APPENDICES TO THE STATUS OF THE PACIFIC COAST GROUNDFISH FISHERY THROUGH 1994 AND RECOMMENDED ACCEPTABLE BIOLOGICAL CATCHES FOR 1995

APPENDIX VOLUME 1

Stock Assessment and Fishery Evaluation

Pacific Fishery Management Council
2130 SW Fifth Avenue, Suite 224
Portland, OR 97201

September 1994

CONTENTS

VOLUME 1

This Stock Assessment and Fishery Evaluation document is published by the Pacific Fishery Management Council pursuant to National Oceanic and Atmospheric Administration Award Number NA47FC0025.

APPENDIX A
PACIFIC WHITING

STATUS OF THE COASTAL PACIFIC WHITING RESOURCE IN 1994

Martin W. Dorn
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE, BIN C15700
Seattle, WA 98115-0070

ABSTRACT

This report assesses the status of the coastal Pacific whiting (*Merluccius productus*) resource in 1994. It reviews recent developments in the Pacific whiting fishery, tabulates and analyzes the 1993 catch statistics, describes a stock synthesis model application using catch and survey data from 1977-93, and presents yield options for 1995-97. The U.S. and Canadian harvest of Pacific whiting in 1993 was 199,994 metric tons (t). In 1994, the yield is expected to be 371,000 t. Assessment surveys conducted during summer of 1992 by National Marine Fisheries Service and the Department of Fisheries and Oceans resulted in estimates of population abundance considerably in excess of forecasts based on earlier surveys and models. A geographic version of the stock synthesis model that divided the population into U.S. and Canadian components was used to assess the Pacific whiting population. Population biomass peaked 1987 and has been declining steadily since that time. The biomass of age 3 and older fish in 1993 was estimated to be 2.871 million t. The age-2 recruitment abundance of the 1990 and 1991 year classes were estimated at 2.336 and 0.198 billion fish respectively, indicating that the 1990 year class is moderately strong (greater than the mean 1977-93 recruitment of 2.041 billion) and that the 1991 year class is a weak year class. A deterministic age-structured population model for Pacific whiting was used to forecast yields for 1995-97. Several harvesting strategies are presented: a constant F strategy, a variable F strategy (where fishing mortality for a particular year is proportional to the level of female spawning biomass), and a hybrid strategy that combines features of the other two policies. Three harvest rates are presented for each harvest strategy. These harvest rates are based on the probability that female spawning biomass will fall below a cautionary level of 623,000 t in long-term simulations of the Pacific whiting population. When a hybrid fishing strategy is applied to the projected numbers at age in 1995, the potential total yield is calculated to be 223,000 t at low harvest rate, 309,000 t at a moderate harvest rate, and 382,000 t at a high harvest rate. If recruitment remains near the 1960-93 median recruitment of 0.954 billion fish, the outlook for the immediate future is for a fairly rapid decline in annual yield in 1996 and 1997. The recruitment of a strong year class to the population would substantially increase the projected yields.

INTRODUCTION

The purpose of this interim report is to update the 1993 Pacific whiting assessment (Dorn et al. 1993) with the 1993 catch and survey data. In the 1993 assessment, estimates of total Pacific whiting abundance were revised upwards from the levels estimated in previous whiting assessments. This altered view of the Pacific whiting population was entirely a result of surveys conducted during summer of 1992 by National Marine Fisheries Service and Department of Fisheries and Oceans. These surveys produced biomass estimates considerably in excess of forecast abundance based on earlier surveys and models. The NMFS acoustic survey had wider areal coverage than earlier surveys, and used improved echo-integration technology. Since the 1992 surveys, there have been no new coastwide surveys to substantiate the 1992 survey result, though a DFO acoustic survey was conducted in August 1993 in Canadian zone. In this assessment, the stock synthesis model was configured to match the 1993 assessment. Several supplemental stock synthesis analyses were also conducted. Other sections of this report review the coastal Pacific whiting fishery in 1993, tabulate and analyze the 1993 catch statistics, and present yield options for 1995 and forecast short term trends in yield.

The Pacific Whiting Fishery in the U.S. Zone in 1993

An ABC of 178,000 t was recommended for the coastal Pacific whiting stock in 1992. U.S. managers allocated 142,000 t or 80 percent of the total ABC to the U.S. whiting fisheries, while Canadian managers allocated 61,000 t to Canadian whiting fisheries, so that 30 percent of the expected U.S. and Canadian harvest would go to Canadian fisheries. In the U.S. zone, the allocation was further divided into an allocation for at-sea processors vessels of 100,000 t, and an allocation of 42,000 t for shore-based processing. To minimize salmon bycatch, at-sea processing and night fishing (midnight to one hour after official sunrise) were prohibited south of 42°N latitude. Additional regulations prohibited fishing in the Kalamath and Columbia River Conservation zones and established a trip limit of 10,000 pounds for whiting caught inside the 100-fathom contour in the Eureka INPFC area.

The at-sea fishery, involving both factory trawlers and motherships, began on April 15. Participation in the fishery consisted of 18 vessels with processing capacity. Two of these vessels operated solely as motherships, 14 vessels operated solely as catcher/processors, and two operated in both capacities. Aggregate weekly catches averaged 30-40,000 t. The offshore fishery closed on May 5 when the at-sea allocation was reached, for an opening of 21 days.

The total shore-based landings were 42,108 t, attaining the initial whiting quota allocated to shore-based processing. No additional late season openings for the at-sea fishery were required to catch the harvest guideline. The leading ports were Newport, Oregon (25,534 t), Astoria, Oregon (10,250 t), Illwaco, Washington (3,188), Crescent City, California (2,526 t), and Eureka, California (573 t). The shore-based fishery in Newport, Astoria, and Illwaco began in April and continued to October. As in 1992, the Crescent City landings were high in May and June, then declined substantially in July and never rebounded. The total U.S. catch in 1993 was 141,211 t; in Canada the total catch was 58,783 t (shore-based processors 11,611 t; foreign joint venture processors, 47,172 t). The total yield of Pacific whiting in 1993 was 199,994 t (Table 1), of which 71 percent was caught in the U.S. zone and 29 percent was caught in the Canadian zone.

For 1994, U.S. and Canadian assessment scientists recommended a coastwide acceptable biological catch (ABC) of 325,000 t. In the absence an agreement on how to allocate the resource between the U.S. and Canada, the Pacific Fisheries Management Council set the U.S. allocation at 260,000 t, 80 percent of the total ABC. Canadian managers set the Canadian allocation at 111,000 t, so that the Canadian allocation would make up 30 percent of the combined U.S. and Canadian catch. Consequently, the combined U.S. and Canadian catch in 1994 is expected to exceed the ABC by approximately 14 percent.

1993 FISHERY STATISTICS

Geographic patterns of fishing activity

During the 21-day opening for the at-sea fishery, fishing occurred from Cape Flattery, Washington, to Coos Bay, Oregon (Figure 1). Fishing was concentrated in two areas: 1) to the south and west of Hecata Bank, 2) and within a strip offshore of the 200 m depth contour from south of the Columbia River to Cape Flattery. Information on fishing positions for the shore-based fleet is not yet available from all state agencies. The Oregon Department of Fish and Wildlife maintains an up-to-date logbook database which includes reported trawl positions. Most of the fishing by the shore-based fleet operating off Oregon tended to occur close to the ports of Newport and Astoria, where most of the whiting was landed (Figure 2). As was seen last year, the shore-based fleet fished close to the shelf break in somewhat shallower water than the at-sea fleet typically operates. The mean distance to port (DTP) for whiting catches landed in Newport was 31.2 nm.; for whiting catches landed in Astoria the mean DTP was 34.2 nm. Over the April-August season for the shore-based fishery, DTP did not increase at either Newport or Astoria (Table 2), suggesting that the component of the whiting population that can be reached by fishing vessels operating out of Newport and Astoria can support the current rate of biomass removals. The DTP declined after June at both Newport and Astoria, which may indicate that whiting become more available in off the central and northern Oregon coast as the season progresses.

Age composition by area and fishery

Estimates of catch at age for the at-sea fleet in 1993 were calculated from length-frequency samples and length-stratified otolith samples collected by observers in the Alaska Fisheries Science Center (AFSC) Domestic Observer Program. All factory trawlers and motherships taking part in the Pacific whiting fishery voluntarily carried observers at their own expense. A complete description of the methods used to estimate catch at age is found in Dorn and Methot (1990). The spatial strata used to compile catch at age and length at age were 1) the southern Columbia (SCOL) region, the area from lat. 43°00'N to Cape Falcon (lat. 45°46'N) in the Columbia INPFC region; and 2) the Vancouver-North Columbia region (VNC), the area from Cape Falcon to the U.S.-Canada border, which includes the northern part of the Columbia INPFC region and the U.S. portion of the Vancouver INPFC region. No temporal strata were used because the at-sea fishery lasted less than a month.

All foreign vessels in the Canadian whiting fishery carried fisheries observers in 1993. The Canadian catch at age statistics were compiled from random samples of otoliths collected by observers. The shore-based landings are sampled by port samplers. The average number of otoliths aged per year to determine the catch at age for the Canadian fisheries is approximately 3000.

Figure 3 shows the estimated catch at age by the at-sea fishery in the two spatial strata in the U.S. zone, and the catch at age from the Canadian zone. The general pattern of increasing age from south to north, noted in previous assessments, is again evident in the catch at age in 1993. The age-3 fish (1990 year-class) are strongly present in the South Columbia INPFC area, moderately abundant in the N. Columbia/Vancouver INPFC area, and uncommon in catch in the Canadian zone. The estimated age composition produced by U.S. and Canadian age readers is highly consistent, with both showing the same pattern of strong and weak year classes.

The shore-based fishery was sampled by port samplers at Newport, Astoria, and Crescent City. A stratified random sampling design was used to estimate the age composition of the landed catch. Table 3 gives the Pacific whiting catch at age by sex and fishery in 1993. The 1984 year class (9-year-old fish) remains the most common year class in the fishery, accounting for 32% of the total catch in numbers. Together, the 1987 and 1988 year classes were more common than the 1984 year class. The 1988 year class is approximately 70% as abundant as the 1987 in the catch (five- and six year old fish). The 1990 year class (3 year-old-fish) is considerably more common in the 1993 catch than it was in the 1992 catch. The 1991 year class, which showed up in 1992 as one-year-old fish, did not show up strongly in the 1993 age composition, suggesting that it is likely to be a weak year class. Overall, the age composition is consistent with a declining population as the extremely strong 1980 and 1984 year classes are replaced by the more moderate sized 1987 and 1988 year classes.

Table 4 gives the estimated U.S. fishery catch at age for 1977-93 (Compiled from a database maintained by the Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115), and the Canadian catch at age for the corresponding years (Mark Saunders, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6. Pers. commun., March 1994).

Trends in Length at Age

Because changes in size have a direct effect on the available yield, growth trends need to be examined to adequately assess the productivity of the resource. The 1993 estimates of mean length at age in the U.S. offshore fishery were compiled using the procedure described in Dorn and Methot (1990). Table 5 contains the 1993 length at age in the U.S. offshore fishery (compiled from a database maintained by the AFSC Domestic Observer Program) and Canadian fishery (Mark Saunders, Pers. commun., March 1994). Also given in Table 4 are bias-corrected a and b coefficients of an exponential length-weight relationship of the form $w = a\,l^b$ (Ricker 1975), estimated using linear regression.

A simple way to examine recent trends in growth is to plot the growth trajectory of the strong 1980, 1984, 1987, and 1990 year classes, which have dominated the catches in recent years (Fig. 4). The 1987 year class continued to have a larger mean length than the 1980 and 1984 year classes at the same age. However, the 1990 year class at age three is smaller than both the 1984 and 1987 year classes were at age three, and is close to the size of the 1980 year class at age three. Both the 1980 and the 1990 year classes experienced an El Niño as juveniles, which may account for their smaller mean length at age (Dorn 1992).

POPULATION ASSESSMENT USING THE STOCK SYNTHESIS MODEL

Data Sources

The data elements used in the synthesis model are as follows: 1) a time series of catch at age from the U.S. and Canadian fisheries for Pacific whiting (1977-93), 2) yields in biomass from the U.S. and Canadian fisheries for the same years, 3) biomass estimates in the U.S. and Canadian zones from the NMFS triennial bottom trawl and acoustic/midwater trawl surveys (1977, 1980, 1983, 1986, 1989, 1992), 4) age composition for the bottom trawl and acoustic surveys for the U.S. and Canadian zones for the same years, 5) DFO acoustic biomass estimates for the Canadian zone in 1990-93, 6) age composition in the Canadian zone from DFO acoustic surveys in the same years.

As in previous assessments, the NMFS acoustic survey biomass estimates for the Canadian zone were expanded upwards to account for incomplete survey coverage. The expansion factors were calculated from DFO acoustic surveys in 1990, 1991 and 1993, and the average of the NMFS and DFO surveys in 1992. The expansion factors are estimated as the ratio of total biomass in the Canadian zone to the biomass in the area covered by the earlier NMFS triennial acoustic/midwater trawl surveys. These expansion factors took into account the increased exploitation rate in the Canadian zone in 1990-93 relative to earlier years by adding the July catch in the Canadian zone to the biomass estimate before calculating the expansion factor. All of the Canadian catch occurred within the area covered by the NMFS triennial acoustic survey transects. This procedure is intended to approximate the biomass that would have been found had the NMFS acoustic surveys in earlier years extended to the northern tip of Vancouver Island. Because the northernmost transect of NMFS acoustic surveys varied from survey to survey, expansion factors were calculated for each survey as follows: 1977-1.47, 1980-1.47, 1983-1.65, 1986-1.78, 1989-1.47. These expansion factors are slightly smaller than the expansion factors estimated in the 1993 assessment using 1990-92 data. No adjustment was made to the survey age composition data because age samples taken by a Canadian survey in 1987 at Triangle Island, near the northern tip of Vancouver Island, showed nearly identical age composition to age samples from the Canadian fishery off southwest Vancouver Island.

Configuration of the geographic stock synthesis model

The modeled population consisted of ages 2-15. When fitting the fishery age composition data, age 15 is treated as an accumulator age. Preliminary models with age 15 as an accumulator age for the survey age composition commonly resulted in an overestimate of the abundance of the age 15+ fish. The smaller sample sizes used to estimate age composition for the surveys could account for the scarcity of the age 15+ fish in the samples relative the number predicted by the model. Another possibility is that the larger fish can evade capture by the mid-water trawls used to estimate age composition for the acoustic surveys. Because of the potential that this phenomenon could influence the overall shape of the survey selectivity curve, the model was configured to fit the age composition only out to age 14, truncating the age 15+ fish.

Several clear cases of aging error were prevented from unduly affecting the fit of the model by having the model accumulate the marginal age groups at different ages during several years. The model accumulated the older fish at age 7 in 1978, age 8 in 1979, age 9 in 1980, etc., because large numbers of the strong 1970 year class were apparently misaged into the 1971 year class starting in 1978. Adding this detail to the model improved the fit to age compositions generated by both U.S. and Canadian age readers. The model also accumulated the age-2 and age-3 fish in 1979 because the strong 1977 year class appeared as 3-year-old fish in 1979 due to a small sample size in the age-length key for that year. In examining the Canadian fishery age composition, an additional source of aging error was discovered in 1984 and 1985, when the strong 1980 year class was apparently misaged into the 1981 year class. This apparent error was handled by having the model accumulate the younger fish to age 4 in 1984 and age 5 in 1985.

Systematic aging error was modeled by specifying the percent agreement between two age readers at age 2 and at age 15, and assuming a linear increase between those ages. The model calculated the level of variance that would produce this level of agreement, taking into account the probability that both readers got the same age, both were off by one year in the same direction, and both were off by two years in the same direction. The probability that both agree and were off by more than two years was assumed to be negligible. The parameters were estimated independently using the percent agreement for the most abundant age groups in the 1989 age sample (ages 2, 5, 9, 12). The estimates of 100 percent agreement at age 2 and 75 percent agreement at age 15 were obtained using linear regression constrained to pass through 1.0 at age 2.

The model runs covered the seventeen years beginning in 1977 and ending in 1993. Two geographic areas, corresponding to the U.S. and Canadian management zones, were defined. The U.S. and Canadian fisheries were modeled using double logistic selectivity functions (Dorn and Methot 1990) and were assumed to harvest only the fish that migrated into their respective management zones. Year- and fishery-specific weights at age were used in all years because significant variation in Pacific whiting weight at age has been observed. In particular, there was a substantial decline in weight at age during the 1980's. Natural mortality was fixed at an age-invariant rate of 0.226 estimated in the 1993 stock assessment (Dorn et al. 1993).

A modified logistic function split the stock between the two areas at the start of each year,

$$m_t = \frac{p_3}{1 + e^{[-p_2(t-p_1)]}} ,$$

where t is age in years, p_1 is the inflection age, p_2 is the slope, p_3 is the fraction of the oldest age group migrating into the Canadian zone, and m_t is the proportion at age migrating into the Canadian zone. The survivors at the end of the year in each zone were combined, then redistributed to the two areas for the start of the following year. Interannual variation in the fraction of the population in each zone was modeled by allowing the parameters p_1, p_2, and p_3 in the migration function to vary from year to year. Estimating these parameters required two steps. First, a single migration function was estimated for all years. The parameters for this function were fixed at their estimated values, and a subsequent run estimated three parameters for each year that gave the difference in p_1, p_2, and p_3 between that year and the mean migration function. Preliminary runs showed that in years without a triennial survey, these parameters tended to shift a large proportion of the population biomass to one zone in an attempt to improve the fit to the fishery age composition for that year. A penalty likelihood component was used to prevent the annual migration curve in the non-survey years from deviating too far from the mean migration curve. This likelihood component had the form

$$l_P = -\sum_i \left[\frac{p_i - \tilde{p}_i}{\sigma_{\tilde{p}_i}}\right]^2$$

where $\tilde{p}_i$ is the prior parameter estimate, and $\sigma_{\tilde{p}_i}$ is the standard deviation of the prior parameter estimate. In this application, 0.0 was used as the prior parameter estimate to force the annual migration coefficients to correspond to the mean migration curve, and $\sigma_{\tilde{p}_i}$ was set to the standard deviation of the annual migration coefficients during the survey years. The penalty likelihood component was given a emphasis level of 5.0 in the basic model.

Treatment of survey time series in the synthesis model

The biomass estimates from the NMFS bottom trawl and acoustic surveys were treated as independent indices of population abundance. The acoustic survey catchability (q) was assumed to be the same in the U.S. and Canadian zones, but because of differences in the geographic coverage of the trawl survey, the model was configured with a different trawl survey catchability for each zone. These catchability coefficients were estimated by the model. Data from the 1992 acoustic survey was reanalyzed to produce a biomass estimate that corresponded as closely as possible to the earlier acoustic biomass estimates and was included in the acoustic time series index. The biomass inshore of 366 m and south of latitude 50° N was estimated using a Sv threshold of -58.5 dB. (In the 1992 survey, a Sv threshold of -58.5 dB was used south of lat. 45°46'N, while north of lat. 45°46'N a -69 dB threshold was used (Dorn et al. 1993). In earlier surveys, a different algorithm was used screen out small scatterers and background noise. Side-by-side comparisons with pollock aggregations in Alaska showed that a -58.5 dB threshold produced similar biomass estimates to the old system. No comparisons between the old system and the EK-500/BI-500 echo-integration system have been made with Pacific whiting.) In the Canadian zone, this total biomass was then expanded up by the northward expansion factor. As in the 1993 assessment, the model was tuned to the measured 1992 acoustic biomass estimate with an assumed catchability of 1.0. Consequently, the 1992 acoustic biomass estimate plays a critical role in determining the absolute size of the population.

Separate selectivity functions were used for the surveys in the U.S. and Canadian zones. For the acoustic survey index in the U.S. zone, an ascending logistic function was used to model the selectivity of the younger fish, but selectivity was assumed to be asymptotic at 1.0 for the older ages. For the acoustic survey in the Canadian zone, the survey selectivity was fixed at 1.0 for all ages. The selectivity for the DFO acoustic surveys was also fixed at 1.0 for all ages. Since whiting are between four and six years old when they begin appearing in significant numbers in the Canadian zone, the assumption of full selectivity for all ages is reasonable to make, and provides a constraint to the model that assists in estimating the migration curves. For the 1992 survey in the U.S. zone, individual age-specific selectivity coefficients were estimated for the age 2 and age 3 fish. These selectivities were estimated in the 1993 assessment by a model that was tuned to the 1992 acoustic biomass estimate plus expanded acoustic biomass estimates for the earlier surveys that accounted for the limited geographic coverage of these surveys. It was necessary to use the expanded biomass estimates for the earlier years because a single year of data is not sufficient to estimate a selectivity pattern. A run that estimated the selectivity of the age-4 fish pushed the selectivity parameter to its bound at 1.0, indicating that fish older than 3 years old are fully selected by the expanded acoustic survey time series. The older fish were assumed to have a selectivity of 1.0. Like the other data sources for the Canadian zone, the 1992 acoustic survey in the Canadian zone was modeled using a fixed selectivity of one for all ages. The trawl survey index selectivities were also estimated in a preliminary run and were assumed to have an ascending logistic form.

Age composition likelihood components for the U.S. and Canadian fisheries and the acoustic survey index were given an emphasis level of 1.0. The U.S. and Canadian zone acoustic survey indices were given an emphasis levels of 5.0. In previous assessments this emphasis level was shown to produce fits to survey biomass that were comparable to the survey biomass coefficient of variation (CV) estimated using sampling theory (Dorn and Methot 1990). The 1992 acoustic biomass estimates for the U.S. and Canadian zones were given emphasis levels of 5.0. This level of emphasis was sufficient to force the model to match the sum of the U.S. and Canadian zone acoustic biomass estimates in 1992 fairly closely. The trawl survey indices and age compositions were given a low emphasis of 0.001 in the final model runs. This low emphasis reflects our belief that the trawl survey does not track the total population biomass because of interannual variation in the fraction of the stock vulnerable to bottom trawl gear. The Canadian zone DFO acoustic survey biomass and age composition were also given low emphasis of 0.001. This survey has been conducted only in four consecutive years, and since it covers only the Canadian zone it is unable to serve as constraint on the total population biomass. Including these surveys with nil emphasis makes it possible to assess their consistency with other data sources.

Results of 1977-93 geographic model runs

The stock synthesis estimation runs tuned to the 1992 NMFS acoustic biomass estimates converged rapidly. The fit to the U.S. fishery age composition data was better than the fit to the Canadian fishery age composition data, though the difference was not great (Table 6). The fit to the survey age composition data, as measured by the average log(likelihood) per annual age composition, was between the U.S. and Canadian fishery fits. To examine the fit of the survey biomass estimates, the population biomass is projected forward to the date at the midpoint of the survey assuming constant fishing and natural mortality. Since the survey vessels move from south to north, the date at the midpoint of the Canadian survey occurs later than the midpoint of the U.S. survey in the same year. The model produces a good fit the NMFS acoustic biomass estimates in the U.S. zone (root mean square error = 0.135), and matches the increase in biomass from 1977 to 1986, and the decline in biomass to 1992 (Fig. 5). The fit to the NMFS acoustic biomass estimates in the Canadian zone in not as good (root mean square error = 0.243), but the estimated population biomass still tracks the observed biomass adequately. The trawl biomass estimates in the U.S. and Canadian zones both show large increases in biomass in 1989 and 1992 that the model is unable to fit. The DFO Canadian zone acoustic surveys show an increase in biomass from 1990 to 1992, followed by a decrease in 1993 that the model is also unable to match. The lower biomass estimate in the Canadian zone in 1993 may have been a result of fish migrating north of the survey area. Pacific whiting were found in groundfish catches during a bottom trawl survey off southeast Alaska. Catches of whiting occurred during the last week of July in tows from Dixon Entrance north along Prince of Wales Island. The mean length of whiting was 52.4 cm (range 45-64 cm), and females comprised 78 percent of the length-frequency samples. These characteristics suggest that these fish were migrating members of the coastal population and not resident fish.

The annual U.S.-Canada migration curves showed large departures from the mean conditions in 1983, when a large proportion of the older fish were found in the Canadian zone, and in 1980 and 1982, when the proportion of the older fish migrating into the Canadian zone was smaller than usual (Fig. 6). The estimated selectivity coefficients for the U.S. and Canadian fisheries, and the NMFS triennial surveys in the U.S. and Canadian zones are given in Table 7. Table 8 gives the estimated population numbers at age for the years 1977-93 for the basic model described above. Table 9 gives estimated time series of population biomass, age-2 recruitment, and percent utilization of the total age 3+ biomass by the U.S. and Canadian fisheries for 1977-93 (see also Figure 7). Table 10 includes these updated estimates for 1977-93 with the estimates of population biomass, spawning biomass, and age-2 recruitment for 1960-76 estimated by Dorn et al. (1993).

Figure 8 shows the expected and observed mean age in the annual age composition for the U.S. and Canadian fisheries. There is a satisfactory fit between the observed mean age for each fishery and the mean age predicted by model. In the U.S. zone, expected mean age generally declines from 1977 to 1983, then increases to 1992. The expected mean age in 1993 is slightly lower than the expected mean age in 1992. A more detailed examination of the fit to the age composition data is shown in Figures 9 and 10. These figures show a contour map of the surface of Pearson residuals (McCullagh and Nelder 1983) of the fit to the U.S. and Canadian fishery age compositions. The Pearson residuals for a multinomial distribution are

$$r_i = \frac{\pi_i - \hat{\pi}_i}{\sqrt{(\hat{\pi}_i(1-\hat{\pi}_i)/n)}}$$

where π_i is the observed age proportion, and n is the sample size for the age composition estimate (nominal value: 400).

The general picture of the whiting population in the 1993 assessment of Pacific whiting remains unchanged for this assessment. Population biomass peaked 1987 and has been declining steadily since that time, though the rate of that decline has slowed in recent years.

Estimating the selectivity of the shore-based fishery in the U.S. zone.

In previous assessments, the catch at age for the at-sea and the shore-based fisheries was combined and used to estimate a single selectivity curve for all U.S. fisheries. Since age samples have been taken from the shore-based catch since 1990, enough information on the selectivity of the shore-based fishery has now accumulated to estimate an independent selectivity curve for the shore-based fishery. Fishery selectivity curves are necessary components of bio-economic models concerned with allocation between the shore-based and at-sea whiting fisheries.

To estimate the shore-based fishery selectivity curve, the basic stock synthesis model was reconfigured to model both the at-sea and the shore-based whiting fisheries. Double logistic selectivity curves were used for each fishery (Dorn and Methot 1990). In 1990, age samples were collected only from northern California ports. In 1991-93, landings in the Oregon ports of Newport and Astoria increased. Whiting landed in these ports were sampled by ODFW personnel in 1991-93. Consequently, it was possible to calculate stratified estimates of catch at age that took into account the geographic distribution of landings. In estimating the shore-based selectivity pattern, two estimation runs were done, one that used the data for 1990-93, and another that omitted the 1990 age composition sample.

The estimated shore-based selectivity pattern shows a maximum selectivity at age nine, and slightly more gradual decline in selectivity for the older and the younger fish than is seen in the at-sea fishery (Table 11, Figure 11). The model did not fit the 1990 age composition data as well as the age composition data for 1990-93. However, when the 1990 data was used to fit the model, the model fit to the other age composition data was not severely degraded, nor did the estimated selective curve change substantially. The selectivity curve estimated using the 1990 data is probably the best to use for modeling work because it is based on more data.

There are many factors that lead to the different selectivity patterns of the at-sea and shore-based fisheries. The shore-based fleet operates in shallower water than the at-sea fleet, and thus closer to the bottom, so it may be more difficult for the larger fish to dive out of the path of the net. Most of the shore-based fishing occurs near Astoria and Newport, while the at-sea fleet ranges from the U.S.-Canada border to northern California. The slightly higher selectivity of the age-2 and age-3 fish for the shore-based fishery may be caused by the delayed northward migration of the younger fish and the longer duration of the shore-based fishery. The at-sea fishery, which in recent years has been closed by the end of May, would not capture the slower migrating young fish.

YIELD FORECASTS FOR 1995-97 AND 1995 ACCEPTABLE BIOLOGICAL CATCH

An age-structured population model was used to forecast yields for 1995-97. The model divided the population numbers at age between the U.S. and Canadian zones using an average age-specific migration curve. Within each zone, Baranov catch equations modeled the effect of the fishery on the population, and an exponential mortality equation updated the population numbers at age to the start of the following year. Table 12 gives the age-specific biological characteristics of Pacific whiting used to simulate the population dynamics. The fishery selectivity coefficients and the migration coefficients estimated for the 1993 whiting assessment were used to project the short term yield because the alternative fishing mortality rates are based on simulations using these values. The weight at age vectors were estimated by averaging weight at age for the years 1991-1993, and are intended to represent the weight at age currently being observed in the U.S.

and Canadian fisheries and in the population. The yield forecasts were based on the assumption of median recruitment for the years 1994-96. The median recruitment of 0.954 billion age-2 fish for 1960-93 was used in the projections (Table 10). It should be recognized, however, that if a strong year class recruits during 1994 or 1995, the yield would be much higher than projected for 1996 and 1997. Conversely, poor recruitment during 1994 and 1995 would tend to decrease the projected yields for 1996 and 1997.

Population abundance at the start of 1993 (estimated by the synthesis model) was projected forward to the start of 1995 by removing the estimated 1993 catch and the expected catch for 1994. In the forecasts for 1995-97, the fishing mortality rate in the Canadian zone was set so that the percentage of the total yield harvested by the Canadian fisheries is equal to the percentage of mature biomass expected to migrate into Canadian waters.

The target fishing mortality rates in Table 13 were estimated by Dorn et al. (1993) using a stochastic age-structured population simulation model. To simulate a recruitment time series, the bootstrap method developed in previous whiting assessments was used. The recruitment estimates for the year classes 1958-90 (33 years) from the stock synthesis model formed the primary sample from which the bootstrap samples were taken. This procedure gave the simulated recruitment time series the following properties: 1) it is independent of female spawning biomass over the range of historical levels and 2) it has the same statistical properties as the observed recruitment, particularly the same mean and variance. However, autocorrelation in the recruitment time series would not be reproduced by the bootstrap procedure.

Table 13 gives the sustainable yield of Pacific whiting for three different harvesting strategies were 1) a constant F strategy; 2) a variable F algorithm developed by Shuter and Koonce (1985); and 3) a hybrid strategy that uses a constant F strategy when female spawning biomass is above the mean level, and a variable F strategy when it is below the mean. For the variable F algorithm, fishing mortality in a given year (y) is calculated by

$$F_y = F_{opt}(SB_y/SB_{opt}),$$

where F_{opt} is the optimum level of fishing mortality, SB_y is the current female spawning biomass level, and SB_{opt} is the mean female spawning biomass for the optimal constant F strategy. For a constant F harvest strategy, yield is approximately proportional to female spawning biomass (Figure 12). For the variable F harvest strategy, the slope of the yield-biomass curve increases with increasing female spawning biomass (Figure 13), so that high biomass levels result in extremely large predicted yields. For the hybrid F strategy, the two curves for the constant F and variable F are joined together at the mean female spawning biomass level (Figure 14).

For each harvest strategy, three harvest rates are determined by the probability that female spawning biomass drops below a cautionary level of 623,000 t, the 0.1 percentile of female spawning biomass of an unfished population. At a low harvest rate, the probability of falling below the cautionary female spawning biomass level is 0.10; for a moderate harvest rate it is 0.20; and for high harvest rate it is 0.30. The labels of low, medium, and high are relative designations, and are not intended to imply judgments about which strategy is best. The foregoing description of the alternative harvest strategies and harvest rates is a brief summary of analyses reported in Dorn et al. (1993). For reference, Table 13 also shows the fishing mortality rate that lowers the mean female spawning biomass to 35 percent of its pristine level.

The 1995-97 yield projections (Table 14) are somewhat lower than predicted by the 1993 Pacific whiting assessment. For example, the Groundfish Management Team used the low harvest rate hybrid fishing strategy as the ABC for 1994. The 1995 yield projected for this harvest strategy was 278,000 t. In this assessment the 1995 projected yield is 223,000 t, a decrease of approximately 20 percent. The decrease is primarily a result of two factors. First, in last year's assessment, it was assumed that the age-2 recruitment of the 1991 year class was equal to the 1960-92 median recruitment (0.941 billion). In this assessment, size of the 1991 year class was estimated to be 0.198 billion (a weak year class), primarily because the age-2 fish were not strongly present in the 1993 fisheries catch at age. Second, the U.S. and Canadian catch in 1994 is expected to exceed the ABC by approximately 17 percent, so that there will be fewer fish available in 1995.

There is no indication that any of the recent year classes are exceptionally strong. The stock synthesis estimate of age-2 recruitment of the 1990 year class is 2.336 billion, indicating that it is an above average year class comparable to 1987 year class. The 1991 year class appears to be a weak year class. The length-frequency and age composition of Newport whiting landings during the 1991-94 show no evidence of incoming strong year classes subsequent to the 1990 year class (Figure 15).

The hybrid F harvest strategy, which has been the preferred harvest strategy since 1991, specifies a total yield of 223,000 t at low harvest rate, 309,000 t at a moderate harvest rate, and 382,000 t at a high harvest rate. The recommended ABC in 1994 was based on the low harvest rate because the estimates of higher population biomass depended only on the 1992 acoustic survey and it seemed reasonable to require at least two corroborating surveys before substantially increasing yields from the fishery. The acoustic survey conducted by DFO in 1993 does not support the higher biomass estimates from the 1992 acoustic surveys, but this survey covered only the Canadian zone. Since the proportion of the population migrating into the Canadian zone is highly variable, this survey has a limited ability to provide inferences about total population abundance. The yield projections for 1996 and 1997 tended to be much lower than the yield in 1995. This is an indication that if recruitment is near the median recruitment over the next few years, the population biomass and the yield of Pacific whiting will decline in the immediate future.

ACKNOWLEDGMENTS

I am grateful to Mark Saunders, Larry Quirollo, Mark Saelens, and Bill Barss for providing me with data. Bill Barss and Julie Lyons merit special mention for providing real-time stock assessment data. Chris Johnston, Julie Lyons, Julie Waltz and Betty Goetz aged the 1993 U.S. fishery samples. I thank Mark Saunders, Sandy McFarlane, and members of the West Coast ad hoc stock assessment review group for their review of an earlier draft of this paper.

REFERENCES

Dorn, M. W. 1992. Detecting environmental covariates of Pacific whiting (Merluccius productus) growth using a growth-increment regression model. Fish. Bull. U.S. 90: 260-275.

Dorn, M. W., and R. D. Methot. 1990. Status of the Pacific whiting resource in 1989 and recommendations for management in 1990. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-182, 84 p.

Dorn, M. W., E. P. Nunnallee, C. D. Wilson and M. W. Wilkins. 1993. Status of the coastal Pacific whiting resource in 1993. In Pacific Fishery Management Council, Status of the Pacific Coast groundfish fishery through 1993 and recommended acceptable biological catches in 1994, p. A1-A82. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p.

McCullagh, P. and J. A. Nelder. 1983. Generalized linear models. Chapman and Hall, New York.

Shuter, B. J., and J. F. Koonce. 1985. A review of methods for setting catch quotas on fish stocks. Unpubl. manuscr., 78 p. Research Section Fisheries Branch, Ontario Ministry of Natural Resources, P.O. Box 50, Maple, Ontario, L0J 1E0. (Contribution to Assessment of Stock and Prediction of Yield Workshop, Thunder Bay, Ontario, Canada, August 1985.)

Table 1.--Annual catches of Pacific whiting (1,000 t) in U.S. and Canadian management zones by foreign, joint venture (JV), and domestic fleets, 1966-93.

	U. S.				Canada				
Year	Foreign	JV	Domestic	Total	Foreign	JV	Domestic	Total	Combined total
1966	137.000	0.000	0.000	137.000	0.700	0.000	0.000	0.700	137.700
1967	168.699	0.000	8.963	177.658	36.713	0.000	0.000	36.713	214.371
1968	60.660	0.000	0.159	60.819	61.361	0.000	0.000	61.361	122.180
1969	86.187	0.000	0.093	86.280	93.851	0.000	0.000	93.851	180.131
1970	159.509	0.000	0.066	159.575	75.009	0.000	0.000	75.009	234.584
1971	126.485	0.000	1.428	127.913	26.699	0.000	0.000	26.699	154.612
1972	74.093	0.000	0.040	74.133	43.413	0.000	0.000	43.413	117.546
1973	147.441	0.000	0.072	147.313	15.125	0.000	0.001	15.126	162.439
1974	194.108	0.000	0.001	194.109	17.146	0.000	0.004	17.150	211.259
1975	205.654	0.000	0.002	205.656	15.704	0.000	0.000	15.704	221.360
1976	231.331	0.000	0.218	231.549	5.972	0.000	0.000	5.972	237.521
1977	127.013	0.000	0.489	127.502	5.191	0.000	0.000	5.191	132.693
1978	96.827	0.856	0.689	98.372	3.453	1.814	0.000	5.267	103.639
1979	114.909	8834	0.937	124.680	7.900	4.233	0.302	12.435	137.115
1980	44.023	27.537	0.792	72.352	5.273	12.214	0.097	17.584	89.936
1981	70.365	43.556	0.839	114.760	3.919	17.159	3.283	24.361	139.121
1982	7.089	67.464	1.024	75.577	12.479	19.676	0.002	32.157	107.734
1983	0.000	72.100	1.050	73.150	13.117	27.657	0.000	40.774	113.924
1984	14.722	78.889	2.721	96.382	13.203	28.906	0.000	42.109	138.491
1985	49.853	31.692	3.894	85.439	10.533	13.237	1.192	24.962	110.401
1986	69.861	81.640	3.463	154.964	23.743	30.136	1.774	55.653	210.617
1987	49.656	105.997	4.795	160.448	21.453	48.076	4.170	73.699	234.147
1988	18.041	135.781	6.876	160.698	39.714	50.182	0.594	90.491	251.189
1989	0.000	203.578	7.418	210.996	31.589	66.256	1.687	99.532	310.528
1990	0.000	170.972	12.828	183.800	3.976	69.293	3.411	76.680	260.480
1991	0.000	0.000	217.371	217.371	6.043	76.254	22.225	104.522	321.893
1992	0.000	0.000	208.817	208.817	0.000	68.000	18.370	86.370	295.187
1993	0.000	0.000	141.211	141.211	0.000	47.172	11.611	58.783	199.994
Mean 1966-93				139.590				44.367	183.957

Sources: 1966-80 from Bailey et al. 1980; 1981-93 from Pacific Fishery Information Network (PacFIN), Pacific Fishery Management Council, Metro Center, Suite 170, 2000 SW. First Avenue, Portland, OR 97201; 1991-93 at-sea catches from Northwest Regional Office, Sand Point Way, Seattle, WA; Canadian catches reported by Mark Saunders, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6, Pers. commun., April 1994.

Table 2. Distance to port (nm) for Pacific whiting hauls made by shore-based vessels operating out of Astoria and Newport.

	mean(DTP)	sd(DTP)	N. of tows
Astoria			
April	36.9	6.9	15
May	31.8	7.3	8
June	37.5	3.1	88
July	33.5	6.8	114
August	31.9	9.2	108
Newport			
April	26.3	1.4	25
May	28.1	3.7	52
June	35.8	15.9	236
July	28.9	7.2	288
August	30.7	7.8	331

Table 3.--Pacific whiting catch at age (millions of fish) by sex and fishery in 1993.

	Shore-based		At-sea		Canada		Total	
Age	Males	Females	Males	Females	Males	Females	Males	Females
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.86	0.66	0.17	0.21	0.07	0.00	1.10	0.87
3	10.67	14.55	22.09	23.18	0.42	0.35	33.18	38.08
4	1.36	1.50	3.38	2.83	1.61	0.91	6.36	5.24
5	5.24	5.39	17.43	14.84	5.26	7.65	27.93	27.88
6	8.41	7.56	21.79	21.89	8.00	9.54	38.19	39.00
7	0.80	0.28	0.95	1.72	1.12	0.77	2.88	2.77
8	0.43	0.15	0.99	1.49	0.14	0.07	1.56	1.71
9	14.27	8.60	31.00	27.99	21.12	19.50	66.38	56.10
10	0.12	0.00	1.12	0.57	0.14	0.07	1.37	0.64
11	0.00	0.03	0.38	0.02	0.07	0.07	0.45	0.12
12	0.00	0.00	0.19	0.01	0.07	0.07	0.26	0.08
13	3.81	3.33	7.08	6.73	7.44	5.05	18.33	15.12
14	0.03	0.00	0.00	0.09	0.14	0.07	0.17	0.16
15+	0.41	0.58	0.96	0.52	0.14	0.07	1.50	1.17
Total	46.39	42.62	107.53	102.11	45.74	44.20	199.66	188.93

Sources: U.S. offshore catch statistics estimated from a database maintained by the Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115. Canadian statistics reported by Mark Saunders, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6, Pers. commun., April 1994.

Table 4.--Catch at age (millions of fish) for the Pacific whiting fisheries, 1977-93. Separate tables are given for the U.S. fisheries, the Canadian fisheries and the combined fisheries. The aggregate catch from the foreign, joint venture and domestic fisheries is included in these estimates.

