 year running average. The staff decided to no longer use the twice applied running median smoother (which had been in use for nearly a decade) as it recently proved to be too unstable at the end point (the median smoother estimate was 4.1% for 1992). The final quota set for Area 2A in 1992 reflected the 4.5% partition applied to the 2A-2B constant exploitation yield (CEY). The CEY for this combined area was computed using a 0.33 exploitation rate. The 0.33 exploitation rate was used as a phase in to a 0.30 rate; a rate that was determined to be the appropriate coastwide level of exploitation (Parma 1993). In 1993, a 0.30 rate will be applied to Areas 2A and 2B to complete the phase in. We now consider some alternative partitioning methods.

Variability is reduced the annual density statistic used for partitioning by averaging or smoothing (e.g. with running medians) annual area specific CPUEs over time. An optimal smoother will reduce the year-to-year variation observed in the data while tracking significant trends. Median smoothers are often employed because they tend to react robustly to outliers. Running averages on the other hand change more gradually, but may be unduly influenced (for an extended period of time) by high or low outlying values. Estimates of the endpoint percentage under various smoothing procedures are given in Figure 8. The 1992 Area 2A percentages follow from application of the smoothers to CPUE for Areas 2A and 2B. The smoothed endpoint estimate (the smoothed 1992 estimate for example) for each area is then multiplied by fixed habitat measures to determine the biomass partitioned to each area and the final percentage is determined from the ratio of partitioned Area 2A biomass to the combined 2A-2B biomass estimate.

Figure 8 shows the results of three types of smoothers relative to the results of not applying any smoothing algorithm. Clearly, the median smoother did not significantly modify the results from the no smooth option. The other algorithms arrive at lower percentages for recent years. The higher set represents 5, 10, and 15 year running averages on CPUE. The lower set takes similar running averages for catch and divides them by running averages for effort, which is essentially an effort weighted running average. Both sets of running averages put more emphasis on the lower CPUE observed in earlier years (not shown). The results for these years range from 2.5% to 6.5% which is not dissimilar to previous findings based on analysis of habitat measures, CPUE, extended cohort analysis runs (5.3%-6.0% Quinn et al. 1985) and those based on historical catch ratios for years when vessels were free to fish throughout the area and when seasons were identical (5.2%) or alternatively when seasons or quotas were separate (4.5%).

Updated relative habitat values for Areas 2A and 2B were computed using the method of Quinn et al. (1985) based on CPUE statistics and exploitable biomass estimates derived from Virtual Population Analysis (VPA). The VPA was conducted on Areas 2A and 2B separately for the years 1935-1992 using final fishing mortalities estimated by CAGEAN for 2A-2B combined (Parma, pers. com.). Recomputed mean and median statistics of relative habitat for the years 1950-1980 indicate, respectively, that 5.4% and 5.2% of the Area 2A-2B habitat resides in Area 2A. These values are slightly lower than those currently used of, 5.7% and 5.5% respectively as derived by Quinn et al. (1985).

Algorithm choice depends on what factors one wishes to optimize. One can 1) follow variations in the stock estimates closely in an attempt to maximize yield, but run the risk of having quotas which vary significantly from year-to-year; or alternatively one can 2) act to minimize the year-to-year variations in the quota while potentially forfeiting some long term yield. In order for either option to be viable we presuppose that the risk to the stock is minimized. In terms of the algorithms presented above a five year running average seems reasonable. It would reduce year-to-year variation in the quota and yet it would respond quickly to significant trends in the population.

ADDITIONAL INFORMATION

The IPHC staff have received many requests for information over the last few weeks. Enclosed as appendices are some tables we have sent out summarizing catch statistics, landings, and CPUE in various alternative ways.

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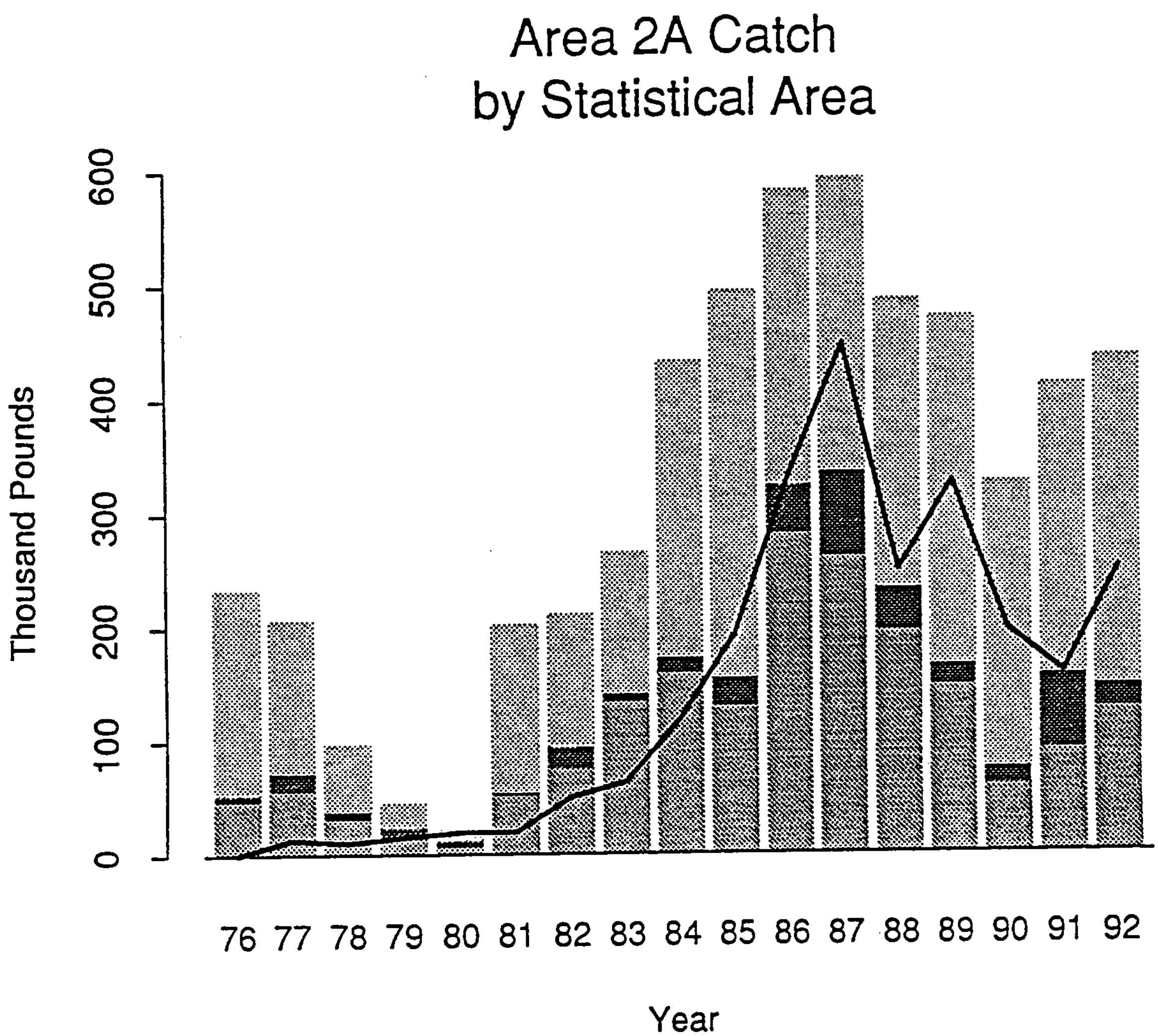

Figure 1. **Catch in pounds by statistical areas 007-030 (bottom), 040 (middle), and 050 (top). Area 2A total sport catch is shown as the superimposed line.**

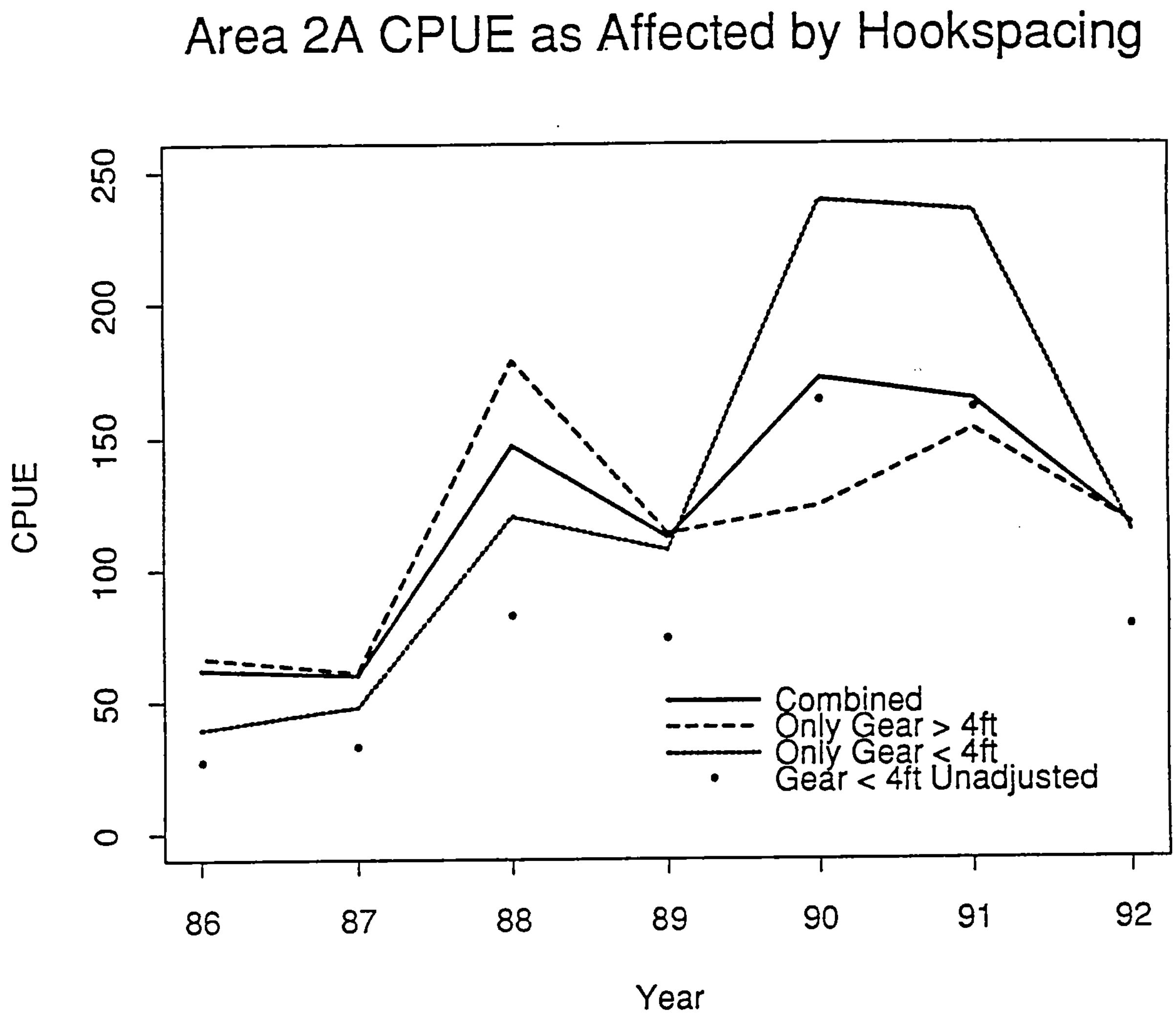

Figure 2. **Catch per unit of effort for gear with spacing greater than or equal to four foot spacing, gear with less than four foot spacing, and combined. CPUE for gear with less than four foot spacing has been adjusted upward by a factor of 1.46 as shown to acocunt for differences in catch per hook at different hook spacing increments.**

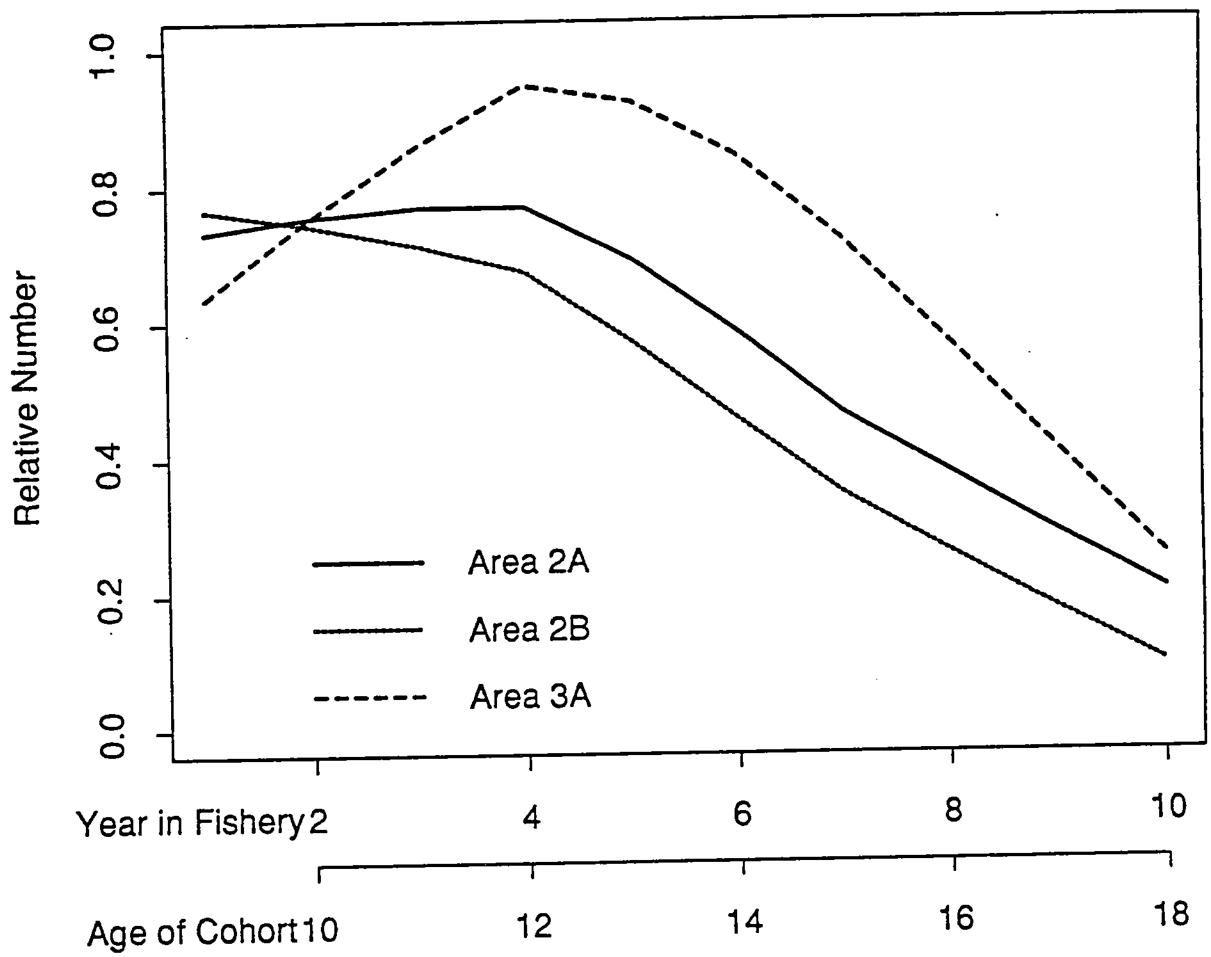

Figure 3. **Smoothed relative catch of fully observed cohorts.**

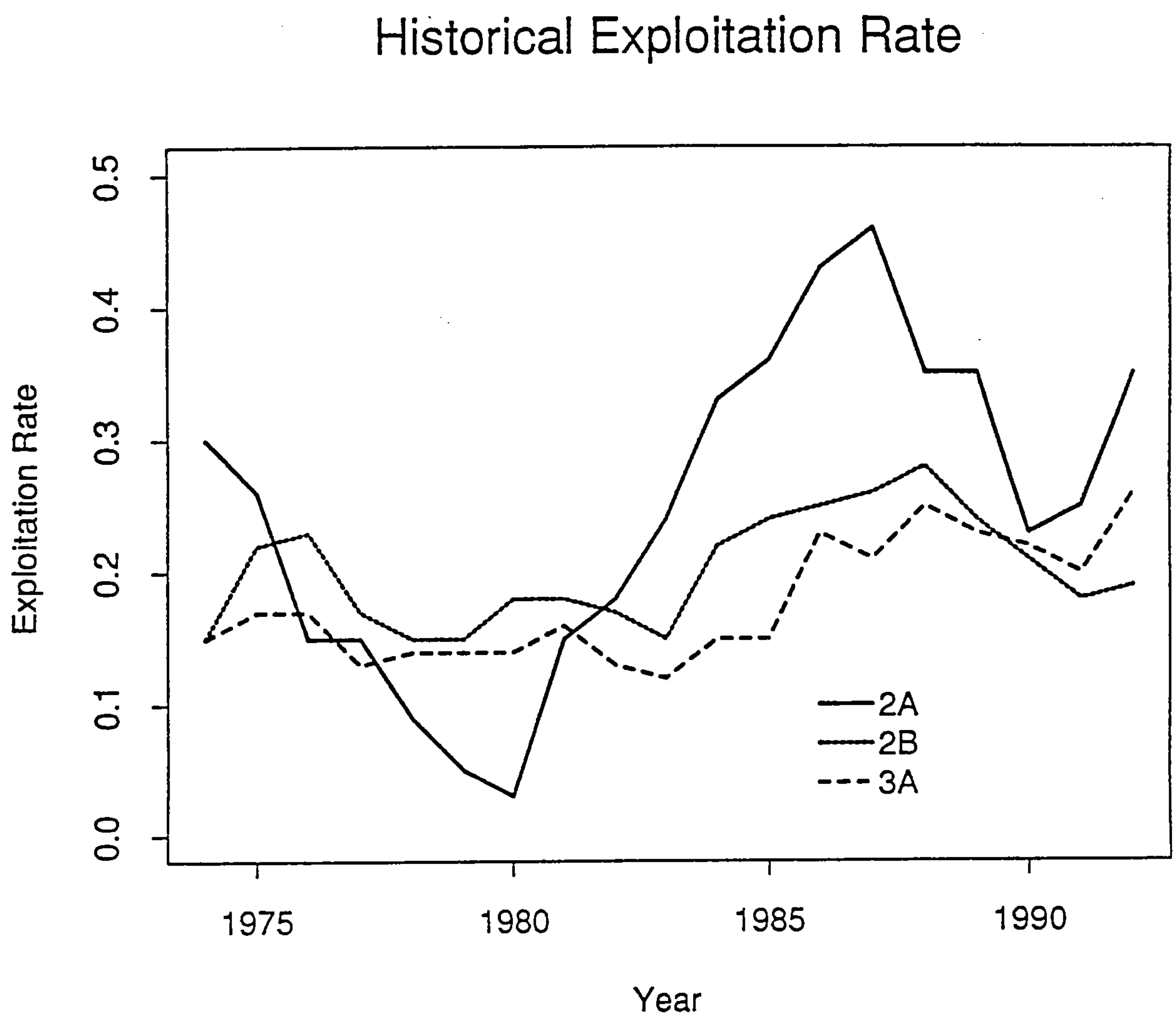

Figure 4. **HIstorical exploitation rate calculated as total removals (other than bycatch) as a proportion of the estimated exploitable biomass.**

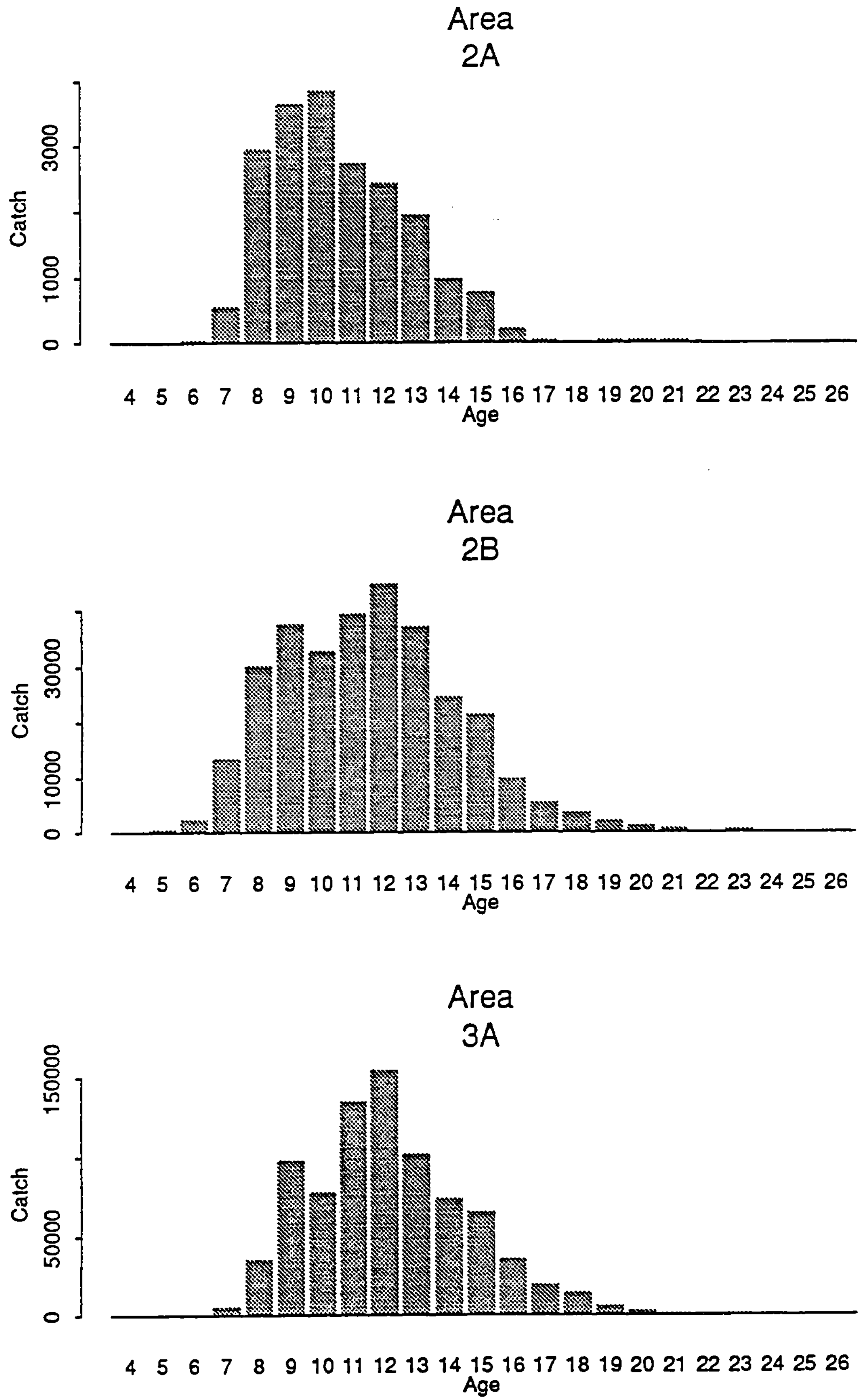

Figure 5. Catch in numbers at age for Areas 2A, 2B, and 3A, 1992.

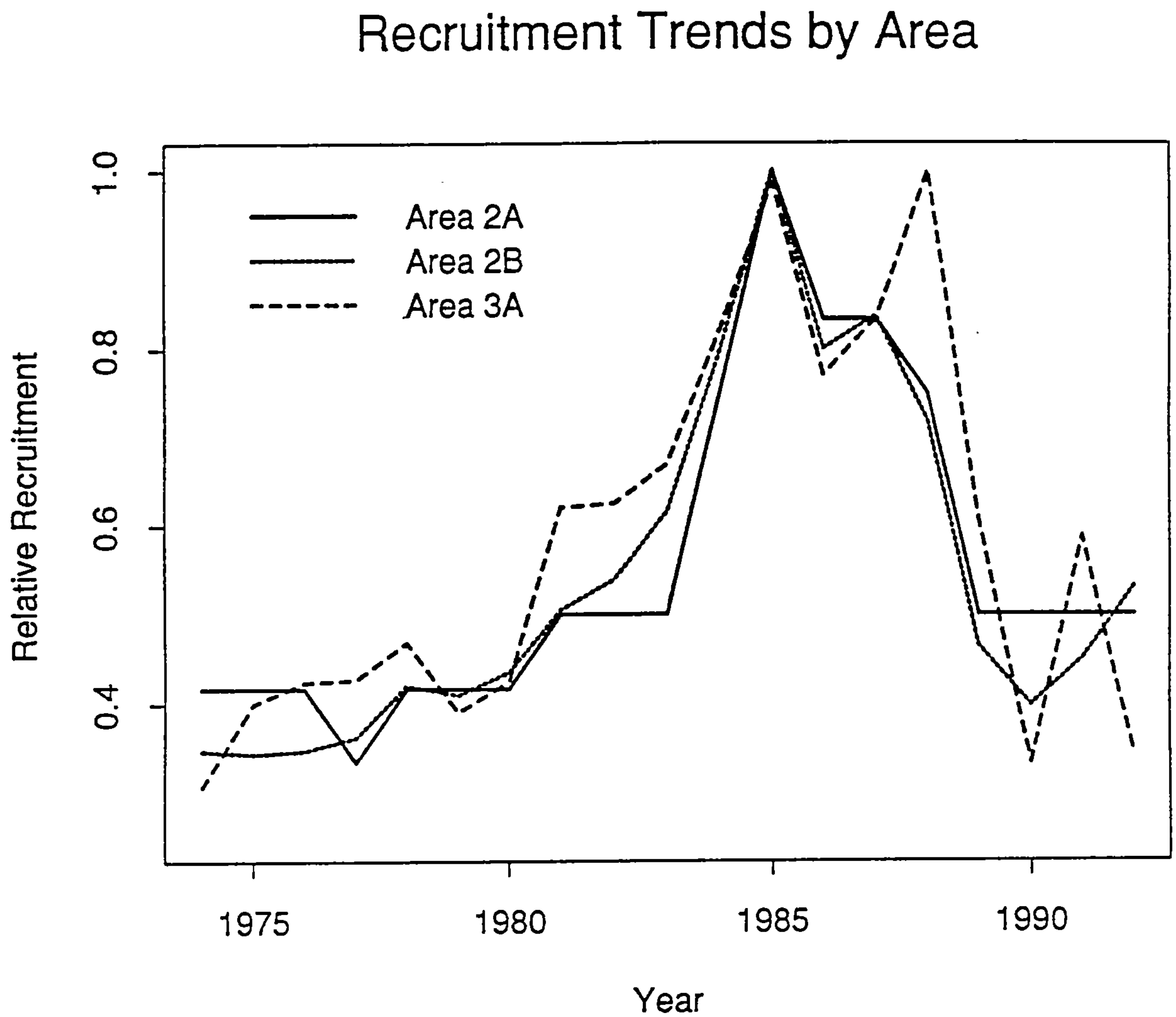

Figure 6. **Recruitment biomass normalized to the maximum annual recruitment value for Areas 2A, 2B, and 3A.**

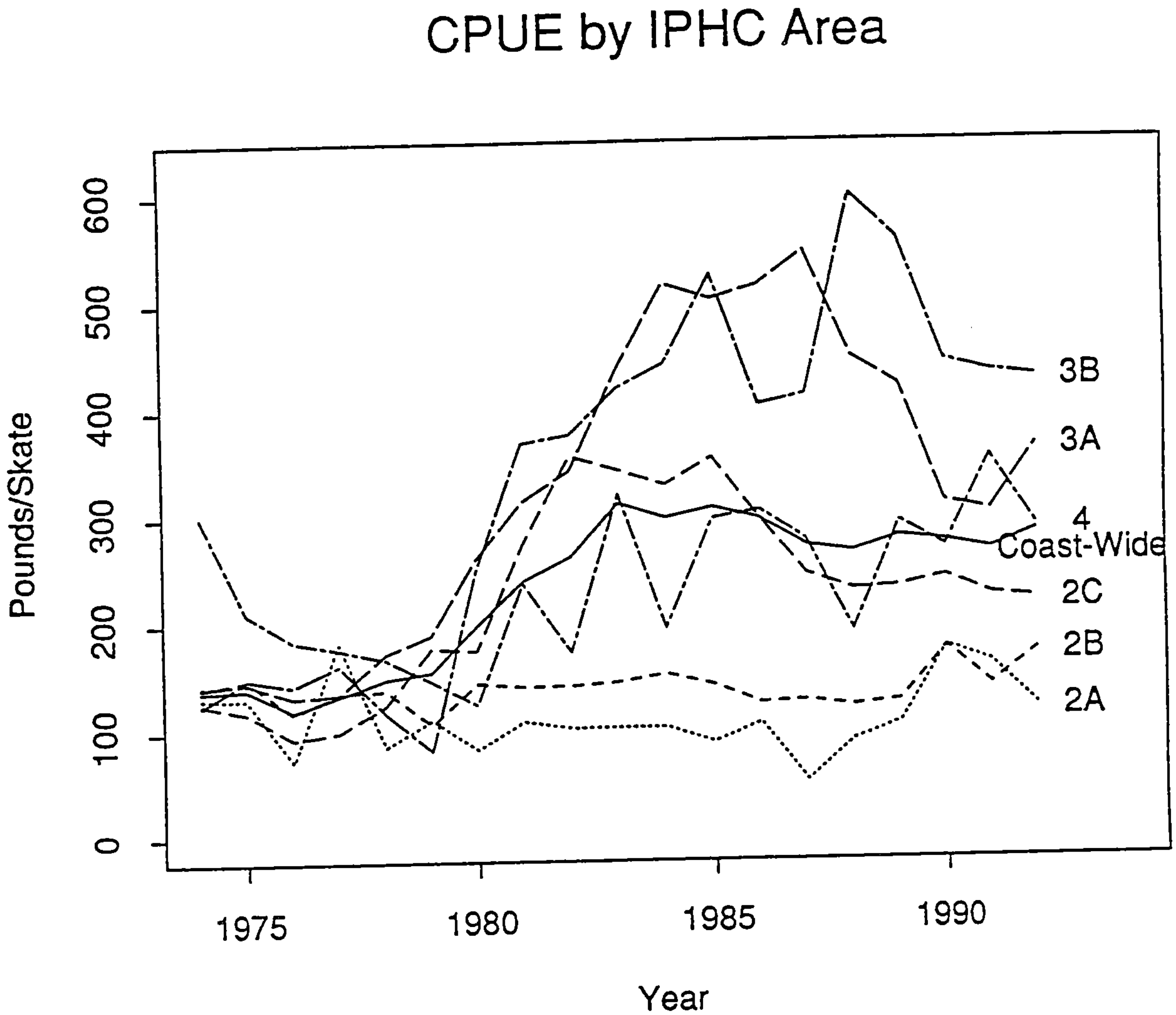

Figure 7. Catch in pounds per unit of effort coast-wide and by IPHC regulatory area.

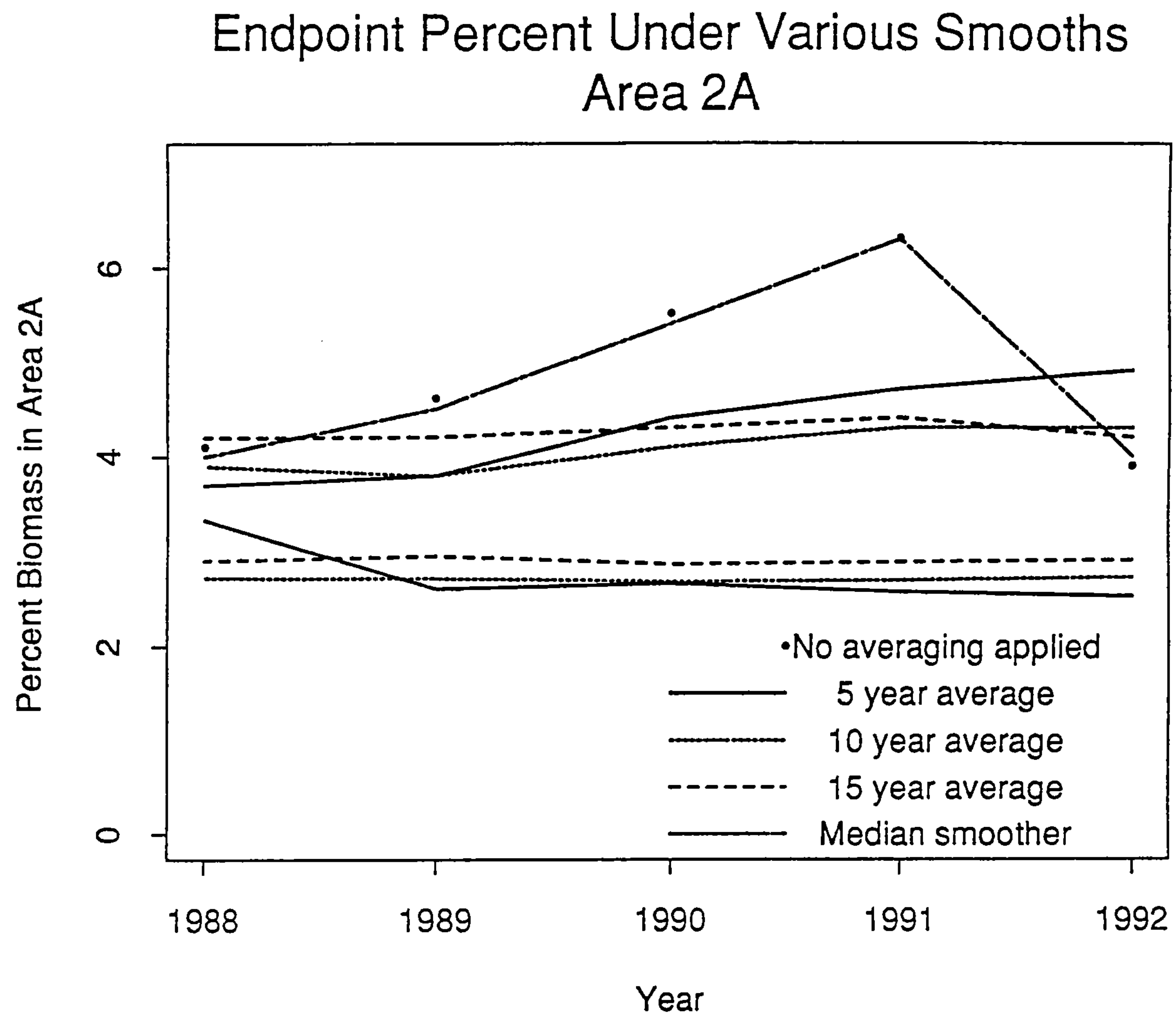

Figure 8. **Smoothed percentage of combined Area 2A-2B biomass partitioned into Area 2A. Points show partitioning based on raw CPUE values. Line through points is the median smoother. The higher set of three lines correspond to 5, 10, and 15 year running average CPUE. The lower set of three lines correspond to 5, 10, and 15 year running catch divided by the respective running effort, namely an effort weighted running average.**

Table 1. **Percent of landed poundage for which useable logbook information was available for Area 2A and Area 3A.**

Percent of Commercial Landings Only.

	Year						
Area	1986	1987	1988	1989	1990	1991	1992
2A	29	26	40	53	32	47	45
3A	33	40	38	45	43	43	40

Percent of Commercial and Sport Landings.

	Year						
Area	1986	1987	1988	1989	1990	1991	1992
2A	18	15	26	31	20	32	29
3A	31	37	35	41	38	36	35

Table 2. **Number of vessels participating Area 2A halibut fishery by user-group (Commercial and Treaty) and by gear type (Fixed-hook, Snap, and Other). Treaty vessel numbers are based on identifiers associated with individual fishers.**

Year	Commercial	Treaty	Fixed	Snap	Other	Total
86	318	54	94	89	189	372
87	322	123	97	93	255	445
88	216	154	61	73	236	370
89	181	124	21	28	256	305
90	167	47	16	25	173	214
91	181	40	17	46	158	221
92	205	65	30	55	185	270

LIST OF APPENDICES

Appendix 1: Area 2A catches by subarea and fishery. Compiled by I. McGregor.

Appendix 2: Area 2A commercial vessel landings. Compiled by H. Gilroy.

Appendix 3: Area 2A commercial catch by statistical area. Compiled by H. Gilroy.

Appendix 4: Area 2A catch and CPUE by statistical area. An update to Table 10 in Scientific Report 74. Compiled by P. Sullivan.

AREA 2A CATCHES BY SUBAREA AND FISHERY

	Area 2A				
	Non-Treaty		Treaty		
Year	Comm.[1]	Sport[2,3]	Comm.	C & S	Total
1929	1,564.0				1,564.0
1930	1,167.0				1,167.0
1931	1,279.0				1,279.0
1932	1,254.0				1,254.0
1933	1,116.0				1,116.0
1934	1,984.0				1,984.0
1935	1,770.0				1,770.0
1936	901.0				901.0
1937	917.0				917.0
1938	951.0				951.0
1939	1,363.0				1,363.0
1940	981.0				981.0
1941	509.0				509.0
1942	718.0				718.0
1943	1,237.0				1,237.0
1944	897.0				897.0
1945	729.0				729.0
1946	900.0				900.0
1947	572.0				572.0
1948	407.0				407.0
1949	618.0				618.0
1950	703.0				703.0
1951	585.0				585.0
1952	617.0				617.0
1953	502.0				502.0
1954	853.0				853.0
1955	612.0				612.0
1956	529.0				529.0
1957	596.0				596.0
1958	523.0				523.0
1959	669.0				669.0
1960	885.0				885.0
1961	497.0				497.0
1962	449.0				449.0
1963	412.0				412.0
1964	280.0				280.0
1965	214.0				214.0

Year	Area 2A				Total
	Non-Treaty		Treaty		
	Comm.[1]	Sport[2,3]	Comm.	C & S	
1966	183.0				183.0
1967	199.0				199.0
1968	138.0				138.0
1969	230.0				230.0
1970	159.0	12.1			171.1
1971	318.0				318.0
1972	369.0	24.4			393.4
1973	225.0	15.8			240.8
1974	515.0	15.3			530.3
1975	460.0	17.3			477.3
1976	238.0	10.3			248.3
1977	207.0	13.4			220.4
1978	97.0	10.0			107.0
1979	46.0	14.6			60.6
1980	22.0	18.7			40.7
1981	202.0	18.6			220.6
1982	211.0	50.3			261.3
1983	265.0	62.6			327.6
1984	431.0	118.1			549.1
1985	489.0	193.1	3.9	10.5	696.5
1986	564.0	333.0	17.4	10.0	924.4
1987	548.0	445.8	43.7	10.9	1,048.4
1988	392.0	248.8	94.0	9.2	744.0
1989	330.0	326.6	142.0	10.0	808.6
1990	203.0	196.7	122.0	9.9	531.6
1991	233.0	158.4	122.0	7.3	520.7
1992	282.0	249.7	155.4	14.2	701.3
1993[4]	310.0	246.5	138.0	14.0	708.5

[1]The commercial catch in Area 2A-1 is derived from IPHC statistical areas 40 and 50. Area 2A-1 does not completely extend through Statistical Area 40; therefore 80% of the catch in Statistical Area 40 is attributed to Area 2A-1 and 20% is attributed to Area 2A-2

[2]The sport catch in Area 2A-1 is assumed to be 100% of the Washington sport landings. A negligible amount occurs south of Westport, Washington and is assumed to be insignificant.

[3]Sport landing estimates are not available where not indicated, but are believed to be minor.

[4]Preliminary

Year	Area 2A-2			% Area 2A
	Non-Treaty		Total	
	Comm.[1]	Sport[2,3]		
1929	1,235.6		1,235.6	79.0
1930	825.8		825.8	70.8
1931	949.2		949.2	74.2
1932	876.4		876.4	69.9
1933	749.2		749.2	67.1
1934	1,616.6		1,616.6	81.5
1935	1,494.4		1,494.4	84.4
1936	718.4		718.4	79.7
1937	715.4		715.4	78.0
1938	721.0		721.0	75.8
1939	1,099.8		1,099.8	80.7
1940	828.4		828.4	84.4
1941	350.4		350.4	68.8
1942	316.0		316.0	44.0
1943	439.0		439.0	35.5
1944	359.6		359.6	40.1
1945	456.4		456.4	62.6
1946	600.0		600.0	66.7
1947	423.6		423.6	74.1
1948	260.6		260.6	64.0
1949	387.6		387.6	62.7
1950	377.6		377.6	53.7
1951	290.8		290.8	49.7
1952	321.4		321.4	52.1
1953	215.6		215.6	42.9
1954	558.4		558.4	65.5
1955	381.4		381.4	62.3
1956	326.8		326.8	61.8
1957	298.4		298.4	50.1
1958	220.6		220.6	42.2
1959	141.4		141.4	21.1
1960	260.0		260.0	29.4
1961	236.8		236.8	47.6
1962	281.2		281.2	62.6
1963	176.8		176.8	42.9
1964	109.8		109.8	39.2
1965	99.2		99.2	46.4

Year	Area 2A-2			% Area 2A
	Non-Treaty			
	Comm.[1]	Sport[2,3]	Total	
1966	81.2		81.2	44.4
1967	75.4		75.4	37.9
1968	52.8		52.8	38.3
1969	75.4		75.4	32.8
1970	48.4		48.4	28.3
1971	114.0		114.0	35.8
1972	104.6		104.6	26.6
1973	7.0		7.0	2.9
1974	68.0		68.0	12.8
1975	38.2	5.0	43.2	9.1
1976	49.0	5.0	54.0	21.7
1977	59.2	5.0	64.2	29.1
1978	33.2	5.0	38.2	35.7
1979	16.0	5.0	21.0	34.7
1980	7.2	5.0	12.2	30.0
1981	52.4	6.6	59.0	26.7
1982	79.6	7.1	86.7	33.2
1983	134.6	7.9	142.5	43.5
1984	161.6	5.1	166.7	30.4
1985	133.9	8.7	142.6	20.5
1986	290.6	35.0	325.6	35.2
1987	275.5	78.2	353.7	33.7
1988	204.2	74.3	278.5	37.4
1989	133.6	134.9	268.5	33.2
1990	61.9	73.1	135.0	25.4
1991	92.9	56.2	149.1	28.6
1992	131.0	84.1	215.1	30.7
1993[4]	114.0	96.8	210.8	29.8

[1]The commercial catch in Area 2A-1 is derived from IPHC statistical areas 40 and 50. Area 2A-1 does not completely extend through Statistical Area 40; therefore 80% of the catch in Statistical Area 40 is attributed to Area 2A-1 and 20% is attributed to Area 2A-2.

[2]The sport catch in Area 2A-1 is assumed to be 100% of the Washington sport landings. A negligible amount occurs south of Westport, Washington and is assumed to be insignificant.

[3]Sport landing estimates are not available where not indicated, but are believed to be minor.

[4]Preliminary

Year	Area 2A-1				Total	% Area 2A
	Non-Treaty		Treaty			
	Comm.[1]	Sport[2 3]	Comm.	C & S		
1929	328.4				328.4	21.0
1930	341.2				341.2	29.2
1931	329.8				329.8	25.8
1932	377.6				377.6	30.1
1933	366.8				366.8	32.9
1934	367.4				367.4	18.5
1935	275.6				275.6	15.6
1936	182.6				182.6	20.3
1937	201.6				201.6	22.0
1938	230.0				230.0	24.2
1939	263.2				263.2	19.3
1940	152.6				152.6	15.6
1941	158.6				158.6	31.2
1942	402.0				402.0	56.0
1943	798.0				798.0	64.5
1944	537.4				537.4	59.9
1945	272.6				272.6	37.4
1946	300.0				300.0	33.3
1947	148.4				148.4	25.9
1948	146.4				146.4	36.0
1949	230.4				230.4	37.3
1950	325.4				325.4	46.3
1951	294.2				294.2	50.3
1952	295.6				295.6	47.9
1953	286.4				286.4	57.1
1954	294.6				294.6	34.5
1955	230.6				230.6	37.7
1956	202.2				202.2	38.2
1957	297.6				297.6	49.9
1958	302.4				302.4	57.8
1959	527.6				527.6	78.9
1960	625.0				625.0	70.6
1961	260.2				260.2	52.4
1962	167.8				167.8	37.4
1963	235.2				235.2	57.1
1964	170.2				170.2	60.8
1965	114.8				114.8	53.6

Sullivan, P.J., 1994. Population assessment, 1993. IPHC Rep. Assess. Res. Act. 1993., pp. 63–131.

Year	Area 2A-1				Total	% Area 2A
	Non-Treaty		Treaty			
	Comm.[1]	Sport[2, 3]	Comm.	C & S		
1966	101.8				101.8	55.6
1967	123.6				123.6	62.1
1968	85.2				85.2	61.7
1969	154.6				154.6	67.2
1970	110.6	12.1			122.7	71.7
1971	204.0				204.0	64.2
1972	264.4	24.4			288.8	73.4
1973	218.0	15.8			233.8	97.1
1974	447.0	15.3			462.3	87.2
1975	421.8	12.3			434.1	90.9
1976	189.0	5.3			194.3	78.3
1977	147.8	8.4			156.2	70.9
1978	63.8	5.0			68.8	64.3
1979	30.0	9.6			39.6	65.3
1980	14.8	13.7			28.5	70.0
1981	149.6	12.0			161.6	73.3
1982	131.4	43.2			174.6	66.8
1983	130.4	54.7			185.1	56.5
1984	269.4	113.0			382.4	69.6
1985	355.1	184.4	3.9	10.5	553.9	79.5
1986	273.4	298.0	17.4	10.0	598.8	64.8
1987	272.5	367.6	43.7	10.9	694.7	66.3
1988	187.8	174.5	94.0	9.2	465.5	62.6
1989	196.4	191.7	142.0	10.0	540.1	66.8
1990	141.1	123.6	122.0	9.9	396.6	74.6
1991	140.1	102.2	122.0	7.3	371.6	71.4
1992	151.0	165.6	155.4	14.2	486.2	69.3
1993[4]	196.0	149.7	138.0	14.0	497.7	70.2

[1]The commercial catch in Area 2A-1 is derived from IPHC statistical areas 40 and 50. Area 2A-1 does not completely extend through Statistical Area 40; therefore 80% of the catch in Statistical Area 40 is attributed to Area 2A-1 and 20% is attributed to Area 2A-2.

[2]The sport catch in Area 2A-1 is assumed to be 100% of the Washington sport landings. A negligible amount occurs south of Westport, Washington and is assumed to be insignificant.

[3]Sport landing estimates are not available where not indicated, but are believed to be minor.

[4]Preliminary

Table 1. Number of different non-Indian commercial vessels that made halibut landings in WA, OR and CA (from Area 2A) and the net pounds landed.

Year	Number of Individual vessels			Pounds Landed			Total lbs
	WA	OR	CA	WA	OR	CA	
1989	71	107(1)	3	181,806	146,251	1,401	329,458
1990	101(3)	64(16)	3	144,098	58,414	1,241	203,753
1991	101(1)	76(14)	5	139,617	89,006	4,182	232,805
1992	120(2)	78(10)	10	160,325	112,196	6,936	279,457

The numbers in brackets are additional vessels with tag, research, or illegal landings

Table 2. Breakdown of Area 2A landings by vessel class for non-Indian commercial vessels in WA and OR/CA from 1989 to 1992.

1989	Washington Landings		Oregon/California Landings	
Vessel Class	Number Landings	Total Pounds	Number Landings	Total Pounds
A	20	4,010	9	2,089
B	5	181	14	2,754
C	5	2,423	10	1,747
D	11	2,620	20	30,967
E	8	33,664	12	22,446
F	4	16,416	19	50,834
G	2	11,993	8	17,490
H	14	109,638	5	18,292
Unknown/research	2	861	15	1,033
Total	71	181,806	112	147,652

1990	Washington Landings		Oregon/California Landings	
Vessel Class	Number Landings	Total Pounds	Number Landings	Total Pounds
A	82	17,035	9	1,041
B	14	3,280	9	1,239
C	24	9,150	13	2,744
D	23	14,922	19	5,105
E	23	15,874	20	22,903
F	8	5,924	14	12,738
G	2	17,521	6	1,779
H	17	60,166	2	11,346
Unknown/tags/illeg.	5	226	19	760
Total	198	144,098	111	59,655

Table 2. (continued)
Breakdown of Area 2A landings by vessel class for non-Indian commercial vessels in WA and OR/CA from 1989 to 1992.

1991	Washington Landings		Oregon/California Landings	
Vessel Class	Number Landings	Total Pounds	Number Landings	Total Pounds
A	40	13,545	8	1,578
B	7	2,663	4	1,432
C	8	3,523	7	2,656
D	16	14,145	23	17,866
E	8	20,940	16	26,180
F	7	11,699	12	20,171
G	5	13,122	5	8,447
H	10	59,948	5	13,797
Unknown/tags/illeg.	2	32	17	1,061
Total	103	139,617	97	93,188

1992		Washington Landings		Oregon/California Landings	
Openings	Vessel Class	Number Landings	Total Pounds	Number Landings	Total Pounds
7/29	A	31	11,149	2	66
7/29	B	7	2,527	2	226
7/29	C	6	2,752	4	1,739
7/29	D	21	13,323	9	16,345
7/29	E	12	22,365	6	6,323
7/29	F	8	16,786	11	13,282
7/29	G	6	7,145	6	15,220
7/29	H	13	27,848	5	14,737
Total		104	103,895	45	67,938
8/12	A	26	4,480	3	630
8/12	B	5	1,012	3	346
8/12	C	4	1,053	8	2,768
8/12	D	19	12,519	22	15,617
8/12	E	11	11,582	13	8,925
8/12	F	10	10,658	9	6,843
8/12	G	3	4,309	4	6,009
8/12	H	7	10,701	4	8,795
Total		85	56,314	66	49,933
	Unknown/tag/illeg	2	116	14	1,261

Sullivan, P.J., 1994. Population assessment, 1993. IPHC
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Area 2A commercial catch (treaty and non-treaty) of Pacific halibut in thousands of pounds (net weight) by IPHC statistical area, 1982 - 1992.

Year	Statistical Area						Total
	<09	10	20	30	40	50	
1982			64	12	18	117	211
1983		16	105	12	8	124	265
1984		51	78	30	13	259	431
1985		67	43	19	25	339	493
1986	12	100	149	21	41	258	581
1987	38	82	94	51	74	257	596
1988	3	61	94	39	36	253	486
1989	12	29	106	1	18	306	472
1990	1	11	47	<1	15	250	325
1991	4	9	70	9	6	257	355
1992	22	11	69	25	20	290	437

Sullivan, P.J., 1994. Population assessment, 1993. IPHC Rep. Assess. Res. Act. 1993., pp. 63–131.

Table 10. Commercial CPUE (standardized) and logbook catch by statistical area in Area 2A.

a. CPUE by statistical area

Year	Regulatory Area 2A					
	010	020	030	040	050	050*
1986	105.9	106.7	32.7	33.6	49.7	
1987	55.7	60.1	48.4	28.0	82.6	
1988	94.9	308.9	99.7	17.9	111.0	
1989	85.2	145.6		57.6	114.4	108.3
1990	162.9	154.7		121.6	180.1	103.4
1991	22.8	241.0	410.4	138.1	155.3	117.8
1992	34.2	208.9	142.9		113.8	104.6

b. Logbook catch (in pounds) used to calculate CPUE

Year	Regulatory Area 2A					
	010	020	030	040	050	050*
1986	48,917	55,743	6,348	3,125	42,706	
1987	41,149	30,687	25,353	15,019	32,942	
1988	25,318	89,344	21,634	1,275	54,903	
1989	20,495	61,535		6,389	151,875	33,458
1990	10,424	6,077		4,620	83,010	13,072
1991	737	41,779	5,746		111,075	59,896
1992	5,648	27,564	9,818	3,064	145,184	95,811

* Treaty only.

POPULATION ASSESSMENT, 1992

by

Patrick J. Sullivan

Introduction

The 1992 Pacific halibut stock assessment examines changes that have occurred in the catch over time and relates this to changes that have taken place in the stock. The analysis is conducted by area and applied to data from Areas 2A-2B, 2C, 3A, 3B, and 4. Information is collected annually on catch, catch per unit effort (CPUE), age composition, and average weight at age. This data is used to determine the exploitable biomass, that is the stock biomass available for harvest. The constant exploitation yield (CEY) is determined, once the exploitable biomass has been estimated, as a fraction of this estimate. An exploitation rate of 0.35 has been used over the last few years, but lower exploitation rates have now been recommended. The yield resulting from these rates represents about a third of the exploitable biomass. Given the CEY, the recommended allowable catch is determined by accounting for removals from other sources (sport catch, wastage, bycatch, and personal use). The procedure is outlined in Figure 1.

