INTERNATIONAL PACIFIC HALIBUT COMMISSION

ESTABLISHED BY A CONVENTION BETWEEN
CANADA AND THE UNITED STATES OF AMERICA

Scientific Report No. 72

Methods of Population Assessment of Pacific Halibut

by

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SEATTLE, WASHINGTON
1985

The International Pacific Halibut Commission has three publications: Annual Reports (U.S. ISSN 0074-7238), Scientific Reports, and Technical Reports (U.S. ISSN 0579-3920). Until 1969, only one series was published (U.S. ISSN 0074-7246). The numbering of the original series has been continued with the Scientific Reports.

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ABSTRACT

Current methods of population assessment for Pacific halibut *(Hippoglossus stenolepis)* are summarized. Factors affecting catch-per-unit-effort (CPUE) data are investigated, leading to standardization of CPUE for hook spacing, gear type, and regional catchability differences. Catch-age data are judged to be of adequate precision and accuracy. Two methods are described for estimating poulation parameters for geographic assessment areas. The first method, catch-age analysis with CPUE partitioning, develops estimates of population parameters from catch-age and auxiliary catch-effort data for the entire population and partitions into assessment areas with CPUE data. The second method, migratory catch-age analysis, analyzes data from each area with links between areas established from information about migration rates. For short-term assessment purposes, two methods of estimating annual surplus production are described: the blind-response method and the biomass-partitioning method. Recent estimates of exploitable biomass, surplus production, and CPUE are contrasted, and historical estimates are constructed when possible. For long-term assessment, the traditional use of maximum sustained yield (MSY) as a long-term goal is contrasted with a more stable management goal, called the policy of constant exploitation yield (CEY). Determination of catch limits from estimates of surplus production, CEY, and of MSY is described, with the CEY approach favored at this time. The effect of commercial and incidental catch in one area on future yield from other areas is investigated. Incidental catch has a larger effect than commercial catch because juvenile fish, which comprise most of the incidental catch, have higher migration rates than adults.

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INTRODUCTION

The International Pacific Halibut Commission (IPHC) has placed major emphasis on timely assessment of the population status of Pacific halibut. Its research programs have been directed at collection of information to assure rational management of the Pacific halibut resource. A logbook program has been in effect since the beginning of the organization to collect catch and effort statistics from fishermen (Myhre et al. 1977). Information from fish processors has been collected to maintain accurate records of the commercial catch (Myhre et al. 1977). Since 1934, landings have been sampled to provide pertinent age, length, and weight composition of the commercial catch (Quinn et al. 1983). Field research programs have provided necessary information on growth, migration, mortality, sex composition, gear efficiency, standardized catches, and other factors (Hoag et al. 1979, 1980; Best and Hardman 1982). Information about incidental catches of Pacific halibut in other fisheries has been obtained for better population assessment (Hoag and French 1976).

Methods used by IPHC to assess population status have evolved with the advent of better mathematical and statistical procedures. In the 1960's the maximum yields that could be obtained on a sustained basis were determined with analyses of yield per recruitment and stock production (IPHC 1960, Chapman et al. 1962). Several investigations have provided information about factors that affect catch-per-unit-effort and its use as an index of population abundance (e.g., Myhre 1969; Skud 1972, 1975, 1978a, b; Hamley and Skud 1978; Quinn et al. 1982). A series of investigations commenced in the 1970's, which involved the use of catch-age information to estimate abundance (Southward 1976; Hoag and McNaughton 1978; Quinn et al. 1984; Deriso et al. 1985). These investigations and scientific field research have led to investigations of fecundity and stock recruitment (Schmitt and Skud 1978; Deriso 1985) and population modeling (Deriso 1980; Quinn 1981).

The purpose of this paper is to provide a concise account of the methods that are currently used for assessing population status. This review relies on material found in recent reviews of methods of determining annual surplus production (Quinn et al. 1984), data sources used in population assessment (Quinn 1985a), and analyses of population dynamics (Deriso 1985).

In this paper, we provide a review of data sources used in analyses, such as catch-per-unit-effort (CPUE) and catch-age data. Several factors are considered in order to use CPUE data for assessment purposes. We then focus on methods of determining population status by geographic areas shown in Figure 1. These assessment areas differ somewhat from current regulatory areas, which often change annually. We provide summaries of two methodologies for estimating population abundance and biomass: 1. catch-age analysis with CPUE partitioning, 2. migratory catch-age analysis. We then describe the determination of annual surplus production (ASP) from biomass estimates

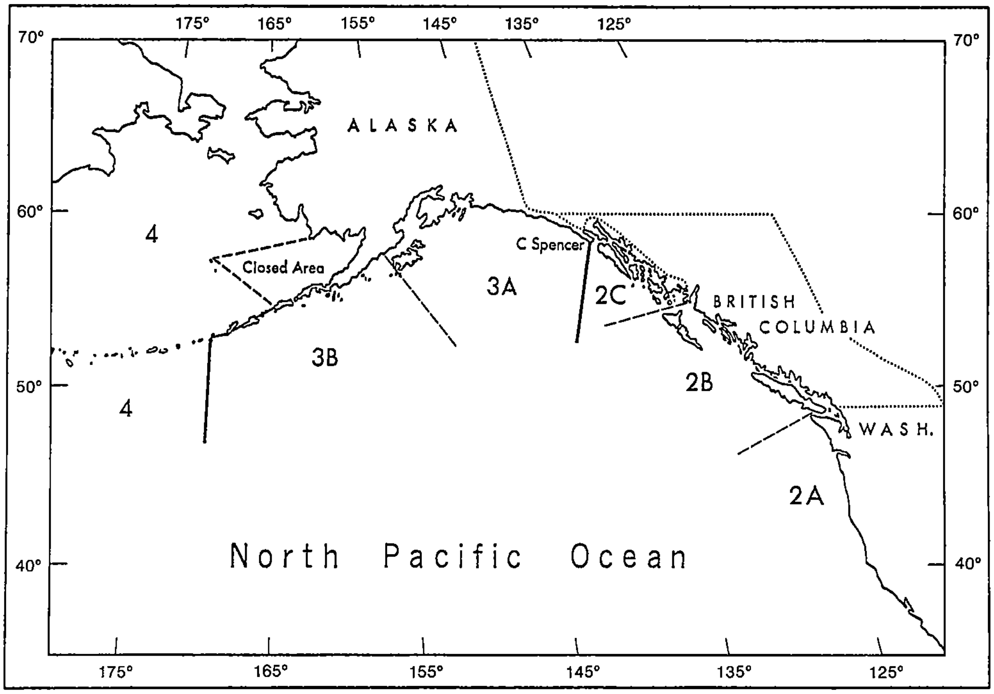

Figure 1. Assessment areas for Pacific halibut.

and commercial and incidental catches. The long-term management objectives of IPHC require that maximum productivity on a geographic basis be determined. To this end, we re-evaluate maximum sustained yield (MSY) and determine exploitation rates which can be used for determining surplus production. Finally, we discuss the various methods and append the results from our analysis of 1984 data.

EVALUATION OF DATA

CATCH-PER-UNIT-EFFORT (CPUE)

CPUE is an index of population density (number or weight of fish per unit area) for a variable of interest (e.g. time, region, gear), if the probability of catching a fish with a unit of effort, termed catchability, is constant for that variable. Recent evaluations of CPUE (summarized below) have revealed that there are both long- and short-term changes in catchability over time, across regions, and between gear types. Hence, direct use of CPUE is not acceptable for assessing population size. However, other methods of assessment require use of CPUE as auxiliary information. In this section, we discuss some of the factors affecting CPUE and attempt to adiust for the important factors.

Statistical Distribution

The underlying distribution of CPUE data is positively skewed, which may be a result of aggregation in the catching process. A convenient model for the data is the root-normal distribution, which is defined as the distribution of a random variable whose square root is normally distributed (Quinn 1985b). An estimator of the median is a better measure of central tendency and has lower variance than the ratio estimator of the mean used by Myhre et al. (1977). However, the mean and median estimates both have the same trend, so no corrections in CPUE were made for this factor.

Short-term Catchability Trend

Logbook data indicate that CPUE tends to decline during a fishing period. This probably is a result of local depletion on heavily frequented fishing grounds and competition among vessels. During closed periods, halibut apparently redistribute themselves over the grounds as CPUE often will again be high at the beginning of the next fishing period. Prospecting prior to the season may also contribute to the high CPUE at the start of the season, as will illegal fishing when the catch prior to the season may be claimed as part of the first day's catch. These "opening day" effects suggest that CPUE from short fishing periods cannot be compared directly with CPUE from long periods. Examples of the decline in CPUE during the season are shown in Figure 2. Both Areas 2B and 2C show a decline in CPUE during the fishing season, but the decline was much sharper in Area 2C where the fishing was more intense. If the season in Area 2C had been as long as the season in Area 2B, average CPUE in Area 2C may have been much lower. On the other hand, CPUE in Area 2C probably would not have declined as sharply if the effective fishing effort was lower as in Area 2B.

Mathematical models of CPUE are being investigated to address these concerns (Quinn[1]). A short-term catchability function of time or effort appears to be applicable to Pacific halibut data. Preliminary results suggest that CPUE should be standardized for catchability declines. In this report, regional catchability corrections are made from trawl-setline experiments (mentioned below).

Gear Type

Two common types of setline gear for catching Pacific halibut are fixed-hook and snap gear (Myhre and Quinn 1984). With fixed-hook gear, hooks are attached to the groundline with gangions, resulting in a fixed spacing of hooks along the groundline. With snap gear, hooks are attached to removable snaps with gangions and are attached to the groundline as the gear is being set. Thus, the spacing between hooks with snap gear can be varied according to the will of the skipper and crew.

CPUE of Pacific halibut is computed using data from vessels with fixed-hook gear, although in some regions, most of the fishing occurs with vessels using snap gear. Based on recent field work and analysis (Myhre and Quinn 1984), the efficiency of fixed-hook and snap gear appears to be the same. Differences still arise in commercial CPUE of vessels of the two gear types, presumably due to differences in fishing grounds, skipper skill, or other vessel characteristics. Only in Regulatory Area 2A did we need to use

[1]Quinn, T.J., II, Standardization of catch-per-unit-effort for short-term trends in catchability. IPHC Working Paper.

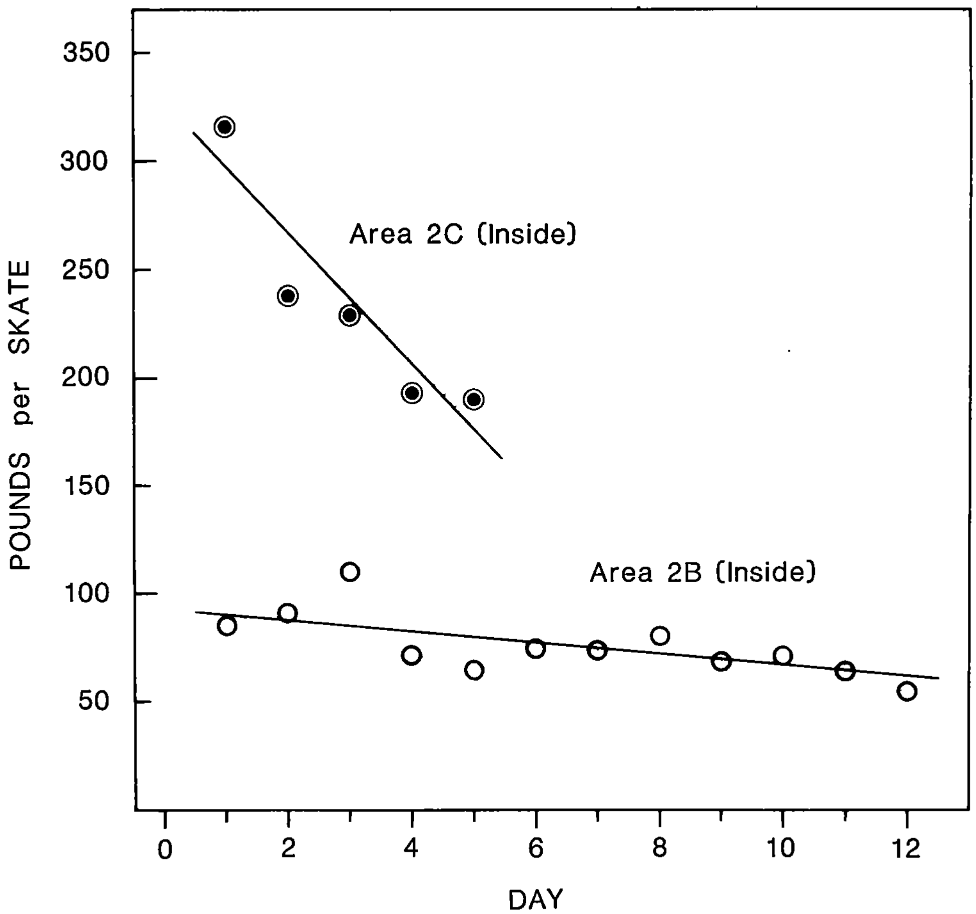

Figure 2. **Examples of the decline in CPUE during the fishing season, Areas 2B and 2C (inside waters), 1983.**

CPUE from snap gear. Incorporation of data from snap gear into the estimation of CPUE is still being investigated.

Regional Catchability Correction

A regional difference in setline catchability has been suggested as one of the factors responsible for a different degree of change in CPUE among regions. In the past two years, IPHC has carried out trawl-setline comparisons in Areas 2B (British Columbia) and 3A (eastern Gulf of Alaska). This experiment could not be done in Area 2C (SE Alaska) for lack of trawlable bottom. Using the results from the trawl as a standard, differences in setline catchability can be uncovered. The results of these studies (Hoag et al. 1984) indicate that relative catchability in Area 3A is 50% higher than in Area 2B. Comparison of CPUE changes with results from other analyses suggests that this phenomenon has occurred since about 1981 and the result for Area 3A applies to Areas 2C and 3B (western Gulf of Alaska) as well. We suspect that these results are evident of above-average availability of halibut in these areas. The causes of increased availability are not known but may be due to changing environmental conditions or shorter fishing periods. In Area 2B, dogfish abundance may be a factor in reducing CPUE in comparison with other areas, because dogfish may compete with halibut for baited hooks.

For stock assessment purposes, we used a variety of CPUE data sets corrected for differential catchability among regions (explained below in the section "Adjusted Data Sets"). Further study is needed concerning regional differences in catchability. Using trawl CPUE as a standard requires the assumption that trawl catchability is constant among regions. This not-unreasonable assumption should be investigated, if possible. Also, further understanding of setline catchability differences is necessary to apply corrections to future data.

Hook Type

The typical hook used with setline gear for catching Pacific halibut had the shape of the letter "J". Recently, a new type of hook with a more circular shape has become predominant in the commercial halibut fishery. In fact, from 1982 to 1984, an almost total conversion occurred from standard J hooks to circle hooks on halibut setline vessels. Coastwide, 77% of the fixed-hook skates fished in 1984 used all circle hooks, 19% used a mixture of J and circle hooks, and only 4% used all J hooks. It was known that circle hook gear was more efficient than J hook gear in catching Pacific halibut, but research was needed to determine a quantitative factor for the gear efficiency of circle hooks. IPHC conducted this research in 1983 and 1984, and preliminary analyses suggest that, on the average, CPUE with circle hooks is 2.2 times higher than with J hooks (Williams and McCaughran[2]). Further analyses are needed to examine regional differences, density effects, and possible differences in length composition of catches. Additional field research is being conducted to determine if CPUE with circle-hook gear is affected by hook spacing in the same way as J-hook gear.

For assessment purposes, several adjustments to the CPUE data were considered. First, CPUE from vessels with mixed hook types (both circle hooks and J hooks) was compared with CPUE from vessels fishing with only one hook type. CPUE from mixed-hook vessels did not differ markedly from J-hook vessels; thus no adjustment was made for mixed-hook vessels. CPUE data in 1982 were not adjusted because very few vessels had circle hooks. The year 1983 was a transition year and it was not possible to keep track of vessels which changed gear during the season. Thus, CPUE in 1983 was contaminated by an unknown quantity of circle hooks and could not be used at all. The average of CPUE in 1982 and adjusted CPUE in 1984 was used in place of actual CPUE data in 1983. Logbook effort from vessels using circle hooks in 1984 was multiplied by the factor 2.2 to adjust for the circle hook effect. Then, adjusted CPUE was calculated for all fixed-hook vessels as usual.

[2]Williams, G.H., and D.A. McCaughran. Results of comparative fishing of J hooks and circle hooks. 1985 IPHC Stock Assessment Document II: Research Results, 1984, p. 34-49.

Adjusted Data Sets

Four sets of CPUE data by assessment areas 2A, 2B, 2C, 3A, 3B, and 4 were constructed for use in the assessment of Pacific halibut in 1984. The circle hook adjustment was made in all data sets. The first data set contained CPUE values with only the circle-hook adjustment (Base Correction).