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
U.S. fisheries																
1977	0.00	1.81	3.80	54.35	11.23	19.93	68.11	11.05	5.80	2.72	1.45	0.73	0.18	0.00	0.00	181.16
1978	0.01	0.02	4.56	8.58	51.87	9.48	20.32	38.57	5.74	2.48	1.28	0.52	0.20	0.05	0.01	143.69
1979	0.00	4.34	8.74	17.41	10.15	48.01	15.47	29.48	20.82	4.25	1.70	0.50	0.22	0.05	0.03	161.16
1980	0.00	0.13	24.67	2.16	6.90	7.16	20.11	9.57	11.99	9.92	1.74	1.35	1.01	0.59	0.14	97.42
1981	13.38	1.25	2.30	97.62	6.89	9.64	6.77	23.33	6.26	7.24	7.05	0.95	0.48	0.12	0.13	183.43
1982	0.00	27.51	1.93	1.57	57.88	5.02	5.78	5.02	11.96	2.43	2.53	4.64	0.34	0.13	0.03	126.77
1983	0.00	0.00	86.60	7.22	3.63	36.79	4.68	3.72	3.32	5.24	1.62	1.00	1.00	0.16	0.14	155.12
1984	0.00	0.00	2.59	164.97	7.18	5.18	17.54	2.17	1.24	0.82	1.34	0.21	0.20	0.31	0.03	203.78
1985	2.27	0.55	1.32	12.36	113.50	9.74	4.30	6.75	0.61	0.34	0.24	0.36	0.00	0.00	0.00	152.34
1986	0.00	62.92	12.88	1.85	9.34	171.79	21.55	10.76	12.45	1.53	1.05	0.38	0.79	0.15	0.05	307.49
1987	0.00	0.00	124.20	6.58	1.68	2.72	151.56	7.89	3.09	14.87	0.57	0.15	0.15	1.25	0.00	314.71
1988	0.00	1.22	1.31	172.76	8.02	1.40	2.60	96.93	5.16	0.72	8.32	0.15	0.24	0.00	0.65	299.49
1989	0.00	8.65	9.57	3.88	257.20	7.80	2.46	2.74	106.63	6.62	0.87	5.37	0.03	0.12	0.57	412.51
1990	0.00	5.69	85.34	10.97	1.92	152.02	2.56	1.14	0.71	95.97	0.47	0.00	6.07	0.00	0.41	363.27
1991	0.00	0.95	43.96	98.32	19.35	6.00	151.49	6.63	1.31	0.93	60.10	2.11	0.00	9.74	0.65	401.54
1992	0.97	18.53	9.94	51.95	109.58	10.27	5.09	131.94	4.84	2.38	0.79	42.06	0.63	0.20	1.88	391.05
1993	0.00	1.90	70.49	9.07	42.90	59.65	3.75	3.06	81.86	1.81	0.43	0.20	20.95	0.12	2.47	298.66
Canadian fisheries																
1977	0.00	0.01	0.01	0.25	0.09	0.30	1.83	0.53	0.50	0.42	0.40	0.35	0.16	0.00	0.00	4.85
1978	0.00	0.00	0.00	0.20	0.35	0.28	1.06	1.31	1.12	0.62	0.48	0.21	0.18	0.09	0.00	5.90
1979	0.00	0.00	0.00	0.21	0.62	1.30	1.14	2.10	3.02	1.10	0.79	0.37	0.25	0.17	0.12	11.18
1980	0.00	0.00	0.00	0.00	0.47	0.62	2.46	0.92	1.18	6.74	1.27	0.62	0.62	0.20	0.00	15.07
1981	0.00	0.00	0.00	1.01	0.27	1.41	1.38	4.28	0.85	2.36	6.18	1.49	0.60	0.85	0.00	20.66
1982	0.00	0.00	0.00	0.69	13.35	1.10	1.44	1.41	4.41	1.00	0.78	6.04	0.59	0.47	0.00	31.27
1983	0.00	0.06	14.02	1.03	1.80	32.15	1.29	1.87	1.67	5.59	0.77	0.26	3.41	0.26	0.13	64.30
1984	0.00	0.00	1.11	13.27	1.73	9.26	20.86	2.04	2.35	1.54	4.81	0.93	0.80	2.65	0.37	61.71
1985	0.00	0.06	0.06	2.45	8.03	1.65	3.25	9.62	0.49	0.55	0.55	1.65	0.37	0.00	1.59	30.33
1986	0.00	0.14	0.14	0.28	3.97	38.41	2.41	2.41	11.48	1.28	0.57	0.99	1.42	0.43	1.42	65.33
1987	0.00	0.00	0.90	0.60	0.15	2.56	70.71	2.86	2.86	10.38	0.60	0.45	1.20	0.90	1.20	95.38
1988	0.00	0.00	0.31	15.28	0.62	1.13	2.36	66.66	2.26	1.44	7.90	0.51	0.21	0.21	0.62	99.48
1989	0.00	0.00	0.20	0.59	35.55	0.20	0.39	0.59	69.34	1.76	1.37	8.59	0.39	0.20	1.17	120.32
1990	0.00	0.00	2.80	2.08	0.21	48.67	0.73	0.21	0.00	27.50	0.42	0.00	1.25	1.04	2.08	86.99
1991	0.00	0.00	0.11	6.11	2.46	0.43	70.60	0.54	0.00	0.21	47.47	0.21	0.11	2.25	0.11	130.60
1992	0.00	0.00	0.67	7.63	17.81	3.55	0.40	56.83	0.27	0.00	0.13	30.79	0.07	0.13	1.21	119.48
1993	0.00	0.07	0.77	2.52	12.91	17.54	1.89	0.21	40.62	0.21	0.14	0.14	12.49	0.21	0.21	89.93
Combined fisheries																
1977	0.00	1.82	3.81	54.60	11.32	20.23	69.94	11.58	6.30	3.14	1.85	1.08	0.34	0.00	0.00	186.01
1978	0.01	0.02	4.56	8.78	52.21	9.76	21.38	39.88	6.86	3.10	1.76	0.73	0.38	0.14	0.01	149.58
1979	0.00	4.34	8.74	17.62	10.76	49.31	16.61	31.58	23.83	5.34	2.49	0.87	0.46	0.22	0.15	172.34
1980	0.00	0.13	24.67	2.16	7.36	7.77	22.57	10.49	13.16	16.65	3.00	1.97	1.62	0.78	0.14	112.49
1981	13.38	1.25	2.30	98.63	7.16	11.05	8.16	27.60	7.11	9.60	13.23	2.44	1.08	0.97	0.13	204.09
1982	0.00	27.51	1.93	2.25	71.24	6.11	7.22	6.43	16.37	3.43	3.31	10.67	0.94	0.60	0.03	158.04
1983	0.00	0.06	100.61	8.25	5.43	68.93	5.96	5.58	4.99	10.83	2.39	1.26	4.41	0.42	0.27	219.42
1984	0.00	0.00	3.71	178.24	8.91	14.43	38.39	4.20	3.58	2.36	6.15	1.14	1.00	2.97	0.40	265.49
1985	2.27	0.61	1.38	14.81	121.52	11.39	7.55	16.37	1.10	0.89	0.79	2.02	0.37	0.00	1.59	182.67
1986	0.00	63.06	13.02	2.13	13.31	210.20	23.96	13.17	23.93	2.80	1.62	1.37	2.20	0.58	1.46	372.82
1987	0.00	0.00	125.10	7.18	1.83	5.28	222.27	10.74	5.95	25.25	1.17	0.60	1.35	2.15	1.20	410.09
1988	0.00	1.22	1.62	188.05	8.64	2.53	4.96	163.59	7.42	2.15	16.22	0.67	0.44	0.21	1.26	398.96
1989	0.00	8.65	9.76	4.46	292.75	8.00	2.85	3.32	175.98	8.38	2.24	13.96	0.42	0.31	1.74	532.82
1990	0.00	5.69	88.14	13.05	2.13	200.69	3.29	1.35	0.71	123.47	0.89	0.00	7.32	1.04	2.49	450.26
1991	0.00	0.95	44.07	104.43	21.81	6.43	222.09	7.17	1.31	1.14	107.57	2.32	0.11	11.99	0.76	532.14
1992	0.97	18.53	10.61	59.58	127.39	13.82	5.49	188.77	5.11	2.38	0.92	72.85	0.70	0.33	3.08	510.53
1993	0.00	1.97	71.26	11.59	55.81	77.19	5.64	3.27	122.48	2.02	0.57	0.34	33.44	0.33	2.68	388.59

Sources: U.S. statistics estimated from a database maintained by the Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115. Canadian statistics reported by Mark Saunders, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6, Pers. commun., April 1994.

Table 5.--U.S. and Canadian mean length at age (cm) for the at-sea fishery and coefficients of a length-weight relationship (cm to g) for Pacific whiting in 1993. The coefficients for the Canadian length-weight relationship were estimated using 1992 samples because individual fish weights were not sampled in 1993.

	Males		Females	
Age	U.S.	Canada	U.S.	Canada
	Length at age			
2	33.8	---	34.4	---
3	38.2	41.0	38.3	43.0
4	40.7	44.3	41.0	44.5
5	43.5	44.5	43.6	45.2
6	44.8	45.2	45.2	46.3
7	44.1	46.1	45.4	47.5
8	45.1	45.5	45.8	---
9	46.4	46.2	47.1	47.7
10	46.8	46.0	46.1	---
11	45.9	---	55.0	---
12	47.3	---	61.0	---
13	47.3	46.7	48.0	48.8
14	---	---	---	---
15+	46.6	---	51.2	---
a	0.0211	0.2667	0.0159	0.1288
b	2.6479	2.0289	2.7323	2.2256

Sources: U.S. statistics estimated using a database maintained by the Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115. Canadian statistics reported by Mark Saunders, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6, Pers. commun., April 1994.

Table 6.--Log-likelihood components for the basic geographic stock synthesis model tuned to the 1992 biomass estimate. The 1993 biomass estimate is for the age 3 and older fish at the start of the year. Components with an emphasis level of 0.001 have negligible influence in fitting the model.

Likelihood component	Emphasis level	Likelihood
U.S. catch age composition	1.0	-246.685
Canadian catch age composition	1.0	-305.084
U.S. zone acoustic survey index	5.0	9.251
U.S. zone acoustic survey age composition	1.0	-98.411
Canadian zone acoustic survey index	5.0	5.059
Canadian zone acoustic survey age composition	1.0	-101.192
1992 U.S. zone acoustic biomass	5.0	2.051
1992 U.S. zone acoustic age composition	0.001	-103.847
1992 Canadian zone acoustic biomass	5.0	0.849
1992 Canadian zone age composition	0.001	-101.185
DFO acoustic survey biomass	0.001	-83.722
DFO acoustic survey age composition	0.001	-141.456
U.S. zone trawl survey index	0.001	-51.151
U.S. zone trawl survey age composition	0.001	-241.422
Canadian zone trawl survey index	0.001	-63.644
Canadian zone trawl survey age composition	0.001	-322.268
Penalty component	5.0	-3.560
Total likelihood	---	-684.230
1993 biomass (mt)		2,871,480.0

Table 7.--Estimated selectivity at age for the Pacific whiting fisheries and surveys estimated using the basic geographic model tuned to the 1992 acoustic survey biomass estimate. The "U.S. zone acoustic index" selectivity pattern is associated with the NMFS triennial acoustic surveys in the U.S. zone, while the "Canadian zone acoustic index" selectivity pattern is associated with the NMFS triennial acoustic surveys in the Canadian zone. The "U.S. zone trawl index" selectivity pattern is associated with the NMFS triennial trawl surveys in the U.S. zone, while the "Canadian zone trawl index" selectivity pattern is associated with the NMFS triennial trawl surveys in the Canadian zone. The U.S. and Canadian fisheries were modeled using double logistic selectivity functions. For the U.S. zone survey index, only the ascending limb of the selectivity curve was estimated. For the Canadian zone survey index, the selectivity of all ages was fixed at unity. The selectivity curve for the 1992 U.S. zone acoustic estimates was modeled by estimating individual selectivity coefficients for the age two and age three fish. Both of the Canadian zone acoustic survey selectivities were fixed at unity for all ages.

Age	U.S. fishery	Canadian fishery	U.S. zone. acou. index	Can. zone acou. index	U.S. zone 1992 acou.	Can. zone 1992 acou.	Canadian DFO	U.S. zone trawl index	Can. zone trawl index
2	0.05	0.39	0.43	1.00	0.53	1.00	1.00	0.17	0.17
3	0.21	0.44	0.60	1.00	0.79	1.00	1.00	0.24	0.24
4	0.57	0.49	0.75	1.00	1.00	1.00	1.00	0.33	0.33
5	0.87	0.55	0.86	1.00	1.00	1.00	1.00	0.43	0.43
6	0.97	0.62	0.92	1.00	1.00	1.00	1.00	0.54	0.54
7	1.00	0.69	0.96	1.00	1.00	1.00	1.00	0.64	0.64
8	0.99	0.78	0.97	1.00	1.00	1.00	1.00	0.73	0.73
9	0.97	0.86	0.98	1.00	1.00	1.00	1.00	0.81	0.81
10	0.92	0.95	0.99	1.00	1.00	1.00	1.00	0.87	0.87
11	0.82	1.00	0.99	1.00	1.00	1.00	1.00	0.92	0.92
12	0.63	0.94	0.99	1.00	1.00	1.00	1.00	0.95	0.95
13	0.40	0.70	0.99	1.00	1.00	1.00	1.00	0.97	0.97
14	0.21	0.39	0.99	1.00	1.00	1.00	1.00	0.99	0.99
15	0.09	0.17	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Survey catchability			0.536	0.536	1.000	1.000	0.657	0.151	0.019

Table 8. Numbers at age (millions of fish) for the coastal population of Pacific whiting as estimated by the stock synthesis model, 1977-1993. Separate tables are given for the U.S. zone, the Canadian zone and the total population.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15
U.S. Zone														
1977	507.2	353.7	1,316.1	264.4	217.0	1,125.1	152.3	101.5	40.7	36.9	28.3	15.0	0.0	0.0
1978	230.8	401.7	272.2	925.2	160.9	124.2	695.8	111.2	89.0	41.1	40.5	32.6	17.7	0.0
1979	3,958.9	182.1	305.3	186.6	577.3	107.4	91.6	533.5	86.1	69.2	32.1	31.9	26.0	14.3
1980	373.8	3,140.3	142.3	233.1	145.0	469.2	87.2	73.4	425.4	68.7	55.5	26.1	26.4	34.0
1981	408.7	296.3	2,428.6	100.8	140.0	81.1	281.6	56.8	49.6	290.6	47.2	38.5	18.3	43.1
1982	12,051.6	320.7	217.3	1,514.0	59.4	94.8	62.1	223.4	45.3	39.7	233.7	38.4	31.9	52.1
1983	131.1	9,314.7	215.8	104.5	632.7	25.7	41.7	27.3	98.1	19.9	17.5	103.8	17.3	38.6
1984	112.7	103.8	7,199.4	161.8	91.0	660.8	28.1	45.8	30.0	107.6	21.8	19.3	116.3	64.2
1985	186.5	89.4	80.6	5,218.6	109.5	65.3	496.7	21.3	34.7	22.7	81.4	16.6	14.9	142.5
1986	9,557.9	146.8	67.6	54.0	3,006.1	64.7	41.9	325.9	14.0	22.8	14.9	53.9	11.1	106.6
1987	0.1	7,549.0	111.6	45.8	33.5	2,142.4	53.8	36.9	291.7	12.6	20.6	13.6	49.9	112.1
1988	393.7	0.1	5,771.6	78.0	30.1	24.1	1,646.7	42.0	28.8	227.6	9.9	16.3	11.0	135.3
1989	2,566.5	309.8	0.1	3,709.1	44.1	18.2	15.7	1,094.1	27.9	19.2	151.6	6.6	11.2	105.0
1990	1,349.9	1,936.4	198.9	0.0	1,862.4	26.0	11.6	10.2	710.1	18.1	12.5	100.3	4.5	82.2
1991	260.4	1,064.9	1,480.6	145.6	0.0	1,494.0	21.2	9.4	8.3	577.3	14.8	10.4	85.4	76.7
1992	2,325.4	202.2	765.4	917.6	89.4	0.0	1,117.7	16.0	7.2	6.3	441.3	11.5	8.3	135.8
1993	197.2	1,793.1	138.4	423.3	497.2	53.1	0.0	696.0	10.0	4.5	3.9	283.6	7.7	102.2
Canadian zone														
1977	1.7	3.2	29.6	14.1	26.2	288.9	73.8	78.3	41.8	43.9	36.2	19.7	0.0	0.0
1978	0.3	2.4	7.4	98.4	46.2	56.1	358.4	59.0	47.6	22.0	21.7	17.5	9.5	0.0
1979	6.7	1.5	11.9	27.3	192.6	48.6	44.7	264.7	42.9	34.5	16.0	15.9	13.0	7.1
1980	0.2	6.1	1.1	6.5	13.2	100.6	28.6	27.8	168.1	27.4	22.2	10.5	10.6	13.6
1981	0.3	1.2	52.5	10.2	42.7	38.9	150.7	31.0	27.2	159.6	25.9	21.2	10.1	23.7
1982	24.1	4.1	15.7	373.4	23.3	40.9	27.2	98.1	19.9	17.4	102.7	16.9	14.0	22.9
1983	0.6	289.5	40.2	75.7	804.5	36.9	60.8	40.0	143.8	29.2	25.6	152.1	25.4	56.6
1984	0.2	0.9	354.5	35.3	46.3	431.4	19.3	31.6	20.7	74.4	15.1	13.4	80.5	44.5
1985	0.2	0.4	2.1	654.7	41.7	39.1	331.0	14.5	23.7	15.5	55.6	11.4	10.2	97.4
1986	26.2	1.8	3.6	10.8	1,555.6	52.4	38.9	313.5	13.6	22.2	14.5	52.3	10.8	103.6
1987	0.0	60.5	4.8	8.4	14.8	1,261.0	33.7	23.4	185.0	8.0	13.1	8.6	31.6	71.1
1988	0.5	0.0	186.5	10.4	10.2	11.6	863.5	22.4	15.4	121.9	5.3	8.7	5.9	72.5
1989	5.1	3.5	0.0	860.2	22.3	11.7	10.6	744.2	19.0	13.1	103.3	4.5	7.7	71.6
1990	13.5	102.6	45.1	0.0	1,476.1	22.2	10.1	8.9	617.4	15.8	10.9	87.3	3.9	71.5
1991	0.7	14.5	98.7	36.0	0.0	935.6	13.9	6.3	5.5	383.1	9.8	6.9	56.6	50.9
1992	10.2	4.3	68.1	241.8	39.7	0.0	599.9	8.7	3.9	3.4	239.1	6.3	4.5	73.6
1993	1.0	53.2	20.5	183.6	315.7	36.5	0.0	486.2	7.0	3.1	2.8	198.2	5.4	71.4
Total population														
1977	508.9	356.9	1,345.6	278.5	243.3	1,414.0	226.1	179.8	82.5	80.7	64.5	34.7	0.0	0.0
1978	231.1	404.1	279.5	1,023.6	207.1	180.3	1,054.2	170.2	136.6	63.1	62.1	50.0	27.2	0.0
1979	3,965.6	183.6	317.2	213.9	769.8	156.0	136.3	798.3	129.0	103.7	48.1	47.9	39.0	21.5
1980	374.0	3,146.4	143.4	239.6	158.2	569.9	115.8	101.3	593.5	96.1	77.8	36.5	37.0	47.6
1981	409.0	297.5	2,481.1	111.0	182.7	120.0	432.3	87.8	76.8	450.3	73.2	59.7	28.4	66.8
1982	12,075.7	324.8	233.0	1,887.4	82.6	135.7	89.3	321.5	65.3	57.1	336.4	55.3	45.9	75.0
1983	131.7	9,604.3	256.0	180.1	1,437.2	62.6	102.5	67.3	241.9	49.1	43.1	255.8	42.7	95.3
1984	112.9	104.7	7,553.9	197.2	137.2	1,092.2	47.4	77.5	50.7	182.0	37.0	32.6	196.8	108.7
1985	186.7	89.8	82.7	5,873.3	151.1	104.4	827.8	35.8	58.4	38.1	137.0	28.0	25.1	239.8
1986	9,584.1	148.6	71.2	64.8	4,561.7	117.1	80.8	639.5	27.6	45.0	29.4	106.2	21.9	210.2
1987	0.1	7,609.5	116.4	54.1	48.4	3,403.4	87.5	60.3	476.7	20.6	33.6	22.2	81.5	183.2
1988	394.2	0.1	5,958.2	88.5	40.3	35.8	2,510.2	64.3	44.3	349.5	15.2	25.0	16.9	207.9
1989	2,571.6	313.3	0.1	4,569.3	66.4	29.8	26.3	1,838.3	46.9	32.2	254.9	11.2	18.9	176.6
1990	1,363.5	2,038.9	244.0	0.0	3,338.4	48.3	21.7	19.0	1,327.5	33.9	23.4	187.6	8.4	153.7
1991	261.0	1,079.4	1,579.2	181.6	0.0	2,429.6	35.1	15.7	13.8	960.4	24.7	17.3	142.0	127.6
1992	2,335.5	206.5	833.5	1,159.4	129.1	0.0	1,717.6	24.7	11.0	9.7	680.4	17.8	12.9	209.3
1993	198.2	1,846.2	158.9	606.9	812.8	89.6	0.0	1,182.2	17.0	7.6	6.7	481.7	13.1	173.6

Table 9.--Time series of estimated biomass, recruitment, and utilization for 1977-93 for the basic stock synthesis model. U.S. and Canadian percent utilization is the catch in biomass divided by the total biomass of age 3+ fish. Population biomass is in millions of tons of age-3 and older fish at the start of the year. Recruitment is presented as billions of age-2 fish at the beginning of the year.

Year	Begin. biomass	Begin. spawn. biomass	Recruits (billion)	U.S. util.	Can. util.	Total util.
1977	3.231	1.480	0.509	3.9%	0.2%	4.1%
1978	2.616	1.390	0.231	3.8%	0.2%	4.0%
1979	2.533	1.103	3.966	4.9%	0.5%	5.4%
1980	3.416	1.353	0.374	2.1%	0.5%	2.6%
1981	3.074	1.375	0.409	3.7%	0.8%	4.5%
1982	2.674	1.343	12.076	2.8%	1.2%	4.0%
1983	5.001	2.056	0.132	1.5%	0.8%	2.3%
1984	4.935	2.093	0.113	2.0%	0.9%	2.8%
1985	4.821	2.371	0.187	1.8%	0.5%	2.3%
1986	3.827	2.166	9.584	4.0%	1.5%	5.5%
1987	5.818	2.309	0.000	2.8%	1.3%	4.0%
1988	5.039	2.221	0.394	3.2%	1.8%	5.0%
1989	4.639	2.190	2.572	4.5%	2.1%	6.7%
1990	4.154	2.118	1.363	4.4%	1.8%	6.3%
1991	3.963	1.686	0.261	5.5%	2.6%	8.1%
1992	2.984	1.520	2.336	7.0%	2.9%	9.9%
1993	2.871	1.262	0.198	4.9%	2.0%	7.0%
Avg. 1977-93	3.859	1.767	2.041	3.7%	1.3%	5.0%

Table 10. Estimated time series of Pacific whiting age 3+ population biomass, spawning biomass, and age-2 recruitment (billions), 1960-93. Estimates for the years 1960-76 are from Dorn et al. (1993).

Year	Age 3+ biomass	Spawning biomass	Age-2 recruitment
1960	4.557	2.197	0.515
1961	4.111	1.968	1.177
1962	3.939	1.843	1.778
1963	4.021	1.801	3.801
1964	4.874	2.024	0.629
1965	4.663	2.102	0.893
1966	4.470	2.128	1.237
1967	4.193	1.949	1.663
1968	4.016	1.809	1.750
1969	4.042	1.794	1.974
1970	4.134	1.816	1.468
1971	3.989	1.779	1.014
1972	3.769	1.730	5.601
1973	5.182	2.058	0.491
1974	4.834	2.122	0.581
1975	4.344	2.100	2.181
1976	4.335	1.959	0.402
1977	3.231	1.480	0.509
1978	2.616	1.390	0.231
1979	2.533	1.103	3.966
1980	3.416	1.353	0.374
1981	3.074	1.375	0.409
1982	2.674	1.343	12.076
1983	5.001	2.056	0.132
1984	4.935	2.093	0.113
1985	4.821	2.371	0.187
1986	3.827	2.166	9.584
1987	5.818	2.309	0.000
1988	5.039	2.221	0.394
1989	4.639	2.190	2.572
1990	4.154	2.118	1.363
1991	3.963	1.686	0.261
1992	2.984	1.520	2.336
1993	2.871	1.262	0.198
Average 1960-93	4.090	1.859	1.819

Table 11. Selectivity curves for the at-sea and shore-based (SB) fisheries for Pacific whiting in the U.S. zone. The estimated selectivity for the shore-based fishery was estimated with and without the age composition data for 1990.

Age	At-sea	SB with 1990	SB w/o 1990
2	0.05	0.15	0.17
3	0.20	0.32	0.33
4	0.56	0.57	0.54
5	0.87	0.79	0.74
6	0.97	0.91	0.88
7	1.00	0.97	0.95
8	0.99	0.99	0.99
9	0.98	1.00	1.00
10	0.94	0.99	0.98
11	0.84	0.95	0.94
12	0.66	0.84	0.82
13	0.42	0.62	0.60
14	0.21	0.33	0.34
15	0.09	0.13	0.15

Table 12. Summary of age-specific characteristics of Pacific whiting used in the age-structured model to forecast short-term yield.

Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
USSLCT	0.050	0.210	0.560	0.860	0.970	1.000	0.990	0.970	0.920	0.800	0.600	0.360	0.170	0.070
CANSLCT	0.380	0.430	0.480	0.550	0.610	0.690	0.770	0.860	0.950	1.000	0.930	0.710	0.410	0.190
MATURE	0.000	0.500	0.750	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
PROPFEM	0.480	0.501	0.512	0.520	0.524	0.526	0.529	0.536	0.539	0.544	0.553	0.561	0.568	0.575
USWT	0.283	0.363	0.445	0.495	0.531	0.555	0.578	0.587	0.568	0.603	0.607	0.717	0.674	0.766
CANWT	0.283	0.574	0.617	0.659	0.697	0.731	0.744	0.761	0.771	0.776	0.793	0.826	0.857	0.903
POPWT	0.259	0.359	0.460	0.528	0.575	0.618	0.644	0.655	0.652	0.711	0.686	0.729	0.776	0.797
NMORT	0.226	0.226	0.226	0.226	0.226	0.226	0.226	0.226	0.226	0.226	0.226	0.226	0.226	0.226
USCAN	0.002	0.011	0.051	0.166	0.297	0.352	0.365	0.368	0.369	0.369	0.369	0.369	0.369	0.369
1993 AC	0.198	1.846	0.159	0.607	0.813	0.090	0.000	1.182	0.017	0.008	0.007	0.482	0.013	0.174
1994 AC	0.954	0.157	1.431	0.118	0.435	0.578	0.064	0.000	0.834	0.012	0.006	0.005	0.361	0.147
1995 AC	0.954	0.750	0.118	0.970	0.074	0.270	0.357	0.039	0.000	0.509	0.007	0.004	0.004	0.381

1993 estimated yield: U.S.-141,000 t Canada- 59,000 t

1994 expected yield: U.S.-260,000 t Canada- 111,000 t

1994 beginning of the year spawning biomass: 1,168,000 t

1995 beginning of the year spawning biomass: 977,000 t

USSLCT = U.S. fishery selectivity at age
CANSLCT = Canadian fishery selectivity at age
MATURE = Proportion of sexually mature females
PROPFEM = Proportion by weight of females in the population
USWT = United States fishery weight at age (g)
CANWT = Canadian fishery weight at age (g)
POPWT = Population weight at age (g)
NMORT = Natural mortality rate
USCAN = Proportion of fish migrating into Canadian zone
1993 AC = 1993 initial age composition (billions)
1994 AC = 1994 initial age composition (billions)
1995 AC = 1995 initial age composition (billions)

Table 13. Sustainable yield of Pacific whiting for different harvesting strategies as estimated by Dorn et al. (1993). SB_{opt} used in the variable F and hybrid F algorithms is the mean female spawning biomass level at a constant F strategy where the probability is 0.20 that the female spawning biomass goes below the cautionary level of female spawning biomass (SB_{caut}) of 623,000 t. Yield and biomass are reported in 1,000 t (kt).

Harvest rate	F_{opt}	Total yield (kt)	CV	SB_{opt}	Spawn. biom. (kt)	CV	% of pristine spawning biomass	% years below SB_{caut}
				Constant F				
Low	0.17	262	50.7	---	1,253	47.5	57.9	10.0
Moderate	0.24	316	53.5	---	1,080	51.8	49.9	20.7
High	0.31	355	55.4	---	956	54.7	44.1	31.0
35% prist. spawn. biom.	0.47	397	59.4	---	746	60.1	34.5	51.1
				Variable F strategy				
Low	0.22	321	82.5	1,080	1,068	41.0	49.4	10.7
Moderate	0.33	363	81.1	1,080	938	41.6	43.3	20.7
High	0.42	381	82.9	1,080	858	43.1	39.7	30.2
35% prist. spawn. biom.	0.55	394	84.6	1,080	770	44.7	35.6	42.5
				Hybrid F strategy				
Low	0.23	298	60.0	1,080	1,167	46.1	53.9	9.7
Moderate	0.33	336	65.2	1,080	996	47.0	46.0	19.8
High	0.42	359	68.8	1,080	896	47.6	41.5	29.3
35% prist. spawn. biom.	0.63	396	76.6	1,080	760	50.0	35.1	47.3

F_{opt} = level of fishing mortality required to achieve the stated management objective

CV = coefficient of variation

Table 14. Summary of the 1995-97 potential annual yields of Pacific whiting. Yield and biomass projections are in millions of tons. All projections are based on median recruitment of 0.954 billion age-2 fish for 1994-1997.

Management strategy	Harvest rate	Year	Fishing Mortality	Total yield	Spawn. biomass	Age-2+ biomass
Constant F	Low	1995	0.17	0.185	0.978	2.224
		1996	0.17	0.159	0.843	2.026
		1997	0.17	0.145	0.785	1.921
	Moderate	1995	0.24	0.254	0.978	2.224
		1996	0.24	0.208	0.809	1.961
		1997	0.24	0.185	0.730	1.818
	High	1995	0.31	0.320	0.978	2.224
		1996	0.31	0.250	0.776	1.898
		1997	0.31	0.216	0.681	1.725
Variable F	Low	1995	0.20	0.214	0.978	2.224
		1996	0.17	0.154	0.829	1.999
		1997	0.16	0.133	0.774	1.902
	Moderate	1995	0.30	0.309	0.978	2.224
		1996	0.24	0.199	0.781	1.908
		1997	0.22	0.164	0.711	1.782
	High	1995	0.38	0.382	0.978	2.224
		1996	0.29	0.224	0.746	1.839
		1997	0.26	0.180	0.668	1.699
Hybrid F	Low	1995	0.21	0.223	0.978	2.224
		1996	0.18	0.159	0.824	1.990
		1997	0.16	0.137	0.768	1.890
	Moderate	1995	0.30	0.309	0.978	2.224
		1996	0.24	0.199	0.781	1.908
		1997	0.22	0.164	0.711	1.782
	High	1995	0.38	0.382	0.978	2.224
		1996	0.29	0.224	0.746	1.839
		1997	0.26	0.180	0.668	1.699

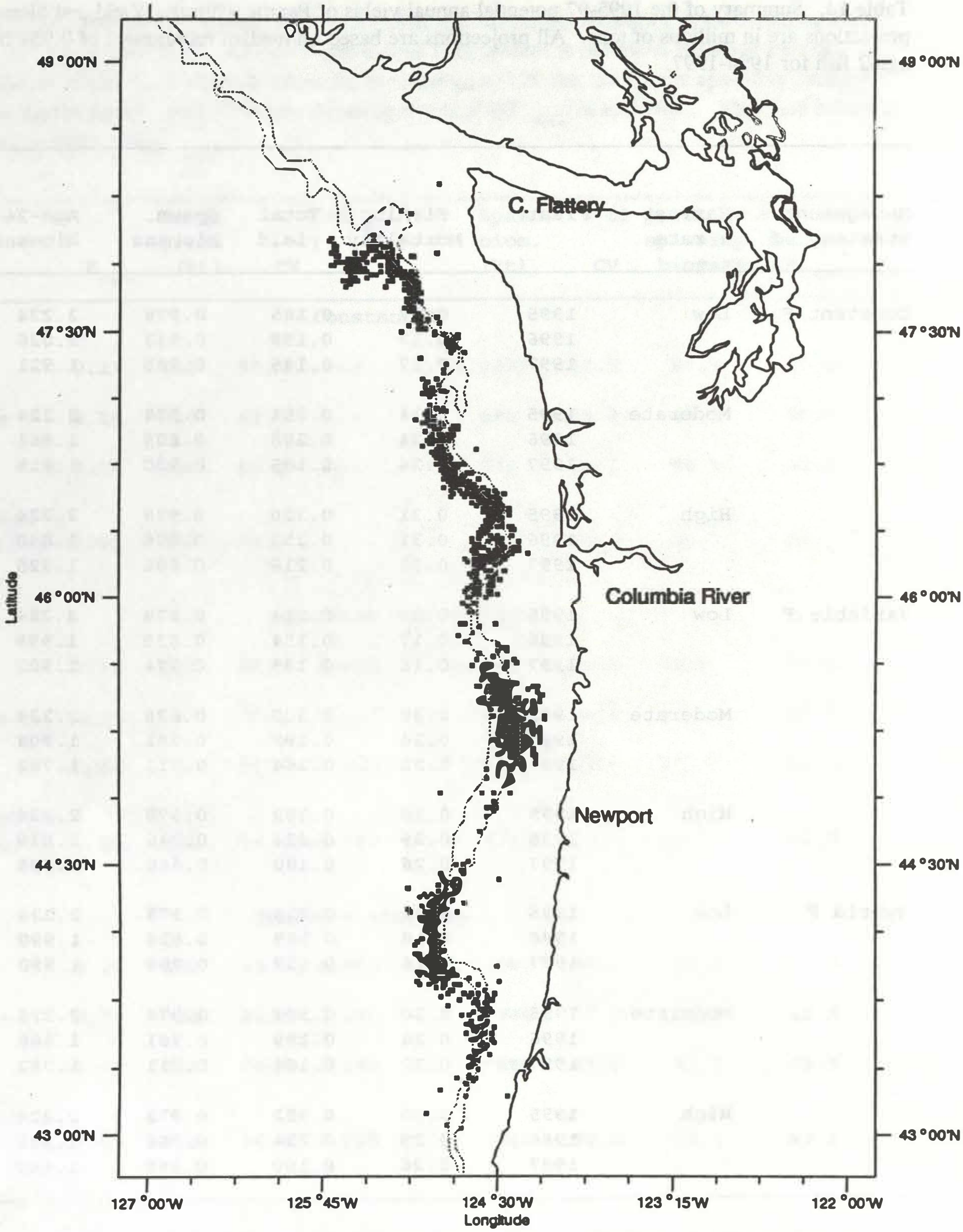


Figure 1. Trawl positions of factory trawlers and catcher boats participating in the 1993 at-sea fishery for Pacific whiting. The 200 m and 300 m depth contours are shown in the figure.

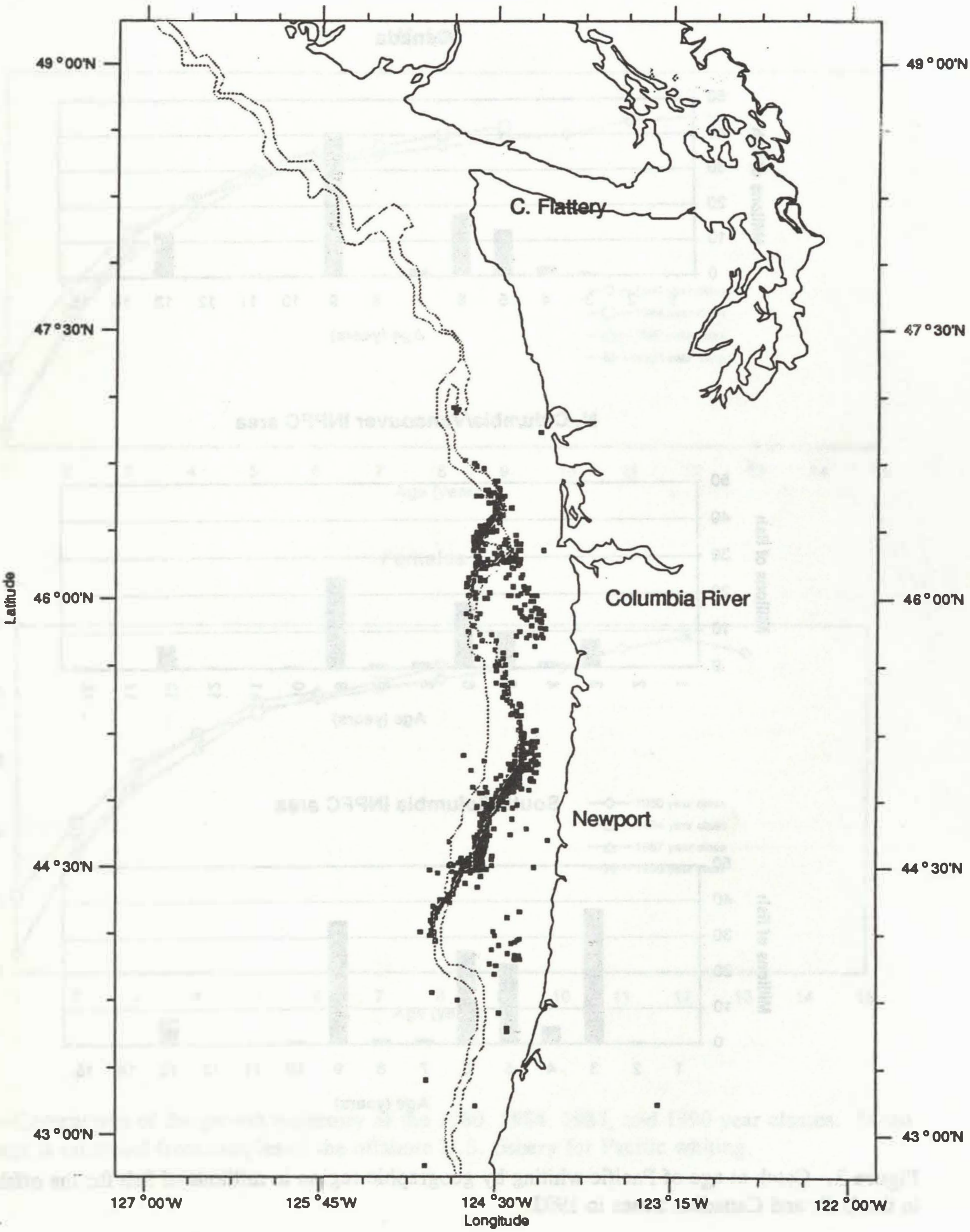


Figure 2. Trawl positions shore-based boats participating in the 1993 fishery for Pacific whiting. Position data is for landings in Oregon ports only. The 200 m and 300 m depth contours are shown in the figure.

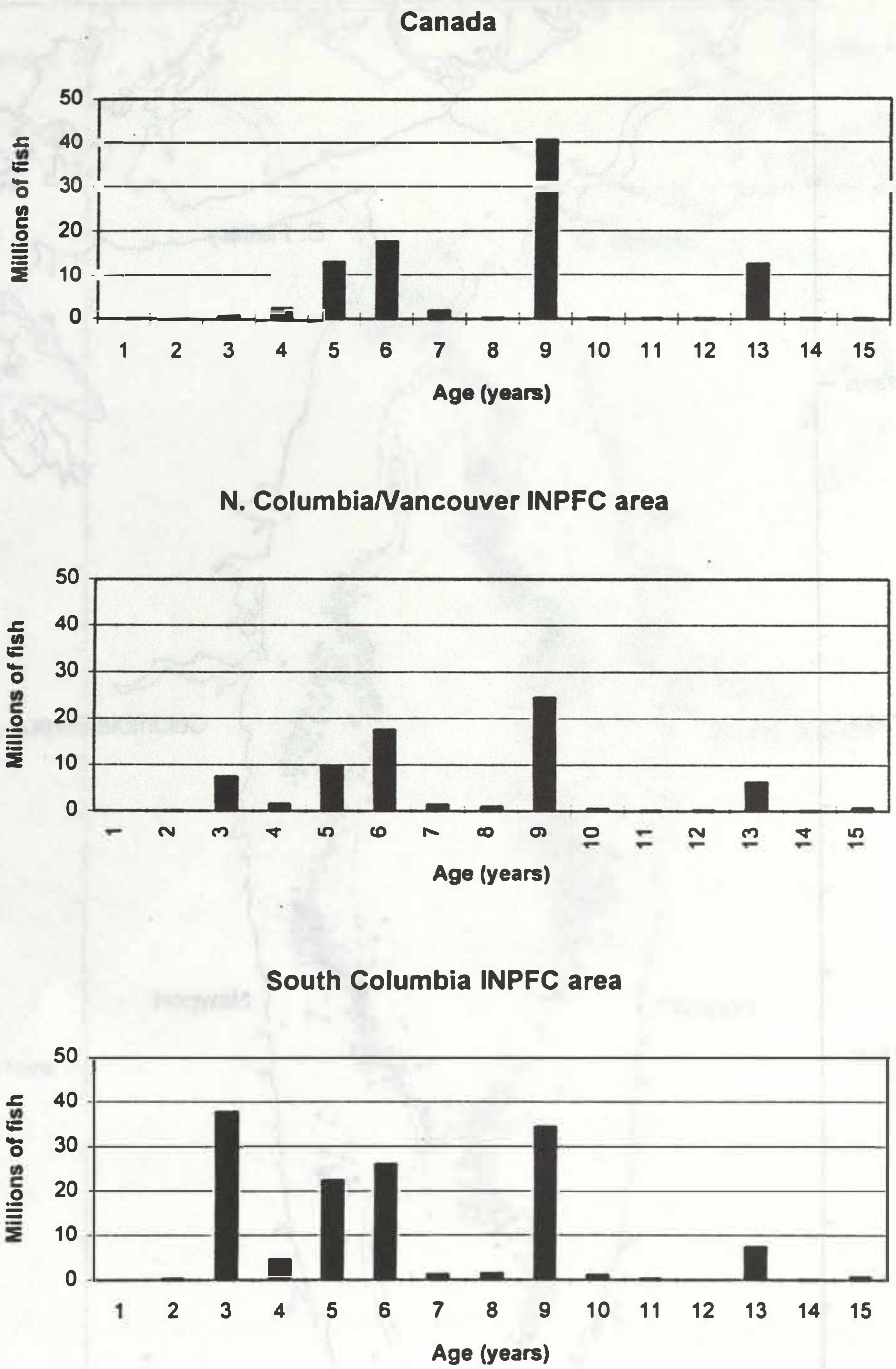
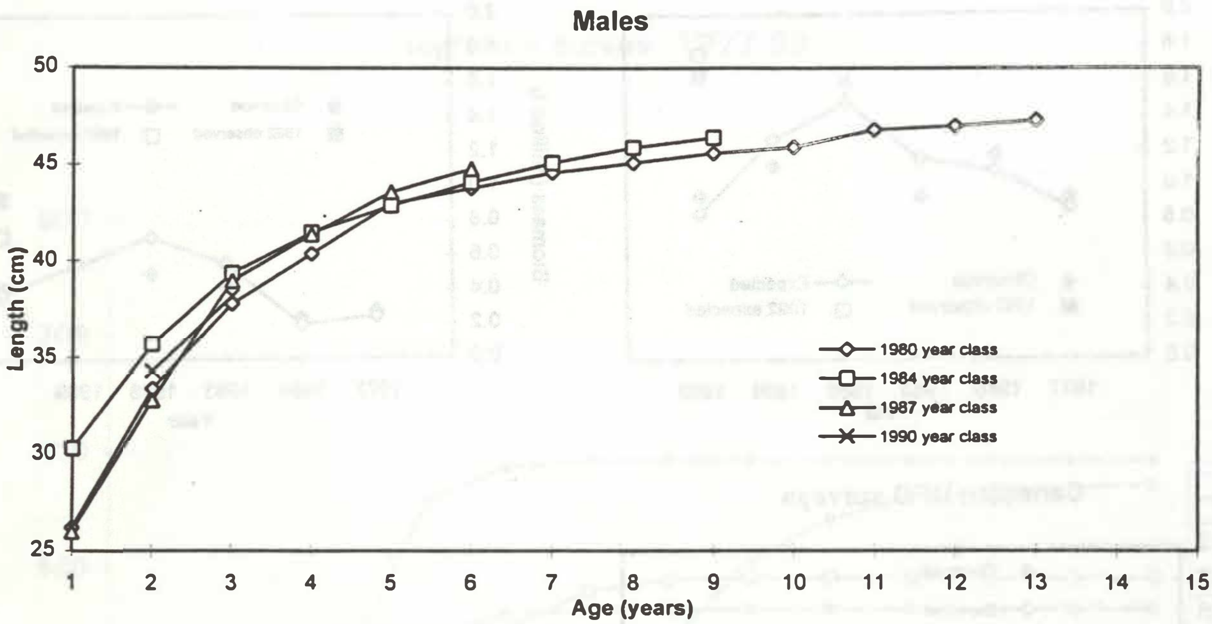


Figure 3.--Catch at age of Pacific whiting by geographic region in millions of fish for the offshore fleet in the U.S. and Canadian zones in 1993.



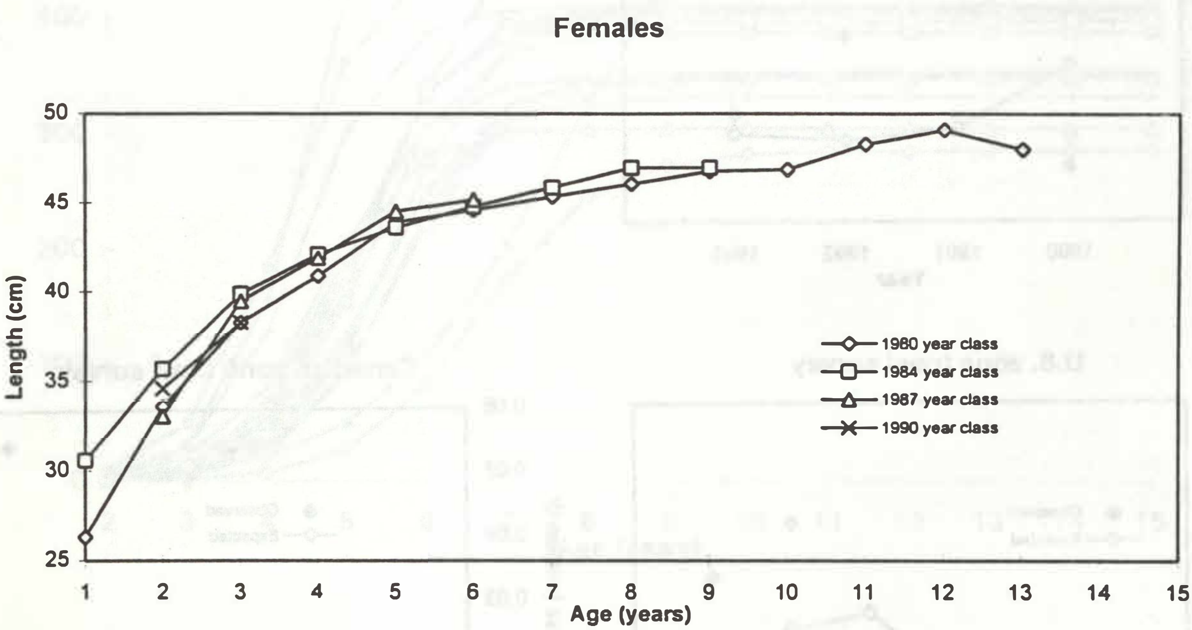


Figure 4.--Comparison of the growth trajectory of the 1980, 1984, 1987, and 1990 year classes. Mean length at age is estimated from samples of the offshore U.S. fishery for Pacific whiting.