Stock Assessment

This year's stock assessment indicates that the total exploitable biomass of Pacific halibut in 1992 is 265.8 million pounds. This represents an overall decline in biomass this year of 11%, a rate similar to the 5-10% declines observed in previous years. Figure 2 shows the trends in exploitable biomass for the total stock. Figures 3 through 8 give the area-by-area trends in exploitable biomass, recruitment, and CPUE. The estimated exploitable biomass decreased by 6% in area 2A, increased by 3% in area 2B, and decreased by 6%, 13%, 34%, and 12% respectively in areas 2C, 3A, 3B, and 4.

Recruitment of 8-year-old halibut appears to have dropped off coastwide, reflecting a drop in recruitment in areas 3A, 3B, and 4 and a leveling off of recruitment in area 2C. Recruitment has continued to increase in areas 2A and 2B. This year's fifteen-year-old year class, which recruited strongly as eight-year-olds in 1985 (Figures 2 through 8) is contributing less and less to the fishery in terms of yield. The lower recruitment of recent years indicates that the stock will continue its decline at a rate of about 5-10% per year over the next several years. A return to historically low levels of recruitment, as indicated this year by area 3A 8-year-olds, supports the hypothesis of cyclically driven recruitment. If this hypothesis continues to hold, then low recruitment should be expected over the next

Sullivan, P.J., 1993. Population assessment, 1992. IPHC Rep. Assess. Res. Act. 1993., pp. 33–62.

several years.

Areas 2B and 3A show an upturn in CPUE over last year's values, while all other areas show a decline.

Each year, in addition to estimating the current year's stock levels, stock levels for previous years are re-estimated using updated information. Changes in the level of bycatch, waste, and sport catch coupled with the inherent variability observed in the stock dynamics and the measurement process may result in adjustments to previous abundance estimates. This can cause the allowable catch to be higher than expected in some areas where stock abundance indicates more of a decline. The recommended allowable catch estimates are always based on the most current available information.

Constant Exploitation Yield

Results from the 1992 stock assessment are used in determining the total and setline constant exploitation yields. These yields are shown in Table 1 along with the 1992 catch and quota. The overall CEY is obtained by multiplying the area specific exploitable biomass by the constant exploitation yield rate. This year three rates are presented: 0.30, 0.33, and 0.35, as shown in Tables 1a, 1b, and 1c respectively. A 35% exploitation rate was used in the past. This year, however, the staff is recommending lower rates. Once the exploitation rate has been chosen and applied equally to all areas, the biomass removal from other sources is subtracted out to determine the allowable setline catch. The setline constant exploitation yields indicate the harvest that should be taken by the setline commercial fishery in order to maintain optimal yields and viability of the stock. It should be realized, however, that the stock is currently above its estimated sustainable level and that future yields will be lower than those which we are now experiencing.

Bycatch

Adjustments to the allowable catch for bycatch shown in Table 1 represent compensation to the stock for losses in the stock's reproductive potential due to losses from bycatch. The allowable catch is reduced in line 1.4 of Table 1 by one pound for every pound of bycatch removed. The bycatch reduction in each area is made in proportion to the estimated exploitable biomass in that area.

IPHC Stock Assessment

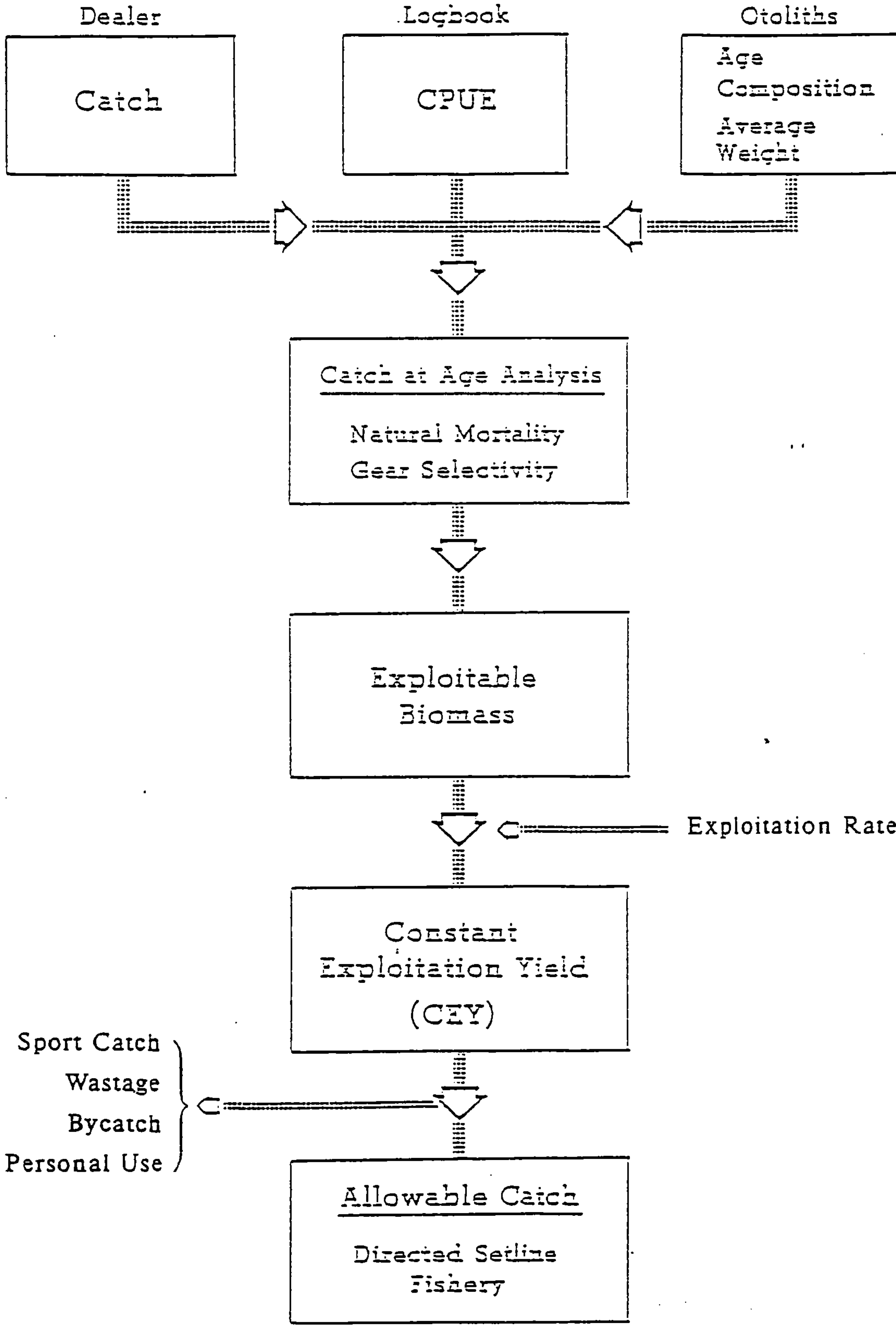
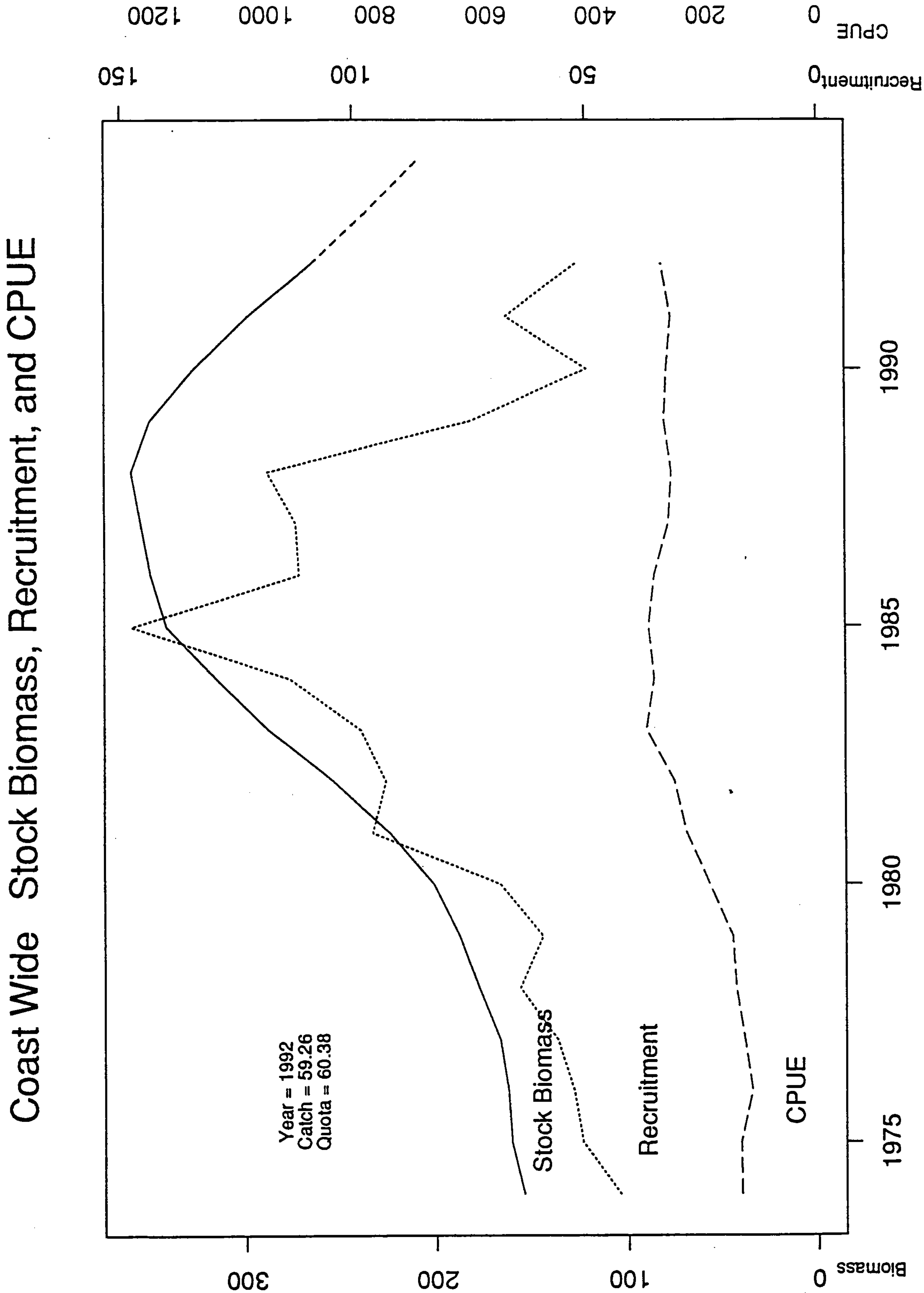
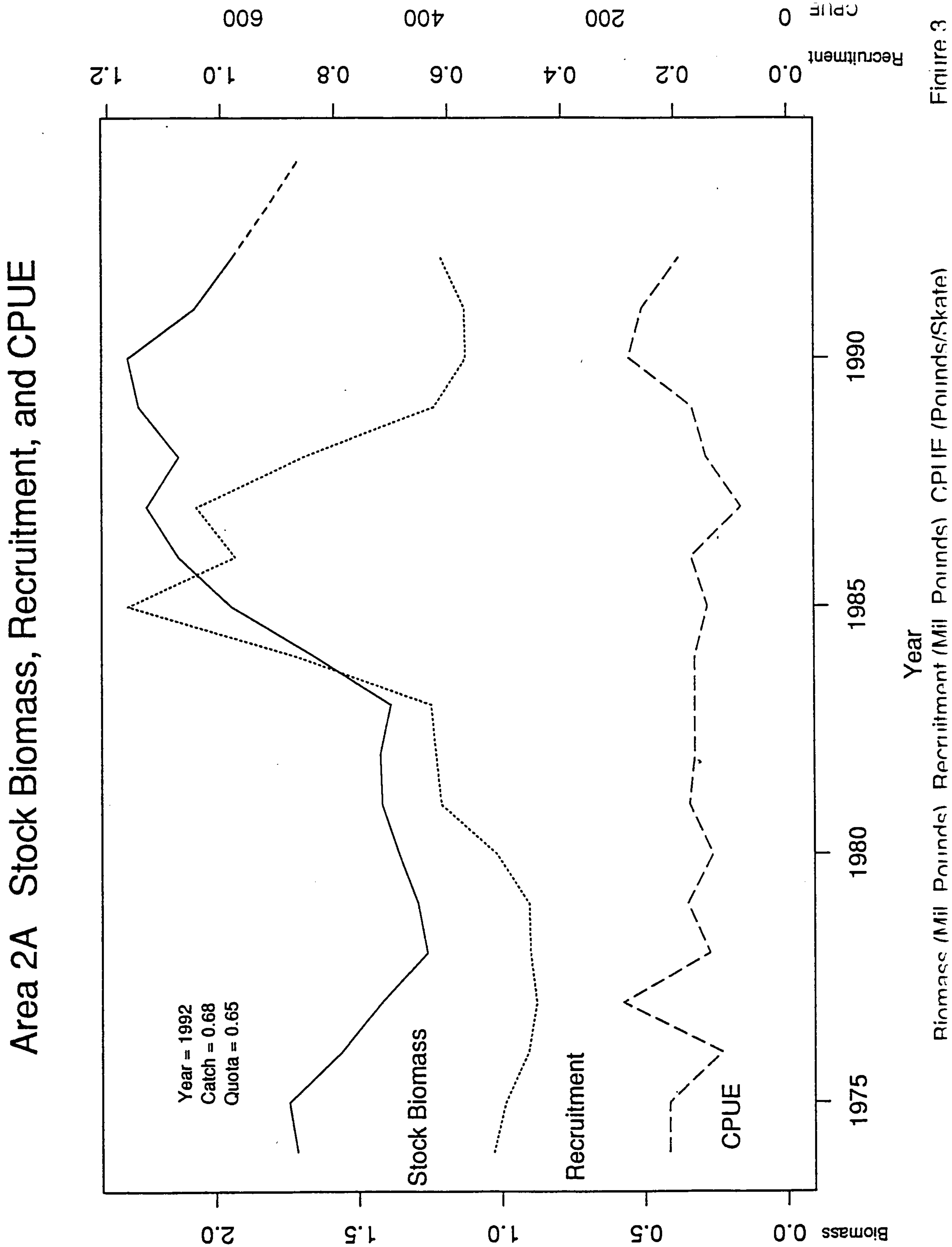


Figure 1

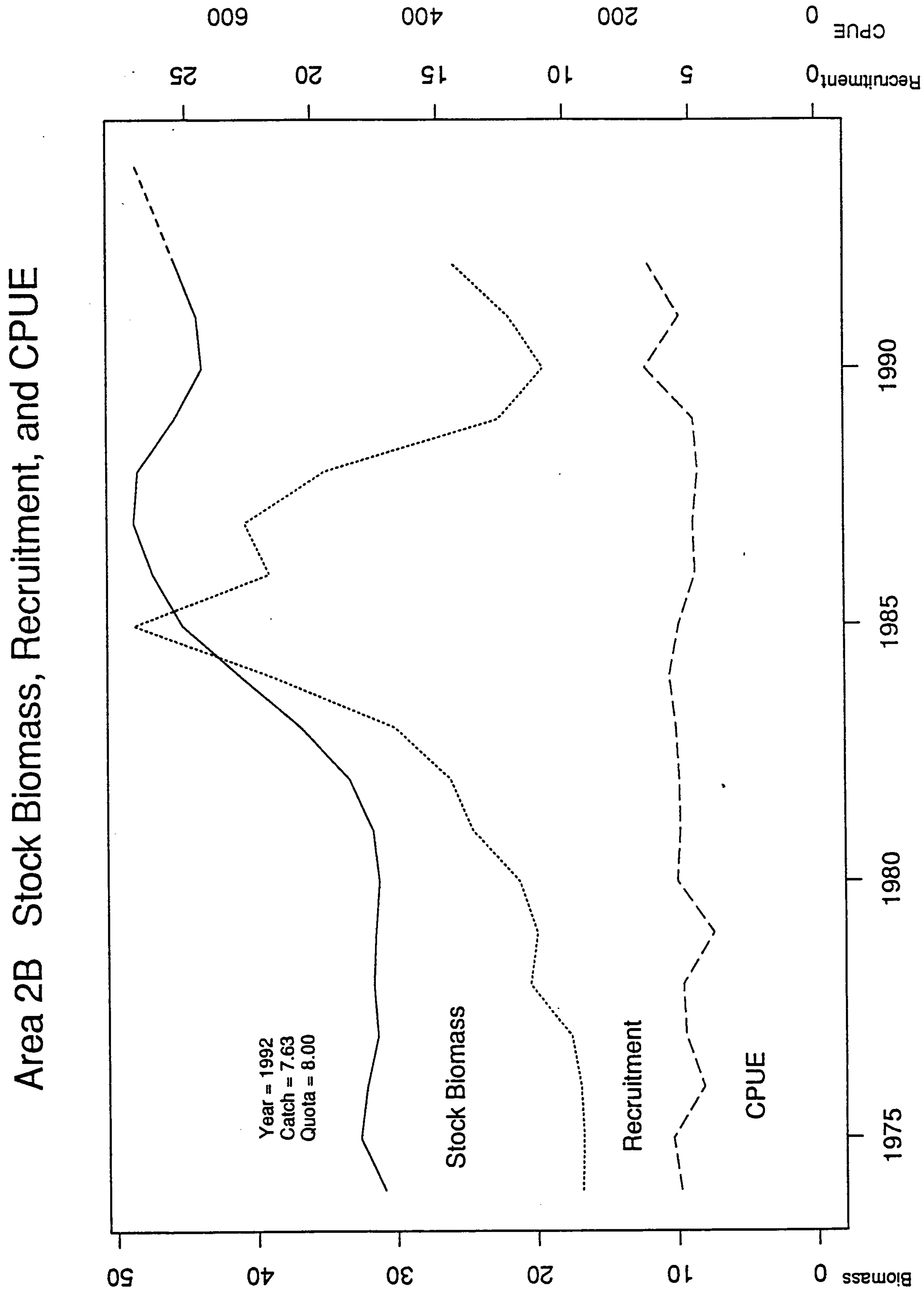
Sullivan, P.J., 1993. Population assessment, 1992. IPHC Rep. Assess. Res. Act. 1993., pp. 33–62.



Sullivan, P.J., 1993. Population assessment, 1992. IPHC Rep. Assess. Res. Act. 1993., pp. 33–62.



Sullivan, P.J., 1993. Population assessment, 1992. IPHC Rep. Assess. Res. Act. 1993., pp. 33–62.



Sullivan, P.J., 1993. Population assessment, 1992. IPHC
Rep. Assess. Res. Act. 1993., pp. 33–62.

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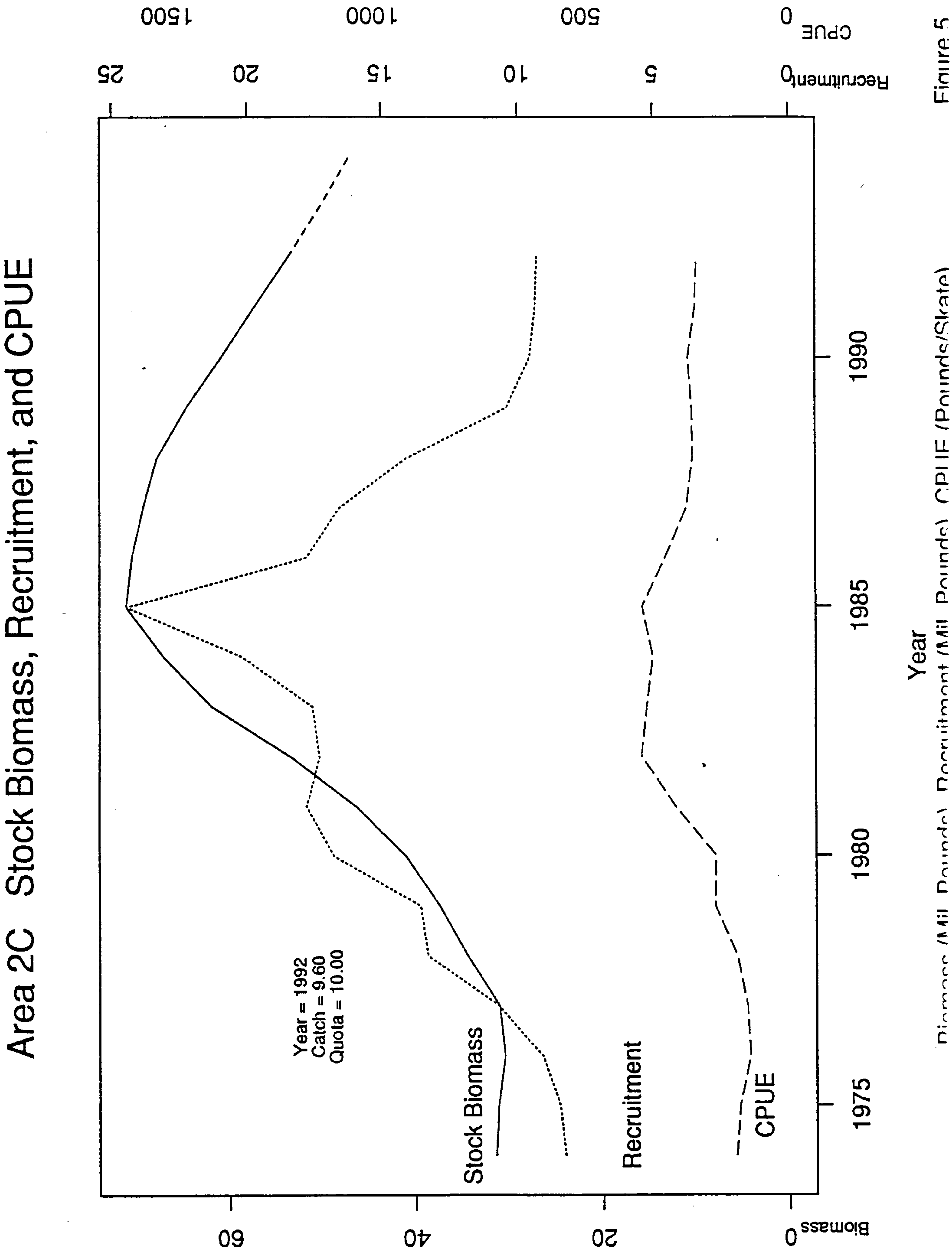

Area 2C Stock Biomass, Recruitment, and CPUE
Year = 1992
Catch = 9.60
Quota = 10.00
Stock Biomass
Recruitment
CPUE
Year
1975
1980
1985
1990
Biomass
0
20
40
60
Recruitment
0
5
10
15
20
25
CPUE
0
500
1000
1500
Figure 5

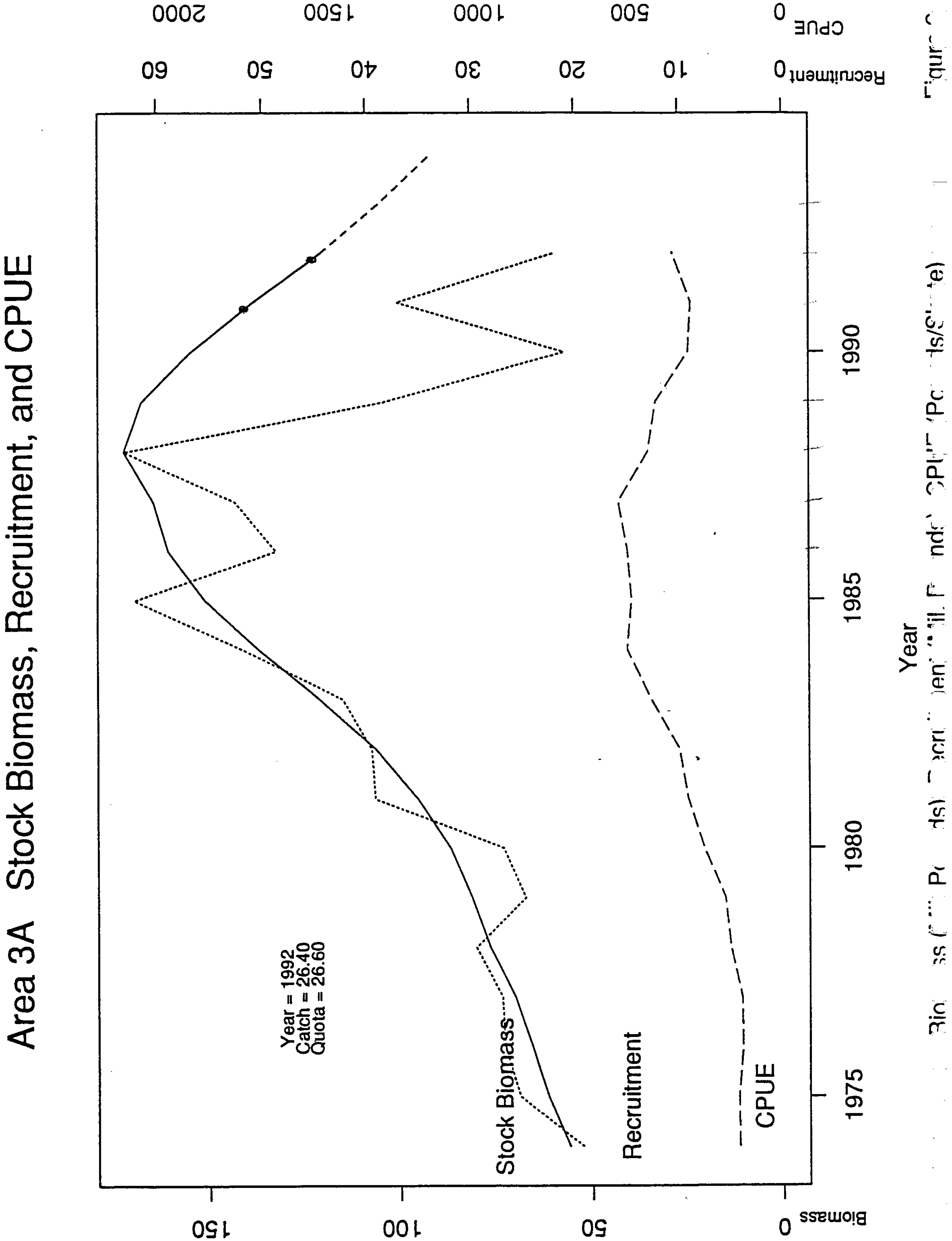
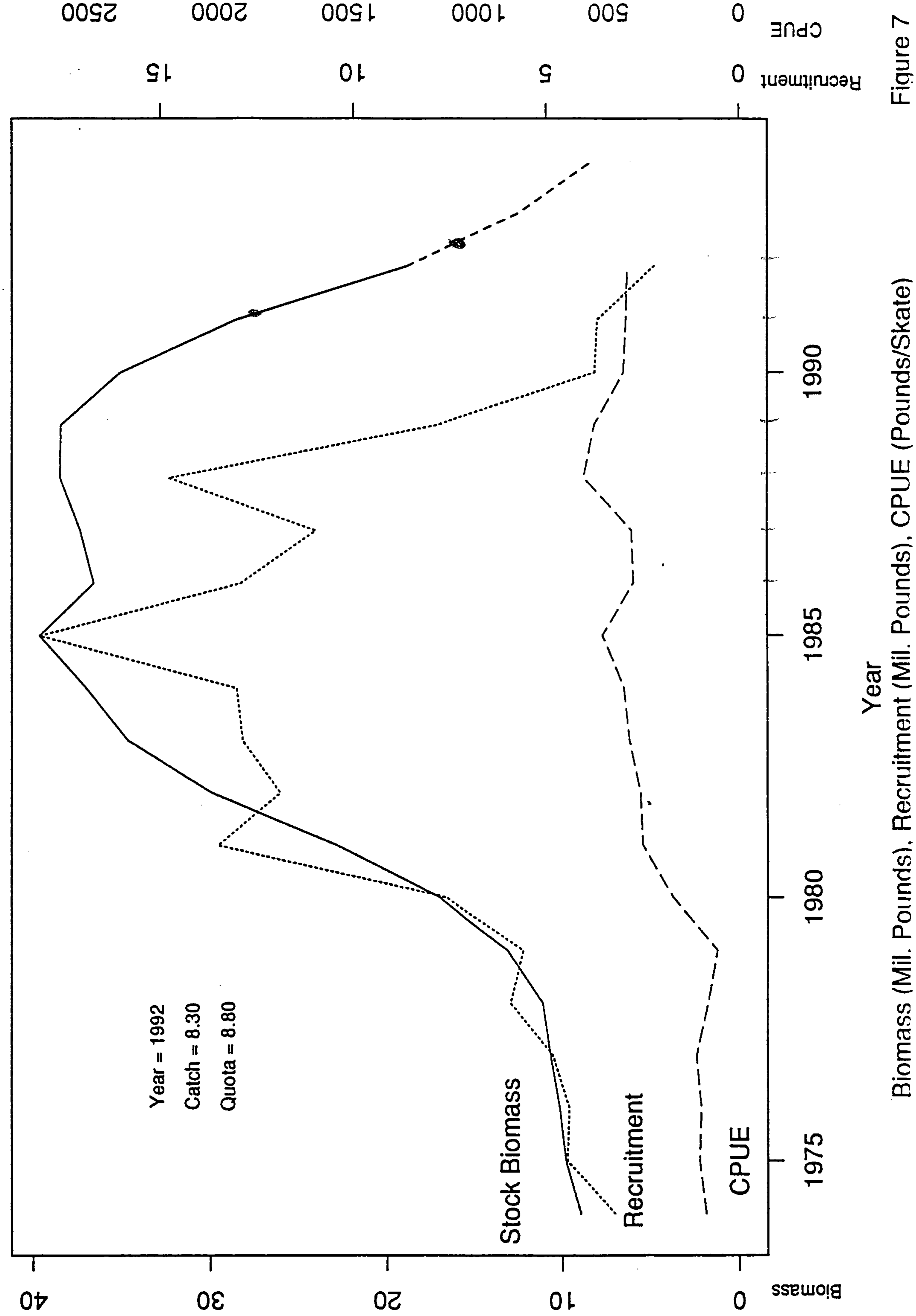

Area 3A Stock Biomass, Recruitment, and CPUE
Year = 1992
Catch = 26.40
Quota = 26.60
Stock Biomass
Recruitment
CPUE
Year
1975
1980
1985
1990
Biomass
0
50
100
150
Recruitment
0
10
20
30
40
50
60
CPUE
0
500
1000
1500
2000

Figure 7

Area 3B Stock Biomass, Recruitment, and CPUE



Area 4 Stock Biomass, Recruitment, and CPUE

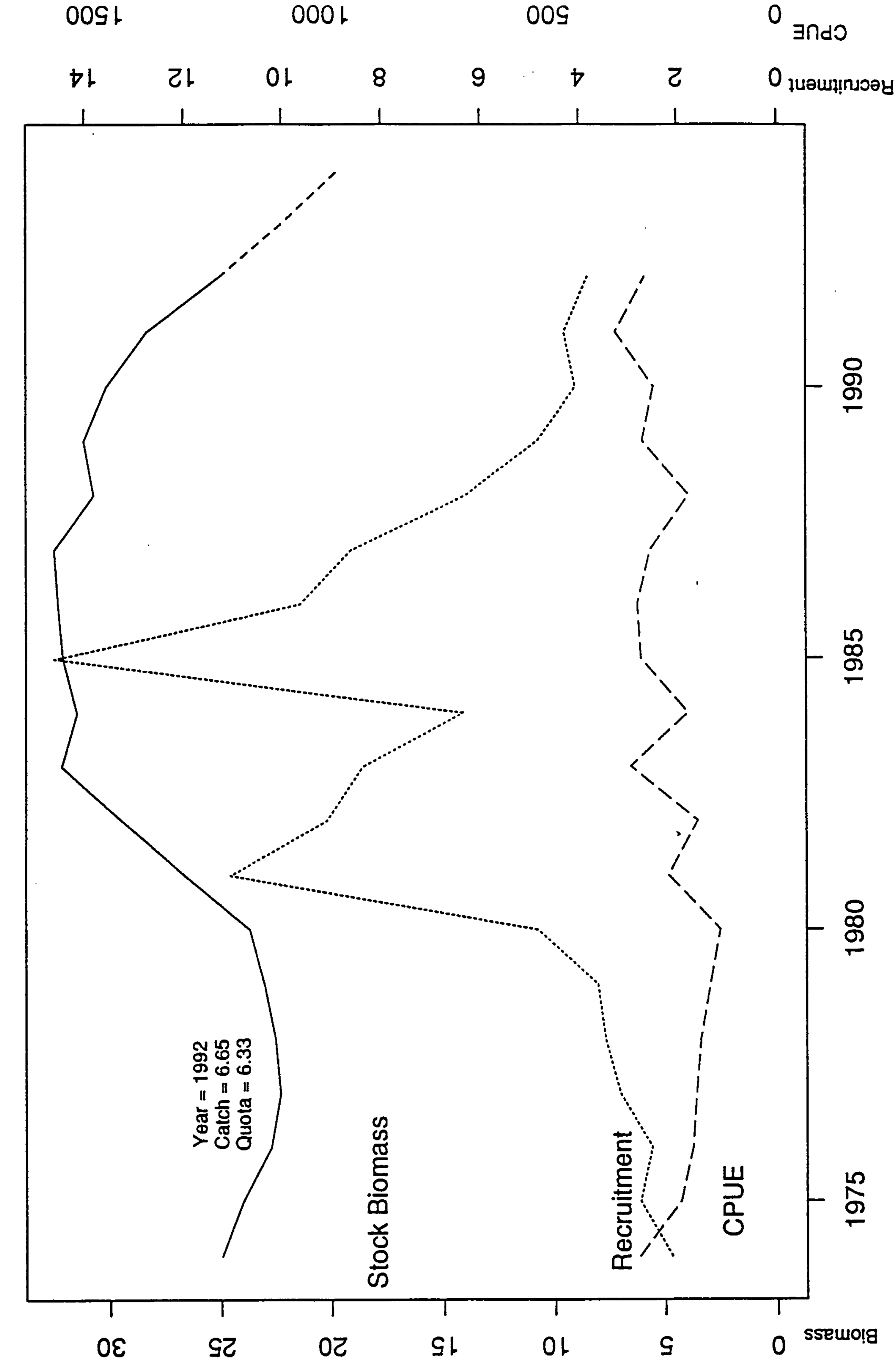


Table 1a. 1992 Assessment of Yield – Rate = .30

		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1992 Quota	0.65*	8.00	10.00	26.60	8.80	6.33	60.38
	1992 Catch	0.68*	7.63	9.60	26.40	8.30	6.65	59.26
1.2	CEY	0.58*	13.68	16.09	36.21	5.66	7.52	79.74
1.3	OTHER CATCHES							
	Sport	— *	0.88	1.68	4.42	0.00	0.06	7.04
	Waste	0.01	0.20	0.47	1.04	0.45	0.28	2.45
	Bycatch	0.11	2.69	3.17	7.13	1.12	1.48	15.70
	Personal Use	0.00	0.10	0.37	0.49	0.03	0.11	1.10
	TOTAL	0.12	3.87	5.69	13.08	1.60	1.93	26.29
1.4	SETLINE CEY	0.46*	9.81	10.41	23.13	4.07	5.59	53.45

Estimates in million pounds by subarea.

* Sport catch included for area 2A.

Table 1b. 1992 Assessment of Yield – Rate = .33

		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1992 Quota	0.65*	8.00	10.00	26.60	8.80	6.33	60.38
	1992 Catch	0.68*	7.63	9.60	26.40	8.30	6.65	59.26
1.2	CEY	0.64*	15.05	17.70	39.83	6.23	8.27	87.72
1.3	OTHER CATCHES							
	Sport	— *	0.88	1.68	4.42	0.00	0.06	7.04
	Waste	0.01	0.20	0.47	1.04	0.45	0.28	2.45
	Bycatch	0.11	2.69	3.17	7.13	1.12	1.48	15.70
	Personal Use	0.00	0.10	0.37	0.49	0.03	0.11	1.10
	TOTAL	0.12	3.87	5.69	13.08	1.60	1.93	26.29
1.4	SETLINE CEY	0.52*	11.17	12.01	26.75	4.64	6.34	61.43

Estimates in million pounds by subarea.

* Sport catch included for area 2A.

Table 1c. 1992 Assessment of Yield – Rate = .35

		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1992 Quota	0.65*	8.00	10.00	26.60	8.80	6.33	60.38
	1992 Catch	0.68*	7.63	9.60	26.40	8.30	6.65	59.26
1.2	CEY	0.68*	15.96	18.78	42.24	6.61	8.77	93.04
1.3	OTHER CATCHES							
	Sport	— *	0.88	1.68	4.42	0.00	0.06	7.04
	Waste	0.01	0.20	0.47	1.04	0.45	0.28	2.45
	Bycatch	0.11	2.69	3.17	7.13	1.12	1.48	15.70
	Personal Use	0.00	0.10	0.37	0.49	0.03	0.11	1.10
	TOTAL	0.12	3.87	5.69	13.08	1.60	1.93	26.29
1.4	SETLINE CEY	0.55*	12.09	13.09	29.16	5.01	6.84	66.75

Estimates in million pounds by subarea.

* Sport catch included for area 2A.

REPORT OF ASSESSMENT AND RESEARCH ACTIVITIES

POPULATION ASSESSMENT, 1992 TECHNICAL SUPPLEMENT

by

Patrick J. Sullivan

The tables and figures to follow provide more detail on the 1992 stock assessment. Table A.1 shows commercial CPUE estimates adjusted to Circle hook standardized equivalence. Table A.2 shows commercial catch of fish ages eight and older, pounds net weight, by area and year. Table A.3 shows total removals, this represents the commercial catch with sport catch, and mortality from gear lost added. Table A.4 shows the estimated exploitable biomass by area and year. Table A.5 gives the estimated historical exploitation rate calculated as total removals divided by exploitable biomass. Table A.6 shows the annual surplus production (ASP), provided for historical comparisons. Table A.7 shows the estimated total instantaneous fishing mortality rates. Table A.8 provides estimates of 8-year-old recruitment in millions of pounds.

Because the total catch values used in the stock assessment include sport catch and wastage the the exploitation rates given in Table A.5 and mortality rates shown in Table A.7 are slightly higher than the rates resulting from commercial fishing alone. The values shown in Tables A.5 and A.7 can be used to examine the relative harvest rate in each area under the historical harvest time series. Tables A.4 through A.8 are estimates from the CAGEAN routine and thus the entries throughout the entire table will change each year as updated and more recent information become available.

Figures A.1 through A.6 show the fit of the model to the observed data. The heights of the blocks represent the observed values the heights of the lines represent the estimated values. Figure A.1 shows the observed versus estimated efforts for each closed area run. Figures A.2 through A.6 show the observed versus estimated catches for Areas 2A-2B, 2C, 3A, 3B, and 4. The figures are to scale across both age and time.

The fisheries in Areas 2A and 4 were under trip limits the entire season this year, leading to speculation about the quality of the CPUE statistics used. Examination of the data indicates that the 1992 data is comparable to the 1991 data in its representation of the fishery. First, the logbook information collected indicated if gear was shook or if poundage was discarded, thus the effect of overages on the CPUE due to the trip limits could be accounted for. Second, in an examination of only those vessels that fished in both years, a similar trend in CPUE can be seen in comparison with the statistics generated from the entire fleet. Fleet wide statistics indicate a drop in CPUE of 25% in 2A and 18% in

Sullivan, P.J., 1993. Population assessment, 1992. IPHC Rep. Assess. Res. Act. 1993., pp. 33–62.

4, whereas the CPUE of only those fishing in both years dropped 27% in 2A and 16% in 4. The drop in CPUE does not appear to be due to lack of participation by "more efficient"fishermen during trip limit openings.

The fishery in area 2B has proceeded under an IVQ management program for the last two years. Concerns were raised regarding the CPUE statistics gathered from this area under this new management regime. The logbook data indicates that changing to an IVQ system has resülted in a change in fishing strategies by part of the fleet. This kind of change will affect the quality of the estimator, but appropriately modified estimates were not significantly different in value than those arrived at using the more conventional approach. A better estimator will have to be developed and applied to the entire time series of catch and effort data, but the current estimator seems adequate in the short term. These results are discussed in greater depth in a report to follow entitled "Snap and Conventional Gear, IVQs, and CPUE".

Effort

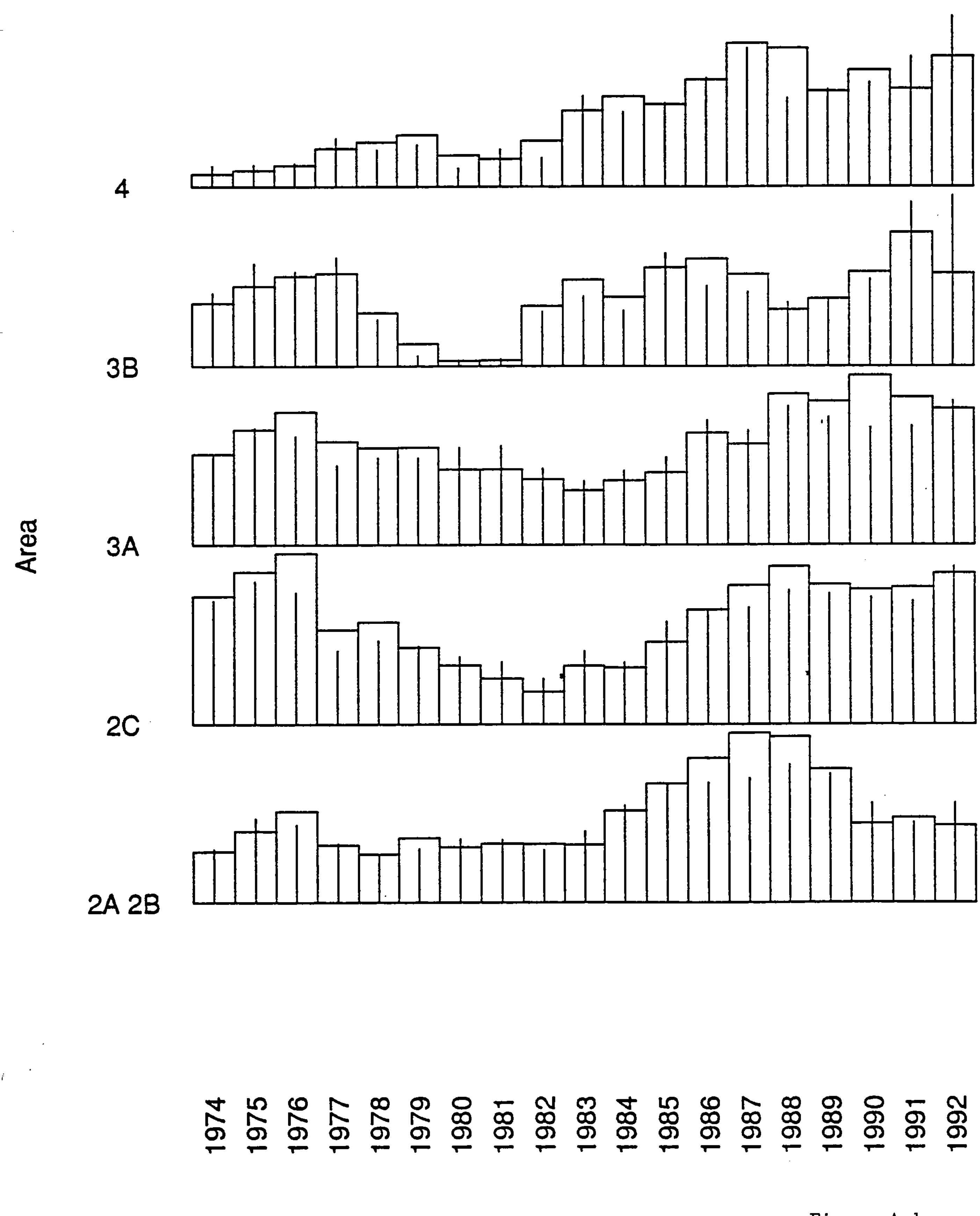


Figure A.1

2A 2B Age Composition

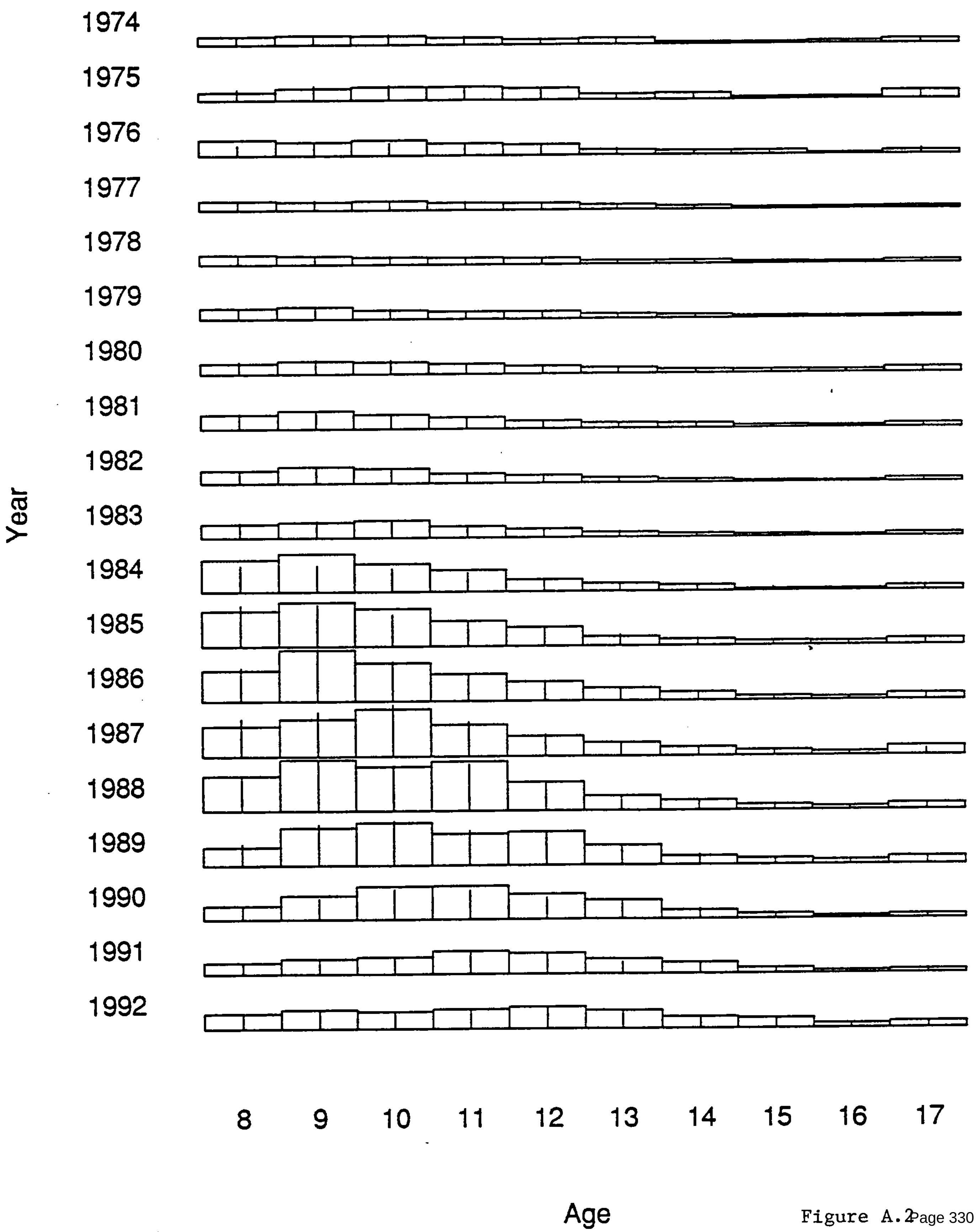


Figure A.2

2C Age Composition

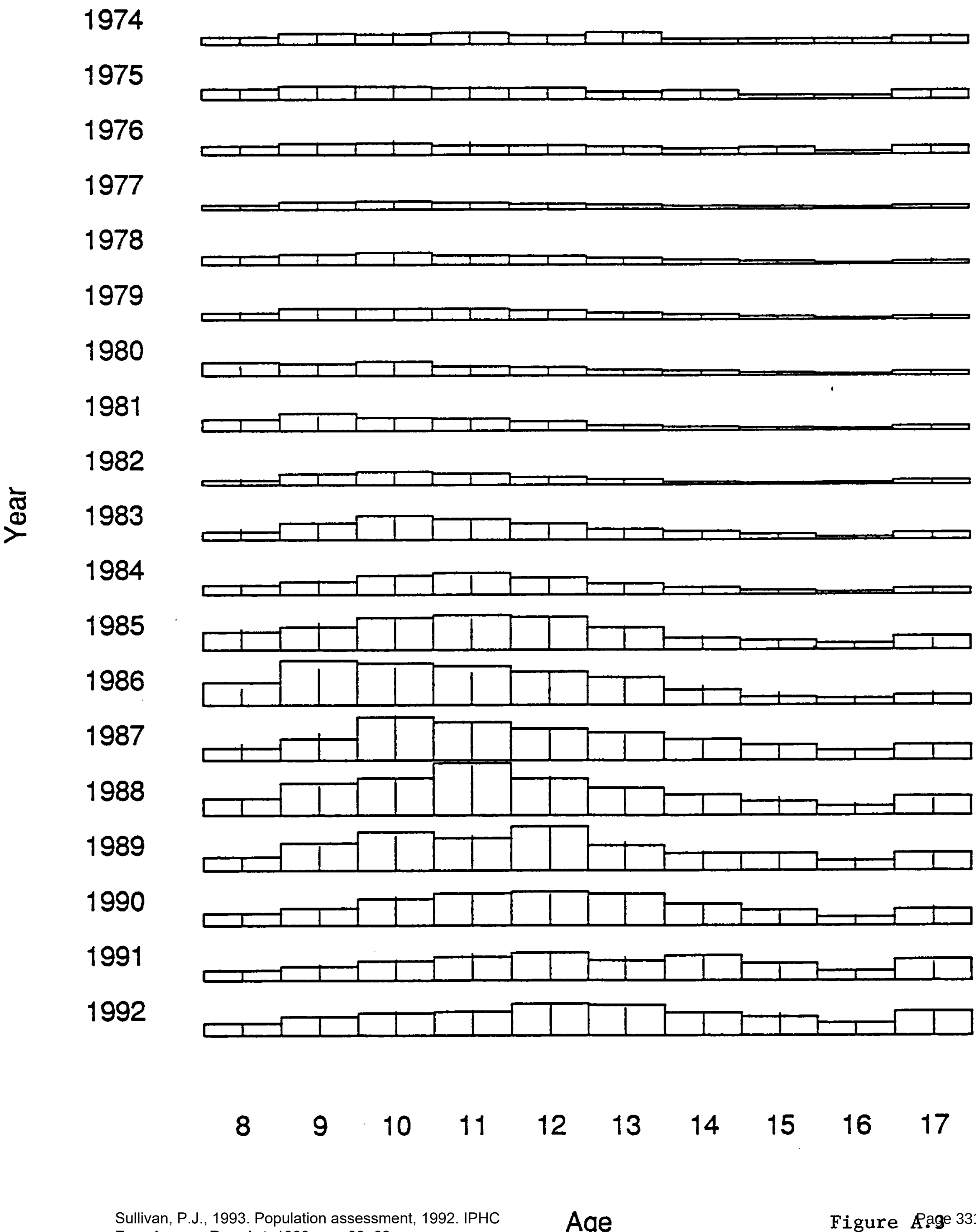
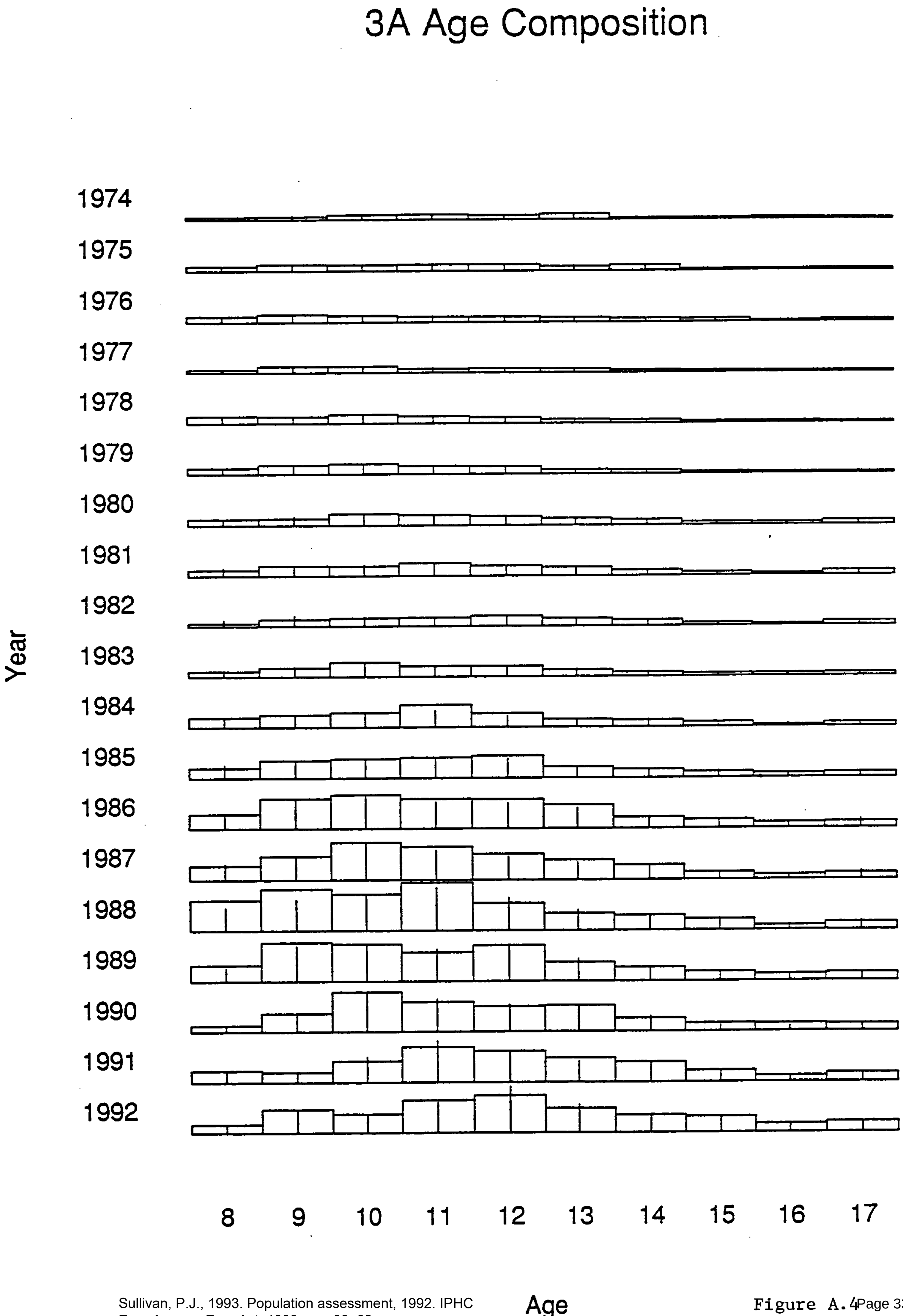


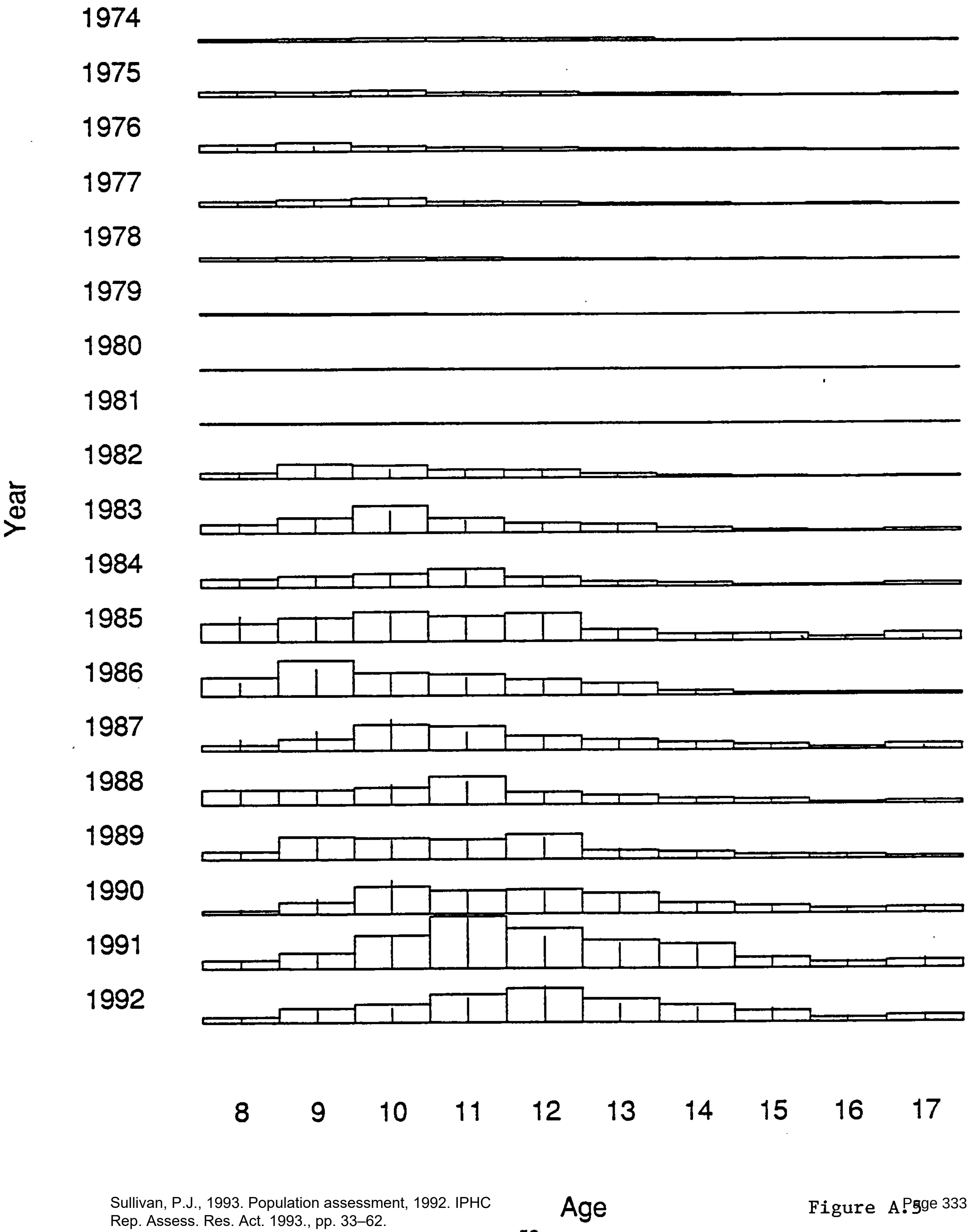
Figure A.9



Sullivan, P.J., 1993. Population assessment, 1992. IPHC Rep. Assess. Res. Act. 1993., pp. 33–62.