The other data sets were adjusted by the regional catchability correction from the trawl-setline experiments between Area 2B and other areas. The catchability difference from the experiments was relative, so it is not known if catchability is too high in Areas 2C, 3A, and 3B or too low in Area 2B. CPUE Adjustment I assumes that catchability is too low in Area 2B and multiplies CPUE by a factor of 1.5 in this area since 1981. CPUE Adjustment II assumes that CPUE is too high in Areas 2C, 3A, and 3B and divides CPUE by a factor of 1.5 in these areas since 1981. CPUE Adjustment III is a middle alternative between Adjustments I and II, and multiplies CPUE by 1.25 in Area 2B and divides CPUE by 1.25 in Areas 2C, 3A, and 3B since 1981.

The Base Correction and above three CPUE data sets covering the years 1979-1984 are recorded for each regulatory area in Appendix Tables 1-4, respectively. The Base Correction set of CPUE values is included to show the effect of the circle-hook correction, but only the fully-adjusted data sets are used in the analysis below.

CATCH-AGE DATA

The types of data collected by IPHC are described in Quinn (1985a). One of the most important data sources used in analysis of Pacific halibut is catch-age information from sampling landings of the commercial setline catch. The sampling design of the program to obtain catch-age information has been thoroughly reviewed and improved (Quinn et al. 1983a) and a summarized description of the current design may be found in Quinn et al. (1983b). Analysis of the historical data has revealed certain problems regarding missing data (Deriso and Quinn 1983). Estimates of population size are influenced by the missing data algorithm used, because age composition of the catch differed among regions over the historical period.

One novel feature of the sampling program since the 1960's is that all information is obtained from otolith measurements. Fish age is determined from visual inspection of annuli on the otolith, and fish length and weight are predicted from otolith measurements. These relationships are based on measurements pooled over many years and regions. Based on a field study of fish enumerations (Ian McGregor, T. Quinn, unpublished data), the otolith-weight/fish-weight relationship used since 1978 appears to be biased by about 10%, perhaps due to differences in fish growth or fish processing. Catch estimates since 1978 are reduced by 10% to correct for the bias. Errors in age reading may also affect catch-age estimates, and validation studies are in progress.

Catch-age estimates used in the assessments herein are based on the standard missing data algorithm described in Quinn et al. (1983a) and Deriso and Quinn (1983). We consider the estimates to be sufficiently precise (e.g. having small sampling variability) except in regions with small catches. We consider the estimates to be sufficiently accurate (e.g. with little statistical bias from the true values) with the assumption that the corrected otolith-fish relationships used to generate fish length and weight do not vary over time or space. This assumption is currently under investigation through the examination of research survey data, which include actual measurements of fish length.

CATCH-AGE ANALYSIS WITH CPUE PARTITIONING

CATCH-AGE ANALYSIS

Catch-at-age analysis utilizes relationships between catch and population parameters by age and year to estimate absolute abundance of year classes. Details and evaluation of this method, as well as a general review of catch-age methods, can be found in Deriso et al. (1985).

Catch at age C(t,a) is related to its earlier recruitment abundance by:

$$C(t,a) = \mu(t,a) \exp\left[-\sum_{j=1}^{a-1} Z(t-j,a-j)\right] N(t-a+1,1). \tag{1}$$

where

$$\mu(t,a) = \frac{F(t,a)}{Z(t,a)}[1-\exp(-Z(t,a))]$$

$$Z(t,a) = F(t,a) + M(t,a),$$

N(t,a) = population abundance at the beginning of year t for fish aged a reference years old ,

F(t,a) = fishing mortality rate in year t for age a-year-olds ,

and M(t,a) = natural mortality rate of a-year-olds in year t.

There are too many parameters to be estimated in equation (1) from catch information alone. We assume that fishing mortality is separable into a product of an age-specific selectivity coefficient, s(a), and a full-recruitment fishing mortality, f(t):

$$F(t,a) = s(a)\, f(t),$$

where s(a) = 1 for fully-recruited ages. The separability assumption is of fundamental importance in those models since it reduces the number of unknown fishing mortality parameters from AxT unknowns (A = number of ages, T = number of years of data) to less than A+T unknowns (T fishing mortality rates and fewer than A age-specific selectivity coefficients). Parameter estimation is thus feasible, especially when we assume values known for natural mortality.

Observed catch-at-age data, denoted C′(t,a), are assumed to differ from predictions in (1) by a log-normal random variable and thus non-linear least squares can be applied to minimize

$$SSQ(catch) = \sum_{t,a} (\log C'(t,a) - \log C(t,a))^2, \tag{2}$$

the negative part of a log-likelihood equation. The SSQ is called the residual sum of squares.

Fishing effort information is the primary source of auxiliary information to increase precision of parameter estimates. We assume that the relationship between the logarithms of fishing mortality and catchability times fishing effort is not exact, but the difference can be modeled by the normal distribution,

$$
\begin{aligned}
&\epsilon(t) = && \log f(t) - \log (qE(t)) \\
\text{where } &\epsilon(t) \sim && \text{normal } (0,\sigma^2) \text{ random variable ,} \\
&q = && \text{catchability coefficient ,} \\
&E(t) = && \text{observed fishing effort .}
\end{aligned}
$$

Residuals analysis of several data sets has suggested this assumption is reasonable.

This approach is selected for Pacific halibut because catchability tends to vary annually. This implies we add to the minimization criterion in (2) an auxuiliary sum of squares term

$$SSQ(\text{effort}) = \lambda \sum_t [\epsilon(t)]^2 \qquad (3)$$

where λ is the ratio of variances (variance of observed logarithm catch from that predicted in (1) divided by the variance of observed logarithm effort, σ^2). We consider λ to be a weighing term that adjusts the amount of influence of auxiliary information. This notion of adding an auxiliary sum of squares term can be applied to any type of auxiliary data available (such as for fish density estimates from survey cruises). A spawner-recruit relationship is another source of information, which adds to model structure (Deriso et al. 1985). A multinomial measurement error model and a process error model have also been evaluated (Deriso et al. 1985), but are not used here.

Natural mortality rate is chosen at an assumed value ($M = 0.2$), since reliability of estimates for that parameter seem especially poor (Quinn, Deriso, and Neal, unpublished data). The effect of changing the value of M has been studied elsewhere (Deriso and Quinn 1983), having little effect on total mortality Z but changing the partitioning among M and F. For assessment purposes, the choice of $\lambda = 0.5$ provided adequate influence of catch-effort information in terms of robustness of estimates. We did not use the spawner-recruit relationship because the data series was too short (years 1974-1984).

Pacific halibut catch data were combined across regions to obtain a total population estimate of ages 8-20, corresponding to our definition of the adult population. Halibut older than age 20 are not abundant in the catch and they are subject to possibly higher aging errors than younger fish. Based on previous studies (Quinn et al. 1984), fish aged 15-20 are assumed to be fully-recruited.

After the model is fitted to the data, estimates of model parameters are synthesized into the following fundamental population estimators on an annual basis: biomass and surplus production of the total population, biomass and surplus production of the exploitable population, year-class strength (abundance of age 8 fish), and fishing mortality of fully-recruited fish. The exploitable population is calculated by summing over all age classes, the product of age-specific abundance and the proportion of this age class fully vulnerable to fishing gear (the s(a) coefficient). Annual surplus production is defined in a later section. Exploitable biomass is the essential quantity in determining surplus production.

CPUE PARTITIONING

The goal of CPUE partitioning is to partition exploitable biomass estimated from catch-age analysis into assessment subareas.

Relative Habitat

The estimation of subarea biomass from CPUE data requires additional information about halibut habitat or bottom area. From Gulland (1969), the deterministic relationship between abundance N and CPUE is modeled as

$$CPUE_r = \tilde{q}_r N_r / A_r \,, \tag{4}$$

where $\tilde{q}$ is fishing effectiveness (related to catchability), A is bottom area, and subscript r is subarea. CPUE and N may be in either numbers or biomass of fish. Assuming fishing effectiveness between subareas is constant, then CPUE should be combined across subareas by weighting by bottom area, i.e.,

$$CPUE = \Sigma\, a_r\, CPUE_r \,,$$

where $a_r = A_r/A$ is relative bottom area and the lack of a subscript implies summation over the subscript. Then, relative abundance is estimated by

$$P_r = a_r\, CPUE_r/CPUE = a_r\, CPUE_r/\Sigma\, a_r\, CPUE_r. \tag{5}$$

Bottom area estimates from planimeter tracings of the area between 0 and 150 fathoms were made by IPHC (G. St-Pierre, IPHC, unpublished data) and are shown in Table 1. These areas define the range where halibut could conceivably occur. Bottom areas in Areas 2A and 3B are much larger than the areas where fishing has taken place historically.

Recently a different measure, habitat, was defined (Hoag et al. 1983) to be areas where halibut fishing has occurred historically, and Area 2 habitat values and recalculated bottom areas from that study are shown in Table 1. The differences are prominent, especially in Area 2A which has a lot of bottom area but little habitat. Habitat estimates are not available for Areas 3A, 3B, or 4.

An alternative indirect means of determining halibut habitat can be developed from abundance and CPUE data. The concept is to determine a coefficient Q_r for each subarea r that relates $CPUE_r$ and N_r.

From (4), Q_r may be written as

$$Q_r = \frac{N_r}{CPUE_r} = \frac{A_r}{\tilde{q}_r}$$

Each Q_r may be considered a measure of habitat that refers to bottom area corrected for fishing effectiveness. Correspondingly, estimated relative habitat is

$$Q_r^* = \frac{Q_r}{Q} = \frac{N_r/CPUE_r}{\Sigma N_r/CPUE_r} \,. \tag{6}$$

Relative habitat for halibut assessment subareas is estimated as follows. Abundance N_r of 8- to 20-year-olds from open-population cohort analysis (Deriso and Quinn 1983), catch C_r in numbers of 8- to 20-year-olds, and effort E_r were compiled by each subarea r. Then, $CPUE_r$ is calculated as C_r/E_r.

Table 1. Measures of halibut bottom area and habitat.

Subarea	2A	2B	2C	3A	3B	4	Total
Bottom area (A_r) [Square nm]	6235[1]	21371	13250	42828	33950	3394[2]	121028
Relative bottom area (a_r)	.052	.177	.110	.354	.280	.028	
Area 2 bottom area (Hoag et al. 1983)	11656	31599	14617				
Area 2 habitat (Hoag et al. 1983)	921	14338	9661				
Estimated relative habitat from catch in numbers (Q_r^*)							
Mean	.012	.192	.192	.344	.194	.065	
Median	.011	.198	.185	.366	.175	.065	
Estimated relative habitat from catch in weight (Q_r^*)							
Mean	.014	.233	.198	.331	.166	.058	
Median	.014	.241	.195	.352	.142	.057	

[1]Does not include statistical area 00 (waters south of about 43°30′N latitude).

[2]Does not include the Bering Sea

For each year and subarea, Q_r^* was estimated from equation (6). The values vary over time, and further study is needed to determine if this variability is due to spatial changes in the distribution of fishing effort.

To provide an overall statistic, we computed the mean and median habitat percentages over the years 1935-1970 in each subarea (Table 1). No catch was recorded in Area 4 in many years, and mean and median habitat percentages were used to fill in the missing data before considering other areas. The means and medians are close; however, the median is considered more reliable because of skewness in the distribution. Complimentary analyses were made with catch and abundance in weight (Table 1). The major differences from values obtained from catch in numbers are that Area 2B is higher and Area 3B is lower. The median values from catch in weight across years will be used to partition total habitat biomass into assessment subareas in subsequent sections, because CPUE values in weight are used in population assessment and average fish weight differs among subareas.

Subarea Biomass

The estimated relative biomass of each subarea for a given year is

$$P_r = Q_r^* \, CPUE_r / \sum_r Q_r^* \, CPUE_r \; . \tag{7}$$

The median values of Q_r^* from catch in weight were combined with CPUE data each year using equation (7) to estimate relative biomass. Because few landings have occurred in Area 4, the median relative biomass, .088, is used for all years, and other values are adjusted to sum to 1- .088 = .912. The estimates are highly variable and are smoothed with a robust non-linear procedure (Velleman 1981) to reduce variability in the subarea estimates. Relative biomass in Area 2A is generally 1% or less of the total population. Relative biomasses in Areas 2B and 2C have generally been fairly close, oscillating between 10% and 20% of the total population. Relative biomasses in Areas 3A and 3B have been somewhat variable, but are near 40% and 20%, respectively.

Exploitable biomass by subarea is obtained by multiplying the smoothed relative biomass estimates by total exploitable biomass from catch-age analysis. An important feature of this approach is that CPUE information is used in both components of estimation. Exploitable biomass estimates for subareas for 1974-1984 are shown in Appendix Tables 5, 6, and 7 for CPUE Adjustments I, II, and III. The magnitude of exploitable biomass depends on which data set is used, but relative biomass is similar for the major subareas.

COHORT ANALYSIS

Cohort analysis is one of the most common techniques for estimating historical abundance from catch-age data. It involves solving an approximation to the Baranov catch-age equation (1), which results in an iterative scheme to calculate abundance of each age of a particular year class (Hoag and McNaughton 1978). The assumption of separability of fishing mortality and age selectivity is not required in cohort analysis in contrast to catch-age analysis, but it is necessary to obtain values of fishing mortality of the oldest age in recent years and all ages in the last year in order to start the iterative process. As in catch-age analysis, natural mortality is assumed known. Cohort analysis is useful for historical data, because estimates of year classes that have completed their fishable lifespan are insensitive to the starting fishing mortality value.

Cohort analysis was first applied to Pacific halibut data by Hoag and McNaughton (1978). They used incidental catch information and commercial setline catch-age data for ages 3-20 over the years 1935-1976 and assumed that fishing mortality of the oldest age was equal to 0.2. Quinn et al. (1984) and Deriso and Quinn (1983) reconsidered data sources and re-applied cohort analysis to Pacific halibut. These studies did not use incidental catch data, because they were of poor quality and influenced the estimates too much. As a result, only ages 8-20 were used, because incidental catch for these ages is relatively small and can be considered a part of natural mortality. Also, values of fishing mortality for the iterative process were taken from an earlier version of catch-age analysis, so that estimates could be obtained for the most recent years as well as historically.

This report updates the previous analyses to the most recent year (1984) and uses the more powerful version of catch-age analysis developed by Deriso et al. (1985) to obtain starting values of fishing mortality. New catch-age estimates were available for the period 1970-1984 according to the algorithms of Quinn et al. (1983a); estimates from previous years are from Hoag and McNaughton (1978). Also, CPUE partitioning is used to provide the subarea estimates over the period 1935-1984. The CPUE data set with Adjustment III is used as auxiliary information in catch-age analysis and as the data source for CPUE partitioning.

Table 2. Estimates of exploitable biomass (millions of pounds) by subarea using cohort anlaysis with CPUE partitioning. Initial values for cohort analysis were taken from catch-age analysis of total population data, CPUE Adjustment III.