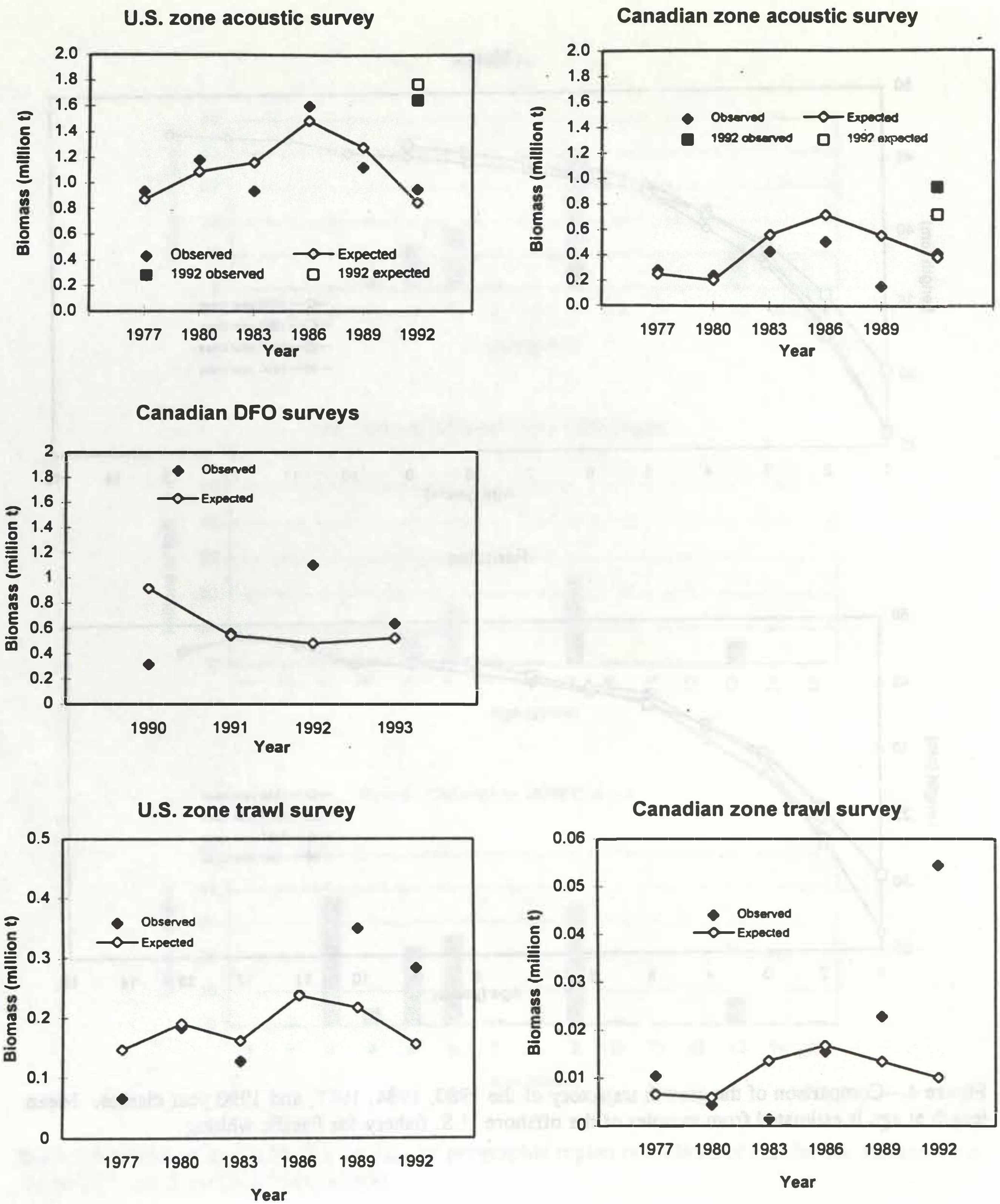


Figure 5--Observed and predicted survey biomass estimates for the geographic stock synthesis model tuned to the 1992 acoustic survey biomass.

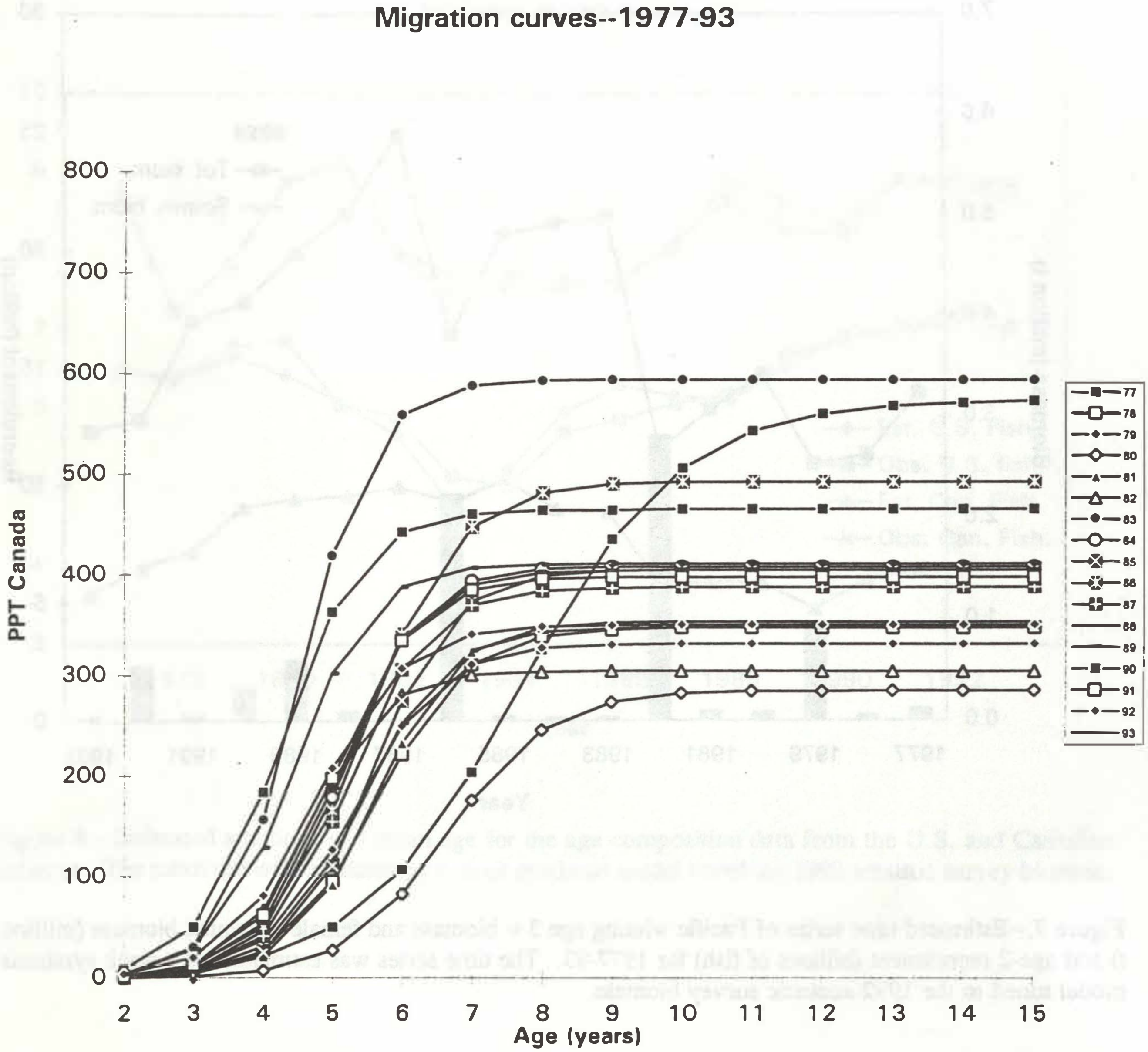


Figure 6.--Annual migration curves estimated using a geographic version of the synthesis model tuned to the 1992 acoustic survey biomass. These curves represent the annual age-specific fraction of the population migrating into Canadian waters.

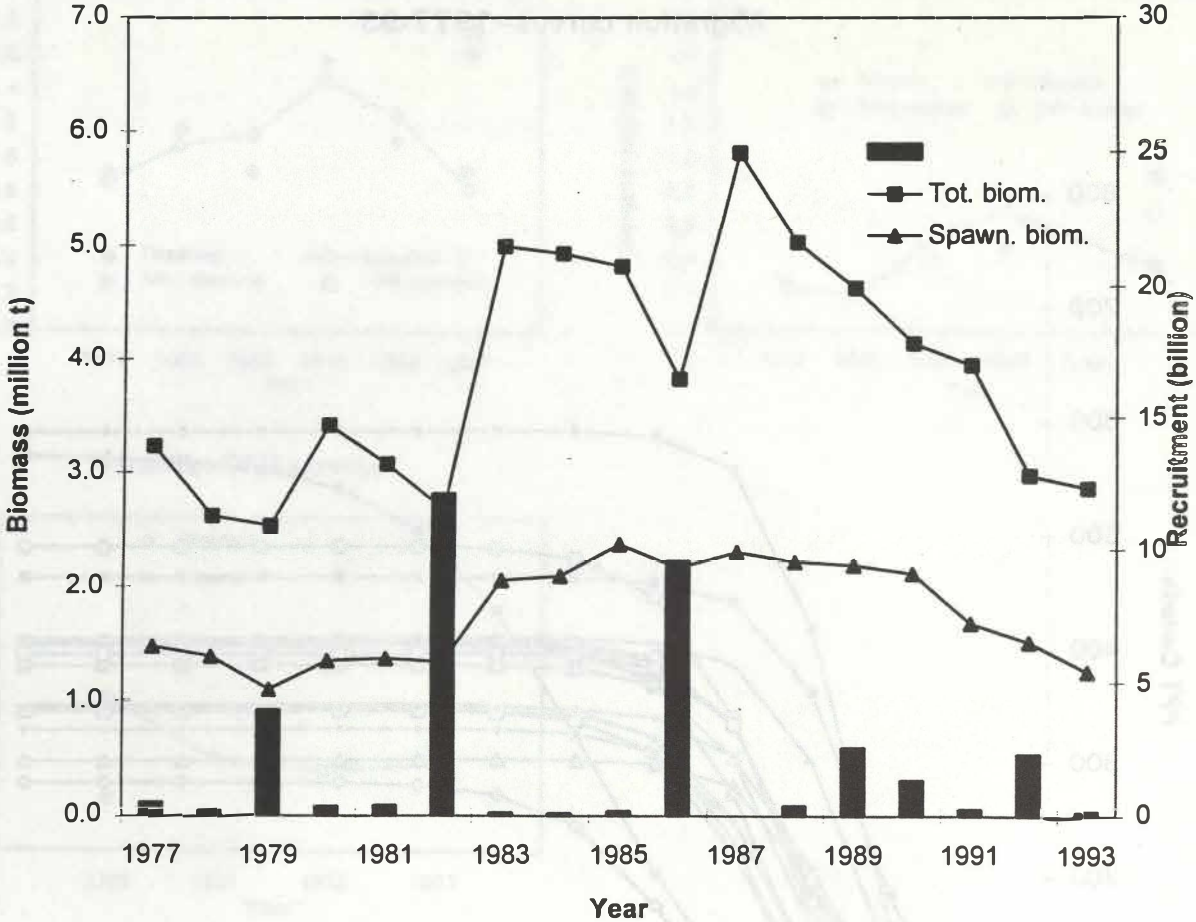


Figure 7.–Estimated time series of Pacific whiting age 3+ biomass and female spawning biomass (million t) and age-2 recruitment (billions of fish) for 1977-93. The time series was estimated by a stock synthesis model tuned to the 1992 acoustic survey biomass.

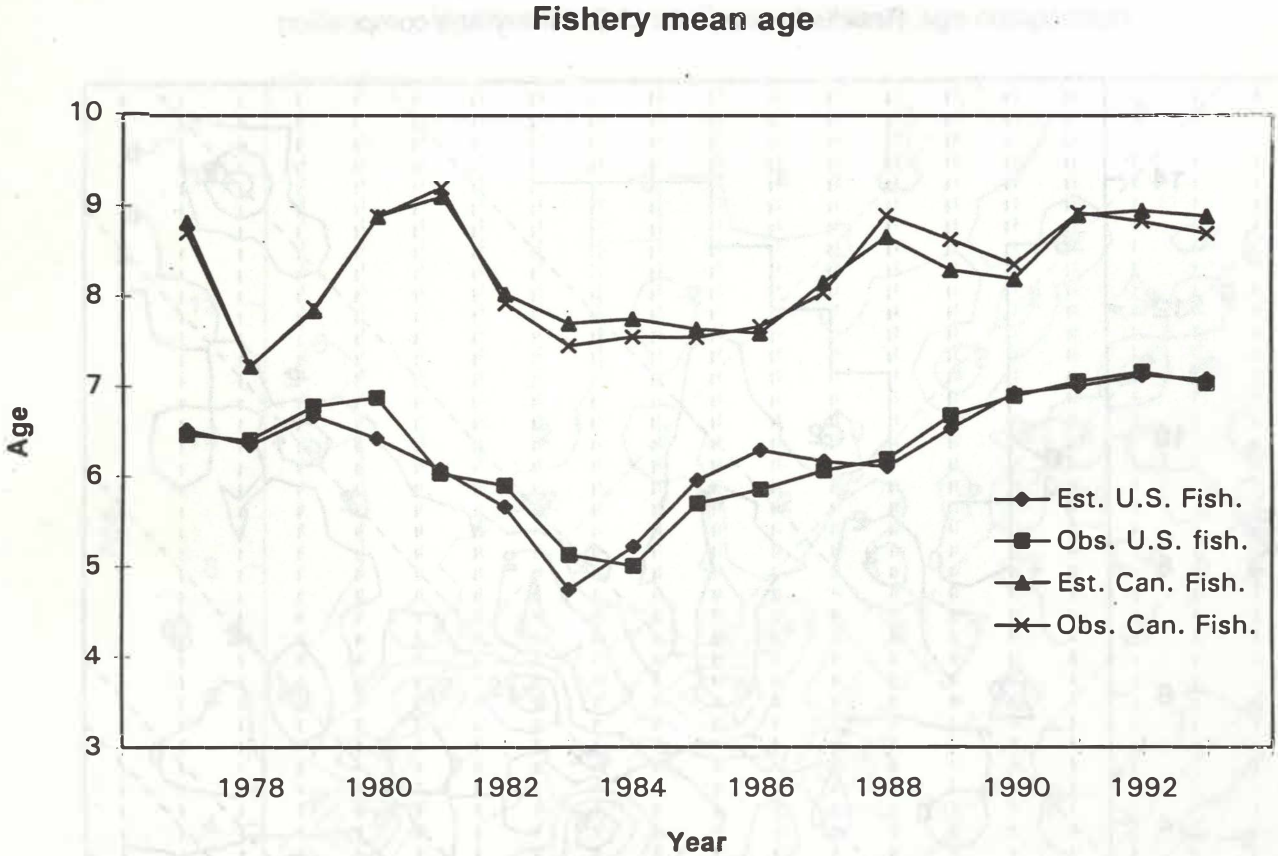


Figure 8.--Estimated and observed mean age for the age composition data from the U.S. and Canadian fisheries. The mean age was estimated by a stock synthesis model tuned the 1992 acoustic survey biomass.

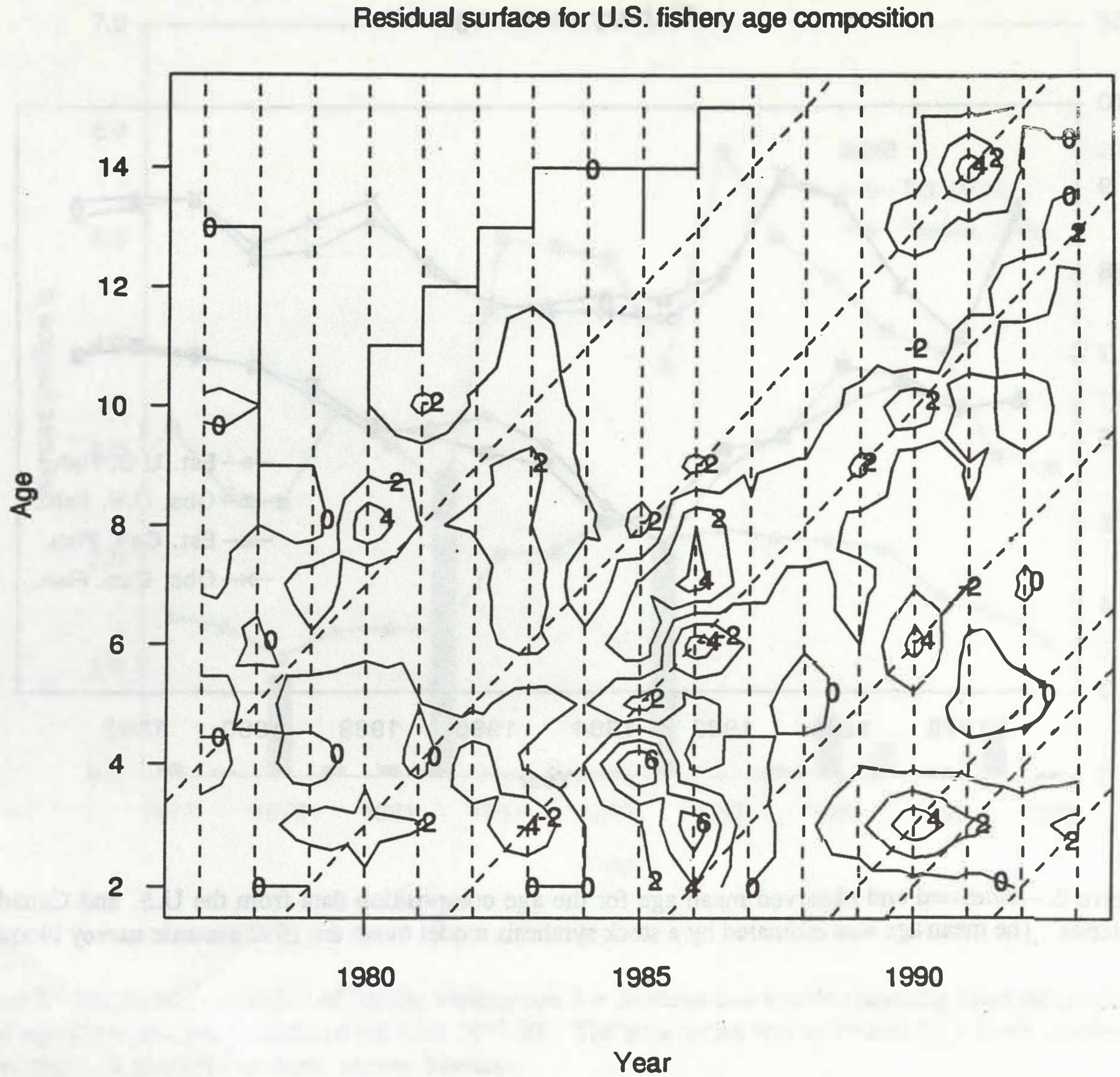


Figure 9.--Residual surface of the stock synthesis model fit to the U.S. fishery age composition. Diagonal dotted lines show the strong year classes (1973, 1977, 1980, 1984, 1987, 1988, and 1990).

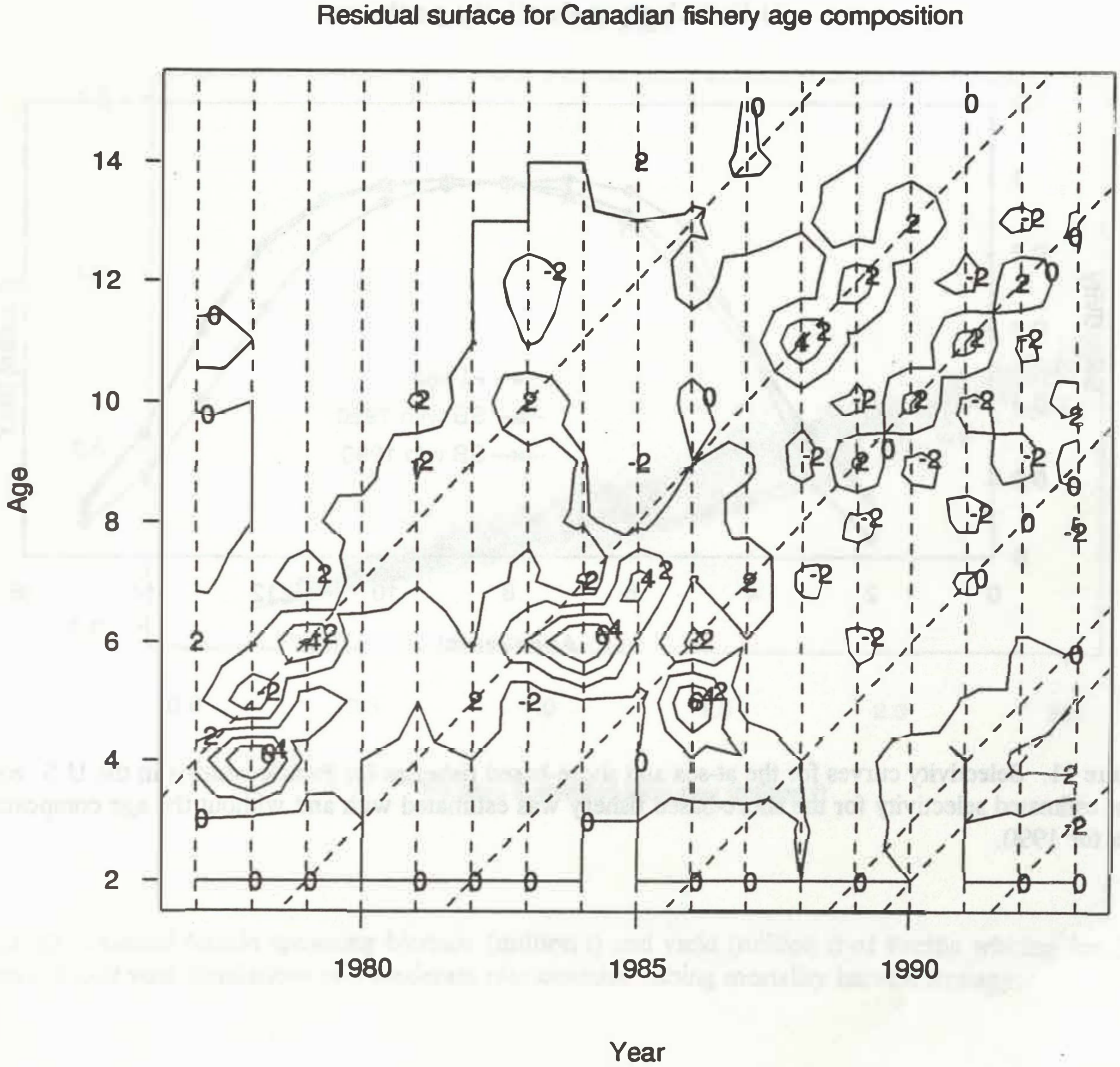


Figure 10.--Residual surface of the stock synthesis model fit to the Canadian fishery age composition. Diagonal dotted lines show the strong year classes (1973, 1977, 1980, 1984, 1987, 1988, and 1990).

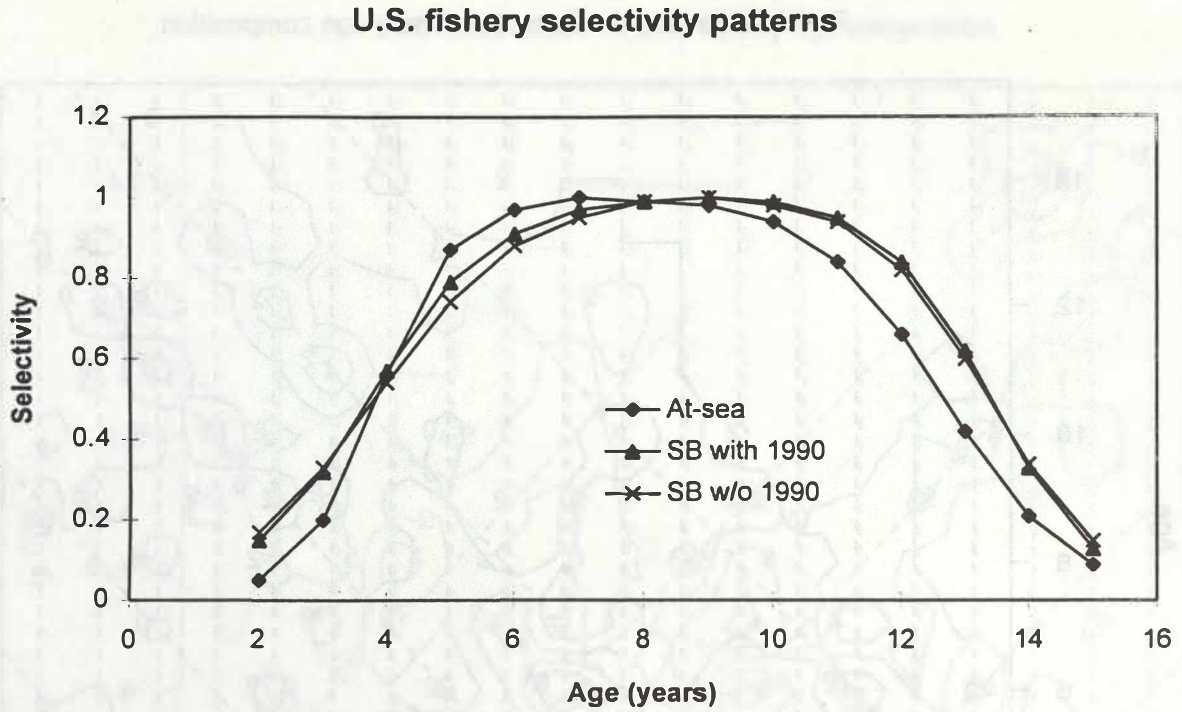


Figure 11. Selectivity curves for the at-sea and shore-based fisheries for Pacific whiting in the U.S. zone. The estimated selectivity for the shore-based fishery was estimated with and without the age composition data for 1990.

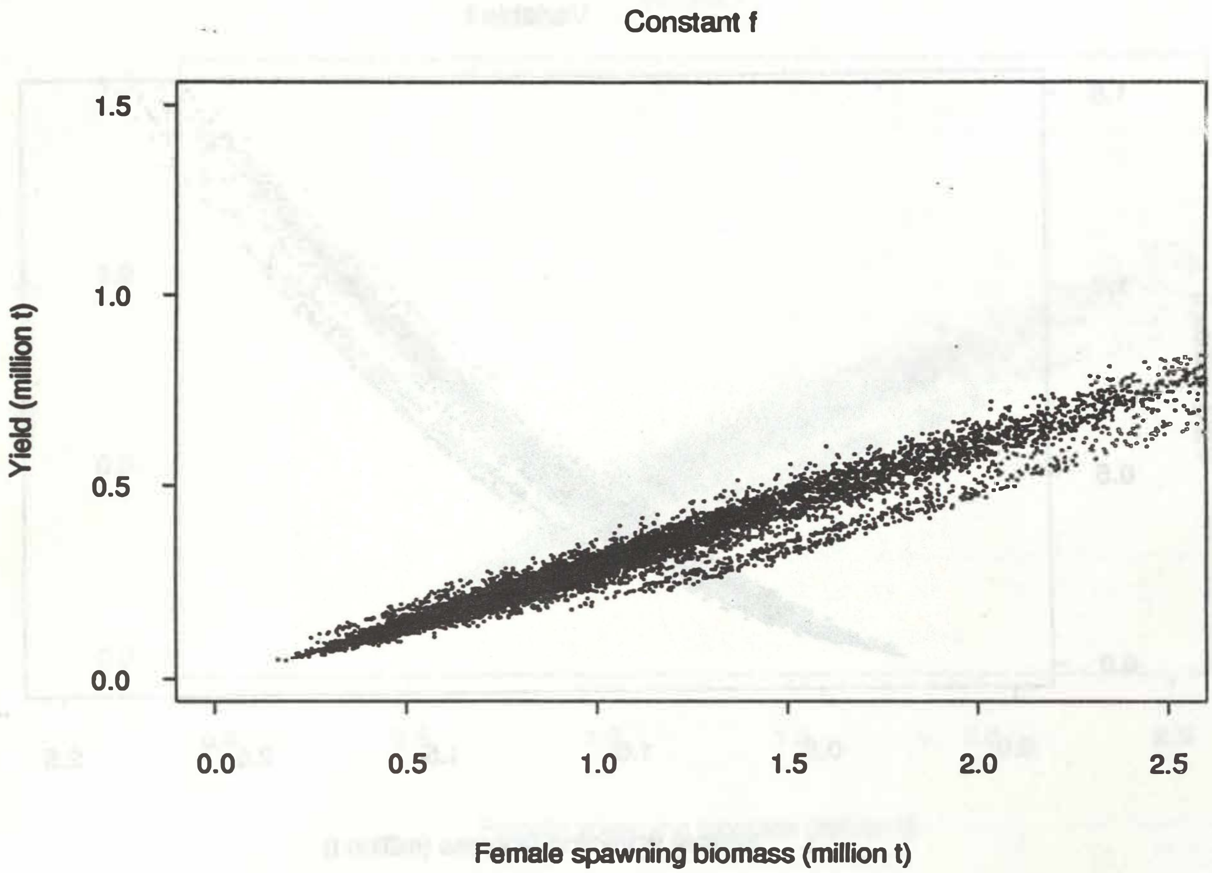


Figure 12.--Annual female spawning biomass (million t) and yield (million t) of Pacific whiting for 10 replicate 1,000 year simulations of a moderate rate constant fishing mortality harvest strategy.

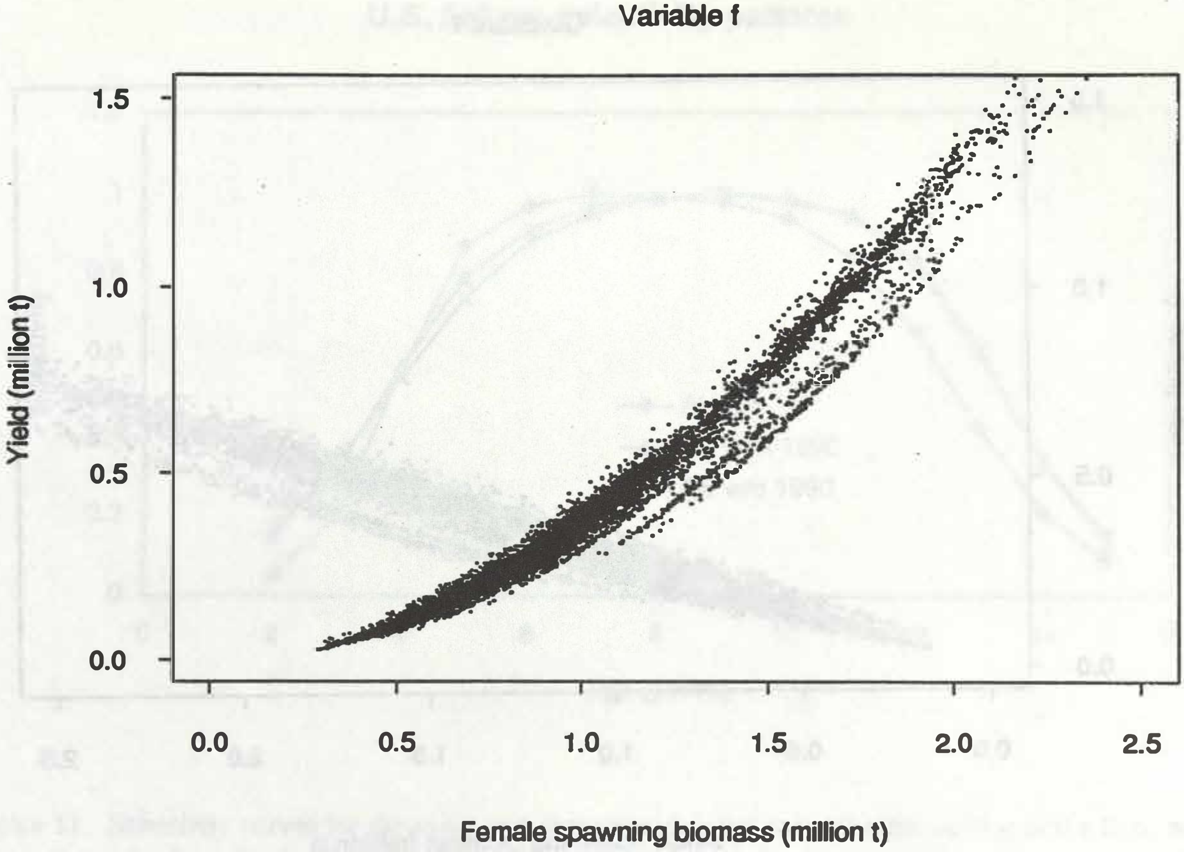


Figure 13.--Annual female spawning biomass (million t) and yield (million t) of Pacific whiting for 10 replicate 1,000 year simulations of a moderate rate variable fishing mortality harvest strategy.

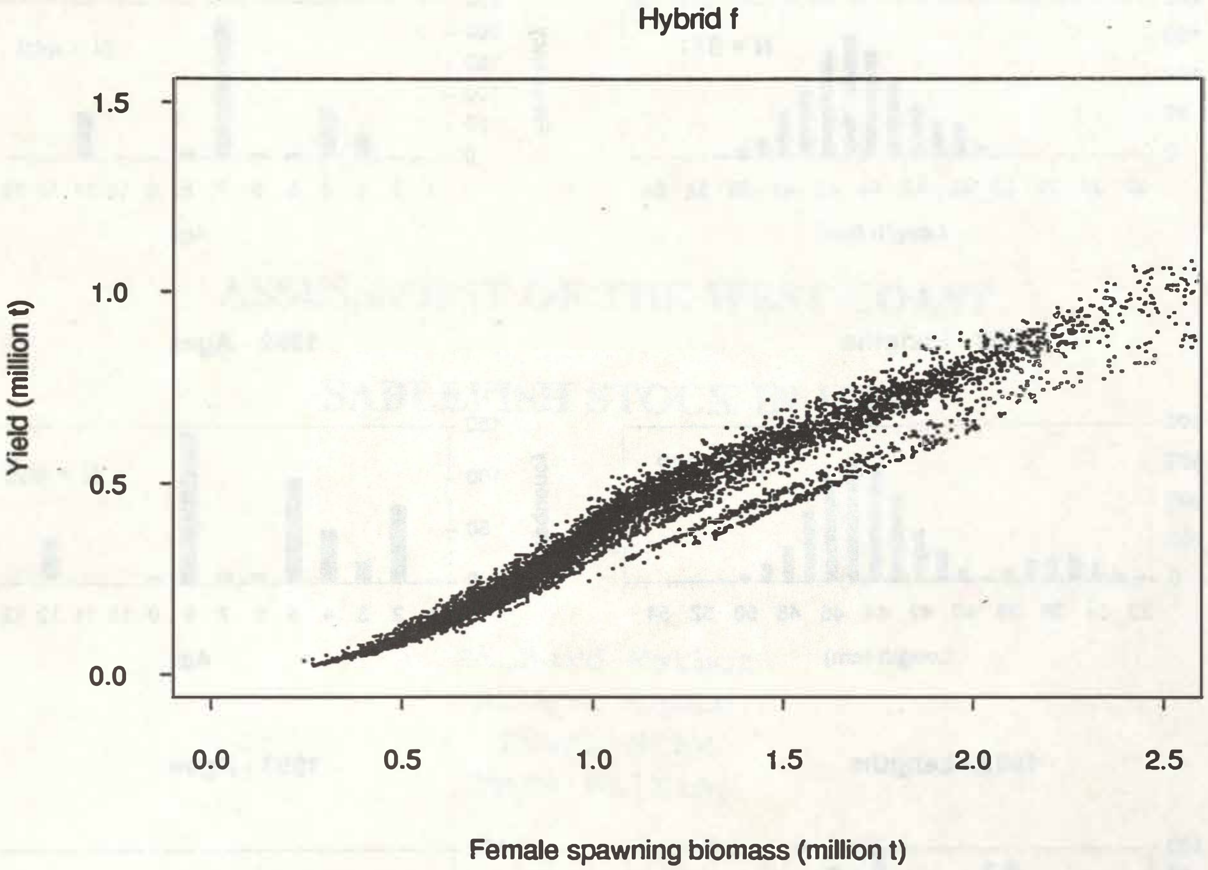


Figure 14.--Annual female spawning biomass (million t) and yield (million t) of Pacific whiting for 10 replicate 1,000 year simulations of a moderate rate hybrid fishing mortality harvest strategy.

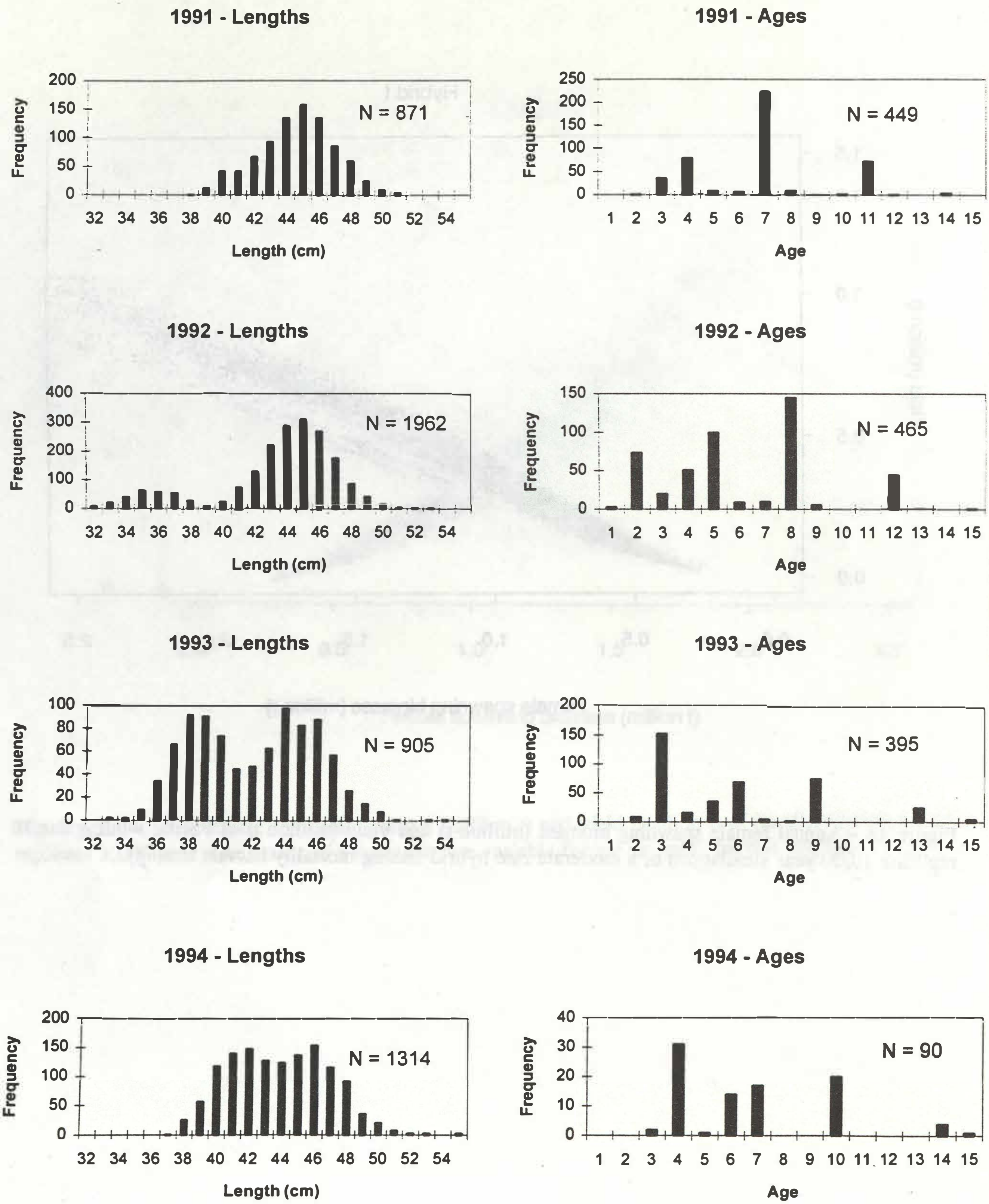


Figure 15.--Length-frequency and age-composition samples of Pacific whiting from the Newport shore-based fishery, 1991-94 (William Barss, Oregon Department of Fish and Wildlife, Marine Science Drive, Building 3, Newport, OR 97365 Pers. commun., August 1994). The 1994 length-frequency is a prelimary estimate based on samples collected from May 24 to August 3, 1994. The 1994 age composition is a preliminary estimate based on samples collected on August 3, 10, and 16, 1994.

ASSESSMENT OF THE WEST COAST SABLEFISH STOCK IN 1994

by

Richard Methot
Robert Lauth
Frank Shaw
Mark Wilkins

October 1994

National Marine Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way, NE., Bldg. 4
Bin C15700
Seattle, WA 98115-0070

ABSTRACT

The sablefish stock in the Monterey through the U.S.-Vancouver INPFC areas is assessed in 1994 through application of the synthesis model to fishery size and age composition data from 1986-1993 and trawl and pot survey data. The Conception area is excluded because the persistent smaller size-at-age and delayed maturity in that area indicate low rates of mixing with stocks to the north. Pot surveys conducted during 1979-1991 indicate a substantial decline in sablefish abundance, especially for medium and large fish in the 225-450 fathom depth zone. No pot surveys have been conducted since 1991. Slope trawl surveys during 1990-1993 have measured the biomass in the 100-700 fathom depth zone between Pt. Conception and the US-Canada border to be 61,409 mt, which represents approximately the age 2+ biomass with a reduced availability for the larger females. Survey biomass in the Monterey-Vancouver area is estimated to be about 51,000 mt. The triennial shelf trawl survey in 1992 measured a record high 55,021 mt of young sablefish in the 30-200 fathom depth zone of the Monterey - Vancouver INPFC areas.

The synthesis model was configured to explore trade-offs in fitting the biomass levels measured in the slope trawl surveys, the trend in numbers of sablefish in the pot survey, and the trend in recruitments from the shelf trawl surveys. No conventional model scenario could be found that fit all well. The slope trawl surveys indicate that about 30% of the biomass is in waters deeper than 500 fathoms, and all sources of information indicate that sablefish in these deep waters are old. A preliminary model with an emigration rate of about 3% per year, beginning at about age 4, from the <500 fathom depth zone to the >500 fathom depth zone can explain this pattern. When this emigration rate is incorporated as an extra amount of natural mortality in a model of only the <500 fathom portion of the stock, the model can achieve a reasonable fit to the decline in the pot survey while estimating that the catchability coefficient for the slope trawl survey (Q) is near 1.0 for 50 cm sablefish (medium and large sablefish would have a Q that is only 30% of this level). This result substantially narrows the range of plausible model results. Previously, values of slope Q near 2.0 were necessary to fit the trend in the pot survey.

An optimistic model scenario indicates that the slope trawl survey has a Q of 0.53 (relative to Mon-Van biomass of 51,000 mt), fits trends in the shelf trawl surveys and the fishery size and age composition data well, but provides a degraded fit to the trend in

the pot survey, even in the shallow zone model with enhanced mortality. This scenario indicates that fishing mortality over the past eight years has been close to the target level of $F_{35\%}$ (7.5% exploitation rate on the age 2+ biomass) and that the female spawning biomass recently increased to slightly above its long-term target level. Under this scenario, the annual catch plus discard could be 11,107 mt during 1995-1998, and MSY may be 8,535 mt. A pessimistic model scenario has a slope survey Q of 0.94 and provides a reasonable fit to the trend of the pot survey if migration to deep water is accounted for. This scenario indicates that harvests during 1986-1992 were nearly at the overfishing level, the spawning biomass during 1990-1993 was nearly stable at a level below the target, and the annual catch plus discard at $F_{35\%}$ should decline to 6,281 mt during 1995-1998, and MSY may be 7,216 mt. Under an intermediate scenario (Q=0.68) the annual catch plus discard could be 8,689 mt during 1995-1998, and MSY may be 7,831 mt.