Figure A.4

3B Age Composition



4 Age Composition

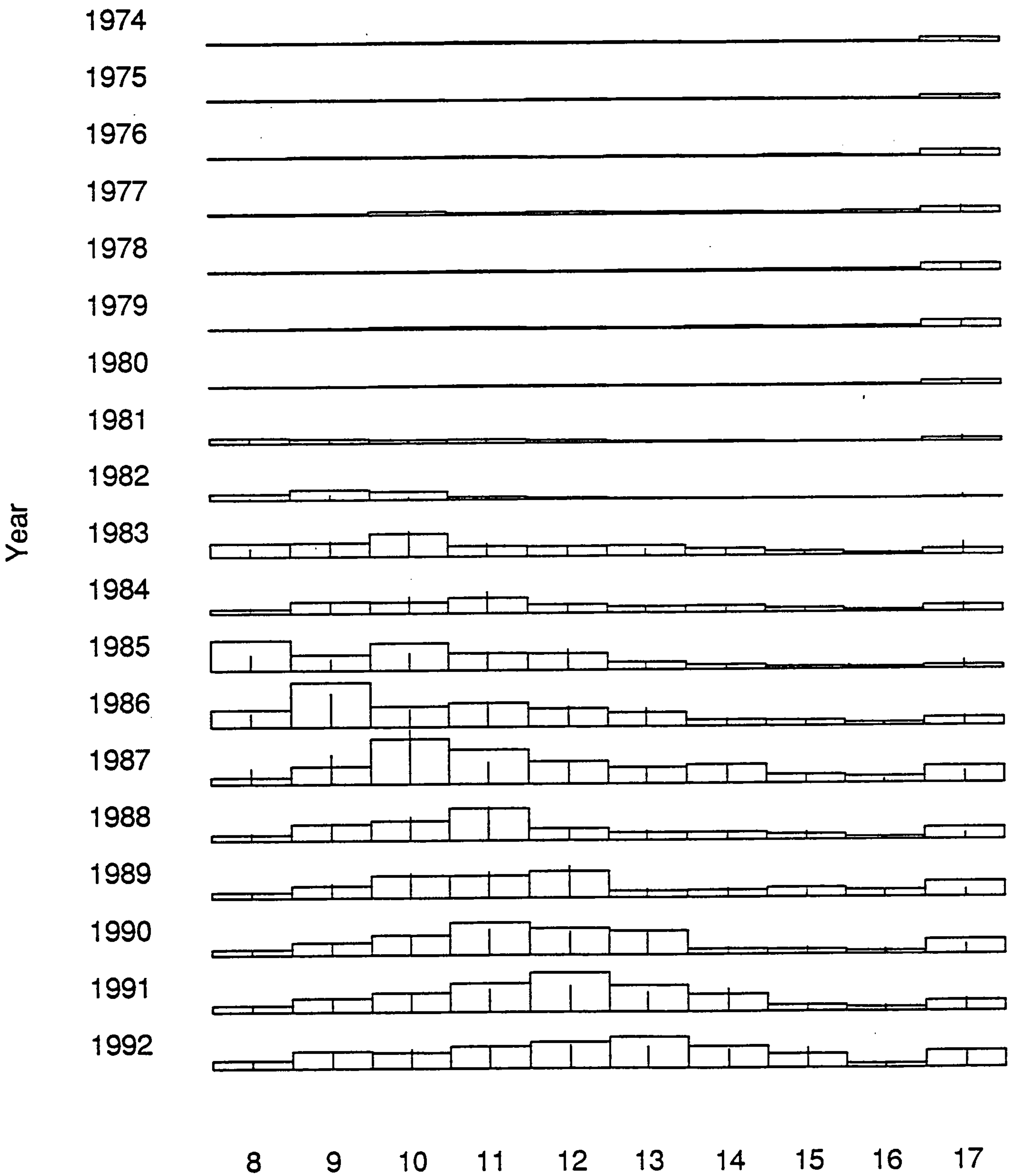


TABLE A.1 Commercial CPUE* (pounds per skate)

	AREA						
Year	2A	2B	2C	3A	3B	4	Overall
1974	130.70	141.00	126.00	142.40	124.70	301.10	137.90
1975	130.60	148.70	117.40	145.30	149.30	210.70	139.70
1976	71.70	116.70	92.80	131.40	142.20	184.20	118.50
1977	182.20	135.30	99.40	134.60	161.30	176.20	133.20
1978	85.50	138.00	124.10	171.90	116.40	166.70	147.90
1979	110.00	105.80	176.60	189.00	80.80	146.10	154.10
1980	82.00	143.70	174.70	260.60	249.50	124.20	197.20
1981	107.60	140.60	273.60	313.50	368.30	236.80	237.40
1982	101.60	141.40	355.90	342.60	375.80	172.50	259.80
1983	102.10	144.40	342.80	437.00	419.40	320.00	310.80
1984	101.80	151.10	328.50	516.00	441.40	193.60	296.40
1985	87.50	141.20	354.10	501.50	525.10	296.40	310.20
1986	105.90	123.80	296.40	514.80	403.00	304.60	297.60
1987	50.30	126.30	244.50	546.20	412.40	276.40	276.60
1988	89.20	120.90	229.70	447.30	598.60	191.30	265.30
1989	105.10	125.80	232.10	421.10	557.70	293.40	281.40
1990	175.60	174.90	240.90	311.60	443.70	269.10	275.90
1991	160.60	139.60	224.10	303.00	433.00	353.70	269.40
1992	119.60	171.60	220.00	364.00	428.20	288.90	285.90

* Standardized C hook equivalence.

TABLE A.2 Commercial Catch (million pounds)

Year	2A	2B	2C	3A	3B	4	Total
	AREA						
1974	0.51	4.62	5.60	8.19	1.67	0.71	21.30
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	5.42	3.19	8.64	3.19	1.22	21.87
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	22.53
1980	0.02	5.65	3.24	11.96	0.28	0.71	21.86
1981	0.20	5.66	4.01	14.23	0.45	1.19	25.74
1982	0.21	5.53	3.50	13.53	4.80	1.43	29.01
1983	0.27	5.44	6.40	14.12	7.75	4.43	38.39
1984	0.43	9.06	5.85	19.97	6.50	3.17	44.98
1985	0.50	10.39	9.20	20.85	10.89	4.28	56.11
1986	0.58	11.23	10.61	32.78	8.83	5.60	69.63
1987	0.59	12.25	10.68	31.31	7.76	6.88	69.47
1988	0.49	12.86	11.37	37.86	7.08	4.70	74.35
1989	0.47	10.47	9.53	33.74	7.85	4.94	66.98
1990	0.32	8.57	9.73	28.85	8.69	5.43	61.60
1991	0.35	7.19	8.68	22.87	11.93	5.99	57.02
1992	0.42	7.63	9.60	26.40	8.30	6.65	59.00

TABLE A.3 Total Removals (million pounds)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	0.51	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	21.87
1978	0.10	4.61	4.32	10.29	1.32	1.35	21.99
1979	0.05	4.86	4.53	11.33	0.39	1.37	22.53
1980	0.02	5.65	3.24	11.97	0.28	0.71	21.87
1981	0.20	5.65	4.01	14.23	0.45	1.19	25.73
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	44.97
1985	0.50	10.49	9.42	21.78	11.09	4.44	57.71
1986	0.59	11.43	11.04	34.65	9.23	5.90	72.83
1987	0.60	12.42	11.05	32.90	8.10	7.14	72.20
1988	0.49	12.91	11.57	39.37	7.20	4.76	76.30
1989	0.48	10.51	9.73	35.19	8.04	5.06	69.00
1990	0.33	8.65	9.98	29.74	8.91	5.65	63.26
1991	0.36	7.26	9.03	24.02	12.35	6.23	59.25
1992	0.43	7.68	9.93	26.98	8.48	6.80	60.30

TABLE A.4 Exploitable Biomass (Closed Subarea)

Year	2A	2B	2C	3A	3B	4	Total
				AREA			
1974	1.69	30.41	30.17	54.46	8.97	24.89	150.59
1975	1.71	32.02	29.62	59.45	9.82	23.94	156.56
1976	1.53	31.43	28.60	62.81	10.17	22.65	157.18
1977	1.38	30.52	28.75	66.65	10.68	22.22	160.20
1978	1.22	30.69	31.76	72.85	11.11	22.42	170.05
1979	1.25	30.44	34.23	76.92	13.14	22.93	178.91
1980	1.31	30.10	37.25	81.86	16.99	23.59	191.09
1981	1.36	30.36	42.04	89.48	22.80	26.54	212.57
1982	1.36	31.82	48.48	99.38	29.88	29.35	240.27
1983	1.32	34.94	56.23	112.89	34.65	32.02	272.04
1984	1.57	38.90	60.77	127.28	36.98	31.31	296.81
1985	1.83	42.59	64.27	139.65	39.63	31.93	319.90
1986	2.01	44.61	63.37	147.62	36.57	32.13	326.30
1987	2.10	45.73	61.88	149.95	37.32	32.28	329.28
1988	1.99	45.27	60.11	155.70	38.46	30.49	332.02
1989	2.11	42.68	57.02	150.88	38.43	30.93	322.06
1990	2.15	40.80	54.01	138.82	35.08	29.95	300.80
1991	1.94	41.29	50.86	124.52	28.53	28.18	275.31
1992	1.83	42.92	47.96	109.57	18.88	24.93	246.09

Estimates in million pounds by subarea.

TABLE A.5 Historical Exploitation Rates (Closed Subarea)

	AREA							
Year	2A	2B	2C	3A	3B	4	Total	+Bycatch
1974	0.30	0.15	0.19	0.15	0.19	0.03	0.14	0.26
1975	0.27	0.22	0.21	0.18	0.26	0.03	0.18	0.25
1976	0.16	0.23	0.19	0.18	0.27	0.03	0.18	0.26
1977	0.15	0.18	0.11	0.13	0.30	0.05	0.14	0.21
1978	0.08	0.15	0.14	0.14	0.12	0.06	0.13	0.20
1979	0.04	0.16	0.13	0.15	0.03	0.06	0.13	0.21
1980	0.02	0.19	0.09	0.15	0.02	0.03	0.11	0.21
1981	0.15	0.19	0.10	0.16	0.02	0.04	0.12	0.19
1982	0.15	0.17	0.07	0.14	0.16	0.05	0.12	0.17
1983	0.20	0.16	0.11	0.12	0.22	0.14	0.14	0.18
1984	0.27	0.23	0.10	0.16	0.18	0.10	0.15	0.18
1985	0.27	0.25	0.15	0.16	0.28	0.14	0.18	0.20
1986	0.29	0.26	0.17	0.23	0.25	0.18	0.22	0.25
1987	0.29	0.27	0.18	0.22	0.22	0.22	0.22	0.25
1988	0.25	0.29	0.19	0.25	0.19	0.16	0.23	0.27
1989	0.23	0.25	0.17	0.23	0.21	0.16	0.21	0.26
1990	0.15	0.21	0.18	0.21	0.25	0.19	0.21	0.27
1991	0.19	0.18	0.18	0.19	0.43	0.22	0.22	0.27
1992	0.23	0.18	0.21	0.25	0.45	0.27	0.25	0.31

Calculated as total removals divided by exploitable biomass.

TABLE A.6 Annual Surplus Production (Closed Subarea)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	0.54	6.24	5.05	13.18	2.52	-0.24	27.28
1975	0.27	6.53	5.23	13.96	2.90	-0.66	28.24
1976	0.09	6.37	5.68	14.88	3.24	0.28	30.55
1977	0.05	5.60	6.19	14.84	3.62	1.42	31.72
1978	0.12	4.36	6.79	14.37	3.34	1.86	30.85
1979	0.11	4.51	7.55	16.28	4.24	2.03	34.70
1980	0.07	5.91	8.03	19.58	6.09	3.67	43.35
1981	0.20	7.11	10.46	24.13	7.54	3.99	53.43
1982	0.17	8.66	11.24	27.03	9.56	4.10	60.78
1983	0.52	9.40	10.94	28.51	10.08	3.71	63.15
1984	0.69	12.75	9.35	32.33	9.16	3.79	68.07
1985	0.67	12.51	8.52	29.75	8.03	4.64	64.11
1986	0.68	12.55	9.56	36.98	9.99	6.04	75.81
1987	0.48	11.95	9.29	38.64	9.24	5.35	74.95
1988	0.61	10.32	8.48	34.55	7.17	5.20	66.34
1989	0.51	8.63	6.71	23.13	4.68	4.08	47.75
1990	0.12	9.14	6.83	15.44	2.36	3.88	37.77
1991	0.25	8.89	6.13	9.07	2.70	2.98	30.02
1992	0.23	9.24	5.78	7.98	1.79	2.64	27.66

Estimates in million pounds by subarea.

TABLE A.7 Total Instantaneous Fishing Mortality (Closed Subarea)

	AREA				
Year	2A-2B	2C	3A	3B	4
1974	0.15	0.23	0.19	0.23	0.03
1975	0.24	0.27	0.26	0.33	0.03
1976	0.22	0.25	0.24	0.30	0.03
1977	0.17	0.14	0.17	0.35	0.07
1978	0.14	0.16	0.19	0.15	0.05
1979	0.16	0.14	0.19	0.03	0.06
1980	0.18	0.12	0.21	0.02	0.03
1981	0.18	0.11	0.21	0.02	0.05
1982	0.15	0.08	0.16	0.17	0.04
1983	0.15	0.13	0.16	0.25	0.17
1984	0.20	0.11	0.19	0.20	0.14
1985	0.24	0.18	0.22	0.40	0.15
1986	0.24	0.20	0.32	0.28	0.20
1987	0.25	0.21	0.29	0.26	0.25
1988	0.28	0.24	0.35	0.22	0.16
1989	0.26	0.22	0.32	0.23	0.18
1990	0.20	0.22	0.29	0.31	0.19
1991	0.15	0.20	0.28	0.58	0.24
1992	0.19	0.26	0.34	0.60	0.31

TABLE A.8 Recruitment (Closed Subarea)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	0.5	9.2	7.8	18.5	3.2	2.1	41.3
1975	0.5	9.1	7.9	24.0	4.4	2.7	48.7
1976	0.4	9.2	8.4	25.3	4.4	2.5	50.2
1977	0.4	9.5	9.8	25.4	4.8	3.2	53.1
1978	0.4	11.1	12.2	27.7	5.9	3.4	60.7
1979	0.4	10.7	12.3	23.1	5.6	3.6	55.8
1980	0.5	11.4	15.2	25.0	7.6	4.8	64.5
1981	0.6	13.1	16.1	36.3	13.5	11.0	90.7
1982	0.6	13.9	15.6	36.5	11.9	9.0	87.6
1983	0.6	15.8	15.9	38.9	12.9	8.3	92.3
1984	0.8	20.3	18.2	47.5	13.0	6.3	106.1
1985	1.1	25.3	21.9	56.6	18.1	14.5	137.6
1986	0.9	20.2	15.9	44.1	12.9	9.6	103.6
1987	1.0	21.0	14.7	47.4	11.0	8.5	103.6
1988	0.8	18.1	12.4	56.7	14.8	6.2	109.0
1989	0.6	11.7	9.2	34.2	7.8	4.8	68.3
1990	0.5	10.0	8.4	18.8	3.7	4.0	45.6
1991	0.5	11.3	8.3	33.3	3.7	4.3	61.4
1992	0.6	13.4	8.3	19.7	2.2	3.8	47.9

Estimates in million pounds by subarea.

REPORT OF ASSESSMENT AND RESEARCH ACTIVITIES

POPULATION ASSESSMENT, 1991

by

Patrick J. Sullivan

Introduction

The Pacific halibut stock assessment for 1991 is a catch-at-age analysis conducted by area and applied to data from Areas 2A-2B, 2C, 3A, 3B, and 4. Information is gathered from catch, catch per unit effort (CPUE), age composition and average weight data. This data is used in determining the exploitable biomass, the stock biomass available for harvest. Once the exploitable biomass has been estimated, the constant exploitation yield (CEY) is determined as a fraction of this estimate. Based on an optimal exploitation rate of 0.35, this yield represents a little over a third of the exploitable biomass. The recommended allowable catch is finally determined by accounting for the removals from other sources (sport catch, wastage, bycatch, and subsistence). This procedure is outlined in Figure 1.

Stock Assessment

Results from the stock assessment indicate that the total exploitable biomass of Pacific halibut in 1991 is 262.6 million pounds. This represents an overall decline in biomass this year of 10%, a rate similar to the 5-10% declines observed in previous years. We believe that the stock is well above its own sustainable level given the production we have seen it exhibit in the past. It is, therefore, not surprising for us to expect a continued decline over the next several years. Figure 2 shows the trends in exploitable biomass for the total stock. Figures 3 through 8 give the area-by-area trends in exploitable biomass, recruitment, and CPUE. The estimated exploitable biomass showed no change in area 2A, declined 6-7% in areas 2B, 2C and 4, 11% in area 3A, and 21% in area 3B.

Recruitment of 8-year-old halibut appears to have leveled off or increased this year in all areas. This year's fourteen-year-old year class, which recruited strongly as eight-year-olds in 1985 (Figures 2 through 8) is contributing less and less to the fishery in terms of yield. The lower recruitment of recent years indicates that the stock will continue its decline at a rate of about 5-10% per year over the next several years, but if recruitment continues to improve, as it did this year, then stock sizes should begin to stabilize.

Areas 2A and 2B show a downturn in CPUE over last year's slightly higher values, while area 4 shows an increase. All other areas show little change.

Sullivan, P.J., 1992. Population assessment, 1991. IPHC
Rep. Assess. Res. Act. 1991., pp. 41–87.

Each year, in addition to estimating the current year's stock levels, stock levels for previous years are re-estimated using updated information. Changes in the level of bycatch, waste, and sport catch coupled with the inherent variability observed in the stock dynamics and the measurement process may result in adjustments to previous abundance estimates. This can cause the allowable catch to go up in some areas where stock abundance indicates a decline. New annual estimates of halibut average weight, new estimates of halibut catchability, and the addition of sport catch and wastage to the commercial removals in the analysis represent the latest updates. Catch corrections in areas 3B and 4 have led to part of the shift observed in the exploitable biomasses estimated for those areas. The recommended allowable catch estimates are always based on the most current available information.

Constant Exploitation Yield

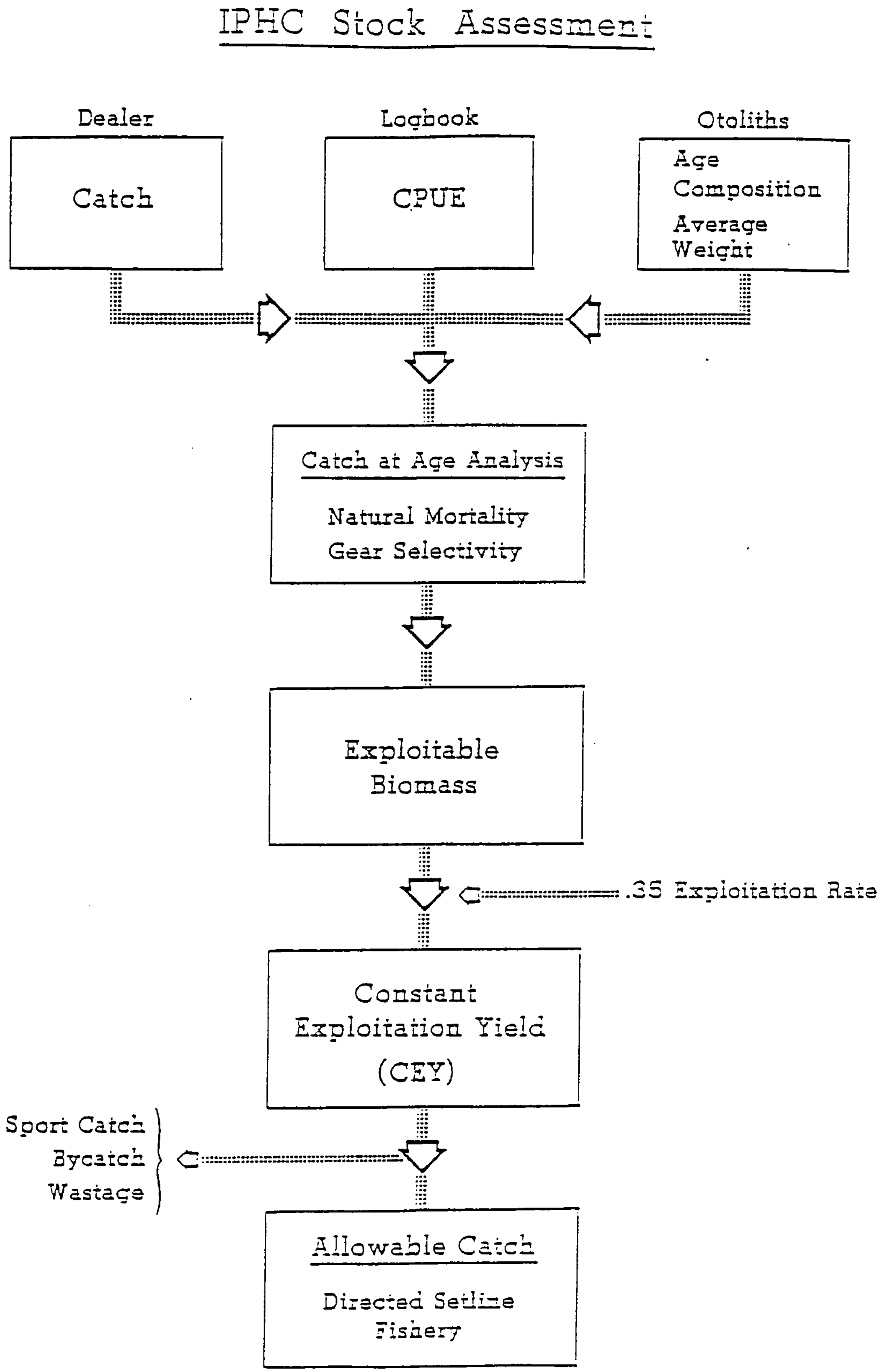
Results from the 1991 stock assessment are used in determining the total and setline constant exploitation yields. These yields are shown in Table 1 along with the 1991 catch and quota. The overall CEY is obtained by multiplying the area specific exploitable biomass by the constant exploitation yield rate of 0.35. Once the exploitation rate is applied equally to all areas, the biomass removal from other sources is subtracted out to determine the allowable setline catch. The setline constant exploitation yields indicate the harvest that should be taken by the setline commercial fishery in order to maintain optimal yields and viability of the stock. It should be realized, however, that the stock is currently above its estimated sustainable level and that future yields will be lower than those which we are now experiencing.

Bycatch

Adjustments to the allowable catch for bycatch shown in Table 1 represent compensation to the stock for losses in the stock's reproductive potential due to losses from bycatch. The allowable catch is reduced in line 1.4 of Table 1 by one pound for every pound of bycatch removed. The bycatch reduction in each area is made in proportion to the estimated exploitable biomass in that area.

Research

This year the staff conducted research on CPUE and average weight and examined the effect these two factors have on the stock estimates. Changes in how catchable halibut are relative to how their abundance changes is an ongoing concern. Changes in gear type, as occurred in the transition from J hooks to Circle hooks, and changes in the prosecution of the fishery, as occurred this year with the implementation of IVQ's in Canada, can cause changes in CPUE that are not associated with changes in halibut abundance. Our research continues to focus on these questions.



IPHC Stock Assessment
Dealer
Catch
Logbook
CPUE
Otoliths
Age
Composition
Average
Weight
Catch at Age Analysis
Natural Mortality
Gear Selectivity
Exploitable
Biomass
.35 Exploitation Rate
Constant
Exploitation Yield
(CEY)
Sport Catch
Bycatch
Wastage
Allowable Catch
Directed Setline
Fishery

Figure 1

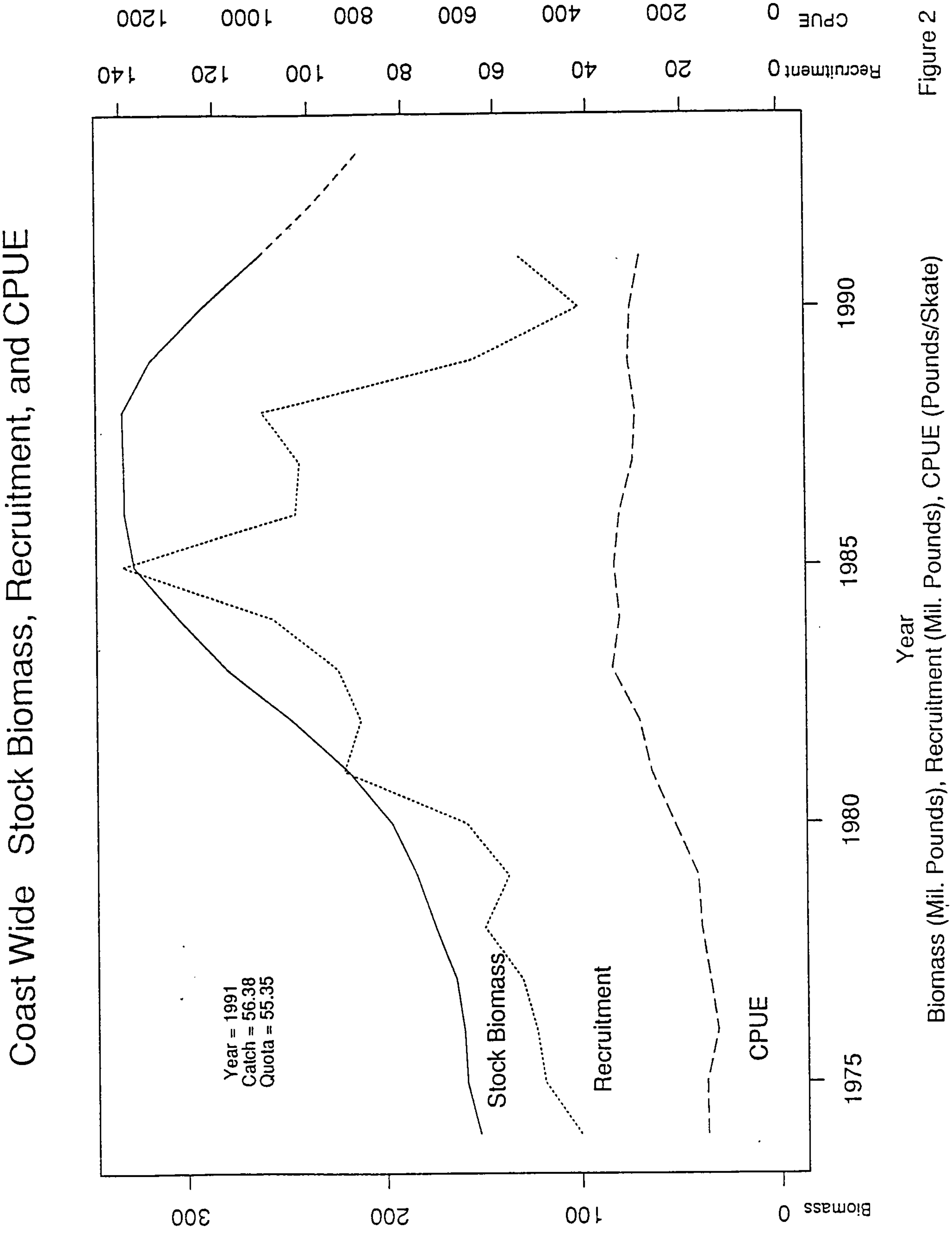

Coast Wide Stock Biomass, Recruitment, and CPUE
Year = 1991
Catch = 56.38
Quota = 55.35
Stock Biomass
Recruitment
CPUE
Biomass 0 100 200 300
Recruitment 0 20 40 60 80 100 120 140
CPUE 0 200 400 600 800 1000 1200
1975 1980 1985 1990
Year
Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

Figure 2

44

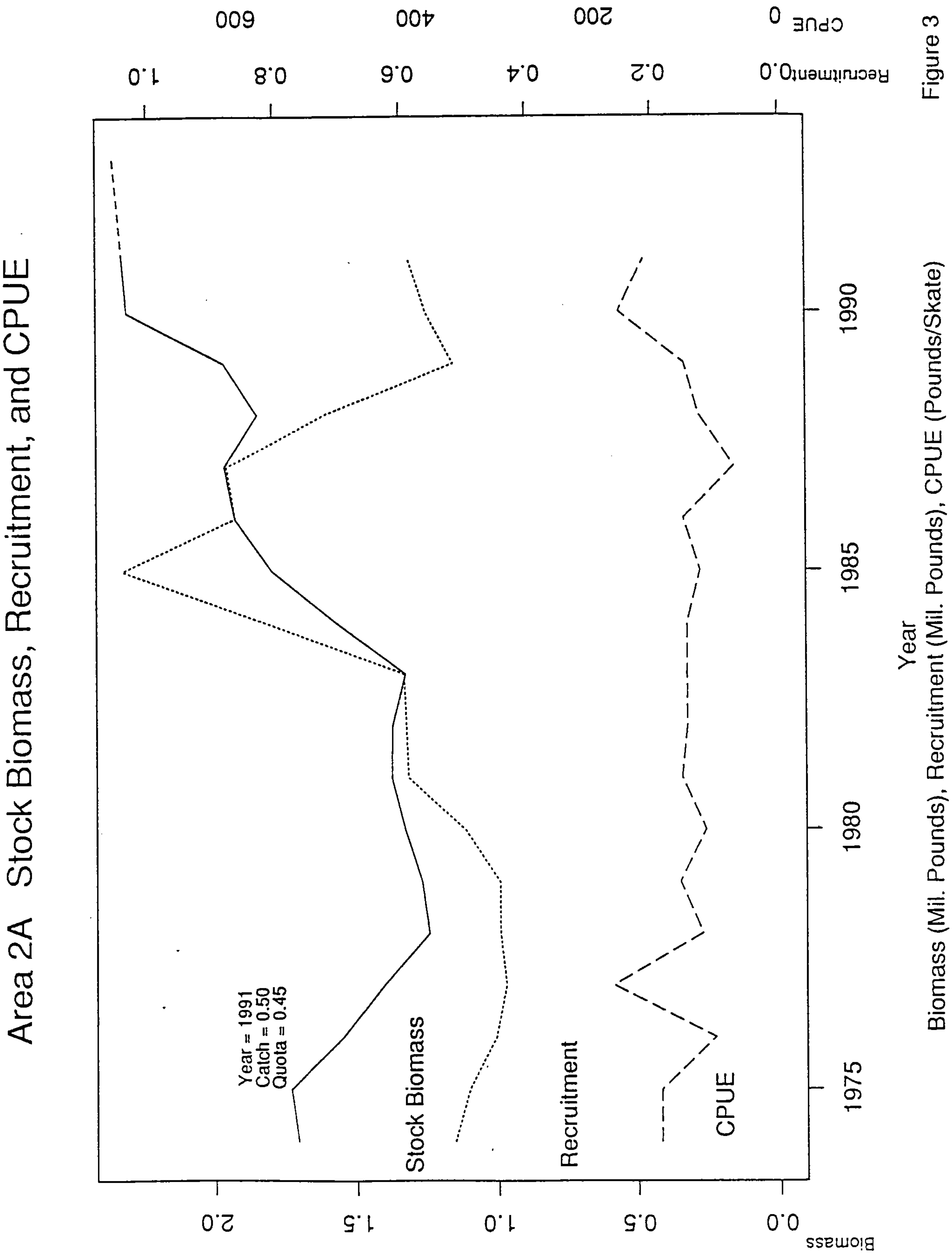

Area 2A Stock Biomass, Recruitment, and CPUE
Year = 1991
Catch = 0.50
Quota = 0.45
Stock Biomass
Recruitment
CPUE
1975
1980
1985
1990
Year
Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)
Biomass
0.0
0.5
1.0
1.5
2.0
Recruitment
0.0
0.2
0.4
0.6
0.8
1.0
CPUE
0
200
400
600

Figure 3

45

Area 2B Stock Biomass, Recruitment, and CPUE

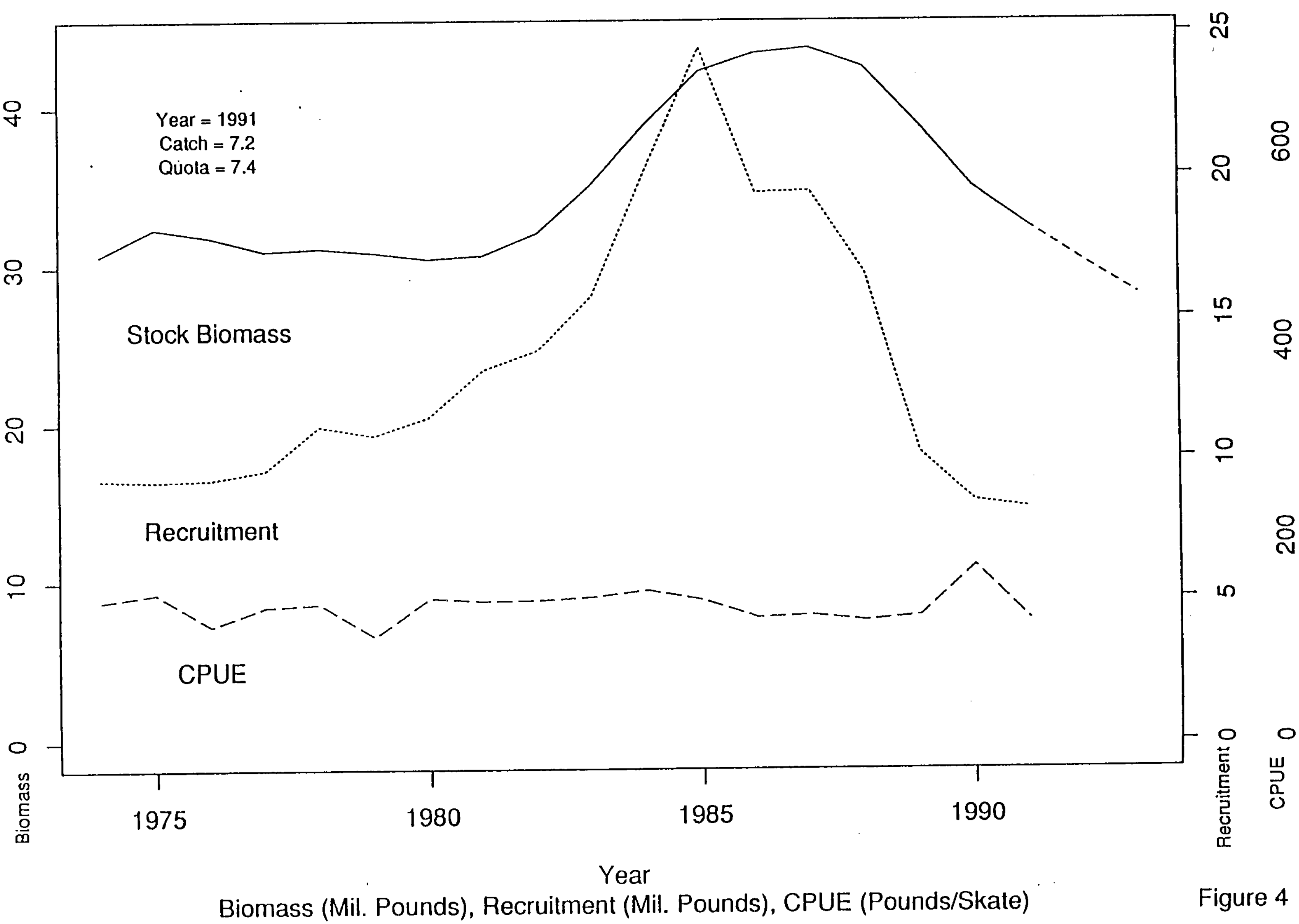


Figure 4

46

Area 2C Stock Biomass, Recruitment, and CPUE

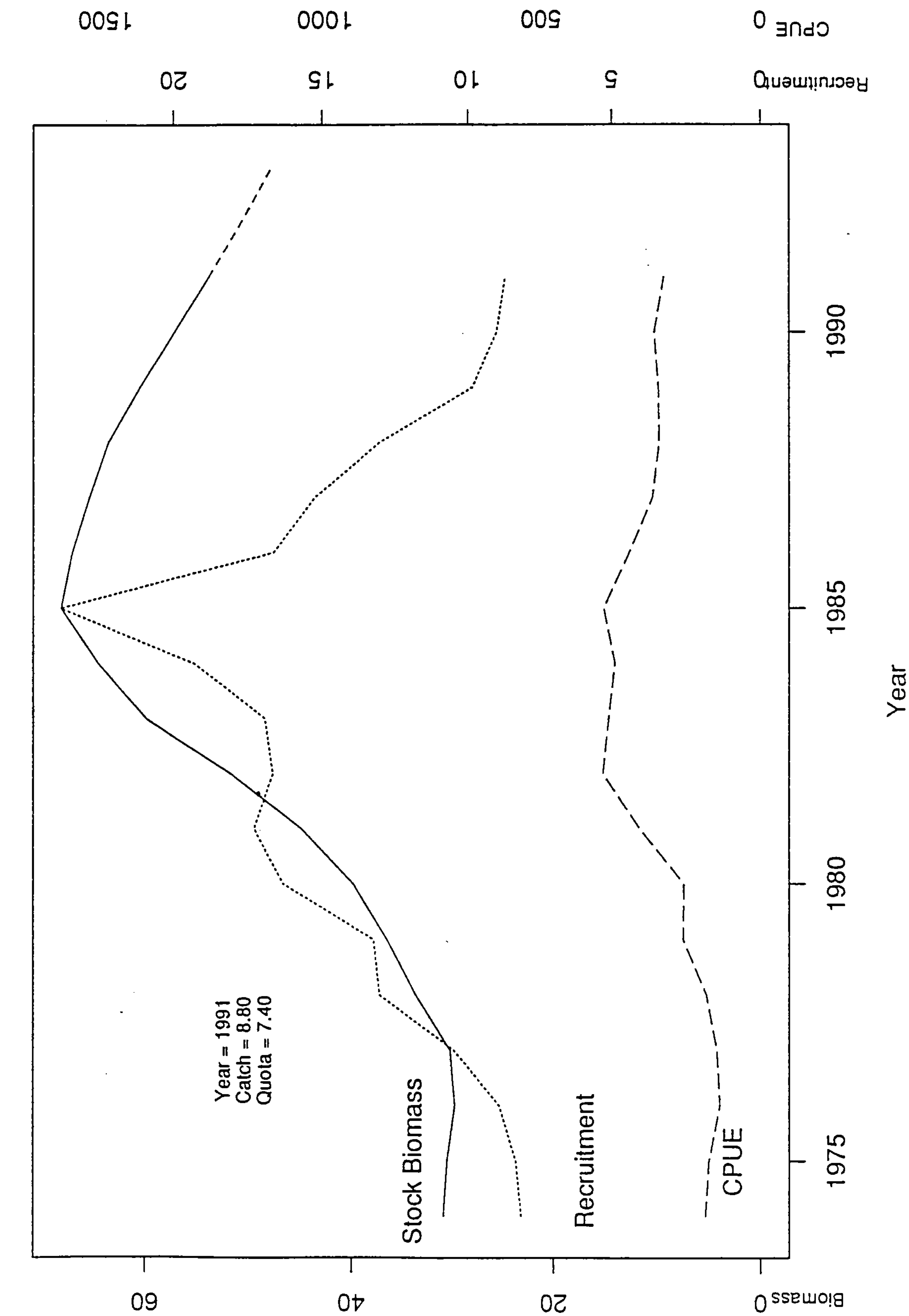


Figure 5

47

Area 3A Stock Biomass, Recruitment, and CPUE

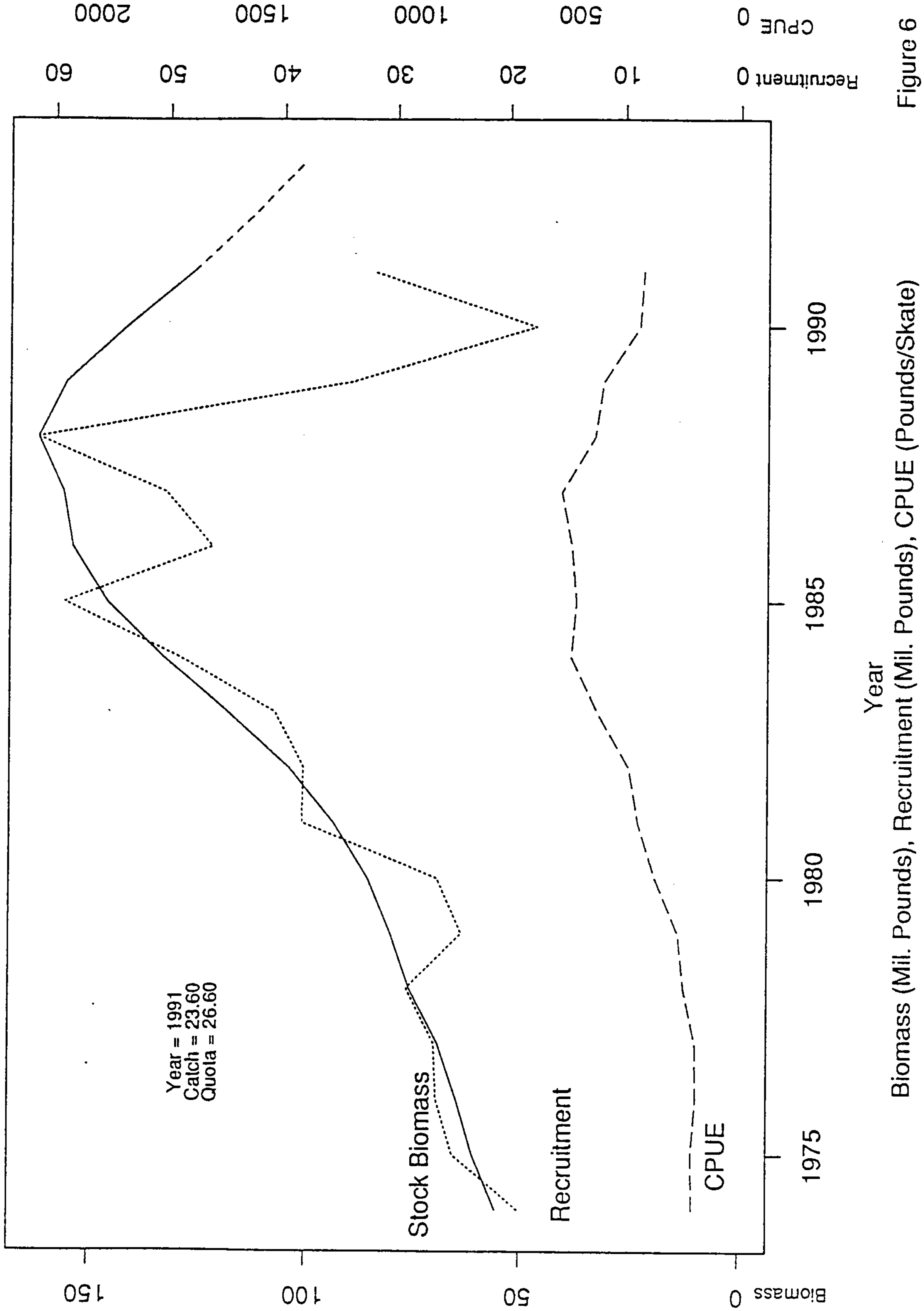


Figure 6

48

Area 3B Stock Biomass, Recruitment, and CPUE

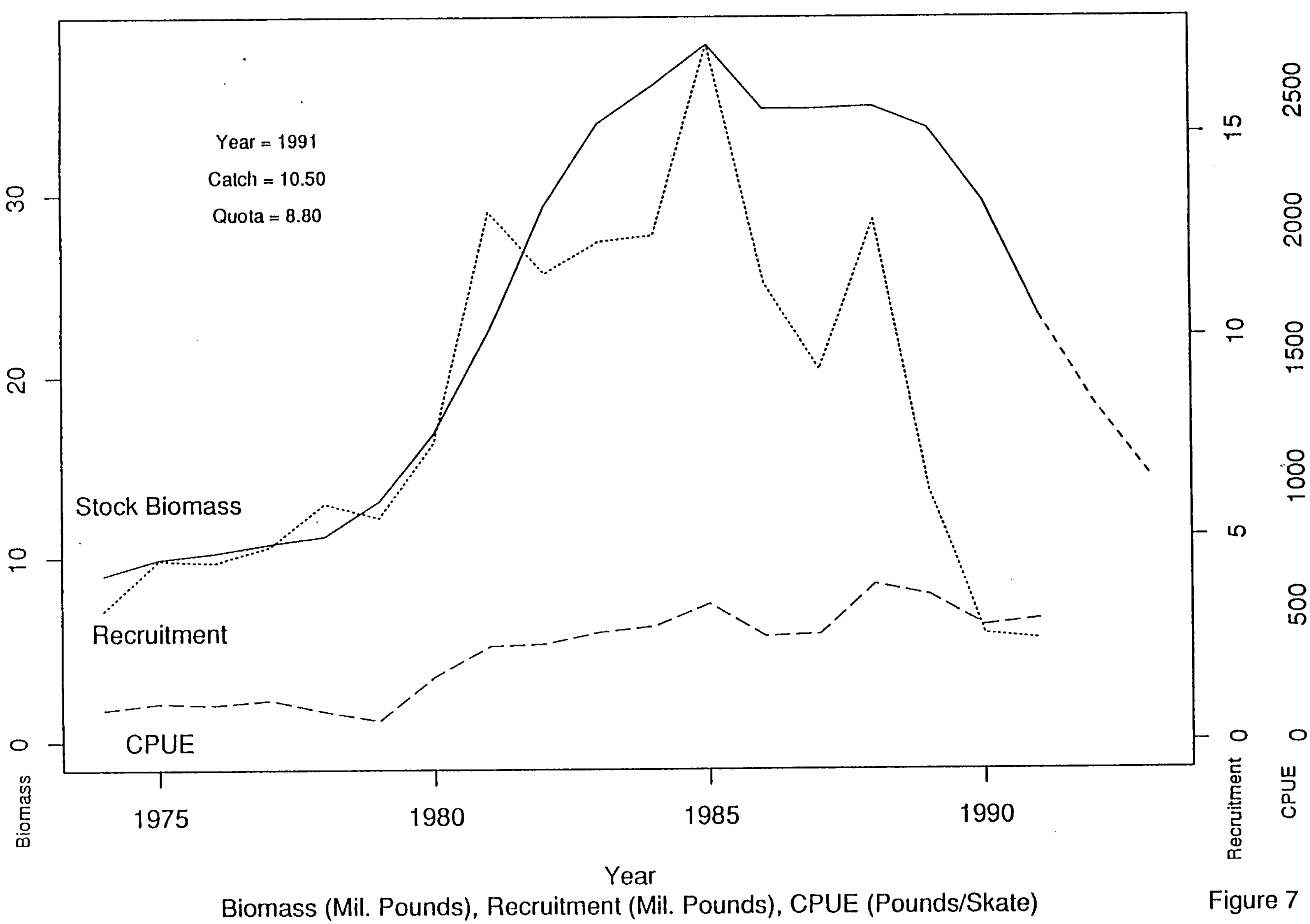
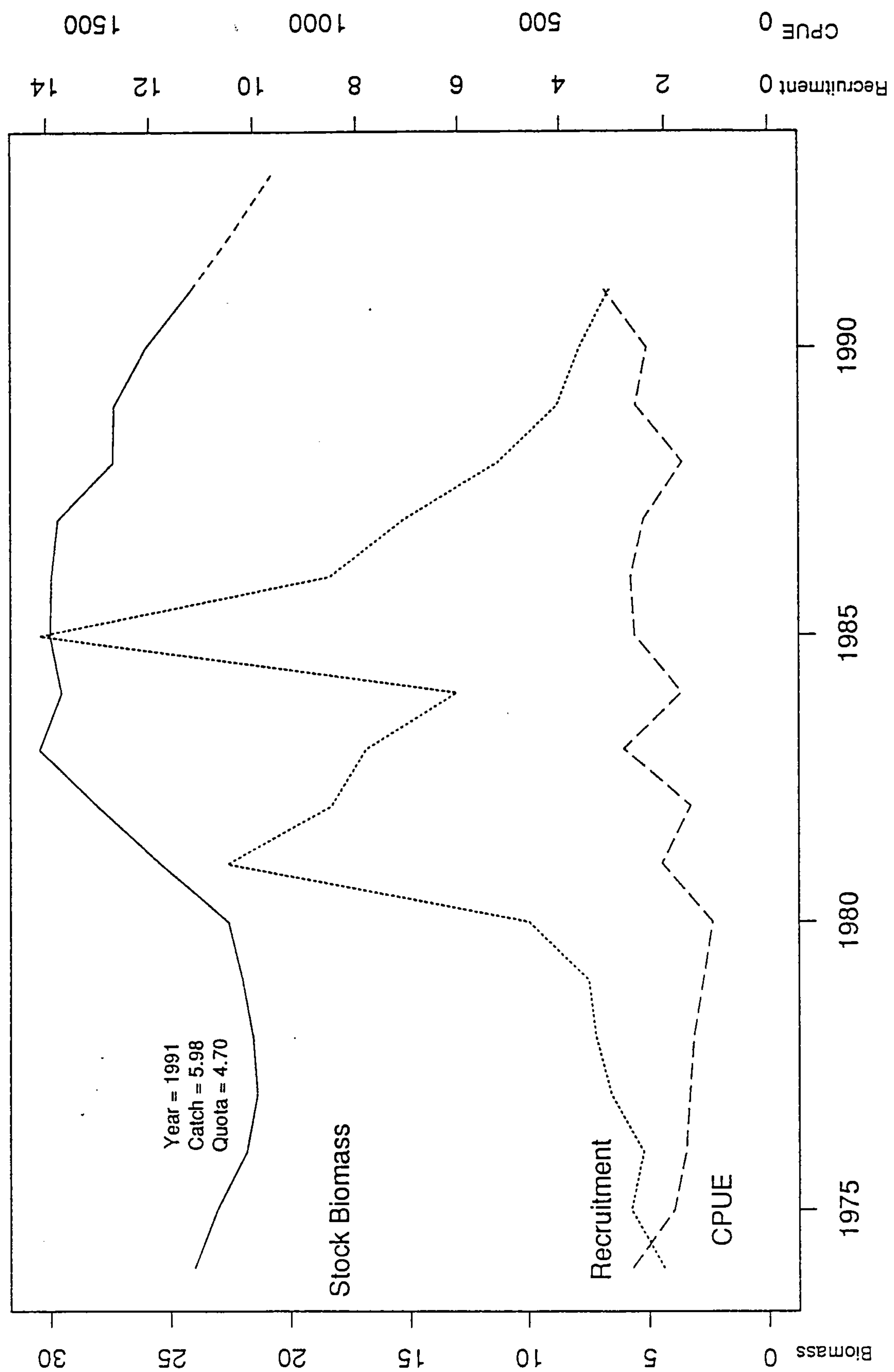


Figure 7

49

Area 4 Stock Biomass, Recruitment, and CPUE



Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

Figure 8

50

TABLE 1. 1991 Assessment of Yield

		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1991 Quota	0.45*	7.40	7.40	26.60	8.80	4.70	55.35
	1991 Catch	0.50*	7.20	8.80	23.60	10.50	5.98	56.58
1.2	CEY	0.81	11.40	18.84	44.23	8.19	8.45	91.93
1.3	OTHER CATCHES							
	Sport	— *	0.77	1.47	3.75	0.00	0.04	6.03
	Waste	0.01	0.20	0.57	1.54	0.69	0.33	3.34
	Bycatch	0.15	2.10	3.46	8.13	1.51	1.55	16.90
	Subsistence	0.00	0.05	0.72	0.96	0.06	0.21	2.00
	TOTAL	0.16	3.12	6.22	14.38	2.26	2.13	28.27
1.4	SETLINE CEY	0.65*	8.29	12.61	29.85	5.93	6.32	63.66

Estimates in millions of pounds by subarea.