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1935	195.649	1.367	32.746	30.249	77.481	37.743	17.021
1936	192.304	1.372	31.913	28.306	76.302	37.629	16.782
1937	189.394	1.394	31.153	26.155	75.328	37.650	16.574
1938	188.462	1.429	30.808	25.026	75.563	38.279	16.546
1939	192.237	1.462	31.104	24.863	78.325	40.054	16.928
1940	204.123	1.486	32.354	25.645	84.050	43.057	17.945
1941	222.257	1.550	34.647	28.157	91.695	46.569	19.480
1942	242.936	1.721	38.008	31.869	100.395	49.712	21.303
1943	265.579	1.997	42.860	35.775	109.748	52.408	23.347
1944	288.939	2.372	49.374	39.352	117.519	55.219	25.432
1945	308.936	2.898	56.513	42.461	121.259	57.592	27.184
1946	321.142	3.469	62.376	45.314	121.690	58.454	28.269
1947	325.374	3.624	65.765	48.083	120.447	58.385	28.665
1948	325.264	3.915	66.835	50.631	118.574	57.201	28.652
1949	322.882	3.870	66.571	52.579	117.241	54.192	28.505
1950	319.760	3.762	66.201	53.769	116.451	50.905	28.344
1951	318.326	3.679	66.858	54.615	115.267	48.943	28.247
1952	318.675	3.665	69.460	55.844	112.676	48.304	28.226
1953	320.891	3.766	73.800	57.950	109.318	48.279	28.332
1954	325.423	3.993	77.436	60.046	107.360	48.677	28.668
1955	330.881	4.166	78.617	60.836	107.709	49.754	29.114
1956	336.623	4.206	77.906	60.179	111.893	51.388	29.533
1957	344.421	4.189	76.032	58.096	121.758	53.701	30.087
1958	357.465	4.153	74.417	55.644	135.742	57.280	31.145
1959	376.281	4.122	73.967	54.287	150.277	62.041	32.856
1960	392.409	4.099	74.106	53.963	160.323	65.889	34.419
1961	398.255	4.061	74.379	53.902	163.422	67.158	34.994
1962	394.920	3.966	73.907	53.275	162.094	66.537	34.718
1963	378.509	3.786	71.425	51.640	154.910	63.388	33.313
1964	345.747	3.529	66.597	49.022	139.295	57.059	30.437
1965	305.021	3.233	60.133	45.513	119.590	49.844	26.843
1966	266.024	2.971	53.149	41.323	101.458	43.673	23.410
1967	233.477	2.819	46.822	37.053	87.189	38.735	20.546
1968	208.845	2.790	42.014	33.443	77.024	34.955	18.377
1969	191.378	2.811	38.953	30.765	69.973	32.016	16.825
1970	178.075	2.777	37.305	28.781	64.258	29.251	15.607
1971	165.722	2.613	36.308	27.078	58.802	26.281	14.458
1972	153.447	2.323	35.268	25.406	53.566	23.312	13.352
1973	142.752	2.019	34.101	23.737	49.680	20.953	12.440
1974	136 445	1.802	33.149	22.188	48.206	19.709	11.926
1975	134.771	1.648	32.598	21.103	48.112	19.435	11.802
1976	135.495	1.507	32.137	20.686	49.246	19.554	11.862
1977	138.041	1.367	31.196	20.979	52.377	19.827	12.047
1978	142.035	1.217	29.274	22.482	56.082	20.340	12.359
1979	146.670	1.044	27.159	25.396	58.954	21.143	12.745
1980	153.573	0.902	26.270	29.030	61.859	22.496	13.327
1981	166.557	0.841	26.680	32.797	67.170	24.881	14.461
1982	189.268	0.845	29.170	36.509	77.158	28.788	16.522
1983	216.957	0.879	33.705	39.551	89.898	33.454	19.105
1984	240.165	0.924	37.972	41.493	100.934	37.359	21.316

Table 3. **Estimates of exploitable biomass (millions of pounds) by subarea using cohort analysis with CPUE partitioning and fixed age selectivity from catch age analysis.**

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1935	159.323	1.110	26.453	24.458	62.989	30.483	13.834
1936	163.323	1.153	27.164	23.935	64.787	31.983	14.261
1937	169.321	1.243	28.104	23.565	67.710	33.981	14.862
1938	177.375	1.345	29.171	23.448	71.786	36.328	15.618
1939	186.750	1.406	30.245	23.693	76.404	38.831	16.465
1940	196.137	1.422	31.156	24.554	80.750	41.134	17.284
1941	204.935	1.438	32.049	26.063	84.592	42.810	18.019
1942	214.715	1.529	33.702	28.111	88.716	43.922	18.854
1943	227.159	1.713	36.772	30.491	93.607	44.907	19.971
1944	241.604	1.987	41.324	32.860	98.154	46.180	21.267
1945	255.824	2.403	46.813	35.186	100.952	47.969	22.513
1946	268.141	2.904	52.095	37.805	102.191	49.606	23.583
1947	277.868	3.292	56.121	40.975	102.966	50.203	24.450
1948	284.581	3.462	58.592	44.341	103.927	49.851	25.109
1949	288.243	3.474	59.681	47.018	104.800	48.458	25.516
1950	289.458	3.412	60.115	48.662	105.110	46.302	25.667
1951	289.305	3.351	61.065	49.745	104.579	44.622	25.682
1952	289.698	3.331	63.178	50.848	102.051	43.921	25.704
1953	291.635	3.405	66.475	52.526	98.587	43.784	25.785
1954	294.499	3.580	69.498	54.252	97.120	43.992	25.939
1955	298.445	3.707	70.589	54.921	97.977	44.842	26.174
1956	302.911	3.734	69.832	54.166	101.690	46.291	26.432
1957	305.811	3.674	67.150	51.472	108.750	47.822	26.607
1958	306.918	3.527	63.259	47.525	116.732	49.304	26.695
1959	307.150	3.385	59.939	44.180	122.085	50.540	26.775
1960	305.317	3.248	57.588	41.947	123.660	51.096	26.739
1961	298.540	3.054	55.525	40.175	122.500	50.645	26.261
1962	284.449	2.836	52.981	38.202	117.526	48.420	25.067
1963	262.981	2.626	49.682	35.958	107.774	44.208	23.165
1964	238.208	2.432	46.026	33.848	95.687	39.349	20.967
1965	215.519	2.281	42.482	32.089	84.374	35.287	18.969
1966	196.117	2.200	39.071	30.329	74.879	32.197	17.267
1967	179.579	2.188	35.949	28.399	67.244	29.776	15.814
1968	167.602	2.239	33.740	26.785	61.985	28.074	14.760
1969	159.415	2.318	32.579	25.639	58.426	26.701	14.030
1970	151.517	2.353	31.929	24.581	54.887	24.961	13.299
1971	142.816	2.275	31.426	23.464	50.890	22.728	12.478
1972	134.419	2.054	31.021	22.345	47.096	20.469	11.706
1973	128.217	1.808	30.684	21.274	44.671	18.871	11.181
1974	125.441	1.645	30.446	20.339	43.979	18.174	10.977
1975	124.965	1.521	30.271	19.636	44.334	18.043	10.958
1976	125.793	1.395	29.953	19.263	45.883	18.148	11.028
1977	128.902	1.274	29.147	19.600	49.067	18.529	11.266
1978	135.104	1.154	27.914	21.447	53.406	19.386	11.767
1979	144.365	1.024	27.028	25.159	58.170	20.851	12.553
1980	157.347	0.927	26.796	29.968	63.606	23.079	13.677
1981	175.692	0.896	27.676	34.788	71.084	26.273	15.288
1982	202.018	0.908	31.072	39.095	82.483	30.761	17.667
1983	232.241	0.944	36.192	42.406	96.280	35.835	20.471
1984	257.609	0.994	40.732	44.495	108.272	40.074	22.865

Exploitable biomass estimates from 1935-1984 for subareas and the total population are shown in Table 2. Estimated biomass increased in Areas 2A, 2B, and 2C from 1935 to 1955, decreased until the mid-1970's, and increased since then. The trend in Areas 3A and 3B is similar, but two peaks in abundance occurred: one about 1945 and another about 1961. The recent increase in biomass started in Area 3A about 1975. From this geographic centrum, increases in adjacent Areas 2C, 3B, and 4 commenced in 1977. In 1982, increases started in Areas 2A and 2B, the southern part of the range of Pacific halibut.

The previous estimates of exploitable biomass are based on smoothed annual age selectivity estimates from cohort analysis. These estimates vary substantially over the time period because of changes in halibut availability, minimum size limits, and gear modifications. For comparative purposes, an alternative set of exploitable biomass estimates was calculated using the most recent age selectivity estimates from catch-age analysis. This results in a set of estimates with the same component of each age in the determination of exploitable biomass (Table 3). The trends in biomass are similar to those in Table 2 which were based on variable age-selectivity over time. The major effect of using fixed age-selectivity is to lower biomass substantially in the years before 1973, when age-selectivity was higher due to a smaller minimum size limit.

MIGRATORY CATCH-AGE ANALYSIS

A new analytical method, called migratory catch-age analysis, has been developed to provide biomass estimates for assessment areas that are independent of CPUE partitioning. Migratory catch-age analysis uses age-structured commercial catch data for 4 grouped subareas with sufficient data (2A + 2B, 2C, 3A, 3B + 4). Area 3B is defined for historical consistency as the combination of the Chirikof and Shumagin regions and differs somewhat from the Area 3B in the 1983 and 1984 regulations. Each group is analyzed separately, but is linked to other groups with migration rates and population abundance information. CPUE data is used only to stabilize estimates, not to partition biomass.

The analysis of tagging data (Deriso and Quinn 1983, p. 69) was updated to obtain new estimates of annual migration rates. Summer release information was joined with summer recovery information from one to three years after release. Other recovery data were excluded, because halibut exhibit short-term movements from summer feeding grounds to winter spawning grounds. The multinomial distribution was used to estimate annual migration rates from percentages of recaptures by area, corrected for natural and fishing mortality (Deriso, unpublished[3]). Migration rates for adult fish (age 8 years and over) vary by age; we present rates for four groups of ages in Table 4. Migration is even more extensive for younger fish. However, migratory catch-age analysis requires data from only the adult population.

[3]Deriso, R.B. 1982. Migration studies. Int. Pacific Halibut Commission, Stock Assessment Data and Analysis 1981 (Document No. 12): 74-81.

Table 4. New estimates of annual migration rates based on recent analyses (Deriso, unpublished).

	Age 8			
	To Area			
From Area	2A+2B	2C	3A	3B+4
2A+2B	0.9982	0.0013	0.0005	0.0000
2C	0.0200	0.9767	0.0032	0.0000
3A	0.0095	0.0108	0.9671	0.0125
3B+4	0.0099	0.0210	0.0743	0.8947
	Ages 9 to 11			
	To Area			
From Area	2A+2B	2C	3A	3B+4
2A+2B	0.9960	0.0029	0.0010	0.0000
2C	0.0122	0.9858	0.0020	0.0000
3A	0.0010	0.0070	0.9788	0.0081
3B+4	0.0064	0.0138	0.0481	0.9319
	Ages 12 to 14			
	To Area			
From Area	2A+2B	2C	3A	3B+4
2A+2B	0.9901	0.0072	0.0026	0.0000
2C	0.0095	0.9889	0.0015	0.0000
3A	0.0047	0.0053	0.9837	0.0062
3B+4	0.0049	0.0103	0.0366	0.9481
	Ages 15 to 20			
	To Area			
From Area	2A+2B	2C	3A	3B+4
2A+2B	1.0000	0.0000	0.0000	0.0000
2C	0.0000	1.0000	0.0000	0.0000
3A	0.0000	0.0000	1.0000	0.0000
3B+4	0.0000	0.0000	0.0000	1.0000

The major assumptions of migratory catch-age analysis are the same as for catch-age analysis with the additional assumption that migration rates are constant over time. The method has similar workings to catch-age analysis with one important difference. At the start of each year, some of the population is shifted to other subareas according to migration rates. Mathematically, this results in an additional equation. Letting $\underset{\sim}{N}(a,t)$ be the vector of area-specific abundances for age a and Θ_a be the matrix of migration rates at age a, the abundances are updated at the start of year t by the equation

$$\underset{\sim}{N}(a,t+\epsilon) = \Theta_a \underset{\sim}{N}(a,t) \ , \qquad (8)$$

where ϵ is an arbitrarily small time increment. These new abundances are then used in equation (1). The convergence procedure is iterative. The parameter estimates for one area are obtained given the estimates for the other areas and the procedure is continued across areas until convergence is obtained for all areas. A strong advantage of this approach is that estimates of year-class strength, full-recruitment fishing mortality, and age selectivity are obtained for each subarea, which result in population abundance estimates by subarea. Exploitable biomass is then easily computed as

$$B_t = \sum_a s_a N_{at} W_{at} \qquad (9)$$

where B_t is exploitable biomass in year t, s_a is selectivity of age a fish, N_{at} is population abundance, and W_{at} is average fish weight. Another advantage of the migratory procedure is that problematic CPUE data are used only as auxiliary information rather than as a direct partitioning tool in these four area groups. After this process is completed, the four grouped subareas are partitioned into the six assessment subareas. This required partitioning 2A+2B and 3B+4 into individual areas with CPUE and habitat information.

A disadvantage of the migratory procedure is that the estimates are more variable than catch-age analysis because of the focus on smaller subareas with more variable data sets. Migratory analysis resulted in convergence problems, due to the iterative search procedure and limited fishing in some years in Area 3B+4. To overcome convergence problems, we did not use catch data from 1979 and 1980 or effort data from 1979-1981 in Area 3B + 4. We also explored the value of λ for catch-effort with sensitivity analyses and settled on a value of 2.0 to provide slightly stronger influence of catch-effort data than for total population analysis.

The migration rate data are also subject to limitations. The values are reasonable only if reporting rates of tag recoveries are constant, which may not be so. Further, migration rates may have short-term and long-term trends that are not accounted for in the estimation.

Because migratory catch-age analysis is a new procedure, we concentrated on exploring initial parameters, catch-age data, and catch-effort λ with a single set of CPUE data, Adjustment III. In addition to sensitivity analyses, we also applied catch-age analysis to each subarea independently as if there were no mirgration (closed subarea analysis). Examination of migration rates (Table 4) shows that this assumption is not too unrealistic, except in Area 3B+4, where the overall annual migration rate to other areas ranges from 5 to 11% of the population for ages under 15. Results of the closed subarea analysis are shown in Appendix Table 8.

Results from migratory catch-age analysis are shown in Appendix Table 9, which used final parameter estimates from closed subarea analysis as initial parameters in the iterations. Other initial conditions resulted in different final results, but the results presented are those with the lowest sum of squares. Interestingly, the closed area analysis had a lower sum of squares than the migratory analysis, perhaps reflecting the uncertainty in migration rates. The effect of including migration in the analysis was to increase biomass in Areas 2A, 2B, and 2C and to lower biomass in Areas 3A, 3B, and 4. Total biomass in most recent years in migratory analysis was lower than in closed analysis, both of which were much higher than catch-age analysis with CPUE partitioning.

Comparison of estimates of biomass from the two methods (catch-age analysis with CPUE partitioning, migratory catch-age analysis) with CPUE estimates over the most recent time period (1974-1984) provides a means of cross-validation among methods. The comparison for Area 2B is shown in Figure 3. The three curves show the same trend over the time period (1974-1984). There was no apparent increase or decrease in CPUE or biomass until about 1982, when they all started increasing. The comparison for Area 2C is given in Figure 4. All three curves increase over the time period by a factor of 2-3 times. The two biomass estimates differ in magnitude, especially in most recent years. This is due to the competing influences of CPUE and catch-age information. The partitioning method is influenced by relative changes in CPUE among areas, but the migratory method is influenced by the catch-age data and actual CPUE data among areas. The comparison for Area 3A is given in Figure 5. All three curves show a sharply increasing trend over the time period. Assessments of Areas 2A, 3B, and 4 show similar results. The similarity of biomass trends between methods, which are all based on different amounts

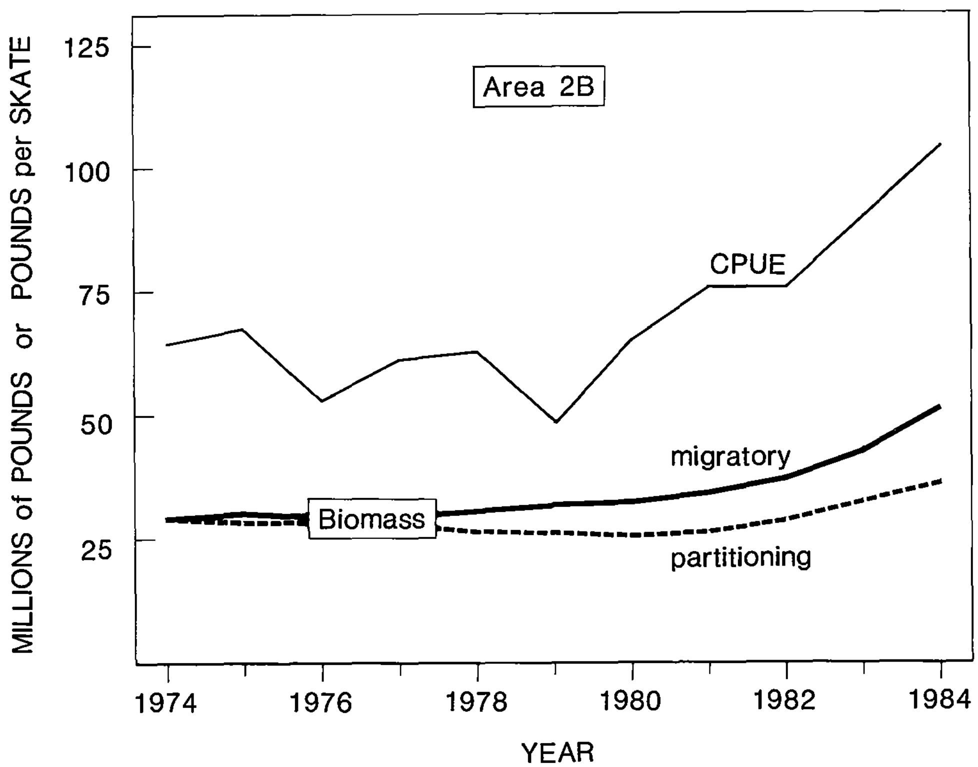

Figure 3. CPUE (pounds/skate) and estimated exploitable biomass (millions of pounds) from two methods, catch-age analysis with CPUE partitioning and migratory catch-age analysis, Area 2B, 1974-1984.

of influence of CPUE information, suggests that the increasing trend in abundance is a realistic indication of the population in each area. However, the difference in most recent biomass estimates suggests that they must be used cautiously.