TABLE OF CONTENTS

INTRODUCTION

Sablefish along the coasts of Washington, Oregon, and California (Figure 1) have a long history of exploitation by trawl, fish trap (pot), and longline gear. Recent assessments indicated that the stock has been fished down to near its optimal level (Methot and Hightower, 1988, 1989, 1990; Methot, 1992), but each of these assessments noted that the decline observed in the pot survey (Parks and Shaw, 1990) was steeper than the degree of fishing-down indicated by the assessment model.

This assessment follows the general approach used in the previous three assessments of the west coast sablefish stock. The assessment model is the size-structured version of the synthesis model as described by Methot (1990). The model is fit to fishery size and age data, and trawl and pot survey data. New data available for this assessment include the 1993 fishery size composition data, age composition from the 1991 southern pot survey and from the 1991 slope trawl survey, the 1992 shelf trawl survey (Zimmermann, et al. in prep.). Most importantly, the set of slope trawl surveys (Raymore and Weinberg, 1990) now includes southern-central Oregon in 1984, 1988, 1989, and 1993; the Eureka INPFC area in 1990 the northern Monterey area in 1991, and the northern Columbia-Vancouver area in 1992.

RECENT FISHERY

In 1993 the sablefish Harvest Guideline (HG) for landed catch was reduced from 8,900 mt to 7,000 mt on the basis of the assessment conducted in 1992 (Methot, 1992). In 1993, the HG was divided into a 300 mt portion expected to be harvested by tribal fisheries on the Washington coast, and the remaining quota was split into a 58% allocation for trawl and 42% for fixed gear. In 1994 a license limitation plan was implemented for the groundfish fishery. The 7,000 mt HG was divided into a 300 mt tribal portion, a 9.4% allocation (630 mt) for vessels without permits, and the remainder was split into a 58% allocation (3,521 mt) for trawl and 42% for fixed gear (2,549 mt).

Sablefish are the target species by the fixed gear fleet and the season has shortened as the quota has decreased and the number of participants has increased. In 1990 the fully open fixed gear season was closed on June 23. In 1991, the fully open season lasted seven weeks, April 1 to May 23. In 1992, about 1,300 mt was landed under early season trip limits of up to 1,500 lbs per day, and the fully open season lasted from May 12 through May 26. In 1993 there was only a 250 lbs per day trip limit prior to the open season on May 12. The open season extended through June 1. In 1994, the fully open season lasted from May 15 through June 3. During the fully open seasons of 1992 and 1993, the fleet landed approximately 120 mt/day.

Sablefish are harvested by the trawl fishery in assocation with other species so trip limits have been imposed in order to extend the sablefish harvest guideline throughout the year and prevent a prohibition on landing of sablefish. Beginning in 1989, the trawl fishery has operated under a sablefish trip limit of 1,000 pounds per trip or 25% of the deepwater complex (sablefish, Dover sole and thornyheads), whichever was greater. In addition, there have been various limits on the catch of the total deepwater complex (55,000 pounds cumulative per four weeks during most of 1993). Because of these various trip limits and size limits, it is assumed that 20% of the total trawl-caught sablefish are discarded. In 1993, a minimum mesh size of 4.5 in was required in all non-pelagic groundfish trawls.

FISHERY DATA

Catch Biomass

Domestic and foreign landings for 1956-1980 from the HAL database (Lynde 1986) were combined with PacFIN data for 1981-1993 (Table 1). The total for the INPFC Monterey area was reduced to account for some 1985-1990 Morro Bay landings incorrectly assigned to that area instead of the correct Conception area. The total for the INPFC Conception area was increased to account for landings incorrectly assigned to the unknown INPFC area. Gears other than longline (HKL), pot (POT), and trawl (TWL) were pooled into a miscellaneous category, except that shrimp trawl (TWS) landings were merged with landings for the trawl gear group. Gear codes were not available for landings by foreign vessels prior to 1981. Based on reported historical gear use, the following assignments were made: Japan-longline, USSR and Poland-TWL, Korea-POT, and other countries-MSC. Miscellaneous landings were apportioned over known-gear totals by year and area. The distribution of landings by State and major gear group is shown in Figure 2. In recent years the landings by pot vessels has declined and over half the sablefish catch is landed in Oregon.

Market Categories

Sablefish may be dressed (headed and gutted) and/or sorted by size prior to landing or prior to recording on a State fish ticket. Condition (dressed vs. whole) is not coded on fish tickets in California (Table 2a), but the distribution of biological samples indicates a high percentage dressed for the pot fishery. The probability of dressing ranges from near zero for the Oregon trawl fleet (Table 2b) to near 100% for the Washington longline fleet (Table 2c). The market categories are ocean-run (unsorted), small (3-5 pounds, approx. 52-61 cm FL when round, approx. 60 -70 cm when dressed), medium (5-7 pounds, approx. 62-67 cm whole, 70-77 cm dressed), and large (>7 pounds, >= 68 cm whole, >= 78 cm dressed). In addition, some landings in Oregon are coded as extra small. The design of the coastwide sablefish port sampling program anticipated taking random age and size composition samples <u>within</u> each market category for each gear, then expanding each estimate by the total catch biomass for each stratum. Sablefish assessments in 1988-1990 used these expanded estimates. In 1992 some potential biases were detected in this expansion process so the assessment model was revised to utilize fishery data within market category. A shortcoming of the approach used in 1992 was its inability to account for the expected difference in body length for whole vs dressed fish, and its substantial complexity. Here in 1994 the fishery port sampling data were intensively scrutinized to improve the fidelity with which biological samples correspond to the appropriate fish ticket market category. Although some ports and gear types have been severely undersampled, the assessment is based on expanded estimates for each gear type in the fishery. Nevertheless, several of the issues raised in 1992 remain:

a. <u>Small sample size:</u> The large number of strata creates a logistical problem and causes some strata to be inadequately sampled.

b. No sex or age data is available from dressed fish which predominate in some strata (i.e. WA longline). Extrapolation from other gears and areas is necessary and may introduce some bias.

c. In 1993 landings in some Oregon and California ports were sorted into market categories <u>after</u> a sample of ocean-run fish was collected. In these circumstances, the grade information on the commercial fish tickets does not match the grade information on the port sample. In one port all the samples were ocean-run and all the fish tickets had sorted catch, so it was obvious that all the graded catch on fish tickets should be combined into one aggregate catch to be applied to the ocean-run samples (i.e., as is done in Washington). However, in other ports it is ambiguous to determine which of the sorted landings should be re-combined into the ocean-run category and which should be left as sorted landings. Also, the broad size distribution within the Small category suggests some ambiguity between ocean-run and small categories in past years. This technical sampling issue needs to be addressed before 1995.

The size composition of sampled sablefish within market category has been fairly constant over time, so the market category data itself is important component of the fishery biological data. The market category data is documented in Tables 2abc and described below for each major element of the fishery:

a. Washington longline - Percentage large (%L) was 60-70% by weight for both dressed and whole fish during 1981-1984. Fishery increased in magnitude in 1985 and %L decreased to about 20% as the landings of L remained nearly steady while the landings of S increased several fold. Since 1988 all fish have been dressed and the %L is now less than 5%. Port samples of dressed, ocean-run fish during 1986-1993 indicate 3.5% by number are at least 76 cm, and 13.5% by number are at least 68 cm. The similarity of the %L in whole versus dressed fish is perplexing because dressed fish are not expected to be 7 lbs until the FL is about 77 cm. Perhaps the %L in dressed was inflated by a reduced probability of dressing smaller fish. The important, and perhaps unresolvable question, is interpretation of the high %L (e.g. low landings of S) during the early 1980s. Were the small fish effectively avoided by the earlier fishery?, were they discarded with some level of mortality? or are they now proportionally more abundant as the fishery has reduced the abundance of L fish?. The assessment model will allow for changing selectivity over time, so the working assumption is a combination of the first and third above.

b. Oregon longline - Most sablefish were landed whole (round) until 1991 when about half were dressed. The %L in whole fish has an overall downward trend during 1983-1991. The %L in dressed fish is, as expected, much lower.

c. California longline - Nearly all biological samples from longline landings in the Eureka and Monterey INPFC areas are from whole fish so we assume that few longline fish are dressed in this area. The %L for California longline during 1984-87 is similar to that in Oregon, but a greater drop occurs in California beginning in 1988.

d. Oregon fishpot - Most sablefish are landed whole and the %L has gradually declined. The %L jumps up in 1987-1988 when the % ocean-run was higher; presumably much of the fish coded as whole, unspecified size fish are in the small size range. This makes sense because it may be more advantageous for a fisherman to sort by size if there are larger sablefish in the catch. Washington fishpot showed similar levels of %L during the early 1980s, but this component of the fleet is now inactive.

e. California fishpot - Although condition (whole vs. dressed) is rarely coded on the fish tickets, there are nearly as many dressed samples as whole, so there must be a high proportion of dressed landings. The %L for California pot is low (Table 2a). Lack of condition data on fish tickets is a severe limitation to interpreting sablefish fishery data from California.

f. Trawl - In Oregon nearly all trawl caught sablefish are landed whole. About 15-40% are landed ocean-run. The %L has been relatively stable at 5-10%. In Washington, nearly all trawl caught sablefish are landed as whole and specified. The %L is similar to that in Oregon. An upward trend beginning in 1988 may be a sign of increasing high-grading. The few fish that are dressed in Washington have a high %L, apparently high-grading of dressed fish offsets the expected low percentage of fish larger than 76 cm. In California, trawl-caught sablefish are assumed to be nearly all landed whole on the basis of the whole/dressed distribution of port samples. These sablefish are 3-5% L with a small increasingly trend in recent years. The %Medium is unexpectedly low for trawl, especially in the earlier years (Table 2a). This seems due to the fact that, during some of these years, processors did not recognize a separate Small and Medium category (Peter Leipzig, personal comm.).

Catch per unit Effort

The coastwide logbook program provides tow-by-tow information on retained catch and tow duration. A summary of these data from the Eureka and Monterey areas are presented as a first step towards derivation of an alternative index of trends in stock abundance. This derivation will be a difficult, and perhaps impossible, exercise. It must take into account changing fishing power of the vessels and changing targeting behavior as a result of changing market conditions and changing fishery regulations, especially those regarding trip limits. Nevertheless, a summary of the data are presented here in order to demonstrate the degree of consistency in the patterns and, hopefully, to stimulate analytical efforts to accomplish the calibration. Figures 3 and 4 present mean sablefish catch per hour towed in each year and 100 fathom depth stratum in the Monterey and Eureka INPFC areas. Shallow stratum show little trend and deeper stratum have about a 50% decline in CPUE over the 1981 to 1991 period. Figures 5 and 6 show sablefish as a percentage of sablefish, Dover sole and thornyheads. Beginning in April 1989, the %sablefish per trip could not exceed 25% of this deepwater complex. Figure 5 shows that the %sablefish in the Eureka area tended to be near this level in the early years, declined during the early 1980s, then increased coincident with regulations in the late 1980s. In the Monterey area (Figure 6) the average %sablefish is much higher in shallow and deep water tows than in the mid-depths.

Size Composition

Expansions for each year (1986-1993) x gear (HKL, POT, TWL) x sex are based on the following strata: state (C.Cal, N. Cal, Oregon, Washington), condition (whole vs. dressed) and grade (large, medium, small, extra small, and ocean-run). One observation is generated for combined sexes. A split sex observation is generated by applying the average, size- and gear-specific sex ratio to the combined sexes observation. These observations are assigned a weighting of 200 which implies that a size with a proportion of 0.1 has a CV of 20%. Note that in 1992, sablefish port sampling was suspended in California and Oregon in order to initiate lingcod sampling. Coastwide sablefish sampling resumed in 1993. The time series of fishery size compositions is shown later in conjenction with model fits to these data. The following non-standard observations are included in the model:

a. Longline observation from 1950's Eureka fishery (Phillips, 1954) with mean size of 72 cm. This observation is input as the 1971 longline fishery. Other reports from Oregon and Washington suggest that mean weight of sablefish landed in 1910's was even greater than this mean size.

b. Longline, pot and trawl observations from 1983 selectivity study (Klein, 1986). These samples were given a reduced weight of 50 vs. a normal weight of 200.

c. For each year from 1981 to 1985, expand the market category data for pot and longline by the 1986 sample data. These pseudo-observations were given a reduced weight (50).

d. Trawl discard: use 1983 sample from Hankin which shows size-related discard in the Eureka area; and 1987 sample from trawl trip limit study (Pikitch, et al. 1989) which shows all types of discard primarily in the Columbia area. The 1987 discard observation was repeated in 1990. In addition, the size composition of the retained fish from the trip limit study is included in the model for 1987.

Age Composition

The fishery age data from 1987-1990 are processed through the use of year/gear/sex specific age-length keys. Age data from 1986 were not used because of concerns over the ageing criteria. Lack of personnel has prevented ageing of the 1991 and 1993 samples. No otoliths were collected in 1992. Data from all grades are combined because inspection of the data did not indicate any obvious difference in the distribution of age-at-length between market categories. Data from all areas was combined in the age-length keys. Each key was produced on the basis of the 22 size and 17 age bins eventually used in the Synthesis modelling. Within each size bin, the entire 1987-1990 age data were combined and scaled to a total of 3 fish. This "low N background" distribution was added to each year's key in order to fill in the blanks. Each key was expanded, on the basis of the size distributions (by year, gear, sex) estimated above, and used to calculate the age distribution and mean length-at-age.

In the future it may be advisable to create some area strata because the predominately shallow water WA trawl fishery harvests younger sablefish than the deep water fishery from Eureka and southern Oregon.

Ageing Error

The level of agreement between readers at Tiburon is used as the observed level of precision. The observed vector of %agreement was:

Age:	1	2	3	4	5	6	7	8	9	10	11	12	13
%Agree:	94	83	68	45	41	38	36	34	32	30	28	27	26

Age:	14	15	16	17	18	19	20	21	22	23	24	25
%Agree:	24	23	22	21	20	19	18	17	16	15	15	14.

Ageing error is used within the model to blur the expected actual age composition before comparing the result to the observed age composition. Thus the model may estimate a yearclass to be strong, even though the observed age composition has only a broad bump. Ageing error also affects the observed size-at-age and is accounted for in the generation of expected values for mean size-at-age (Methot, 1990).

Discard

The size-specific component of discard by trawlers was examined in the 1988 and 1990 assessments. Data from the Eureka area in 1984 indicated 50% retention at 42.8 cm[1], and more extensive data from the Columbia-Vancouver areas in 1985-1987 indicated 50% retention at 40.1 cm (Pikitch, unpubl. data).

$$R = \frac{1.0}{(1.0 + \exp(\alpha * (L - \beta)))}$$

Where: R = fraction retained; L = size

Period	β	α
1971-84	42.8	-1.092
1985-present	40.1	-0.526

[1]Characteristics of blackcod captured off Eureka, California by vessels belonging to the Fishermen's Marketing Association, July 1983-August 1984. A report submitted to the Fishermen's Marketing Assoc. by Shunji Fujiwara and David Hankin, Dec. 1984.

These two retention curves are provided to the model as representing the periods 1971-1984 and 1985-present. The size composition of the discarded sablefish (as measured in 1983 and 1987) are provided to the model so that the model can estimate selectivity curves that are consistent with the size composition of the retained and discarded fish given the estimated retention function.

Estimation of the magnitude of total, mortal discarded biomass is problematic. The following assumptions are made:

a. Mortal discard by fixed gear is negligible. Note, however, that a substantial number of small sablefish probably were handled and released prior to 1985 when the landings of small sablefish increased by nearly 1000 mt.

b. All estimated discard by trawl gear is mortal. This is probably not strictly true. However the true percentage mortality is not known. Underestimation of mortal discard by fixed gear will somewhat offset any overestimation of trawl discard.

c. In years prior to trip limits, there is no set level of trawl discard. The only discard in these years will be that estimated due to the size-specific retention function. This means that there is no assumed discard due to lack of market.

d. The extrapolation to total, coastwide discard in 1985-87 by Pikitch et al. (1988) was appropriate. The mean percentage discard in these 3 years was 23.5% of total trawl catch (discard = 30.7% of landed catch).

e. In 1982 a 3000 lb trip limit was imposed on October 13. This is approximately as restrictive as the trip limits during 1985-87 so the assumed discard factor in 1982 was 30.7%.

f. The assumed level of discard in 1988 - present is 20% of total trawl catch (25% of landed trawl catch) which is the rate measured by Pikitch et al. (1988) when 6,000 to 12,000 trip limits were in effect.

Year:	82	85	86	87	88	89	90	91	92
Discard:	3181	2322	2179	2019	1396	1437	1278	1220	1220.

SURVEY DATA

Pot Surveys

Sablefish pot surveys were conducted in 1979, 1980, 1981, 1983, 1985, 1987, and 1989 in the northern (Columbia and Vancouver areas) and in 1984, 1986, 1988, and 1991 in the southern (Conception, Monterey and Eureka areas). Age composition data are available from the 1983 and 1989 northern pot surveys and the 1986 and 1991 southern pot surveys. The northern survey routinely samples at 150, 225, 300, 375 and 450 fathoms and the southern survey samples at 225, 300, 375, 450, and 525 fathoms (Table 3-4). A substantial review of the area and depth-specific patterns in abundance, size and age composition was included in the previous assessment (Methot, 1992) and is not repeated here.

For the purpose of this stock assessment, only samples from the common depths 225 - 450 fathoms are selected. The time series of relative abundance is little changed by deleting the 150 fathom samples from the north and the 525 fathom samples from the south. Samples from the two southernmost sites (in Conception area) are not included because of the persistent low mean size-at-age in the southern area. In 1984-85, large sablefish were relatively low in abundance in the area south of San Francisco and in the southern portion of the Columbia area. The reduced abundance south of San Francisco is in accord with Phillips (1954) who states, "Southward of Eureka, there is a decrease in the proportion of the fish that are over six pounds round weight, or more than 27 inches, total length. The greatest discrepancy occurs in the Monterey region. Although all dealers along the coast prefer the larger sizes, it is apparent that not many large fish are available to the fishermen in the latter region." By 1988-89, the abundance of large sablefish had been reduced to a similar level all along the coast (Methot, 1992).

<u>Pot survey index in model</u>

Treatment of the northern and southern pot surveys as equivalent measures of the stock trend seems plausible from the trend of the data (Figure 7). However, there could be some consistent difference in the mean density or size composition of the sablefish stock between the two survey areas. A more correct procedure is to treat the two surveys as different measures of the stock trend, each with its own selectivity characteristics relative to the entire stock, but even this approach ignores the true geographic difference and the potential for a strong yearclass to appear primarily in only one of the areas. A compromise approach is to combine the alternating northern and southern surveys as pairs of observations (Table 4). In this approach the southern surveys in 1984, 1986, 1988 and 1991 were interpolated to the years of the northern survey (1983, 1985, 1987, and 1989) and then added to the northern survey. Thus, each observation supplied to the model is based on coastwide data (8 northern sites plus 7 of the 9 southern sites). Size composition data from the pot surveys are not combined between areas because of possible influence of individual yearclasses. The size composition data from the northern and southern surveys do not exhibit any obvious regional effect (Figure 19).

Early surveys at 4 of the 8 sites in the northern area generally indicated higher abundance, especially for the large and medium categories. However, the sharp drop from 1979 to 1980 and the increase from 1981 to 1983 are not plausibly explained by a change in the abundance of the stock because of the large number of age groups involved in the medium and large categories. An additional component due to changing stock distribution or catchability may have occurred. Because of the small number of sites involved, the 1979-1981 observations are given a lower weighting (higher CV) in the model.

<u>Medium and Large Pot Survey Index</u>

The decline in the medium and large sablefish is a consistent signal in the pot survey. However, the model's ability to track this signal is hindered by the variability in the more abundant small and extra small sablefish. In this assessment, the medium and large data are replicated as an additional index. The selectivity pattern for this survey is 1.00 for all sizes greater than 62 cm, and declining with advancing age according to the pattern estimated for the overall pot survey.

<u>Age composition in pot surveys</u>

Age composition from samples of the pot survey seem to clearly indicate that the ontogenetic movement of sablefish into deeper water is related more to age than to size (Methot, 1992):

a. Size-at-age is relatively similar in the three major depth zones (150 fathoms, 225-450 fathoms, and >= 525 fathoms).

Therefore, the larger sablefish at a given age are not found in deeper water.

b. Age-at-size increases greatly in deeper water.

c. Age composition at 150 fathoms contains no old sablefish.

d. Age composition at >525 fathoms contains no young sablefish.

The low mean size-at-age observed in the northern survey area is perplexing. Sablefish off British Columbia and Alaska are much larger than sablefish off the West Coast and a monotonic trend in size-at-age was expected along the West Coast. This latitudinal decline in mean size-at-age is most apparent for females beginning at age 6:

Area:	CON	EUR-MON	COL-VAN in 1983	COL-VAN in 1989	Alaska
Age					
4	52.0	55.2	54.6	56.2	57.2
5	53.0	58.3	56.4	59.3	61.5
6	56.5	60.6	60.9	57.4	65.1
7	59.9	62.1	59.9	59.1	68.3
25+	61.9	66.0	63.6	58.6	87.7.

In the northern area the distribution of size-at-age for ages older than 6 sometimes appeared bi-modal with most females not much larger than males and a few larger females. One interpretation of this pattern is that the large fish experience high fishing mortality in the 225 - 450 fathom depth range so the population is becoming dominated by slow growing sablefish, with an occasional large migrant from deeper waters or northern areas. This long upper tail to the size-at-age distribution is accomodated in the synthesis model by assuming a lognormal distribution of size-at-age.

Trawl Surveys on Continental Slope

Trawl surveys have been conducted on the continental slope and outer continental shelf (100 - 700 fathoms) in the southern-central Columbia area in 1984 (Raymore and Weinberg, 1990), 1988, and 1989, in the Eureka area in 1990, and in the northern half of the Monterey area in 1991. In 1992 the survey covered the Vancouver and northern Columbia area, and in 1993 the survey returned to the southern and central Columbia area (Figure 8). All surveys were conducted in the October-November period and all were stratified by 100 fathom intervals. Typically 10 samples were taken in each stratum. The 300 fathom in the Eureka and southern Columbia areas was resampled enroute to the 1991 Monterey survey area. In addition, the Morro Bay and Half Moon Bay area was sampled in 1987, and the Morro Bay are was sampled in 1988 (Butler, et al., 1989). The depth-specific density of sablefish is similar in the 1984, 1988 and 1989 Columbia area surveys and lower in the 1990-93 surveys (Tables 5 and 6). The decline in density is observed primarily in the 200-499 fathom depth range. In deeper water, where there is less fishing and the population is dominated by the oldest sablefish, there has been no observed decline. In shallower water (100-199 fathoms), where there is substantial trawl fishery effort but the sablefish population is dominated by 1-3 year old individuals, there has been no obvious decline in mean density, although the variability is great.

It is important to determine whether the decline observed in the central Columbia area represents: (1) random variability, (2) a change in catchability, or (3) a true population decline.

The decline probably does not reflect simple random variability. The 90% CI for the 1989 survey (19,561 - 37,500 mt) does not overlap the 90% CI for the 1993 survey (3,461 - 18,852 mt), and the change is consistent across the three middle depth strata.

There is no obvious change in methodology that would have caused a change in sablefish catchability. Tow speed was reduced from 3 knots in 1984 to 2 knots for all subsequent years in order to extend the survey depth from 500 to 700 fathoms. This change did not cause a decrease in sablefish catch rates in 1988-89 relative to 1984. The vessel <u>Miller Freeman</u> was used in one year with high catch rates (1988) and all the surveys from 1990-1993 so there is no obvious vessel effect. All surveys were conducted during September-December. The 1984 and 1989 surveys were conducted early (September-October), the 1988 survey was the latest (November-December), and all subsequent surveys occurred during an intermediate time (October-November). These small variations in timing could affect sablefish availability, but these is no obvious reason for sablefish availability to dip sharply in October.

Net performance, particularly with regard to susceptibility to mud loading and decreased net opening, has been raised as an issue that could affect sablefish catch rates. While there is little quantitative information on these issues, all examinations to date have not detected any patterns that would compromise interpretation of the slope survey data. "Mud tows" have always occurred, but their incidence and severity was not measured prior to the latter portion of the 1993 survey. In this portion of the 1993 survey there was no significant difference in sablefish catch rates for tows with mud versus tows without mud within each depth stratum (Figure 9). In previous surveys the mean catch rate of bottom invertebrates may be an index of the frequency of mud tows and does not show a trend over time (R. Lauth, pers. comm.).

While the change in sablefish catch rate appears statistically significant and unexplainable by any change in methodology, it also seems unrealistic from a population perspective. In the 200-499 fathom depth zone, the 3,854 mt measured in 1993 is only 19% of the biomass measured in 1988-1989. This is a greater decline than the 1985-1989 decline in the pot survey, which also has been considered unrealistic in previous stock assessments (Methot, 1992). Other major deepwater species showed some, but lesser, declines between the 1988-89 and 1993 surveys:

Species	1993/(1988-89)
Longspine thornyheads	0.31
Shortspine thornyheads	0.42
Sablefish	0.19
Dover sole	0.33.

In the modelling effort below, the biomass levels observed in the 1984-1989 Columbia area surveys are not used. Only the 1990-1993 surveys are used, but a rigid assumption with regard to catchability is not imposed.

Absolute Biomass

The slope trawl surveys can provide estimates of absolute biomass if the catchability coefficient (Q) is 1.0 (e.g. all fish in measured path between trawl wingtips are captured and there is no herding by the doors and sweeps) and the sablefish density in trawlable habitat is the same, on average, as that in untrawlable habitat. Although these assumptions are not testable with available data, the previous assessment (Methot, 1992) relied upon these assumptions and estimated an absolute biomass of sablefish throughout the Monterey-Vancouver areas from the 1984-1991 slope trawl surveys. This involved extrapolating the high densities observed in the southern-central Columbia area in 1984-1989 to the entire Columbia and Vancouver area and resulted in an estimate of 106,714 mt. However, the assessment noted that the decline in the pot survey implied that the Q for this estimate of slope trawl survey biomass should be closer to 2.0 than to 1.0.

Substituting the biomass measured throughout the Columbia-Vancouver area in 1992-1993 and including results of the 1988 survey off Morro Bay results in an estimate of only 61,409 mt for the area between Pt. Conception (latitude 34° 30') and the US-Canada border. This biomass estimate includes 13,408 mt between San Francisco (latitude 38°) and Pt. Conception, and 13,755 mt in the 500-699 fathom depth range north of San Francisco. The biomass estimate of 61,409 mt is only 58% of the "absolute" biomass estimate used to tune the 1992 assessment. If this lower biomass level actually indicates absolute biomass, it is more, but not completely, consistent with the decline in the pot survey. The decline in the "BIGPOT" index still implies that Q is greater than 1.0 for the slope trawl survey.

On the other hand, comparison of the slope survey results to those of the shelf survey suggest that slope survey Q may be less than 1.0. The trawl surveys on the continental shelf also cover the 101-200 fathom depth range and observed levels of sablefish abundance in this depth range are similar, on average, to the levels observed in the slope surveys (Table 7). However, pairwise comparisons of the two surveys (1989 shelf Eureka >> 1990 slope Eureka; 1992 shelf Columbia >> 1992-1993 slope Columbia, 1992 shelf Vancouver < 1992 slope Vancouver) suggest that the shelf survey may be more efficient at catching sablefish. The shelf survey uses a roller bobbin footrope and a tow speed of 3 knots while the slope survey uses a chain-disc footrope and a tow speed of 2 knots.

The biomass estimate of 61,409 mt is used in the model as an estimate of the biomass in 1992 and 1993[2]. The model will be run with a range of Q values for this biomass estimate; Q<1.0 will be more consistent with the high biomass and lack of decline in the shelf survey and Q>1.0 will be more consistent with the decline in the pot survey.

---

[2] Note that the value of 61,409 mt was used in this 1994 assessment. It would have been more appropriate to use a value of about 51,000 mt to represent only the Vancouver - Monterey areas. Thus, the slope survey Q values reported in the Tables should be multiplied by 0.83 to convert them to a Q that is relative to only the Monterey-Vancouver biomass.

The model is provided with each survey's observation of size composition (except the 1987-88 Morro Bay area surveys are not used for size composition), and age and size-at-age data from the 1989 and 1991 survey. The 1989 survey had a large fraction of the biomass in the 200-299 fathom depth zone, but no age composition samples were obtained from this stratum. Because of this problem, slope survey age composition data were completely de-emphasized in the final model runs. Size composition data for sizes less than 42 cm are truncated in order to prevent the high variability of age 1 numbers from interfering with the model's ability to estimate size-specific selectivity patterns for the slope trawl survey. These size selectivity patterns will define the degree to which the survey misses small fish that usually are found shallower than 100 fathoms (the survey limit) and the degree to which the survey misses large sablefish that can avoid a trawl towed at 2 knots. Thus, the specified Q level will apply only to the sizes with selectivity equal to 1.0, other sizes may have a lower selectivity which results in a lower effective Q for those sizes. The model produces an estimate of 0.3 for the selectivity of the medium and large sized sablefish.

Trawl Surveys on Continental Shelf

The shelf trawl survey (30-200 fathoms) was conducted in 1980, 1983, 1986, 1989 and 1992 from Monterey Bay or Pt Conception in the south to at least the U.S.-Canada border in the north. The sablefish biomass measured in the area between Monterey Bay and the U.S.-Canada border has ranged from 27,924 mt in 1986 to 57,159 mt in 1992 (Table 7). The high biomass in 1992 was dominated by fish in the 44-49 cm size range (approximately age 2-3) which were most abundant in the southern portion of the Columbia area. These biomass estimates and associated size compositions are input to the model as an index of trends in abundance of young sablefish. The model will use information in the size compositions to estimate the degree to which selectivity to this survey declines with increasing age.

The sablefish size mode near 38 cm allows extraction of an age 1 index (defined as the 32-41 cm size range). This index was at its lowest level in 1992 (Table 8). The model's selectivity pattern for this index is fixed at 1.0 for age 1 and for all sizes.

The biomass from the shelf survey and the age 1 index are input to the model as relative indexes with no specified Q. If the model results in Q estimates that are greater than 1.0, this may simply mean that the natural mortality (plus unmeasured fishery discard mortality) for age 1 and 2 sablefish is greater than the assumed constant level of 0.07 for all ages.

BIOLOGICAL FACTORS

Growth

Estimates of the maximum size of sablefish have declined as more size-at-age data have become available. In the 1988 assessment, the growth curve was based on some biased age data from the 1983 and 1985 pot surveys. In that assessment, the estimated mean maximum size was 77.5 cm for females and 64.5 cm for males. Subsequent assessments had some decline in the estimated maximum size, but none of these assessments directly incorporated the size-at-age data and none had size-at-age data from the surveys. Both pot and trawl surveys now indicate that mean size-at-age is much less than the level estimated in these past assessments. These survey and fishery size-at-age data are included in the model and the distribution of size-at-age is modeled as a lognormal distribution (Parma and Deriso, 1990) rather than a normal distribution.

The growth model is:

$$L = L_\infty + (L_1 - L_\infty) * e^{(K*(1.66-A))}$$

Typical parameter values were:

L_1 38.4 cm (both sexes in August at age 1.66 years)
L_∞ 63.8 cm (female) and 55.4 cm (male)
K 0.274 (female) and 0.331 (male)
standard deviation of size at age 1 - 2.03 (both sexes at age 1.0 in January)
standard deviation of size at age 25 - 9.07 (female) and 5.49 (male)

where the standard deviation of size at age is assumed to increase linearly with mean size.

Natural Mortality

The estimate of natural mortality has declined since the first use of Synthesis for sablefish in 1988. In that first assessment, it was noted that the observed maximum age suggested that M was 0.08. However, a M of 0.15 was used in the assessment because it provided a better fit to the data, and it was rationalized on the basis of emigration to deep water or to the north. A similar rationale will be used at the end of this assessment. In the 1989 assessment, changes in the model and addition of another year of fishery data caused the model to have its best fit to the fishery data at the lowest level of M (0.05). No usable survey age composition data were available at that time. Final results in that year were obtained from a M of 0.0875 which was midway between two levels (0.075 and 0.100) that provided reasonable fits to some of the survey data. This same level of M was used in the 1990 assessment, although the maximum age of sablefish continued to suggest a lower value.

The estimate of M was reconsidered in the 1992 assessment because of the availability of more survey age composition data and with the evidence that the oldest sablefish reside in deep water. The maximum ages observed in the 1983, 1986, and 1989 pot surveys and the 1989 slope surveys were 51 years for females and 64 for males. (Note: a female sablefish from the Aleutian Islands was recently aged at greater than 90 years (D. Anderl, pers. comm). According to Hoenig (1983) the average relationship between maximum observed age and total mortality rate is:

$$\ln(Z) = 1.44 - 0.982 * \ln(T_m).$$

The maximum observed ages then imply that Z is about 0.09 for females and 0.07 for males. These values for estimated Z probably are intermediate between M and true Z. The long history of sablefish exploitation suggest that they may be close to true Z. On the other hand, the oldest sablefish found in deep water off the coasts of California, Oregon and Washington may have experienced little fishing mortality until recently. The level of natural mortality used in the 1992 and 1994 assessments was 0.07.

Maturity and Body Weight

Percentage mature is assumed to follow a logistic function of length. The length at 50% mature was estimated by McDevitt (1987) from data in Phillips and Inamura (1954) to be approximately 67 cm. Mason et al. (1983) estimated, from data collected off Vancouver Island in 1980, that the size at 50% mature was 58.3 cm. Parks and Shaw (1983) estimated the value to be 56.3 cm off California. Here the value of 55.3 cm estimated by Parks and Shaw (1987) for Oregon and Washington is used:

$$M = 1.0 / [1.0 + e^{(-.2491*(L-55.3))}].$$

The length-weight relationship used here is taken from data collected on all of the pot surveys. There is no apparent difference in the relationship between males and females (Phillips and Inamura, 1954; Fujuwara and Hankin, 1988; Klein, 1986).

$$W(kg) = .0000024419*L(cm)^{3.346942}$$

ASSESSMENT MODEL

Selectivity

The depth specific pattern in age composition reinforces the decision to restrict the pot index to the depths 225-450 fathoms. However, the pattern forces reconsideration of a fundamental assumption of the 1988-1990 sablefish assessments; availability to each fishery and to each type of survey is a function only of size. It is more accurate to model the availability of small/young sablefish as a function of size, and to model the availability of large/old sablefish as a function of size and/or age. The following assumptions are made:

a. Selectivity for small/young sablefish in all fisheries and surveys is a function only of size and is the same for both sexes;

b. Longline fishery selectivity for large/old sablefish is a function only of age, because the fishery will tend to target on larger sablefish but will not encounter old, deep-living sablefish in proportion to their abundance.

c. Trawl and pot fishery selectivity for large/old sablefish is a function of both size and age because the trawl fishery has reduced effort in deep water and because of the general perception that trawlers are less able to capture large sablefish.

d. Selectivity for large/old sablefish in the slope trawl surveys is a function only of size. The survey covers a wide depth range (100-700 fathoms) so should encounter old sablefish in proportion to their abundance, but the small mean size-at-age observed in this survey suggests that the larger sablefish avoid the trawl.

e. Selectivity for large/old sablefish in the pot surveys is a function of size and age. The age specific component is necessary because the survey does not include samples deeper than 450 fathoms. The need for the size specific component is not obvious, however the mean size-at-age in this survey seems small relative to the historical occurrence of large sablefish. However, the model estimates little size-specific decline in selectivity.

In past applications of Synthesis to sablefish, selectivity for each type of sample has been assumed constant over time. This year's detailed examination of a longer time series of size and age composition data identified some obvious and logical deviations from this assumption:

a. In 1988 the percentage old sablefish in the pot fishery increased. This is in accord with anecdotal reports of movement of this fishery into deeper water.

b. The percentage old sablefish in the trawl fishery has been increasing. This is in accord with movement of the trawl fishery into deeper water, where thornyheads are targeted, and perhaps with increased high-grading as the trip limits have become more restrictive.

c. The mean size observed in the historical longline fishery was about 72 cm. This is about 10 cm greater than the mean size observed today and about 8 cm greater than the mean asymptotic size for females. The model can explain some of this shift by fishing down, but a shift in selectivity (i.e. reduced high-grading) is also necessary.

d. The pot survey began collecting a higher percentage of fish less than about 44 cm beginning in 1983. The early surveys with rectangular traps used a larger mesh size than the later surveys with conical traps.

The selectivity parameters (Table 9) are used to define size and age-specific logistic functions. Males and females share the same ascending size-specific function defined by three parameters:

a. selectivity at 32 cm
b. size at inflection
c. slope at inflection.

The declining, age-specific selectivities require three parameters for each sex:

a. age at inflection
b. slope at inflection.
c. selectivity at 25 years of age (with value for males defined relative to the value for females)

The declining, size-specific selectivity requires three parameters (same for each sex):

a. size at inflection
b. slope at inflection.
c. relative selectivity at 90 cm

Model Results

There are several important sources of information to be reconciled in this assessment. Most important are the four-fold decrease in the pot survey during the 1980s, the measured biomass of 61,409 mt in the slope trawl surveys of the early 1990s (51,000 mt for the Van-Mon area), and the lack of trend in young fish observed in the shelf trawl surveys. Also important are the size-at-age data that indicate that few sablefish grow as large as the sablefish commonly harvested off this coast during the past several decades. The age composition data are important for indicating that natural mortality is low, and for identifying that older sablefish are found in deep water. Trends in fishery size and age data provide little information on population trends because the selectivity patterns of the fisheries are allowed to change over time.

In one configuration of the synthesis model, the catchability coefficient for the slope trawl survey was fixed at a specified value in the range 0.6 to 2.2 (upper third of Table 10). The model was allowed to estimate a population that would attempt to match the observed slope survey biomass (61,409 mt), given the specified Q value. The emphasis on fitting the slope survey biomass was set at a high (10) level, while most other emphasis levels were set at a nominal level of 1.0. The emphasis for the slope trawl survey age composition was set at 0.01 because of the gap in sampling in 1989, and the emphasis for the slope survey size-at-age was set at 0.1.

At low levels of Q (i.e. slope survey underestimates absolute abundance) the model achieves its best fit to the trend in the shelf survey age 1 numbers and the shelf survey biomass and its worst fit to the trends in the pot survey, especially the medium and large fish in the pot survey. The fit to most of the fishery data was improved as Q increased to about 1.2, although a modified scheme of changing selectivity over time probably could alter this pattern. The fit to the BIGPOT survey continued to increase slightly as Q reached levels of 2.2, but never reduced all pattern in the residuals. This dichotomy in fit to the trawl and pot surveys is essentially identical to the result obtained two years ago.

In a second configuration of the model, the catchability coefficient for the slope trawl survey was estimated by the model. In this configuration the model was profiled through a range of values for the parameter that defined the virgin recruitment level (middle third of Table 10, Figure 11). In a comparison to the first configuration, low survey Q values correspond to high estimates of ending biomass which tend to correspond to high estimates of virgin recruitment. In this second configuration, the emphasis on all survey components was increased to 10. The emphasis on the slope survey biomass becomes irrelevant because the model matches the biomass level exactly by estimating the arbitrary scaling factor, Q. In this second configuration, the emphasis on the slope survey size composition was reduced to 0.1 because these individual size composition observations from short sections of the coast may not fully represent the size composition for the entire area. This model fits all survey data reasonably well (Figure 12) and, as in the first configuration, the best model fits tend to occur at low biomass, high Q levels. At higher levels of initial abundance, this scenario tends to boast recruitments during the early 1970s (Figure 13), presumably in order to steepen the population decline during the 1980s and achieve a better fit to the pot survey.

The calculated Q for the shelf trawl survey tends to be about 1.8 for both the age 1 index and the biomass in this survey. While this value seems to indicate that the shelf trawl survey overestimates the abundance of young sablefish, an alternative explanation is simply that these young fish have a higher natural mortality than do the older sablefish. If the shelf survey is forced to have a Q no greater than 1.0, then the model can achieve a comparably good fit by estimating that age 1 natural mortality is about 0.3, declining linearly to about 0.2 at age 2, and 0.07 (fixed) for ages 3 and older.

The third configuration of the model is essentially the same as the second configuration, except the emphasis on the pot surveys is reduced to a nil level (0.001). With no constraint provided by the trend in the pot survey and with the slope survey Q allowed to have any value, the fit to all other components is essentially flat (range of 312 to 320 in total log(likelihood)) even though the estimated ending biomass ranges from 80,000 to 371,000 mt (Table 10, bottom third). Clearly the model requires some estimate of population trend or absolute biomass in order to provide a specific result. The model estimates reasonable patterns of size and age selectivity (Table 11, Figure 14 from run with virgin recruitment at 11,972 thousand fish). Figure 15 displays the interplay between size and age selectivity for the trawl fishery. At young ages there is high selectivity, presumably because there is proportionally more fishing effort in shallow water, but because of the size selectivity, only the largest of the young fish are selected. The model provides a good fit to the size and age composition data (Figures 16-27). The estimated population levels (Table 12, Figure 28) do not decline as steeply as the second configuration model that retains emphasis on the pot survey. The high abundance of young sablefish in the 1992 shelf trawl survey has resulted in an estimate of the 1990 yearclass that is similar in magnitude to the large 1977 and 1979 yearclasses. Note, however, that the size composition for this 1992 survey is not fit well; it seems to indicate that most of the biomass is in the 46-48 cm size range (3 year old), but other size and age data are inconsistent with a strong 1989 yearclass.

Exploratory Migration Model

The fundamental shortcoming of the above model configurations is that they assume a "well mixed unit-stock". However, all available information indicates consistent, depth-related patterns in the stock's distribution. The pot survey, slope trawl survey, and shelf trawl survey have a consistent pattern with depth and time: little or no decline in shallow water where new recruits dominate, little decline in deep water (>500 fathoms) where fishing has been light and old fish dominate, and steep decline in 200-500 fathoms where middle-aged fish are most subject to fishing mortality. Although the pot survey is modeled with declining availability for older ages, the survey is assumed to be a measure of age/size specific abundance that is proportional to the entire age/size specific stock. Thus, the observed decline is occurring only in the shallow (<500 fathom) zone, but the model's potential for decline is buffered by including all the older fish, some of which are actually in deep water and out of the range of the survey and most of the fishery. Potential reconciliation of the decline in the pot survey with the level of biomass measured in the trawl survey seems to require explicit modeling of this phenomenon.

The age-specific version of the synthesis model allows for definition of areas and explicit, age-specific migration between areas. Unfortunately, this version of synthesis is not size-structured so many of the details of the current analysis cannot be accomodated. An exploratory migratory analysis was configured by splitting the sablefish data at 500 fathoms. The shelf trawl survey is unaffected. The standard pot survey is also unaffected because it used data only from 225-450 fathoms. The BIGPOT survey could not be defined because it is a size-based subset of the standard pot survey. The slope survey was split into two portions with 43,000 mt in the shallow zone and 18,000 mt in the deep zone (size and age composition data were also split). The longline fishery was assumed to occur entirely within the shallow zone. No logbook data are available to define the changing depth distribution of the pot fishery. It was arbitrarily split 50:50 between shallow and deep beginning in 1988, and no size or age composition were included. Logbook data from California were used to define the percentage of the trawl catch that occurred in the deep zone (2% in 1978 increasing to near 20% by 1988). The trawl and pot deep catches were combined and it was assumed that the entire deepwater portion of the stock was available to this fishery. This deepwater catch was as high as 2,000 mt in 1988-89 and about 1,300 mt since 1992. Size and age composition data from the fisheries were completely de-emphasized in this model; fishery selectivity patterns were assumed to be asymptotic with age and constant over time. The results of this model include an estimate of the migration rate from the shallow zone to the deep zone. Beginning at about age 4, about 3% (per age, per year) of the fish are estimated to move from the shallow zone to the deep zone. This results in about 30% of the current biomass estimated to be in the deep zone, in accord with the biomass distribution in the slope trawl surveys. Fish in the shallow zone are estimated to experience a steeper decline than fish in the deep zone, but this is difficult to compare to the BIGPOT survey which is defined in terms of a size range. The lesson from this model is that only a low rate of emigration (3% per year per age) is necessary to account for the observed proportion of the stock occurring in deep water.