* Sport catch included for area 2A.

REPORT OF ASSESSMENT AND RESEARCH ACTIVITIES

POPULATION ASSESSMENT, 1991 TECHNICAL SUPPLEMENT

by

Patrick J. Sullivan, Ana M. Parma, and Bernard A. Vienneau

The tables and figures to follow provide more detail on the 1991 stock assessment. Table A.1 shows commercial CPUE estimates adjusted to Circle hook standardized equivalence. Table A.2 shows commercial catch of fish ages eight and older, pounds net weight, by area and year. Table A.3 shows total removals, this represents the commercial catch with sport catch, and mortality from gear lost added. Table A.4 shows the estimated exploitable biomass by area and year. Table A.5 shows the annual surplus production (ASP), provided for historical comparisons. Table A.6 shows the estimated total instantaneous fishing mortality rates. Because the catch now includes sport catch and wastage these mortality rates are slightly higher than the rates resulting from commercial fishing alone. The figures shown in Table A.6 can be used to examine the relative harvest rate in each area under the historical harvest time series. Tables A.4 through A.6 are estimates from the CAGEAN routine and thus the entries throughout the entire table will change each year as updated and more recent information become available.

Figures A.1 through A.6 show the fit of the model to the observed data. The heights of the blocks represent the observed values the heights of the lines represent the estimated values. Figure A.1 shows the observed versus estimated efforts for each closed area run. Figures A.2 through A.6 show the observed versus estimated catches for Areas 2A-2B, 2C, 3A, 3B, and 4. The figures are to scale across both age and time.

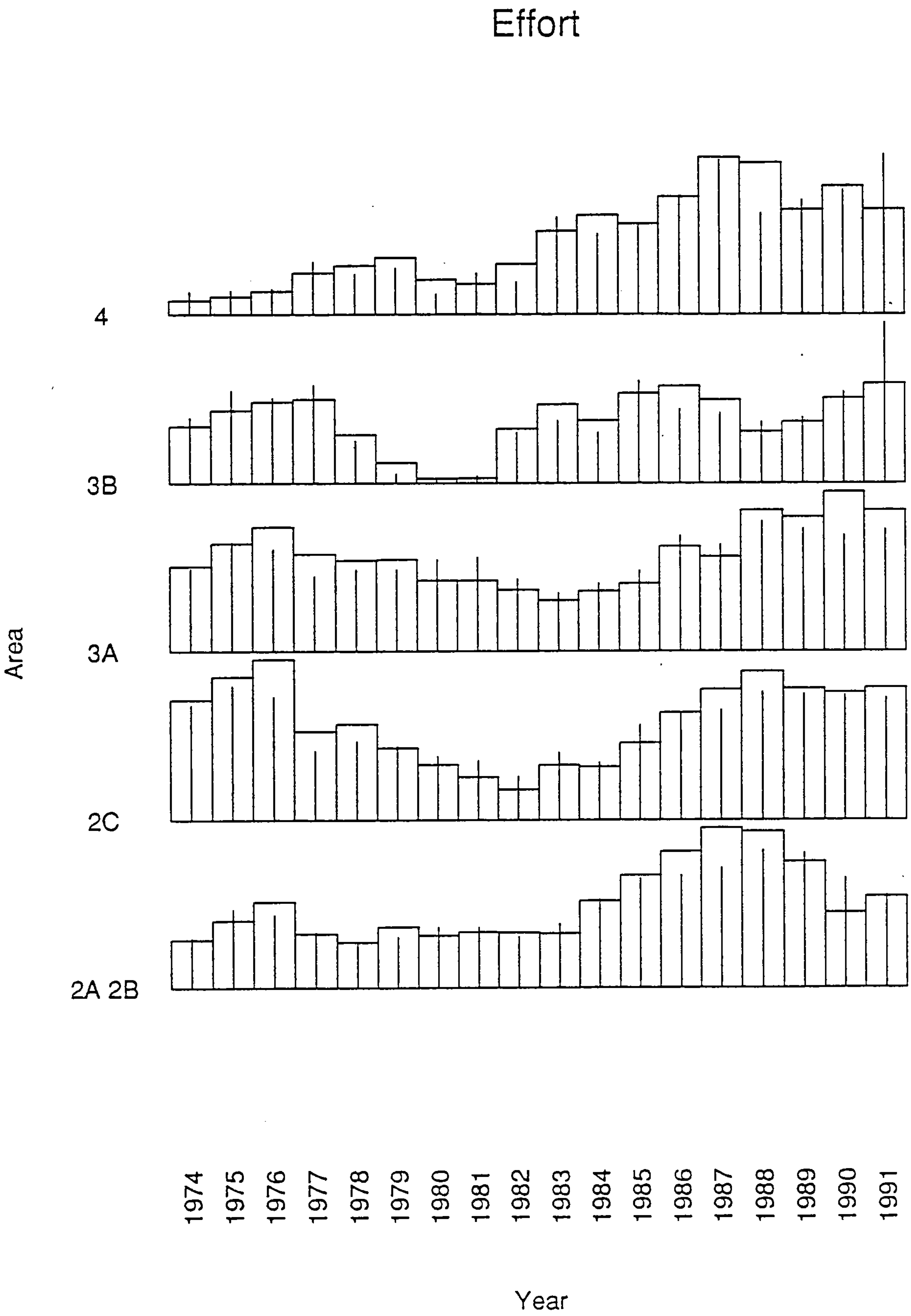
Starting last year stock sizes for Areas 3B and 4 were estimated separately. Previously, the two areas were combined and CPUE-habitat partitioning was used to determine the area specific biomasses. The report entitle "Area 3B and 4 Estimation" by P. Neal and P. Sullivan, in last years Report of Commission Activities discussed this change. Unfortunately, the area specific catches were not updated in last year's stock assessment (although they were correctly included for the analysis given in the above report). Consequently, this year, a portion of the observed catches were shifted from the 3B summary files to where they appropriately belong in the area 4 summary files. The result of this change was an apparent shift in exploitable biomass between the two areas, although the combined biomass of the two areas remained the same. This and other modifications to the analysis are discussed in a section entitled "Assessment Methods" given later in this report.

The fishery in area 2B is now under an IVQ management program. Consequently, Canadian

Sullivan, P.J., 1992. Population assessment, 1991. IPHC Rep. Assess. Res. Act. 1991., pp. 41–87.

halibut longliners are able to go fishing at any time from May through November. This is in contrast to last year's restricted seasons of one week in April-May and one in September. A concern arose about how this might affect annual CPUE estimates. Figures A.7 and A.8 show the distribution of CPUE as it changes by month for fixed-hook and snap gear. The horizontal line indicates the overall 1991 CPUE estimate for each gear type computed from all the data. Given this preliminary analysis, we note that there does appear to be a seasonal effect, however, this effect appears to be different between gear types. Therefore, it is unlikely that the apparent trends reflect true seasonal trends in density. The overall CPUE estimate reflects mainly the CPUE observed in the May, June, and October fisheries when the bulk of the landings were made. However, it is higher than a CPUE estimate based on the 1991 May and September values alone. It is difficult to judge what the effect actually is since it is not clear how the seasonal pattern will change from year to year, how seasonal changes in density affect that pattern, or how the relative contribution of the two gear types may affect the combined result. Until further analysis suggests otherwise we shall use the overall CPUE estimate in the stock assessment.

One of the more significant changes made this year was the inclusion of sport catch and wastage (due to gear loss) as part of the total removals going into the CAGEAN analysis. Tables A.2 and A.3 reflect this difference. In the past only commercial catch removals (i.e. those shown in Table A.2) were included. If sport catch and wastage could be assumed to occur at a constant rate then it could be argued that their effect is represented through the natural mortality term. However, recently, better records are being kept of both these sources of removals, and it has become clear that there may be an expanding sport fishery in some areas and that wastage may vary with the type of fishery (i.e. IVQ versus one or two day openings). This has led us to explicitly include these removals in the analysis. The effect is a 10-15% increase in the overall catch resulting in a 10% increase in the estimated biomass over recent years as shown in Figure A.9. As better information becomes available on the age composition of the sport catch, and the effects of management programs on wastage these two inputs will be updated.



Effort
4
3B
3A
2C
2A 2B
Area
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
Year

Figure A.1

2A 2B Age Composition

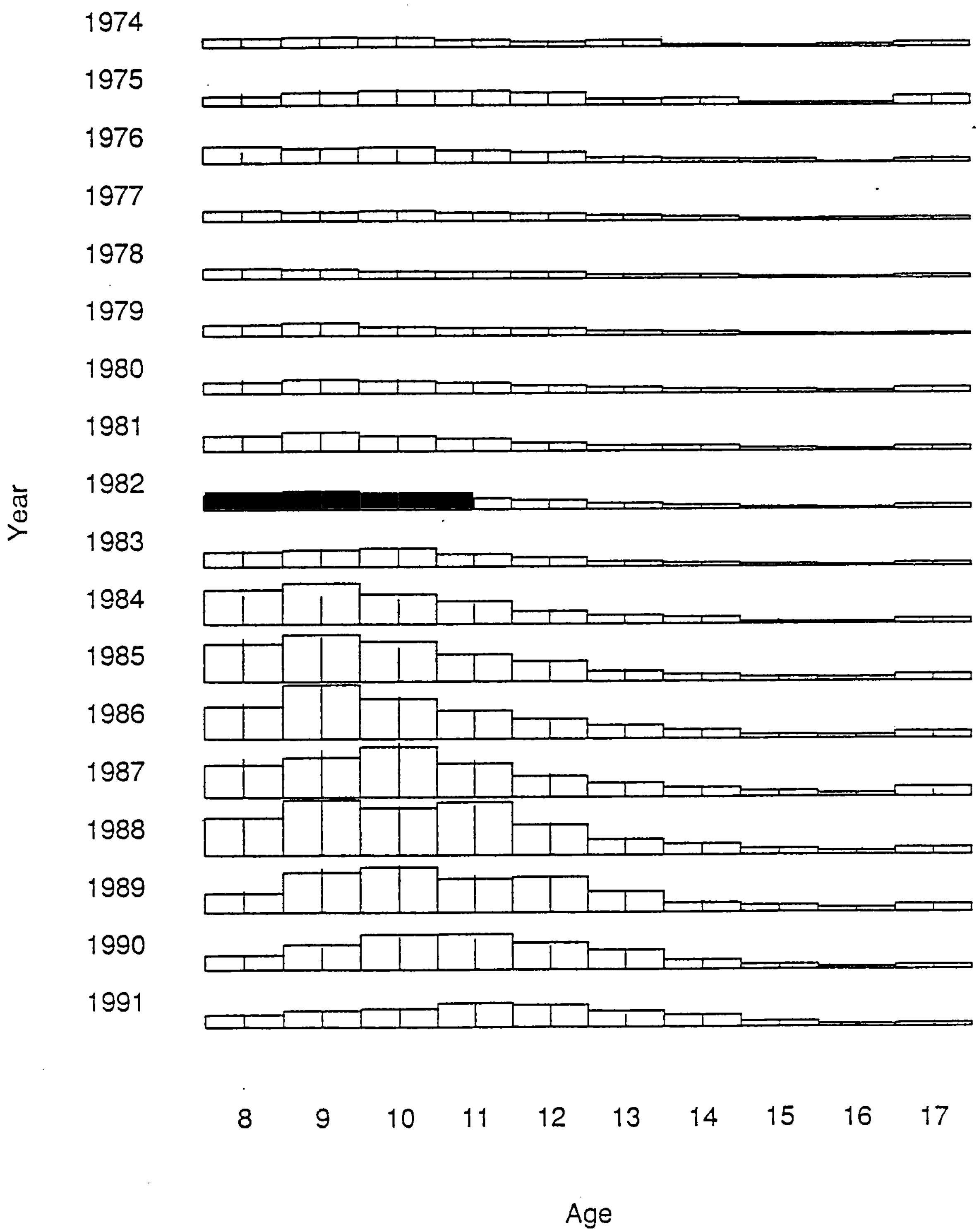


Figure A.2

Sullivan, P.J., 1992. Population assessment, 1991. IPHC Rep. Assess. Res. Act. 1991., pp. 41–87.

2C Age Composition

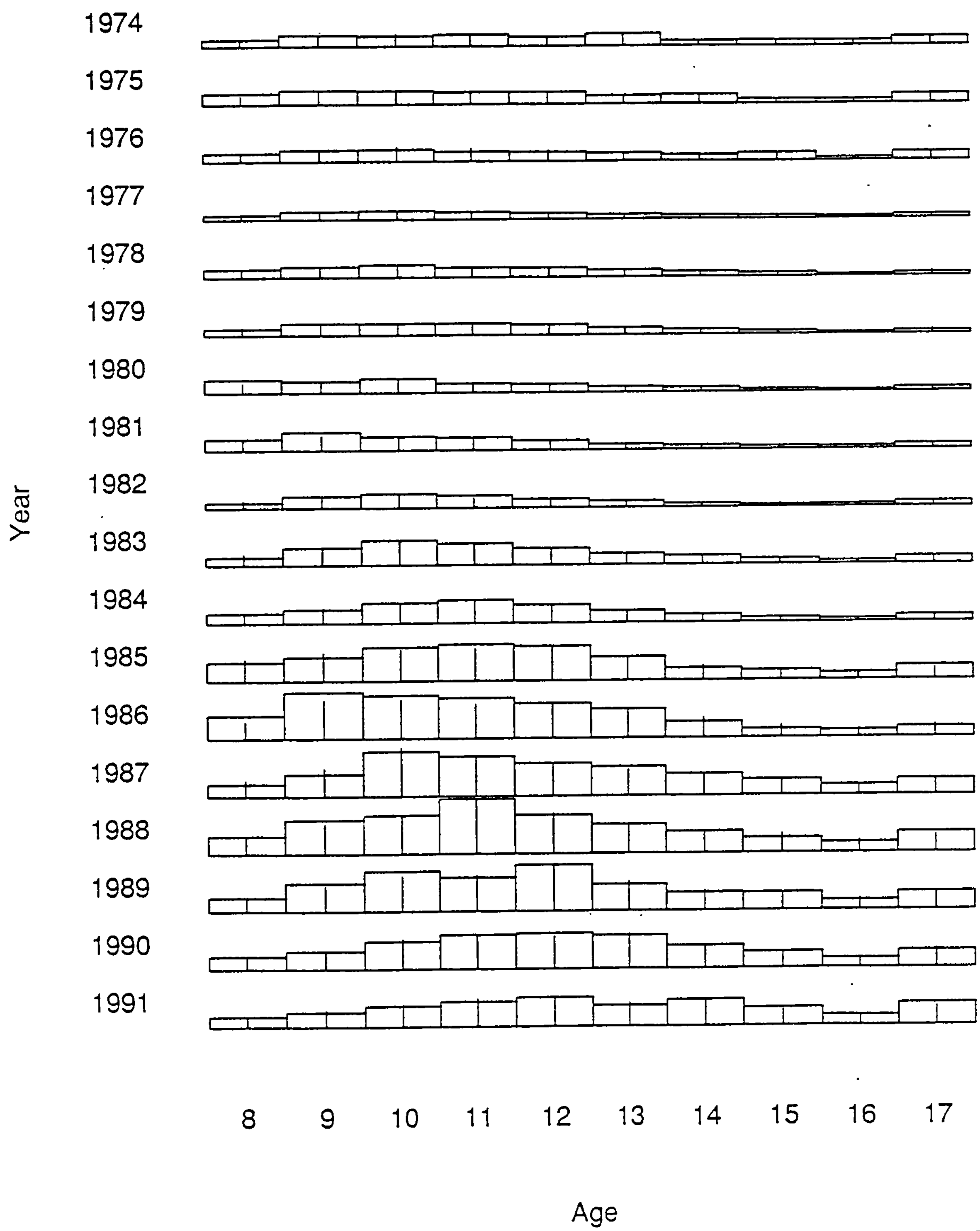


Figure A.3

Sullivan, P.J., 1992. Population assessment, 1991. IPHC
Rep. Assess. Res. Act. 1991., pp. 41–87.

3A Age Composition

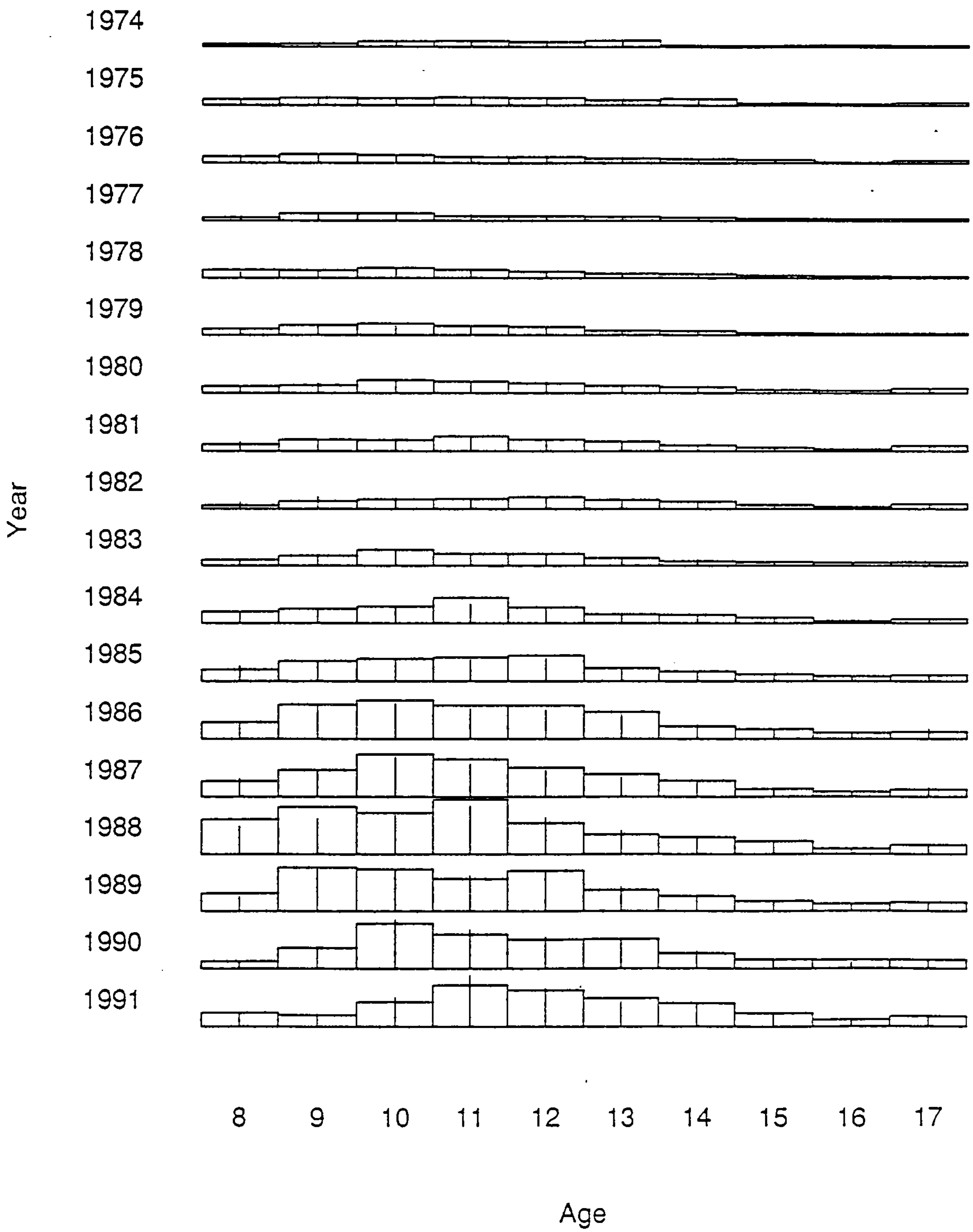


Figure A.4

Sullivan, P.J., 1992. Population assessment, 1991. IPHC
Rep. Assess. Res. Act. 1991., pp. 41–87.

3B Age Composition

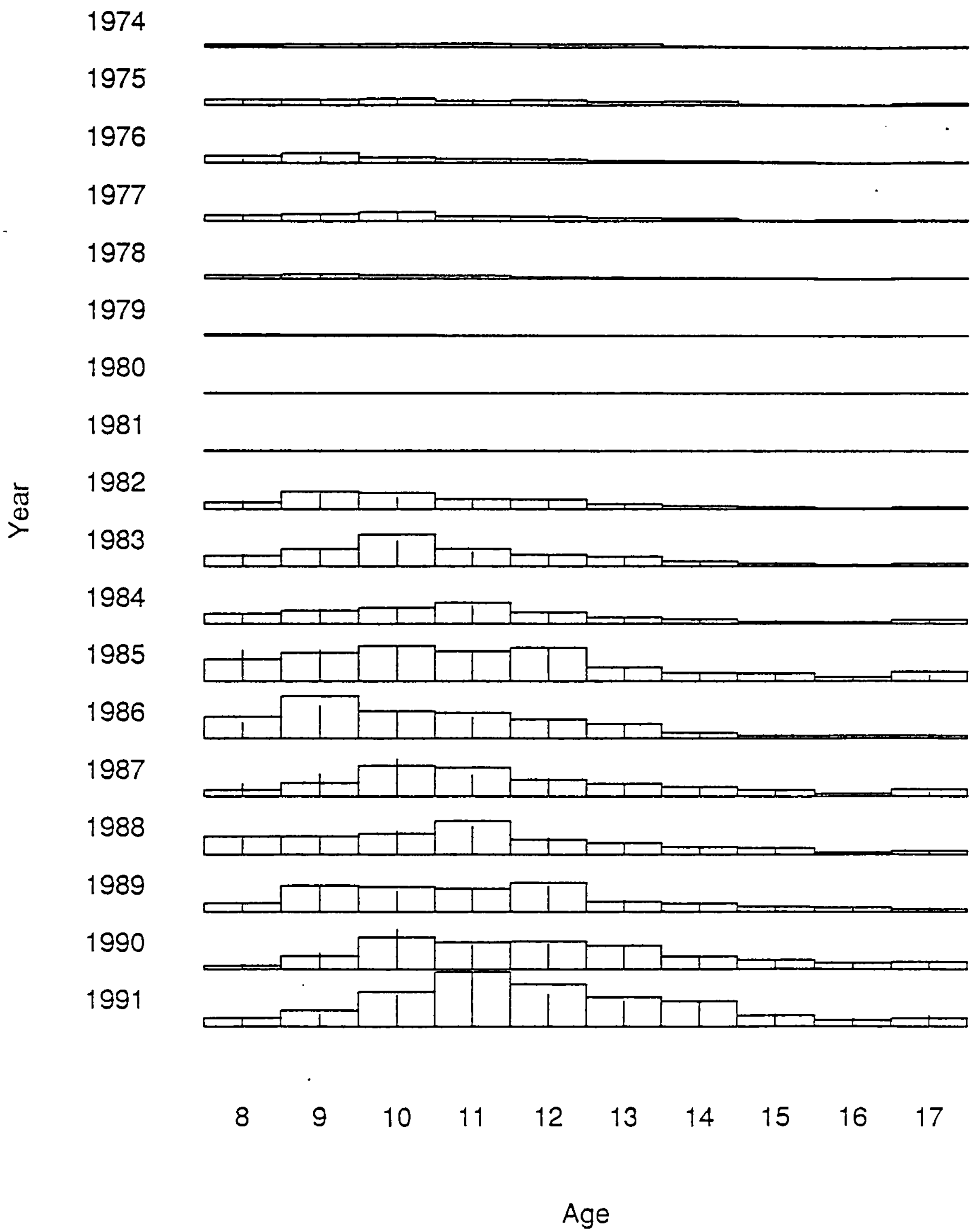


Figure A.5

Sullivan, P.J., 1992. Population assessment, 1991. IPHC Rep. Assess. Res. Act. 1991., pp. 41–87.

4 Age Composition

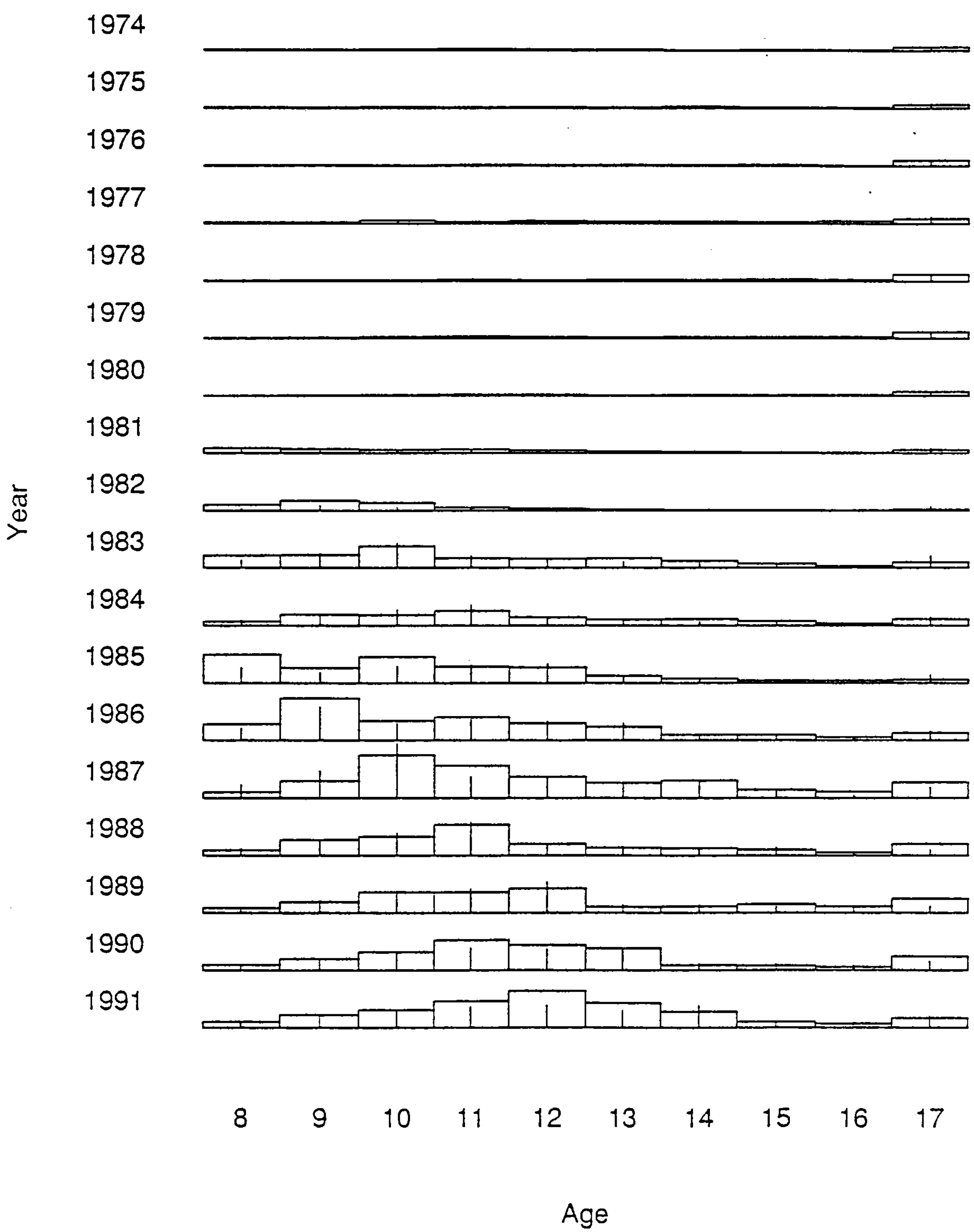


Figure A.6

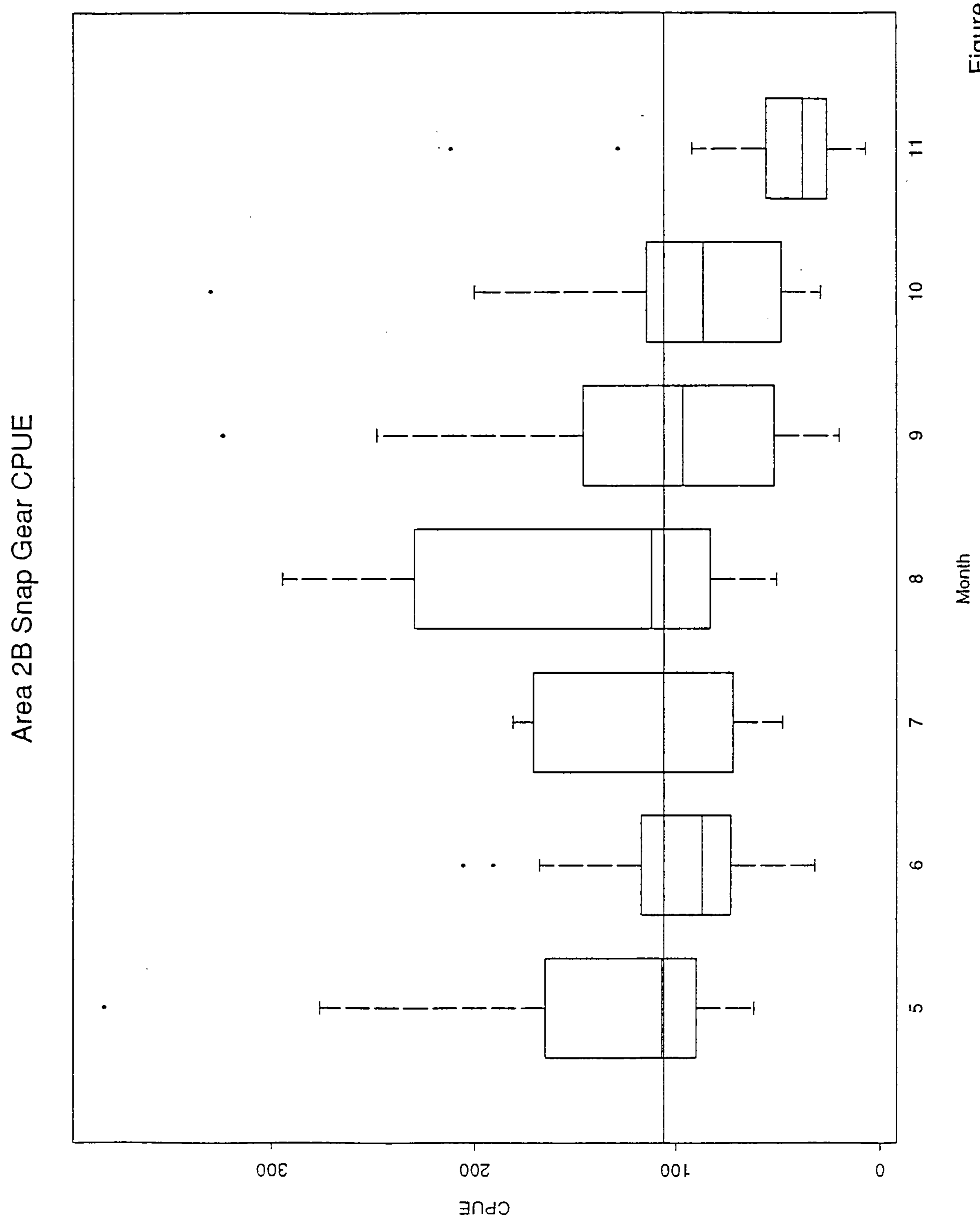
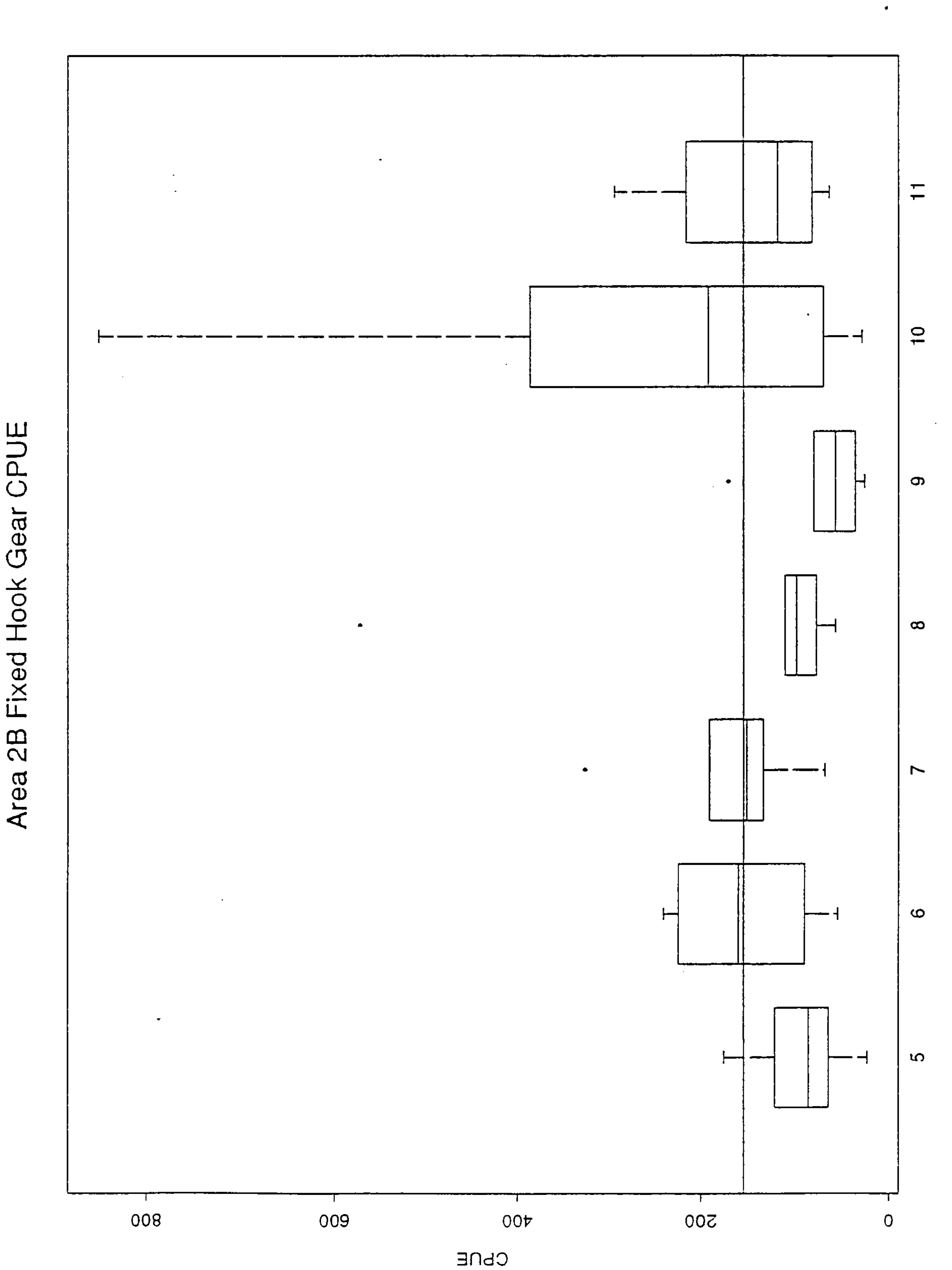


Figure A.7

61

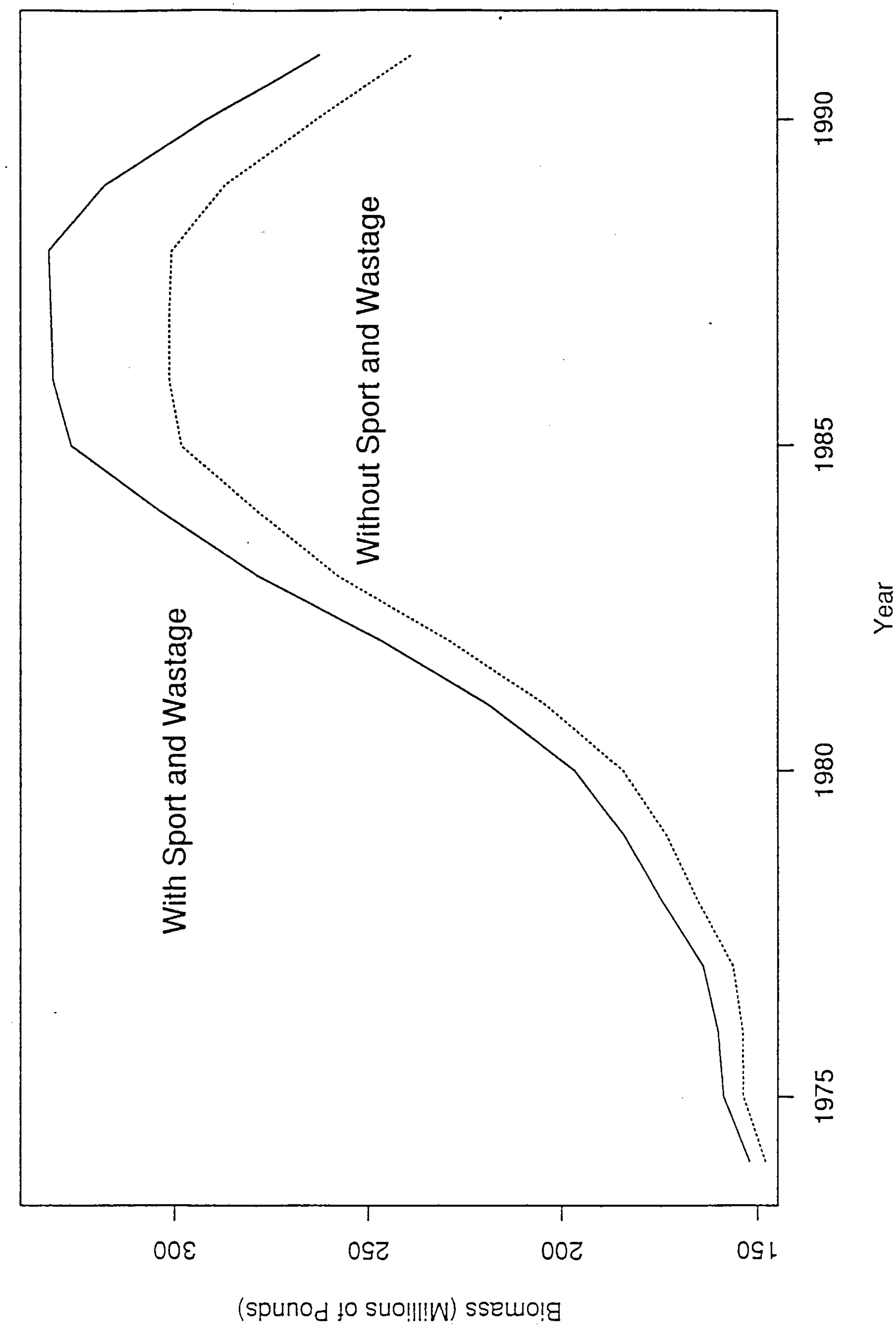


Area 2B Fixed Hook Gear CPUE
CPUE
0
200
400
600
800
Month
5
6
7
8
9
10
11

Figure A.8

62

Total Exploitable Biomass



Effect of Adding Noncommercial Catch

Figure A.9

63

TABLE A.1 Commercial CPUE* (pounds per skate)

Year	2A	2B	2C	3A	3B	4	Overall
				AREA			
1974	130.7	141.0	126.0	142.4	124.7	301.1	137.9
1975	130.6	148.7	117.4	145.3	149.3	210.7	139.7
1976	71.7	116.7	92.8	131.4	142.2	184.2	118.5
1977	182.2	135.3	99.4	134.6	161.3	176.2	133.1
1978	85.5	138.0	124.1	171.9	116.4	166.7	148.0
1979	110.0	105.8	176.6	189.0	80.8	146.1	154.6
1980	82.0	143.7	174.7	260.6	249.5	124.2	197.6
1981	107.6	140.6	273.6	313.5	368.3	236.8	239.1
1982	101.6	141.4	355.9	342.6	375.8	172.5	261.3
1983	102.1	144.4	342.8	437.0	419.4	320.0	311.4
1984	101.8	151.1	328.5	516.0	441.4	193.6	297.3
1985	87.5	141.2	354.1	501.5	525.1	296.4	307.3
1986	105.9	123.8	296.4	514.8	403.0	304.6	296.4
1987	50.3	126.3	244.5	546.2	412.4	276.4	271.1
1988	89.2	120.9	229.7	447.3	598.6	191.3	265.5
1989	105.1	125.8	232.1	421.1	557.7	293.4	279.1
1990	175.6	174.9	240.9	311.6	443.7	269.1	274.5
1991	148.0	121.6	219.5	300.4	467.5	360.4	254.3

* Standardized C hook equivalence.

TABLE A.2 Commercial Catch (million pounds)

Year	AREA 2A	2B	2C	3A	3B	4	Total
1974	0.51	4.62	5.60	8.19	1.67	0.71	21.30
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	5.42	3.19	8.64	3.19	1.22	21.87
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	22.53
1980	0.02	5.65	3.24	11.96	0.28	0.71	21.86
1981	0.20	5.66	4.01	14.23	0.45	1.19	25.74
1982	0.21	5.53	3.50	13.53	4.80	1.43	29.01
1983	0.27	5.44	6.40	14.12	7.75	4.43	38.39
1984	0.43	9.06	5.85	19.97	6.50	3.17	44.98
1985	0.50	10.39	9.20	20.85	10.89	4.28	56.11
1986	0.58	11.23	10.61	32.78	8.83	5.60	69.63
1987	0.59	12.25	10.68	31.31	7.76	6.88	69.47
1988	0.49	12.86	11.37	37.86	7.08	4.70	74.35
1989	0.47	10.47	9.53	33.74	7.85	4.94	66.98
1990	0.32	8.57	9.73	28.85	8.69	5.43	61.60
1991	0.35	7.20	8.80	23.60	10.50	5.98	56.43

TABLE A.3 Total Removals (million pounds)

Year	AREA						
	2A	2B	2C	3A	3B	4	Total
1974	0.51	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	5.44	3.26	8.84	3.19	1.22	22.17
1978	0.11	4.62	4.40	10.58	1.32	1.35	22.37
1979	0.06	4.88	4.70	11.70	0.39	1.37	23.10
1980	0.04	5.66	3.57	12.45	0.28	0.71	22.72
1981	0.22	5.68	4.33	14.98	0.45	1.20	26.85
1982	0.26	5.60	3.99	14.25	4.80	1.44	30.34
1983	0.33	5.54	6.95	15.06	7.75	4.43	40.05
1984	0.55	9.18	6.47	21.00	6.50	3.18	46.87
1985	0.69	11.02	10.10	22.99	11.09	4.44	60.33
1986	0.92	11.80	11.77	36.55	9.23	5.92	76.20
1987	1.04	12.75	11.83	34.88	8.10	7.17	75.78
1988	0.74	13.42	12.65	42.63	7.20	4.80	81.44
1989	0.80	11.11	11.28	38.20	8.04	5.09	74.52
1990	0.53	9.45	11.39	33.60	8.91	5.70	69.58
1991	0.51	8.04	10.76	28.63	10.98	6.27	65.18

TABLE A.4 Exploitable Biomass (Closed Subarea)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	1.71	30.76	31.00	55.55	9.04	24.01	152.08
1975	1.73	32.43	30.65	60.92	9.90	23.09	158.72
1976	1.55	31.89	29.88	64.75	10.24	21.84	160.14
1977	1.40	31.01	30.34	69.12	10.74	21.40	164.01
1978	1.24	31.17	33.66	75.76	11.14	21.56	174.53
1979	1.27	30.90	36.48	80.20	13.10	22.01	183.96
1980	1.33	30.51	39.83	85.55	16.86	22.60	196.67
1981	1.38	30.72	44.87	93.68	22.50	25.40	218.56
1982	1.37	32.10	51.75	104.07	29.37	28.00	246.67
1983	1.33	35.12	59.84	118.22	33.87	30.46	278.84
1984	1.57	38.90	64.60	133.04	35.90	29.56	303.58
1985	1.80	42.26	68.25	145.83	38.19	30.02	326.35
1986	1.93	43.38	67.17	153.90	34.65	29.96	331.00
1987	1.96	43.69	65.48	156.07	34.66	29.70	331.56
1988	1.85	42.53	63.60	161.93	34.79	27.39	332.10
1989	1.97	38.92	60.51	155.46	33.59	27.33	317.78
1990	2.31	34.99	57.12	141.64	29.64	26.03	291.73
1991	2.33	32.58	53.82	126.38	23.39	24.15	262.65

Estimates in million pounds by subarea.

TABLE A.5 Annual Surplus Production (Closed Subarea)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	0.54	6.29	5.26	13.55	2.52	-0.22	27.95
1975	0.27	6.59	5.47	14.43	2.90	-0.62	29.04
1976	0.09	6.40	5.99	15.41	3.22	0.28	31.40
1977	0.06	5.61	6.58	15.48	3.59	1.37	32.69
1978	0.13	4.34	7.22	15.02	3.28	1.81	31.80
1979	0.12	4.48	8.05	17.05	4.14	1.96	35.80
1980	0.09	5.87	8.62	20.59	5.92	3.52	44.61
1981	0.22	7.06	11.20	25.37	7.32	3.80	54.96
1982	0.21	8.63	12.08	28.39	9.29	3.90	62.51
1983	0.57	9.32	11.71	29.88	9.78	3.52	64.79
1984	0.78	12.53	10.12	33.79	8.80	3.63	69.64
1985	0.82	12.14	9.03	31.06	7.54	4.39	64.98
1986	0.95	12.11	10.08	38.72	9.24	5.65	76.76
1987	0.93	11.59	9.96	40.74	8.24	4.87	76.32
1988	0.85	9.80	9.56	36.16	6.00	4.74	67.11
1989	1.15	7.18	7.89	24.38	4.09	3.78	48.47
1990	0.55	7.04	8.09	18.33	2.66	3.82	40.50
1991	0.55	6.56	7.62	16.36	2.10	3.55	36.74

Estimates in million pounds by subarea.

Sullivan, P.J., 1992. Population assessment, 1991. IPHC
Rep. Assess. Res. Act. 1991., pp. 41–87.