Migratory cohort analysis, developed in Deriso and Quinn (1983), is the logical extension of cohort analysis to migratory populations. Migratory cohort analysis could be updated using migratory catch-age analysis results, in an analogous manner to the section "Cohort Analysis." This would provide historical estimates that would be less sensitive to CPUE data and catchability changes. Before we can undertake this project, there are three unresolved problems. The first problem involves the convergence difficulties with migratory catch-age analysis, which until resolved, forces the method to remain an experimental approach. The second is whether migration rates vary over the time period. The data are highly variable among tagging experiments and several problems remain unresolved. The third problem is the lack of data in certain areas in some years. For example, Area 4 has had consistent fishing effort only since 1970.

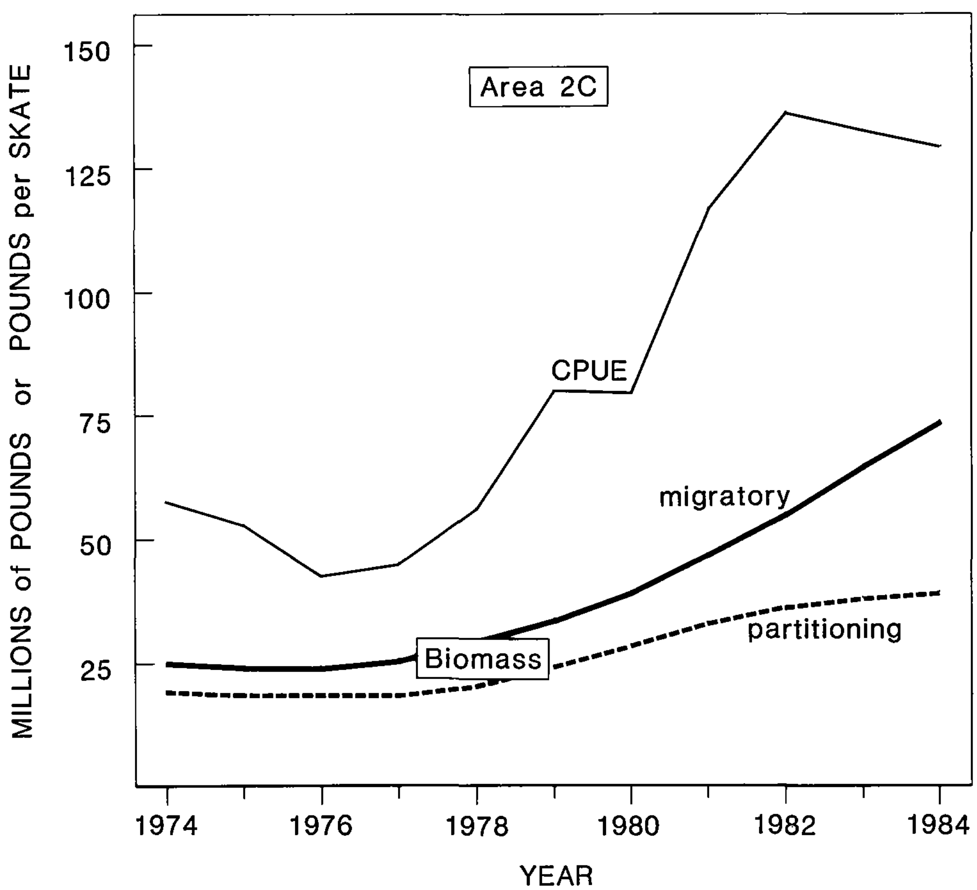

Figure 4. CPUE (pounds/skate) and estimated exploitable biomass (millions of pounds) from two methods, catch-age analysis with CPUE partitioning and migratory catch-age analysis, Area 2C, 1974-1984.

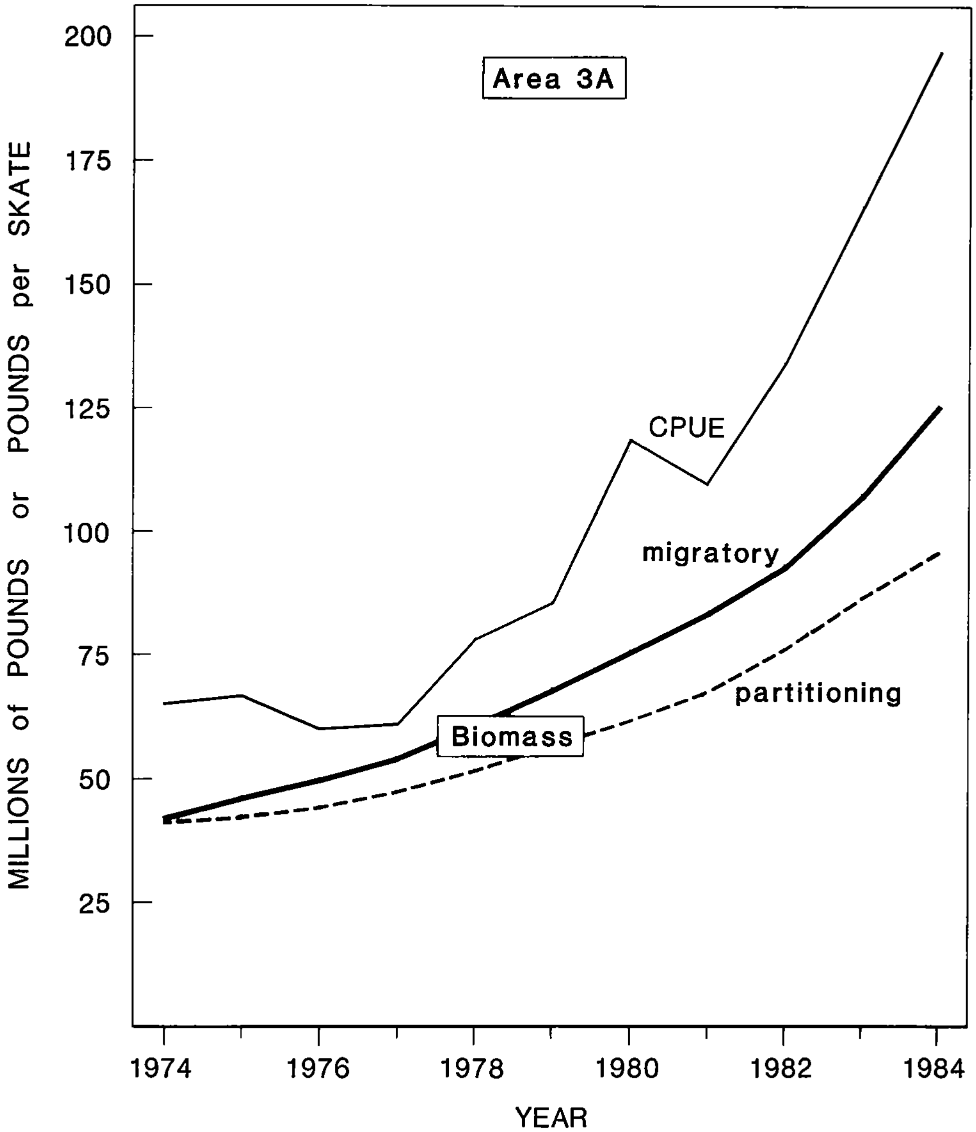

Figure 5. CPUE (pounds/skate) and estimated exploitable biomass (millions of pounds) from two methods, catch-age analysis with CPUE partitioning and migratory catch-age analysis, Area 3A, 1974-1984.

DETERMINATION OF SURPLUS PRODUCTION

Annual surplus production (ASP) is defined as the excess of what is required to replenish the population biomass each year due to removals from fishing and other causes. If factors affecting the population and the fishery remain constant, then biomass increases when catch is held below surplus production and vice versa. In the study of population dynamics in fisheries, the theory of stock production has been advanced to understand the relationship between surplus production, population biomass, and fishing mortality (Ricker 1975; Pella and Tomlinson 1969; Fletcher 1978). At equilibrium, surplus production should be a downward-concave function of biomass or fishing mortality, increasing from a value of 0 at zero biomass to the value of maximum sustained yield (see the next section) and decreasing to a value of 0 at virgin biomass prior to exploitation. In practice, behavior of ASP is not so well-behaved, often exhibiting cyclic or chaotic behavior. One use of ASP in fisheries management is as a tool for rebuilding a depleted population by keeping catch below ASP (Quinn et al. 1984; Deriso 1985). We will consider two procedures for determining ASP.

BLIND RESPONSE

A non-parametric estimator of ASP developed in Chapman et al. (1962) is the catch plus the change in biomass in a year, or

$$ASP(t) = C(t) + B(t+1) - B(t) \ . \qquad (9)$$

In the most recent year T, ASP is projected from the ratio of ASP to biomass in the previous year, i.e.

$$ASP(T) = B(T) \times ASP(T-1)/B(T-1) \ .$$

This represents the catch that could have been taken in year t without changing the biomass. We term this method the "blind response" method because none of the dynamics of the population enters in, except what happened in that year. In practice, ASP estimates from this approach tend to be highly variable from year to year, especially in years when biomass is rapidly changing. To overcome this limitation, we applied a non-linear smoother (Velleman 1981) to the estimates to remove extraneous variability.

This method of determining ASP was applied to subarea biomass estimates from catch-age analysis with CPUE partitioning using the three adjusted CPUE data sets (Appendix Tables 5-7), and from closed subarea and migratory catch-age analysis (Appendix Tables 8-9). Values of commercial setline catch used in (9) are given in Appendix Table 10 for each subarea. For all methods, ASP estimates have increased since 1974. Important differences in the estimates among the methods reflect the uncertainty in the CPUE values. Negative estimates of surplus production in Area 2A are not realistic, exposing another limitation of this method.

Historical estimates of ASP, the surplus production available to be caught by the setline fishery, were also calculated over the time period 1935-1984 using exploitable biomass estimates from Table 3 and commercial setline catch data from Appendix Table 10. Exploitable biomass with fixed selectivity is used so that a fixed proportion of each age would be used over the entire time period. As a result, the values of ASP are derived from a well-defined population, not subject to the vagaries of changing age selectivity and regulation. ASP of the entire halibut population ranged from 50 to 70 million pounds from 1935 to 1960, declined to a low of 27 million pounds in 1975, and has since increased to about 69 million pounds in 1984 (Table 5). Recent values of ASP should be used with caution, as few data on the most recent year classes are available. Subarea estimates are more variable than for the total population, especially in Areas 2A and 4 when few data were collected. The historical range of ASP has been 5 to 24 million pounds in Area 2B, 5 to 13 million pounds in Area 2C, 12 to 30 million pounds in Area 3A, and 3 to 16 million pounds in Area 3B.

Table 5. **Estimates of annual surplus production (millions of pounds) available to the setline fishery using the blind-response method for subareas and the total population, calculated from exploitable biomass from Table 3 (fixed age selectivity) and commercial setline catch from Appendix Table 10.**

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1935	52.226	1.499	14.534	7.665	21.967	6.869	0.480
1936	54.499	1.250	15.244	7.589	23.029	6.869	0.592
1937	56.935	1.066	16.229	7.532	24.251	6.869	0.704
1938	58.891	0.999	17.289	7.588	25.213	6.856	0.773
1939	60.378	0.984	18.061	7.940	25.750	6.827	0.801
1940	61.601	0.969	18.412	8.670	26.018	6.805	0.835
1941	62.726	0.967	18.617	9.555	26.096	6.924	0.938
1942	64.385	1.037	19.088	10.303	25.784	7.507	1.082
1943	66.045	1.164	19.794	10.919	24.824	8.410	1.150
1944	66.655	1.225	20.300	11.686	23.589	8.962	1.150
1945	66.431	1.208	20.443	12.450	22.522	9.071	1.081
1946	65.099	1.075	20.246	12.747	21.717	8.735	0.894
1947	62.257	0.813	19.632	12.668	21.292	7.694	0.646
1948	59.205	0.618	18.992	12.233	21.196	6.390	0.380
1949	57.426	0.571	18.771	11.514	21.281	5.336	0.170
1950	56.963	0.586	19.538	11.020	21.596	4.537	0.098
1951	58.171	0.627	21.848	10.850	21.944	4.079	0.132
1952	61.294	0.670	24.167	10.809	22.397	3.965	0.216
1953	64.194	0.685	24.943	10.790	23.773	4.339	0.286
1954	65.516	0.669	23.762	10.673	26.210	5.643	0.312
1955	66.066	0.605	20.592	10.211	28.558	7.410	0.325
1956	66.436	0.518	17.447	9.576	29.796	8.715	0.463
1957	66.516	0.471	15.769	9.302	30.141	9.566	1.142
1958	66.362	0.465	15.081	9.523	29.435	10.360	2.425
1959	65.688	0.463	14.826	9.964	26.519	10.978	3.736
1960	63.052	0.428	14.380	10.185	21.825	11.189	4.569
1961	57.822	0.341	13.507	10.110	17.234	11.113	4.826
1962	51.732	0.244	12.361	9.743	13.962	10.949	4.540
1963	47.024	0.183	10.948	9.203	12.405	10.857	3.347
1964	44.390	0.157	9.538	8.902	12.230	10.872	1.548
1965	43.452	0.153	8.695	8.817	12.848	11.097	0.388
1966	43.497	0.173	8.491	8.655	13.899	11.630	0.187
1967	44.017	0.200	8.718	8.297	14.843	12.186	0.343
1968	44.745	0.212	9.310	7.809	15.273	12.497	0.449
1969	44.942	0.188	9.866	7.261	15.346	12.414	0.468
1970	43.753	0.139	10.043	6.578	15.196	11.566	0.406
1971	40.266	0.115	9.756	5.742	14.571	9.679	0.274
1972	34.817	0.135	8.808	5.106	13.527	7.145	0.196
1973	30.127	0.177	7.577	4.911	12.688	4.780	0.236
1974	27.951	0.203	6.648	5.011	12.392	3.289	0.380
1975	27.485	0.206	5.967	5.319	12.380	2.779	0.624
1976	27.821	0.161	5.289	5.880	12.667	2.737	1.024
1977	29.044	0.063	4.735	6.750	13.490	2.766	1.557
1978	31.384	-0.006	4.537	7.695	14.791	2.812	2.030
1979	35.453	-0.019	5.034	8.262	16.949	2.988	2.385
1980	42.190	0.024	6.605	8.357	20.348	3.870	2.763
1981	50.772	0.138	8.555	8.306	23.929	6.433	3.269
1982	58.908	0.251	9.864	8.392	26.289	10.447	3.967
1983	65.018	0.309	10.487	8.582	27.421	13.896	4.731
1984	69.071	0.337	10.787	8.756	28.038	15.757	5.305

Table 6. Estimates of annual surplus production (millions of pounds) for subareas using the biomass-partitioning method, calculated from exploitable biomass from Table 3, and total setline ASP from Table 5.

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1935	52.226	0.366	8.670	7.991	20.734	9.923	4.544
1936	54.499	0.381	9.047	8.120	21.527	10.682	4.741
1937	56.935	0.399	9.451	7.914	22.717	11.444	5.010
1938	58.891	0.471	9.717	7.656	23.851	12.073	5.182
1939	60.378	0.483	9.781	7.608	24.695	12.498	5.313
1940	61.601	0.431	9.795	7.700	25.380	12.936	5.421
1941	62.726	0.439	9.785	7.966	25.843	13.172	5.520
1942	64.385	0.451	10.044	8.434	26.527	13.263	5.601
1943	66.045	0.528	10.567	8.982	27.277	13.011	5.812
1944	66.655	0.533	11.331	9.132	27.262	12.598	5.866
1945	66.431	0.598	12.157	9.101	26.373	12.356	5.846
1946	65.099	0.716	12.694	9.114	24.803	12.108	5.729
1947	62.257	0.747	12.638	9.152	22.848	11.393	5.479
1948	59.205	0.770	12.196	9.236	21.373	10.420	5.210
1949	57.426	0.689	11.830	9.418	20.788	9.590	5.053
1950	56.963	0.684	11.791	9.627	20.791	9.057	5.070
1951	58.171	0.640	12.100	9.947	21.291	8.958	5.177
1952	61.294	0.674	13.240	10.665	21.943	9.317	5.394
1953	64.194	0.770	14.765	11.491	21.890	9.629	5.649
1954	65.516	0.786	15.658	12.120	21.358	9.762	5.765
1955	66.066	0.859	15.856	12.354	21.273	9.976	5.814
1956	66.436	0.864	15.546	12.091	21.924	10.165	5.846
1957	66.516	0.798	14.634	11.241	23.613	10.376	5.787
1958	66.362	0.730	13.604	10.220	25.417	10.618	5.773
1959	65.688	0.723	12.743	9.328	26.275	10.839	5.715
1960	63.052	0.694	11.854	8.638	25.788	10.593	5.549
1961	57.822	0.578	10.755	7.806	23.765	9.830	5.088
1962	51.732	0.517	9.622	6.932	21.314	8.794	4.552
1963	47.024	0.470	8.888	6.395	19.280	7.900	4.138
1964	44.390	0.444	8.567	6.303	17.889	7.280	3.906
1965	43.452	0.478	8.603	6.518	16.990	7.083	3.824
1966	43.497	0.478	8.699	6.786	16.529	7.134	3.828
1967	44.017	0.528	8.847	6.999	16.418	7.307	3.873
1968	44.745	0.582	8.994	7.159	16.556	7.517	3.938
1969	44.942	0.674	9.123	7.191	16.494	7.550	3.955
1970	43.753	0.700	9.101	7.044	15.882	7.219	3.850
1971	40.266	0.644	8.818	6.563	14.335	6.402	3.503
1972	34.817	0.522	8.043	5.780	12.186	5.257	3.029
1973	30.127	0.422	7.200	5.031	10.454	4.399	2.621
1974	27.951	0.363	6.764	4.584	9.755	4.025	2.432
1975	27.485	0.357	6.679	4.343	9.730	3.985	2.419
1976	27.821	0.306	6.677	4.229	10.099	4.034	2.448
1977	29.044	0.290	6.622	4.357	11.037	4.182	2.527
1978	31.384	0.282	6.528	4.865	12.491	4.488	2.730
1979	35.453	0.248	6.488	6.133	14.394	5.105	3.084
1980	42.190	0.253	6.919	8.143	17.045	6.160	3.671
1981	50.772	0.254	7.920	10.154	20.461	7.616	4.417
1982	58.908	0.236	9.072	11.546	23.917	8.954	5.125
1983	65.018	0.260	10.143	12.028	26.852	10.013	5.722
1984	69.071	0.276	10.982	11.604	29.217	10.775	6.147

BIOMASS PARTITIONING

A second method of determining surplus production supposes that the surplus production should be proportional to the biomass of an area, which would result in a uniform exploitation rate across subareas. If the "blind response" method is used to obtain ASP for the total population from equation (9), then the exploitation rate R of the total population in a given year is

$$R = ASP/B \ .$$

Then ASP for each subarea (r) is estimated to be

$$ASP(r) = R\ B(r) \ ,$$

or

$$ASP(r) = ASP \times B(r)/B \ .$$

Thus this approach is called biomass partitioning, because subarea ASP is obtained by partitioning total ASP by relative subarea biomass.