The knowledge gained from the age-structured, migration model can be applied to the size-structured model by treating emigration as an extra component of natural mortality. Data for the size model were reconstructed to exclude information from deeper than 500 fathoms. Unfortunately, the fishery size and age data could not be explicitly reconfigured in this manner because most samples have no depth information and some samples indicate that a wide range of depths were fished on the trip. This model was run at three levels of natural mortality: 0.07, 0.10, and 0.12. The higher levels of natural mortality are intended to incorporate potential levels of emigration to deep water, although this model cannot accumulate these fish in another area, they are simply lost to the system. As the natural mortality is increased, this model achieves better fits to the decline in the BIGPOT survey at lower levels of Q for the slope survey (Figure 29). The best Q is 2.00 {1.66 relative to 51,000 mt survey biomass} when M is 0.07, 1.66 {1.38} when M is 0.10, and 1.19 {.99} when M is 0.12. In these models with higher M, the fit to all likelihood components other than the BIGPOT, is best when slope Q is near 1.0. The lesson from this model with data from only the shallow area is that the decline in the pot survey is not inconsistent with a slope survey Q near 1.0. This model narrows the range between the optimistic and the pessimistic assessment scenario. The pessimistic scenario moves from a slope Q approaching 2.0 in the non-migratory model (in order to reduce the biomass and get a good fit to the declining BIGPOT survey) to a slope Q that is near 1.0 in the migratory model. Simultaneously matching the BIGPOT survey decline and the slope survey biomass requires a model that explicitly accounts for the emigration to deep water.

POTENTIAL YIELD FOR 1995

With the knowledge gained from the migratory and the enhanced mortality models above, we return to the original, size-structured, entire depth zone model to estimate potential yield. The results are taken from the third configuration in which there was nil emphasis on the pot survey, but the range of reasonable slope survey Q values is guided by the fit to the BIGPOT survey in the high mortality configuration. These calculations are presented for three scenarios in Figures 30-32. In each figure:

a. The upper bold curve is the relationship between yield and female spawning biomass with constant recruitment at the fixed virgin level. Yield in this curve is equal to landed catch plus discard.

b. The lower bold curve is similar to the upper curve except that Beverton-Holt recruitment curve applies and recruitment is assumed to decline by 10% when female spawning biomass declines by half (A=0.889).

c. The lower jagged trajectory is the time series of landed catch plotted against estimated female spawning biomass; the upper trajectory includes trawl discard. The last (leftmost) point on the trajectories is 1994.

d. The rightmost point on the trajectory is the estimated virgin stock and the second point is the equilibrium state in 1971.

e. The rays from the origin represent constant exploitation rates corresonding to $F_{0.1}$, $F_{20\%}$ (overfishing), and $F_{35\%}$ (target). Where $F_{35\%}$ is the fishing mortality that would reduce female spawning biomass per recruit to 35% of its unfished level.

f. The lower left panel shows the scatterplot of recruitment vs. female spawning biomass. The bold line shows the expected relationship under the fixed level of virgin recruitment and the assumed degree of density-dependence.

g. The lower right panel shows a 200 year simulation that starts from the estimated population age composition at the beginning of 1995, proceeds with five years of recruitment at the average level, then continues with recruitments randomly drawn from the set of estimated values. Thus, the five years labelled "FORECAST" near the top of the page are the first five points in the 200 year simulation.

A conservative model scenario (Figure 30) is taken from the run with nil emphasis on the pot survey and virgin recruitment set at 10,775 thousand fish, which implies a slope Q of 1.13 {0.97 for Mon-Van} for small sablefish. Estimated size-selectivity patterns indicate that medium and large sablefish have a Q that is only 30% of this level. This model provides a reasonable fit to the trend of the pot survey if migration to deep water is accounted for. This scenario indicates that harvests during 1986-1992 were nearly at the overfishing level, and that spawning biomass during 1990-1993 was nearly stable at a level below the target. The annual catch plus discard at $F_{35\%}$ should decline to 6,144 mt during 1995-1998, and MSY may be 7,221 mt. This scenario represents a substantial narrowing of the range in the sablefish potential yield calculations. In the previous assessment (Methot, 1992) the migration model was not explored, and the pessimistic scenario suggested a short-term potential yield of only 3,050 mt.

An optimistic scenario (Figure 31) is taken from the run with nil emphasis on the pot survey and virgin recruitment set at 13,169 thousand fish, which implies a slope Q of 0.64 {0.53 for Mon-Van}. Slope survey Q values that are this low do not fit well in the high mortality, shallow data configuration (Figure 29). This scenario indicates that fishing mortality over the past eight years has been close to the target level of $F_{35\%}$ (7.5% exploitation rate on the age 2+ biomass) and that the female spawning biomass recently increased to slightly above its long-term target level. Under this scenario, the annual landed catch plus discard could increase to 10,975 mt during 1995-1998, and MSY may be 8,534 mt. This long-term projection is similar to that in the optimistic scenario calculated in 1992 and essentially identical to current harvest levels, however the short-term projections are boosted due to the estimated large 1990 yearclass. Although increased sablefish abundance is in accord with the 1992 shelf trawl survey and anecdotal reports from the fishery, it is not indicated in any of the fishery size composition data or in the 1992-1993 slope surveys. Thus, an increased ABC on the basis of this scenario seems risky.

Under an intermediate scenario (Figure 32) with virgin recruitment set to 11,972 thousand fish and calculated slope Q=0.82 {0.68 for Mon-Van}, the annual landed catch plus discard could be 8,557 mt during 1995-1998, and MSY may be 7,839 mt. This scenario is documented in Table 12 and is recommended as the basis for management in 1995-1998.

ACKNOWLEDGEMENTS

This assessment is made possible only through the collective efforts of scientists, technicians, and fishermen too numerous to identify. Surveys were conducted by the RACE division of the Alaska Fisheries Science Center. Otolith ageing was done by the Age & Growth task of the AFSC and by the Tiburon laboratory of the Southwest Fisheries Science Center. The port sampling program was coordinated through the Tiburon laboratory. Biological samples from the fishery were collected by Washington Department of Fisheries, Oregon Department of Fish and Wildlife and California Department of Fish and Game. Fishery catch statistics were provided through the Pacific States Marine Fisheries Commission's PacFIN database.

LITERATURE CITED

Butler, J.L. C.A. Kimbrell, W.C. Flerx, and R.D. Methot. 1989. The 1987-88 demersal fish surveys off central California (34° 30'N to 36° 30'N). NOAA Tech. Memo. 133: 44p.

Fujiwara, S. and D.G. Hankin. 1988. Aging discrepancy related to asymmetrical otolith growth for sablefish Anoplopoma fimbria in northern California. Nippon Suisan Gakkaishi 54: 27-31.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. (U.S.) 82: 898-903.

Klein, S.J. 1986. Selectivity of trawl, trap, longline and set-net gears to sablefish, (Anoplopoma fimbria). NWAFC Processed Rep. 86-06, 84 p.

Lynde, M.V.H. 1986. The historical annotated landings (HAL) database: documentation of annual harvest of groundfish from the northeast Pacific and Eastern Bering Sea from 1956 to 1980. U.S. Dep. Comm., NOAA Tech. Memo. NMFS F/NWC-103. 197 p.

Mason, J.E., R.J. Beamish, and G.A. McFarlane. 1983. Sexual maturity, fecundity, spawning, and early life history of sablefish (Anoplopoma fimbria) off the Pacific coast of Canada. Can. J. Fish. Aquat. Sci. 40: 2126-2134.

McDevitt, S.A. 1987. The status of the sablefish resource in waters off the U.S. west coast. appendix B In: Status of the Pacific coast groundfish fishery through 1987 and recommended acceptable biological catches for 1988. Pac. Fish. Manage. Council, Portland, OR 97201.

McFarlane, G. A. and R.J. Beamish. 1983a. Preliminary observations on the juvenile biology of sablefish (Anoplopoma fimbria) off the west coast of Canada. P. 119-136. In: Proceedings of the International Sablefish Symposium. Alaska Sea Grant Rep. 83-3.

McFarlane, G. A. and R.J. Beamish. 1983b. Biology of adult sablefish (Anoplopoma fimbria) in waters off western Canada. P. 59-80. In: Proceedings of the International Sablefish Symposium. Alaska Sea Grant Rep. 83-3.

Methot, R. D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. INPFC Bull. 50: 259-277.

Methot, R. D. 1992. Assessment of the west coast sablefish stock in 1992. In Status of the Pacific coast groundfish fishery through 1992 and recommended acceptable biological catches for 1993. Pacific Fishery Management Council, Portland, Oregon.

Methot, R. D. and J. Hightower. 1988. Status of the Washington-Oregon-California sablefish stock in 1988. In Status of the Pacific coast groundfish fishery through 1988 and recommended acceptable biological catches for 1989. Pacific Fishery Management Council, Portland, Oregon.

Methot, R. D. and J. Hightower. 1989. Status of the Washington-Oregon-California sablefish stock in 1989. In Status of the Pacific coast groundfish fishery through 1989 and recommended acceptable biological catches for 1990. Pacific Fishery Management Council, Portland, Oregon.

Methot, R. D. and J. Hightower. 1990. Status of the Washington-Oregon-California sablefish stock in 1990. In Status of the Pacific coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991. Pacific Fishery Management Council, Portland, Oregon.

Parks, N. B., and F. R. Shaw. 1987. Changes in relative abundance and size composition of sablefish in coastal waters of Washington and Oregon, 1979-1985. NOAA Technical Memorandum NMFS F/NWC-124.

Parks, N. B., and F. R. Shaw. 1989. Relative abundance and size composition of sablefish (Anoplopoma fimbria) in the coastal waters of California and southern Oregon, 1984-1988. NOAA Technical Memorandum NMFS F/NWC-167.

Parks, N. B., and F. R. Shaw. 1990. Changes in relative abundance and size composition of sablefish in coastal waters of Washington and Oregon, 1979-1989. NOAA Technical Memorandum NMFS F/NWC-188.

Phillips, J. B. 1954. The Sablefish fishery of California. I. History and research. Pac. Marine Fish. Comm. Bull. 3: 6-22.

Phillips, J.B. and S. Imamura. 1954. The sablefish fishery of California. Pac. Mar. Fish. Comm. Bull. 3: 5-38.

Pikitch, E. K., D. L. Erickson, and J. R. Wallace. 1988. An evaluation of the effectiveness of trip limits as a management tool. NWAFC Processed Report 88-27.

Raymore, P. A. and K. L. Weinberg. 1990. The 1984 Pacific west coat upper continental slope surveys of spring and autumn groundfish resources. NOAA Tech. Memo. NMFS F/NWC-179.

Weinberg, K.L., M.E. Wilkins, and T.A. Dark. 1984. The 1983 Pacific west coast bottom trawl survey of groundfish resources: Estimates of distribution, abundance, length and age composition. NOAA Tech. Memo. NMFS F/NWC-70. 106 p.

Zimmermann, M. M.E. Wilkins, R.R. Lauth, and K.L. Weinberg. in prep. The 1992 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, and length composition. NOAA Tech. Memo. AFSC-131: 111 p. + appendices.

Table 1. Sablefish landed catch off coasts of Washington, Oregon, and California.

AREA:	VAN-COL			EUR-MON			CON		
GEAR:	HKL	POT	TWL	HKL	POT	TWL	HKL	POT	TWL
YEAR									
1935-52	1047	0	313						
1956-70	1196		475	490		839	3		69
56	748		1578	383		884	0	0	19
57	1629		347	423		557	0	0	10
58	712		313	144		634	0	0	1
59	1291		507	108		760	0	0	6
60	1851		545	130		954	0	0	11
61	997		335	145		942	0	0	119
62	954		1028	156		818	0	0	101
63	873		308	67		726	0	0	167
64	959		197	469		738	0	0	198
65	632		168	530		1058	0	0	147
66	282		185	717		367	0	0	139
67	1611		158	1963		715	0	0	60
68	972		170	947		831	32	0	15
69	3033		191	1167		1288	0	0	26
70	1397	114	1099	0	0	1312	7	0	11
71	914	120	1096	598	73	1355	0	0	80
72	2137	1	1124	1360	353	2309	3	3	29
73	876	413	526	246	440	3260	4	25	14
74	2266	389	462	176	2854	2563	2	1	22
75	1737	5280	464	0	416	2849	0	0	79
76	1149	7803	609	76	9165	2845	0	2772	100
77	1445	552	1164	0	2518	2450	0	1070	51
78	1641	591	1752	75	2720	4182	6	2599	52
79	3596	4299	2582	641	3302	4889	1	4971	92
80	1097	2381	1546	298	595	2346	45	801	37
81	1225	1573	1945	720	1851	3688	4	502	46
82	1079	2943	4748	571	2729	5575	1	906	39
83	776	2278	3911	250	1560	3410	413	1839	84
84	1034	2506	4888	64	518	3996	0	945	125
85	2478	2420	3377	491	1346	3739	1	4	441
86	2737	1447	2489	1043	834	4086	20	10	515
87	3218	1479	3219	939	488	2991	14	58	357
88	2784	1381	2698	415	662	2595	17	3	287
89	2139	1059	2749	359	900	2619	77	1	358
90	1553	874	2565	564	673	2390	91	8	315
91	2434	642	2615	895	329	2140	89	102	206
92	1971	363	2807	1035	223	2337	88	154	294
93	1739	617	2843	578	174	1772	76	55	263

Table 2a. Reported catch by grade (Large, Medium, Small, eXtra small, and Unspecified) in California.

		ALL CONDITIONS					
YR	GEAR	L	M	S	X	U	ALL
84	HKL	9	8	6		2	25
85	HKL	98	92	121		7	318
86	HKL	250	223	209		14	696
87	HKL	244	224	347		47	862
88	HKL	67	77	196		52	392
89	HKL	23	27	151		163	364
90	HKL	60	88	128		233	509
91	HKL	67	198	231		247	743
92	HKL	102	130	347		95	674
93	HKL	49	61	148		109	367
84	POT	3	0	37		947	987
85	POT	33	59	282		475	849
86	POT	21	46	233		355	655
87	POT	20	31	119		158	328
88	POT	25	42	130		412	609
89	POT	14	28	131		695	868
90	POT	19	33	108		428	588
91	POT	18	28	77		225	347
92	POT	6	7	47		110	170
93	POT	10	8	104		11	133
84	TWL	68	85	1578		1176	2907
85	TWL	92	56	1987		1448	3583
86	TWL	143	193	2148		846	3330
87	TWL	94	161	1598		1226	3079
88	TWL	71	128	1221		1029	2449
89	TWL	78	124	1216		1152	2570
90	TWL	100	220	1289		595	2204
91	TWL	128	310	1508		145	2090
92	TWL	117	272	1648		57	2094
93	TWL	116	233	1106		25	1480

Table 2b. Reported catch by grade (Large, Medium, Small, eXtra small, and Unspecified) and Condition (Round, Dressed) in Oregon.

		ROUND						DRESSED					
YR	GEAR	L	M	S	X	U	ALL	L	M	S	X	U	ALL
83	HKL	157	121	150	0	37	465	41	40	4	1	1	87
84	HKL	108	57	41	0	15	221	4	1	0	0	1	6
85	HKL	153	122	123	4	29	431	16	16	22	6	23	83
86	HKL	252	246	295	20	36	849	41	57	44	23	68	233
87	HKL	265	269	326	6	21	887	5	18	44	45	0	112
88	HKL	141	175	237	6	23	582	3	9	44	57	13	126
89	HKL	105	96	92	6	55	354	1	3	26	36	5	71
90	HKL	109	74	92	18	2	295	4	11	38	44	4	101
91	HKL	81	99	156	53	1	389	7	30	112	187	10	346
92	HKL	114	121	163	77	0	475	36	59	156	173	0	424
93	HKL	59	84	142	62	0	347	20	40	108	143	1	312
83	POT	315	258	667	40	35	1315	1	2	0	0	0	3
84	POT	167	238	610	0	37	1052	0	0	0	0	777	777
85	POT	286	347	731	129	56	1549	0	0	1	0	349	350
86	POT	215	330	581	68	6	1200	18	43	111	45	5	222
87	POT	233	297	481	2	175	1188	4	23	81	55	339	502
88	POT	147	219	313	16	223	918	0	0	0	0	282	282
89	POT	145	268	446	35	1	895	0	0	0	0	1	1
90	POT	103	218	451	10	0	782	0	0	0	0	0	0
91	POT	68	165	325	28	0	586	5	14	50	57	1	127
92	POT	41	73	130	20	0	264	3	14	41	72	0	130
93	POT	53	85	207	39	0	384	5	19	68	173	0	265
83	TWL	202	46	1678	11	768	2705	18	8	3	0	16	45
84	TWL	136	23	1926	58	613	2756	9	5	0	0	1	15
85	TWL	147	40	100	109	2445	2841	1	0	0	0	0	1
86	TWL	159	67	160	12	1723	2121	0	1	0	0	0	1
87	TWL	122	135	1099	21	1141	2518	1	1	0	0	0	2
88	TWL	127	141	1184	59	625	2136	3	2	2	0	4	11
89	TWL	191	241	974	439	740	2585	4	2	1	0	12	19
90	TWL	197	310	1108	488	416	2519	0	0	0	0	0	0
91	TWL	322	401	1039	335	335	2432	1	1	0	0	1	3
92	TWL	237	293	1398	280	149	2357	6	13	6	39	35	99
93	TWL	220	266	770	740	6	2002	8	42	35	119	206	410

Table 2c. Reported catch by grade (Large, Medium, Small, eXtra small, and Unspecified) and Condition (Round, Dressed) in Washington.

		ROUND						DRESSED					
YR	GEAR	L	M	S	X	U	ALL	L	M	S	X	U	ALL
81	HKL	144	39	18		0	201	215	15	30		48	308
82	HKL	9	6	7		2	24	217	80	98		0	395
83	HKL	14	4	4		0	22	206	73	54		0	333
84	HKL	97	33	6		4	140	371	111	149		2	633
85	HKL	129	105	170		0	404	298	218	1005		0	1521
86	HKL	56	38	165		1	260	365	132	1011		30	1538
87	HKL	19	18	28		0	65	225	330	1669		0	2224
88	HKL	0	0	3		0	3	135	207	1733		0	2075
89	HKL	0	1	4		0	5	90	190	1388		101	1769
90	HKL	0	0	3		0	3	44	172	1044		0	1260
91	HKL	0	0	1		2	3	30	225	1648		0	1904
92	HKL	0	0	3			3	23	163	853		0	1039
93	HKL	3		10		0	13	31	111	724		0	866
81	POT	560	250	371		28	1209	32	37	0		0	69
82	POT	589	349	642		0	1580	12	7	20		0	39
83	POT	493	422	481		1	1397	25	0	51		0	76
84	POT	269	318	363		4	954	20	24	10		0	54
85	POT	87	100	246		27	460	98	0	331		0	429
86	POT	0	0	0		0	0	2	6	30		1	39
87	POT	0	0	0		0	0	0	0	0		0	0
88	POT	4	19	157		0	180	0	0	0		0	0
89	POT	3	11	149		0	163	0	0	0		0	0
90	POT	2	7	55		0	64	0	3	36		0	39
91	POT	0	0	0		0	0	0	0	0		0	0
81	TWL	64	3	394		6	467	68	11	22		0	101
82	TWL	105	131	1345		37	1618	21	32	46		0	99
83	TWL	95	85	985		43	1208	10	9	73		0	92
84	TWL	533	30	1624		31	2218	16	5	10		0	31
85	TWL	111	40	550		2	703	9	8	27		0	44
86	TWL	41	20	434		11	506	15	1	34		0	50
87	TWL	33	75	673		0	781	9	1	40		0	50
88	TWL	39	26	484		0	549	21	9	97		0	127
89	TWL	40	51	339		0	430	7	8	30		0	45
90	TWL	35	47	232		1	315	8	5	21		0	34
91	TWL	49	46	205		0	301	6	8	12		0	25
92	TWL	36	36	254		0	326	6	13	39	35	6	99
93	TWL	21	28	181		1	231	8	42	119	206	35	410

Table 3. Catch rates for sablefish (numbers per pot) in the standard pot surveys. Depths are in fathoms.

Sablefish Numbers in Pot Surveys

ALL SIZES

DEPTH	79	80	81	83	84	85	86	87	88	89	91
150	6.57	10.14	2.64	2.58		4.74	1.99	1.37	4.08	1.79	2.25
225	8.98	6.65	7.89	13.87	15.18	11.71	5.96	3.02	17.54	3.46	5.19
300	14.50	8.01	4.16	17.38	14.04	10.73	6.35	3.93	12.44	3.98	3.64
375	12.37	4.12	4.91	9.84	7.80	4.96	3.76	2.41	5.76	1.70	2.81
450	14.57	5.05	4.68	4.99	6.58	4.92	2.90	3.28	4.46	1.09	0.95
525					4.13	8.00	2.63	2.84	4.79	0.89	1.27
600							2.36	1.65	3.54	0.66	1.61
225-450	12.61	5.96	5.41	11.52	10.90	8.08	4.74	3.16	10.05	2.56	3.15

LARGE

DEPTH	79	80	81	83	84	85	86	87	88	89	91
150	0.96	0.73	0.42	0.23		0.20	0.09	0.06	0.04	0.01	0.06
225	1.57	0.73	0.54	0.54	0.34	0.29	0.18	0.14	0.10	0.03	0.08
300	0.91	0.50	0.18	0.97	0.31	0.32	0.27	0.10	0.12	0.10	0.05
375	1.24	0.23	0.30	0.23	0.29	0.19	0.37	0.15	0.04	0.11	0.14
450	1.20	0.15	0.19	0.17	0.16	0.26	0.11	0.10	0.09	0.03	0.10
525					0.23	0.19	0.09	0.24	0.13	0.04	0.14
600							1.11	0.44	1.10	0.11	0.90
225-450	1.23	0.40	0.30	0.48	0.27	0.27	0.23	0.12	0.09	0.07	0.09

MEDIUM

DEPTH	79	80	81	83	84	85	86	87	88	89	91
150	1.17	0.89	0.41	0.44		0.48	0.10	0.15	0.08	0.08	0.09
225	1.73	0.75	0.59	0.81	1.11	0.50	0.55	0.25	0.45	0.11	0.23
300	1.36	0.45	0.23	1.34	0.73	0.46	0.40	0.17	0.32	0.18	0.20
375	1.04	0.29	0.31	0.33	0.59	0.24	0.44	0.18	0.20	0.15	0.26
450	1.40	0.27	0.29	0.25	0.42	0.28	0.33	0.23	0.26	0.06	0.14
525					0.62	0.55	0.39	0.37	0.47	0.08	0.29
600							0.76	0.54	1.09	0.04	0.55
225-450	1.38	0.44	0.35	0.68	0.71	0.37	0.43	0.21	0.31	0.13	0.21

% LARGE by number

DEPTH	79	80	81	83	84	85	86	87	88	89	91
150	15%	7%	16%	9%		4%	4%	4%	1%	0%	3%
225	17%	11%	7%	4%	2%	2%	3%	5%	1%	1%	2%
300	6%	6%	4%	6%	2%	3%	4%	2%	1%	3%	1%
375	10%	6%	6%	2%	4%	4%	10%	6%	1%	6%	5%
450	8%	3%	4%	3%	2%	5%	4%	3%	2%	3%	11%
525					5%	2%	4%	8%	3%	4%	11%
600							47%	26%	31%	16%	56%
225-450	10%	7%	6%	4%	3%	3%	5%	4%	1%	3%	3%

Table 4. Sablefish mean numbers per pot at 225, 300, 375, and 450 fathoms in NMFS pot surveys. The Northern area survey covers the Columbia and U.S. Vancouver area. The southern area survey covers the Eureka, Monterey, and Conception areas. In this summary, data from the two sites in the Conception area are omitted.

YEAR	AREA	N SITES	TOTAL	EXSM	52-61 cm SML	62-67 cm MED	≥68 cm LRG	MED+LRG
1979	N	4	12.61	2.90	7.10	1.38	1.23	2.61
1980	N	4	5.96	2.07	3.05	0.44	0.40	0.84
1981	N	4	5.41	2.05	2.71	0.35	0.30	0.65
1983	N	4	11.52	5.01	5.35	0.68	0.48	1.16
1984	S	7	10.90	4.97	4.94	0.71	0.27	0.99
1985	N	8	8.08	4.54	2.91	0.37	0.27	0.64
1986	S	7	4.74	1.99	2.09	0.43	0.23	0.66
1987	N	8	3.16	1.41	1.43	0.21	0.12	0.33
1988	S	7	10.05	6.35	3.31	0.31	0.09	0.40
1989	N	8	2.56	1.22	1.15	0.13	0.07	0.19
1991	S	7	3.15	1.70	1.14	0.21	0.09	0.30

EXSM in 1979-1981 reduced due to larger mesh on pots

YEAR	AREA	N SITES	TOTAL	EXSM	SML	MED	LRG	MED+LRG
83-89	N		6.33	3.04	2.71	0.35	0.23	0.58
84-91	S		7.21	3.75	2.87	0.42	0.17	0.59
83-84	N+S	15	11.21	4.99	5.15	0.70	0.38	1.07
85-86	N+S	15	6.41	3.26	2.50	0.40	0.25	0.65
87-88	N+S	15	6.60	3.88	2.37	0.26	0.10	0.36
89-91	N+S	15	2.85	1.46	1.15	0.17	0.08	0.25
83	N+Si		11.21	4.99	5.15	0.70	0.38	1.07
85	N+Si		7.95	4.01	3.21	0.47	0.26	0.73
87	N+Si		5.28	2.79	2.06	0.29	0.14	0.43
89	N+Si		4.58	2.62	1.69	0.19	0.08	0.27

N+Si interpolates the southern area survey to the year of the northern area survey, then adds the two surveys.

Table 5. Sablefish in slope trawl surveys.

BIOMASS (mt)

AREA	YR	DEPTH 100	200	300	400	500	600	TOTAL
CON+SMON	87	1367	1439	916	851	3624	2628	10825
	88	104	2090	2876	3621	3284	1433	13408
NMON	91	915	917	1966	436	2080	1719	8033
EUR	90	1431	971	3873	1492	1892	3339	12998
SCOL	84	2641	3301	2379	499	0	0	8820
	93	984	511	734	120	165	835	3349
CCOL	84	7549	5111	7119	6128	0	0	25907
	88	1015	4623	11454	2806	1310	998	22206
	89	4444	13027	6656	2375	1281	748	28531
	93	5854	1317	2185	352	246	1202	11156
NCOL	92	3511	1368	1315	1252	746	813	9005
VAN	92	1311	412	686	333	624	94	3460

NUMBERS (thousands)

AREA	YR	DEPTH 100	200	300	400	500	600	TOTAL
CON+SMON	87	2819	1331	782	579	2032	1610	9153
	88	165	1803	1910	2543	1887	785	9092
NMON	91	1014	708	1209	276	1054	703	4964
EUR	90	2322	681	2481	900	984	1341	8709
SCOL	84	1813	2331	1437	293	0	0	5874
	93	857	372	493	97	101	374	2293
CCOL	84	4974	2832	4672	4217	0	0	16696
	88	1100	4334	7724	1612	716	425	15911
	89	3538	12220	3992	1643	764	396	22553
	93	5543	600	1441	231	152	579	8547
NCOL	92	4299	1301	844	877	436	379	8136
VAN	92	1081	342	403	225	346	32	2429

AREA	Degrees latitude
CON+SMON	34.50 - 38.00
NMON	38.00 - 40.50
EUR	40.50 - 43.00
SCOL	43.00 - 44.11
CCOL	44.11 - 45.38
NCOL	45.38 - 47.30
VAN	47.30 - 48.50

Table 6. Sablefish in slope trawl surveys: density and mean body wt.

DENSITY (mt/sq.n.mi.)

AREA	YR	DEPTH 100	200	300	400	500	600	MEAN
CON+SMON	87	2.5	1.6	0.9	1.2	4.4	4.0	2.3
	88	0.2	2.3	2.9	5.1	4.0	2.2	2.9
NMON	91	3.7	3.9	6.8	1.4	5.8	4.5	4.4
EUR	90	4.6	3.0	8.0	3.0	3.3	8.2	5.0
SCOL	84	8.6	15.1	13.0	4.0			10.6
	93	3.2	2.3	4.0	1.0	1.1	5.1	2.9
CCOL	84	15.7	8.4	26.0	27.5			16.3
	88	2.1	7.6	41.8	12.6	7.4	4.6	11.2
	89	9.2	21.4	24.3	10.7	7.2	3.5	14.4
	93	12.1	2.2	8.0	1.6	1.4	5.6	5.6
NCOL	92	9.1	5.2	4.3	3.7	2.1	2.6	4.6
VAN	92	3.8	3.4	4.5	1.9	3.2	0.6	3.0

MEAN BODY WT. (kg)

AREA	YR	DEPTH 100	200	300	400	500	600	MEAN
CON+SMON	87	0.48	1.08	1.17	1.47	1.78	1.63	1.18
	88	0.63	1.16	1.51	1.42	1.74	1.83	1.47
NMON	91	0.90	1.30	1.63	1.58	1.97	2.44	1.62
EUR	90	0.62	1.43	1.56	1.66	1.92	2.49	1.49
SCOL	84	1.46	1.42	1.66	1.70			1.50
	93	1.15	1.38	1.49	1.24	1.63	2.23	1.46
CCOL	84	1.52	1.80	1.52	1.45			1.55
	88	0.92	1.07	1.48	1.74	1.83	2.35	1.40
	89	1.26	1.07	1.67	1.45	1.68	1.89	1.27
	93	1.06	2.20	1.52	1.52	1.62	2.07	1.31
NCOL	92	0.82	1.05	1.56	1.43	1.71	2.15	1.11
VAN	92	1.21	1.21	1.70	1.48	1.80	2.96	1.42

AREA	Degrees latitude
CON+SMON	34.50 - 38.00
NMON	38.00 - 40.50
EUR	40.50 - 43.00
SCOL	43.00 - 44.11
CCOL	44.11 - 45.38
NCOL	45.38 - 47.30
VAN	47.30 - 48.50

Table 7. Results of the shelf trawl surveys. Comparable strata from the slope trawl survey are also shown.

Sablefish Biomass on Continental Shelf

30-100 fathoms

YR	CON	SMON	NMON	EUR	COL	VAN	Total
77*		389	389	548	3513	848	5687
80			15815	8324	9470	1711	35320
83			1475	832	16647	431	19385
86			9515	4211	6269	1740	21735
89	92	50	15505	354	10609	2261	28871
92	6	31	668	44	10783	6646	18178
Mean	50	157	7227	2386	9549	2273	21640

* only sampled 50-100 fathoms

101-200 fathoms

YR	CON	SMON	NMON	EUR	COL	VAN	Total
77		623	623	117	3605	1667	6635
80			366	347	4988	731	6432
83			1963	1571	6723	914	11171
86			948	693	3675	873	6189
89	291	155	792	3475	4111	771	9595
92	53	16	429	1130	36539	814	38981
90 slope				1431			
92 slope						1311	
92-93 slope					8549		
Mean	175	265	840	1252	9447	1012	

30-200 fathoms

YR	CON	SMON	NMON	EUR	COL	VAN	Total
77*		1012	1012	665	7118	2515	12322
80			16181	8671	14458	2442	41752
83			3438	2403	23370	1345	30556
86			10463	4904	9944	2613	27924
89	383	205	16297	3829	14720	3032	38466
92	59	47	1097	1174	47322	7460	57159
Mean	50	157	7227	2386	9549	2273	21640

* only sampled 50-200 fathoms

Table 8. Survey values used in the synthesis model. All are used as relative indexes except the slope trawl survey which is interpreted with a specified value for the catchability coefficient. Note that the slope survey value of 61,409 mt extends to Pt. Conception; a value of about 51,000 mt is appropriate for the Van-Mon INPFC areas.

YR	PER	MONTH	TYPE	VALUE	S.E.	CV
SHELF TRAWL SURVEY: AGE 1 NUMBERS						
80	1	8	4	29762	-1	0.30
83	1	8	4	14640	-1	0.30
86	1	8	4	18288	-1	0.30
89	1	8	4	21991	-1	0.30
92	1	8	4	9217	-1	0.30
SHELF TRAWL SURVEY: YOUNG BIOMASS						
80	1	8	5	41752	-1	0.30
83	1	8	5	30556	-1	0.30
86	1	8	5	27924	-1	0.30
89	1	8	5	38466	-1	0.30
92	1	8	5	57158	-1	0.30
POT SURVEY: SOUTHERN INDEX ADDED TO NORTHERN INDEX						
71	1	10	6	15.00	9.00	0.60
79	1	10	6	12.61	5.04	0.40
80	1	10	6	5.96	2.38	0.40
81	1	10	6	5.41	2.16	0.40
83	1	10	6	11.21	2.24	0.20
85	1	10	6	7.95	1.59	0.20
87	1	10	6	5.28	1.06	0.20
89	1	10	6	4.58	0.92	0.20
POT SURVEY: ONLY >= 62 CM						
71	1	10	7	3.225	1.29	0.40
79	1	10	7	2.608	1.04	0.40
80	1	10	7	0.841	0.34	0.40
81	1	10	7	0.653	0.26	0.40
83	1	10	7	1.073	0.21	0.20
85	1	10	7	0.73	0.15	0.21
87	1	10	7	0.429	0.09	0.21
89	1	10	7	0.271	0.05	0.18
SLOPE TRAWL SURVEY: MON-VAN BIOMASS FROM 1990-1993 SURVEYS						
92	1	10	8	61409	-1	0.30
93	1	10	8	61409	-1	0.30