TABLE A.6 Total Instantaneous Fishing Mortality (Closed Subarea)

	AREA				
Year	2A-2B	2C	3A	3B	4
1974	0.15	0.22	0.19	0.23	0.03
1975	0.24	0.26	0.25	0.32	0.03
1976	0.22	0.24	0.24	0.29	0.03
1977	0.17	0.13	0.17	0.34	0.07
1978	0.14	0.15	0.19	0.15	0.05
1979	0.15	0.14	0.19	0.03	0.06
1980	0.18	0.12	0.21	0.02	0.03
1981	0.18	0.11	0.22	0.02	0.06
1982	0.15	0.08	0.17	0.17	0.04
1983	0.15	0.13	0.16	0.25	0.18
1984	0.21	0.11	0.19	0.20	0.15
1985	0.26	0.19	0.23	0.41	0.16
1986	0.26	0.21	0.33	0.29	0.22
1987	0.28	0.22	0.30	0.28	0.28
1988	0.32	0.25	0.37	0.24	0.18
1989	0.32	0.25	0.35	0.26	0.21
1990	0.26	0.24	0.33	0.36	0.23
1991	0.22	0.24	0.34	0.64	0.29

APPENDIX I

HALIBUT SUBSISTENCE CATCHES

by

Ian R. McGregor

Alaska

Tables 5.6, 5.9, 5.10, 5.14, 5.17, and 5.20 in the IFQ analysis for Alaska indicate a documented subsistence catch of 1.2 million pounds annually in 1990 in the communities surveyed. Many communities however have not been surveyed, so the actual subsistence catch is higher than 1.2 million pounds. Extrapolating catch rates to unsurveyed communities suggests that the total subsistence catch could be near 2.95 million pounds in 1990. This amounts to about 125,000 people in Alaska each consuming 25 pounds per year, which seems reasonable. Some of this fish may have been previously recorded in the sport fish catches, which are estimated at 4.88 million pounds in 1990. If 1.0 million pounds are duplicated, an estimate of combined sport and subsistence catch is 6.83 million pounds. A summary of the catch by regulatory area is as follows:

	REGULATORY AREA			
	2	**3**	**4**	**Total**
Subsistence	.72	1.00	.23	1.95
Sport	1.56	3.30	.02	4.88
Total	2.28	4.30	.25	6.83

British Columbia

There is a native food fish fishery for halibut in British Columbia. There are some catch records available for the years 1985-1989 which indicate annual catches between 135 and 717 fish. If these fish average 25 pounds, the annual catch would range from 3,375 pounds to 17, 925 pounds. It is our understanding that the catch records are incomplete in that no catch information is available concerning some permits which were issued. However, we suspect that the total catch is approximately 50,000 pounds.

HALIBUT SUBSISTENCE CATCHES

ALASKA

Tables 5.6, 5.9, 5.10, 5.14, 5.17, and 5.20 (attached) in the IFQ analysis for Alaska indicate a documented subsistence catch of 1.2 million pounds annually in 1990 in the communities surveyed. Many communities however have not been surveyed, so the actual subsistence catch is higher than 1.2 million pounds. Extrapolating catch rates to unsurveyed communities suggests that the total subsistence catch could be near 2.95 million pounds in 1990. This amounts to about 125,000 people in Alaska each consuming 25 pounds per year, which seems reasonable. Some of this fish may have been previously recorded in the sport fish catches, which are estimated at 4.88 million pounds in 1990. If 1.0 million pounds are duplicated, an estimate of combined sport and subsistence catch is 6.83 million pounds. A summary of the catch by regulatory area is as follows:

Area	2	3	4	Total
Subsistence	.72	1.00	.23	1.95
Sport	1.56	3.30	.02	4.88
	------	------	----	------
Total	2.28	4.30	.25	6.83

BRITISH COLUMBIA

There is a native food fish fishery for halibut in British Columbia. There are some catch records available for the years 1985-1989 which indicate annual catches between 135 and 717 fish. If these fish average 25 pounds, the annual catch would range from 3,375 pounds to 17, 925 pounds. It is our understanding that the catch records are incomplete in that no catch information is available concerning some permits which were issued. However, we suspect that the total catch is approximately 50,000 pounds.

Table 5.6: 1990 Population, Distribution of Halibut Permits and Landings in Southeast Alaskan Communities (Area 2C)

Community	Pop.	Native	Permits	Halibut	
	N	Pop. %	N	Commerc. Lbs.	Subsist.* Lbs.
Juneau	26,751	11.2	213	390,151	n/a
Ketchikan	13,459	11.1	128	1,036,245	n/a
Sitka	8,588	21.4	278	3,638,138	206,112
Petersburg	3,207	10.9	215	2,283,585	102,303
Wrangell	2,479	17.9	109	556,897	47,597
Metlakatla	1,407	80.2	27	234,650	11,256
Craig	1,260	32.3	65	677,596	16,884
Haines	1,238	18.9	74	44,198	18,322
Hoonah	795	79.9	59	703,747	29,733
Klawock	722	66.0	13	**	22,815
Kake	700	84.1	43	**	14,700
Skagway	692	4.6	2	**	4,429
Angoon	638	88.6	53	**	14,929
Thorne Bay	569	2.8	6	**	22,020
Hydaburg	384	84.9	28	**	9,178
Saxman	369	71.1	#	**	3,727
Gustavus	258	2.0	17	39,327	16,202
Pelican	222	18.3	40	1,132,088	12,632
Coffman Cove	186	0.0		**	5,264
Klukwan	129	83.7	#	**	150
Port Alexander	119	5.8	17	**	3,713
Hollis	111	18.0		**	1,032
Hyder	99	1.3	2	**	4,712
Tenakee Springs	94	5.1	5	**	4,362
Edna Bay	86	0.0	23	**	5,452
North Whale Pass	75	0.0	0	**	1,586
Port Protection	62	5.6	#	**	2,220
Elfin Cove	57	7.1	19	**	1,767
Kasaan	54	56.0	1	**	540
Point Baker	39	5.6	18	**	1,365
Meyers Chuck	37	0.0	5	**	2,853
Excursion Inlet##				1,052,386	
Killisnoo##				245	
Misc. SE Alaska Ports				3,676	
Totals	64,886		1,460	11,792,929	

Population data are from the 1990 U.S. Census; 1990 permit and commercial landings data are from IPHC files.

* 1990 Subsistence landings data are estimated from Alaska Dept. of Fish and Game baseline studies for 1987; estimated landings are in pounds of dressed fish (H&G).

** Any commercial landings were at other ports or are shown in the Misc. S.E. Alaska Ports category.

n/a Data not available.

\# IPHC permit data are based upon postal zip codes; many Alaskan communities share zip codes, and CFEC data indicate that halibut permit holders reported elsewhere reside here.

\## These are cannery or floating processor sites.

Table 5.8: Population, Mean Household Size, and Mean Taxable Income for Selected Communities with Halibut Harvests (Area 2C)

Community	Population (N)	Native Pop. (%)	Household Size (N)*	Mean Taxable Income ($)**
Alaska, State	53[illegible],[illegible]43	16.2	2.8[illegible]	
Juneau	26,751	11.2	2.66	24,250
Petersburg	3,207	10.9	2.77	21,211
Angoon	638	88.6	4.09	11,563

Population data is from the 1990 census, U.S. Bureau of Census
* Household size in mean number of persons
** Mean taxable income per income return, 1981-1985; Alaska Department of Revenue.

Table 5.9: 1990 Population and Distribution of Halibut Permits and Landings in Southcentral Alaskan Communities (Area 3A)--Kodiak Island, Prince William Sound and Yakutat Communities

Community	Pop. N	Native Pop. %	Halibut Permits N	Halibut Commerc. Lbs.	Halibut Subsist.* Lbs.
Kodiak City	6,365	14.0	404	11,573,328	325,252
Valdez	4,068	5.7	29	598,497	n/a
Other Kodiak	3,643	9.5	#	**	n/a
Kodiak Station	2,291	0.6	0	**	n/a
Cordova (Eyak)	2,110	14.9	114	1,816,665	33,971
Yakutat	534	62.1	39	918,046	22,428
Old Harbor	284	92.6	12	**	16,103
Whittier	243	8.6	8	280,882	n/a
Port Lions	222	73.5	21	**	19,003
Ouzinkie	209	94.2	20	**	7,064
Larsen Bay	147	71.4	6	**	6,806
Tatitlek	119	77.9	1	**	2,785
Chenega Bay	94	77.0	0	**	3,882
Akhiok	77	96.2	#	**	1,871
Karluk	71	100.0	#	**	3,202
Port Bailey##				728,754	n/a
Alitak##				689,458	n/a
Totals	20,477		654	16,605,630	
Other Area 3A Communities	306,832		948	12,965,282	
Totals	327,309		1,602	29,570,912	

Population data are from the 1990 Census; 1990 permit and commercial landings data are from IPHC files.
* 1990 Subsistence landings data are estimated from Alaska Dept. of Fish and Game baseline studies for 1987; estimated landings are in pounds of dressed fish (H&G).
** Any commercial landings were at other ports.
n/a Data not available.
\# IPHC permit data are based upon postal zip codes; many Alaskan communities share zip codes, and CFEC data indicate that halibut permit holders reported elsewhere reside here.
\#\# These are cannery/floating processor sites.

Table 5.10: 1990 Population and Distribution of Halibut Permits and Landings in Southcentral Alaskan Communities (Area 3A)--Kenai Peninsula and Anchorage Area Communities.

Community	Pop. N	Native Pop. %	Halibut Permits N	Halibut Commerc. Lbs.	Halibut Subsist.* Lbs.
Anchorage	226,338	5.1	196	42,994	n/a
Matsu area	31,027	3.7	#	**	n/a
Kenai area	13,522	3.2	#	**	n/a
Kenai City	6,327	6.1	99	1,223,591	53,147
Wassila	4,028	4.7	23	**	n/a
Sterling	3,802	1.7	9	**	n/a
Homer	3,660	3.0	293	5,877,869	94,428
Soldotna	3,482	3.1	73	**	n/a
Palmer	2,866	3.5	9	**	n/a
Nikiski	2,743	4.0	14	**	n/a
Seward	2,699	12.9	52	5,183,281	n/a
Big Lake	1,477	0.7	2	**	n/a
Fritz Creek	1,426	1.0	0	**	n/a
Anchor Point	866	1.8	53	**	n/a
Ninilchik	456	17.0	30	195,724	5,700
Kasilof	383	0.0	47	**	n/a
Seldovia	316	24.4	29	441,823	2,496
Willow	285	1.4	4	**	n/a
Cooper Landing	243	1.7	1	**	n/a
Port Graham	166	87.6	#	**	7,736
Hope	161	2.9	0	**	n/a
English Bay	158	79.0	#	**	6,051
Tyonek	154	92.9	0	**	n/a
Moose Pass	81	6.6	0	**	n/a
Clam Gulch	79	0.0	14	**	n/a
Halibut Cove	78	0.0	#	**	n/a
Sub-Totals	306,832		948	12,965,282	
Other Area 3A Communities	20,477		654	16,605,630	
Totals	327,309		1,602	29,570,912	

Population data are from the 1990 U.S. Census; 1990 permit and commercial landings data are from IPHC files.

* 1990 Subsistence landings data are estimated from Alaska Dept. of Fish and Game baseline studies for 1987; estimated landings are in pounds of dressed fish.

** Any commercial landings were at other ports.

n/a Data not available.

\# IPHC permit data are based upon postal zip codes; many Alaskan communities share zip codes, and CFEC data indicate that halibut permit holders reported elsewhere reside here.

Table 5.14: 1990 Population and Distribution of Halibut Permits and Landings in Southwest Alaskan Communities (Area 3B)

Community	Pop. N	Native Pop. %	Halibut Permits N	Halibut Commerc. Lbs.	Halibut Subsist.* Lbs.
Sand Point	878	57.1	58	1,058,103	n/a
King Cove	541	79.8	38	1,598,466	n/a
Chignik Bay	188	53.4	9	918,322	9,062
Cold Bay	148	4.4	0	**	n/a
Chignik Lake	133	89.1	#	**	3,259
Perryville	108	92.8	2	**	5,130
Nelson Lagoon	83	93.2	0	**	0
False Pass	68	86.7	3	**	2,604
Chignik Lagoon	53	85.4	7	**	1,919
Ivanof Bay	36	92.5	0	**	1,462
Totals	2,236		117	3,574,891	

Population data are from the 1990 U.S. Census; 1990 permit and commercial landings data shown are from IPHC files.
* 1990 Subsistence landings data are estimated from Alaska Dept. of Fish and Game baseline studies for 1987; estimated landings are in pounds of dressed fish (H&G).
** Any commercial landings were at other ports.
\# IPHC permit data are based upon postal zip codes; many Alaskan communities share zip codes, and CFEC data indicate that halibut permit holders reported elsewhere reside here.

Table 5.15: Fleet Composition by Area, Size Class, and Percent of Catch in the Halibut Fishery Off Alaska, 1984 and 1990

IPHC Area	Vessel Size (ft)	1984 N	1984 % Fleet	1984 % Catch	1990 N	1990 % Fleet	1990 % Catch
3B	< 26'	24	7.2	2.8	5	1.3	0.1
	26-30'	12	3.6	1.3	3	0.8	<0.1
	31-35'	40	12.0	6.3	46	12.0	4.9
	36-55'	157	47.0	29.1	195	50.8	29.7
	56' >	92	27.5	57.5	131	34.1	64.7
	n/a	9	2.7	2.9	4	1.0	0.6

Area, vessel, and catch data provided by IPHC, 1991; all percentages are rounded.
n/a Vessel size data not available for these vessels.

Table 5.16: Population, Mean Household Size, and Mean Taxable Income for Selected Alaskan Communities with Halibut Harvests

Community	Population (N)	Native Pop. (%)	Household Size (N)*	Mean Taxable Income ($)**
Alaska, State	530,043	16.2	2.80	
Sand Point	878	57.1	2.85	24,254
King Cove	541	79.8	2.98	19,167
Chignik Bay	188	53.4	3.48	16,403

Population data is from the 1990 census, U.S. Bureau of Census
* Household size in mean number of persons
** Mean taxable income per income tax return, 1981-1985; Alaska Department of Revenue.

Table 5.17: 1990 Population, Distribution of Halibut Permits and Landings in Aleutian Islands and West Bering Sea Communities (Areas 4A,B,C,D)

Community	Pop. N	Native Pop. %	Halibut Permits N	Halibut Commerc. Lbs.	Halibut Subsist.* Lbs.
Adak Station	4,633	0.8	3	1,970	n/a
Unalaska/ Dutch Harbor	3,089	15.1	10	1,096,677	n/a
Saint Paul	763	87.7	14	145,152	n/a
Shemya Station	664	0.2	0	**	n/a
Akutan	589	39.6	10	1,417,727	n/a
Saint George	138	96.8	10	43,587	n/a
Atka	73	96.8	4	12,604	n/a
Nikolski	36	96.0	#	**	n/a
Totals	9,985		51	2,717,717	
(Civilian)	(4,688)				

Population data are from the 1990 U.S. Census; 1990 permit and commercial landings data are from IPHC files.

* 1990 subsistence landings data are estimated from Alaska Dept. of Fish and Game baseline studies for 1987; estimated landings are in pounds of dressed fish (H&G).

** Any commercial landings were at other ports.

n/a Data not available

\# IPHC permit data are based on postal zip codes; many Alaskan communities share zip codes, and CFEC data indicate that halibut permit holders reported elsewhere reside here.

Table 5.18: Population, Mean Household Size, and Mean Taxable Income for Selected Alaskan Communities with Halibut Harvests

Community	Population (N)	Native Pop. (%)	Household Size (N)*	Mean Taxable Income ($)**
Alaska, State	530,043	16.2	2.80	
Unalaska	3,089	15.1	2.57	20,055
Saint Paul	763	87.7	3.68	17,369
Akutan	589	39.6	4.50	8,241

Population data is from the 1990 census, U.S. Bureau of Census

* Household size in mean number of persons

** Mean taxable income per income tax return, 1981-1985; Alaska Department of Revenue.

Table 5.20: 1990 Population, Distribution of Halibut Permits and Landings in East Bering Sea Communities (Area 4E)

Community	Pop. N	Native Pop. %	Permits N	Halibut Commerc. Lbs.	Halibut Subsist.* Lbs.
Bethel	4,674	67.6	#	**	n/a
Nome	3,500	58.5	1	**	n/a
Dillingham	2,017	57.0	20	**	0
King Salmon	696	5.9	2	**	n/a
Emmonak	642	91.2	0	**	n/a
Togiak	613	94.3	17	**	n/a
Naknek	575	50.6	13	**	n/a
Pilot Station	463	94.2	#	**	n/a
Toksook Bay	420	93.7	8	**	n/a
New Stuyahok	391	94.0	3	**	n/a
Manokotak	385	92.9	5	**	n/a
Chefornak	320	96.1	#	**	n/a
Tununak	316	95.0	#	3,413	29,514
Newtok	207	94.7	1	**	n/a
Aleknagik	185	89.6	2	**	n/a
Mekoryak	177	95.6	17	7,730	n/a
Nightmute	153	97.5	#	**	n/a
South Naknek	136	85.5	7	**	n/a
Egegik	122	76.0	1	**	268
Port Heiden	119	64.1	1	**	167
Sheldon Point	109	95.1	1	**	n/a
Levelock	88	100.0	0	**	396
Pilot Point	53	86.4	#	**	186
Ugashik	7	100.0	1	**	0
Bristol Bay (General)				25,401	n/a
Totals	16,369		100	36,544	

Population data are taken from the 1990 U.S. Census; 1990 permit and commercial landings data are from IPHC files.
* 1990 subsistence landings data are estimated from Alaska Dept. of Fish and Game baseline studies for 1987; estimated landings are in pounds of dressed fish (H&G).
** Any commercial landings were at other ports or are shown in the Bristol Bay (general) category.
n/a Data not available.
\# IPHC permit data are based upon postal zip codes; many Alaskan communities share zip codes and CFEC data indicate that halibut permit holders reported elsewhere reside here.

REPORT OF ASSESSMENT AND RESEARCH ACTIVITIES

ASSESSMENT METHODS

by

Patrick J. Sullivan, Ana M. Parma, and Bernard A. Vienneau

This section reviews and documents the analytical procedures used as of 1991 for Pacific halibut stock assessment and reports the changes that are taking place this year. Procedures employed in the analysis of halibut abundance are updated and revised periodically. Year-to-year adjustments and technical observations on the assessment are generally discussed in the technical supplement to the population assessment report. This report reviews current practices, updates the documentation provided by Quinn, Deriso, and Hoag (1985), lists the modifications and correction factors used, makes and discusses modifications made this year, and it is meant as a baseline document for future modifications. First we discuss the methods as they were implemented in the 1990 stock assessment, second we discuss the modifications we have made for the 1991 stock assessment, and third we explore the consequences of these modifications.

Stock Assessment Methods Used in 1990

The 1991 Report on Commission Activities contains a section entitled "Population Assessment, 1990" that discusses the status of the Pacific halibut stock (Sullivan 1991a). The population assessment for 1990 is an area by area analysis applied to data from Areas 2A-2B, 2C, 3A, 3B, and 4. It uses catch data, effort data, age composition data, average weight data, and average weight at age data. The CAGEAN catch-at-age analysis program is used in the analysis (Deriso, Quinn, and Neal 1985). A flow diagram of data files and computer programs is given in Figure 1.

Average Weight An otolith weight to fish length to fish weight relationship described by Quinn et al. (1983) is used to compute average weight and average weight at age in the catch for use in data processing for catch-age analysis. A 10% adjustment, based on Ian McGregor's port observation (Quinn et al. 1985, page 10) was made in the programs SMTHCC6.FOR and MAKECC.FOR for the years greater than or equal to 1978. The factor adjusts the average weight up by 10% and the number of fish in the catch down by 10% prior to the catch-age analysis. In SMTHCC6.FOR the average weights at age are smoothed by age over time using a robust smoothing algorithm (Velleman 1980).

Regional Catchability Correction The following factors are applied over years greater than or equal to 1981.

Area	2A-2B	2C	3A	3B	4
Factor	1.25	0.80	0.80	0.80	1.00

Equation:

$$CPUE = CPUE \times Factor$$

and then

$$Effort = Catch/CPUE$$

These factors were initially discussed in Quinn, et al. 1985, page 10, in which 2C was included in 3A-3B adjustment, later Deriso and Neal 1988, page 49, gave arguments for not making the adjustment in 2C. The program SIMPADJM.FOR does the first set of conversions prior to running CAGEAN and BOGUST1.FOR does the conversion back for 2C for the CPUE tables, but not for the effort data that goes into CAGEAN, so 2C is still affected by the correction.

J-Hook Circle-Hook Adjustment The following factors are applied to all areas for current years upon entry into the database (page 9, Quinn et al. 1985).

Hook Type	' '	C	J	Mixed
Factor	0.45	1.00	0.45	0.73

Equation:

$$Number\ of\ skates = Number\ of\ skates \times Factor$$

The adjustment program EFFSKT.SF that makes these changes is located in the directory IPHC.CMR.ABF on the microvax. Note that SIMPADJM.FOR divides effort in the historic effort file (NEWCCPUE.DAT) by 2.2 for years up to and including 1986 in order to make circle hooks the standard in the file D_ CPUE_ 74_ 90_ MD.DAT. The effort value for 1983 in the historic file is supposed to result from an average using the 1982 and 1984 CPUE values (page 9, Quinn et al. 1985), but this does not appear to be the case.

Snap-Fixed Gear Adjustment These factors are applied in all years (Deriso and Price 1987, page 23, also discussed in Sullivan 1991b, page 169).

Gear Type	Fixed	Snap	Tub
Stat Areas	All	000-081	All
Conversion	1.00	0.71	1.00

Equation:

$$Number\ of\ skates = Number\ of\ skates \times Factor$$

Note, however, that the snap gear factor is applied only in statistical areas south of Vancouver Island (i.e. statistical areas 000-081). In areas north of 081 only fixed gear is used in the CPUE computations. These computations are performed by the program EFFSKT.SF.

CPUE Partitioning Under closed area stock assessments, we no longer need CPUE partitioning except to separate out Area 2A from Area 2B. To do this the CPUE's are smoothed in BOGUST1.FOR to be used as input into REL.FOR which does the partitioning. The theory behind this is given in Quinn et al. 1985, pages 12-15. The relative habitat values used in REL.FOR are given below:

Area	2A	2B	2C	3A	3B	4
Factor	.014	.241	.195	.352	.142	.057

as given in Quinn et al. 1985, page 14.

Modifications Introduced in 1991

Catch Updates and the 3B-4 Split An error was made in incorporating the catch updates and the 3B-4 split in last year's stock assessment (Sullivan and Neal, 1990) even though the numbers and figures were correct in the analysis leading up to the assessment as presented in another section of the report (Neal and Sullivan, 1990). The error was this: the catches were not updated as indicated in Table A.2 of the 1990 report; instead the values that were used were those given for Areas 2A-3A in Table A1.2 of the 1989 report and the catches for 3B and 4 were those under the 1981 boundary definitions. All catches, and boundary definitions, have been corrected as is reflected in Table A.2 in the Technical Supplement to the Population Assessment given in this document. The effect of these modifications is discussed below.

Average Weight Fish lengths were taken this year to get more direct weight estimates. New values for calculating average weight at age and average weight from otolith weight are used this year for data taken from 1974 to 1990.

The accuracy of the predicted fish weight from otolith measurements (weights or lengths) was discussed in 1983 (Quinn and McGregor, 1983). In 1981, it was found that average fish weight was under-estimated by 12%; however, in 1977, data from Hecate Strait indicated that there were no problems in the predictive relationship. A correction of 10% was applied to the average weight from 1978 onward, as discussed above. Clark (1992) examined survey setline data to derive new relationships that reflect the changes observed with time in otolith weight to fish weight. These new relationships are meant to replace the previous

10% correction. Predictive relationships differ among areas (2B, 2C, and 3-4) and periods (years through 1984 and years since 1984).

Ideally these new relationships should be applied to all otoliths measured back to 1974 for all areas for use in the stock assessment, but this will be a time consuming and complicated process. Until this process is completed, the factors given in Table 1 (which were derived from the same analysis: Clark, 1992) will be applied as an interim adjustment. The effects of removing the 10% correction factor and applying the newly derived correction factors are discussed below.

Regional Catchability Correction In 1982, IPHC staff noted that the halibut setline CPUE index for Area 2B was no longer tracking the CPUE indexes of more northern management areas (for example, Area 2C) as it had historically. This led to the analysis of a number of possible scenarios for explaining this departure (Deriso, et al. 1983). This trend continued for a number of years and so the area-specific catchability corrections (shown earlier) were applied in 1985 (Deriso, 1986). While there is support for the claim that catchability is different in the different areas (Hoag et al. 1984, Kaimmer et al. 1992) there is no evidence that the catchability of halibut in Area 2B changed relative to the other areas with time. It is not clear when and why these relative differences in catchability originated. It is also possible that the departure between trends of commercial CPUE in areas 2B and 2C my be reflecting actual changes in relative density. Recent observations indicate that departures in the CPUE indexes between Areas 2B and 2C may have been a short term phenomenon (Figure 2).

The exploitable biomass estimates are currently calculated using closed area runs, whereby the biomass is estimated independently for each area. Independent estimates of catchability are also calculated for each area under this approach, making any area specific catchability correction factor redundant and inappropriate. While the IPHC staff will continue to monitor these data, there appears to be no reason to continue to apply the area specific 25% catchability correction. Thus, the catchability correction factors have been removed from the exploitable biomass computations.

Gear Adjustments The shift from J-hook to Circle-hook and shifts between snap gear and fixed gear can cause apparent shifts in halibut catchability. More generally, catchability may be viewed broadly as resulting from changes in gear efficiency or targeting, changes in fish availability or behavior, or some combination of factors. The influence of CPUE statistics on recent IPHC catch-at-age analyses suggests that changes are occurring in the fishery which represent themselves as changes in the estimates of catchability (Parma 1992). Some shifts in catchability are easier to track, such as those pertaining to clear shifts in gear choice. Others are not so easy to track, such as those relating to the fleet behavior or the behavior of the stock.

The ideal situation for measuring an effect is when gear changes occur gradually over time so that parallel series of CPUE observations may be obtained with the two gear types.

In situations where that is not the case, two approaches may be used to take changes in catchability into account: 1) conduct an experiment where CPUE is measured with and without the gear change and use the measured difference as a factor to adjust one data set to the other's standard, or 2) explicitly model the change and let the effect be estimated simultaneously with other factors.

There are advantages and disadvantages to both approaches. The first is useful when the change is new, or has occurred only over a limited time period, but the estimate is usually restricted in its scope being based on a limited number and variety of observations. The second better reflects the nature of the fishery if the model assumptions are correct, but requires that an extended series of observations be available for robust estimation.

Given that the time series of data available since the conversion to Circle-hook is relatively long, given that data for snap *and* fixed gear are currently available back to 1983, and given the changes that have occurred in catchability estimates over a series of years, it seems reasonable to apply the second approach and try to model and explicitly estimate the change in catchability by creating two catchability groups, one for the years 1974-1982 and another for the years 1983-1991.

The modification is implemented as follows. CPUE is adjusted to reflect the Circle-hook standard using the factor given above and is adjusted for hook spacing (Sullivan 1991b). No other adjustment is made to CPUE, so that the CPUE values reflect the actual average CPUE observed in the fishery in a given year adjusted for hook spacing and to Circle-hook standard units. A break is made in 1983, and catchability is estimated for each time period, to accommodate the shift from J-hooks to Circle-hooks.

The conversion from J-hook to Circle-hook was an abrupt occurrence in the fishery, so a parallel series of J-hook and Circle-hook CPUEs does not exist. Consequently, differences in the estimates of catchability between the two time periods may thus reflect trends in the fishery other than those specifically related to the change in hook type.

If time permits, snap and fixed gear data back to 1983 will also be incorporated into the assessment, with estimates of catchability, selectivity, and fishing mortality made independently for each gear type and time period. The same age-composition data will be used for both the snap and fixed hook gear, and selectivity will be assumed constant over the entire time series for all gear types. If the snap-fixed gear modification to the analysis takes place this year it will be discussed in the technical supplement to the population assessment section in this document (Sullivan and Vienneau 1991).

Effects of Modifications in the Procedures on Biomass Estimates

To examine the effects that the modifications have on the exploitable biomass estimates, the CAGEAN analysis was applied to the 1974-1990 data with these changes incorporated. Figures 3 through 8 indicate these effects for each area starting with the catch corrections, then applying the new average weight corrections and removing the 10% weight adjustment, then removing the 25% catchability adjustment, and finally by allowing two catchability groups (1974-1982, 1983-1991). Each biomass estimate shows the cumulative effects of each adjustment so that contrasting the original with the estimate representing the two catchability time periods shows the total effect resulting from all the adjustments.

We now discuss why the modifications have produced the effects observed. The catch corrections had the biggest effect on Areas 3B and 4. Basically catch was shifted from Area 3B to Area 4, due to the boundary shift. (Note that the boundary definition played no role in the 'assessment' prior to last year because Areas 3B and 4 were pooled and correct CPUE was used to partition the quota.) Thus, catch went down in 3B and up in 4 (as seen by CAGEAN) and consequently the estimated biomass went down in 3B and up in 4.

The effect that the weight modifications have on the biomass estimates is more recondite. The first thing to note is that core of the CAGEAN procedure uses catch in numbers to estimate abundance in numbers. Average weight is used at the beginning of the analysis to change catch in biomass to catch in numbers. Average weight is used again at the end of the analysis to change abundance in numbers to stock biomass. The average weight used in the beginning has more of an influence on the estimates than that used at the end because it affects catch numbers which get accumulated and have a nonlinear effect on the abundance estimates. The average weight used at the end has only a linear effect. So the problem is best addressed in terms of how average weight affects catch in numbers. The second point to note is that both corrections are applied differentially over time. The 10% correction is applied from 1978 on in the 1974-1990 series while the new weight corrections, while applied to the entire series, are different in value for the years 1974-1984 in contrast to the years 1985-1990.

Consider the new weight factors used in Areas 3A, 3B, and 4. The correction adjusts average weight to be higher prior to 1984 and lower after 1984. Consequently, catch in numbers decreases prior to 1984 and increases after 1984. The net effect is a shift to a greater catch rate over time leading to an increase in the corresponding abundance. The pattern is similar but less pronounced for Area 2C and shows no change in the early years and a relative decrease in later year in 2A and 2B. The later is caused by having virtually no change in the initial catch in numbers with an increase in later catch.

Now consider the removal of the 10% adjustment factor. Removing the adjustment causes catch in numbers to increase after 1977 by 10%. Thus, the effect of this adjustment factor is of the same magnitude and in the same direction as that just discussed for the new average weight values. The 10% factor appeared to be valid at the time it was incorporated, but the weights appear to have changed again in the opposite direction in recent years. Removing the 10% adjustment factor will not change catch numbers initially (i.e. years 1974-1977), but will increase numbers later for all age groups, thus increasing the apparent catch rate, leading to a larger biomass estimate.

To briefly summarize the weight modifications, it was initially believed that using the new calculated average weights and removing the 10% adjustment factor would provide a better set of estimates but that the net effect of the changes would balance each other out. As it turned out, both modifications caused an effect in the same direction, thus increasing the biomass estimates (as shown in Figures 3 through 8).

The removal of the 25% catchability correction has a similar effect to that shown above for the weight factors. Again, since this 25% adjustment was applied to just one part of the series, this caused a shift in the effort time series. There would have been no effect on the biomass estimates if these factors had been applied uniformly over the entire time series. The net effect is fairly clear, CPUE will increase by 25% in Areas 2C, 3A, and 3B and decrease by 25% in Areas 2A and 2B, and the biomass estimates will change by roughly the same magnitude and in the same direction in these areas.

The last modification to be discussed is the modeling of two separate catchability groups. Between 1982 and 1984 the halibut fleet changed almost entirely from J-hooks to Circle-hooks. So it seems natural to model this break explicitly by estimating two catchability parameters for the different time periods. However, the implications of this change go beyond the difference in catchability of the two hook types. Even with the 0.45 J-hook to Circle-hook adjustment factor included, a dual catchability group approach greatly alters the biomass estimates. Part of this difference is due to the model's attempt to account for apparent trends in catchability that are exhibited by the data (Deriso et al. 1983, Parma 1992). Effort residuals in Area 3A suggest that 1979-1980 might be a more appropriate break point, while a contrast in CPUE between 2B and 2C suggests 1980-1981 might be considered (Deriso et al. 1983). We found that, despite the significant change that having two catchability groups has on the response of the CAGEAN estimates, the modified estimates were fairly robust to the choice of break points in the range 1979-1983. This, the timing of the J-hook–Circle-hook transition, and an attempt to implement both snap gear with fixed hook gear (which data is currently available for back to 1983), suggests to us that the 1982-1983 breakpoint is (at present) the most appropriate.

The cumulative effect shows a net increase in exploitable biomass in Areas 2C, 3A, and 4, no net change in Area 3B, and a decrease in exploitable biomass in Areas 2A and 2B.

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1991 STOCK ASSESSMENT

Programs & Data Relationships

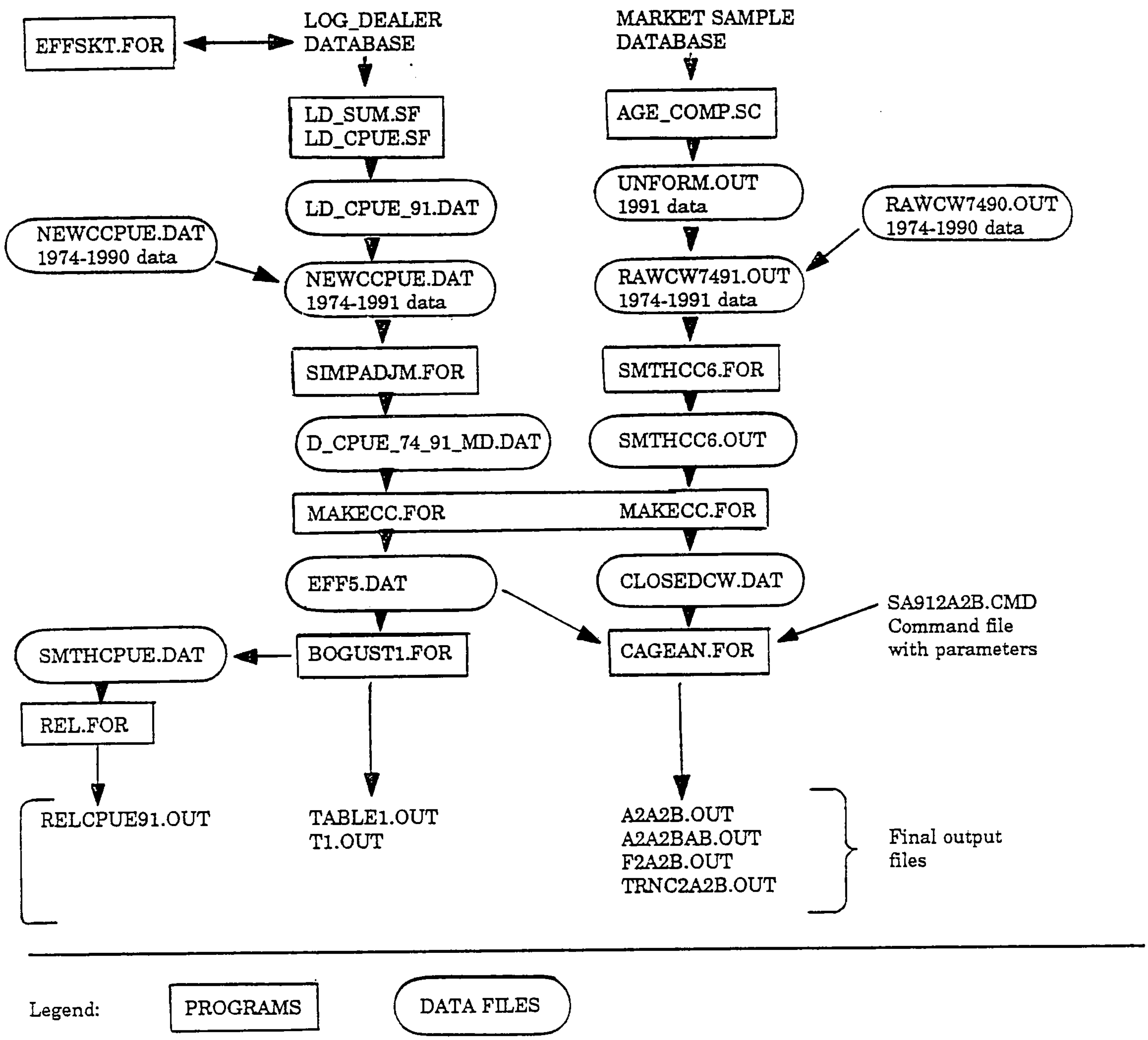

Figure 1: Schematic diagram showing the passage of effort data, catch data, and average weight at age data through the series of programs used for computing the stock assessment.

CPUE Area 2B and 2C

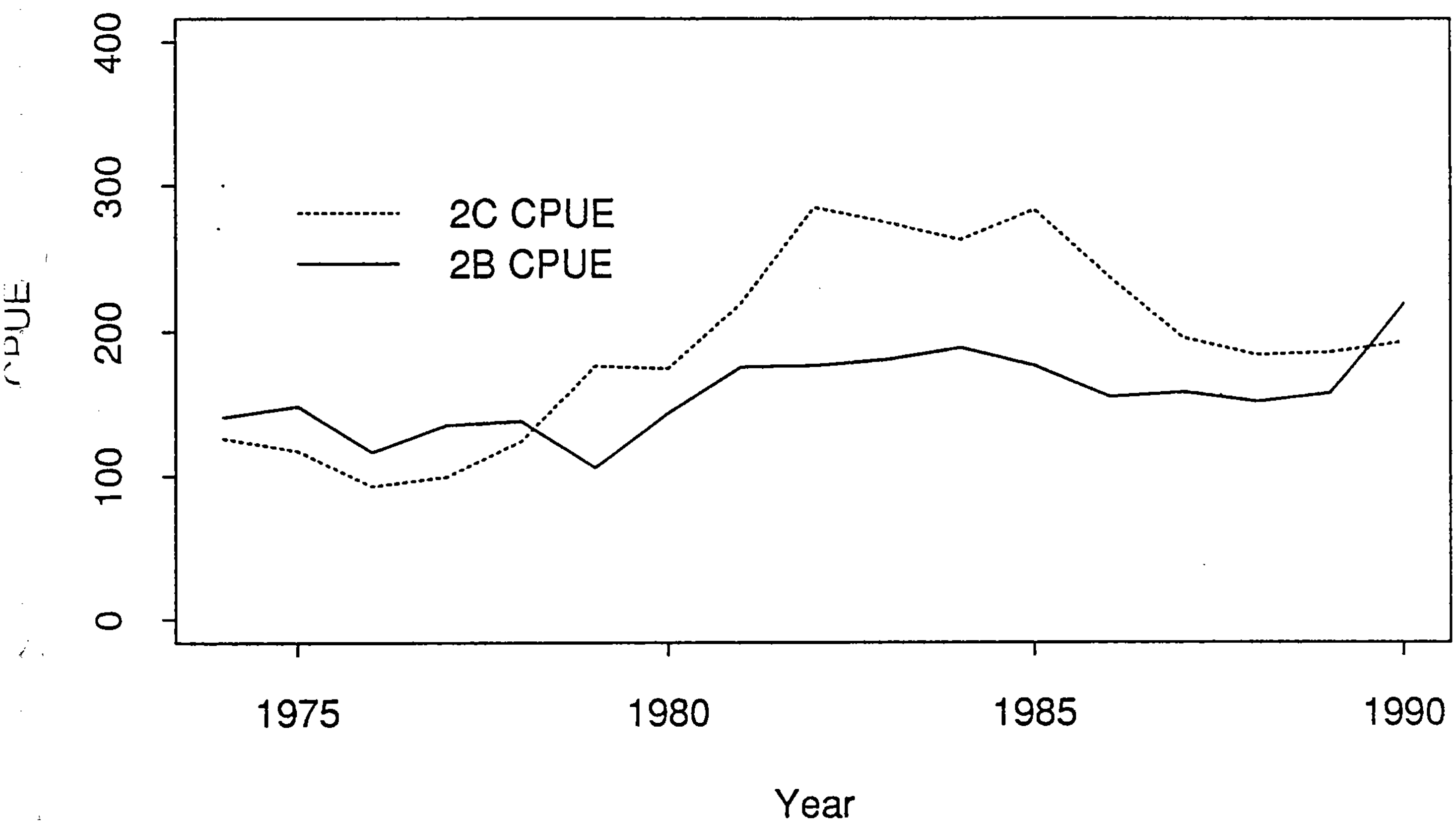

Figure 2

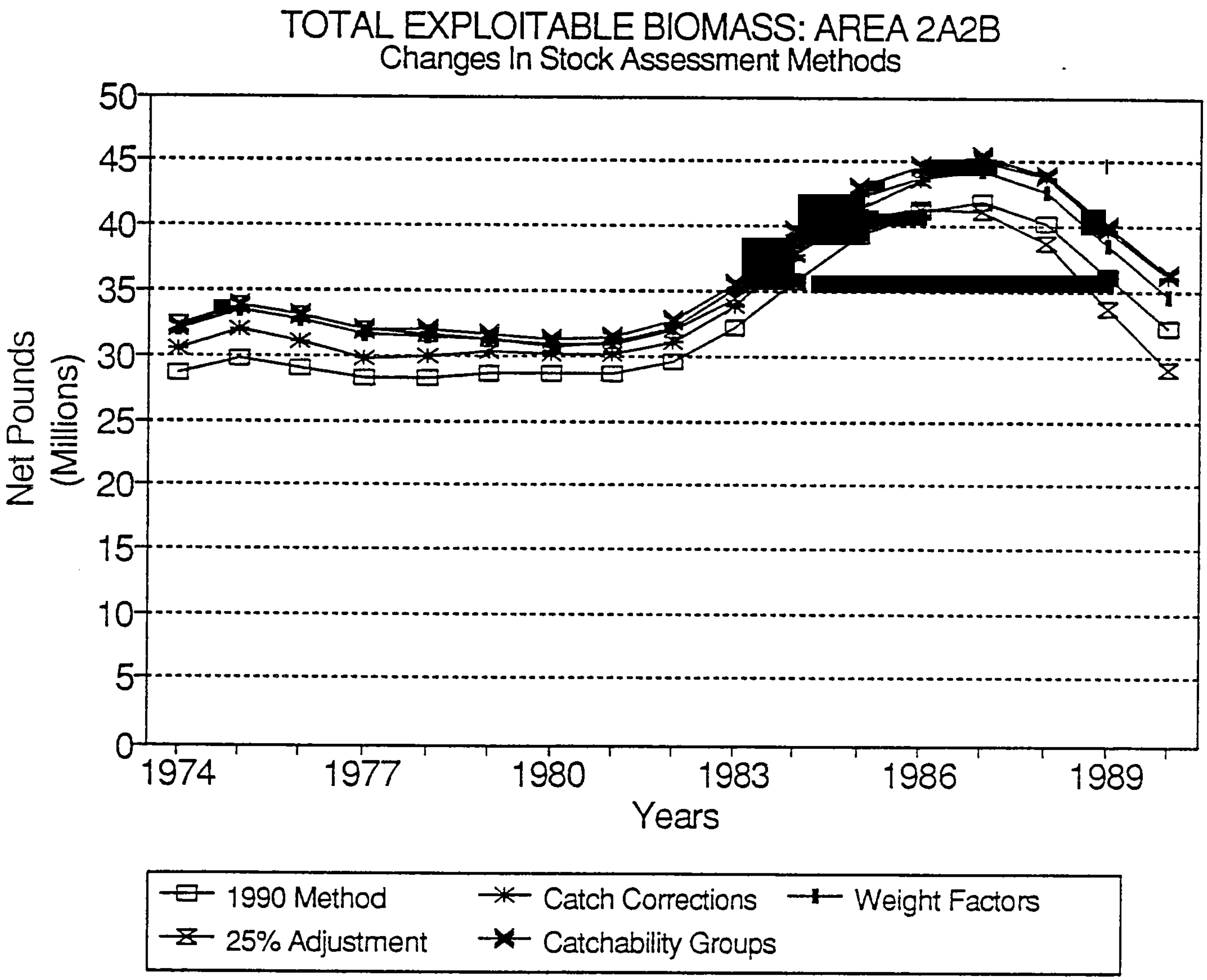

Figure 3: Total exploitable biomass for regulatory area 2A and 2B combined showing the cummulative effects from changes in the method of computing stock assessment. Changes were applied to data on catch at age, average weight at age, and effort as well as parameters to the CAGEAN program. Order of changes were: 1) catch correction; 2) weight factors; 3) 25% adjustment; 4) catchability groups.

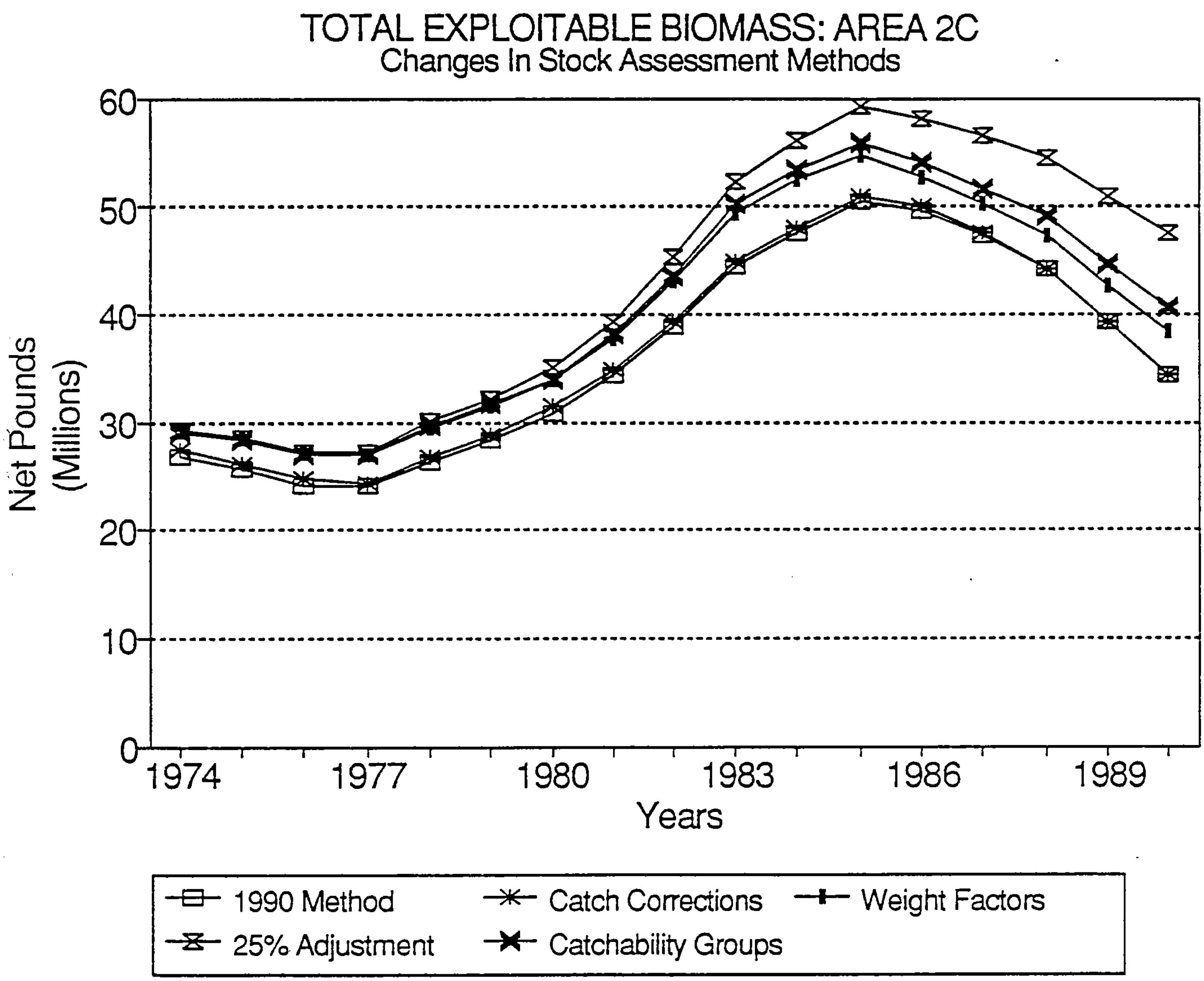

Figure 4: Total exploitable biomass for regulatory area 2C showing the cummulative effects from changes in the method of computing stock assessment. Changes were applied to data on catch at age, average weight at age, and effort as well as parameters to the CAGEAN program. Order of changes were: 1) catch correction; 2) weight factors; 3) 25% adjustment; 4) catchability groups.

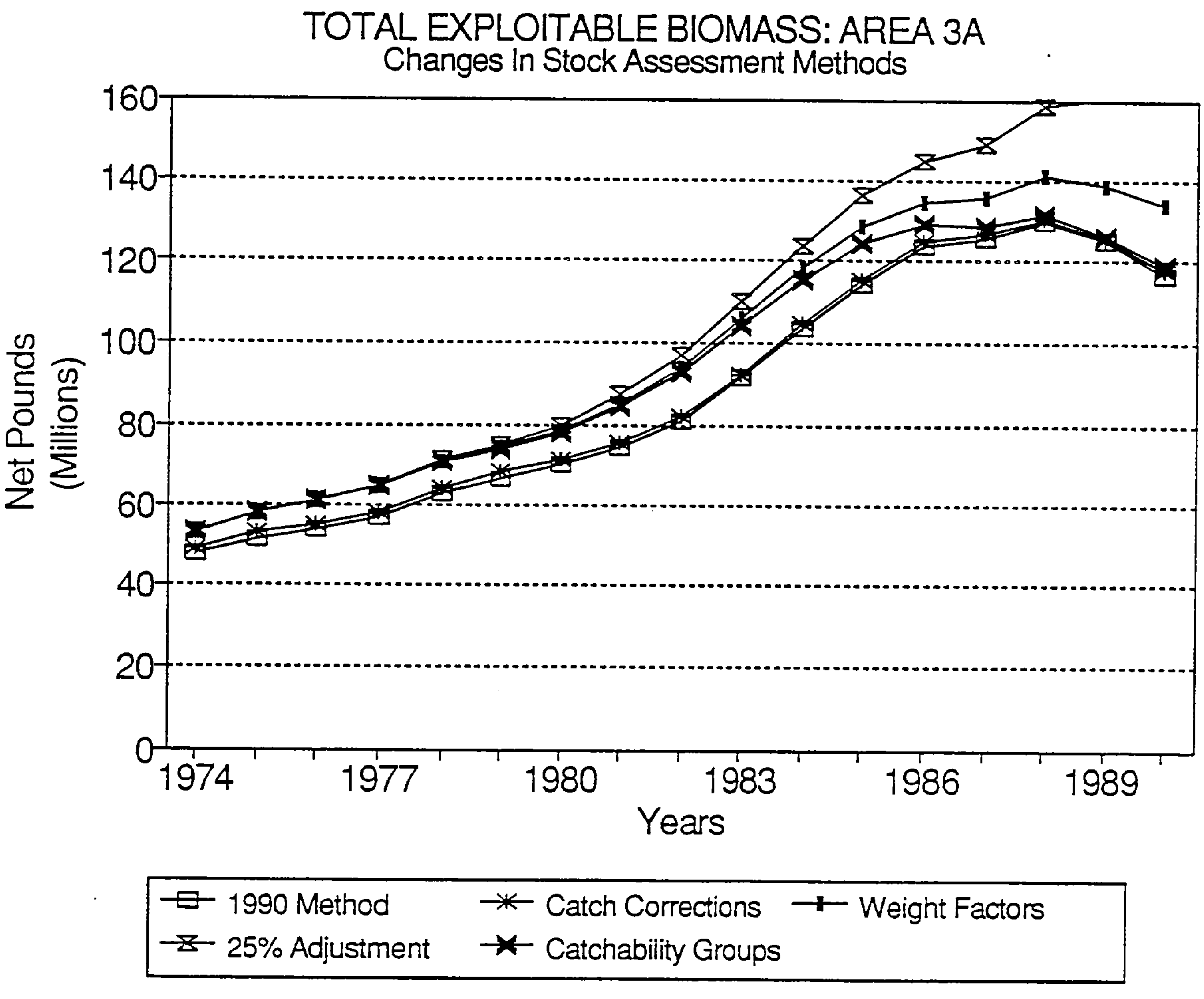

Figure 5: Total exploitable biomass for regulatory area 3A showing the cummulative effects from changes in the method of computing stock assessment. Changes were applied to data on catch at age, average weight at age, and effort as well as parameters to the CAGEAN program. Order of changes were: 1) catch correction; 2) weight factors; 3) 25% adjustment; 4) catchability groups.