The biomass-partitioning method generally produces less variable estimates than the "blind response" method, because ASP for the total population is more stable and the allocation to subareas is based on relative biomass, which is also more stable over time. This method can also be generalized to different exploitation rates in subareas, although this has not yet been accomplished. Another advantage is that estimates of subarea ASP cannot be negative, unless ASP for the total population is negative.

Estimates of subarea ASP are shown in Appendix Tables 5-9 for the various methods of estimating biomass. The two methods of estimating ASP are shown in each table and they produce the same estimates for the total population, but the partitioning among subareas is slightly different.

Historical estimates of ASP with this method are shown in Table 6 and use exploitable biomass estimates from Table 3 (fixed selectivity) and setline ASP for the total population from Table 5. Subarea ASP estimates from this method are less variable than from the blind response method. According to this method, the historical range of ASP has been 0.2 to 0.9 million pounds in Area 2A, 6 to 16 million pounds in Area 2B, 4 to 12 million pounds in Area 2C, 10 to 29 million pounds in Area 3A, 4 to 13 million pounds in Area 3B, and 2 to 6 million pounds in Area 4.

CONSIDERATION OF INCIDENTAL CATCH

The estimates of surplus production determine the excess of biomass that is available to the commercial setline fishery. The Pacific halibut population is also subjected to losses from incidental catches in other fisheries, even though retention of halibut is mostly prohibited. The incidental catch is generally made up of juvenile halibut. The total productivity of the population is then the setline surplus production, combined with incidental catch losses adjusted for growth and mortality from juvenile to adult progression. This adjustment is explained in Quinn et al. (1984) and involves multiplying incidental catch mortality by a factor of 1.58. This adjustment was 20-40 million pounds in the 1960's and 1970's, representing the loss to the setline fishery from incidental catches. Recently incidental losses have declined, and the adjustment is now about 10-20 million pounds.

Historically, total productivity of Pacific halibut has ranged from 60-80 million pounds, but declined from 1965-1975 (Quinn et al. 1984). Setline surplus production declined even more rapidly than total productivity from about 1960 to 1975, because losses from incidental catches are subtracted from total productivity to obtain setline ASP. Due to regulation of both incidental catches and commercial setline catches and possibly fortuitous density-dependent survival and growth (Deriso 1985), both total productivity and setline ASP have increased dramatically since 1975.

Estimates of incidental catch for each subarea have been made recently, but it is not clear how to adjust subarea ASP for these losses. Hence, no estimates of total productivity could be produced for subareas. Further discussion of this problem is in the later section "Considerations for Determining Catch Limits."

DETERMINATION OF MSY

STOCK PRODUCTION ANALYSIS

Maximum sustainable yield, MSY, is the maximum average yield that can be obtained on a sustained basis. The paper by Chapman et al. (1962) provides estimates of MSY based on analysis of catch and effort data. In this section results are updated by the analysis of recent total catch and fishing effort data on Pacific halibut. Results are given for regression of CPUE data to the three types of population models analyzed in Deriso (1985a): (1) a delay-difference model (Deriso 1980) where all random errors in the regression are assumed to occur in the measurement of CPUE as an index of abundance (so-called measurement error), (2) a delay-difference model where all random errors in the regression are assumed to occur in the population dynamics of halibut (so-called process error, Ludwig and Walters 1981), (3) a discrete Schaefer model with only process error (Hilborn 1979).

The population models we used for CPUE analysis have the potential to describe density-dependent population mechanisms. In the delay-difference model applications, a Ricker spawner-recruit relationship is used for the renewal part of this population model. In the Schaefer model, a logistic type (quadratic) function describes production of the stock.

The delay-difference population model uses total catch (in weight) and effort data as state variables for a model with implicit age structure (Deriso 1980). The version applied to Pacific halibut is as follows:

$$B_{t+1} = (1+\rho)\ell S_t - \rho\ell^2 \frac{S_t}{B_t} S_{t-1} + F(S_{t+1-k})$$

where $S_t = B_t - C_t$ = escapement of catchable adults in year t

and B_t = biomass of the catchable population

C_t = catch

ρ = Brody's growth coefficient for weight

ℓ = annual natural survival fraction

$F(S)$ = spawner-recruit function, which is assumed to be a density-dependent function for halibut ($F(S)=\alpha S \exp(-\beta S)$, where α and β are spawner-recruit parameters to be estimated)

k = age of recruitment in the setline fishery (k=5 prior to 1973 and k=6 after the minimum size limit was changed)

The measurement error approach essentially treats the delay-difference equation as a simulation model where log-transformed predicted biomass estimates for each year are fitted simultaneously to the sum of log (CPUE) data plus additive log-catchability coefficients; such an approach treats catchability as a random variable. The process error approach is explained in Deriso (1980); this approach essentially treats the model as a regression equation where observed CPUE data are used as independent variables to predict CPUE forward one time-step. Prior information on growth rates and natural mortality (Deriso 1982) were used to fix those values at $\ell = 0.82$ and $\rho = 1.0$.

The delay-difference model has the advantage of retaining biological realism available in more complex age-structured treatments while preserving the simplicity of stock assessment available in traditional stock production models. The growth and survival parameters of the model could be estimated directly, but studies have concluded that auxiliary information is needed to stabilize and uniquely identify these parameters (Deriso 1980, and unpublished data).

Commercial and adjusted incidental catches of halibut from the N.E. Pacific Ocean and Bering Sea are combined for catch data in the models, with fishing effort adjusted upward so that CPUE from setline data equals CPUE in the combined data sets. The models all fit 1929 through 1982 data reasonably well since $R > 0.90$ in all regressions. Results are presented for two sets of analysis: (1) with data for years 1929-1982 (unadjusted for recent area differences in catchability) and applied to all three models; (2) a detailed update, 1929-1984, for the delay-difference model with measurement error.

An interesting way to view parameter estimates from the model regressions is as isoclines on a CPUE vs. Effort graph in Figure 6. The lines drawn for each model define isoclines, the locus of points where the stock would theoretically be at equilibrium should conditions (e.g. fishing effort) be held constant for a number of years. The halibut data clearly do not portray a stock in equilibrium. Rather, the arrows show a history of clockwise motion of CPUE values around the graph. The changes in halibut data below and above the isoclines are consistent with model predictions: below the isoclines population abundance should increase, and above the isoclines abundance should decrease. Unfortunately, it is not clear whether lowered density dependence or reduction in fishing effort was responsible for increases in CPUE when it was below the isoclines. These effects are clearly confounded in the Figure since effort was generally declining below the isoclines. A similar remark can be made about the declining trend in CPUE for values above the isoclines since effort was usually increasing above the isoclines. From an experimental point of view, increasing effort with lower CPUE values would generate more contrast in the data and better determine the importance of density-dependent mechanisms in controlling population growth.

All models indicate density dependence, as seen by the negative slope of isoclines in Figure 6 constructed for fits to the 1929-1982 data. Maximum sustainable yields are indicated for each of the models by circles on the isoclines. These MSY estimates suggest the stock has never been held at MSY, but rather has oscillated around these points. Observed CPUE in 1982 of 124 lbs/skate is near the MSY abundance estimate of 112 lbs/skate predicted by the delay-difference model with the all measurement error assumption, but yields could be higher by increasing effort approximately 50% (see also Figure 7). MSY fishing effort is even higher for the models with the all process error assumption (approximately a 100% increase from current levels). These predicted high MSY effort levels produce an increase in yield as shown in Figure 7 of some 25 million pounds from current levels. The marginal return on this additional fishing effort (in

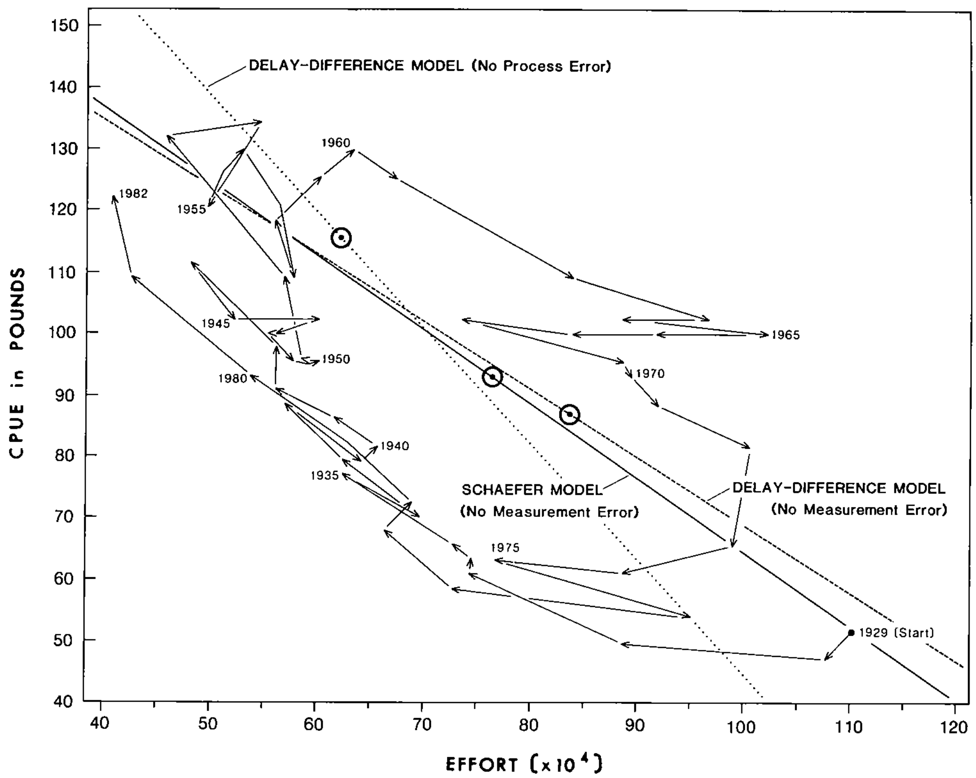

Figure 6. CPUE vs. effort phase plane. Isoclines (straight lines) are equilibrium conditions predicted from three model regressions. Arrows connect the time sequence of observed data and MSY conditions are identified by circled points on the isoclines.

terms of additional yield) can be as low as 50% of the current catch per unit of effort, according to forecasts of the models with all process error, which suggests that economics play an important role in any such management decision.

Results of the updated analysis for years 1929-1984 gave similar results, as expected. Figure 8 shows predicted equilibrium catch as a function of CPUE, which has a maximum MSY = 71.4 million pounds when CPUE = 111 lbs/skate. These estimates are based on a medium adjustment of the CPUE data for recent changes in catchability in different areas (referred to as CPUE Adjustment III). This analysis also estimates that true CPUE in 1982 was 110 lbs/skate, so we assume the Pacific halibut stock was at MSY in 1982. In Figure 8, a broad range of CPUE values produces high catches. Equilibrium catches in excess of 60 million pounds are available for population densities ranging from 70 to 150 lbs/skate.

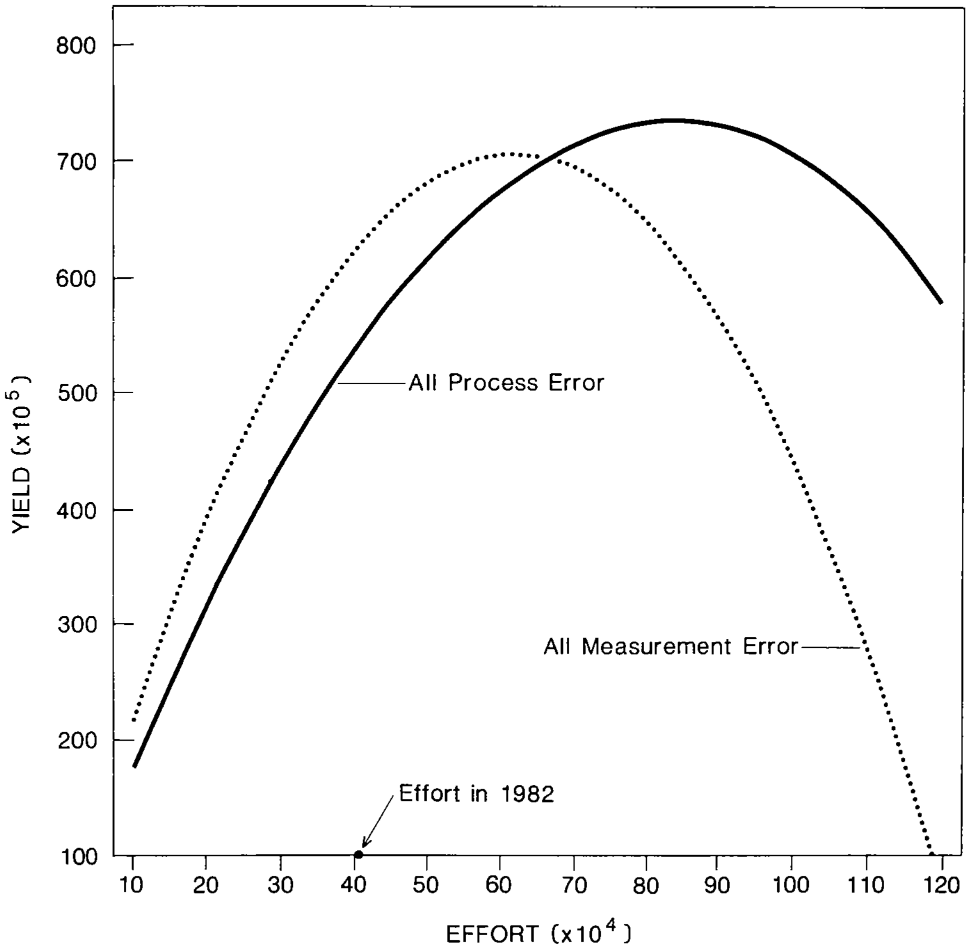

Figure 7. Equilibrium total yield (setline plus incidental) vs. adjusted fishing effort as predicted by two delay-difference model regressions. Yield in units of pounds. Adjusted effort in 10^4 skates.

The MSY estimate of 71.4 million pounds compares favorably with the 68-70 million pounds found for Pacific halibut, excluding the Bering Sea, by Chapman et al. (1962); they make a "best" estimate of 32 million pounds for Area 2 and 36-38 million pounds for Area 3 (as defined in 1962). Optimal CPUE also compares favorably since they give estimates of CPUE at MSY ranging from 95 to 120 lbs/skate.

We have not made an independent assessment of MSY for each of the subareas. How one partitions our total MSY among subareas is therefore uncertain. We assume that the percent of setline catch taken historically (1929-1984) from each subarea is a measure of percent MSY in each subarea; the following table gives subarea estimates based on this partitioning.

	Maximum Sustained Yield (10^6 pounds)						
	Area						Combined
	2A	2B	2C	3A	3B	4	Areas
All gear	0.9	19.1	11.8	28.1	10.1	1.5	71.4
Setline only:							
(a) 10 million incidental	0.8	16.4	10.2	24.1	8.7	1.3	61.4
(b) 20 million incidental	0.7	13.7	8.5	20.2	7.2	1.1	51.4

The numbers are comparable to those in Chapman et al. (1962) for Area 2 (our Area 2 MSY = 31.8 versus their estimate of 32 million pounds.) Our Area 4 estimates appear low, however, since this area includes a fair portion of what used to be Area 3 in 1962. That underestimate appears due to incidental catch in Area 4 which is not included in our partitioning procedure.