Table 9. Synthesis model parameters for nil emphasis on pot surveys and virgin recruitment set at 11,972 thousand fish.

```
sabl94.dt2          LOOP1: 12  LIKE:  319.57  DELTA LIKE:    0.02 ENDBIO:    111295.
JUNK
sbe.p10
nil pot emphasis
  100.0    0.1              BEGIN AND END DELTA F PER LOOP1
   2  0.95                  FIRST LOOP1 FOR LAMBDA & VALUE
   1.500                    MAX VALUE FOR CROSS DERIVATIVE
   1 READ HESSIAN
HL_14.H01
   1 WRITE HESSIAN
HL_14.H01
   0.005                    MIN SAMPLE FRAC. PER AGE
   1  25   2  25            MINAGE, MAXAGE,  SUMMARY AGE RANGE
  71  93                    BEGIN YEAR, END YEAR
  1       12  0   0   0     NPER, MON/PER
  1.00                      SPAWNMONTH
  3  5 NFISHERY, NSURVEY
  2 N SEXES
   10000.  REF RECR LEVEL
  0 MORTOPT
    0.070000     0.010000   10.000000 'NAT-MORT       '   0    1 !  1
 -999.000000     0.060000    0.150000 'NATMORT        '   0    1 !  2
 HKL        TYPE:  1
 19 SELECTIVITY PATTERN
   0   2   0   3   4   0    0  AGE TYPES USED
      1.00000        0.30 ' HKL CATCH          '  ! # =  1 VALUE:     -0.00
      1.00000        0.30 ' HKL AGECOMP        '  ! # =  2 VALUE:    -80.60
      1.00000        0.21 ' HKL SIZECOMP       '  ! # =  3 VALUE:   -174.74
      1.00000       -1.00 ' HKL SIZE@AGE       '  ! # =  4 VALUE:    258.31
    0.000000    -0.100000    0.200000 'HKL INITIAL SEL '  0   71 !  3
    0.000000     0.000000   75.000000 'HKL-YNG INFLECT '  0   71 !  4
    0.000000     0.001000    3.000000 'HKL-YNG SLOPE   '  0   71 !  5
    5.859105     1.000000   24.000000 'HKL-F INFLECT   '  2   71 !  6
    0.349988     0.001000    4.000000 'HKL-F SLOPE     '  2   71 !  7
    0.290912     0.001000    1.000000 'HKL-F FINAL SEL '  2   71 !  8
 -999.000000     0.010000   24.000000 'HKL-M INFLECT   '  0   71 !  9
 -999.000000     0.001000    4.000000 'HKL-M SLOPE     '  0   71 !  10
   -0.160215    -0.500000    0.500000 'HKL-M FIN rel Fe'  1   71 !  11
   65.000000    32.000000   65.000000 'HKL-L INFLECT   '  0   71 !  12
    0.500000     0.001000    2.000000 'HKL-L SLOPE     '  0   71 !  13
    1.000000     0.001000    1.000000 'HKL-L FINAL SEL '  0   71 !  14
 POT        TYPE:  2
 19 SELECTIVITY PATTERN
   0   6   0   7   8   0    0  AGE TYPES USED
      1.00000        0.30 ' POT CATCH          '  ! # =  5 VALUE:     -0.00
      1.00000        0.30 ' POT AGECOMP        '  ! # =  6 VALUE:    -70.61
      1.00000        0.21 ' POT SIZECOMP       '  ! # =  7 VALUE:   -171.16
      1.00000       -1.00 ' POT SIZE@AGE       '  ! # =  8 VALUE:    166.99
    0.000000    -0.100000    0.100000 'POT INITIAL SEL '  0   71 !  15
    0.000000     0.000000   65.000000 'POT-YNG INFLECT '  0   71 !  16
    0.441672     0.001000    3.000000 'POT-YNG SLOPE   '  2   71 !  17
    5.771895     1.000000   20.000000 'POT-F INFLECT   '  2   71 !  18
    0.419680     0.001000    4.000000 'POT-F SLOPE     '  2   71 !  19
    0.000000     0.000000    1.000000 'POT-F FINAL SEL '  0   71 !  20
 -999.000000     0.010000   24.000000 'POT-M INFLECT   '  0   71 !  21
 -999.000000     0.001000    4.000000 'POT-M SLOPE     '  0   71 !  22
   -0.500000    -0.500000    0.500000 'POT-M FIN rel Fe'  1   71 !  23
   55.532104    32.000000   65.000000 'POT-L INFLECT   '  2   71 !  24
    0.302601     0.001000    2.000000 'POT-L SLOPE     '  2   71 !  25
    0.259310     0.001000    1.000000 'POT-L FINAL SEL '  2   71 !  26
 TWLFISH    TYPE:  3
 19 SELECTIVITY PATTERN
   0  10   0  11  12   0    0  AGE TYPES USED
```

```
      1.00000       0.30 ' TRAWL CATCH        ' ! # =  9 VALUE:      -0.00
      1.00000       0.30 ' TRAWL AGECOMP      ' ! # = 10 VALUE:     -59.02
      1.00000       0.21 ' TRAWL SIZECOMP     ' ! # = 11 VALUE:    -161.91
      1.00000      -1.00 ' TRAWL SIZE@AGE     ' ! # = 12 VALUE:     445.99
     0.001863  -0.200000   0.100000 'TWL INITIAL SEL '  1  71 !  27
     0.000000   0.000000  60.000000 'TWL-YNG INFLECT '  0  71 !  28
     0.568938   0.001000   4.000000 'TWL-YNG SLOPE   '  2  71 !  29
     4.061117   1.000000  24.000000 'TWL-F INFLECT   '  2  71 !  30
     0.603648   0.001000   4.000000 'TWL-F SLOPE     '  2  71 !  31
     0.000000   0.000000   1.000000 'TWL-F FINAL SEL '  0  71 !  32
  -999.000000   0.010000  24.000000 'TWL-M INFLECT   '  0  71 !  33
  -999.000000   0.001000   8.000000 'TWL-M SLOPE     '  0  71 !  34
    -0.109340  -0.500000   0.500000 'TWL-M FIN rel Fe'  1  71 !  35
    59.860893  32.000000  65.000000 'TWL-L INFLECT   '  2  71 !  36
     0.767777   0.001000   2.000000 'TWL-L SLOPE     '  2  71 !  37
     0.539220   0.001000   1.000000 'TWL-L FINAL SEL '  2  71 !  38
SHELF       TYPE:  4
 3 SELECTIVITY PATTERN
  0   0   0   0   0   0   0  AGE TYPES USED
     1.836104  0  1  2 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
     10.00000       0.30 ' SHELF ABUND        ' ! # = 13 VALUE:       5.44
     1.000000   0.000000   2.000000 'SHLF AGE 1      '  0 -80 !  39
     1.000000   0.010000  38.000000 'SHLF MALE SEL   '  0 -80 !  40
SLFBIO      TYPE:  5
19 SELECTIVITY PATTERN
  0   0   0  15   0   0   0  AGE TYPES USED
     1.825135  0  1  1 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
     10.00000       0.30 ' SLFBIO ABUND       ' ! # = 14 VALUE:       5.79
      1.00000       0.21 ' SLFBIO SIZE CCMP   ' ! # = 15 VALUE:     -96.33
     1.000000  -0.200000   1.000000 'SHELF INITIAL SE'  0 -80 !  41
    30.000000   0.010000  55.000000 'SHELF-YNG INFLEC'  0 -80 !  42
     0.100000   0.001000   4.000000 'SHELF-YNG SLOPE '  0 -80 !  43
     1.032540   0.010000  55.000000 'SHELF-F INFLECT '  2 -80 !  44
     0.582786   0.001000   4.000000 'SHELF-F SLOPE   '  2 -80 !  45
     0.000000   0.001000   1.000000 'SHELF-F FINAL SE'  0 -80 !  46
  -999.000000   0.010000  55.000000 'SHELF-M INFLECT '  0 -80 !  47
  -999.000000   0.001000   8.000000 'SHELF-M SLOPE   '  0 -80 !  48
     0.000000  -0.500000   0.500000 'SHELF-M FIN relF'  0 -80 !  49
    60.000000   0.010000  65.000000 'SHELF-L INFLECT '  0 -80 !  50
     0.500000   0.001000   8.000000 'SHELF-L SLOPE   '  0 -80 !  51
     1.000000   0.001000   1.000000 'SHELF-L FINAL SE' -2 -80 !  52
POTSVY      TYPE:  6
19 SELECTIVITY PATTERN
  0  17   0  18  19   0   0  AGE TYPES USED
     0.000300  0  1  2 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
      0.00100       0.30 ' POTSVY SURV ABUND  ' ! # = 16 VALUE:       4.95
      1.00000       0.21 ' POTSVY AGE COMP    ' ! # = 17 VALUE:     -71.40
      1.00000       0.21 ' POTSVY SIZE CCMP   ' ! # = 18 VALUE:    -122.64
      1.00000      -0.30 ' POTSVY SIZE@AGE    ' ! # = 19 VALUE:     331.34
     0.013575  -0.200000   1.000000 'PTSVY INITIAL SE'  1 -71 !  53
     0.000000   0.010000  55.000000 'PTSVY-YNG INFLEC'  0 -71 !  54
     0.680580   0.001000   4.000000 'PTSVY-YNG SLOPE '  2 -71 !  55
     6.129460   0.010000  55.000000 'PTSVY-F INFLECT '  2 -71 !  56
     0.293135   0.001000   4.000000 'PTSVY-F SLOPE   '  2 -71 !  57
     0.152361   0.001000   1.000000 'PTSVY-F FINAL SE'  2 -71 !  58
     7.203099   0.010000  55.000000 'PTSVY-M INFLECT '  2 -71 !  59
     1.015170   0.001000   8.000000 'PTSVY-M SLOPE   '  2 -71 !  60
     0.006318  -0.500000   0.500000 'PTSVY-M FIN relF'  1 -71 !  61
    54.100906   0.010000  65.000000 'PTSVY-L INFLECT '  2 -71 !  62
     1.772792   0.001000   8.000000 'PTSVY-L SLOPE   '  2 -71 !  63
     0.744116   0.001000   4.000000 'PTSVY-L FINAL SE'  2 -71 !  64
BIGPOT      TYPE:  7
 2 SELECTIVITY PATTERN
```

```
  0   0   0   0   0   0   0  AGE TYPES USED
   0.000194  0  1  2 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
    0.00100       0.30 ' BIGPOT ABUND        '  ! # = 20 VALUE:      -4.58
   6.000000   -0.200000    1.000000 'BIGPOT SELTYPE  '   0 -71 !  65
  62.000000    0.010000   55.000000 'BIGPOT MINSIZE  '   0 -71 !  66
 100.000000    0.001000    4.000000 'BIGPOT MAXSIZE  '   0 -71 !  67
SLOPE     TYPE:  8
 19 SELECTIVITY PATTERN
  0  22   0  23  24   0   0  AGE TYPES USED
   0.817129  0  1  1 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
    1.00000       0.30 'SLOPE SURV ABUND    '  ! # = 21 VALUE:       2.40
    0.01000       0.21 ' SLOPE AGE COMP     '  ! # = 22 VALUE:     -74.78
    0.10000       0.21 ' SLOPE SIZE COMP    '  ! # = 23 VALUE:     -78.40
    0.10000      -0.30 ' SLOPE SIZE@AGE     '  ! # = 24 VALUE:     162.35
   0.144304   -0.200000    1.000000 'SLP INITIAL SEL '   1 -84 !  68
  43.898445    0.010000   99.089996 'SLP-YNG INFLECT '   2 -84 !  69
   0.593727    0.001000   10.000000 'SLP-YNG SLOPE   '   2 -84 !  70
  10.000000    1.000000   24.000000 'SLP-F INFLECT   '   0 -84 !  71
   0.600000    0.001000    4.000000 'SLP-F SLOPE     '   0 -84 !  72
   1.000000    0.000000    1.000000 'SLP-F FINAL SEL '   0 -84 !  73
  10.000000    0.010000   24.000000 'SLP-M INFLECT   '   0 -84 !  74
   0.600000    0.001000    8.000000 'SLP-M SLOPE     '   0 -84 !  75
   0.000000   -0.500000    0.500000 'SLP-M FIN rel Fe'   0 -84 !  76
  58.021519   32.000000   65.000000 'SLP-L INFLECT   '   2 -84 !  77
   0.367102    0.001000    2.000000 'SLP-L SLOPE     '   2 -84 !  78
   0.284439    0.001000    1.000000 'SLP-L FINAL SEL '   2 -84 !  79
 0 SPECAVLOPT
 1 INCLUDE DISCARD (0/1/2)
-1.000 -1.000 -1.000  0.000  BACKGROUND RATIO OF DISCARD TO LANDINGS
 1 AGEERR: 1: MULTINOMIAL,  0: S(LOG(P))=CONSTANT,  -1: S=P*Q/N
200.000 : MAX N FOR MULTINOMIAL
 4 1=%CORRECT, 2=C.V., 3=%AGREE, 4=READ %AGREE @AGE
0.938 0.826 0.681 0.446 0.412 0.383 0.359 0.337 0.318 0.301 0.284 0.270 0.256
0.243 0.231 0.220 0.209 0.199 0.189 0.179 0.170 0.162 0.153 0.145 0.137
   0.100000    0.010000    0.300000 'OLD DISCOUNT    '   0   1 !  80
   0.000000    0.001000    0.100000 '%MIS-SEXED      '   0 -71 !  81
 0 END OF EFFORT
 0 FIX n FMORTs
 8 ENVIRONMENTAL FXN
sabl92.en1
  4  1  1 PARM AFFECTED, FXN TYPE, ENVVAR USED
   1.000000  -50.000000   50.000000 'ENVR HKL SML    '   0  71 !  82
 16  1  2 PARM AFFECTED, FXN TYPE, ENVVAR USED
   1.000000   -5.000000  100.000000 'ENVR POT SML    '   0  71 !  83
 28  1  3 PARM AFFECTED, FXN TYPE, ENVVAR USED
   1.000000   -5.000000  100.000000 'ENVR TWL SML    '   0  71 !  84
 20  1  5 PARM AFFECTED, FXN TYPE, ENVVAR USED
   1.000000   -5.000000  100.000000 'ENVR POT FINAL  '   0  71 !  85
 32  1  4 PARM AFFECTED, FXN TYPE, ENVVAR USED
   1.000000   -5.000000  100.000000 'ENVR TWL FINAL  '   0  71 !  86
  5  1  6 PARM AFFECTED, FXN TYPE, ENVVAR USED
   1.000000   -5.000000  100.000000 'ENVR HKL SLP    '   0  71 !  87
 54  1  7 PARM AFFECTED, FXN TYPE, ENVVAR USED
   1.000000   -5.000000  100.000000 'ENVR POTSVY SML '   0  71 !  88
114  1  8 PARM AFFECTED, FXN TYPE, ENVVAR USED
   1.000000    1.000000    1.000000 'ENV_AGE1 SIZE   '   0  71 !  89
 24 ESTIMATE N ENVIRON VALUES
-71  1  YEAR,PARM.
 84  YEAR-END
  72.710754   30.000000   90.000000 'ENV HKL 71-84   '   2  71 !  90
-85  1  YEAR,PARM.
 87  YEAR-END
  50.431747   30.000000   90.000000 'ENV HKL 85-87   '   2  84 !  91
```

```
-88  1  YEAR,PARM.
 90  YEAR-END
   52.572735   30.000000    90.000000 'ENV HKL 88-90    '   2  87 !  92
-91  1  YEAR,PARM.
 95  YEAR-END
   50.668911   30.000000    90.000000 'ENV HKL 91-95    '   2  90 !  95
-71  6  YEAR,PARM.
 84  YEAR-END
    0.166139    0.100000     5.000000 'ENV HKL SL 71-84'   2  71 !  94
-85  6  YEAR,PARM.
 95  YEAR-END
    0.419340    0.050000     5.000000 'ENV HKL SL 85-95'   2  83 !  95
-71  2  YEAR,PARM.
 84  YEAR-END
   52.599888   -5.000000    90.000000 'ENV POT 71-84    '   2  71 !  96
-85  2  YEAR,PARM.
 87  YEAR-END
   51.487114   30.000000    90.000000 'ENV POT 85-87    '   2  84 !  97
-88  2  YEAR,PARM.
 95  YEAR-END
   51.229851   30.000000    90.000000 'ENV POT 88-95    '   2  87 !  98
-71  5  YEAR,PARM.
 87  YEAR-END
    0.998088    0.010000     1.500000 'EV POT-F 71-87  '   2  71 !  99
-88  5  YEAR,PARM.
 95  YEAR-END
    2.247634    0.010000     5.000000 'ENV POT-F 88-95 '   2  87 ! 100
-71  3  YEAR,PARM.
 85  YEAR-END
   40.203690   32.000000    75.000000 'ENV TWL 71-85    '   2  71 ! 101
-86  3  YEAR,PARM.
 89  YEAR-END
   39.533600   32.000000    75.000000 'ENV TWL 86-89    '   2  85 ! 102
-90  3  YEAR,PARM.
 91  YEAR-END
   40.916779   32.000000    75.000000 'ENV TWL 90-91    '   2  89 ! 103
-92  3  YEAR,PARM.
 95  YEAR-END
   45.878689   32.000000    75.000000 'ENV TWL 92-95    '   2  91 ! 104
-71  4  YEAR,PARM.
 88  YEAR-END
    0.354221    0.010000     1.000000 'ENV TWL-F 71-88 '   2  71 ! 105
-89  4  YEAR,PARM.
 95  YEAR-END
    0.872682    0.010000     1.000000 'ENV TWL-F 89-95 '   2  88 ! 106
-71  7  YEAR,PARM.
 82  YEAR-END
   48.511181   35.000000    55.000000 'ENV POTSVY 71-82'   2  71 ! 107
-83  7  YEAR,PARM.
 95  YEAR-END
   45.004684   35.000000    55.000000 'ENV POTSVY 83-95'   2  82 ! 108
 80  8  YEAR,PARM.
    0.094823   -2.000000     2.000000 'AGE1 IN 80       '   1  79 ! 109
 83  8  YEAR,PARM.
   -0.768420   -2.000000     2.000000 'AGE1 IN 83       '   1  82 ! 110
 86  8  YEAR,PARM.
   -0.149885   -2.000000     2.000000 'AGE1 IN 86       '   1  85 ! 111
 89  8  YEAR,PARM.
    1.083432   -2.000000     2.000000 'AGE1 IN 89       '   1  88 ! 112
 92  8  YEAR,PARM.
    0.000000   -2.000000     2.000000 'AGE1 IN 92       '  -1  91 ! 113
  0  CANNIBALISM
  1  GROWTH: 1=CONSTANT, 2=MORT. INFLUENCE
```

```
  1.6600  AGE AT WHICH L1 OCCURS
  2 1=NORMAL, 2=LOGNORMAL
   38.400002   35.000000   45.000000 'FEMALE L1        '  0   1 ! 114
   63.488426   60.000000   85.000000 'FEMALE LINF      '  2   1 ! 115
    0.285310    0.080000    0.550000 'FEMALE K         '  2   1 ! 116
    2.030517    1.000000    3.000000 'FEMALE sdev1     '  2   1 ! 117
    8.725133    2.000000   12.000000 'FEMALE sdev2     '  2   1 ! 118
 -999.000000   35.000000   45.000000 'MALE L1          '  0   1 ! 119
   55.543076   50.000000   85.000000 'MALE LINF        '  2   1 ! 120
    0.338395    0.080000    0.550000 'MALE K           '  2   1 ! 121
 -999.000000    0.020000    2.580000 'MALE sdev1       '  0   1 ! 122
    5.271430    2.000000    6.000000 'MALE sdev2       '  2   1 ! 123
 25 PENALTIES: PARM, PRIOR, SD or CV, PICK, LABEL, X, PENALTY
    1.00000     -0.89 'PARM. PENALTY      '   ! # = 25 VALUE:      -3.14
  6   5.00000   0.30000  !    2HKL-F INFLECT      5.85911  -0.27934
  7   0.50000   0.30000  !    2HKL-F SLOPE        0.34999  -1.41380
 18   5.00000   0.30000  !    2POT-F INFLECT      5.77189  -0.22900
 19   0.50000   0.30000  !    2POT-F SLOPE        0.41968  -0.34073
 30   5.00000   0.30000  !    2TWL-F INFLECT      4.06112  -0.48062
 31   0.50000   0.30000  !    2TWL-F SLOPE        0.60365  -0.39431
 -1  1.0  1.0
  0  DEFINE N MARKET CAT.
 26  STOCK-RECR
  1 1=B-H, 2=RICKER
    0.00100       -0.60 ' SPAWN-RECR-IND      '   ! # = 26 VALUE:       0.47
    1.00000       -0.30 ' SPAWN-RECR-MEAN     '   ! # = 27 VALUE:       6.21
    1.000000    0.200000    3.000000 'VIRGIN RECR MULT'  0   1 ! 124
    0.889000    0.100000    0.990000 'B/H  S/R PARAM  '  0   1 ! 125
    0.783574    0.100000    2.000000 'BACK. RECRUIT   '  2   1 ! 126
    0.600000    0.100000    0.990000 'S/R STD.DEV.    '  0   1 ! 127
    0.000000   -0.100000    0.100000 'RECR TREND      '  0   1 ! 128
    1.000000    0.010000   10.000000 'RECR-MULT       '  0   1 ! 129
  0 INIT AGE COMP
 -999.000000    0.001000   10.000000 'RECR 71  YC  70 '  0  71 ! 130
 -999.000000    0.001000   10.000000 'RECR 72  YC  71 '  0  72 ! 131
 -999.000000    0.001000   10.000000 'RECR 73  YC  72 '  0  73 ! 132
 -999.000000    0.001000   10.000000 'RECR 74  YC  73 '  0  74 ! 133
 -999.000000    0.001000   10.000000 'RECR 75  YC  74 '  0  75 ! 134
 -999.000000    0.001000   10.000000 'RECR 76  YC  75 '  0  76 ! 135
 -999.000000    0.001000   10.000000 'RECR 77  YC  76 '  0  77 ! 136
    2.506045    0.001000   10.000000 'RECR 78  YC  77 '  2  78 ! 137
    0.153479    0.001000   10.000000 'RECR 79  YC  78 '  2  79 ! 138
    2.045154    0.001000   10.000000 'RECR 80  YC  79 '  2  80 ! 139
    0.778779    0.001000   10.000000 'RECR 81  YC  80 '  2  81 ! 140
    1.188511    0.001000   10.000000 'RECR 82  YC  81 '  2  82 ! 141
    0.746422    0.001000   10.000000 'RECR 83  YC  82 '  2  83 ! 142
    0.681439    0.001000   10.000000 'RECR 84  YC  83 '  2  84 ! 143
    0.880107    0.001000   10.000000 'RECR 85  YC  84 '  2  85 ! 144
    1.255652    0.001000   10.000000 'RECR 86  YC  85 '  2  86 ! 145
    1.190826    0.001000   10.000000 'RECR 87  YC  86 '  2  87 ! 146
    1.024816    0.001000   10.000000 'RECR 88  YC  87 '  2  88 ! 147
    1.095212    0.001000   10.000000 'RECR 89  YC  88 '  2  89 ! 148
    1.248158    0.001000   10.000000 'RECR 90  YC  89 '  2  90 ! 149
    2.906787    0.001000   10.000000 'RECR 91  YC  90 '  2  91 ! 150
    0.481361    0.001000   10.000000 'RECR 92  YC  91 '  2  92 ! 151
 -999.000000    0.001000   10.000000 'RECR 93  YC  92 '  0  93 ! 152
```

Table 10. Table of log(likelihoods) for three sets of model runs. First set is profiled on slope survey Q and estimates initial recruitment. The second and third sets profile on the level of virgin recruitment and treat the slope survey as a relative index. The second set retains emphasis on the pot surveys, and the third set reduces the pot survey emphasis to a nil level. A constant is subtracted from each column in table to enhance presentation. The TOTAL column is the sum of all components, weighted by the emphasis factors. Slope Q is relative to a biomass of 61,409 mt.

SLOPE	VIRGIN		LONGLINE FISHERY			POT FISHERY			TRAWL FISHERY			PAR.
Q	RECR.	TOTAL	AGE	SIZE	L@A	AGE	SIZE	L@A	AGE	SIZE	L@A	PEN.
		EMPH:	1	1	1	1	1	1	1	1	1	1
2.20	10159	194	8.5	12.3	0.3	1.6	8.4	3.4	26.7	14.9	4.4	2.6
2.00	10263	194	9.0	12.5	0.3	0.8	8.6	3.6	27.5	13.9	4.7	2.6
1.80	10476	194	8.4	12.6	0.1	1.9	10.6	3.4	26.4	12.7	4.1	3.0
1.60	10674	195	8.1	13.3	0.3	1.6	9.4	3.5	26.4	13.7	4.8	2.9
1.40	10866	194	8.8	12.2	0.3	1.3	10.1	3.4	26.7	12.0	4.5	2.8
1.20	11132	193	8.8	11.9	0.6	2.7	8.7	3.6	25.6	12.6	4.1	2.7
1.00	11516	191	8.4	11.7	0.4	1.8	9.0	3.5	25.5	11.8	4.7	2.7
0.80	12047	180	7.4	11.3	0.2	2.3	8.5	3.5	25.1	10.2	4.6	2.3
0.60	13222	176	8.3	10.3	0.2	4.5	7.7	3.2	23.1	9.8	4.2	2.3
		EMPH:	1	1	1	1	1	1	1	1	1	1
1.69	10775	398	8.3	8.0	1.0	2.7	7.4	2.7	21.2	5.9	3.7	1.1
1.22	11972	373	4.9	4.1	1.1	3.5	10.8	2.6	14.4	1.9	3.0	1.1
0.92	13169	345	2.7	6.3	0.8	5.4	10.7	2.6	9.3	0.0	2.1	0.6
0.75	14367	315	0.0	6.9	0.3	6.7	9.3	2.1	4.3	0.9	0.1	0.5
0.63	15564	294	1.0	4.9	0.5	7.8	7.8	1.1	0.0	0.6	0.0	1.6
0.58	16761	301	5.3	3.7	0.5	6.9	5.1	0.0	6.6	9.4	2.6	0.4
0.53	17958	299	7.0	2.1	0.6	7.5	3.1	0.3	7.8	9.7	4.7	1.2
0.48	19155	297	7.3	1.4	0.1	9.1	2.0	1.3	9.1	12.3	4.5	0.5
0.45	20353	294	7.2	1.5	0.6	8.7	1.6	0.7	9.4	11.6	3.1	0.7
0.43	21550	292	6.8	0.0	0.0	9.4	0.0	1.3	8.9	11.1	4.5	1.1
		EMPH:	1	1	1	1	1	1	1	1	1	1
1.13	10775	312	13.4	13.6	0.8	0.0	5.7	3.7	25.4	10.7	3.6	0.0
0.82	11972	320	12.0	12.1	0.9	1.0	6.7	4.0	24.1	12.4	3.2	1.4
0.64	13169	320	12.0	11.7	0.9	2.8	5.2	3.1	22.5	13.0	3.3	1.2
0.54	14367	319	10.5	12.0	0.9	4.6	5.3	3.2	20.8	13.9	3.4	1.0
0.46	15564	318	11.8	10.1	0.9	4.7	4.6	2.2	19.8	14.0	4.0	1.4
0.46	16761	312	12.6	8.3	0.9	6.0	5.3	2.4	18.6	13.6	3.8	1.8
0.40	17958	318	13.2	7.9	0.9	5.6	3.8	2.1	19.1	14.6	5.2	2.2
0.37	19155	316	13.5	7.1	0.8	6.4	3.2	3.9	18.7	13.6	5.7	1.8
0.33	20353	314	13.6	7.1	0.5	7.3	1.4	3.8	18.4	15.1	5.3	1.6
0.32	21550	316	12.4	6.6	0.6	6.6	1.4	4.1	18.7	15.3	6.8	2.4

SLOPE Q	VIRGIN RECR.	SHELF TRAWL SURVEY AGE 1	BIO	SIZE	POT SURVEY NUM	AGE	SIZE	L@A	BIGPOT NUM	SLOPE TRAWL SURVEY BIO	AGE	SIZE	L@A	SPAWN/ RECR	1993 age 2+ BIOMASS
	EMPH:	1	1	1	1	1	1	1	1	10	0.01	1	0.1	1	
2.20	10159	0.0	0.0	6.8	4.7	20.0	10.4	3.9	16.4	0.2	34.5	28.0	7.6	8.3	46180
2.00	10263	0.6	0.4	6.9	4.7	19.7	10.3	4.0	16.0	0.2	33.4	27.7	8.1	8.3	49516
1.80	10476	0.1	0.7	6.7	4.6	20.2	9.8	3.7	15.5	0.2	35.4	28.5	7.1	8.3	54121
1.60	10674	1.7	1.5	6.7	4.5	20.5	10.0	3.8	14.5	0.2	34.1	26.8	7.3	8.3	61330
1.40	10866	2.1	2.1	7.3	4.3	20.5	10.3	3.6	14.2	0.2	34.9	27.1	7.7	8.3	66425
1.20	11132	2.8	2.6	7.9	4.1	20.8	10.5	3.6	13.1	0.2	36.0	26.1	7.8	8.1	76277
1.00	11516	3.3	3.4	7.4	3.7	22.1	11.5	3.5	11.8	0.2	34.4	24.7	8.4	8.2	88711
0.80	12047	3.2	3.8	9.1	3.3	20.4	9.0	3.9	10.0	0.1	34.8	22.8	8.4	8.1	105850
0.60	13222	4.5	4.4	10.2	2.4	20.8	11.5	4.1	6.9	0.0	34.9	19.8	6.7	7.9	142519
	EMPH:	10	10	1	10	1	1	1	10	1	0.01	0.1	0.1	1	
1.69	10775	7.4	4.2	0.0	4.6	18.7	8.2	2.6	18.7	0.2	15.5	5.0	9.9	8.3	53405
1.22	11972	7.5	4.7	3.0	4.2	19.0	8.7	0.0	17.7	0.2	36.9	14.4	9.6	5.2	73452
0.92	13169	7.6	4.8	3.5	3.8	17.8	9.8	0.7	15.9	0.2	44.6	16.6	9.9	1.6	97035
0.75	14367	7.6	4.9	4.6	3.4	16.7	10.4	1.0	14.1	0.2	46.8	16.8	9.3	0.0	123265
0.63	15564	7.6	4.9	5.0	3.3	16.5	9.6	0.7	12.9	0.2	48.0	17.6	8.2	0.0	152580
0.58	16761	7.4	4.7	4.8	3.6	8.7	5.0	0.9	12.8	0.2	45.1	12.9	4.9	5.0	187687
0.53	17958	7.4	4.6	5.2	3.6	6.1	3.1	1.8	12.8	0.2	44.4	13.9	3.5	5.7	219437
0.48	19155	7.5	4.5	4.4	3.5	3.8	2.8	2.2	12.6	0.2	43.9	14.3	1.5	5.2	246101
0.45	20353	7.3	4.5	6.3	3.6	0.2	4.2	2.4	12.7	0.2	41.9	14.8	0.0	4.7	273200
0.43	21550	7.4	4.5	6.2	3.6	0.0	0.0	5.3	12.8	0.2	42.0	17.2	0.8	4.0	301559
	EMPH:	10	10	1	0.001	1	1	1	0.001	1	0.01	0.1	0.1	1	
1.13	10775	7.4	4.7	4.8	3.2	21.3	13.5	1.9	13.6	0.2	0.0	0.0	9.5	5.8	79628
0.82	11972	7.5	4.9	5.2	2.1	21.6	13.1	2.8	10.1	0.2	16.8	5.7	9.7	6.8	111295
0.64	13169	7.6	5.0	5.8	1.1	21.3	12.8	3.6	6.7	0.2	20.4	2.9	10.1	7.2	145111
0.54	14367	7.5	5.0	6.6	0.5	21.1	11.3	2.8	4.6	0.2	25.9	3.5	9.7	8.0	176124
0.46	15564	7.6	5.1	7.5	0.0	21.7	10.7	3.2	2.5	0.2	27.1	1.8	9.0	7.4	214192
0.46	16761	7.5	5.0	8.1	1.2	18.4	8.4	3.7	2.8	0.2	35.4	4.0	6.9	8.1	236828
0.40	17958	7.5	5.0	7.7	0.4	20.2	9.7	4.5	1.2	0.2	34.4	4.5	7.2	8.0	274858
0.37	19155	7.5	5.0	8.0	0.5	20.1	7.6	4.4	1.2	0.2	36.9	4.6	5.9	8.3	302773
0.33	20353	7.5	5.0	8.0	0.1	18.9	5.5	6.6	0.1	0.2	37.1	3.7	5.7	8.1	338363
0.32	21550	7.5	5.1	8.2	0.2	18.7	6.6	5.4	0.0	0.2	37.8	6.0	6.0	8.2	370897

Table 11. Estimated patterns of size and age selectivity with nil emphasis on the pot survey and virgin recruitment set to 11,972 thousand fish. The mean selectivity at age is the product of the age selectivity and the mean size selectivity at age (sum product of size selectivity and the lognormal distribution of size at age).

SIZE SPECIFIC SELECTIVITIES (MALE SAME AS FEMALE)

YEAR	TYPE	SEX	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	68	72	76	80	90
71	HKL	F	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.08	0.11	0.15	0.20	0.33	0.50	0.67	0.81	1.00
85	HKL	F	0.00	0.00	0.00	0.01	0.01	0.03	0.06	0.13	0.26	0.45	0.66	0.82	0.91	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
88	HKL	F	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.13	0.25	0.44	0.65	0.81	0.91	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00
91	HKL	F	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.12	0.25	0.43	0.64	0.80	0.90	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
71	POT	F	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.10	0.22	0.43	0.71	0.94	1.00	0.92	0.80	0.70	0.63	0.56	0.54	0.53	0.53	0.53
85	POT	F	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.15	0.31	0.56	0.84	1.00	0.99	0.88	0.75	0.65	0.58	0.51	0.49	0.49	0.48	0.48
88	POT	F	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.16	0.33	0.59	0.86	1.00	0.98	0.86	0.73	0.63	0.56	0.50	0.48	0.47	0.47	0.47
71	TWLFISH	F	0.00	0.02	0.08	0.22	0.47	0.74	0.90	0.97	0.99	1.00	1.00	1.00	0.98	0.91	0.76	0.62	0.56	0.54	0.54	0.54	0.54	0.54
86	TWLFISH	F	0.00	0.03	0.11	0.29	0.56	0.80	0.93	0.98	0.99	1.00	1.00	1.00	0.98	0.91	0.76	0.62	0.56	0.54	0.54	0.54	0.54	0.54
90	TWLFISH	F	0.00	0.01	0.05	0.16	0.37	0.65	0.85	0.95	0.99	1.00	1.00	1.00	0.98	0.91	0.76	0.62	0.56	0.54	0.54	0.54	0.54	0.54
92	TWLFISH	F	0.00	0.00	0.01	0.01	0.04	0.10	0.26	0.53	0.78	0.93	0.98	1.00	0.99	0.92	0.77	0.62	0.57	0.55	0.55	0.55	0.55	0.55
71	SHELF	F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
71	POTSVY	F	0.01	0.02	0.02	0.02	0.02	0.03	0.06	0.18	0.46	0.81	1.00	0.95	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
83	POTSVY	F	0.01	0.01	0.02	0.02	0.05	0.13	0.35	0.68	0.90	0.98	1.00	0.89	0.76	0.76	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
71	BIGPOT	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
83	BIGPOT	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
71	SLOPE	F	0.15	0.15	0.16	0.18	0.23	0.37	0.62	0.85	0.97	1.00	0.98	0.92	0.82	0.68	0.55	0.44	0.38	0.32	0.31	0.30	0.30	0.30

AGE SPECIFIC SELECTIVITIES ONLY

YEAR	TYPE	SEX	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22-25
71	HKL	F	1.00	0.96	0.90	0.84	0.77	0.70	0.63	0.56	0.50	0.45	0.41	0.38	0.35	0.34	0.32	0.31	0.31	0.30	0.30	0.30	0.29	0.29
71	HKL	M	1.00	0.95	0.88	0.81	0.72	0.63	0.54	0.46	0.39	0.33	0.28	0.24	0.21	0.19	0.17	0.16	0.15	0.14	0.14	0.14	0.13	0.13
71	POT	F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
71	POT	M	1.00	0.97	0.93	0.88	0.83	0.77	0.71	0.66	0.61	0.58	0.56	0.54	0.52	0.52	0.51	0.51	0.50	0.50	0.50	0.50	0.50	0.50
71	TWLFISH	F	1.00	0.93	0.84	0.73	0.62	0.53	0.46	0.42	0.39	0.37	0.37	0.36	0.36	0.36	0.36	0.35	0.35	0.35	0.35	0.35	0.35	0.35
71	TWLFISH	M	1.00	0.92	0.82	0.69	0.56	0.45	0.37	0.32	0.29	0.27	0.26	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.24	0.24	0.24
71	SHELF	F	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	SHELF	M	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	SLFBIO	F	1.00	0.72	0.48	0.30	0.18	0.10	0.06	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	SLFBIO	M	1.00	0.72	0.48	0.30	0.18	0.10	0.06	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	POTSVY	F	1.00	0.95	0.89	0.83	0.75	0.68	0.60	0.53	0.46	0.40	0.35	0.31	0.27	0.24	0.22	0.20	0.19	0.18	0.17	0.17	0.16	0.16
71	POTSVY	M	1.00	1.00	0.99	0.97	0.92	0.81	0.62	0.42	0.28	0.21	0.18	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
71	BIGPOT	F	1.00	0.95	0.89	0.83	0.75	0.68	0.60	0.53	0.46	0.40	0.35	0.31	0.27	0.24	0.22	0.20	0.19	0.18	0.17	0.17	0.16	0.16
71	BIGPOT	M	1.00	1.00	0.99	0.97	0.92	0.81	0.62	0.42	0.28	0.21	0.18	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
88	POT	F	1.00	1.07	1.17	1.29	1.43	1.57	1.72	1.85	1.96	2.04	2.11	2.15	2.18	2.20	2.22	2.23	2.24	2.24	2.24	2.24	2.25	2.25
88	POT	M	1.00	1.04	1.10	1.17	1.26	1.34	1.43	1.51	1.57	1.62	1.66	1.69	1.71	1.72	1.73	1.74	1.74	1.74	1.74	1.75	1.75	1.75
89	TWLFISH	F	1.00	0.99	0.97	0.95	0.93	0.91	0.89	0.89	0.88	0.88	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
89	TWLFISH	M	1.00	0.98	0.94	0.90	0.86	0.83	0.80	0.79	0.78	0.77	0.77	0.77	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76

Table 12. Model results with nil emphasis on pot surveys, virgin recruitment set to 11,972,000. The calculated slope survey Q is 0.82 relative to a survey biomass of 61,409 mt.

	AGE 1 - 25+			AGE 2 - 25+				TOTAL
YEAR	BEG BIO	SP. BIO	RECRUIT	BEG BIO	MID BIO	SP. BIO	RECRUIT	CATCH
PRISTINE	319934	148730	11972	315991	311747	148721	11163	0
EQUIL	268907	121745	11972	264964	260752	121736	11163	3115
71	267545	121742	7836	264964	260371	121736	11163	4241
72	264338	121145	7836	261758	255455	121139	7279	7384
73	257555	118642	7836	254974	248773	118637	7267	5868
74	250842	116232	7836	248261	240648	116226	7262	8795
75	241282	111586	7836	238702	229954	111580	7268	10842
76	229429	105399	7836	226848	212664	105393	7263	21754
77	207005	92809	7836	204424	197483	92803	7256	8250
78	204256	88312	25060	196002	187785	88293	7251	11261
79	195200	82769	1535	194694	184351	82768	23069	19778
80	183249	74165	20452	176441	170838	74149	1408	8444
81	180494	72137	7788	177929	172063	72131	18902	11332
82	175823	69416	11885	171908	160838	69407	7175	20825
83	159949	63096	7464	157641	150877	63091	10773	12510
84	151281	59884	6814	149037	141668	59879	6880	13224
85	141948	56246	8801	139049	129946	56239	6215	16173
86	130733	50781	12557	126662	118482	50772	7999	14815
87	121931	45811	11908	118008	110646	45802	11344	14353
88	114131	41440	10248	110756	105046	41432	10741	11931
89	109903	38639	10952	105812	100527	38626	9302	11262
90	107068	36843	12482	102957	98496	36833	9972	10226
91	111634	35947	29068	102060	97981	35925	11544	10296
92	112996	35597	4814	111410	109412	35594	26897	9956
93	114201	36596	7392	111767	109438	36591	4483	8942
Forecast								
94	114979	38997	7462	112522	110485	38991	6886	8221
95	116283	41488	7620	113773	111237	41483	6953	8900
96	115820	42250	10758	112276	108593			8687
97	115745	42436	10758	112201	108652			8480

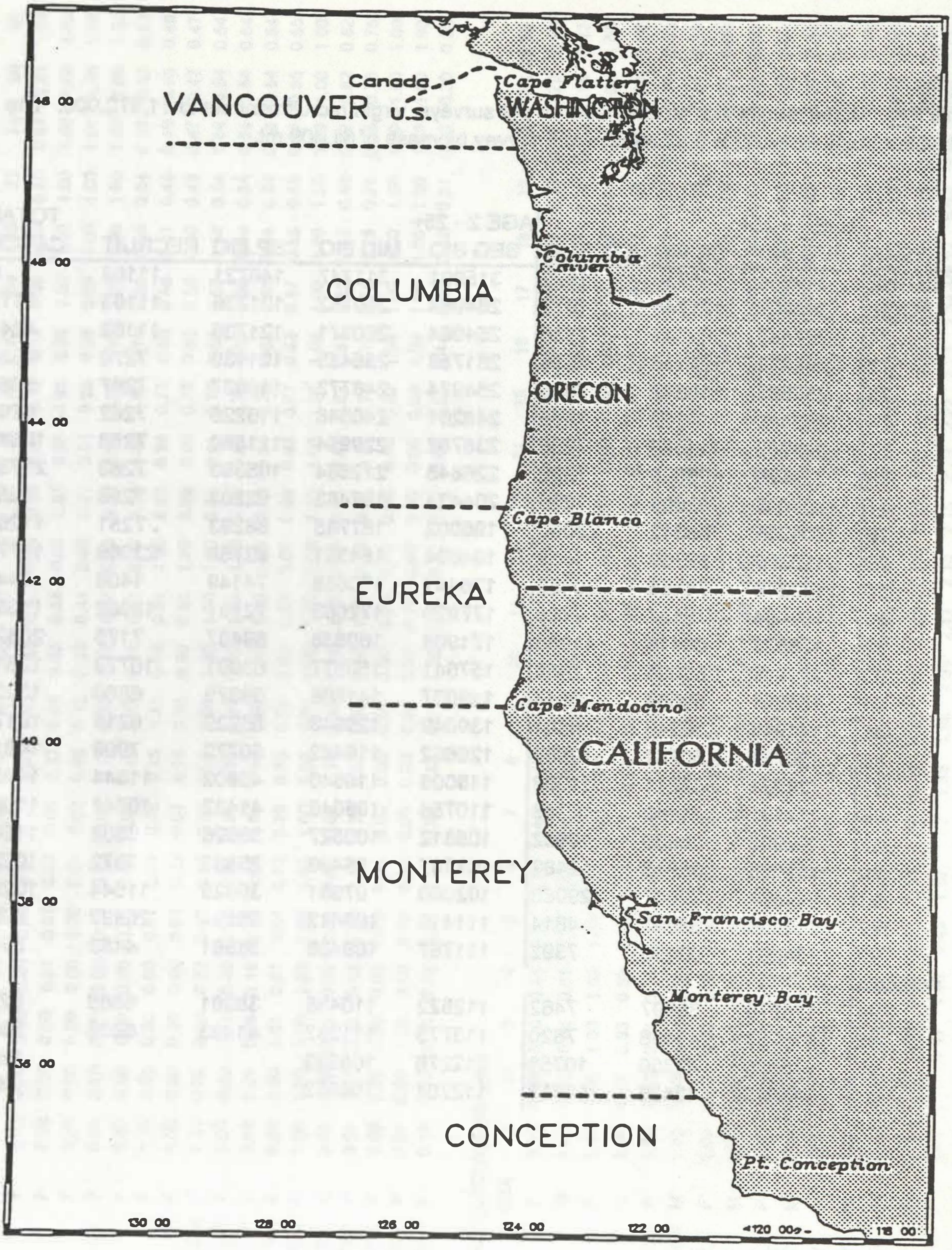


Figure 1. Map of the Washington, Oregon, and California coasts.

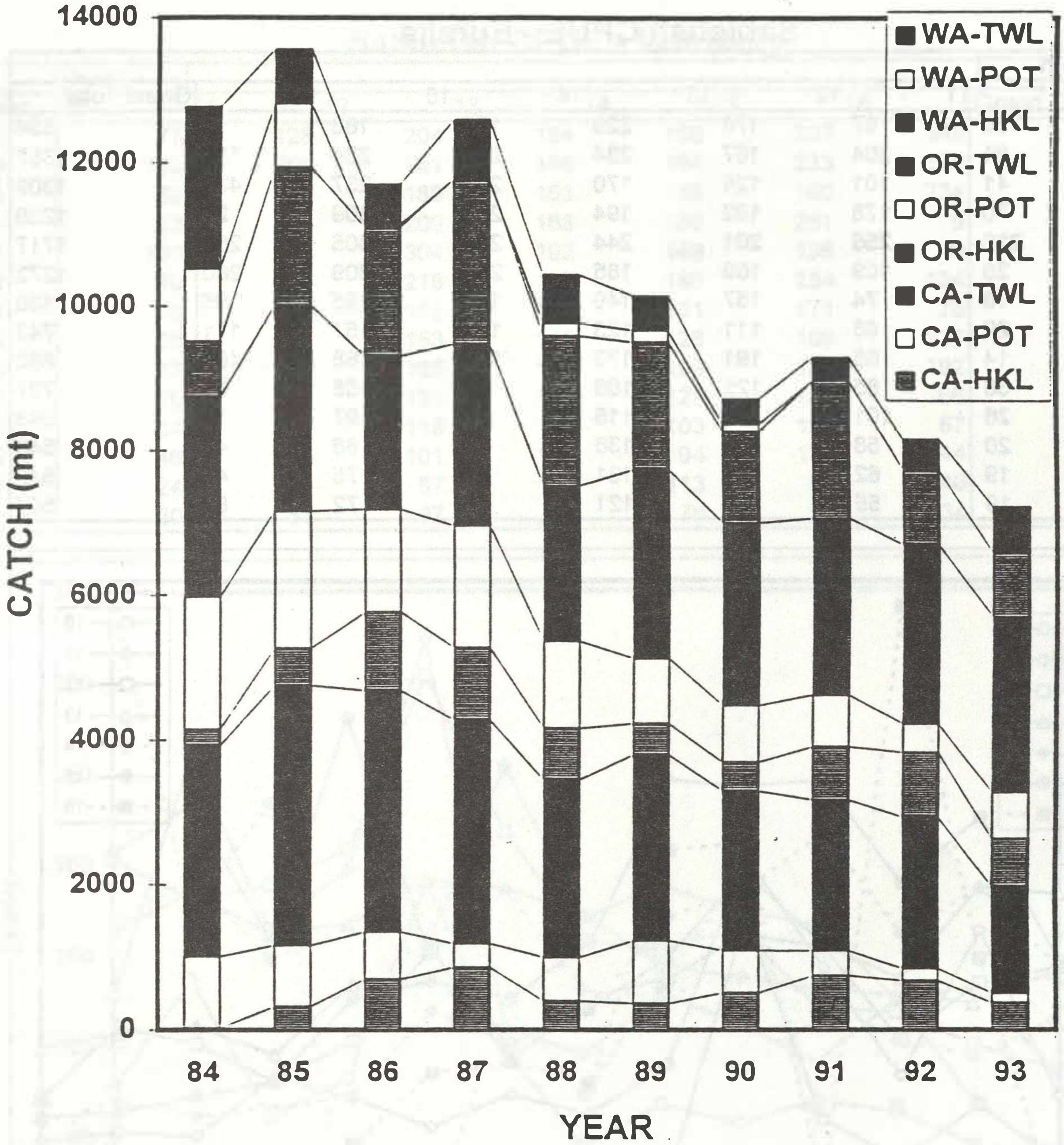


Figure 2. Recent trends in the distribution of sablefish catch among states and major gear groups.

Sablefish CPUE - Eureka

Year	Depth 10	11	12	13	14	15	16	Grand Total
78	38	87	178	229	178	183	0	894
79	81	204	167	234	233	284	184	1387
80	41	101	126	170	202	237	431	1309
81	70	178	192	194	273	309	21	1238
82	212	256	201	244	232	305	266	1717
83	26	109	169	185	213	309	260	1272
84	18	74	157	149	149	195	95	836
85	29	88	111	123	124	157	111	743
86	14	65	191	173	147	168	103	860
87	36	85	125	166	87	155	53	707
88	26	101	97	116	78	97	34	548
89	20	58	123	136	73	86	43	540
90	19	62	136	131	83	75	43	548
91	19	55	85	121	68	72	87	507

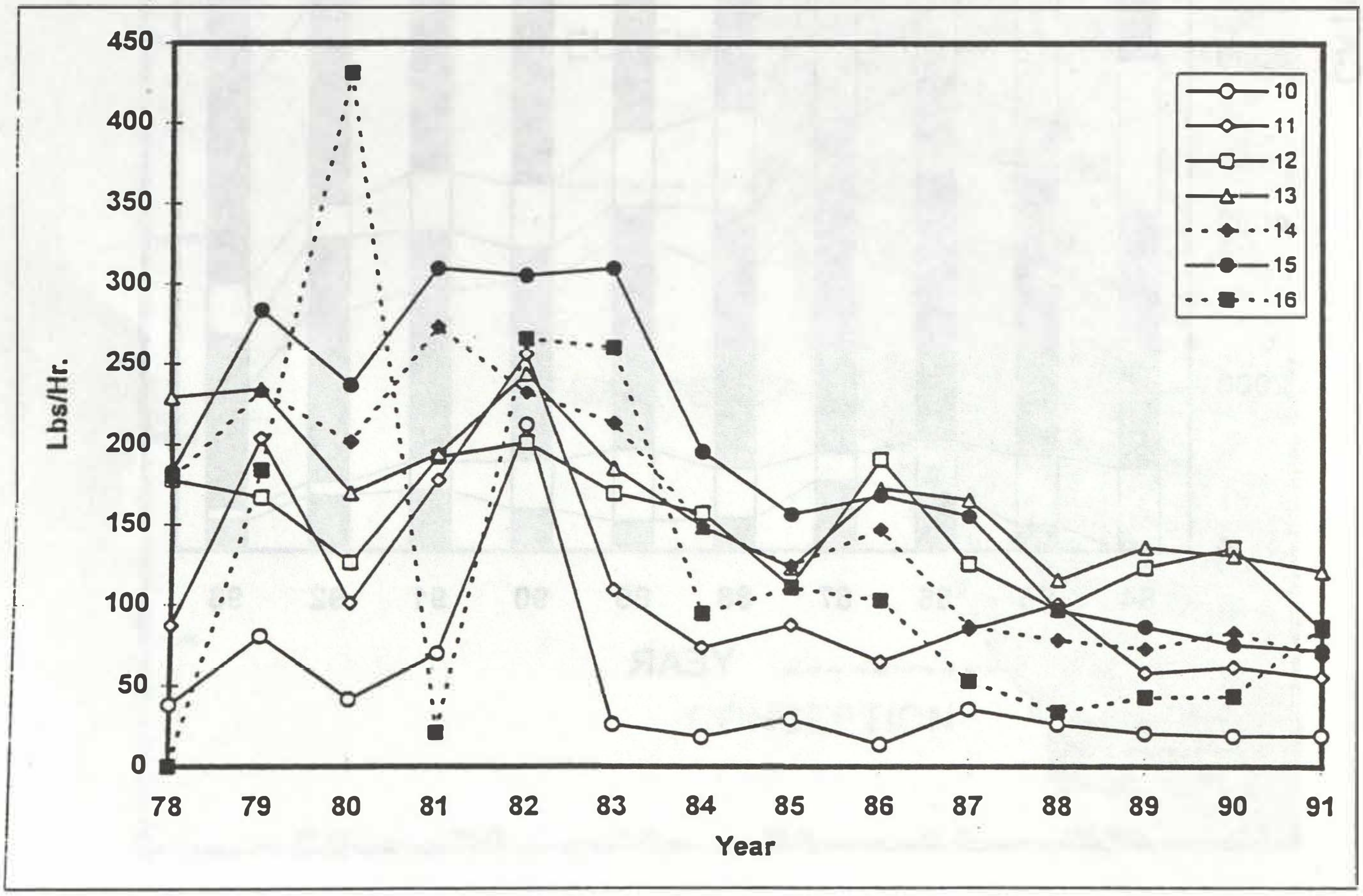


Figure 3. Trawl fishery catch per hour in the Eureka area from CDFG logbooks.