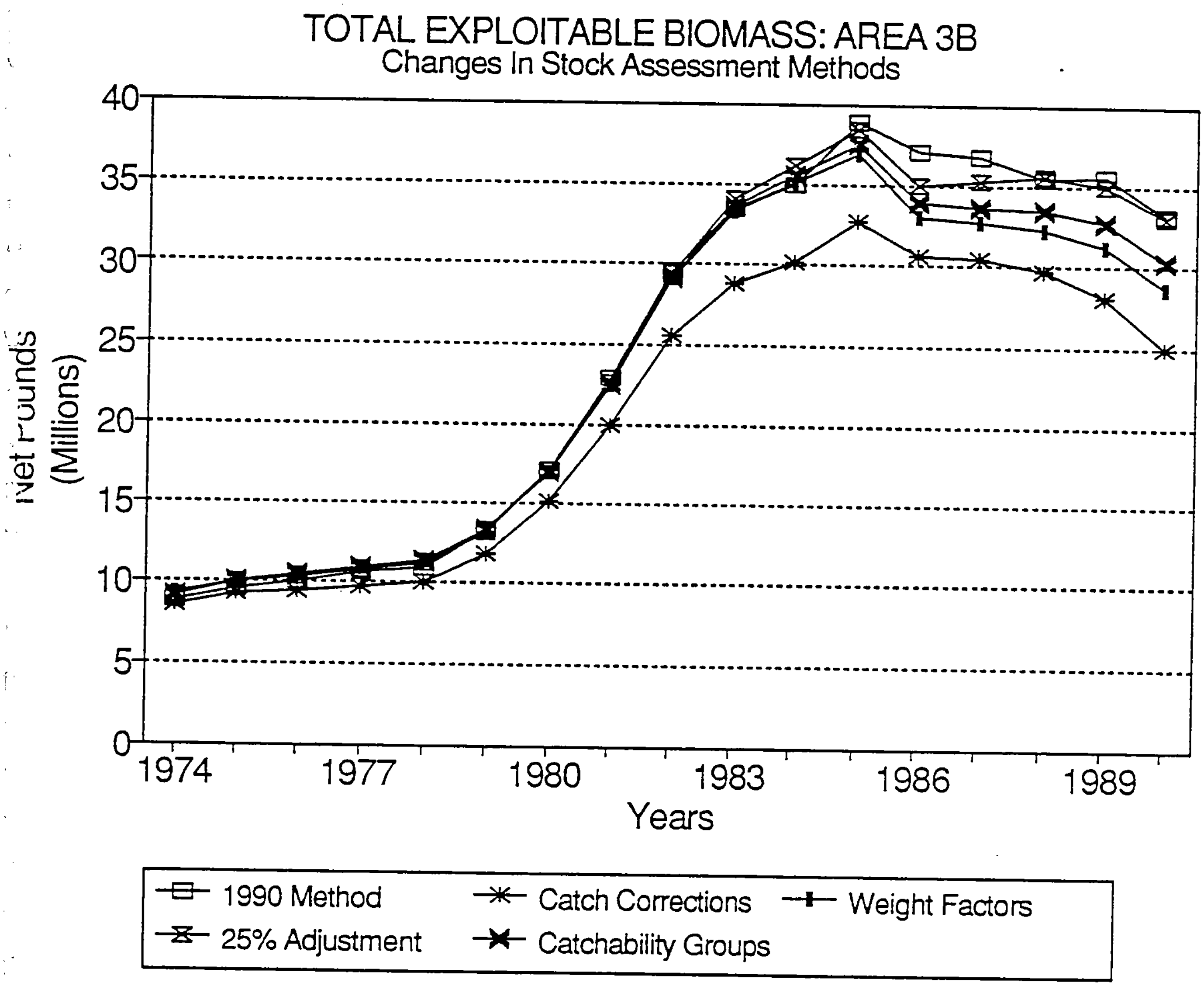

Figure 6: Total exploitable biomass for regulatory area 3B showing the cummulative effects from changes in the method of computing stock assessment. Changes were applied to data on catch at age, average weight at age, and effort as well as parameters to the CAGEAN program. Order of changes were: 1) catch correction; 2) weight factors; 3) 25% adjustment; 4) catchability groups.

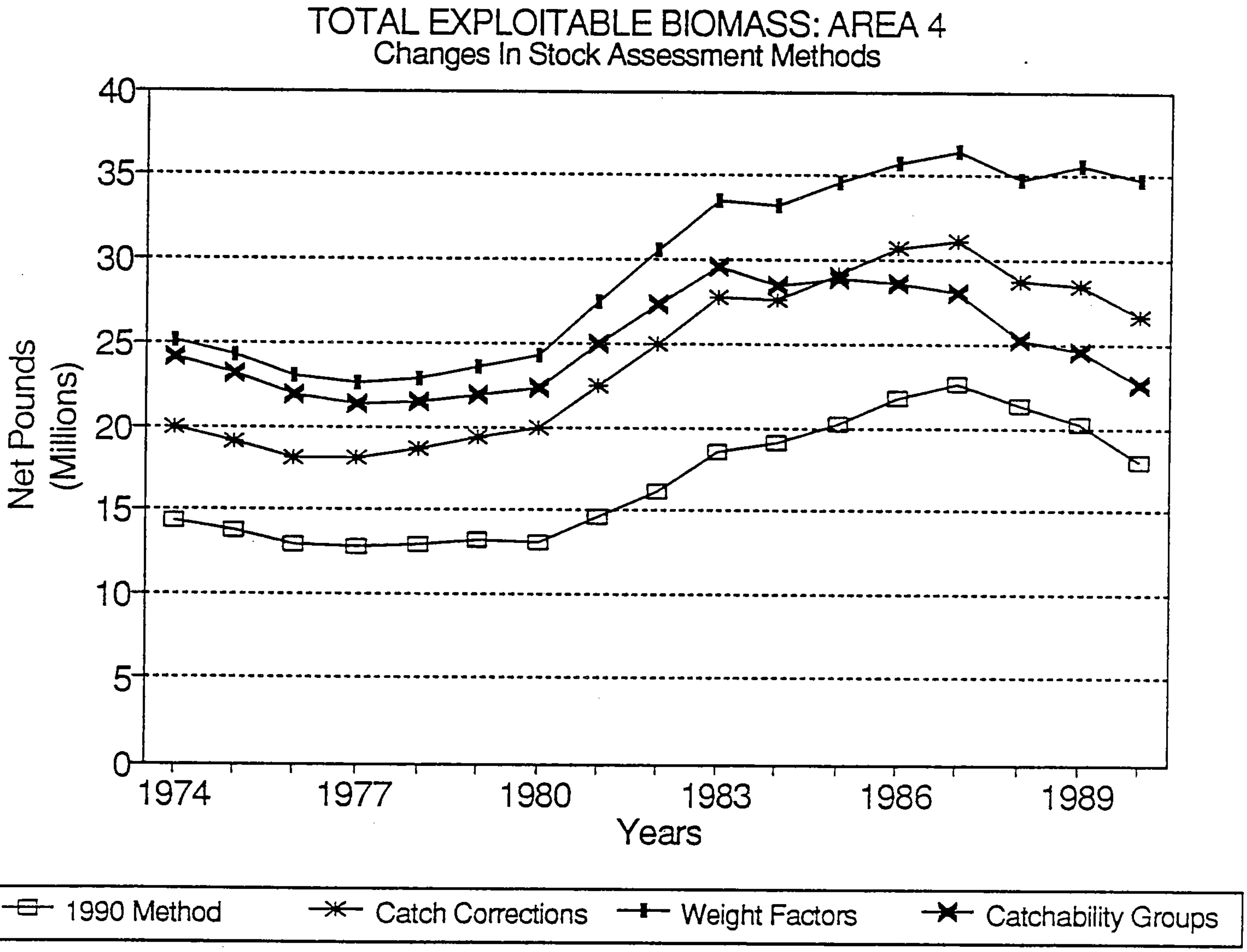

Figure 7: Total exploitable biomass for regulatory area 4 showing the cummulative effects from changes in the method of computing stock assessment. Changes were applied to data on catch at age, average weight at age, and effort as well as parameters to the CAGEAN program. Order of changes were: 1) catch correction; 2) weight factors; 3) catchability groups. Note that the 25% adjustment to catchability did not apply to regulatory area 4.

Table 1. Correction factors applied to present mean weights at age to approximate effect of new estimator.

Age	Area 2B		Area 2C		Area 3 and 4	
	≤ 1984	> 1984	≤ 1984	> 1984	≤ 1984	> 1984
8	1.10	1.01	1.15	1.07	1.07	0.85
9	1.05	0.94	1.11	1.04	1.06	0.83
10	1.00	0.92	1.09	1.01	1.06	0.85
11	0.99	0.91	1.09	1.00	1.06	0.87
12	0.99	0.91	1.10	1.01	1.06	0.88
13	0.98	0.92	1.10	1.01	1.07	0.91
14	0.98	0.91	1.11	1.01	1.07	0.93
15	0.98	0.92	1.12	1.01	1.07	0.95
16	0.98	0.93	1.13	1.02	1.07	0.95
17+	0.98	0.95	1.15	1.02	1.09	1.05

POPULATION ASSESSMENT, 1990

by

Patrick J. Sullivan

Introduction

The Pacific halibut stock assessment for 1990 is an area by area catch-at-age analysis applied to data from Areas 2A-2B, 2C, 3A, 3B, and 4. It uses information compiled from catch, catch per unit effort (CPUE), age composition and average weight data to determine the exploitable biomass; the stock biomass available for harvest. Once the exploitable biomass has been estimated then the constant exploitation yield (CEY) is determined as a fraction of this estimate. Based on an optimal exploitation rate of 0.35, this yield represents a little over a third of the exploitable biomass. The recommended allowable catch is finally determined by accounting for the removals from other sources (sport catch, wastage, and bycatch). This procedure is outlined in Figure 1.

Stock Assessment

Results from the stock assessment indicate that the total exploitable biomass of Pacific halibut in 1990 is 234.7 million pounds. This represents a decline in biomass this year of 8%, a higher rate than the 5-6% decline observed in previous years. Figure 2 shows the trends in exploitable biomass for the total stock. Figures 3 through 8 give the area-by-area trends in exploitable biomass, recruitment, and CPUE. Declines in exploitable biomass range from highs of 11-12% per year in areas 2B, 2C, and 4 to a 6-7% decline in areas 3A and 3B. Area 2A shows a slight increase due to the higher CPUE observed in that area this year. The exploitation rates shown in the figures are setline exploitation rates, that is the commercial setline catch divided by the area's exploitable biomass. The total exploitation rates include the harvest from other sources (sport, waste, and bycatch) in addition to the commercial setline catch.

Recruitment has dropped off dramatically again this year in all areas. This observation is consistent with cyclical patterns of recruitment that have occurred over the last 30 years. This year's thirteen-year-old year class, which recruited strongly as eight-year-olds in 1985 (Figures 2 through 8) is contributing less and less to the current fishery in terms of yield. The lower recruitment shown in later years indicates that the stock will continue its decline at a rate of about 5-10% per year over the next several years.

The overall commercial CPUE has declined from last year, although higher CPUE's can be noted in the southern areas 2A, 2B, and 2C.

One should also note that in addition to estimating this year's stock levels previous year's could vary by area. This is a complicated question that may require an extended analysis depending on the preliminary results.

REPORT OF COMMISSION ACTIVITIES

Population Assessment, 1990

by

Patrick J. Sullivan

Introduction

The Pacific halibut stock assessment for 1990 is an area by area catch-at-age analysis applied to data from Areas 2A-2B, 2C, 3A, 3B, and 4. It uses information compiled from catch, CPUE, age composition and average weight data to determine the exploitable biomass; the stock biomass available for harvest. Once the exploitable biomass has been estimated then the constant exploitation yield (CEY) is determined as a fraction of this estimate. Based on an optimal exploitation rate of 0.35, this yield represents a little over a third of the exploitable biomass. The recommended allowable catch is finally determined by accounting for the removals from other sources (sport catch, wastage, and bycatch). This procedure is outlined in Figure 1.

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The overall commercial CPUE has declined from last year, although higher CPUE's can be noted in the southern areas 2A, 2B, and 2C.

Sullivan, P.J., 1991. Population assessment, 1990.
IPHkC Rep., pp. 1–14.

One should also note that in addition to estimating this year's stock levels previous year's stock levels are re-estimated using updated information. Changes in the level of bycatch, waste, and sport catch coupled with the inherent variability observed in the stock dynamics and the measurement process may result in adjustments to previous abundance estimates. This may cause the allowable catch to go up in some areas where stock abundance indicates a decline, as can be seen this year in the estimates for Areas 3B and 4. The recommended allowable catch estimates are always based on the most current available information.

Recommended Allowable Catch

The results from the stock assessment are used in determining the recommended allowable catch. The constant exploitation yields for the 1990 stock assessment are shown in Table 1 along with the 1990 catch and quota. The overall CEY is obtained by multiplying the area specific exploitable biomass by the constant exploitation yield ratio of 0.35. Once the exploitation rate is applied equally to all areas the biomass removal from other sources is subtracted out to determine the allowable setline catch. The recommended setline allowable catch levels indicate the harvest that should be taken by the setline commercial fishery in order to maintain optimal yields and viability of the stock.

Bycatch

Adjustments to the allowable catch for bycatch represent compensation to the stock for losses in the stock's reproductive potential due to losses from bycatch. The allowable catch is reduced in line 1.4 of Table 1 by one pound for every pound of bycatch removed.

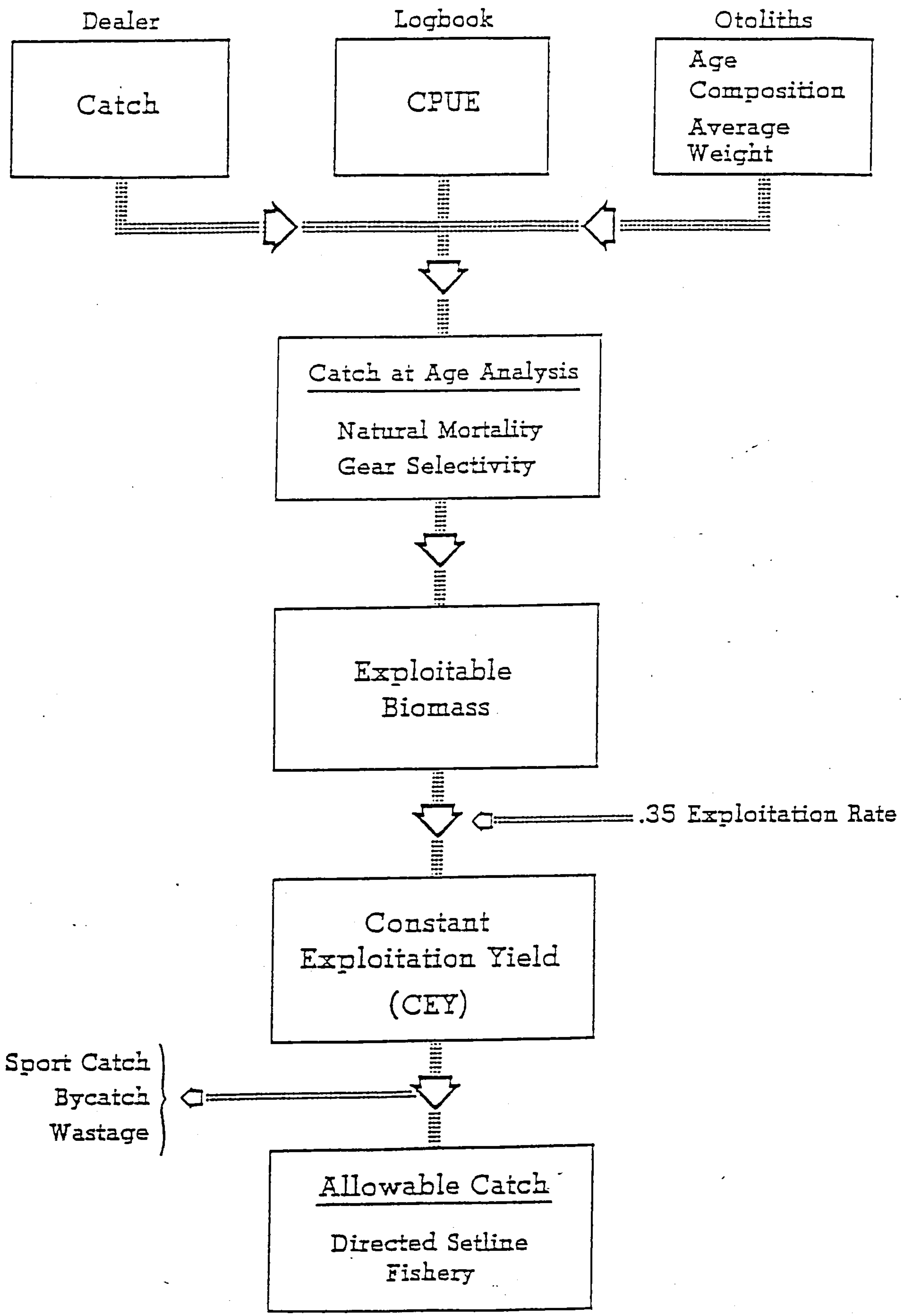
Table 1. 1990 Assessment of Yield

		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1990 Quota	0.52*	7.80	8.00	31.00	7.20	4.10	58.62
	1990 Catch	0.53*	8.50	9.80	29.00	8.10	5.48	61.41
1.2	CEY	0.58	10.64	12.04	40.99	11.61	6.28	82.15
1.3	OTHER CATCHES							
	Sport	— *	0.66	1.71	3.63	0.00	0.02	6.02
	Waste	0.01	0.34	0.35	2.06	0.38	0.23	3.37
	Bycatch	0.12	2.25	2.55	8.68	2.46	1.33	17.40
	TOTAL	0.13	3.25	4.61	14.37	2.84	1.58	26.79
1.4	SETLINE CEY	0.45*	7.39	7.42	26.62	8.77	4.70	55.36

Estimates in million pounds by subarea.

* Sport catch included for area 2A.

IPHC Stock Assessment



Sullivan, P.J., 1991. Population assessment, 1990.
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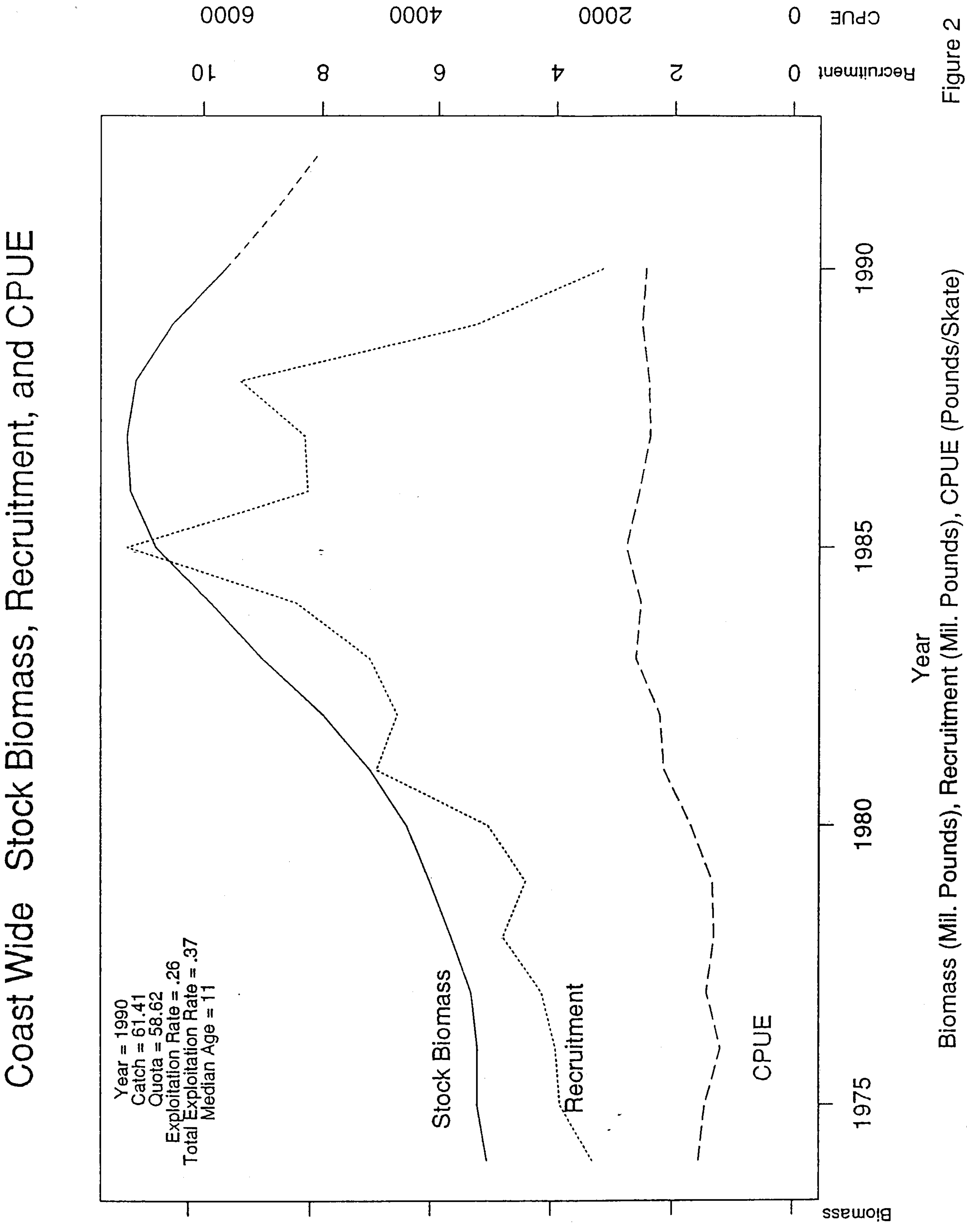
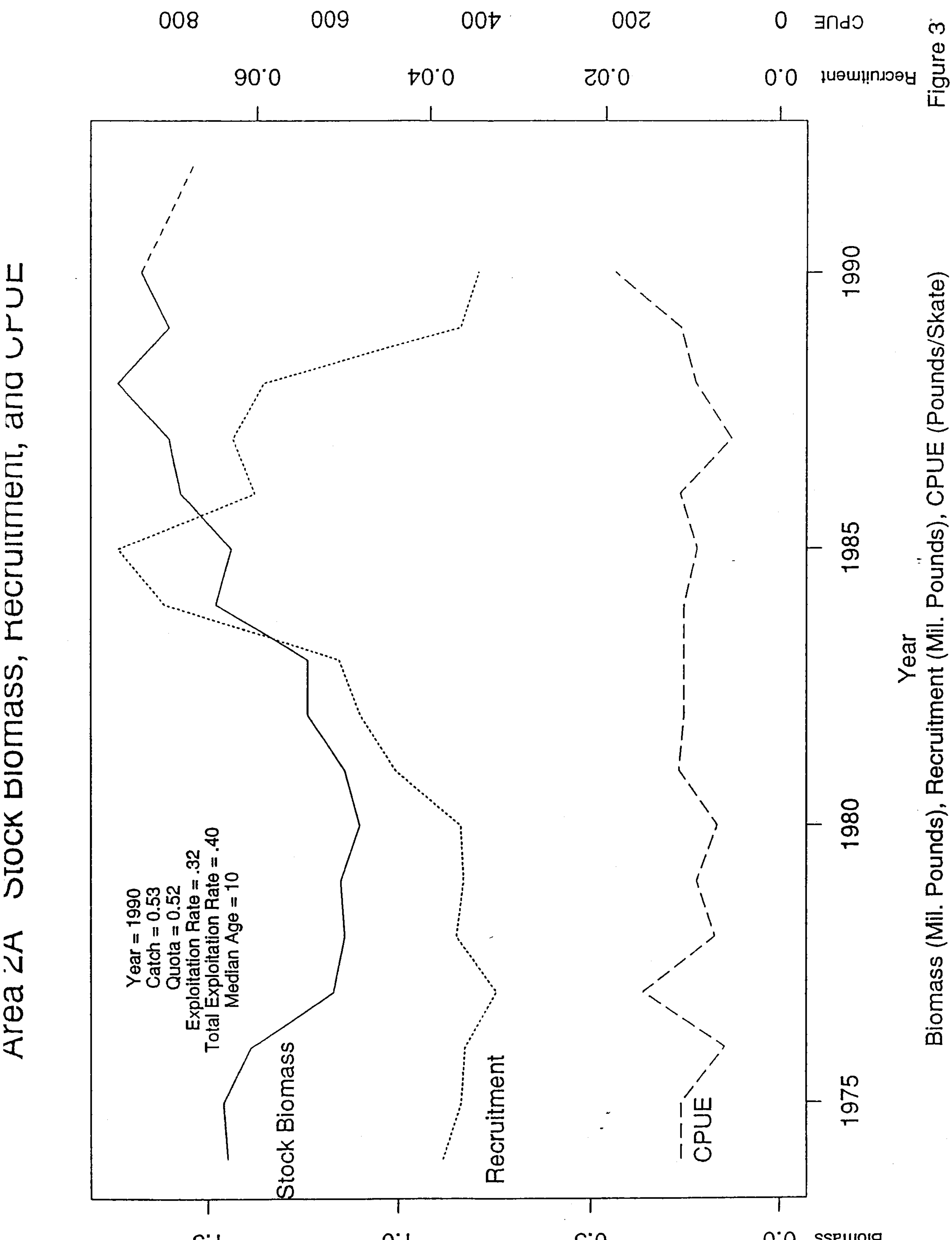
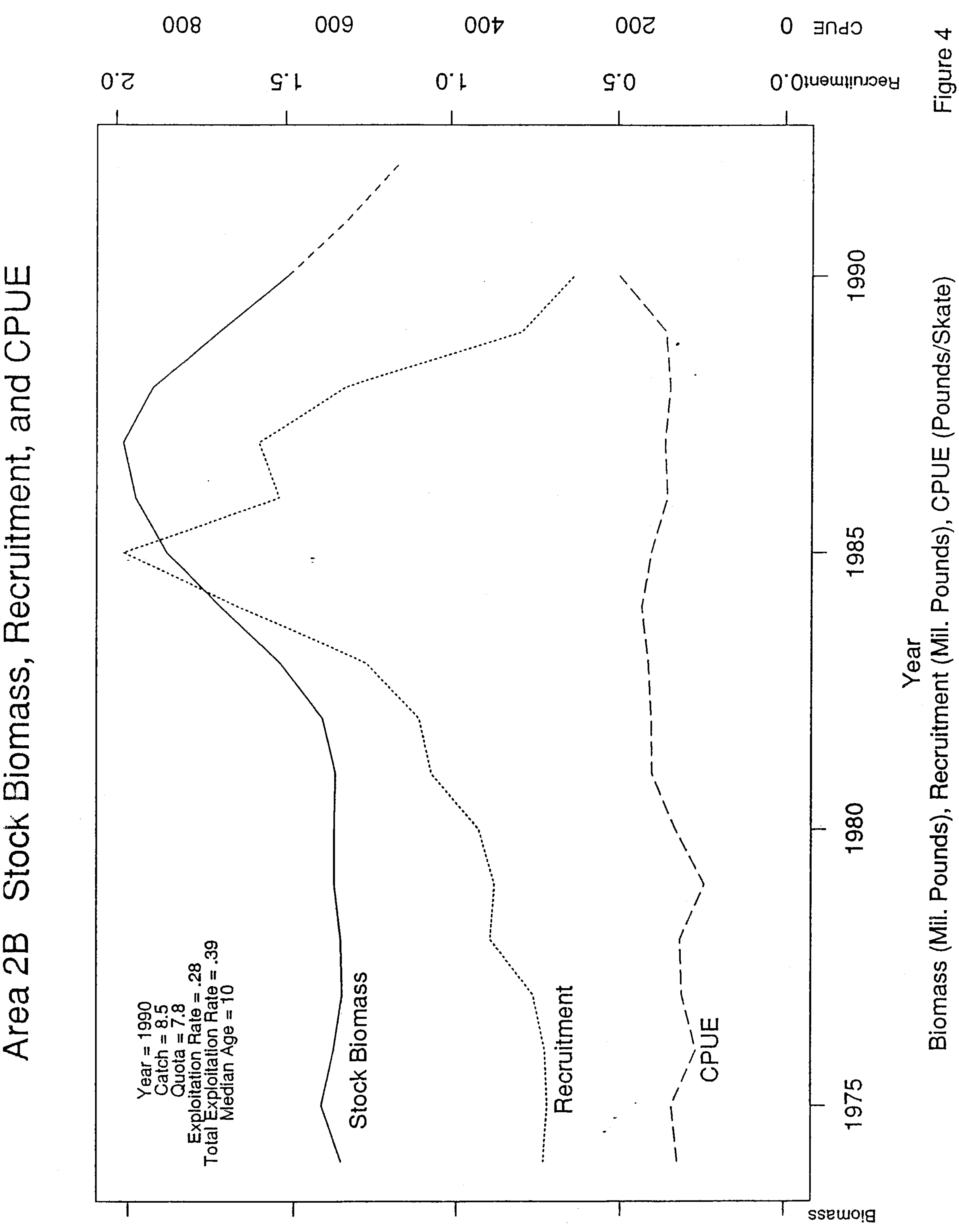
Figure 1



Coast Wide Stock Biomass, Recruitment, and CPUE
Figure 2
Year = 1990
Catch = 61.41
Quota = 58.62
Exploitation Rate = .26
Total Exploitation Rate = .37
Median Age = 11
Stock Biomass
Recruitment
CPUE
Year
Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)
1975
1980
1985
1990
Biomass
0
50
100
150
200
250
Recruitment
0
2
4
6
8
10
CPUE
0
2000
4000
6000


Area 2A Stock Biomass, Recruitment, and CPUE
Figure 3
Year = 1990
Catch = 0.53
Quota = 0.52
Exploitation Rate = .32
Total Exploitation Rate = .40
Median Age = 10
Stock Biomass
Recruitment
CPUE
Year
Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)
Biomass
0.0
0.5
1.0
1.5
Recruitment
0.0
0.02
0.04
0.06
CPUE
0
200
400
600
800
1975
1980
1985
1990



Area 2B Stock Biomass, Recruitment, and CPUE
Figure 4
Year = 1990
Catch = 8.5
Quota = 7.8
Exploitation Rate = .28
Total Exploitation Rate = .39
Median Age = 10
Stock Biomass
Recruitment
CPUE
Year
Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)
1975
1980
1985
1990
Biomass
0
10
20
30
40
Recruitment
0.0
0.5
1.0
1.5
2.0
CPUE
0
200
400
600
800

Area 2C Stock Biomass, Recruitment, and CPUE

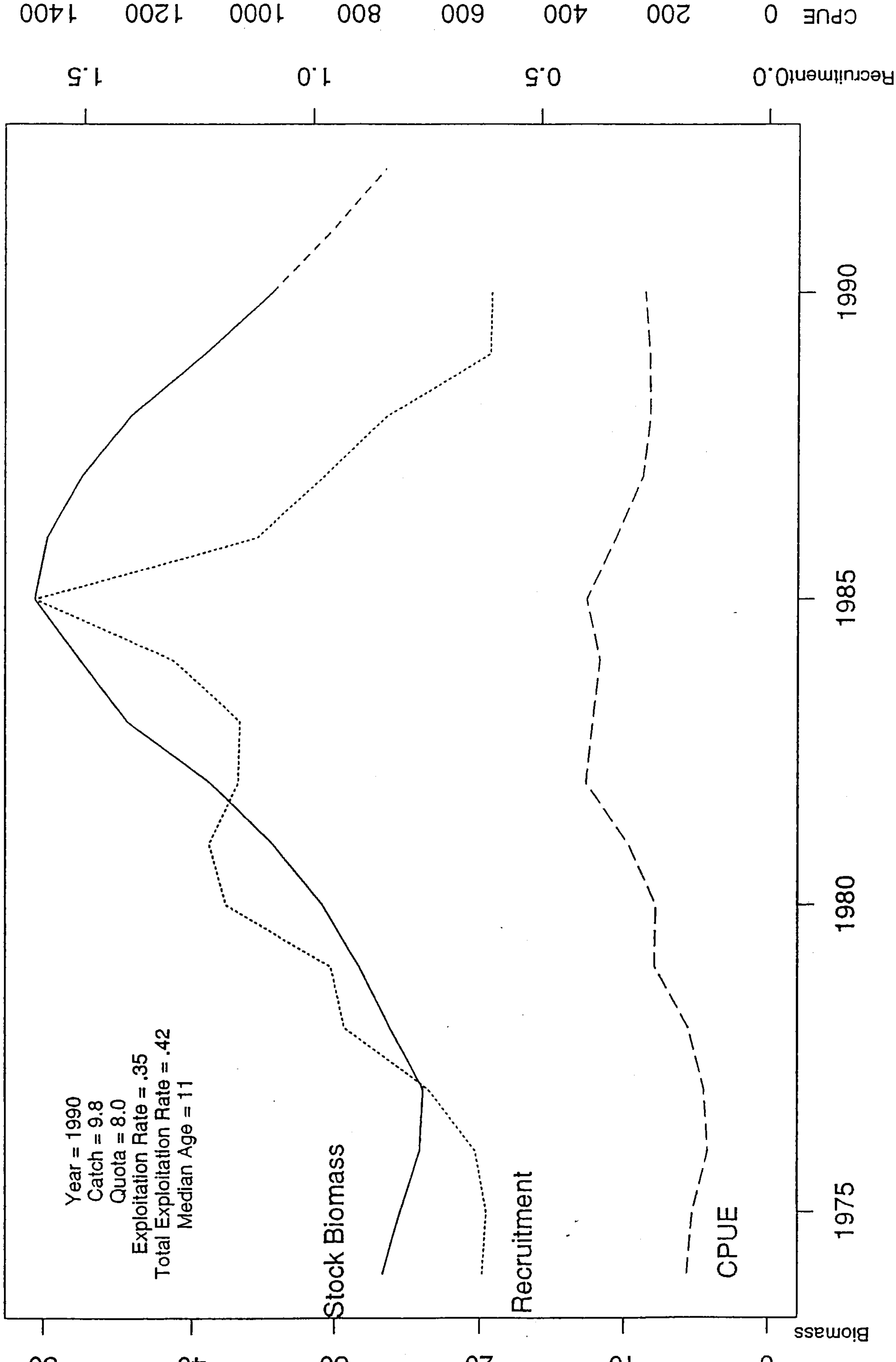
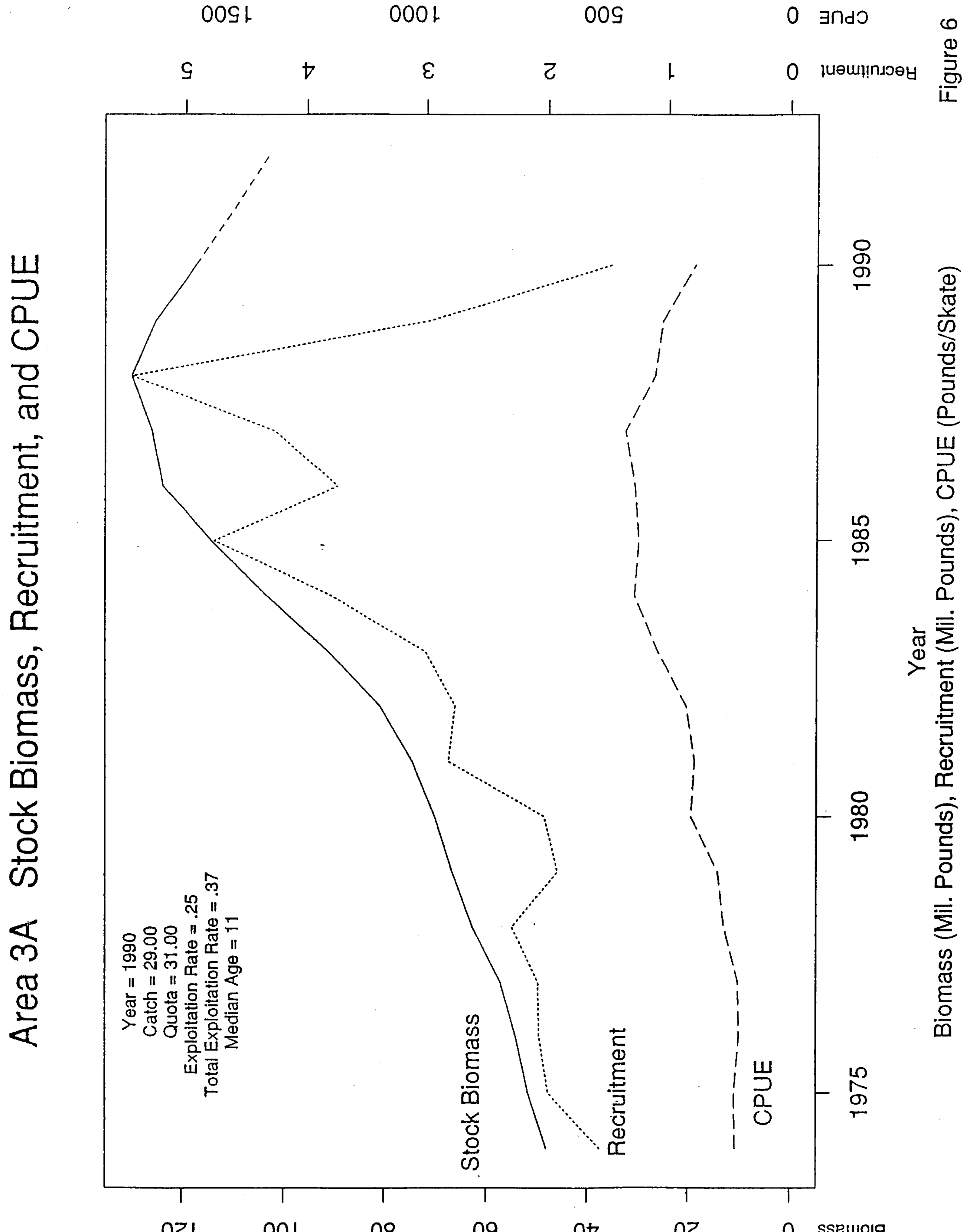
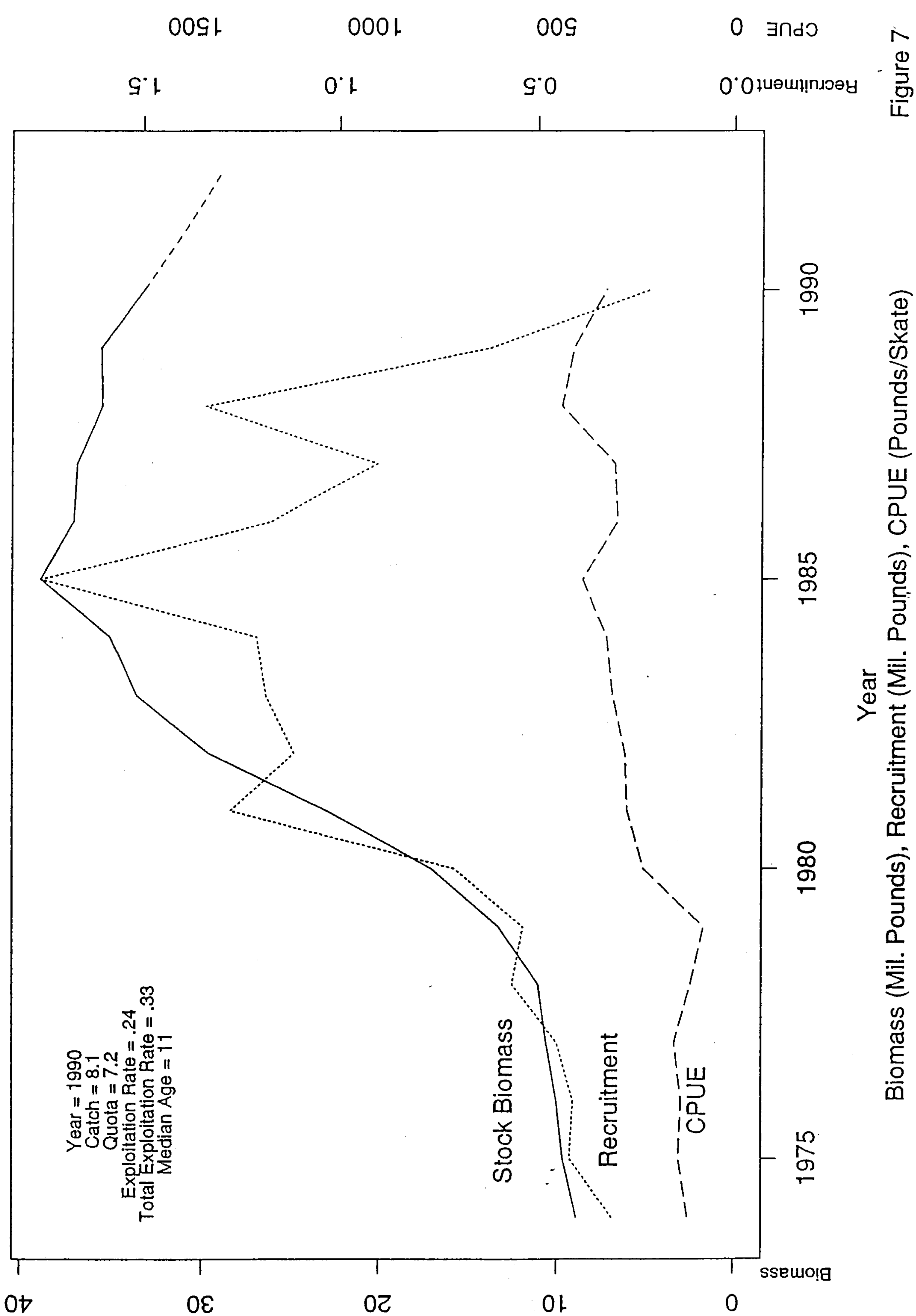


Figure 5

Sullivan, P.J., 1991. Population assessment, 1990. IPHkC Rep., pp. 1–14.


Area 3A Stock Biomass, Recruitment, and CPUE
Figure 6
Year = 1990
Catch = 29.00
Quota = 31.00
Exploitation Rate = .25
Total Exploitation Rate = .37
Median Age = 11
Stock Biomass
Recruitment
CPUE
Year
Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)
1975
1980
1985
1990
Biomass
0
20
40
60
80
100
120
Recruitment
0
1
2
3
4
5
CPUE
0
500
1000
1500



Year = 1990
Catch = 8.1
Quota = 7.2
Exploitation Rate = .24
Total Exploitation Rate = .33
Median Age = 11
Stock Biomass
Recruitment
CPUE
1975
1980
1985
1990
Year
Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)
Biomass
0
10
20
30
40
Recruitment 0.0
0.5
1.0
1.5
CPUE 0
500
1000
1500

Figure 7

Area 4 Stock Biomass, Recruitment, and CPUE

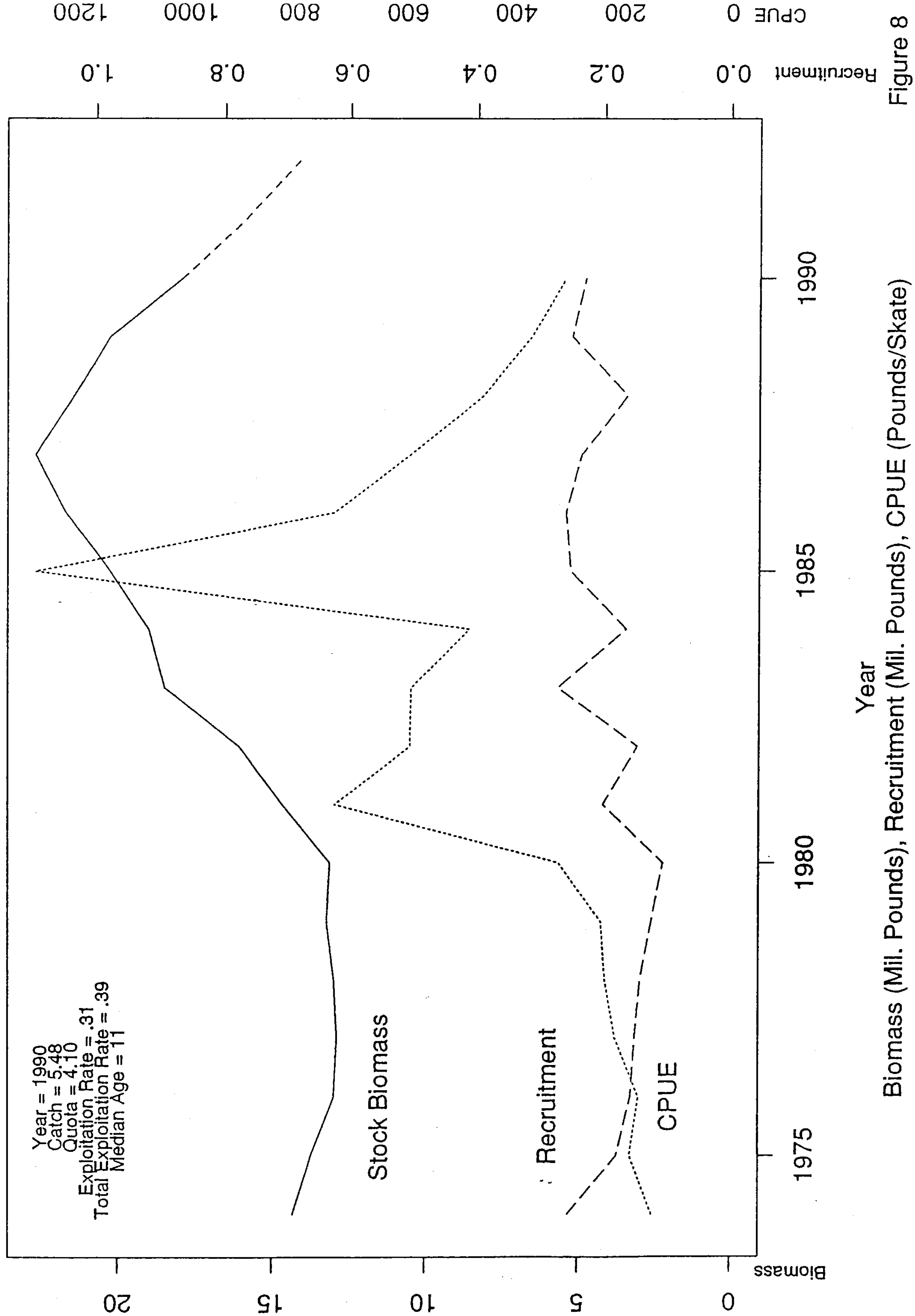


Figure 8

STOCK ASSESSMENT DOCUMENT IV

SECTION 1. POPULATION ASSESSMENT, 1989

by

Patrick J. Sullivan, Phillip R. Neal, and Bernard Vienneau

Introduction

The Pacific halibut stock assessment for 1989 is based on an area by area catch-at-age analysis. It uses information compiled from catch, CPUE, age composition and average weight data to determine the exploitable biomass: the stock biomass available for harvest. Once the exploitable biomass has been estimated then the constant exploitation yield (CEY) is determined as a fraction of this estimate. Based on an optimal exploitation rate of 0.35, this yield represents roughly a third of the exploitable biomass. The recommended allowable commercial catch is finally determined by accounting for the removals from other sources (sport catch, wastage, and bycatch). This procedure is outlined in Figure 1.

Stock Assessment

Results from the stock assessment indicate that the total exploitable biomass of Pacific halibut in 1989 is 232.9 million pounds. This represents a decline in biomass this year of 6%, a rate which is similar to the 5-6% decline observed in previous years. Figure 2 shows the trends in exploitable biomass for the total stock as well as for recruitment and CPUE. Figures 3 through 8 give the area-by-area trends. Declines in exploitable biomass range from highs of 15% per year in areas 2B and 2C to little or no decline in area 3A. These trends are consistent with the respectively higher and lower exploitation rates exhibited in these areas. The exploitation rates shown in the figures are setline exploitation rates, that is the commercial setline catch divided by the area's exploitable biomass. The total exploitation rates include the harvest from other sources (sport, waste, and bycatch) in addition to the commercial

Sullivan, P.J., Neal, P.R., Vienneau, B.A., 1990. Stock Assessment Document IV. Section 1: Population assessment, 1989. IPHC Rep., pp. 1–12.

setline catch.

Recruitment has dropped off dramatically this year in all areas. This observation is consistent with cyclical patterns of recruitment that have occurred over the last 50 years. This year's twelve-year-old year class continues to make up a large component of the catch. This class, which recruited as eight-year-olds in 1985 (see Figures 2 through 8) will continue to influence the catch for several more years. However, the lower recruitment shown in later years combined with exploitation above the recommended 0.35 level indicates that the stock will continue its decline at a rate of about 5-15% per year over the next several years.

While the overall commercial CPUE appears to have increased slightly from last year, significant drops can be noted in areas 3A and 3B.

Recommended Allowable Catch

The results from the stock assessment are used in determining the recommended allowable catch. The constant exploitation yields for the 1989 stock assessment are shown in Table 1(line 1.4) along with the 1989 catch and quota. The overall CEY (line 1.2) is obtained by multiplying the area specific exploitable biomass by the constant exploitation yield ratio of 0.35. Once the exploitation rate is applied equally to all areas the biomass removal from other sources (line 1.3) is subtracted out to determine the allowable setline catch. The recommended setline allowable catch levels indicate the harvest that should be taken by the setline commercial fishery in order to maintain optimal yields and viability of the stock.

Bycatch

The impact of bycatch on the allowable setline catch has been reviewed. Adjustments to the allowable catch for bycatch represent compensation to the stock for losses in the stock's reproductive potential due to losses from bycatch. New estimates of adult reproductive compensation have been developed that better reflect the impact to the fishery from bycatch. The result of this analysis is that the allowable catch is reduced in line 1.4 of Table 1 by one pound for every pound of bycatch removed. This is in contrast to the 1.58 conversion used previously.