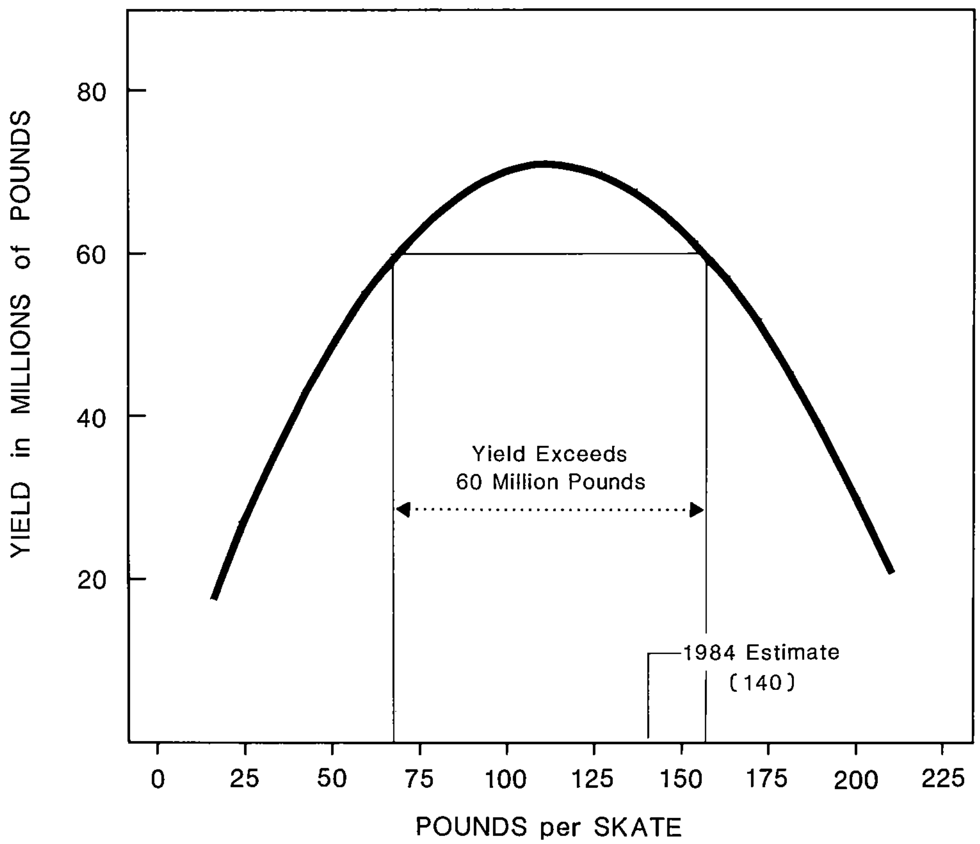

Figure 8. Equilibrium total yield as a function of CPUE. Calculations based on application of delay-difference model with measurement error assumption to 1929-1984 Adjustment III data set.

CONSTANT EXPLOITATION YIELD

The MSY estimates given earlier are difficult to use in actual management of the halibut stock. MSY may reliably indicate the long-term goals of management for maximum yield. However, if annual quotas were always set to MSY, overexploitation and even demise of the stock could occur due to fluctuations in stock abundance. Catches that rise and fall with the abundance of the stock are more appropriate when natural fluctuations occur in the recruitment of young. One such policy is to take a fixed percentage of the stock each year.

The constant exploitation yield (CEY) is the amount of yield obtained by taking catches proportional to stock abundance where the proportionality constant is determined so that MSY is taken when the stock is at the level of abundance that produces MSY. There are several advantages of CEY: (1) catches smoothly rise and fall with the abundance of the stock, (2) each component of the stock is fished with an equal exploitation fraction, (3) subarea estimates can be made without MSY being separately estimated for each subarea. Disadvantages of CEY include: (1) needing to know how much incidental mortality occurs before being able to set longline quotas, (2) if sub-stocks exist and exhibit differential productivity, then they will not be exploited appropriately.

The halibut stock, as a whole, was at the MSY abundance level in 1982 based on analysis in the previous section. We'll use this estimate of the year when MSY was achieved to develop constant exploitation fractions for various CPUE adjustment scenarios. The MSY exploitation fraction is estimated for these scenarios as the ratio of MSY = 71.4 million pounds to stock abundance in 1982. Stock abundances, MSY exploitation fraction (U_{msy}), and current total constant exploitation yield are given below for three adjustments to CPUE.

Adjustment	1982 exploitable biomass (10^6 lbs)	Exploitation U_{msy}	1984 exploitable biomass (10^6 lbs)	1984 Total CEY (10^6 lbs)
I	241	0.30	312	92.6
II	145	0.50	162	80.3
III	187	0.38	227	86.7

These exploitation fractions were multiplied by subarea biomass estimates given in Appendix Tables 5, 6, and 7 to get the following estimates of CEY for each subarea:

CEY Estimates

	Area						
	2A	2B	2C	3A	3B	4	Combined
All Gear							
Adjustment I	0.3	14.1	15.6	39.8	14.6	8.3	92.6
Adjustment II	0.2	12.2	13.6	34.4	12.6	7.2	80.3
Adjustment III	0.3	13.8	14.7	36.6	13.6	7.7	86.7
Setline only:							
(a) 10 million incidental							
Adjustment I	0.3	12.6	13.9	35.5	13.0	7.4	82.6
Adjustment II	0.2	10.7	11.9	30.1	11.0	6.3	70.3
Adjustment III	0.3	12.2	13.0	32.4	12.0	6.8	76.7
(b) 20 million incidental							
Adjustment I	0.3	11.1	12.2	31.2	11.4	6.5	72.6
Adjustment II	0.2	9.2	10.2	25.8	9.4	5.4	60.3
Adjustment III	0.3	10.6	11.3	28.2	10.4	5.9	66.7

During the last 50 years, major systematic changes have occurred in the catchability of Pacific halibut (Quinn 1985a). Therefore, our estimate of CPUE at MSY corresponded to different abundance levels in earlier years. This is a deficiency of our CPUE-based analysis of MSY, which we plan on exploring in future research with a catch-at-age type methodology. For the present, we give a rough estimate of the effect a changing catchability has on the MSY exploitation fraction. Cohort analysis estimates of total adult biomass were made for the years 1951, 1963, and 1982 since CPUE was near our estimated MSY level in each of those years. Abundance estimates are 472, 458, and 388 million pounds for the stock in the years 1951, 1963, and 1982, respectively; this translates into MSY exploitation fractions of 0.15, 0.16, and 0.18 for the adult stock as a whole. We focus here on the stock as a whole since estimates of exploitable stock size are partly dependent on age selectivity estimates, which have changed substantially through the years. Our U_{msy} estimates could be high by 20% based on the difference between estimates for 1951 versus 1982.

An alternative method for calculating the constant exploitation fraction for CEY is presented in Deriso (1985b). This new method is based on yield per recruit theory and shows potential for future management of the halibut fishery. We shall not present technical details here because they are somewhat complex; rather we give a conceptual summary. It is based on calculations of fishing mortality at $F_{0.1}$, which is essentially the level of fishing mortality for which the marginal increase in yield per recruit due to a small increase in fishing mortality is 10% of the marginal yield per recruit in a lightly exploited fishery. The application to Pacific halibut in Deriso (1985b) gave an exploitation fraction of 0.14 for the adult stock as a whole. This estimate is slightly below the 0.15 - 0.18 range for MSY exploitation of the entire adult stock and provides us independent support for an exploitation fraction in the teens.

CONSIDERATIONS FOR DETERMINING CATCH LIMITS

Halibut stocks declined from the early 1960's to the mid-1970's and IPHC responded by reducing catch limits throughout that period. Since then, IPHC has attempted to rebuild stocks by setting catch limits below the annual setline surplus production (ASP). The IPHC staff recommended that catch limits be set at about 75% of the estimated setline ASP during 1980-1983 (Quinn et al. 1984). Stocks increased sharply during this period, and the IPHC staff recommended that catch limits in 1984 be set at 90% of ASP in areas where stocks appeared to be approaching maximum sustained yield (MSY) levels.

Current estimates of short-term productivity (setline ASP and CEY) are compared with the long-term MSY goal in Table 7. ASP estimates for the combined areas range from 48.3 to 79.7 million pounds with a median value of 77.3 million pounds. Median CEY estimates range from 66.7 to 86.7 million pounds, depending on the level of incidental catch. MSY estimates range from 51.4 to 71.4 million pounds, depending on the level of incidental catch. The median estimates of ASP and CEY are higher than the estimates of MSY, suggesting that stock productivity in recent years is above the long-term average. Estimates of ASP and CEY are lower in Areas 2A and 2B than the long-term MSY goal, whereas the opposite occurred in other areas. This difference may reflect an atypical distribution of the halibut stocks in recent years. MSY estimates by area, however, are based on the historical distribution of catch, perhaps reflecting economic factors as well as the distribution of halibut stocks. The fishery first developed in Areas 2A and 2B, where exploitation rates have tended to be higher. In contrast, the fishery in Area 4 did not develop until the 1960's, and the resource in Area 4 has been affected to a greater degree by incidental catches.

Because the current halibut population appears to be at or above the stock level that produces MSY, the objective of rebuilding may no longer be appropriate (except perhaps in Areas 2A and 2B). Setting catch limits requires a clear statement of IPHC objectives. If the objective is to rebuild stocks, then the catch limit should be set below ASP. When stocks are near MSY levels, ASP is not the best parameter upon which to base catch limits, because stock productivity decreases, on the average, as the population increases past the level producing MSY. In this situation, CEY or MSY are appropriate parameters upon which to base catch limits. An advantage of CEY is that it is proportional to current estimates of biomass whereas MSY reflects long-term conditions.

Setting catch limits slightly below estimates of CEY may result in achieving both high and stable yields over time, which should be advantageous both to the harvesting and marketing sectors of the industry. In the past, annual halibut yields to the setline industry have ranged from slightly over 20 million pounds to over 70 million pounds. Although variability due to factors such as incidental catch may be unavoidable, management practices which stress taking maximum yield at all times contribute to the variability in annual harvest. By fishing stocks at slightly below maximum levels, more fish will be available during periods of low productivity. Also, factors such as catchability which are difficult to assess would be less critical in setting catch limits. Figure 9 illustrates the staff recommendations for 1985 catch limits in relation to estimates of 90% of MSY and CEY, the 90% being an arbitrary value for reducing risk of overharvesting. We used the median estimates, which assume 20 million pounds of incidental catch as provided in the section "Constant Exploitation Yield". The staff recommended a catch limit slightly above CEY in Area 2A but below MSY. Area 2A encompasses the southern end of the range for halibut stocks, and the potential yield from this area is relatively small. The catch limit recommendation for Area 2B was slightly below CEY and well below MSY. The recommended catch limit for Area 2B was

Table 7. Summary of 1984 stock assessment estimates of annual surplus production, optimum exploitation yield, and maximum sustained yield.

	2A	2B	2C	3A	3B	4	Combined Areas
			Annual Surplus Production (10^6 pounds)				
Range of Estimates							
Upper	0.5	16.5	20.3	38.9	17.1	6.9	79.7
Lower	0.2	7.3	6.4	19.4	6.4	1.3	48.3
Median	0.3	11.8	11.7	33.0	8.7	4.3	77.3
			Constant Exploitation Yield (10^6 pounds)				
Range of Estimates							
All Gear							
Upper	0.3	14.1	15.6	39.8	14.6	8.3	92.6
Lower	0.2	12.2	13.6	34.4	12.6	7.2	80.3
Median	0.3	13.8	14.7	36.6	13.6	7.7	86.7
Setline only							
(a) 10 million incidental							
Upper	0.3	12.6	13.9	35.5	13.0	7.4	82.6
Lower	0.2	10.7	11.9	30.1	11.0	6.3	70.3
Median	0.3	12.2	13.0	32.4	12.0	6.8	76.7
(b) 20 million incidental							
Upper	0.3	11.1	12.2	31.2	11.4	6.5	72.6
Lower	0.2	9.2	10.2	25.8	9.4	5.4	60.3
Median	0.3	10.6	11.3	28.2	10.4	5.9	66.7
			Maximum Sustained Yield (10^6 pounds)				
All Gear	0.9	19.1	11.8	28.1	10.1	1.5	71.4
Setline only:							
(a) 10 million incidental	0.8	16.4	10.2	24.1	8.7	1.3	61.4
(b) 20 million incidental	0.7	13.7	8.5	20.2	7.2	1.1	51.4

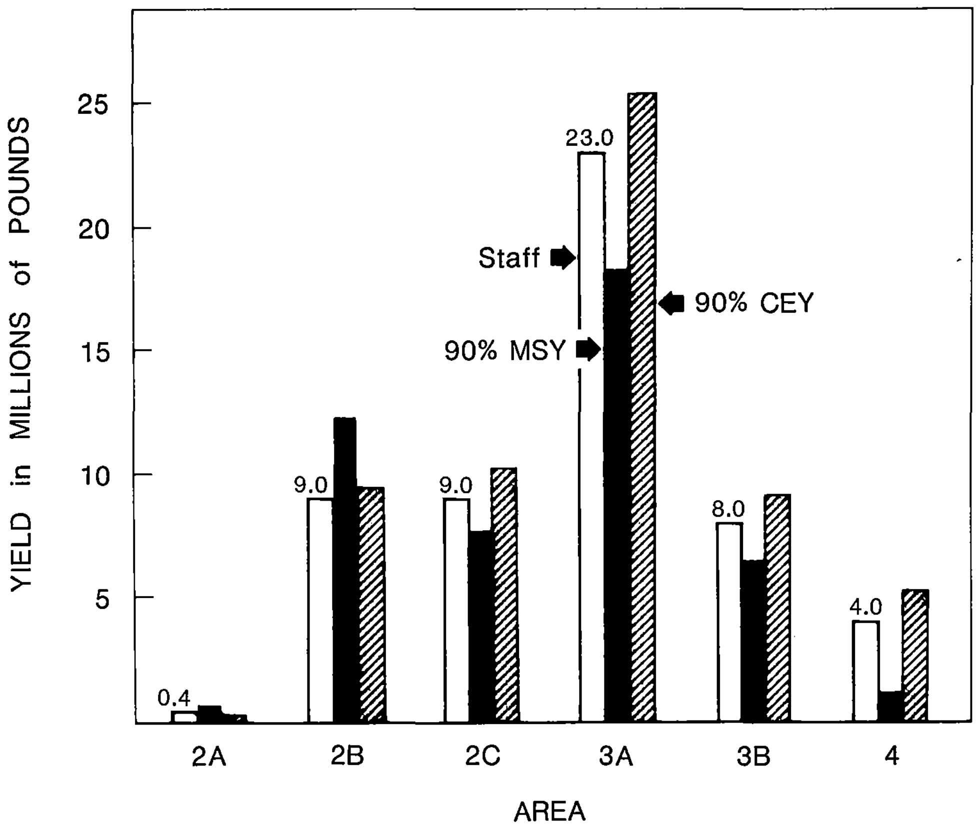

Figure 9. IPHC staff recommendations for catch limits in 1985 in comparison with 90% of estimated maximum sustained yield and 90% of estimated constant exploitation yield in 1984.

more conservative than for other areas because of the high potential for further rebuilding and because the catch limit was increased substantially in 1984. Relatively large numbers of juvenile halibut were observed in Area 2B in 1984, and we anticipate greater production from this area in a few years if these juvenile halibut are allowed to grow.

Areas 2C, 3A, 3B, and 4 provide a different picture; CEY was above estimates of MSY, suggesting above average productivity. Staff recommendations for 1985 catch limits were above MSY estimates but below CEY estimates. We note that MSY estimates are based on the historical distribution of catch by area, and, hence, reflect economic factors as well as the distribution of the resource. The fishery in the western areas (Areas 3B and 4) developed later than in other areas, and exploitation rates by setlines in these areas have been relatively low. Area 4 has also been affected to a greater degree by incidental catches. Therefore, we suspect that MSY estimates for Area 4 and perhaps Area 3B may be underestimated. For all areas combined, the recommended 1985 catch limit was 53.4 million pounds compared to a 90% MSY of 46.0 million pounds and a 90% CEY of 60.0 million pounds.

EFFECTS OF MIGRATION

Halibut are migratory, and catches in one area will reduce the yield available in other areas. To examine the effect of migration, tag release and recovery data were analyzed by area (Deriso, unpublished[3]). The analysis was based on the distribution of tag recoveries and assumes constant exploitation and tag reporting among areas. The effect of migration in Area 2B may be somewhat exaggerated because evidence suggests a higher recovery rate for tags in Area 2B compared to other areas. However, we do not believe this seriously affects the interpretation of the results.