Sablefish CPUE - Monterey

Year	Depth 10	11	12	13	14	15	16	Grand Total
78	77	128	204	164	168	207	348	1297
79	138	260	181	186	194	233	176	1367
80	62	166	189	163	149	160	234	1123
81	83	198	209	168	165	281	0	1105
82	190	323	304	192	149	156	0	1315
83	99	111	218	187	186	254	124	1179
84	46	95	159	172	131	171	73	847
85	68	129	153	145	128	189	135	948
86	57	113	165	138	139	174	192	978
87	70	91	121	131	128	166	66	774
88	64	125	118	128	103	126	67	730
89	46	69	101	123	94	132	44	609
90	24	40	87	140	113	88	40	532
91	30	53	97	95	78	89	34	476

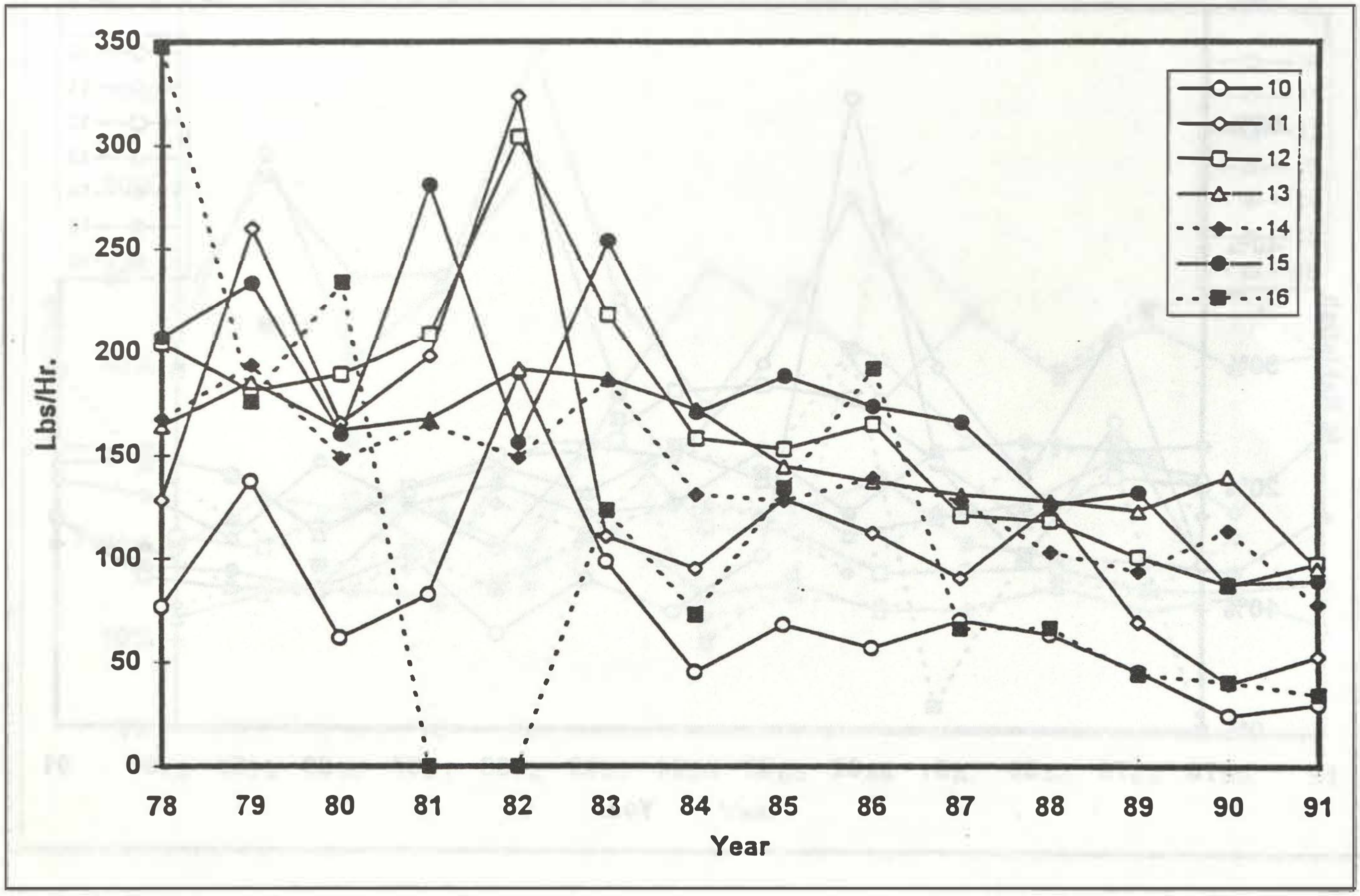


Figure 4. Trawl fishery catch per hour in the Monterey area from CDFG logbooks.

% Sablefish - Eureka

	Depth							
Year	10	11	12	13	14	15	16	Grand Total
78	14%	14%	20%	21%	18%	24%	0%	110%
79	25%	33%	21%	22%	24%	23%	22%	171%
80	14%	21%	17%	19%	22%	24%	14%	131%
81	22%	30%	22%	17%	18%	23%	2%	134%
82	52%	44%	27%	16%	13%	18%	31%	201%
83	14%	30%	28%	20%	18%	23%	21%	155%
84	10%	22%	28%	23%	18%	18%	23%	143%
85	12%	23%	23%	19%	16%	18%	16%	128%
86	8%	15%	22%	22%	19%	20%	11%	117%
87	14%	18%	20%	20%	13%	18%	15%	118%
88	11%	22%	16%	16%	11%	11%	13%	101%
89	11%	16%	21%	21%	12%	13%	17%	110%
90	12%	19%	23%	22%	15%	13%	22%	126%
91	17%	20%	23%	22%	15%	17%	29%	144%

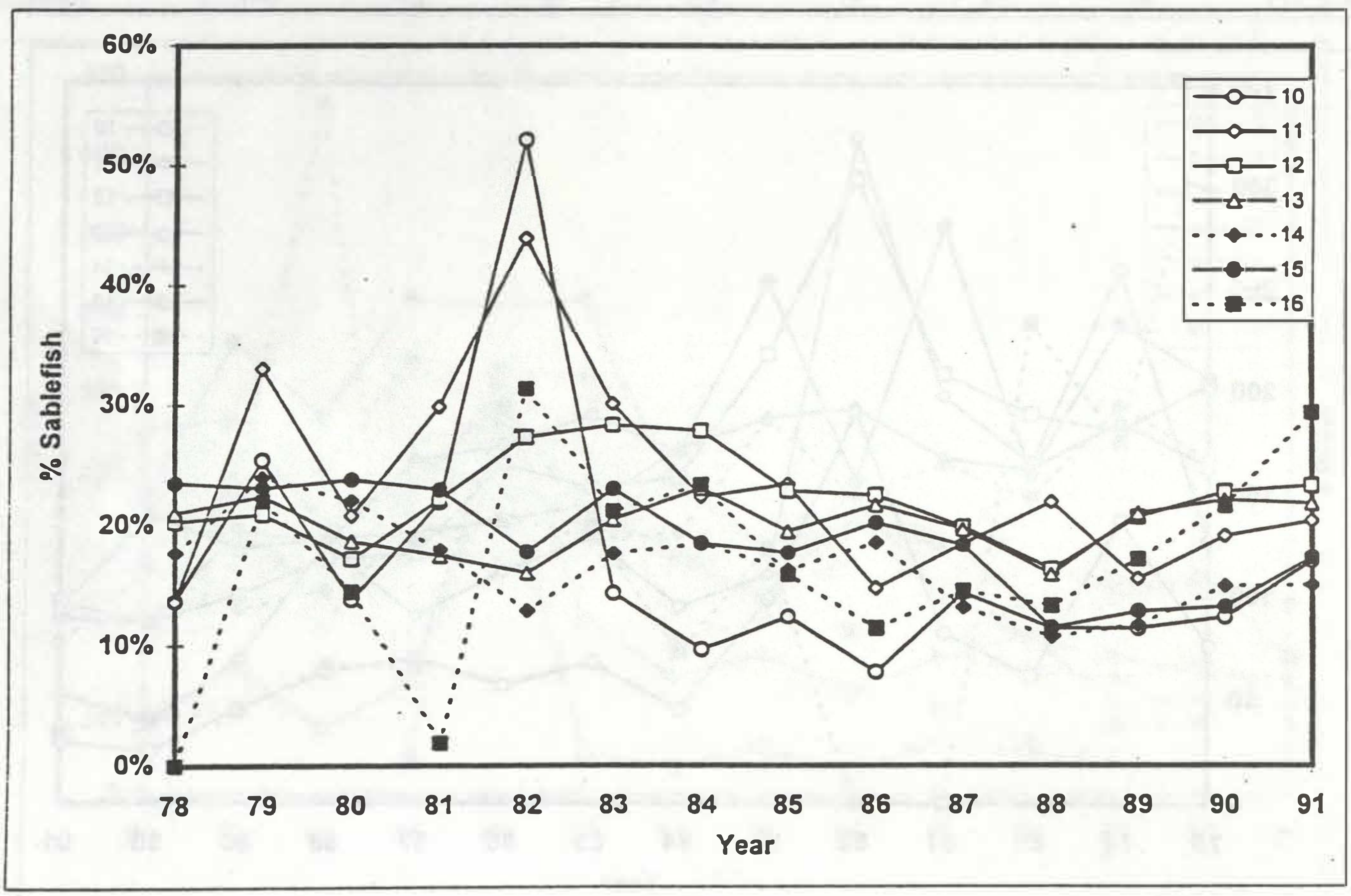


Figure 5. Ratio of sablefish CPUE to CPUE for total of sablefish, Dover sole, and thornyheads in the Eureka area.

% Sablefish - Monterey

Year	Depth 10	11	12	13	14	15	16	Grand Total
78	43%	47%	21%	12%	14%	20%	40%	197%
79	64%	61%	20%	15%	16%	26%	45%	247%
80	41%	50%	25%	16%	15%	24%	32%	204%
81	49%	51%	19%	15%	14%	24%	0%	171%
82	75%	63%	32%	18%	16%	20%	0%	224%
83	48%	38%	32%	22%	22%	37%	34%	234%
84	36%	51%	23%	15%	13%	25%	10%	173%
85	49%	46%	22%	17%	15%	24%	17%	190%
86	37%	41%	18%	13%	14%	28%	57%	208%
87	46%	32%	18%	14%	13%	21%	47%	191%
88	39%	32%	18%	16%	17%	19%	40%	182%
89	45%	31%	16%	14%	15%	19%	47%	187%
90	40%	24%	16%	15%	22%	18%	49%	184%
91	42%	33%	17%	12%	15%	24%	42%	185%

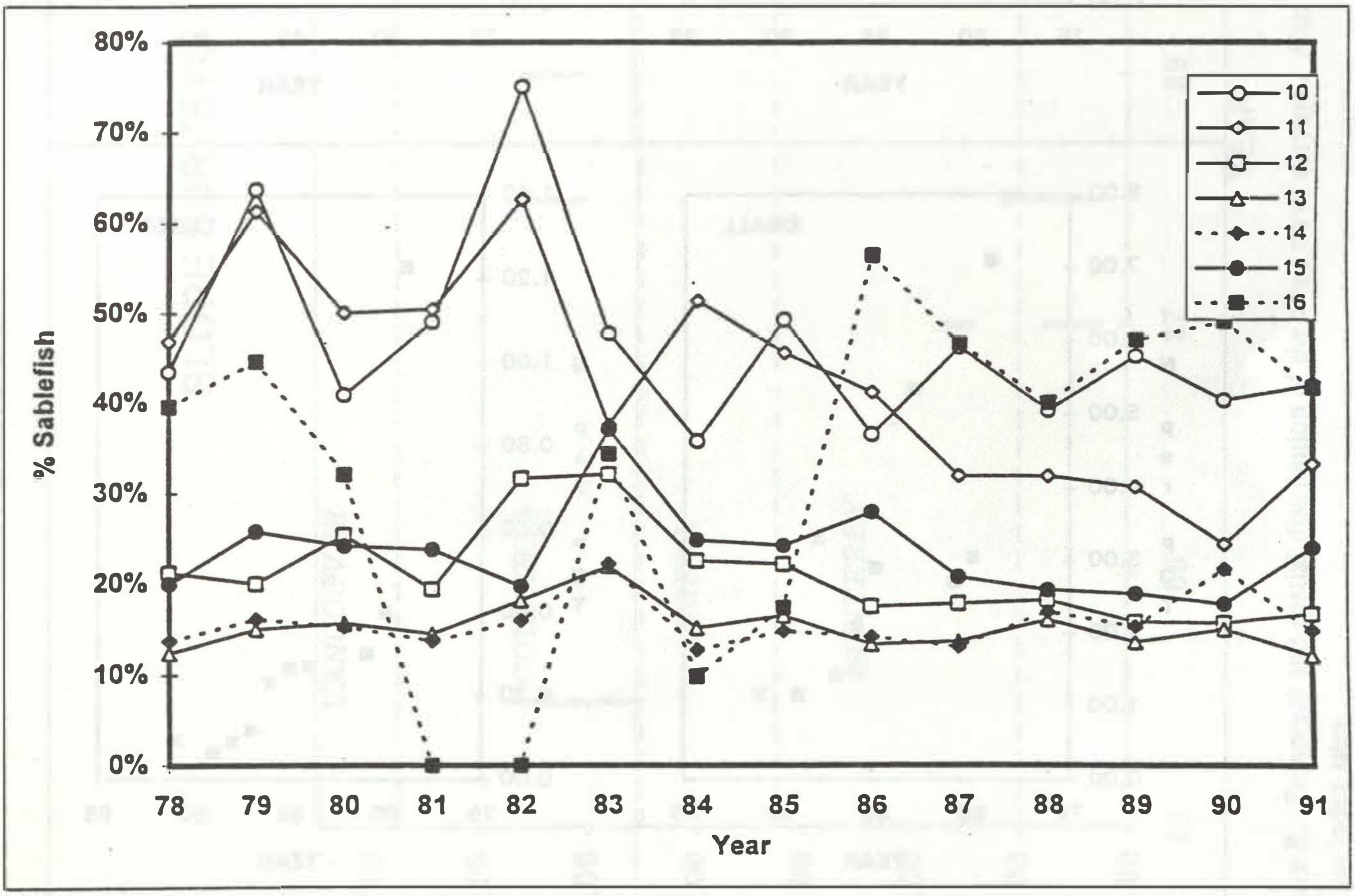


Figure 6. Ratio of sablefish CPUE to CPUE for total of sablefish, Dover sole, and thornyheads in the Eureka area.

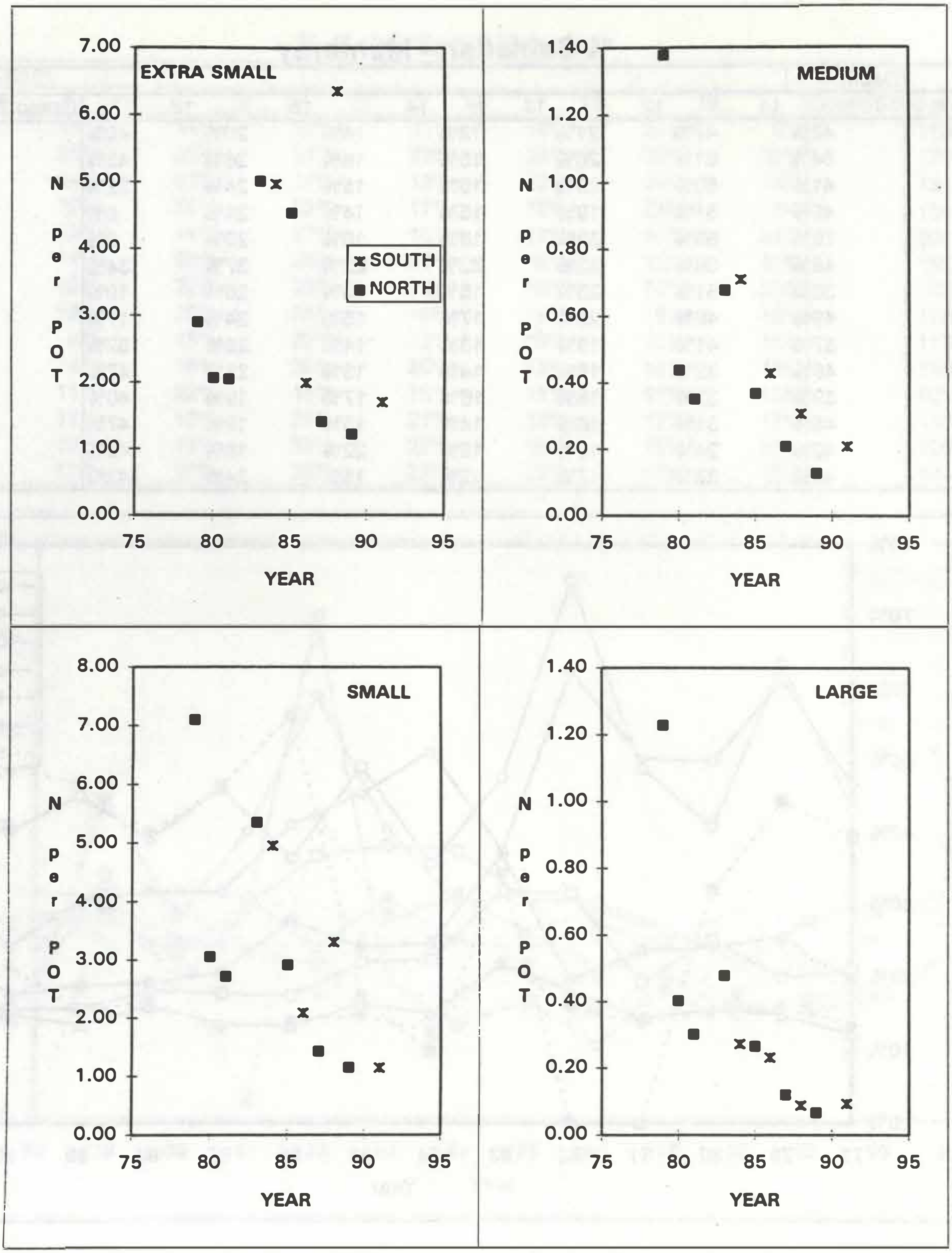


Figure 7. Trends in the northern and southern pot surveys using only samples from depths 225, 300, 375 and 450 fathoms and deleting the two sites in the Conception area. All four size groups are combined in the normal pot survey, medium and large are combined in the "BigPot" survey.

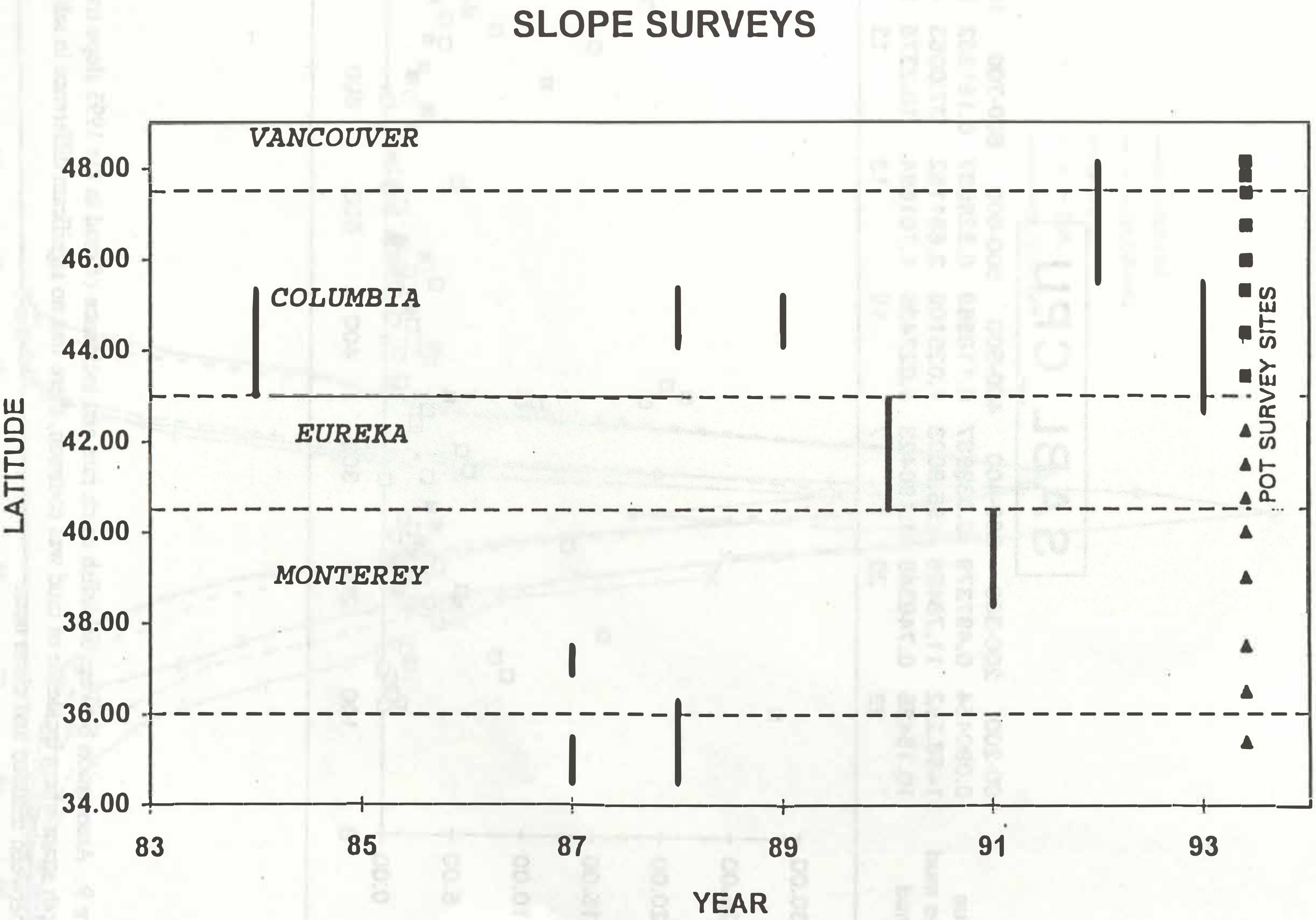


Figure 8. Temporal and spatial distribution of the slope trawl surveys. Also shown are the locations of the pot index sites.

SABL_CPU

	100-200	200-300	300-400	400-500	500-600	600-700	100-700
P value	0.090454	0.497379	0.039987	0.118559	0.529997	0.181982	0.072065
var no mud	1458.252	11.78486	55.8003	1.035108	2.681152	37.0053	427.5827
var mud	10.15465	0.746345	1.190423	1.022435	1.761694	10.2378	5.108992
n	22	20	17	15	13	13	100

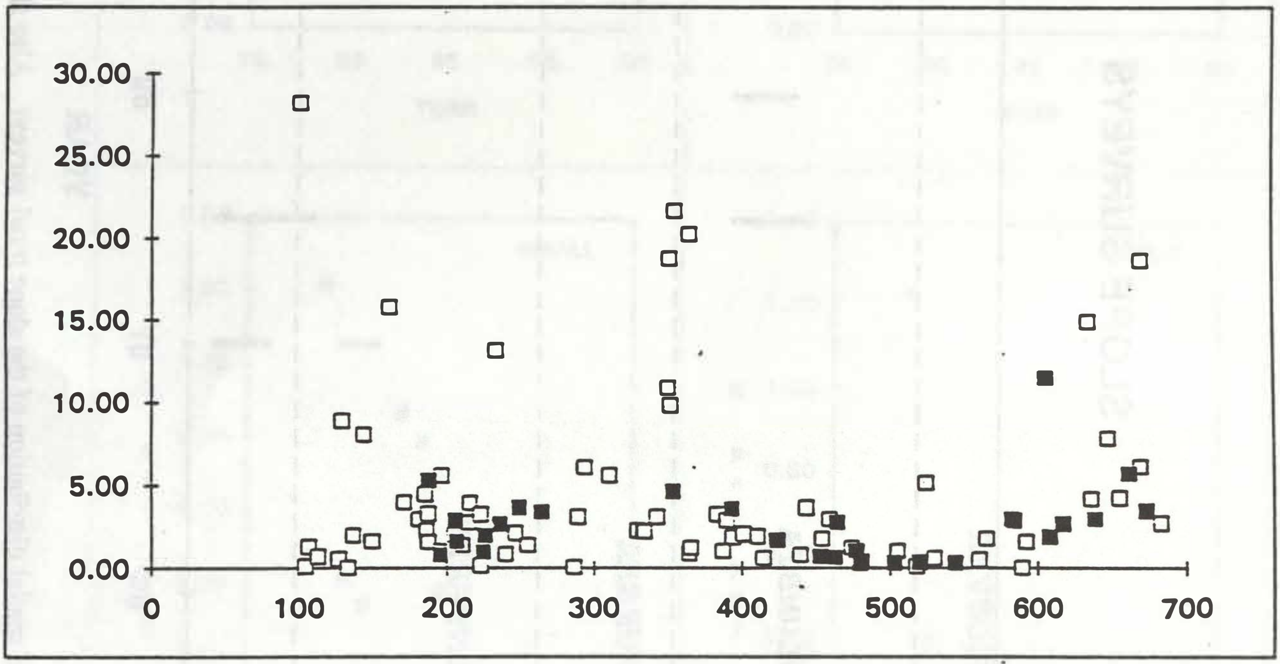


Figure 9. Association between sablefish catch rate and incidence of mud in the 1993 slope trawl survey. In depth strata where incidence of mud was common, there was no significant difference in sablefish catch rate between mudded and clean nets.

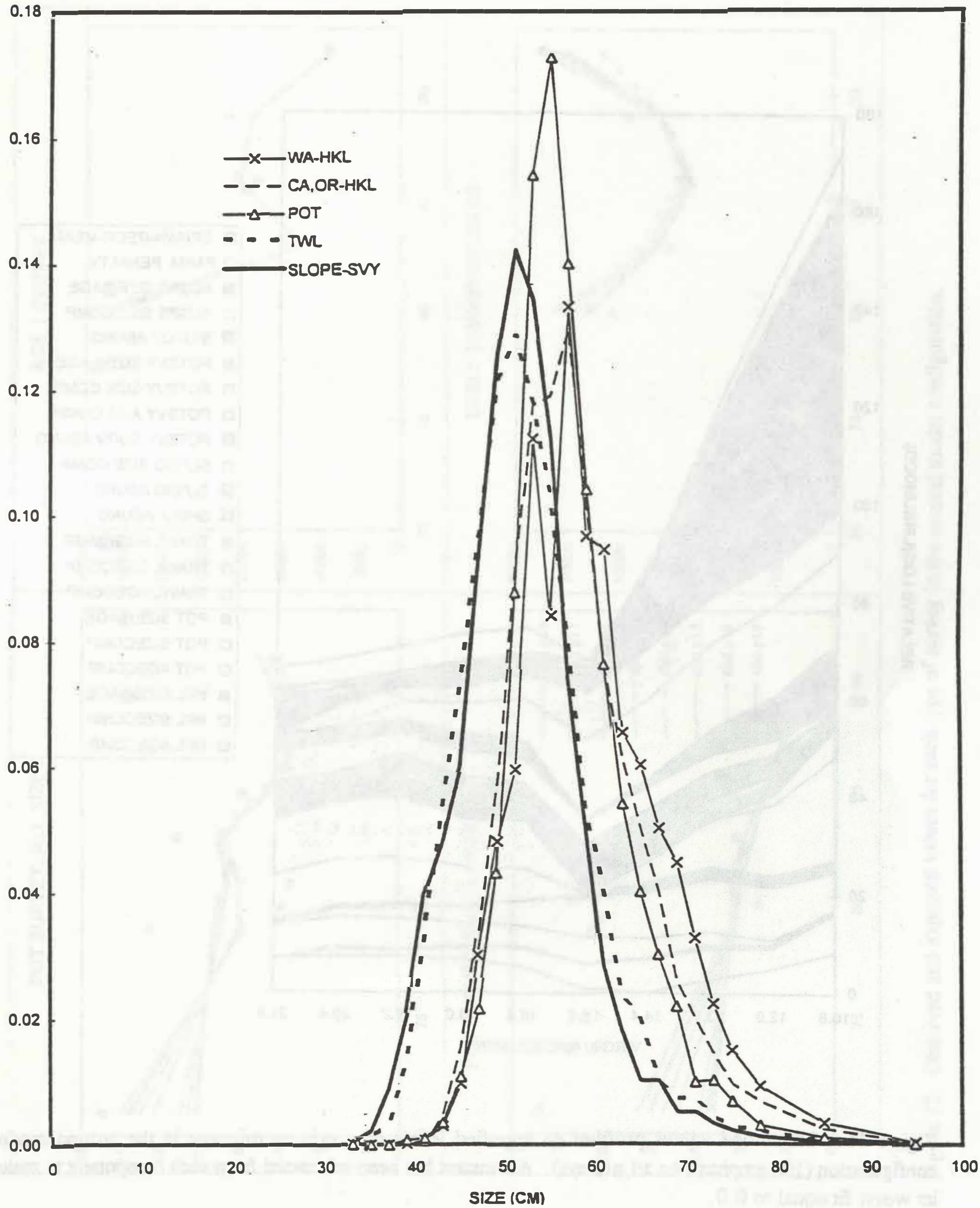


Figure 10. Comparison of mean size compositions in slope trawl surveys and each component of the fishery.

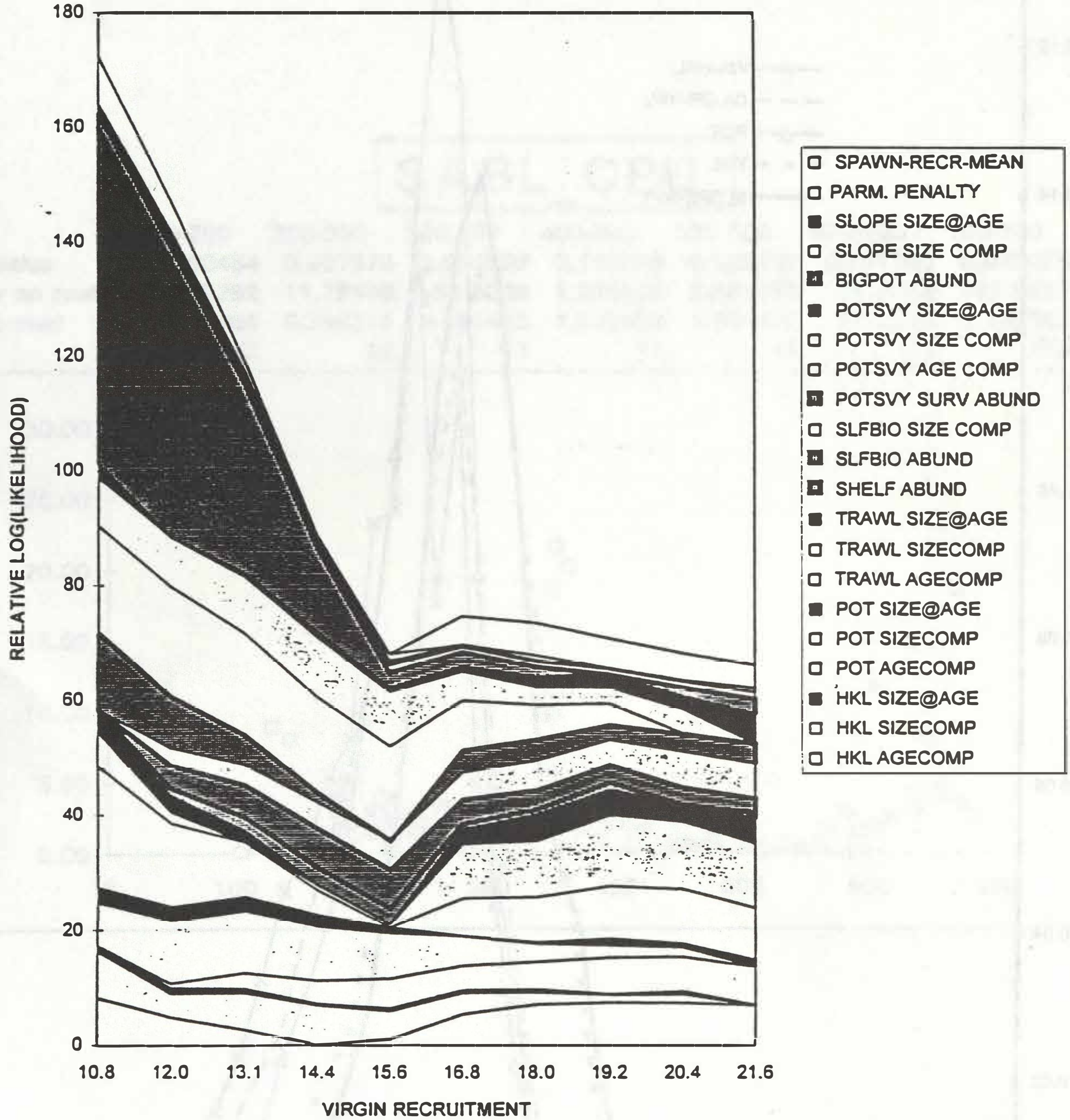


Figure 11. Likelihood values profiled on specified levels of virgin recruitment in the second model configuration (10x emphasis on all surveys). A constant has been subtracted from each component to make its worst fit equal to 0.0.

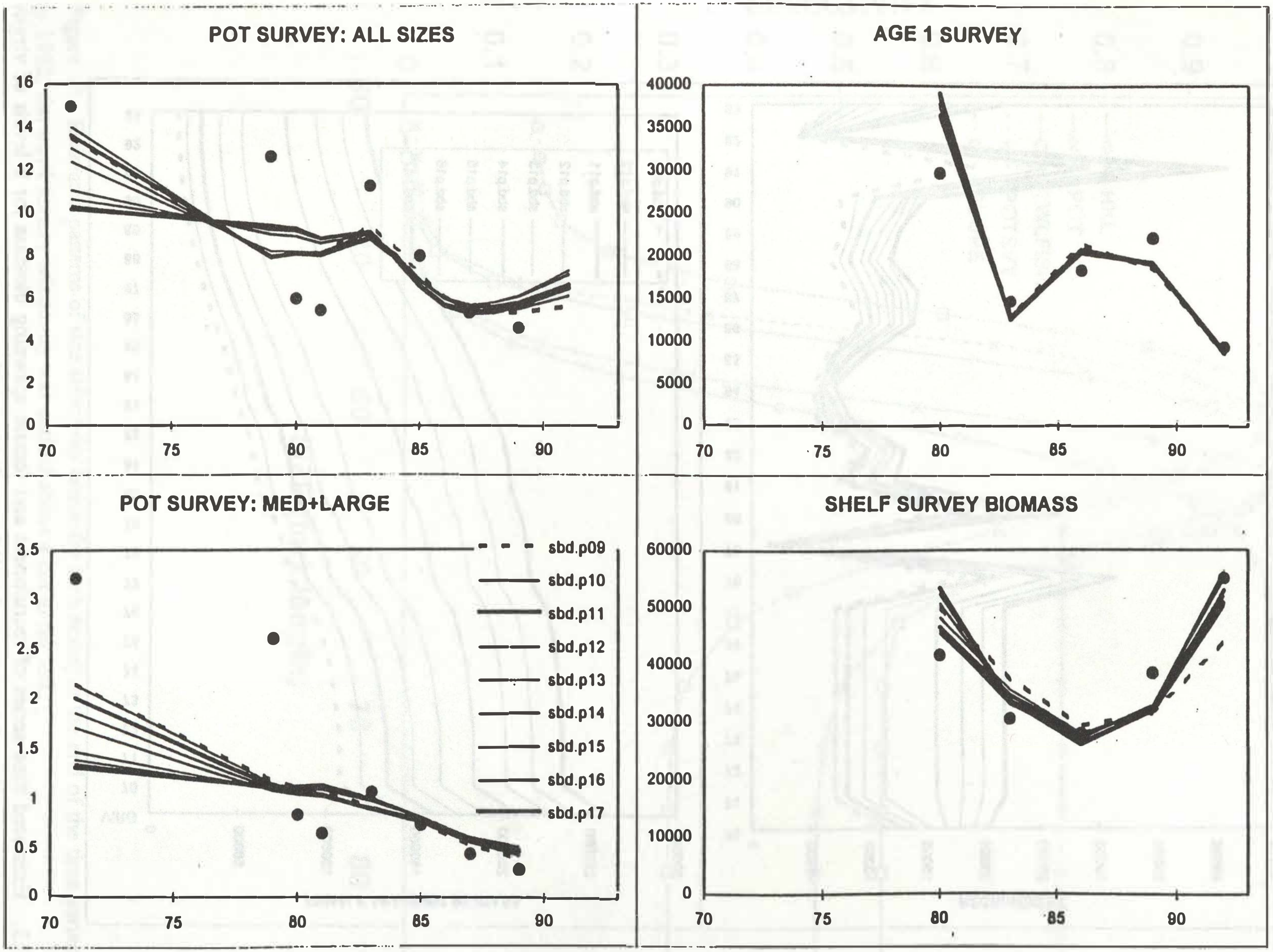


Figure 12. Observed and expected values for each type of survey in the second model configuration.

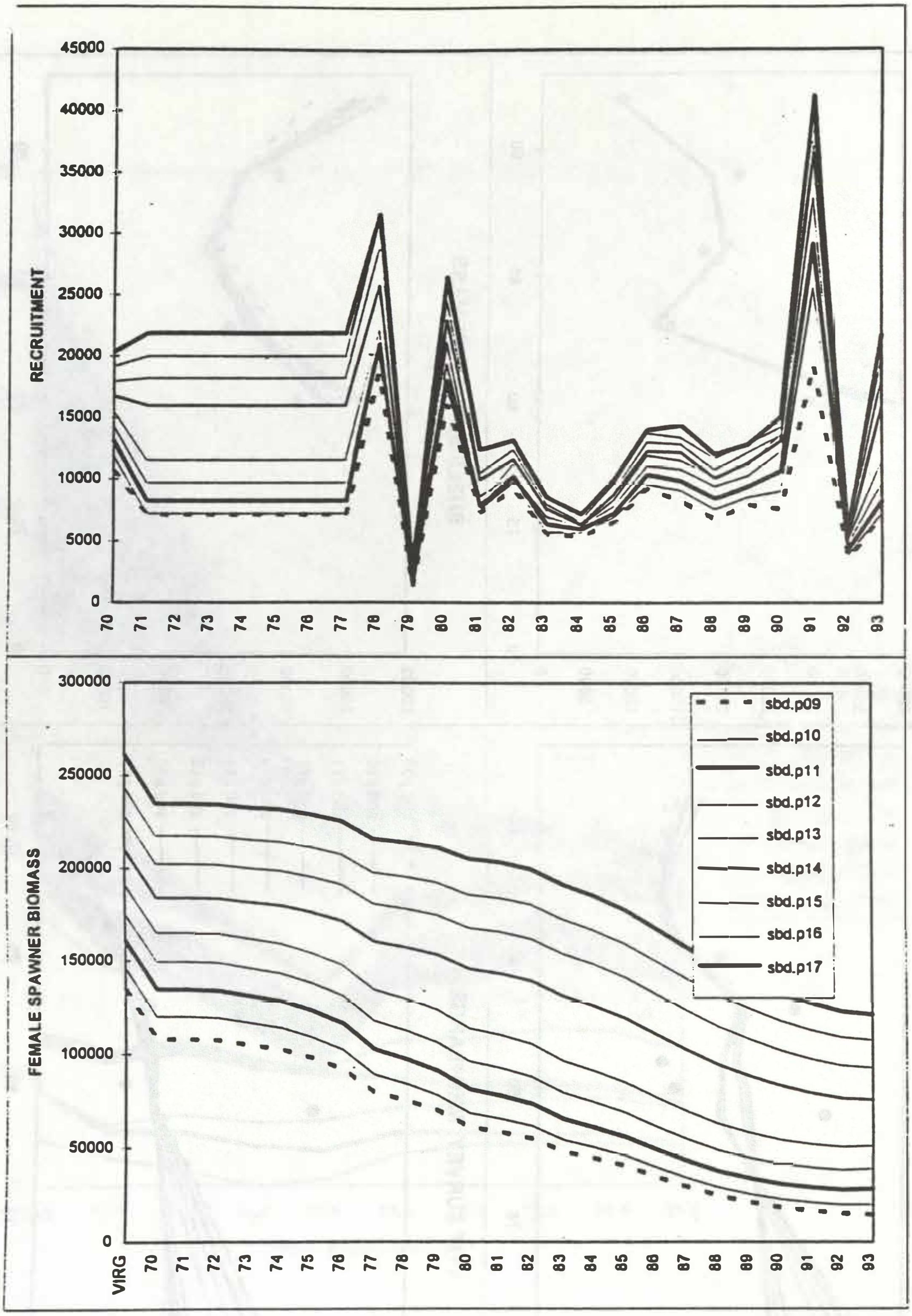


Figure 13. Estimated time series of recruitment and female spawning biomass for 9 levels of virgin recruitment in the second model configuration (10x emphasis on all surveys).

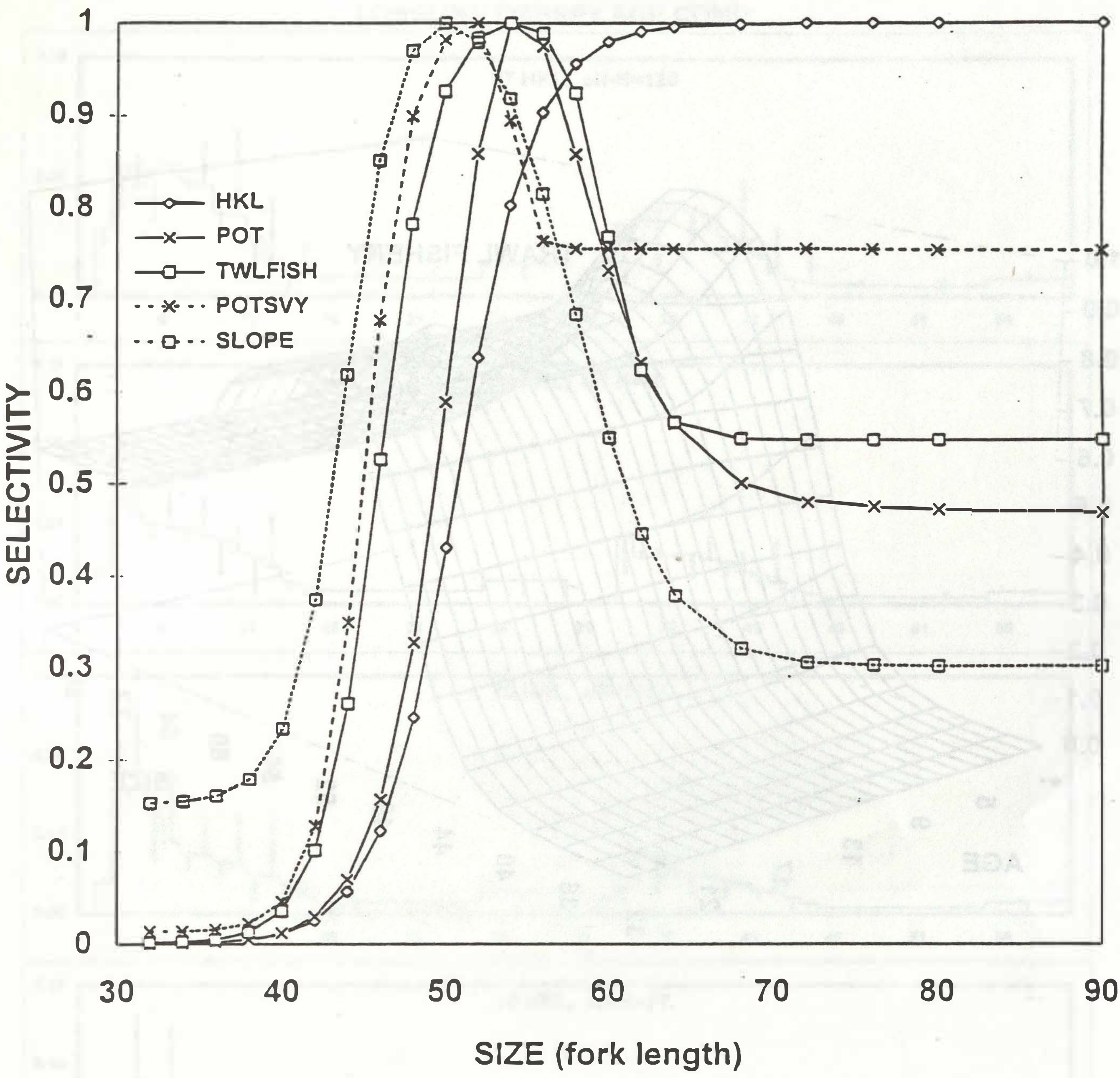


Figure 14. Estimated patterns of size selectivity (same for both sexes) at the end of the time series. Prior to 1992, the trawl fishery selectivity was shifted about 4 cm to the left.