Table 1. 1989 Assessment of Yield

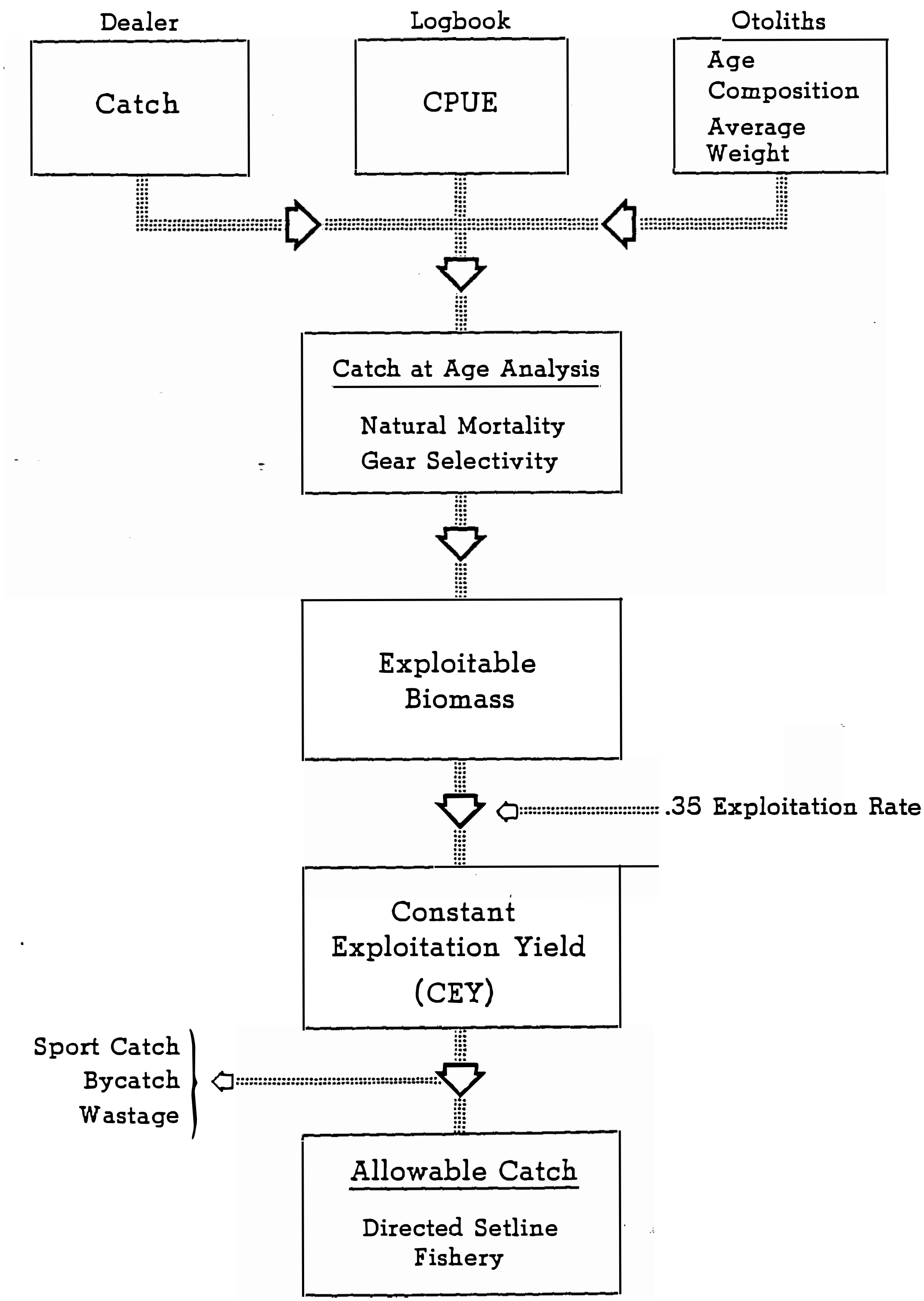
		AREA						
		2A	2B	2C	3A	3B	4	TOTAL
1.1	CATCH/QUOTA							
	1989 Quota	0.65*	10.00	9.50	31.00	8.50	5.00	64.65
	1989 Catch	0.78*	10.10	10.20	34.40	6.00	4.94	66.42
1.2	CEY	0.52*	10.41	11.50	46.48	8.08	4.52	81.53
1.3	OTHER CATCHES							
	Sport	— *	0.56	1.18	3.67	0.00	0.02	5.43
	Waste	0.01	0.34	0.35	2.06	0.38	0.23	3.37
	Bycatch	0.09	1.74	1.92	7.77	1.35	0.75	13.61
	TOTAL	0.10	2.64	3.45	13.50	1.73	1.00	22.41
1.4	SETLINE CEY	0.42*	7.77	8.05	32.99	6.35	3.52	59.10

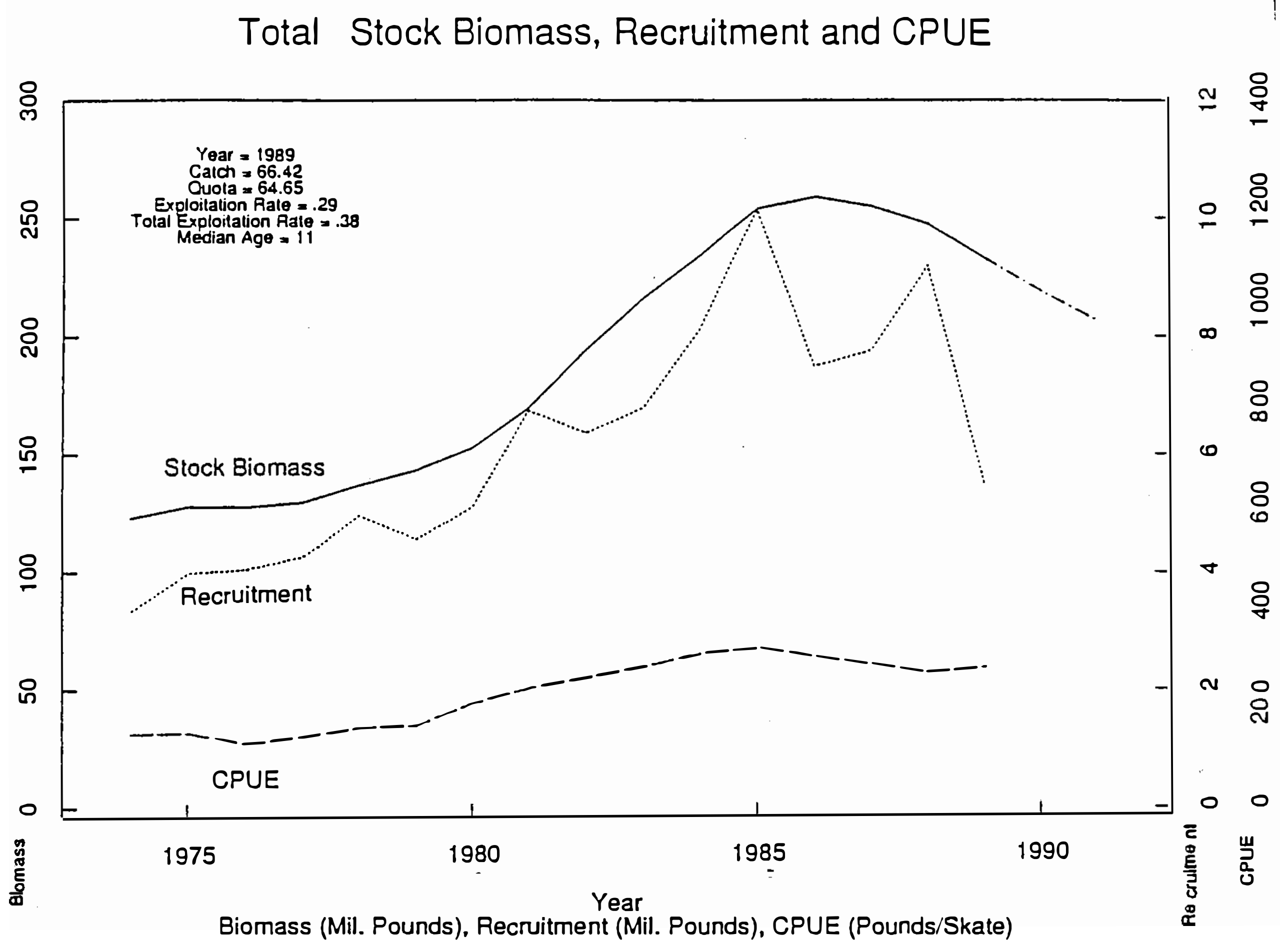
Estimates in million pounds by subarea.

* Sport catch included in setline calculations for area 2A.

Sullivan, P.J., Neal, P.R., Vienneau, B.A., 1990. Stock Assessment Document IV. Section 1: Population assessment, 1989. IPHC Rep., pp. 1–12.

IPHC Stock Assessment





Total Stock Biomass, Recruitment and CPUE
Year = 1989
Catch = 66.42
Quota = 64.65
Exploitation Rate = .29
Total Exploitation Rate = .38
Median Age = 11
Stock Biomass
Recruitment
CPUE
Biomass
Recruitment
CPUE
Year
Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

Figure 2

Sullivan, P.J., Neal, P.R., Vienneau, B.A., 1990. Stock Assessment Document IV. Section 1: Population assessment, 1989. IPHC Rep., pp. 1–12.

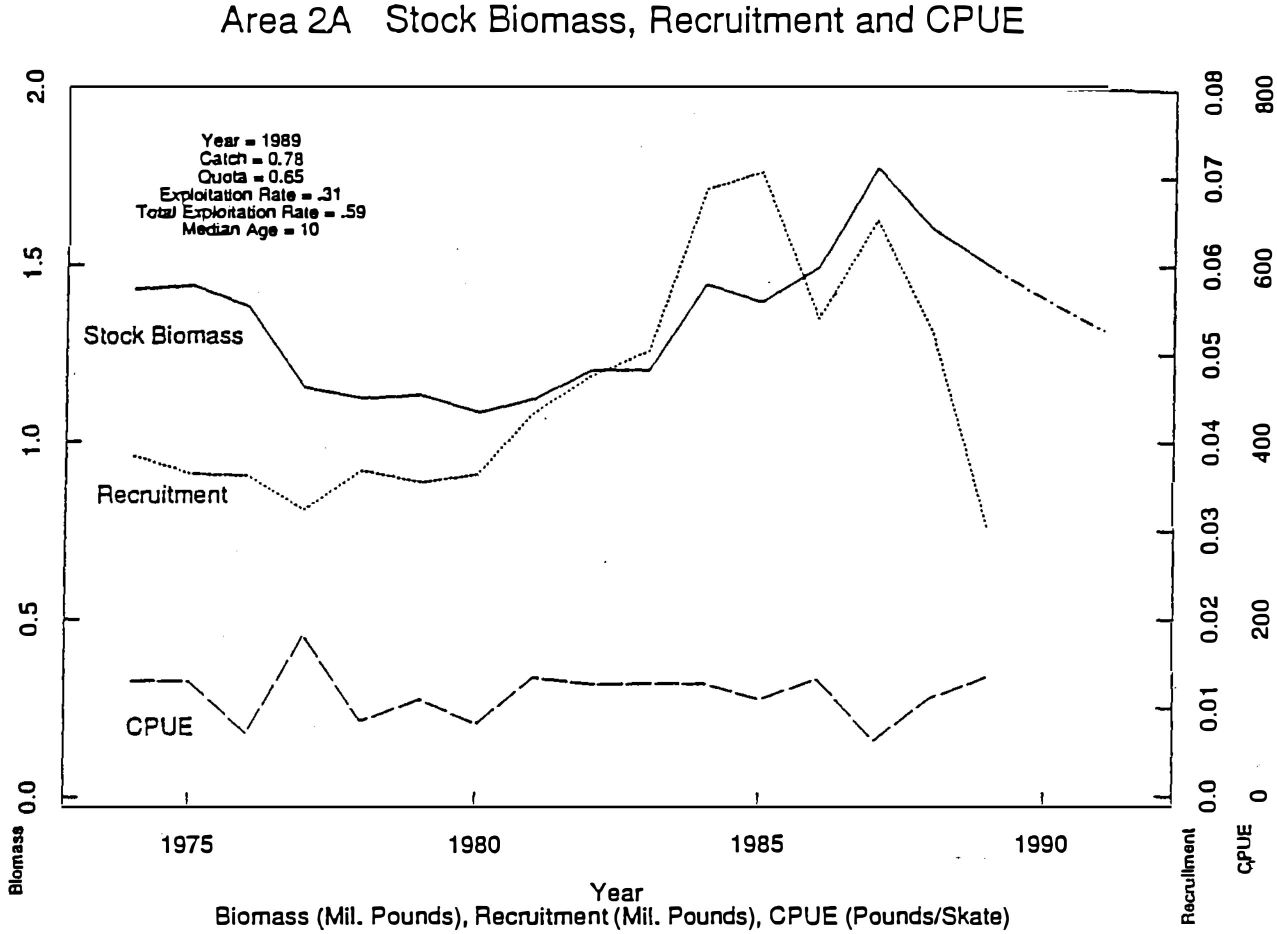


Figure 3

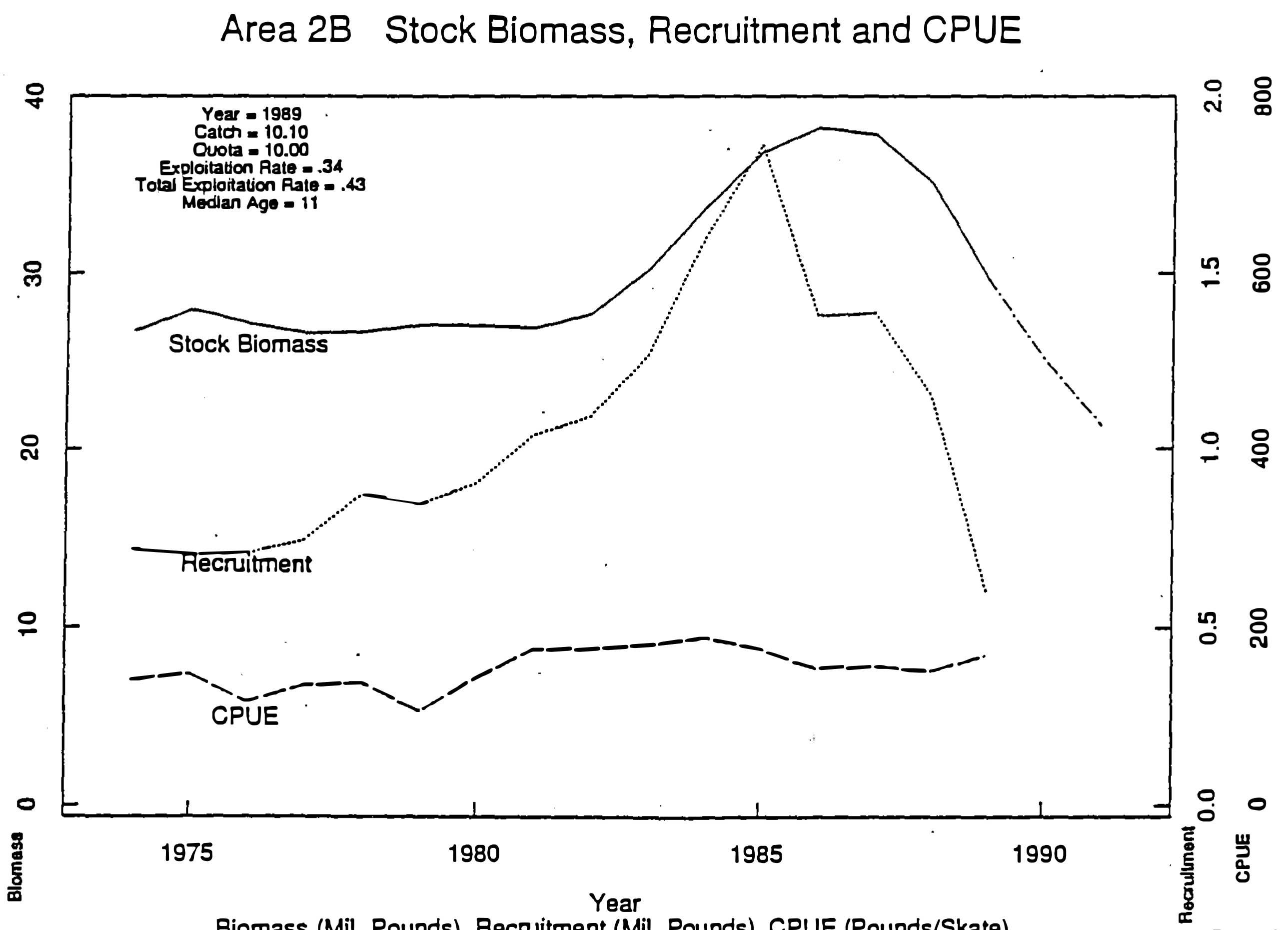


Figure 4

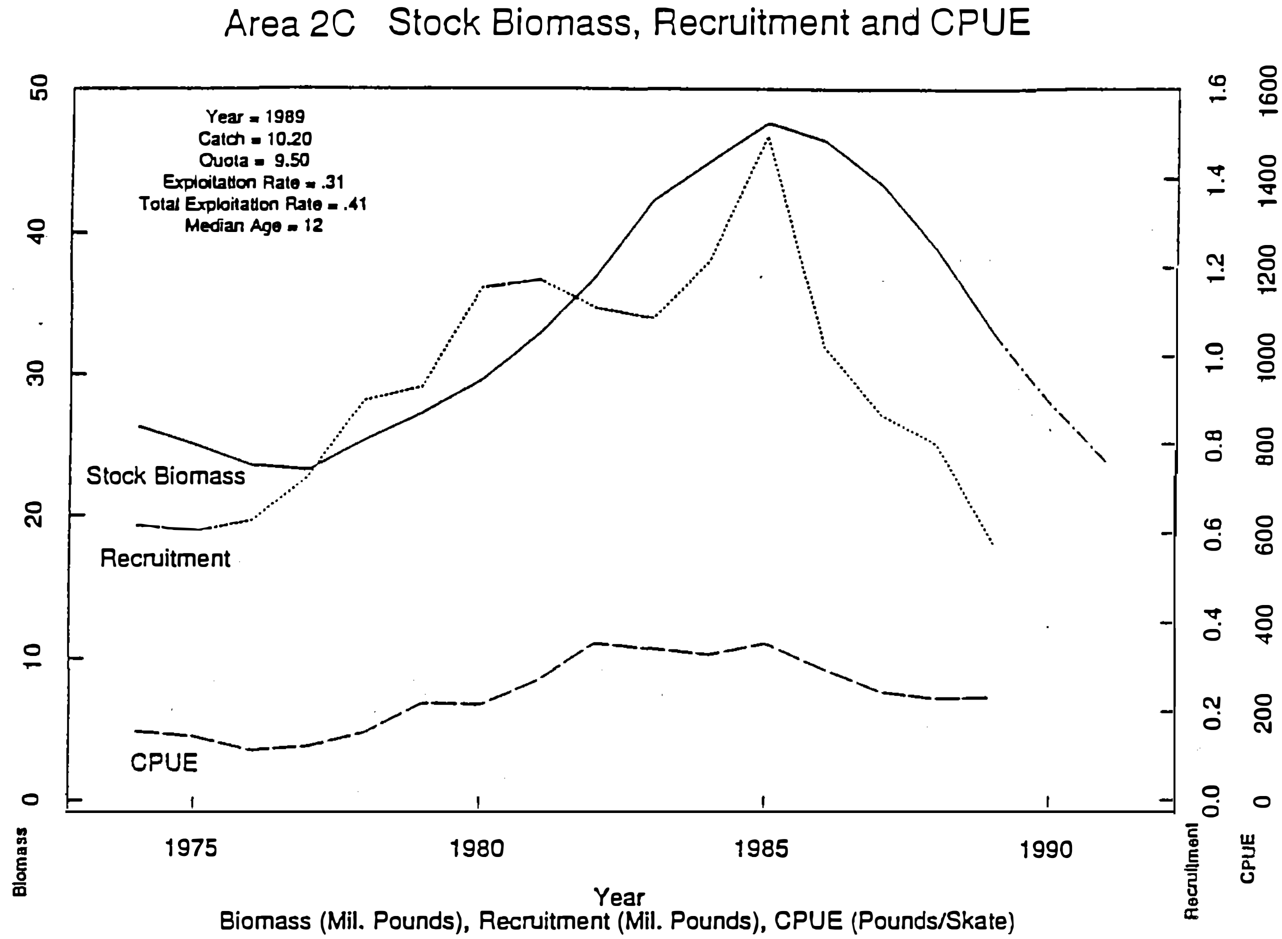
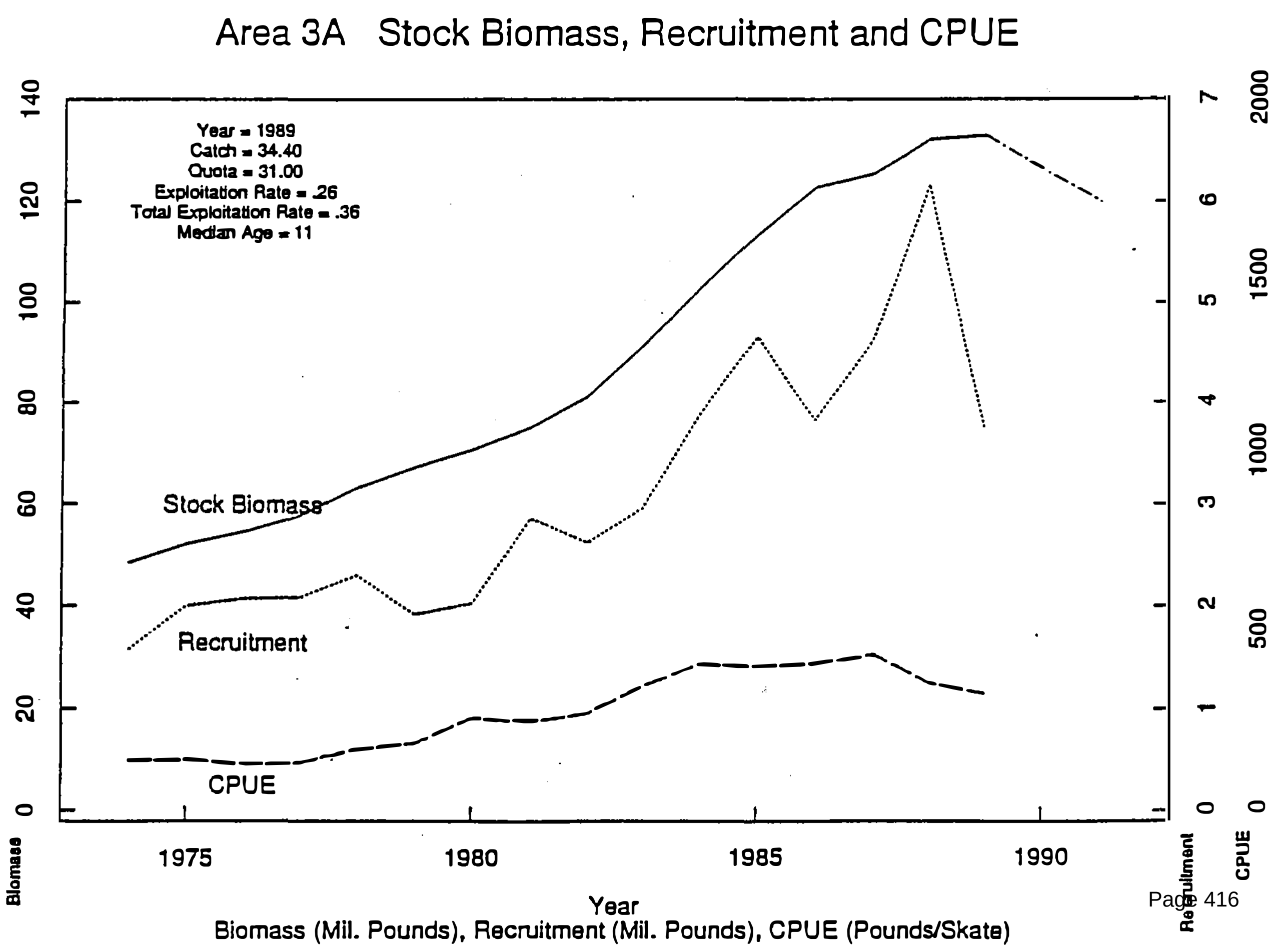

Area 2C Stock Biomass, Recruitment and CPUE
Year = 1989
Catch = 10.20
Quota = 9.50
Exploitation Rate = .31
Total Exploitation Rate = .41
Median Age = 12
Stock Biomass
Recruitment
CPUE
Biomass
Recruitment
CPUE
Year
Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

Figure 5


Area 3A Stock Biomass, Recruitment and CPUE
Year = 1989
Catch = 34.40
Quota = 31.00
Exploitation Rate = .26
Total Exploitation Rate = .36
Median Age = 11
Stock Biomass
Recruitment
CPUE
Biomass
Recruitment
CPUE
Year
Biomass (Mil. Pounds), Recruitment (Mil. Pounds), CPUE (Pounds/Skate)

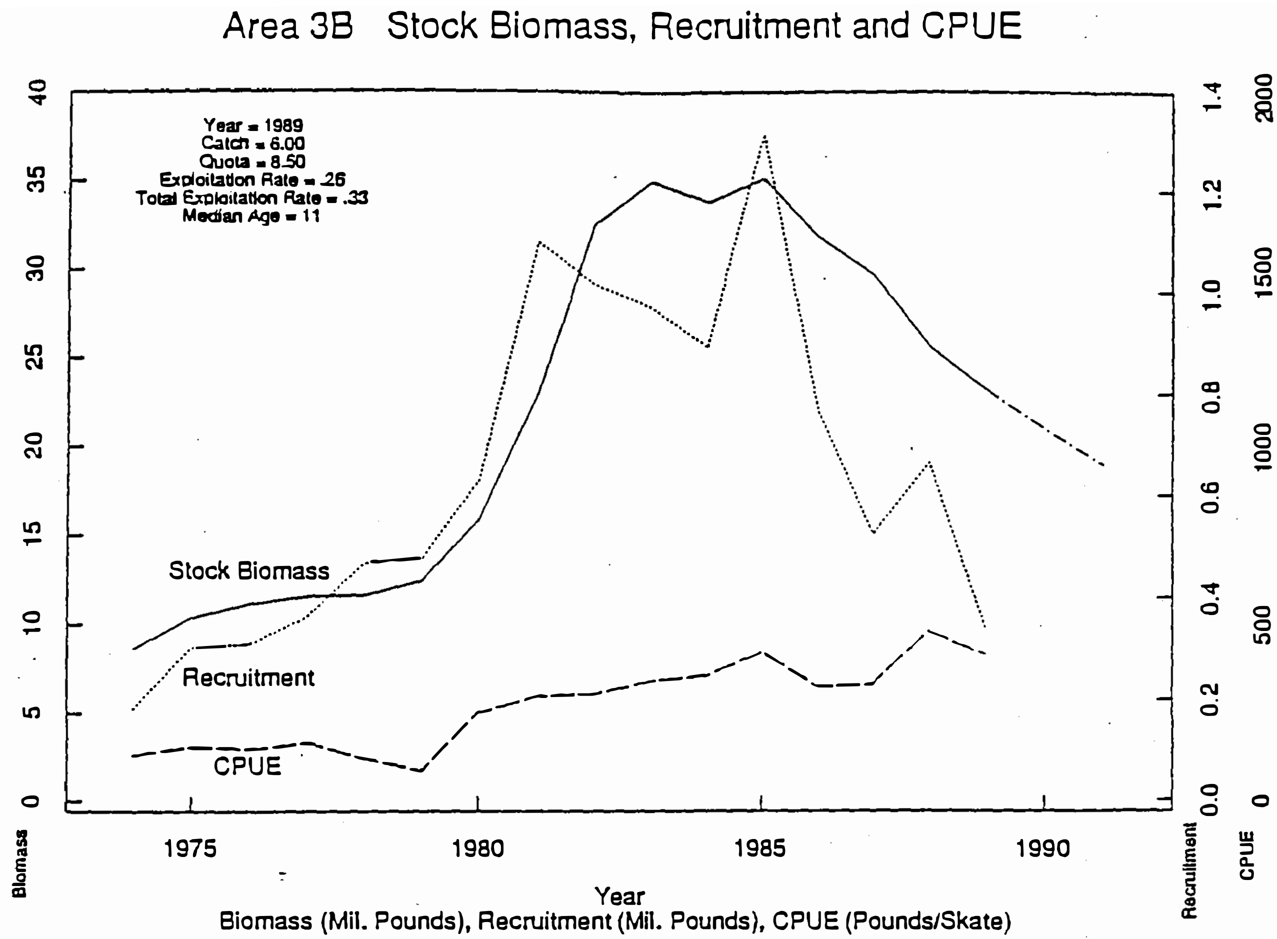


Figure 7

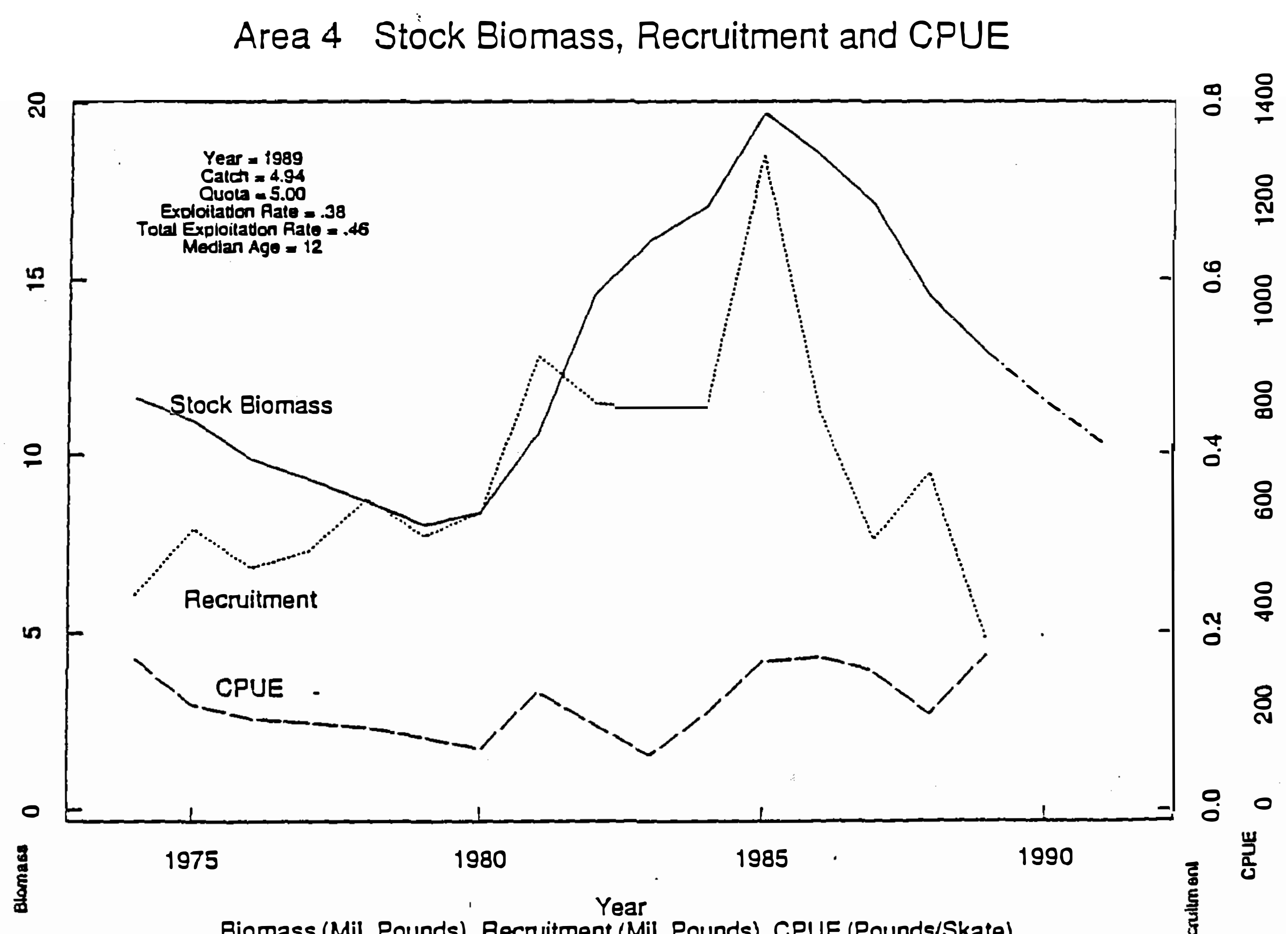


Figure 8

POPULATION ASSESSMENT, 1989

Technical Appendix

The following technical information is provided to document 1989 stock assessment computations. Tables A1.1 and A1.2 show the historical commercial CPUE and commercial catch observations. Table A2.1 presents the estimated exploitable biomass, from the closed subarea run, that was used for this year's stock assessment. The corresponding ASP, equal exploitation CEY, and ASP proportioned CEY are also provided in Tables A2.2, A2.3 and A2.4 respectively. This information can be used for comparison, and calculation, in the multimodel–equal exploitation comparison given in Section 2 of this document. The closed subarea stock assessment is the preferred approach of the three methods used previously because of its straightforward analysis and the validity of the assumptions and the data that go into it. The combined area run depends solely on habitat measures and relative CPUE to determine allocation by area. In contrast the closed area method uses an area by area catch-age analysis to determine allocation, and when combined the total biomasses estimated are comparable to those estimated by the combined method. The migratory run gives slightly different results, not because of migration, but because of a slightly different model used in the estimation to accommodate for migration. The catch-age analysis used in the closed subarea method is believed to be more sound than that used in the migratory analysis, so that given the consistency in trend and the above considerations the closed subarea method appears to be the best choice of the three.

Weighed-out-weight information was used in this year's assessment in order to streamline the stock assessment procedure. This change was successful and is discussed in a later section of this document. The assessment presented here is the most current assessment as of this writing. October effort information has not been included to date and further checks on the consistency of logbook and ticket information will continue throughout the year, but analysis in previous years indicates that these additions and updates do not significantly effect assessment results.

Sullivan, P.J., Neal, P.R., Vienneau, B.A., 1990. Stock Assessment Document IV. Section 1: Population assessment, 1989. IPHC Rep., pp. 1–12.

Table A1.1 Commercial CPUE* (pounds per skate)

	AREA						
Year	2A	2B	2C	3A	3B	4	Overall
1974	130.70	141.00	157.50	142.40	124.70	301.10	145.60
1975	130.60	148.70	146.80	145.30	149.30	210.70	147.50
1976	71.70	116.70	116.00	131.40	142.20	184.20	124.80
1977	182.20	135.30	124.30	134.60	161.30	176.20	138.50
1978	85.50	138.00	155.10	171.90	116.40	166.70	155.10
1979	110.00	105.80	220.80	189.00	80.80	146.10	159.70
1980	82.00	143.70	218.40	260.60	249.50	124.20	204.00
1981	134.40	175.70	273.60	250.80	294.60	236.80	232.30
1982	127.00	176.70	355.90	274.10	300.70	172.50	253.80
1983	127.60	180.50	342.90	349.60	335.50	112.10	275.10
1984	127.20	188.80	328.50	412.80	353.10	193.60	300.10
1985	109.40	176.50	354.10	401.20	420.10	296.40	311.50
1986	132.40	154.70	296.40	411.90	322.40	304.60	292.90
1987	62.90	157.90	244.50	437.00	329.90	276.40	278.40
1988	111.60	151.10	229.60	357.80	478.90	191.30	261.20
1989	135.00	168.00	233.60	326.60	411.70	306.50	271.80

* Standardized C hook equivalence.

Table A1.2 Commercial Catch (million pounds)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	0.51	4.62	5.60	8.19	1.83	0.54	21.31
1975	0.46	7.13	6.24	10.60	2.66	0.53	27.62
1976	0.24	7.28	5.53	11.04	2.81	0.63	27.54
1977	0.21	5.43	3.19	8.64	3.32	1.08	21.87
1978	0.10	4.61	4.32	10.29	1.33	1.35	21.99
1979	0.05	4.86	4.53	11.33	0.39	1.37	22.53
1980	0.02	5.65	3.24	11.97	0.28	0.71	21.87
1981	0.20	5.24	4.49	14.20	0.42	1.18	25.74
1982	0.29	5.54	3.50	13.50	5.77	0.42	29.01
1983	0.36	5.43	6.61	15.58	8.43	1.98	38.38
1984	0.43	9.05	5.86	19.96	7.55	2.12	44.97
1985	0.49	10.38	9.21	20.85	12.46	2.71	56.11
1986	0.55	11.25	10.66	32.74	11.20	3.18	69.58
1987	0.59	12.22	10.72	31.07	10.22	4.46	69.28
1988	0.48	12.50	11.40	38.00	6.20	4.80	73.38
1989	0.46	10.10	10.20	34.40	6.00	4.94	66.10

Sullivan, P.J., Neal, P.R., Vienneau, B.A., 1990. Stock Assessment Document IV. Section 1: Population assessment, 1989. IPHC Rep., pp. 1–12.

Table A2.1 Exploitable Biomass (Closed Subarea)

Year	2A	2B	2C	3A	3B	4	Total
	AREA						
1974	1.43	26.75	26.25	48.45	8.64	11.60	123.12
1975	1.44	27.96	24.96	52.16	10.41	10.95	127.88
1976	1.38	27.16	23.52	54.60	11.17	9.88	127.70
1977	1.15	26.62	23.19	57.69	11.57	9.32	129.54
1978	1.12	26.70	25.32	63.21	11.64	8.67	136.66
1979	1.13	27.07	27.24	67.22	12.46	8.02	143.13
1980	1.08	27.04	29.62	70.60	15.91	8.40	152.65
1981	1.12	26.92	32.93	75.00	23.01	10.64	169.60
1982	1.20	27.73	36.99	81.15	32.65	14.63	194.35
1983	1.20	30.28	42.28	91.31	35.01	16.15	216.23
1984	1.44	33.78	45.02	103.05	33.80	17.12	234.21
1985	1.39	36.85	47.63	113.52	35.15	19.73	254.27
1986	1.49	38.24	46.39	122.74	31.79	18.52	259.18
1987	1.77	37.82	43.31	125.43	29.66	17.14	255.13
1988	1.60	35.14	38.79	132.11	25.54	14.52	247.70
1989	1.50	29.75	32.86	132.81	23.09	12.92	232.93

Table A2.2 Annual Surplus Production (Closed Subarea)

Year	2A	2B	2C	3A	3B	4	Total
	AREA						
1974	0.53	5.83	4.32	11.90	3.61	-0.11	26.07
1975	0.40	6.33	4.80	13.04	3.42	-0.54	27.44
1976	0.02	6.74	5.20	14.13	3.21	0.08	29.37
1977	0.18	5.51	5.32	14.17	3.40	0.42	28.99
1978	0.10	4.98	6.23	14.30	2.15	0.70	28.46
1979	-0.01	4.83	6.92	14.72	3.84	1.75	32.05
1980	0.06	5.53	6.54	16.36	7.37	2.96	38.82
1981	0.29	6.06	8.56	20.35	10.05	5.18	50.49
1982	0.29	8.08	8.79	23.66	8.13	1.94	50.89
1983	0.60	8.93	9.35	27.32	7.21	2.95	56.36
1984	0.38	12.12	8.47	30.43	8.90	4.73	65.03
1985	0.60	11.78	7.98	30.07	9.10	1.50	61.02
1986	0.83	10.83	7.57	35.43	9.07	1.80	65.53
1987	0.42	9.54	6.20	37.75	6.10	1.84	61.85
1988	0.38	7.11	5.47	38.70	3.74	3.21	58.61
1989	0.36	6.02	4.63	38.90	3.38	2.86	56.15

Estimates in million pounds by subarea.

Table A2.3 CEY: Exploitation Rate = 0.35 (Closed Subarea)

Year	AREA 2A	2B	2C	3A	3B	4	Total
1974	0.50	9.36	9.19	16.96	3.02	4.06	43.09
1975	0.50	9.78	8.74	18.26	3.64	3.83	44.76
1976	0.48	9.51	8.23	19.11	3.91	3.46	44.70
1977	0.40	9.32	8.12	20.19	4.05	3.26	45.34
1978	0.39	9.34	8.86	22.12	4.08	3.03	47.83
1979	0.39	9.47	9.53	23.53	4.36	2.81	50.10
1980	0.38	9.46	10.37	24.71	5.57	2.94	53.43
1981	0.39	9.42	11.52	26.25	8.05	3.72	59.36
1982	0.42	9.71	12.95	28.40	11.43	5.12	68.02
1983	0.42	10.60	14.80	31.96	12.25	5.65	75.68
1984	0.50	11.82	15.76	36.07	11.83	5.99	81.97
1985	0.48	12.90	16.67	39.73	12.30	6.91	88.99
1986	0.52	13.39	16.24	42.96	11.13	6.48	90.71
1987	0.62	13.24	15.16	43.90	10.38	6.00	89.30
1988	0.56	12.30	13.58	46.24	8.94	5.08	86.70
1989	0.52	10.41	11.50	46.48	8.08	4.52	81.53

Table A2.4 CEY: ASP Subarea Partitioning (Closed Subarea)

Year	AREA 2A	2B	2C	3A	3B	4	Total
1974	0.87	9.64	7.13	19.66	5.96	-0.17	43.09
1975	0.64	10.32	7.83	21.28	5.57	-0.89	44.76
1976	0.02	10.26	7.91	21.50	4.88	0.12	44.70
1977	0.28	8.62	8.31	22.16	5.31	0.66	45.34
1978	0.17	8.36	10.48	24.04	3.61	1.18	47.83
1979	-0.01	7.55	10.81	23.01	6.00	2.73	50.10
1980	0.08	7.61	9.00	22.52	10.15	4.07	53.43
1981	0.34	7.12	10.06	23.93	11.82	6.09	59.36
1982	0.39	10.80	11.75	31.62	10.87	2.59	68.02
1983	0.80	12.00	12.56	36.69	9.68	3.96	75.68
1984	0.48	15.28	10.67	38.36	11.22	5.96	81.97
1985	0.88	17.18	11.63	43.85	13.27	2.18	88.99
1986	1.15	14.99	10.48	49.04	12.56	2.49	90.71
1987	0.60	13.77	8.95	54.50	8.81	2.66	89.30
1988	0.56	10.52	8.09	57.25	5.54	4.75	86.70
1989	0.52	8.74	6.72	56.49	4.91	4.15	81.53

Estimates in million pounds by subarea.

STOCK ASSESSMENT DOCUMENT IV

SECTION 2. EQUAL EXPLOITATION ASSESSMENT

by

Patrick J. Sullivan

Introduction

The Pacific halibut stock and its assessment are in transition. The stock is showing a downward trend in biomass and management questions, different from those posed in previous years, need to be addressed. In this report we recap the multimodel method of stock assessment as it has been used over the past five years and discuss a restructured version of it that better represents the nature of the fishery. This version, denoted as the "equal exploitation" approach, differs from the "multimodel" approach previously used in two ways. First, it uses the results from just one stock assessment method. Second, but perhaps of greater importance, it improves and simplifies the procedure by which the allowable catch is determined from the exploitable biomass estimates. The IPHC staff believes that using the single stock assessment method, in combination with the simplified approach to determining the allowable catch, provides the best estimates available for management of the stock. Summaries of both the multimodel and the equal exploitation approaches are presented below.

Comparison of Approaches

In principle, the equal exploitation approach to stock assessment is the same as the approach that has been used in previous years. Catch, CPUE, age composition and average weight data are compiled and used in a catch-at-age analysis. To understand how the equal exploitation approach differs from the multimodel approach let us first review the steps involved in the multimodel procedure. Recall

Sullivan, P.J., Neal, P.R., Vienneau, B.A., 1990. Stock Assessment Document IV. Section 1: Population assessment, 1989. IPHC Rep., pp. 1–12.

that three methods of catch-age analysis were used. These three methods were the migratory catch-age analysis, the closed subarea catch-age analysis, and the combined catch-age analysis with CPUE partitioning. These analyses resulted in three estimates of exploitable biomass. The biomasses were used to compute allowable catches by applying management policies which were based on constant exploitation yield, maximum sustainable yield and annual surplus production. Further adjustments were made according the levels of halibut biomass removal that take place in other fisheries.

The way the allowable catch has been conventionally computed was to determine the constant exploitation yield (CEY) and the annual surplus production (ASP) using the stock biomasses arrived at by the three stock estimation methods. The ASP and CEY by subarea were then used to partition the total CEY by subarea for each of the three biomass estimates resulting in six CEY estimates for each area. The maximum of the six CEYs in each area was taken and these values were used, relative to one another, to apportion the maximum and the minimum total CEYs. The maximum and minimum total CEYs were determined directly from the maximum and minimum total biomasses. The midpoint of the maximum and minimum was then used to determine the total allowable catch. Once the total allowable catch was determined catch removals by other fisheries were subtracted out to determine the allowable setline catch.

This procedure, though complicated, served the fishery well during the period of stock build up. Now with the stock showing a downward trend certain features of this approach, such as using ASP in the apportionment of biomass, are not as applicable. A version of the above procedure is now present that is simpler to understand and implement, and that better reflects that nature of the trends in biomass.

The so called equal exploitation approach is this: Obtain exploitable biomass estimates from just one of the three stock assessment procedures, namely the closed subarea stock assessment, multiply by the constant exploitation yield ratio of 0.35 to determine the overall CEY, and subtract out the incidental catch from the overall CEY as above to determine the allowable setline catch.

Sullivan, P.J., Neal, P.R., Vienneau, B.A., 1990. Stock Assessment Document IV. Section 1: Population assessment, 1989. IPHC Rep., pp. 1–12.

The closed subarea method is believed to be the best of the three stock assessment procedures because of its more straightforward analysis and the validity of the assumptions and data that go into it. The combined area analysis, for example, depends solely on habitat measures and relative CPUE to determine allocation by area. In contrast the closed subarea method uses an area specific catch-age analysis to determine abundance in the four major areas (2A+2B,2C,3A,3B+4). When these estimates are combined they give a total biomass estimate that is comparable to that estimated by the combined method. The migratory analysis, in contrast, gives slightly different results, not because of migration, but because of a slightly different model used in the estimation procedure to accommodate for migration. The catch-age analysis used in the closed subarea method is believed to be more sound than that used in the migratory analysis, so that given the consistency in trend and the above considerations the closed subarea method appears to be the best choice of the three estimation methods.

Tables 1.1-1.4 and 2.1-2.4 give the assessment for the migratory and combined analyses,repectively, and can be contrasted with the closed subarea estimates that are shown in the previous section.

Bycatch

The adjustments to the allowable catch for bycatch have been recomputed to represent compensation to the stock for losses in the stock's reproductive potential. The impact of this change on the allowable catch is discussed elsewhere (Document III, Section 4). The IPHC staff believes that the new estimates of adult reproductive compensation better reflect the impact to the fishery from bycatch. The result of this analysis is that the allowable catch is now reduced by 1.00 pound for every pound of bycatch removed. This is in contrast to the 1.58 reduction used previously.

Summary

The total effect these changes have on the setline and total allowable catch are shown by the tables given in Table 3. This set of tables contrasts the effects of the multimodel versus the equal exploitation methods with and without the effects of the change in the bycatch calculations. The sum of the allowable catches by area is seen to be comparable given the adjustments due to bycatch, but the by-area apportionment of these CEYs differs. The equal exploitation approach reflects the process of harvesting from each area equally according to that areas estimated exploitable biomass. Such allowable catch values better reflect the biological considerations necessary to stock management in this period of declining stock biomass.

Table 1.1 Exploitable Biomass (Migratory)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	1.36	25.43	25.24	45.13	9.80	13.15	120.11
1975	1.36	26.42	24.11	48.46	11.65	12.25	124.25
1976	1.29	25.45	23.28	50.47	12.57	11.11	124.17
1977	1.10	25.37	23.52	53.42	13.31	10.72	127.44
1978	1.06	25.26	25.94	57.21	13.65	10.16	133.29
1979	1.06	25.49	28.20	60.31	17.54	11.28	143.89
1980	1.01	25.33	30.52	62.74	22.15	11.69	153.43
1981	1.03	24.96	33.90	65.76	26.56	12.28	164.50
1982	1.10	25.49	37.88	70.49	37.56	16.84	189.36
1983	1.10	27.72	42.97	79.06	40.04	18.47	209.36
1984	1.30	30.64	45.53	89.94	38.85	19.69	225.96
1985	1.23	32.82	48.33	99.36	40.80	22.90	245.44
1986	1.30	33.38	47.23	106.98	37.69	21.96	248.53
1987	1.52	32.32	44.40	107.57	35.59	20.56	241.96
1988	1.34	29.38	39.80	110.62	31.14	17.70	229.97
1989	1.21	23.96	34.36	108.48	28.98	16.22	213.21

Table 1.2 Annual Surplus Production (Migratory)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	0.52	5.61	4.47	11.52	3.68	-0.36	25.45
1975	0.39	6.16	5.41	12.61	3.57	-0.61	27.53
1976	0.05	7.21	5.77	13.99	3.55	0.25	30.81
1977	0.17	5.31	5.60	12.44	3.67	0.52	27.71
1978	0.10	4.84	6.57	13.39	5.21	2.47	32.59
1979	-0.01	4.70	6.85	13.77	5.00	1.77	32.07
1980	0.05	5.28	6.62	14.99	4.69	1.31	32.93
1981	0.27	5.77	8.48	18.93	11.42	5.74	50.60
1982	0.29	7.76	8.60	22.07	8.24	2.05	49.01
1983	0.57	8.35	9.17	26.46	7.24	3.19	54.98
1984	0.36	11.24	8.65	29.38	9.49	5.34	64.45
1985	0.56	10.95	8.11	28.47	9.35	1.77	59.21
1986	0.76	10.19	7.83	33.34	9.10	1.78	63.00
1987	0.41	9.28	6.12	34.11	5.78	1.60	57.30
1988	0.35	7.08	5.97	35.86	4.04	3.33	56.62
1989	0.32	5.77	5.15	35.17	3.76	3.05	53.22

Estimates in million pounds by subarea.

Sullivan, P.J., Neal, P.R., Vienneau, B.A., 1990. Stock Assessment Document IV. Section 1: Population assessment, 1989. IPHC Rep., pp. 1–12.

Table 1.3 CEY: Exploitation Rate = 0.35 (Migratory)

Year	2A	2B	2C	3A	3B	4	Total
	AREA						
1974	0.47	8.90	8.84	15.80	3.43	4.60	42.04
1975	0.48	9.25	8.44	16.96	4.08	4.29	43.49
1976	0.45	8.91	8.15	17.66	4.40	3.89	43.46
1977	0.38	8.88	8.23	18.70	4.66	3.75	44.60
1978	0.37	8.84	9.08	20.02	4.78	3.56	46.65
1979	0.37	8.92	9.87	21.11	6.14	3.95	50.36
1980	0.35	8.87	10.68	21.96	7.75	4.09	53.70
1981	0.36	8.74	11.86	23.02	9.30	4.30	57.57
1982	0.39	8.92	13.26	24.67	13.15	5.89	66.28
1983	0.39	9.70	15.04	27.67	14.01	6.46	73.28
1984	0.46	10.72	15.94	31.48	13.60	6.89	79.08
1985	0.43	11.49	16.91	34.78	14.28	8.02	85.90
1986	0.46	11.68	16.53	37.44	13.19	7.69	86.99
1987	0.53	11.31	15.54	37.65	12.46	7.20	84.68
1988	0.47	10.28	13.93	38.72	10.90	6.19	80.49
1989	0.42	8.39	12.03	37.97	10.14	5.68	74.62

Table 1.4 CEY: ASP Subarea Partitioning (Migratory)

Year	2A	2B	2C	3A	3B	4	Total
	AREA						
1974	0.86	9.27	7.39	19.03	6.09	-0.59	42.04
1975	0.61	9.72	8.55	19.92	5.65	-0.96	43.49
1976	0.07	10.17	8.13	19.74	5.00	0.35	43.46
1977	0.27	8.55	9.02	20.02	5.91	0.84	44.60
1978	0.14	6.93	9.41	19.17	7.46	3.53	46.65
1979	-0.01	7.37	10.76	21.61	7.85	2.78	50.36
1980	0.08	8.61	10.79	24.44	7.65	2.13	53.70
1981	0.31	6.57	9.64	21.54	12.99	6.53	57.57
1982	0.39	10.50	11.62	29.85	11.14	2.77	66.28
1983	0.75	11.13	12.22	35.27	9.65	4.26	73.28
1984	0.44	13.79	10.62	36.05	11.64	6.55	79.08
1985	0.82	15.88	11.77	41.30	13.57	2.56	85.90
1986	1.05	14.07	10.82	46.03	12.56	2.46	86.99
1987	0.61	13.71	9.04	50.41	8.54	2.37	84.68
1988	0.50	10.06	8.48	50.98	5.74	4.73	80.49
1989	0.44	8.09	7.22	49.32	5.27	4.27	74.62

Estimates in million pounds by subarea.

Sullivan, P.J., Neal, P.R., Vienneau, B.A., 1990. Stock Assessment Document IV. Section 1: Population assessment, 1989. IPHC Rep., pp. 1–12.

Table 2.1 Exploitable Biomass (Combined)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	1.53	28.67	25.86	42.04	12.46	16.72	127.28
1975	1.58	30.72	25.45	44.83	14.20	14.94	131.73
1976	1.59	31.37	24.49	46.33	15.24	13.48	132.49
1977	1.34	31.05	25.13	48.66	15.70	12.66	134.55
1978	1.29	30.58	28.58	54.30	16.22	12.07	143.05
1979	1.20	28.78	32.38	58.92	17.51	11.27	150.06
1980	1.11	27.97	35.76	62.30	20.81	10.98	158.92
1981	1.20	29.08	40.27	65.91	24.24	11.21	171.91
1982	1.38	31.93	46.51	76.86	27.76	12.44	196.88
1983	1.33	33.51	49.71	92.76	30.52	14.08	221.92
1984	1.42	33.44	50.05	104.84	31.64	16.03	237.43
1985	1.29	34.33	51.88	116.93	34.22	19.21	257.87
1986	1.33	34.15	49.62	123.26	36.92	21.51	266.79
1987	1.58	33.65	44.43	121.73	39.00	22.53	262.93
1988	1.52	33.37	40.96	112.51	41.27	23.45	253.09
1989	1.65	32.75	38.88	98.02	41.39	23.17	235.86

Table 2.2 Annual Surplus Production (Combined)

	AREA						
Year	2A	2B	2C	3A	3B	4	Total
1974	0.57	6.68	5.19	10.97	3.58	-1.24	25.75
1975	0.47	7.77	5.28	12.10	3.70	-0.93	28.38
1976	-0.01	6.96	6.18	13.38	3.27	-0.19	29.59
1977	0.15	4.96	6.63	14.29	3.84	0.50	30.37
1978	0.01	2.81	8.12	14.91	2.62	0.54	29.00
1979	-0.04	4.04	7.91	14.72	3.68	1.08	31.39
1980	0.11	6.76	7.75	15.58	3.71	0.94	34.86
1981	0.38	8.09	10.74	25.15	3.94	2.42	50.71
1982	0.24	7.12	6.70	29.40	8.53	2.05	54.04
1983	0.45	5.36	6.95	27.66	9.54	3.93	53.89
1984	0.30	9.94	7.69	32.05	10.12	5.30	65.41
1985	0.54	10.20	6.95	27.18	15.16	5.01	65.03
1986	0.79	10.75	5.47	31.22	13.28	4.20	65.71
1987	0.53	11.94	7.24	21.85	12.50	5.39	59.45
1988	0.61	11.88	9.32	23.51	6.32	4.52	56.15
1989	0.67	11.66	8.84	20.48	6.34	4.46	52.44

Estimates in million pounds by subarea.