Halibut migration rates are higher for small halibut than large halibut and setline-caught halibut tend to be larger than trawl-caught halibut. The effect of setline catches was estimated using tagging data for fish over 80 cm long. Table 8 provides estimates of the effect of staff recommendations for 1985 catch limits. In general, the results suggest relatively little impact on yield. For example, the 23 million pound catch limit recommended for Area 3A results in a yield loss of less than 0.5 million pounds in each of Areas 2B, 2C, and 3B.

The effect of incidental catches was examined using levels of catch mortality typical of those estimated for the 1960's and 1970's (Hoag and French 1976; Hoag and Schmitt, unpublished) and tagging data for fish less than 80 cm long. Also, a 50% increase in yield loss due to growth was assumed. Table 9 provides the estimates by area. Because of the small size and higher migration rates, halibut caught incidentally in the trawl fisheries have a relatively greater impact on yield than setline catches. IPHC has worked closely with other management agencies in both Canada and the U.S. to reduce incidental catches and incidental catches have declined in recent years. In 1984, we expect the total effect of incidental catches to be about 10 million pounds, down substantially from earlier levels. The lower incidental catch in 1984 partly reflects reduced fishing for crab and groundfish and may not be representative of future catches. Also, the lower 1984 incidental catch will have little effect on present catch limits because most of the incidental catch is below the minimum size limit. If future incidental catches can be held at the 1984 level, however, substantially higher yields in the setline fishery should be available over the next several years.

Table 8. Effect of migration on the distribution of yield, assuming staff recommendations for 1985 catch limits (millions of pounds).

Area	Catch Limit	Distribution of yield* 2A	2B	2C	3A	3B	4
2A	0.4	0.36	0.02	0.01	—	—	—
2B	9.0	0.02	8.87	0.07	0.04	—	—
2C	9.0	—	0.46	8.50	0.04	—	—
3A	23.0	0.07	0.37	0.48	21.78	0.30	—
3B	8.0	0.05	0.14	0.32	1.52	5.97	0.01
4	4.0	0.01	0.13	0.22	0.65	0.25	2.73
Total	53.4	0.50	9.99	9.60	24.03	6.52	2.74

*Assumes percent recoveries for tagged fish over 80 cm is identical to the distribution of yield.

Table 9. Estimated annual yield loss by area from incidental mortality levels of the 1960's and 1970's (millions of pounds).

Area	Incidental Mortality	Annual Yield Loss* 2A	2B	2C	3A	3B	4	TOTAL
2A	trace	—	—	—	—	—	—	—
2B	2	0.01	2.97	0.02	0.00	0.00	—	3.00
2C	1	—	0.18	1.31	0.01	—	—	1.50
3A	3	0.08	0.77	0.24	3.37	0.04	—	4.50
3B	3	0.03	0.42	0.25	0.68	3.06	0.06	4.50
4	5	—	0.24	0.73	0.65	0.40	5.48	7.50
TOTAL	14	0.12	4.58	2.55	4.71	3.50	5.54	21.00

*Assumes percent recoveries for tagged fish <80 cm is same as relative yield loss; assumes 50% increase in loss due to growth.

ACKNOWLEDGMENTS

Dr. McCaughran provided advice and encouragement throughout this study. Dr. K. Ketchen, Dr. W. Getz, Dr. B. Leaman, and Dr. L. Low kindly reviewed this report. We appreciate comments by Dr. L. Low, P. Rigby, R. Stanley, and Dr. D. Ware on an earlier manuscript. This report would not have been possible without the help of IPHC staff; in particular, P. Neal (computer programming), C. Doyer and P. Severeid (typing), and K. Exelby (illustration).

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Appendix Table 1. **CPUE data set with the Base Correction: fixed-hook gear (except snap gear used for 1984 CPUE in Area 2A), adjusted for circle hooks (circle hook CPUE divided by 2.2), 1983 CPUE values calculated as average of 1982 and 1984 values.**

CPUE Report for Subareas 1979

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	46000.	920.	50.0
2B	4857000.	101040.	48.1
2C	4530000.	56440.	80.3
3A	11335000.	131946.	85.9
3B	390000.	10614.	36.7
4	1369000.	20619.	66.4
ALL	22527000.	321579.	70.1
2A+2B	4903000.	101960.	48.1
2A+2B+2C	9433000.	158400.	59.6
3A+3B	11725000.	142560.	82.2
3B+4	1759000.	31233.	56.3

CPUE Report for Subareas 1980

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	22000.	590.	37.3
2B	5650000.	86528.	65.3
2C	3238000.	40774.	79.4
3A	11966000.	101015.	118.5
3B	277000.	2443.	113.4
4	713000.	12632.	56.4
ALL	21866000.	243982.	89.6
2A+2B	5672000.	87118.	65.1
2A+2B+2C	8910000.	127892.	69.7
3A+3B	12243000.	103458.	118.3
3B+4	990000.	15075.	65.7

CPUE Report for Subareas 1981

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	202000.	6185.	32.7
2B	5654000.	93168.	60.7
2C	4010000.	27454.	146.1
3A	14225000.	103300.	137.7
3B	456000.	2700.	168.9
4	1185000.	11300.	104.9
ALL	25732000.	244107.	105.4
2A+2B	5856000.	99353.	58.9
2A+2B+2C	9866000.	126807.	77.8
3A+3B	14681000.	106000.	138.5
3B+4	1641000.	14000.	117.2

CPUE Report for Subareas 1982

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	211000.	5364.	39.3
2B	5236000.	86841.	60.3
2C	3485000.	20498.	170.0
3A	13507000.	80610.	167.6
3B	5872000.	35600.	164.9
4	407000.	6000.	68.2
ALL	28718000.	234913.	122.2
2A+2B	5447000.	92205.	59.1
2A+2B+2C	8932000.	112703.	79.3
3A+3B	19379000.	116210.	166.8
3B+4	6279000.	41600.	150.9

CPUE Report for Subareas 1983

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	265000.	6200.	42.4
2B	5436000.	75600.	71.9
2C	6398000.	38600.	165.9
3A	14112000.	68200.	206.8
3B	9808000.	51800.	189.5
4	2365000.	31800.	74.4
ALL	38384000.	272200.	141.0
2A+2B	5701000.	81800.	69.7
2A+2B+2C	12099000.	120400.	100.5
3A+3B	23920000.	120000.	199.3
3B+4	12173000.	83600.	145.6

CPUE Report for Subareas 1984

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	375000.	8200.	45.6
2B	8900000.	106600.	83.5
2C	5900000.	36500.	161.8
3A	19600000.	79600.	246.1
3B	5900000.	27600.	214.1
4	3100000.	38500.	80.5
ALL	43775000.	297000.	147.4
2A+2B	9275000.	114800.	80.8
2A+2B+2C	15175000.	151300.	100.3
3A+3B	25500000.	107200.	237.9
3B+4	9000000.	66100.	136.2

Appendix Table 2. CPUE data set with Adjustment I: CPUE multiplied by 1.5 since 1981 in Area 2B to correct for catchability.

CPUE Report for Subareas 1979

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	46000.	920.	50.0
2B	4857000.	101040.	48.1
2C	4530000.	56442.	80.3
3A	11335000.	131940.	85.9
3B	390000.	10615.	36.7
4	1369000.	20617.	66.4
ALL	22527000.	321574.	70.1
2A+2B	4903000.	101960.	48.1
2A+2B+2C	9433000.	158402.	59.6
3A+3B	11725000.	142555.	82.2
3B+4	1759000.	31232.	56.3

CPUE Report for Subareas 1982

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	211000.	5369.	39.3
2B	5236000.	57888.	90.4
2C	3485000.	20500.	170.0
3A	13507000.	80591.	167.6
3B	5872000.	35609.	164.9
4	407000.	5968.	68.2
ALL	28718000.	205925.	139.5
2A+2B	5447000.	63257.	86.1
2A+2B+2C	8932000.	83757.	106.6
3A+3B	19379000.	116200.	166.8
3B+4	6279000.	41577.	151.0

CPUE Report for Subareas 1980

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	22000.	590.	37.3
2B	5650000.	86524.	65.3
2C	3238000.	40776.	79.4
3A	11966000.	101013.	118.5
3B	277000.	2443.	113.4
4	713000.	12633.	56.4
ALL	21866000.	243979.	89.6
2A+2B	5672000.	87114.	65.1
2A+2B+2C	8910000.	127890.	69.7
3A+3B	12243000.	103456.	118.3
3B+4	990000.	15076.	65.7

CPUE Report for Subareas 1983

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	265000.	6250.	42.4
2B	5436000.	50403.	107.8
2C	6398000.	38565.	165.9
3A	14112000.	68240.	206.8
3B	9808000.	51757.	189.5
4	2365000.	31788.	74.4
ALL	38384000.	247003.	155.4
2A+2B	5701000.	56653.	100.6
2A+2B+2C	12099000.	95218.	127.1
3A+3B	23920000.	119997.	199.3
3B+4	12173000.	83545.	145.7

CPUE Report for Subareas 1981

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	202000.	6177.	32.7
2B	5654000.	62098.	91.0
2C	4010000.	27447.	146.1
3A	14225000.	103304.	137.7
3B	456000.	2700.	168.9
4	1185000.	11296.	104.9
ALL	25732000.	213022.	120.8
2A+2B	5856000.	68275.	85.8
2A+2B+2C	9866000.	95722.	103.1
3A+3B	14681000.	106004.	138.5
3B+4	1641000.	13996.	117.2

CPUE Report for Subareas 1984

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	375000.	8224.	45.6
2B	8900000.	71058.	125.2
2C	5900000.	36465.	161.8
3A	19600000.	79642.	246.1
3B	5900000.	27557.	214.1
4	3100000.	38509.	80.5
ALL	43775000.	261455.	167.4
2A+2B	9275000.	79282.	117.0
2A+2B+2C	15175000.	115747.	131.1
3A+3B	25500000.	107199.	237.9
3B+4	9000000.	66066.	136.2

Appendix Table 3. CPUE data set with Adjustment II: CPUE divided by 1.5 in Areas 2C, 3A, and 3B since 1981 to correct for catchability.

CPUE Report for Subareas 1979

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	46000.	920.	50.0
2B	4857000.	101040.	48.1
2C	4530000.	56442.	80.3
3A	11335000.	131940.	85.9
3B	390000.	10615.	36.7
4	1369000.	20617.	66.4
ALL	22527000.	321574.	70.1
2A+2B	4903000.	101960.	48.1
2A+2B+2C	9433000.	158402.	59.6
3A+3B	11725000.	142555.	82.2
3B+4	1759000.	31232.	56.3

CPUE Report for Subareas 1980

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	22000.	590.	37.3
2B	5650000.	86524.	65.3
2C	3238000.	40776.	79.4
3A	11966000.	101013.	118.5
3B	277000.	2443.	113.4
4	713000.	12633.	56.4
ALL	21866000.	243979.	89.6
2A+2B	5672000.	87114.	65.1
2A+2B+2C	8910000.	127890.	69.7
3A+3B	12243000.	103456.	118.3
3B+4	990000.	15076.	65.7

CPUE Report for Subareas 1981

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	202000.	6177.	32.7
2B	5654000.	93147.	60.7
2C	4010000.	41170.	97.4
3A	14225000.	154956.	91.8
3B	456000.	4050.	112.6
4	1185000.	11296.	104.9
ALL	25732000.	310796.	82.8
2A+2B	5856000.	99324.	59.0
2A+2B+2C	9866000.	140494.	70.2
3A+3B	14681000.	159006.	92.3
3B+4	1641000.	15346.	106.9

CPUE Report for Subareas 1982

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	211000.	5369.	39.3
2B	5236000.	86833.	60.3
2C	3485000.	30750.	113.3
3A	13507000.	120886.	111.7
3B	5872000.	53414.	109.9
4	407000.	5968.	68.2
ALL	28718000.	303220.	94.7
2A+2B	5447000.	92202.	59.1
2A+2B+2C	8932000.	122952.	72.6
3A+3B	19379000.	174300.	111.2
3B+4	6279000.	59382.	105.7

CPUE Report for Subareas 1983

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	265000.	6250.	42.4
2B	5436000.	75605.	71.9
2C	6398000.	57848.	110.6
3A	14112000.	102360.	137.9
3B	9808000.	77636.	126.3
4	2365000.	31788.	74.4
ALL	38384000.	351487.	109.2
2A+2B	5701000.	81855.	69.6
2A+2B+2C	12099000.	139703.	86.6
3A+3B	23920000.	179996.	132.9
3B+4	12173000.	109424.	111.2

CPUE Report for Subareas 1984

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	375000.	8224.	45.6
2B	8900000.	106587.	83.5
2C	5900000.	54697.	107.9
3A	19600000.	119464.	164.1
3B	5900000.	41336.	142.7
4	3100000.	38509.	80.5
ALL	43775000.	368817.	118.7
2A+2B	9275000.	114811.	80.8
2A+2B+2C	15175000.	169508.	89.5
3A+3B	25500000.	160800.	158.6
3B+4	9000000.	79845.	112.7

Appendix Table 4. **CPUE data set with Adjustment III: CPUE multiplied by 1.25 in Area 2B and divided by 1.25 in Areas 2C, 3A, and 3B to correct for catchability.**

CPUE Report for Subareas 1979

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	46000.	920.	50.0
2B	4857000.	101040.	48.1
2C	4530000.	56442.	80.3
3A	11335000.	131940.	85.9
3B	390000.	10615.	36.7
4	1369000.	20617.	66.4
ALL	22527000.	321574.	70.1
2A+2B	4903000.	101960.	48.1
2A+2B+2C	9433000.	158402.	59.6
3A+3B	11725000.	142555.	82.2
3B+4	1759000.	31232.	56.3

CPUE Report for Subareas 1980

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	22000.	590.	37.3
2B	5650000.	86524.	65.3
2C	3238000.	40776.	79.4
3A	11966000.	101013.	118.5
3B	277000.	2443.	113.4
4	713000.	12633.	56.4
ALL	21866000.	243979.	89.6
2A+2B	5672000.	87114.	65.1
2A+2B+2C	8910000.	127890.	69.7
3A+3B	12243000.	103456.	118.3
3B+4	990000.	15076.	65.7

CPUE Report for Subareas 1981

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	202000.	6177.	32.7
2B	5654000.	74517.	75.9
2C	4010000.	34309.	116.9
3A	14225000.	129130.	110.2
3B	456000.	3375.	135.1
4	1185000.	11296.	104.9
ALL	25732000.	258804.	99.4
2A+2B	5856000.	80694.	72.6
2A+2B+2C	9866000.	115003.	85.8
3A+3B	14681000.	132505.	110.8
3B+4	1641000.	14671.	111.9

CPUE Report for Subareas 1982

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	211000.	5369.	39.3
2B	5236000.	69466.	75.4
2C	3485000.	25625.	136.0
3A	13507000.	100738.	134.1
3B	5872000.	44512.	131.9
4	407000.	5968.	68.2
ALL	28718000.	251678.	114.1
2A+2B	5447000.	74835.	72.8
2A+2B+2C	8932000.	100460.	88.9
3A+3B	19379000.	145250.	133.4
3B+4	6279000.	50480.	124.4

CPUE Report for Subareas 1983

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	265000.	6250.	42.4
2B	5436000.	60484.	89.9
2C	6398000.	48207.	132.7
3A	14112000.	85300.	165.4
3B	9808000.	64697.	151.6
4	2365000.	31788.	74.4
ALL	38384000.	296726.	129.4
2A+2B	5701000.	66734.	85.4
2A+2B+2C	12099000.	114941.	105.3
3A+3B	23920000.	149997.	159.5
3B+4	12173000.	96485.	126.2

CPUE Report for Subareas 1984

Subarea	Catch (lbs.)	Effort (skates)	CPUE (lbs./skate)
2A	375000.	8224.	45.6
2B	8900000.	85269.	104.4
2C	5900000.	45581.	129.4
3A	19600000.	99553.	196.9
3B	5900000.	34447.	171.3
4	3100000.	38509.	80.5
ALL	43775000.	311583.	140.5
2A+2B	9275000.	93493.	99.2
2A+2B+2C	15175000.	139074.	109.1
3A+3B	25500000.	134000.	190.3
3B+4	9000000.	72956.	123.4

Appendix Table 5. Estimates of biomass and annual surplus production (ASP) using catch-age analysis with CPUE partitioning with the Adjustment I data set.

Biomass in million lbs. by subarea

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	125.614	1.663	31.265	20.469	43.937	18.179	11.002
1975	128.254	1.591	31.265	20.282	45.552	18.571	11.256
1976	132.633	1.498	31.265	20.308	48.522	19.171	11.628
1977	139.853	1.405	31.231	21.324	53.356	20.096	12.208
1978	150.559	1.296	30.966	24.128	59.653	21.523	13.099
1979	164.867	1.126	30.535	28.995	66.580	23.700	14.333
1980	183.388	0.945	30.606	35.242	74.255	26.875	15.944
1981	207.689	0.843	32.151	41.534	84.216	31.212	18.076
1982	241.152	0.830	36.315	47.094	99.031	37.017	21.092
1983	279.562	0.858	42.234	51.396	117.157	43.456	24.643
1984	312.350	0.898	47.555	54.213	133.249	48.873	27.724

ASP in million lbs. by subarea [Blind Response Method]

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	27.252	0.451	5.875	5.754	11.171	2.740	0.763
1975	29.581	0.346	5.875	5.959	12.599	3.132	0.941
1976	31.949	0.197	5.753	6.479	14.137	3.465	1.342
1977	34.182	0.043	5.507	7.524	15.595	3.605	1.933
1978	37.020	-0.054	5.384	8.761	17.209	3.662	2.467
1979	41.513	-0.081	5.806	9.540	19.578	3.931	2.876
1980	48.691	-0.031	7.289	9.662	23.245	4.973	3.325
1981	57.955	0.103	9.291	9.522	27.379	7.672	3.900
1982	66.718	0.235	10.683	9.459	30.331	11.743	4.645
1983	73.129	0.298	11.336	9.464	31.857	15.194	5.453
1984	77.269	0.326	11.658	9.471	32.699	17.056	6.074

ASP in million lbs. by subarea [Biomass Partitioning]

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	27.252	0.354	6.595	4.469	9.511	3.924	2.371
1975	29.581	0.385	7.188	4.674	10.472	4.289	2.603
1976	31.949	0.351	7.668	4.856	11.597	4.633	2.812
1977	34.182	0.342	7.793	5.127	12.989	4.922	2.974
1978	37.020	0.333	7.700	5.738	14.771	5.294	3.221
1979	41.513	0.291	7.555	7.223	16.896	5.936	3.612
1980	48.691	0.243	7.888	9.446	19.720	7.109	4.236
1981	57.955	0.232	8.867	11.707	23.414	8.751	5.042
1982	66.718	0.200	10.074	13.210	27.154	10.275	5.804
1983	73.129	0.219	11.042	13.602	30.495	11.335	6.435
1984	77.269	0.232	11.822	13.058	33.226	12.131	6.877

Appendix Table 6. **Estimates of biomass and annual surplus production (ASP) using catch-age analysis with CPUE partitioning with the Adjustment II data set.**

Biomass in million lbs. by subarea

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	112.888	1.509	27.577	18.172	39.408	16.313	9.875
1975	112.433	1.400	27.290	17.768	39.957	16.241	9.838
1976	112.375	1.263	26.700	17.376	41.074	16.207	9.839
1977	113.512	1.135	25.620	17.411	43.167	16.314	9.932
1978	116.576	1.031	23.950	18.563	46.040	16.698	10.169
1979	121.455	0.912	22.259	21.230	48.982	17.475	10.568
1980	127.626	0.795	21.415	24.480	51.768	18.676	11.097
1981	135.275	0.739	21.274	26.905	54.966	20.257	11.772
1982	145.016	0.741	21.845	28.116	59.472	22.136	12.677
1983	155.064	0.769	23.297	28.531	64.771	23.948	13.662
1984	162.814	0.798	24.799	28.668	69.276	25.313	14.452

ASP in million lbs. by subarea [Blind Response Method]

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	23.842	0.408	5.497	5.523	9.888	2.480	0.465
1975	24.983	0.307	5.377	5.528	10.684	2.480	0.576
1976	26.180	0.173	4.982	5.720	11.605	2.480	0.869
1977	26.950	0.049	4.406	6.090	12.481	2.383	1.290
1978	27.334	-0.016	4.147	6.273	13.277	2.132	1.611
1979	28.270	-0.032	4.423	6.166	14.258	1.923	1.756
1980	30.651	0.010	5.233	5.941	15.783	2.194	1.802
1981	34.731	0.125	6.139	5.814	17.512	3.906	1.934
1982	40.107	0.236	6.720	5.888	18.654	7.266	2.380
1983	45.230	0.289	7.058	6.137	19.135	10.462	2.998
1984	48.830	0.311	7.276	6.472	19.395	12.284	3.458

ASP in million lbs. by subarea [Biomass Partitioning]

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	23.842	0.310	5.770	3.910	8.321	3.433	2.074
1975	24.983	0.325	6.071	3.947	8.844	3.623	2.199
1976	26.180	0.288	6.283	3.979	9.503	3.796	2.304
1977	26.950	0.269	6.145	4.042	10.241	3.881	2.345
1978	27.334	0.246	5.685	4.237	10.906	3.909	2.378
1979	28.270	0.226	5.145	4.919	11.478	4.043	2.459
1980	30.651	0.184	4.965	5.946	12.414	4.475	2.667
1981	34.731	0.174	5.314	6.981	14.031	5.210	3.022
1982	40.107	0.201	6.016	7.941	16.324	6.136	3.489
1983	45.230	0.226	6.830	8.413	18.816	6.965	3.980
1984	48.830	0.244	7.471	8.252	20.948	7.617	4.346

Appendix Table 7. Estimates of biomass and annual surplus production (ASP) using catch-age analysis with CPUE partitioning with the Adjustment III data set.

Biomass in million lbs. by subarea

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	118.468	1.586	29.130	19.218	41.466	17.163	10.353
1975	119.531	1.488	29.042	18.947	42.481	17.293	10.472
1976	121.390	1.368	28.849	18.671	44.402	17.515	10.631
1977	125.144	1.248	28.253	19.003	47.661	17.975	10.926
1978	131.651	1.129	27.141	20.874	51.987	18.868	11.463
1979	140.736	1.003	26.156	24.531	56.651	20.301	12.242
1980	152.291	0.896	25.831	29.048	61.568	22.312	13.246
1981	167.156	0.839	26.429	33.142	67.655	24.971	14.551
1982	187.130	0.833	28.849	36.237	76.388	28.479	16.365
1983	209.372	0.854	32.623	38.241	86.771	32.302	18.452
1984	227.863	0.882	36.029	39.349	95.776	35.449	20.226

ASP in million lbs. by subarea [Blind Response Method]

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	25.386	0.424	5.772	5.637	10.456	2.485	0.612
1975	27.056	0.316	5.697	5.663	11.509	2.776	0.743
1976	28.802	0.173	5.397	5.954	12.673	2.950	1.081
1977	30.211	0.045	4.914	6.675	13.822	2.958	1.581
1978	31.624	-0.019	4.687	7.349	15.035	2.852	1.991
1979	34.061	-0.033	5.053	7.535	16.610	2.780	2.241
1980	38.520	0.009	6.243	7.472	18.937	3.300	2.458
1981	44.872	0.121	7.745	7.438	21.517	5.478	2.779
1982	51.641	0.231	8.749	7.442	23.262	9.232	3.357
1983	57.225	0.286	9.229	7.466	24.084	12.582	4.060
1984	61.103	0.310	9.476	7.508	24.549	14.433	4.581

ASP in million lbs. by subarea [Biomass Partitioning]

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	25.386	0.330	6.143	4.163	8.860	3.656	2.209
1975	27.056	0.352	6.575	4.275	9.578	3.923	2.381
1976	28.802	0.317	6.912	4.378	10.455	4.176	2.535
1977	30.211	0.302	6.888	4.532	11.480	4.350	2.628
1978	31.624	0.285	6.578	4.902	12.586	4.522	2.751
1979	34.061	0.238	6.233	5.893	13.829	4.905	2.963
1980	38.520	0.231	6.317	7.434	15.562	5.624	3.351
1981	44.872	0.224	7.000	8.974	18.083	6.731	3.904
1982	51.641	0.207	7.953	10.122	20.966	7.849	4.493
1983	57.225	0.229	8.927	10.587	23.634	8.813	5.036
1984	61.103	0.244	9.715	10.265	25.847	9.532	5.438

Appendix Table 8. Estimates of biomass and annual surplus production (ASP) using closed subarea analysis with CPUE Adjustment III.

Biomass in million lbs. by subarea

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	120.747	1.554	28.930	24.944	42.129	14.456	8.734
1975	126.813	1.606	30.017	24.453	46.406	15.142	9.189
1976	129.586	1.342	29.272	24.341	50.174	15.220	9.237
1977	135.188	1.279	29.169	25.381	54.807	15.305	9.247
1978	145.955	1.287	29.735	28.972	61.959	14.923	9.079
1979	157.740	1.175	30.707	32.930	69.407	14.662	8.859
1980	172.576	1.158	31.665	37.928	77.287	15.376	9.162
1981	194.778	1.054	32.897	44.672	85.879	19.162	11.114
1982	229.177	0.927	35.693	52.850	96.491	27.485	15.731
1983	262.474	1.046	40.776	62.573	111.739	29.489	16.851
1984	296.306	1.225	48.711	70.864	131.761	27.854	15.891

ASP in million lbs. by subarea [Blind Response Method]

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	28.244	0.427	6.038	5.421	12.970	2.626	0.736
1975	29.732	0.315	6.055	5.855	13.975	2.626	0.736
1976	31.305	0.195	6.064	6.419	15.084	2.535	0.764
1977	32.461	0.096	5.967	7.167	16.196	2.261	0.900
1978	33.944	0.032	5.818	8.179	17.477	1.990	1.297
1979	37.980	0.010	5.978	9.313	19.100	2.367	1.800
1980	45.558	0.030	6.814	10.529	21.395	4.118	2.012
1981	55.172	0.124	8.405	11.935	24.773	6.453	1.995
1982	65.035	0.291	10.760	13.480	29.443	7.743	1.814
1983	73.544	0.440	13.388	14.967	34.605	7.980	1.487
1984	79.687	0.517	15.533	16.169	38.920	7.980	1.300

ASP in million lbs. by subarea [Biomass Partitioning]

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	28.244	0.367	6.779	5.847	9.857	3.389	2.034
1975	29.732	0.387	7.046	5.738	10.882	3.538	2.141
1976	31.305	0.313	7.075	5.885	12.115	3.663	2.223
1977	32.461	0.292	7.012	6.103	13.147	3.668	2.207
1978	33.944	0.305	6.925	6.721	14.426	3.462	2.105
1979	37.980	0.266	7.406	7.938	16.711	3.532	2.127
1980	45.558	0.319	8.337	10.023	20.410	4.055	2.415
1981	55.172	0.276	9.324	12.634	24.331	5.407	3.145
1982	65.035	0.260	10.145	15.023	27.380	7.804	4.487
1983	73.544	0.294	11.399	17.503	31.330	8.237	4.707
1984	79.687	0.319	13.069	19.045	35.461	7.491	4.303

Appendix Table 9. Estimates of biomass and annual surplus production (ASP) using migratory catch-age analysis with CPUE Adjustment III.

Biomass in million lbs. by subarea

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	121.502	1.586	29.518	24.737	41.923	14.798	8.940
1975	127.219	1.637	30.608	24.336	46.070	15.289	9.279
1976	129.607	1.368	29.856	24.410	49.740	15.081	9.152
1977	134.857	1.307	29.801	25.699	54.224	14.853	8.973
1978	145.124	1.319	30.472	29.636	61.260	13.950	8.487
1979	156.443	1.207	31.561	33.979	68.433	13.255	8.008
1980	170.829	1.195	32.657	39.443	75.873	13.573	8.088
1981	191.695	1.093	34.095	46.599	83.712	16.580	9.616
1982	223.505	0.968	37.268	55.187	93.400	23.329	13.353
1983	255.563	1.101	42.944	65.306	107.394	24.702	14.116
1984	288.962	1.300	51.656	73.976	125.921	22.992	13.117

ASP in million lbs. by subarea [Blind Response Method]

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	27.850	0.423	6.036	5.534	12.859	2.386	0.578
1975	29.302	0.314	6.053	6.031	13.879	2.386	0.566
1976	30.855	0.196	6.055	6.672	14.989	2.244	0.559
1977	32.036	0.099	6.004	7.499	16.059	1.855	0.637
1978	33.517	0.036	5.925	8.576	17.226	1.503	0.997
1979	37.282	0.014	6.144	9.741	18.663	1.803	1.496
1980	44.328	0.035	7.062	10.953	20.728	3.430	1.728
1981	53.624	0.130	8.786	12.345	23.849	5.752	1.736
1982	63.722	0.304	11.339	13.886	28.215	7.214	1.616
1983	72.794	0.461	14.188	15.371	33.046	7.701	1.394
1984	79.467	0.544	16.513	16.578	37.073	7.935	1.287

ASP in million lbs. by subarea [Biomass Partitioning]

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1974	27.850	0.362	6.768	5.681	9.608	3.398	2.061
1975	29.302	0.381	7.062	5.597	10.607	3.516	2.139
1976	30.855	0.339	7.097	5.801	11.848	3.579	2.191
1977	32.036	0.320	7.080	6.119	12.878	3.524	2.146
1978	33.517	0.302	7.039	6.837	14.144	3.218	1.944
1979	37.282	0.298	7.531	8.090	16.292	3.169	1.901
1980	44.328	0.310	8.467	10.240	19.682	3.502	2.083
1981	53.624	0.322	9.545	13.031	23.434	4.612	2.681
1982	63.722	0.255	10.642	15.739	26.636	6.627	3.823
1983	72.794	0.291	12.229	18.635	30.573	7.061	4.004
1984	79.467	0.318	14.225	20.344	34.648	6.357	3.576

Appendix Table 10. **Commercial setline catch (millions of pounds) for subareas and the total population.**

YEAR	TOTAL	2A	2B	2C	3A	3B	4
1935	47.343	1.770	14.285	7.504	19.963	3.821	0.000
1936	48.923	0.901	13.699	8.719	20.088	5.516	0.000
1937	49.539	0.917	15.313	7.843	20.465	5.001	0.000
1938	49.553	0.951	16.028	7.130	20.658	4.786	0.000
1939	50.903	1.363	17.691	6.536	21.160	4.153	0.000
1940	53.381	0.981	17.832	7.590	22.497	4.481	0.000
1941	52.231	0.509	16.543	7.238	21.837	6.104	0.000
1942	50.388	0.718	14.391	8.325	21.496	5.458	0.000
1943	53.699	1.237	15.987	8.137	20.511	7.827	0.000
1944	53.435	0.897	15.128	10.324	20.357	6.729	0.000
1945	53.395	0.729	14.588	8.479	20.074	9.520	0.005
1946	60.266	0.900	18.388	9.880	22.395	8.703	0.000
1947	55.700	0.572	17.699	9.468	20.442	7.519	0.000
1948	55.564	0.407	17.667	9.753	19.933	7.804	0.000
1949	56.025	0.618	16.343	9.451	21.115	7.498	0.000
1950	57.234	0.703	17.485	8.809	23.861	6.376	0.000
1951	56.045	0.585	20.089	9.924	20.861	4.586	0.000
1952	62.262	0.617	20.667	9.524	27.269	3.933	0.252
1953	59.837	0.502	23.804	8.405	22.836	4.063	0.227
1954	70.583	0.853	24.985	10.953	29.455	4.296	0.041
1955	57.521	0.612	18.651	8.543	23.059	6.611	0.045
1956	66.681	0.529	20.170	14.491	22.113	9.116	0.262
1957	60.854	0.596	17.687	12.251	22.849	7.432	0.039
1958	64.514	0.523	18.531	11.162	24.521	7.601	2.176
1959	71.243	0.669	16.995	12.905	25.364	11.153	4.157
1960	71.605	0.885	18.182	12.691	21.046	13.135	5.666
1961	69.274	0.497	16.092	12.271	23.068	13.378	3.968
1962	74.862	0.449	15.178	13.091	24.043	14.759	7.342
1963	71.237	0.412	15.863	9.895	22.310	14.558	8.199
1964	59.784	0.280	12.125	7.164	22.557	15.329	2.329
1965	63.176	0.214	12.364	11.674	22.979	14.610	1.335
1966	62.016	0.183	11.383	11.693	25.767	11.721	1.269
1967	55.222	0.199	10.352	9.168	19.657	13.436	2.410
1968	48.594	0.138	10.579	5.677	14.774	16.096	1.330
1969	58.275	0.230	13.162	8.985	20.081	14.495	1.322
1970	54.938	0.159	10.639	9.087	19.906	13.906	1.241
1971	46.654	0.318	10.002	6.453	17.761	11.252	0.868
1972	42.884	0.369	10.280	5.634	16.299	9.538	0.764
1973	31.740	0.225	6.974	5.730	13.498	4.980	0.333
1974	21.306	0.515	4.624	5.605	8.187	1.834	0.541
1975	27.616	0.460	7.127	6.243	10.601	2.655	0.530
1976	27.535	0.238	7.283	5.527	11.044	2.809	0.634
1977	21.868	0.207	5.427	3.186	8.641	3.323	1.084
1978	21.988	0.097	4.607	4.316	10.295	1.327	1.346
1979	22.527	0.046	4.857	4.530	11.335	0.390	1.369
1980	21.866	0.022	5.650	3.238	11.966	0.277	0.713
1981	25.732	0.202	5.654	4.010	14.225	0.456	1.185
1982	28.718	0.211	5.236	3.485	13.507	5.872	0.407
1983	38.384	0.265	5.436	6.398	14.112	9.808	2.365
1984	43.775	0.375	8.900	5.900	19.600	5.900	3.100