Sullivan, P.J., Neal, P.R., Vienneau, B.A., 1990. Stock Assessment Document IV. Section 1: Population assessment, 1989. IPHC Rep., pp. 1–12.

Table 2.3 CEY: Exploitation Rate = 0.35 (Combined)

Year	AREA 2A	2B	2C	3A	3B	4	Total
1974	0.54	10.03	9.05	14.72	4.36	5.85	44.55
1975	0.55	10.75	8.91	15.69	4.97	5.23	46.10
1976	0.56	10.98	8.57	16.21	5.34	4.72	46.37
1977	0.47	10.87	8.80	17.03	5.50	4.43	47.09
1978	0.45	10.70	10.00	19.01	5.68	4.23	50.07
1979	0.42	10.07	11.33	20.62	6.13	3.94	52.52
1980	0.39	9.79	12.52	21.80	7.28	3.84	55.62
1981	0.42	10.18	14.09	23.07	8.48	3.92	60.17
1982	0.48	11.17	16.28	26.90	9.72	4.36	68.91
1983	0.47	11.73	17.40	32.47	10.68	4.93	77.67
1984	0.50	11.71	17.52	36.69	11.07	5.61	83.10
1985	0.45	12.02	18.16	40.93	11.98	6.72	90.25
1986	0.47	11.95	17.37	43.14	12.92	7.53	93.38
1987	0.55	11.78	15.55	42.61	13.65	7.88	92.02
1988	0.53	11.68	14.34	39.38	14.45	8.21	88.58
1989	0.58	11.46	13.61	34.31	14.49	8.11	82.55

Table 2.4 CEY: ASP Subarea Partitioning (Combined)

Year	AREA 2A	2B	2C	3A	3B	4	Total
1974	0.98	11.56	8.98	18.98	6.19	-2.15	44.55
1975	0.76	12.63	8.58	19.65	6.00	-1.51	46.10
1976	-0.01	10.91	9.68	20.96	5.12	-0.29	46.37
1977	0.23	7.69	10.28	22.15	5.96	0.77	47.09
1978	0.02	4.85	14.01	25.73	4.52	0.94	50.07
1979	-0.07	6.77	13.23	24.63	6.16	1.81	52.52
1980	0.18	10.79	12.36	24.86	5.92	1.51	55.62
1981	0.45	9.59	12.74	29.84	4.67	2.87	60.17
1982	0.31	9.08	8.54	37.49	10.88	2.62	68.91
1983	0.66	7.73	10.01	39.86	13.75	5.66	77.67
1984	0.38	12.63	9.77	40.72	12.86	6.73	83.10
1985	0.74	14.16	9.65	37.72	21.04	6.95	90.25
1986	1.13	15.28	7.78	44.36	18.86	5.97	93.38
1987	0.82	18.48	11.21	33.81	19.35	8.35	92.02
1988	0.97	18.74	14.70	37.08	9.97	7.12	88.58
1989	1.05	18.35	13.92	32.24	9.98	7.02	82.55

Estimates in million pounds by subarea.

Table 3a.
Equal Exploitation
Bycatch Compensation Factor = 1.00
(Preferred Approach)

		AREA 2A	2B	2C	3A	3B	4	TOTAL
3a.1	CATCH/QUOTA							
	1989 Quota	0.65*	10.00	9.50	31.00	8.50	5.00	64.65
	1989 Catch	0.78*	10.10	10.20	34.40	6.00	4.94	66.42
3a.2	CEY	0.52*	10.41	11.50	46.48	8.08	4.52	81.53
3a.3	OTHER CATCHES							
	Sport	—*	0.56	1.18	3.67	0.00	0.02	5.43
	Waste	0.01	0.34	0.35	2.06	0.38	0.23	3.37
	Bycatch	0.09	1.74	1.92	7.77	1.35	0.75	13.61
	TOTAL	0.10	2.64	3.45	13.50	1.73	1.00	22.41
3a.4	SETLINE CEY	0.42*	7.77	8.05	32.99	6.35	3.52	59.10

Estimates in million pounds by subarea.

* Sport catch included in setline calculations for area 2A.

Table 3b.
Equal Exploitation
Bycatch Compensation Factor = 1.58

		AREA 2A	2B	2C	3A	3B	4	TOTAL
3b.1	CATCH/QUOTA							
	1989 Quota	0.65*	10.00	9.50	31.00	8.50	5.00	64.65
	1989 Catch	0.78*	10.10	10.20	34.40	6.00	4.94	66.42
3b.2	CEY	0.52*	10.41	11.50	46.48	8.08	4.52	81.53
3b.3	OTHER CATCHES							
	Sport	—*	0.56	1.18	3.67	0.00	0.02	5.43
	Waste	0.01	0.34	0.35	2.06	0.38	0.23	3.37
	Bycatch	0.14	2.75	3.03	12.28	2.13	1.19	21.50
	TOTAL	0.15	3.65	4.56	18.01	2.51	1.44	30.30
3b.4	SETLINE CEY	0.37*	6.76	6.94	28.47	5.57	3.08	51.23

Estimates in million pounds by subarea.

* Sport catch included in setline calculations for area 2A.

Table 3c.
Multimodel with ASP
Bycatch Compensation Factor = 1.00

		AREA 2A	2B	2C	3A	3B	4	TOTAL
3c.1	CATCH/QUOTA							
	1989 Quota	0.65*	10.00	9.50	31.00	8.50	5.00	64.65
	1989 Catch	0.78*	10.10	10.20	34.40	6.00	4.94	66.42
3c.2	CEY	0.72*	12.63	9.58	38.87	9.97	6.83	78.60
3c.3	OTHER CATCHES							
	Sport	—*	0.56	1.18	3.67	0.00	0.02	5.43
	Waste	0.01	0.34	0.35	2.06	0.38	0.23	3.37
	Bycatch	0.12	2.19	1.66	6.73	1.73	1.18	13.61
	TOTAL	0.13	3.09	3.19	12.46	2.11	1.43	22.41
3c.4	SETLINE CEY	0.59*	9.54	6.39	26.41	7.86	5.40	56.19

Estimates in million pounds by subarea.

* Sport catch included in setline calculations for area 2A.

Table 3d.
Multimodel with ASP
Bycatch Compensation Factor = 1.58

		AREA 2A	2B	2C	3A	3B	4	TOTAL
3d.1	CATCH/QUOTA							
	1989 Quota	0.65*	10.00	9.50	31.00	8.50	5.00	64.65
	1989 Catch	0.78*	10.10	10.20	34.40	6.00	4.94	66.42
3d.2	CEY	0.72*	12.63	9.58	38.87	9.97	6.83	78.60
3d.3	OTHER CATCHES							
	Sport	—*	0.56	1.18	3.67	0.00	0.02	5.43
	Waste	0.01	0.34	0.35	2.06	0.38	0.23	3.37
	Bycatch	0.20	3.46	2.62	10.63	2.73	1.87	21.50
	TOTAL	0.21	4.36	4.15	16.36	3.11	2.12	30.30
3d.4	SETLINE CEY	0.51*	8.27	5.43	22.51	6.86	4.71	48.30

Estimates in million pounds by subarea.

* Sport catch included in setline calculations for area 2A.

STOCK ASSESSMENT DOCUMENT III

SECTION 1. POPULATION ASSESSMENT, 1988

by

Patrick Sullivan, William Clark, Phillip Neal, and Russell Price

The Pacific halibut stock assessment for 1988 is based on three methods of catch-age analysis: migratory, closed subarea, and total area with CPUE partitioning. These three are the same methods used for stock assessment in the years 1984 through 1987. Data used in the stock assessment is compiled from logbooks, port samples of otoliths, and dealer catch records.

The total exploitable biomass of Pacific halibut in 1988 is estimated to be about 213.1 million pounds for all areas combined. This represents a decrease in biomass of about 6% from the updated estimate of 1987 exploitable biomass of 226.4 million pounds. This decrease is similar to a 5% decrease in biomass observed between 1986 and 1987 and although the biomass remains close to historically high levels the downward trend observed in abundance is consistent with the two biological interpretations of how the stock size changes with time (these are 1: stock size is correlated with stock density over time; 2: stock size is correlated with environmental changes over time). In either case a downward trend in stock abundance is indicated in the fishery as shown in Figure 1. The information in Table 1 also supports this conclusion, for while total catch increases from 69.3 million pounds to 73.8 million pounds, the catch per unit effort (CPUE) continues to decrease and this year decreases from 278.4 pounds per skate to 261.2 pounds per skate. Adjustments are made to CPUE according to the catchability of a given regulatory area based on research results presented by Quinn et al. (1985). The CPUE is increased by 25% in areas

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2A and 2B and decreased by 25% in areas 3A and 3B for the years 1981 to 1988. The CPUE is not adjusted in areas 2C and 4. In addition to the biological decrease in stock abundance discussed above a decrease in the estimated biomass from last years estimates occurs. The update indicates a 10% drop from last year's preliminary estimate of stock abundance. This decrease is in part (2%) due to an updating of 1987 data and in part (8%) due to information about the 1987 stock level that is present in the 1988 data. Information available in changes in the age composition of the stock and in weight at age play an important role in the stock assessment. This year the 9-year-old component of the stock was quite different than expected based on last year's estimate of recruitment. The effect that this cohort has on the determination of stock abundance will be discussed later in this document.

Table 2 gives a summary of the stock assessment results for 1988. As in previous stock assessment reports the ranges given for each population indicator reflect the span of estimates obtained from the three catch-at-age analyses. Annual surplus production (ASP) measures the stock's productivity and represents the excess in biomass above what is needed to replenish the stock. This value ranges from 70.0 to 84.2 million pounds for 1988. Total removals in 1988 were 96.23 million pounds (73.8 million commercial and 22.4 million bycatch, sport, and waste). This removal is in excess of the annual surplus production of the stock.

The constant exploitation yield (CEY) estimates represent the preferred levels of removal from the stock. A constant exploitation fraction (0.35) is multiplied by the estimates of exploitable biomass to obtain one set of estimates of the CEY for the stock. Another set of estimates is obtained using the ASP estimates. As indicated in line 3 of Table 2 the CEY determined from these two

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sets of estimates ranges from 63.3 million pounds to 85.9 million pounds for all areas combined. The CEY ranges for each subarea are also given in line 3 of Table 2. To obtain the adjusted setline CEY the noncommercial removals are subtracted from the adjusted CEY ranges given in line 3. (The method used for these calculations is documented in previous stock assessment reports and, as in the past, adjusts the bycatch to reflect the estimated impact of the incidental catch loss on future recruitment to the commercial fishery.) The adjusted setline CEY shown in line 5 of Table 2 indicates that a substantial reduction in allowable catch should be made in some regulatory areas. This reduction is due in part to the decrease observed in the biomass and in part to the 34% overall increase in the noncommercial (bycatch, sport, and waste) reductions in the stock. Figure 2 and line 7 of Table 2 give an indication of the proportion of the adjusted CEY which is taken by the commercial and noncommercial components of the fishery in all regulatory areas.

Table 3, Table 4, and Table 5 give the details of the three stock assessment methods (migratory catch-age analysis, closed subarea catch-age analysis, and total area catch-age analysis with CPUE partitioning). Similar trends are observed in all three stock assessment procedures.

Several factors are contributing to the decline in the recommended allowable catch. Direct declines in the allowable catch are resulting from an increasing level of bycatch as was discussed above. Indirect declines in the allowable catch are also occurring due to declines in the exploitable stock biomass. Exceeding the recommended allowable catch contributes to this decline by removing biomass from the stock that otherwise would be available to the fishery in later years. The lower estimates of annual surplus production shown in Table 2 are one indication of this. A drop in the average weight at age also contributes to the decline in biomass. Figure 3 shows the smoothed (averaged) weights at age for 10 year olds as estimated from closed sub-area runs. Recruitment is also a factor, and while recruitment appears to be leveling off in some areas and increasing in others (Figure 4) several years of poorer recruitment will have an effect on the fishery. Exploitation rates (Figure 5) continue to increase indicating that a healthy proportion of the stock is being harvested, but as stocks decline so too must the allowable catch.

Technical Notes

An interesting and perhaps encouraging phenomenon happening in the fishery this year is an increase in the representation of 9-year-old halibut in the catch over the number of 8-year-olds represented in the catch last year. It is not clear what caused this apparent increase in 9-year-olds. The increase may be due to a difference in targeting or a shift in the timing of the openings, however it may reflect a real increase in the abundance of 9-year-olds in the exploitable stock as a result of migration of these halibut from areas outside those commonly visited by the fishery and may indicate that recruitment was better last year. It will take at least another year's observation to confirm this. Regardless of the cause the result of having an increase in the observed number of 9-year-old halibut over the number expected, based on the level of 8-year-olds in the stock last year, is that the estimated total stock biomass is significantly reduced from the estimates obtained over the last several years. Figure 6 shows the reduction in abundance under the closed combined area catch-age analysis with and without the 1988 catch and effort data. A decrease of between 6% and 7% is observed between the two combined area estimates of total stock abundance for the years 1985 through 1987. The circumstances by which this shift occurs in the estimation procedure are complicated but basically reflect an increase in the estimated fishing mortality to account for the increase in 9-year-olds and a decrease in the abundance of older age groups to maintain the level of the catch. To reduce the effect that this change in cohort abundance has on the estimates of stock size an average of two runs of each stock assessment procedure was made. Run 1 removed the influence of the 1987 level of 8-year-olds while run 2 removed the influence of the 1988 level of 9-year-olds. Figure 6 shows these two runs and their average for the combined area estimates of total stock abundance. It is the averaged biomass estimate that is shown in Tables 3 through 5.

Table 1: Preliminary CPUE estimates. Data are standardized to "C" hook equivalence. For further details, see the 1988 stock assessment document, section 5. Area 2A and southern 2B CPUE based in part on conversion of "snap-on" gear to conventional gear, as documented in 1986.

CPUE by Regulatory Area (lbs/skate)

Year	Areas Combined	2A	2B	2C	3A	3B	4
76	124.8	71.7	116.7	116.0	131.4	142.2	184.2
77	138.5	182.2	135.3	124.3	134.6	161.3	176.2
78	155.1	85.5	138.0	155.1	171.9	116.4	166.7
79	159.7	110.0	105.8	220.8	189.0	80.8	146.1
80	204.0	82.0	143.7	218.4	260.6	249.5	124.2
81	232.3	134.4	175.7	273.6	250.8	294.6	236.8
82	253.8	127.0	176.7	355.9	274.1	300.7	172.5
83	275.1	127.6	180.5	342.9	349.6	335.5	112.1
84	300.1	127.2	188.8	328.5	412.8	353.1	193.6
85	311.5	109.4	176.5	354.1	401.2	420.1	296.4
86	292.9	132.4	154.7	296.4	411.9	322.4	304.6
87	278.4	62.9	157.9	244.5	437.0	329.9	276.4
88	261.2	111.6	151.1	229.6	357.8	478.9	191.3

Catch in million lbs. by subarea

Year	Areas Combined	2A	2B	2C	3A	3B	4
76	27.535	.238	7.283	5.527	11.044	2.809	.634
77	21.868	.207	5.427	3.186	8.641	3.323	1.084
78	21.988	.097	4.607	4.316	10.295	1.327	1.346
79	22.527	.046	4.857	4.530	11.335	.390	1.369
80	21.866	.022	5.650	3.238	11.966	.277	.713
81	25.736	.202	5.241	4.495	14.198	.416	1.185
82	29.008	.290	5.538	3.500	13.499	5.766	.416
83	38.384	.363	5.428	6.610	15.580	8.426	1.977
84	44.970	.430	9.054	5.857	19.961	7.545	2.122
85	56.113	.493	10.384	9.211	20.852	12.464	2.709
86	69.576	.549	11.249	10.661	32.738	11.196	3.183
87	69.283	.592	12.218	10.719	31.066	10.224	4.464
88	73.770	.486	12.799	11.441	37.563	6.905	4.576

Table 2. Summary of 1988 population assessment results. The range of estimates corresponds to maximum and min. of results from three methods of catch-age analysis. Note that range values for Combined is more precise than the sum of ranges from individual Reg. Areas, with the exception of Adjusted Setline CEY (#5.)

Reg. Area	2A	2B	2C	3A	3B	4	Combined
1988 Quota	0.48	12.5	11.5	36.0	8.0	5.4	73.9
1988 Catch	0.49	12.8	11.4	37.6	6.9	4.6	73.8
1.							
ASP--total annual surplus production (million lbs)							
Range							
Upper	1.10	13.1	10.1	51.0	16.5	8.0	84.2
Lower	0.92	9.5	8.5	35.8	4.9	3.0	70.0
2.							
Setline ASP--subtract other catches from total ASP							
Range							
Upper	1.00*	9.9	6.0	39.2	14.4	6.9	61.8
Lower	0.82*	6.2	4.5	24.0	2.7	1.9	47.6
3.							
CEY--total constant exploitation yield (million lbs)							
Range							
Upper	0.76	14.1	14.4	54.5	20.5	9.8	85.9
Lower	0.24	5.7	6.3	34.2	3.7	2.5	63.3
4.							
Setline CEY--subtract other catches from total CEY							
Range							
Upper	0.66*	10.9	10.4	42.7	17.9	9.2	63.5
Lower	0.14*	2.5	2.2	22.4	1.1	1.9	41.0
***********							
5.							
Adjusted Setline CEY--proportional allocation, sums to combined CEY							
Range : Note-- maximum relative CEY in 4. is the proportion							
Upper	0.6*	7.5	7.2	29.5	12.4	6.3	63.5
Lower	0.6*	4.8	4.6	18.9	8.0	4.1	41.0
***********							
6.							
MSY--maximum sustainable yield, a long-term reference point							
All gear	0.80	18.6	11.3	29.2	10.0	11.0	80.9
Setline	0.23	15.4	7.3	17.4	7.4	10.3	58.1
7.							
Other catches accounted for in reducing Totals to Setline							
1987 Sport	-*	0.70	0.86	2.05	0.00	0.02	3.63
1988 Waste	0.00	0.05	0.21	1.51	0.12	0.07	1.96
1988 ByCat	0.10	2.46	2.97	8.25	2.44	0.57	16.79
Total	0.10	3.21	4.04	11.81	2.56	0.66	22.38

Note: By-Catch Mortality is apportioned into areas proportional to biomass estimates from closed subarea catch-age analysis.

* CEYs and ASPs for Area 2A include sport catch.

Table 3. Exploitable biomass, constant exploitation yield (CEY), annual surplus production (ASP) for setline, and commerical catches. Estimates based on averages of 2 migratory catch-age analysis runs.

Biomass in million lbs. by subarea

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	120.00	1.23	24.20	22.49	50.40	11.51	10.18
1977	122.50	1.03	23.86	22.55	53.29	12.06	9.72
1978	127.57	0.99	23.50	24.72	57.09	12.20	9.08
1979	136.92	0.98	23.48	26.69	60.08	16.00	9.69
1980	145.06	0.92	23.06	28.68	62.29	19.81	10.31
1981	154.35	0.92	22.28	31.72	64.88	23.62	10.92
1982	175.79	0.96	22.24	35.28	69.13	33.30	14.88
1983	192.69	0.94	23.61	39.85	77.08	35.05	16.17
1984	205.71	1.08	25.30	41.80	87.32	33.29	16.93
1985	220.01	0.96	25.65	43.95	95.95	34.34	19.17
1986	218.88	0.94	24.26	42.20	103.27	30.84	17.37
1987	199.21	0.83	20.71	37.99	97.46	27.57	14.65
1988	180.85	0.67	16.38	32.71	97.64	22.46	10.98

Setline Annual Surplus Production in million lbs

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	30.04	0.05	6.94	5.59	13.93	2.87	0.66
1977	26.93	0.16	5.07	5.35	12.45	2.89	1.01
1978	31.34	0.09	4.59	6.28	13.29	4.91	2.19
1979	30.67	-0.02	4.44	6.52	13.54	4.13	2.05
1980	31.15	0.03	4.87	6.28	14.56	4.04	1.38
1981	47.18	0.24	5.20	8.05	18.45	10.03	5.21
1982	45.91	0.27	6.91	8.07	21.44	6.53	2.69
1983	51.40	0.50	7.11	8.57	25.82	5.22	4.18
1984	59.27	0.31	9.41	8.01	28.59	7.30	5.65
1985	54.98	0.48	8.99	7.46	28.18	6.83	3.05
1986	49.90	0.44	7.71	6.45	26.93	6.00	2.38
1987	50.92	0.43	7.89	5.44	31.24	3.37	2.55
1988	47.23	0.35	6.24	4.68	31.29	2.75	1.91

Total CEY in million lbs when exploitation is 0.35

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	42.00	0.43	8.47	7.87	17.64	4.03	3.56
1977	42.88	0.36	8.35	7.89	18.65	4.22	3.40
1978	44.65	0.35	8.22	8.65	19.98	4.27	3.18
1979	47.92	0.34	8.22	9.34	21.03	5.60	3.39

1980	50.77	0.32	8.07	10.04	21.80	6.93	3.61
1981	54.02	0.32	7.80	11.10	22.71	8.27	3.82
1982	61.53	0.34	7.78	12.35	24.20	11.66	5.21
1983	67.44	0.33	8.26	13.95	26.98	12.27	5.66
1984	72.00	0.38	8.85	14.63	30.56	11.65	5.93
1985	77.01	0.34	8.98	15.38	33.58	12.02	6.71
1986	76.61	0.33	8.49	14.77	36.14	10.80	6.08
1987	69.72	0.29	7.25	13.30	34.11	9.65	5.13
1988	63.30	0.24	5.73	11.45	34.17	7.86	3.84

Setline CEY after subtracting other catches from total CEY

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1988	40.47	-0.33	2.52	7.42	22.37	5.74	2.75

Total CEY when exploitation is 0.35
where partitioning of total CEY is based on subarea ASP

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	42.00	0.06	9.70	7.81	19.48	4.02	0.92
1977	42.88	0.26	8.07	8.52	19.82	4.60	1.61
1978	44.65	0.12	6.54	8.95	18.93	6.99	3.12
1979	47.92	-0.02	6.93	10.19	21.16	6.46	3.21
1980	50.77	0.05	7.94	10.24	23.73	6.58	2.24
1981	54.02	0.28	5.96	9.22	21.13	11.48	5.97
1982	61.53	0.36	9.27	10.81	28.74	8.75	3.61
1983	67.44	0.66	9.33	11.24	33.88	6.85	5.49
1984	72.00	0.38	11.43	9.72	34.73	8.87	6.87
1985	77.01	0.67	12.59	10.45	39.46	9.57	4.27
1986	76.61	0.67	11.83	9.90	41.34	9.21	3.65
1987	69.72	0.60	10.80	7.45	42.77	4.61	3.50
1988	63.30	0.47	8.36	6.27	41.94	3.68	2.57

Setline CEY after subtracting other catches from total CEY
where partitioning of total CEY is based on subarea ASP

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1988	40.47	-0.10	5.15	2.24	30.14	1.56	1.47

ble 4. Exploitable biomass, constant exploitation yield (CEY), annual surplus production (ASP) for setline, and commerical catches. Estimates based on the averages of 2 closed subarea catch-age analysis runs with no migration.

Biomass in million lbs. by subarea

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	131.86	1.41	27.86	24.50	52.63	13.51	11.95
1977	133.56	1.18	27.26	24.27	55	14.08	11.34
1978	140.44	1.15	27.24	26.50		14.28	10.63
1979	146.44	1.14	27.46	28.49		15.21	9.79
1980	155.71	1.08	27.25	30.94		18.98	10.01
1981	172.68	1.11	26.87	34.35	71.	26.70	12.35
1982	197.64	1.18	27.38	38.54	76.	37.21	16.63
1983	218.29	1.17	29.54	43.95		39.49	18.22
1984	234.82	1.38	32.49	46.75		38.21	19.43
1985	253.36	1.30	34.79	49.38	105.69	39.92	22.28
1986	256.26	1.37	35.41	48.11	114.02	36.69	20.66
1987	251.41	1.41	35.14	45.22	116.15	34.93	18.56
1988	243.75	1.36	33.22	41.12	122.32	30.71	15.01

Setline Annual Surplus Production in million lbs

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	29.23	0.01	6.69	5.29	13.84	2.89	0.51
1977	28.75	0.17	5.41	5.41	13.86	2.96	0.94
1978	27.99	0.10	4.82	6.30	14.01	2.03	0.73
1979	31.79	-0.01	4.65	6.98	14.42	4.09	1.66
1980	38.84	0.05	5.28	6.65	15.82	7.95	3.09
1981	50.69	0.27	5.75	8.68	19.60	10.86	5.54
1982	49.67	0.28	7.71	8.91	22.72	7.06	3.00
1983	54.91	0.57	8.37	9.42	26.22	5.70	4.64
1984	63.51	0.35	11.36	8.49	29.09	7.96	6.27
1985	59.01	0.57	11.01	7.94	29.19	7.10	3.22
1986	64.72	0.58	10.97	7.77	34.87	7.52	3.00
1987	61.62	0.55	10.30	6.62	37.24	4.24	2.67
1988	61.40	0.53	9.74	6.02	39.22	3.73	2.16

Total CEY in million lbs when exploitation is 0.35

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	46.15	0.49	9.75	8.58	18.42	4.73	4.18
1977	46.75	0.41	9.54	8.49	19.40	4.93	3.97
1978	49.15	0.40	9.53	9.27	21.22	5.00	3.72
1979	51.26	0.40	9.61	9.97	22.53	5.32	3.42
1980	54.50	0.38	9.54	10.83	23.61	6.64	3.50
1981	60.44	0.39	9.41	12.02	24.96	9.35	4.32
1982	69.17	0.41	9.58	13.49	26.85	13.02	5.82

Sullivan, P.J., Clark, W.G., Neal, P.R., Price, R., 1988. Stock Assessment Document III: Section 1. Population Assessment, 1988. IPHC Rep., pp. 1–16.

1983	76.40	0.41	10.34	15.38	30.07	13.82	6.38
1984	82.19	0.48	11.37	16.36	33.79	13.37	6.80
1985	88.68	0.45	12.18	17.28	36.99	13.97	7.80
1986	89.69	0.48	12.39	16.84	39.91	12.84	7.23
1987	87.99	0.49	12.30	15.83	40.65	12.23	6.50
1988	85.31	0.48	11.63	14.39	42.81	10.75	5.25

Setline CEY after subtracting other catches from total CEY

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1988	62.48	-0.09	8.42	10.36	31.01	8.62	4.16

Total CEY when exploitation is 0.35
where partitioning of total CEY is based on subarea ASP

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	46.15	0.01	10.56	8.36	21.85	4.56	0.81
1977	46.75	0.28	8.79	8.80	22.53	4.82	1.53
1978	49.15	0.17	8.47	11.07	24.61	3.56	1.28
1979	51.26	-0.02	7.49	11.25	23.25	6.60	2.68
1980	54.50	0.07	7.40	9.33	22.19	11.16	4.34
1981	60.44	0.32	6.85	10.35	23.37	12.94	6.60
1982	69.17	0.39	10.73	12.41	31.64	9.83	4.17
1983	76.40	0.80	11.65	13.10	36.48	7.93	6.45
1984	82.19	0.45	14.70	10.98	37.65	10.30	8.11
1985	88.68	0.85	16.54	11.93	43.86	10.66	4.84
1986	89.69	0.81	15.21	10.77	48.32	10.43	4.16
1987	87.99	0.78	14.71	9.46	53.17	6.06	3.81
1988	85.31	0.74	13.53	8.37	54.49	5.18	3.00

Setline CEY after subtracting other catches from total CEY
where partitioning of total CEY is based on subarea ASP

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1988	62.48	0.17	10.32	4.34	42.69	3.06	1.90

1984	80.21	0.48	11.31	16.92	35.45	12.83	3.21
1985	87.12	0.44	11.67	17.60	39.64	13.77	4.01
1986	89.94	0.45	11.61	16.75	41.77	14.94	4.41
1987	88.74	0.44	11.09	14.82	41.44	16.51	4.44
1988	85.87	0.43	10.48	12.88	39.42	18.38	4.29

Setline CEY after subtracting other catches from total CEY

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1988	63.04	-0.14	7.27	8.85	27.62	15.81	3.64

Total CEY when exploitation is 0.35
where partitioning of total CEY is based on subarea ASP

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	44.09	0.01	10.44	9.19	19.86	4.98	-0.38
1977	44.69	0.23	7.44	9.64	20.90	5.85	0.64
1978	47.51	0.05	5.13	12.92	23.91	4.81	0.69
1979	50.65	-0.06	6.67	12.68	23.74	6.90	0.73
1980	53.80	0.18	10.50	11.88	24.12	6.72	0.40
1981	58.31	0.43	9.30	12.26	28.89	5.47	1.95
1982	66.76	0.31	8.89	8.56	36.11	11.08	1.82
1983	75.13	0.64	7.57	9.47	38.86	13.44	5.16
1984	80.21	0.37	12.51	9.65	39.57	12.65	5.46
1985	87.12	0.73	13.87	9.20	36.59	21.50	5.25
1986	89.94	0.72	13.27	7.01	43.22	21.28	4.43
1987	88.74	0.80	15.19	7.52	36.72	22.62	5.89
1988	85.87	0.76	14.09	6.42	34.29	24.72	5.60

Setline CEY after subtracting other catches from total CEY
where partitioning of total CEY is based on subarea ASP

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1988	63.04	0.19	10.88	2.39	22.49	22.16	4.94

Table 5. Exploitable biomass, constant exploitation yield (CEY), annual surplus production (ASP) for setline, and commerical catches. Estimates based on the averages of 2 catch-age analysis runs for total stock with CPUE subarea partition.

Biomass in million lbs. by subarea

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	125.97	1.51	29.82	23.28	44.04	17.49	9.82
1977	127.68	1.28	29.46	23.85	46.17	17.98	8.93
1978	135.75	1.22	29.02	27.12	51.53	18.58	8.27
1979	144.73	1.16	27.76	31.23	56.82	20.39	7.37
1980	153.72	1.08	27.06	34.59	60.26	24.29	6.46
1981	166.60	1.17	28.18	39.02	63.87	28.35	6.00
1982	190.75	1.34	30.90	45.02	74.39	32.62	6.49
1983	214.66	1.29	32.41	48.30	89.51	35.63	7.51
1984	229.16	1.37	32.31	48.35	101.29	36.67	9.17
1985	248.92	1.24	33.36	50.28	113.26	39.33	11.45
1986	256.97	1.29	33.18	47.84	119.35	42.70	12.60
1987	253.55	1.27	31.69	42.34	118.41	47.16	12.68
1988	245.35	1.23	29.93	36.80	112.62	52.50	12.27

Setline Annual Surplus Production in million lbs

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	29.24	0.00	6.92	6.10	13.17	3.30	-0.25
1977	29.95	0.15	4.99	6.46	14.00	3.92	0.43
1978	30.96	0.03	3.34	8.42	15.58	3.13	0.45
1979	31.52	-0.03	4.15	7.89	14.77	4.29	0.45
1980	34.74	0.11	6.78	7.67	15.58	4.34	0.26
1981	49.89	0.37	7.96	10.49	24.72	4.68	1.67
1982	52.91	0.24	7.05	6.78	28.62	8.78	1.44
1983	52.89	0.45	5.33	6.66	27.36	9.46	3.63
1984	64.73	0.30	10.10	7.79	31.93	10.21	4.41
1985	64.16	0.53	10.21	6.77	26.94	15.83	3.86
1986	66.16	0.53	9.76	5.16	31.79	15.66	3.26
1987	61.08	0.55	10.46	5.18	25.27	15.57	4.05
1988	60.20	0.53	9.88	4.50	24.04	17.33	3.92

Total CEY in million lbs when exploitation is 0.35

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1976	44.09	0.53	10.44	8.15	15.42	6.12	3.44
1977	44.69	0.45	10.31	8.35	16.16	6.29	3.12
1978	47.51	0.43	10.16	9.49	18.04	6.50	2.90
1979	50.65	0.40	9.72	10.93	19.89	7.14	2.58
1980	53.80	0.38	9.47	12.11	21.09	8.50	2.26
1981	58.31	0.41	9.86	13.66	22.36	9.92	2.10
1982	66.76	0.47	10.82	15.76	26.04	11.42	2.27
1983	75.13	0.45	11.34	16.90	31.33	12.47	2.63

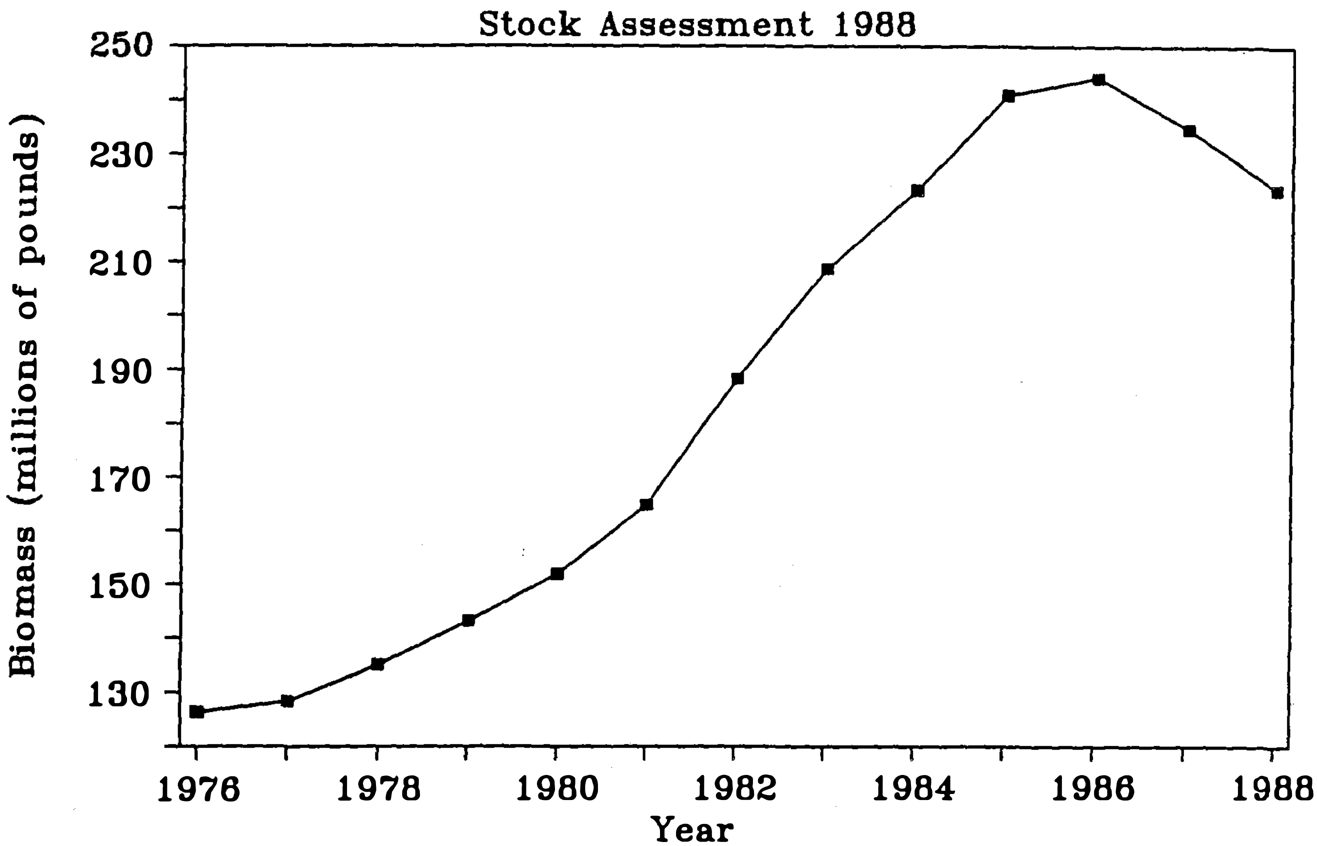

Figure 1 Total exploitable biomass

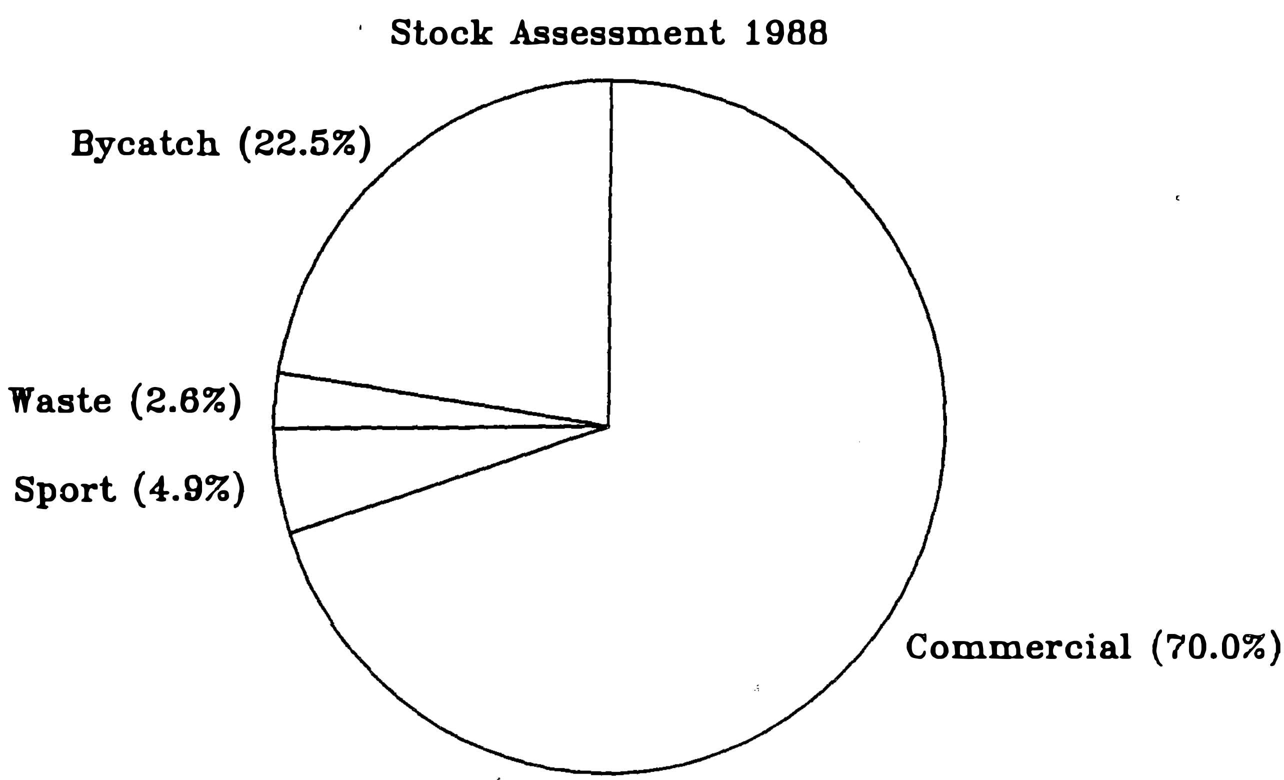

Figure 2 CEY allocation

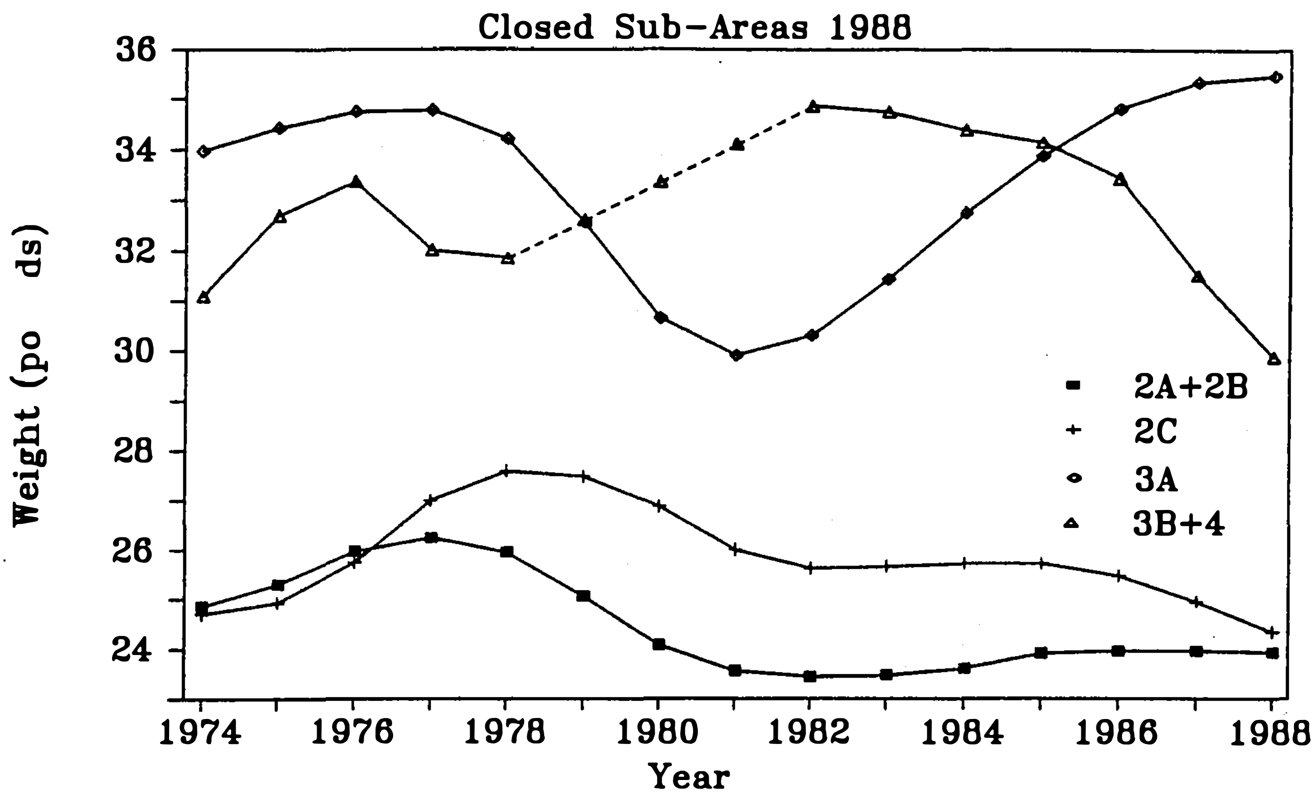

Figure 3 Smoothed weight of 10 year olds

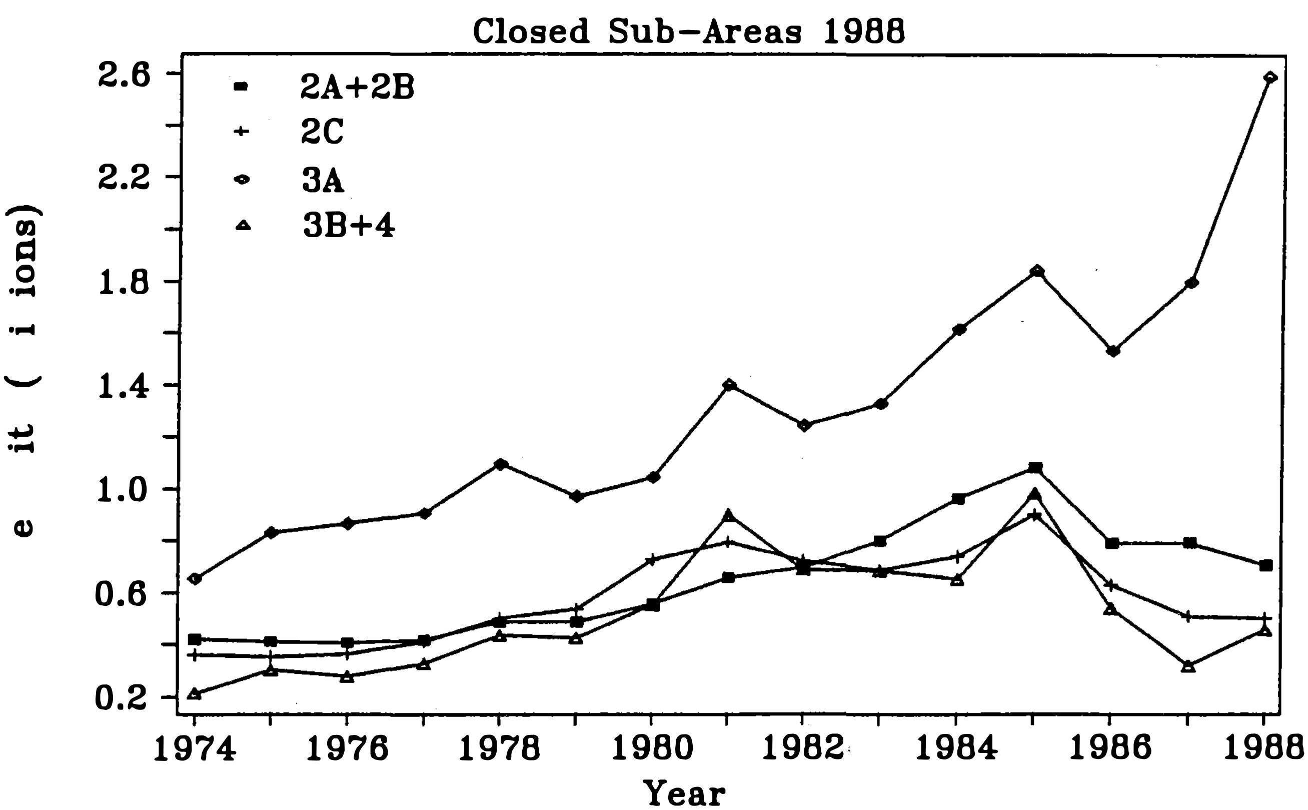

Figure 4 Recruitment

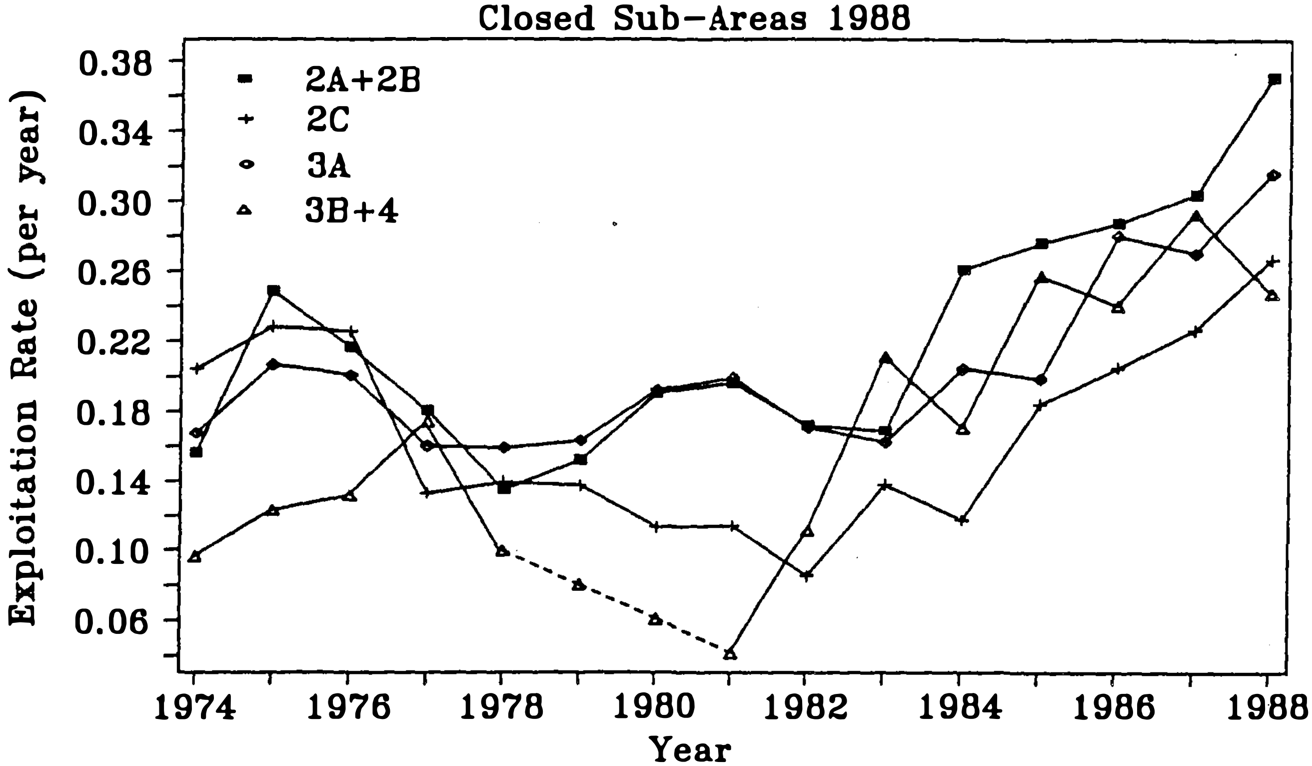

Figure 5 Exploitation rate

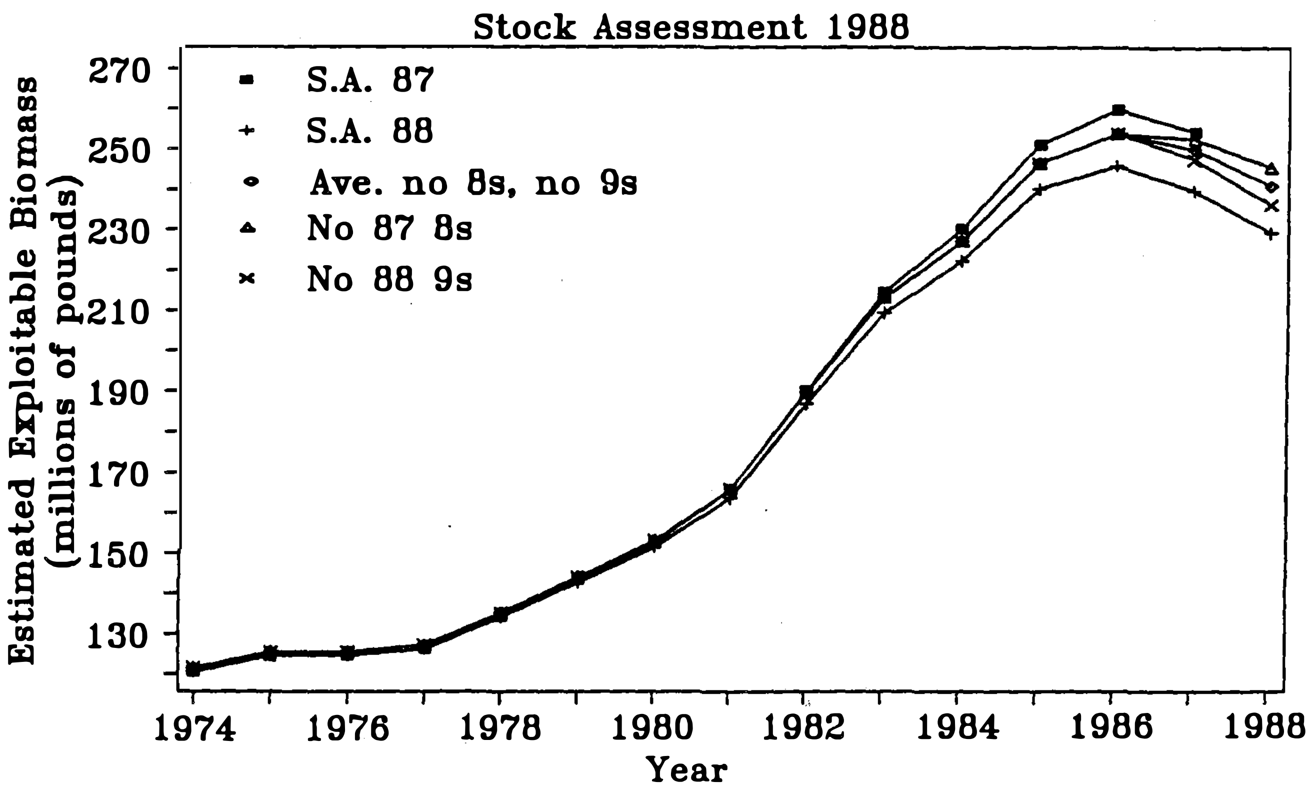

Figure 6 Exploitable biomass (combined run)

Sullivan, P.J., Clark, W.G., Neal, P.R., Price, R., 1988. Stock Assessment Document III: Section 1. Population Assessment, 1988. IPHC Rep., pp. 1–16.