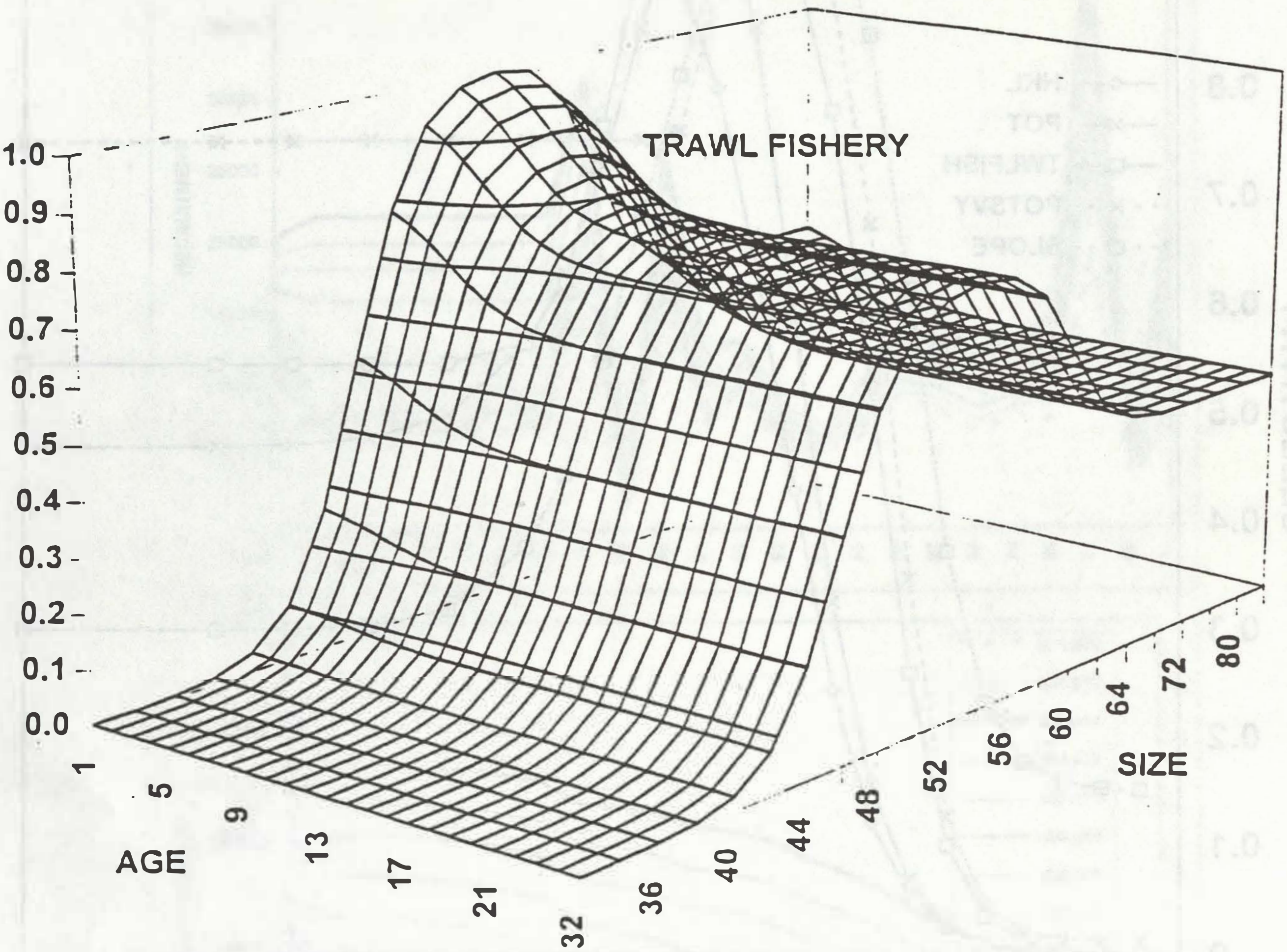
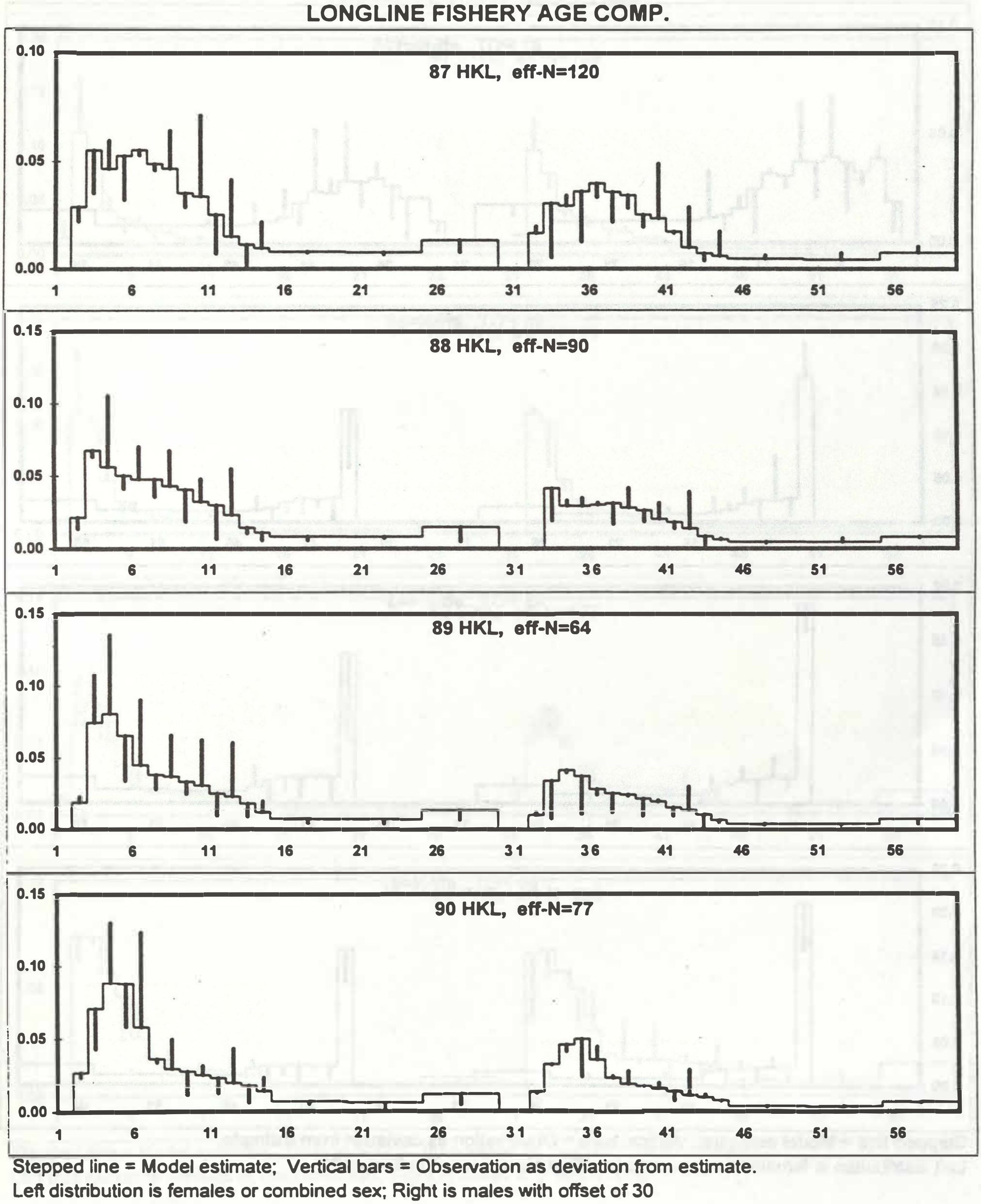
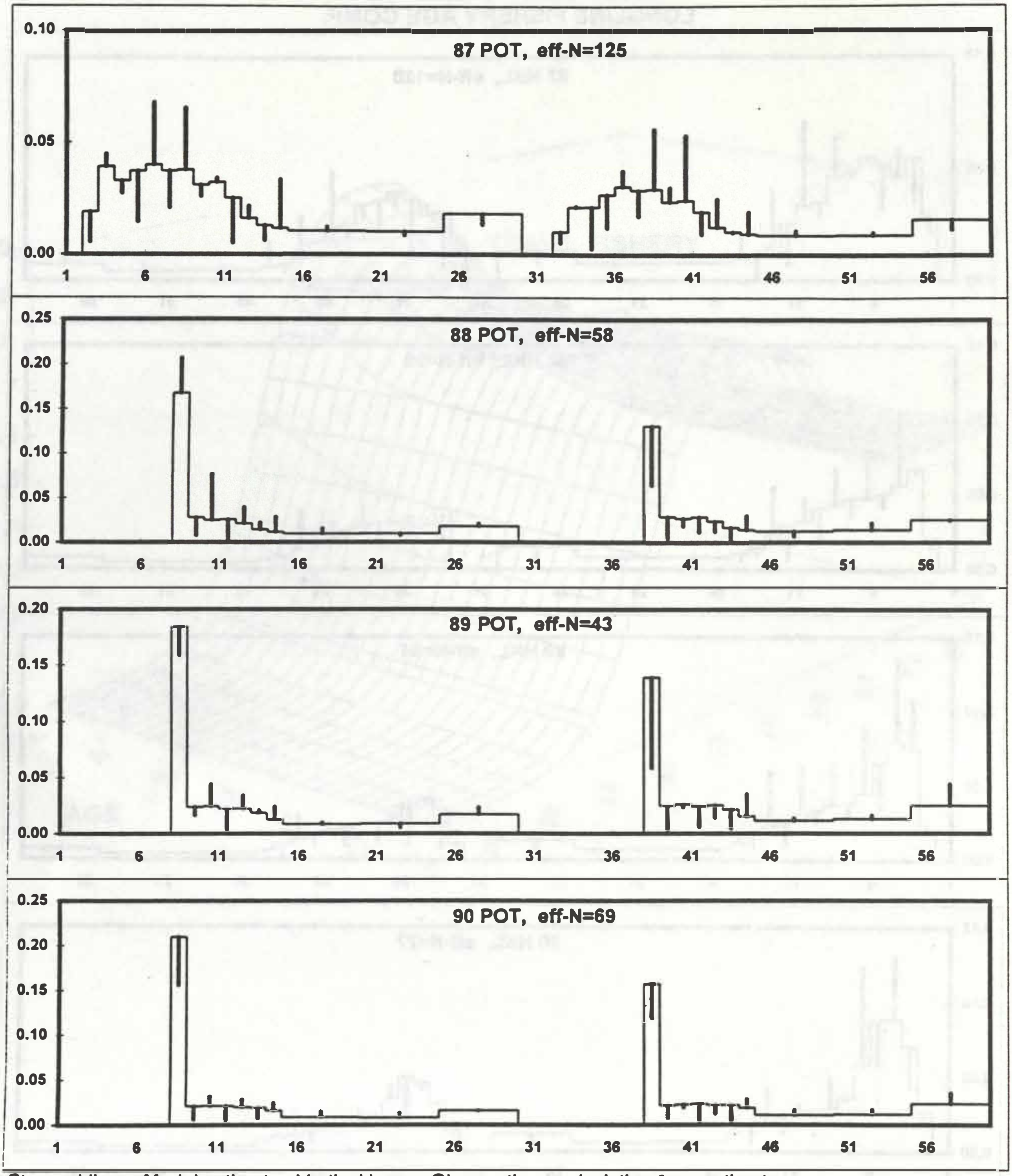


Figure 15. Display of product of size and age selectivity for the trawl fishery. At young ages, the high selectivity occurs only for the upper tail of the size at age distribution.



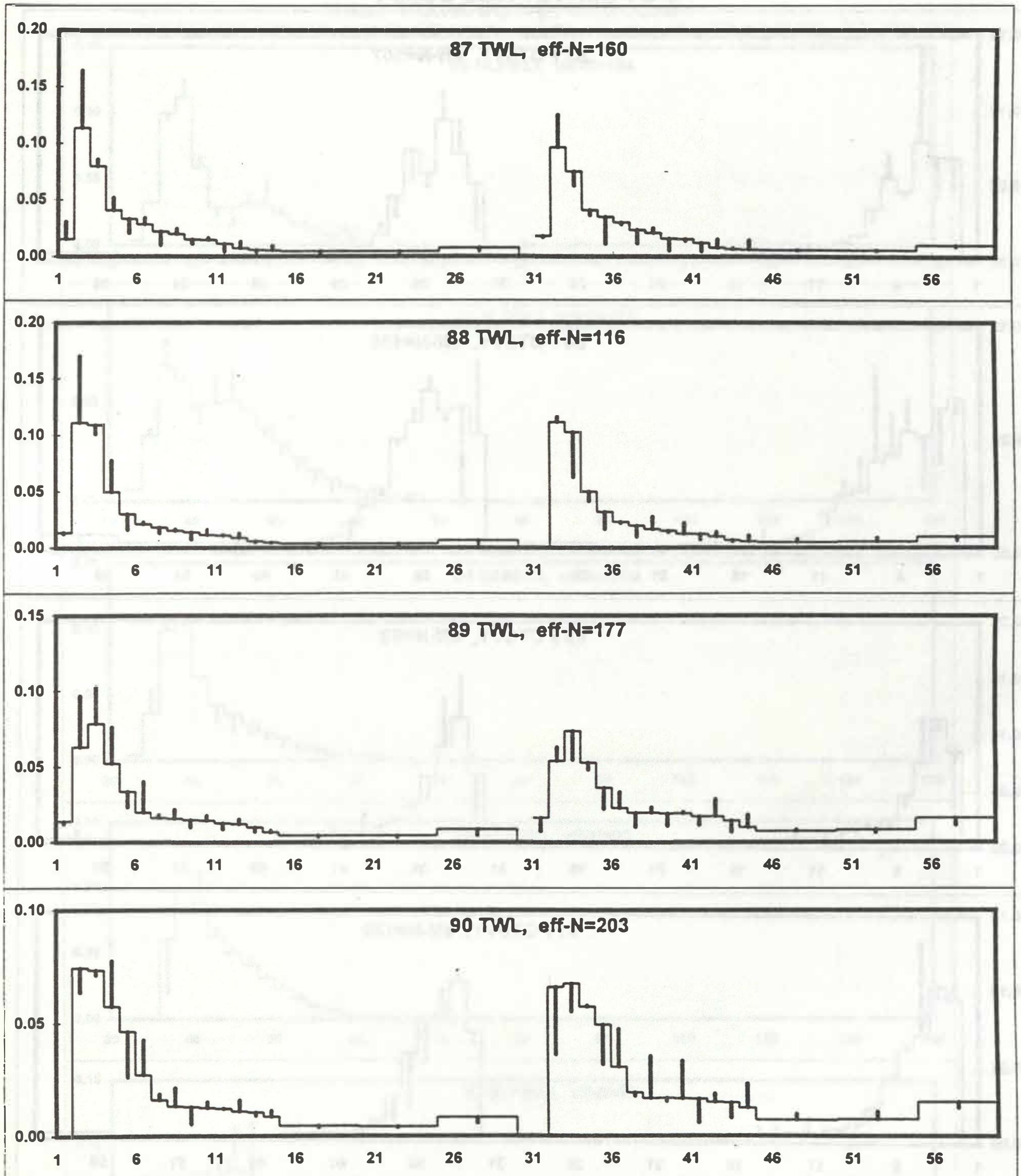
Figures 16-27. Display of observed and expected size and age composition, age composition. The model estimate is the continuous line and the observations are indicated as bold vertical deviations from the expected line. Because of the variable bin widths, the proportion in each bin is divided by the bin width.

POT FISHERY AGE COMP.



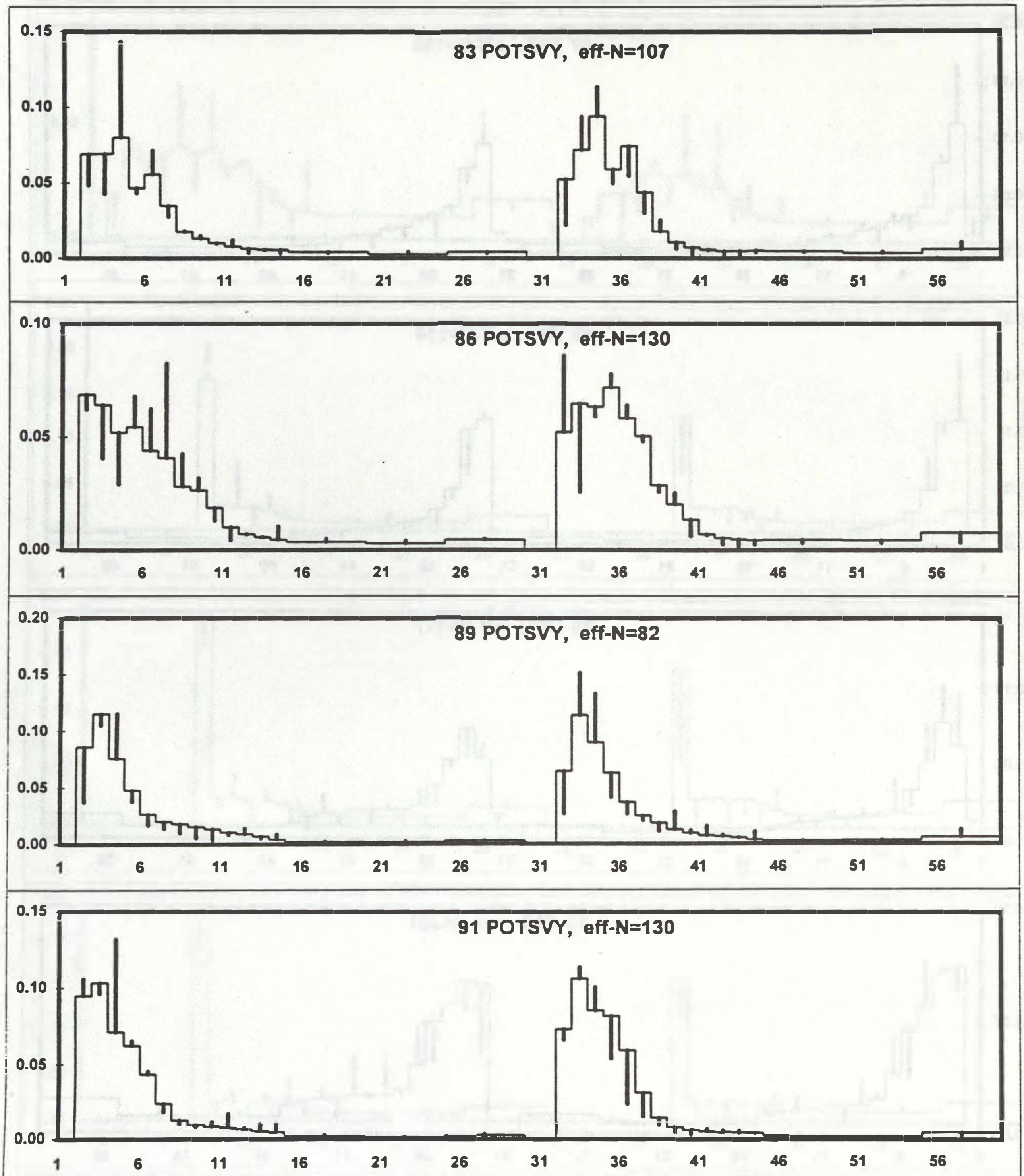
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 30

TRAWL FISHERY AGE COMP.



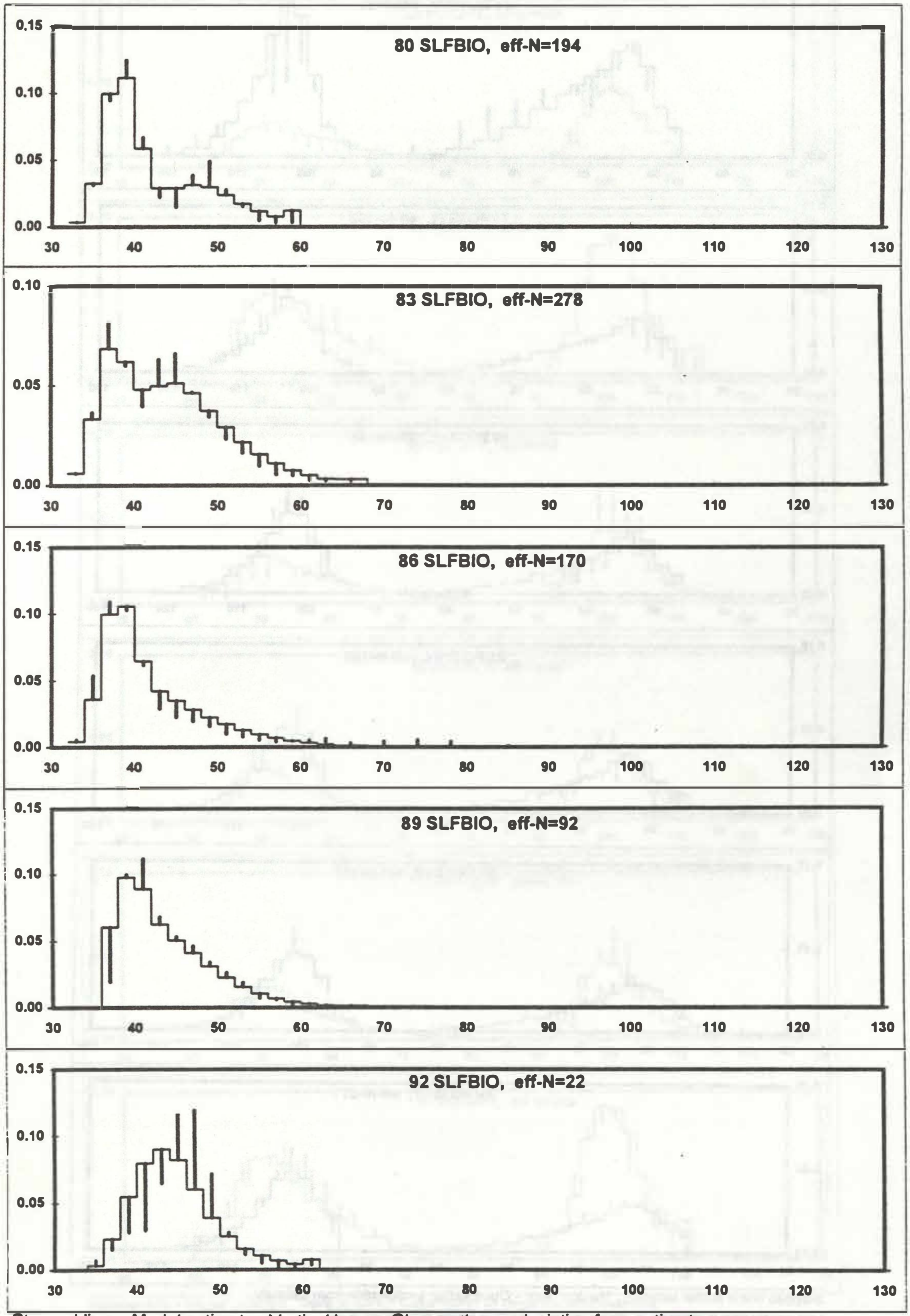
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 30

POT SURVEY AGE COMP.



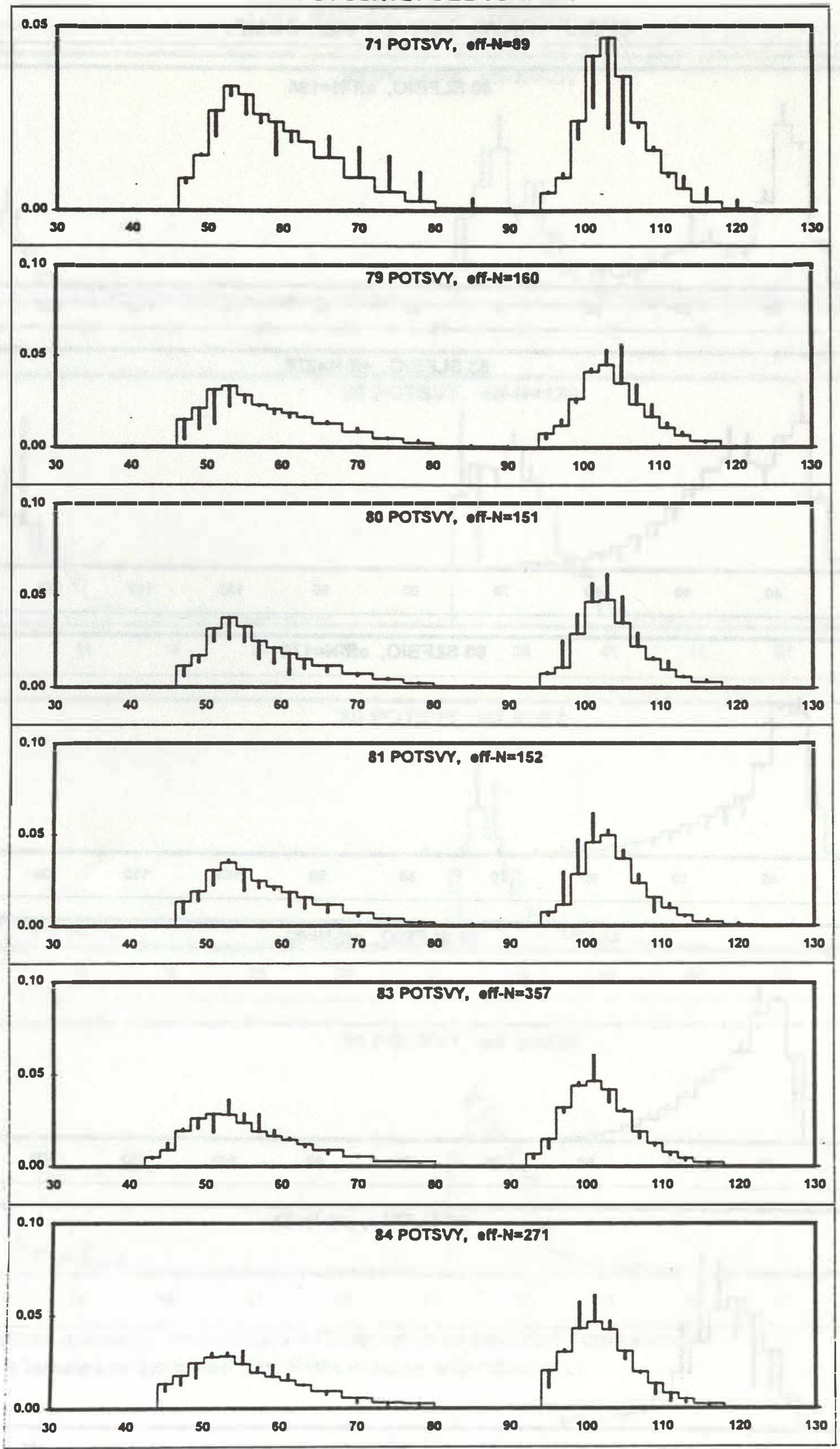
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 30

SHELF TRAWL SURVEY SIZE COMP.



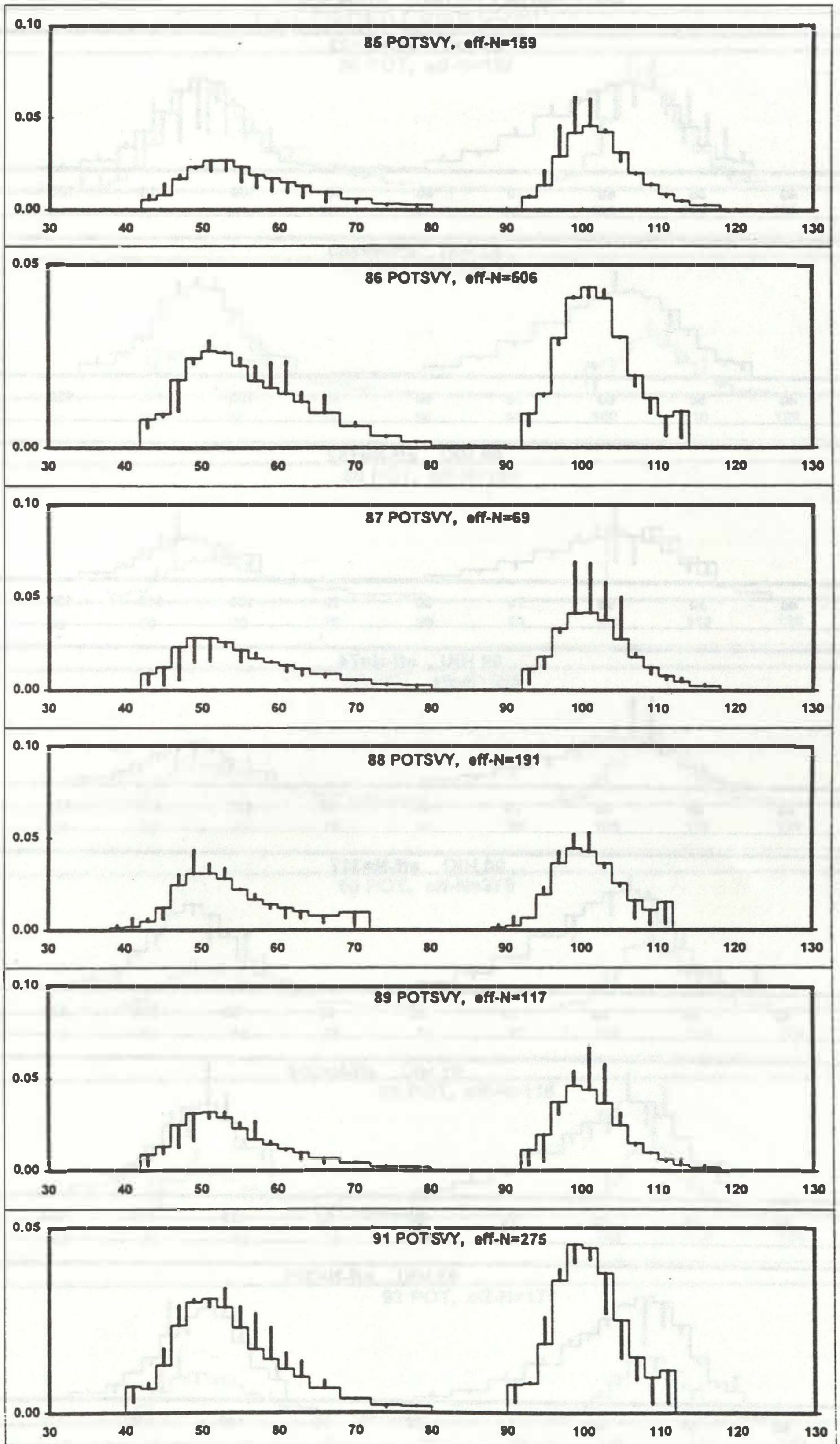
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 50

POT SURVEY SIZE COMP.



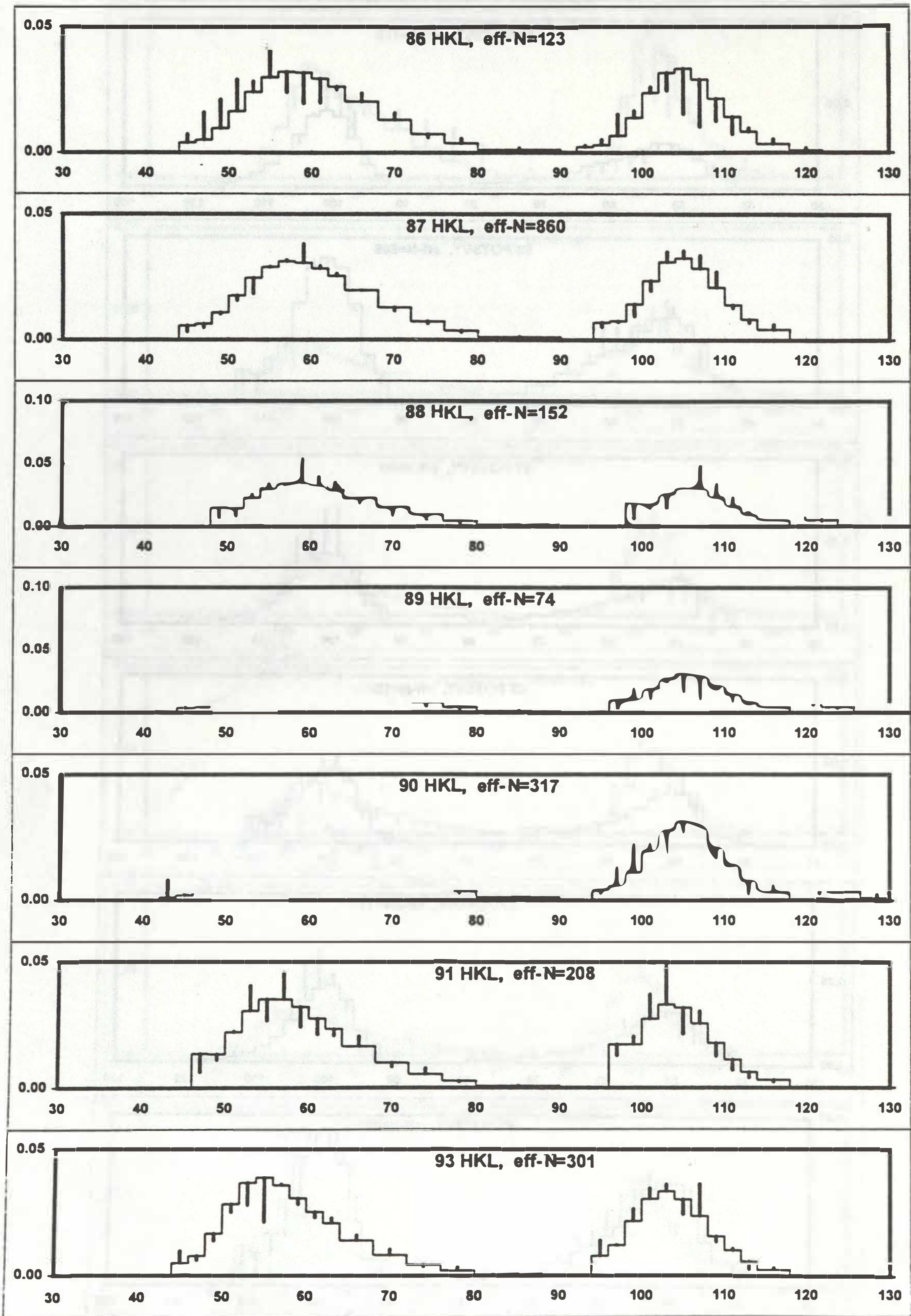
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 50

POT SURVEY SIZE COMP.



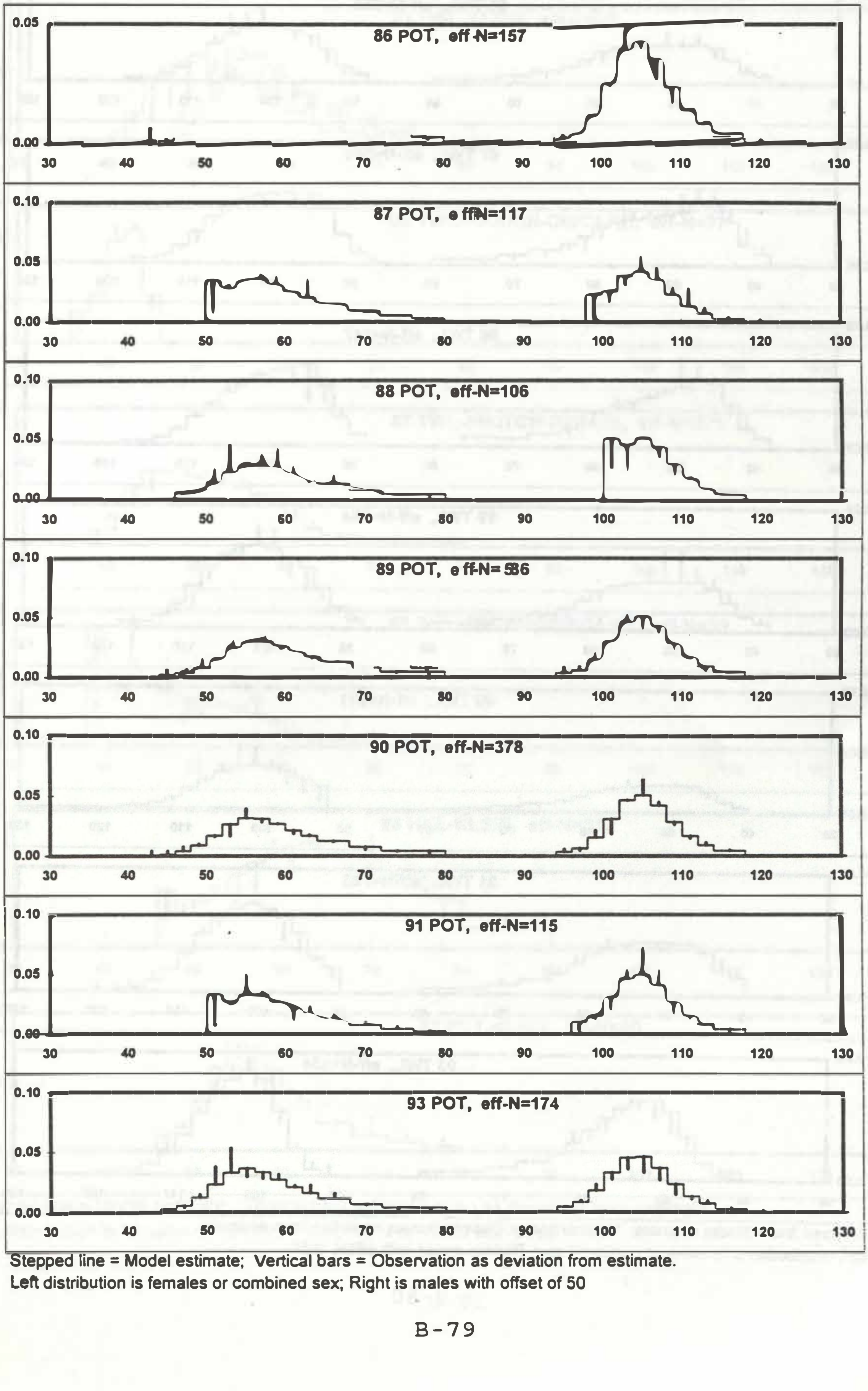
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 50

LONGLINE FISHERY SIZE COMP.



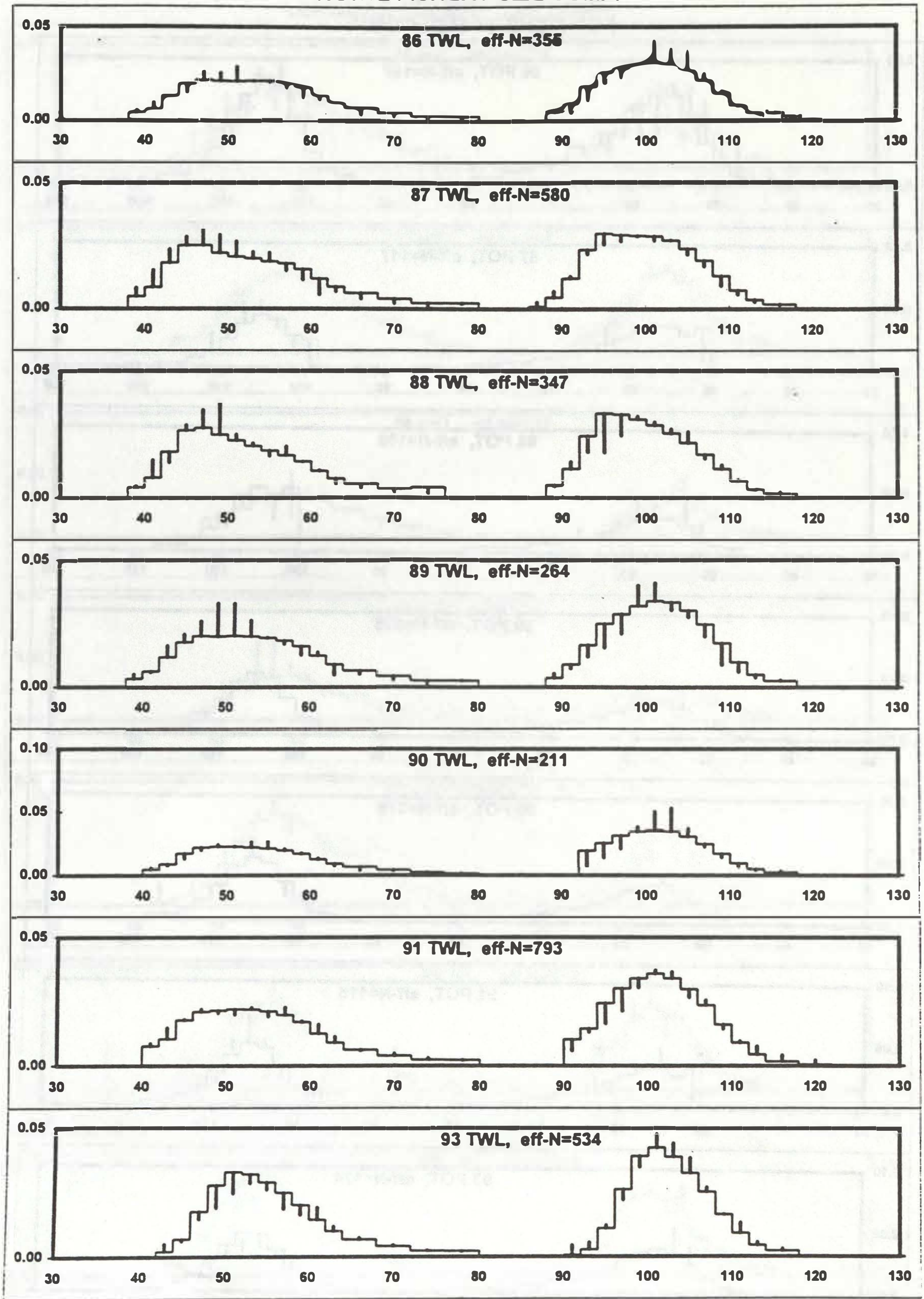
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 50

POT FISHERY SIZE COMP.

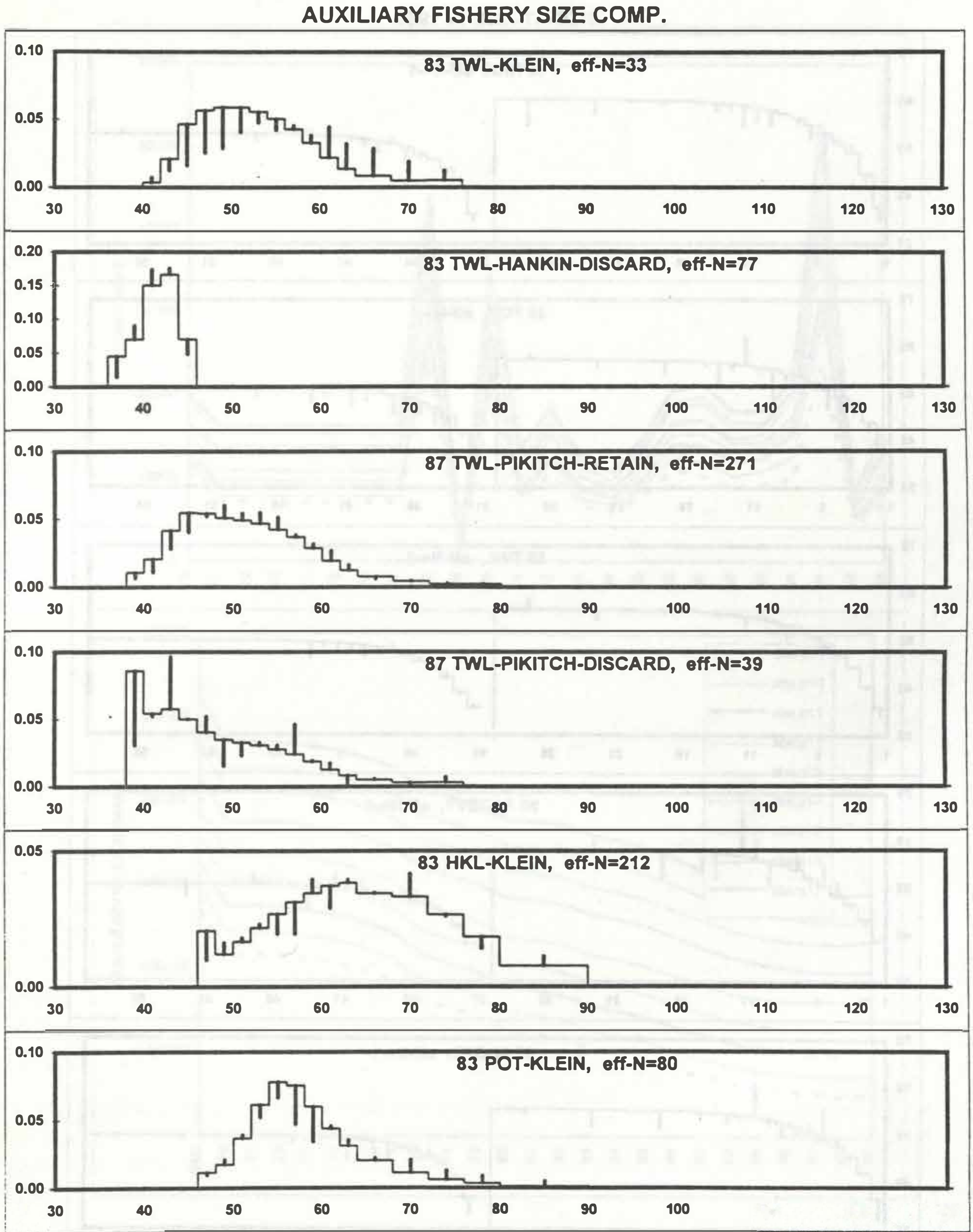


Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 50

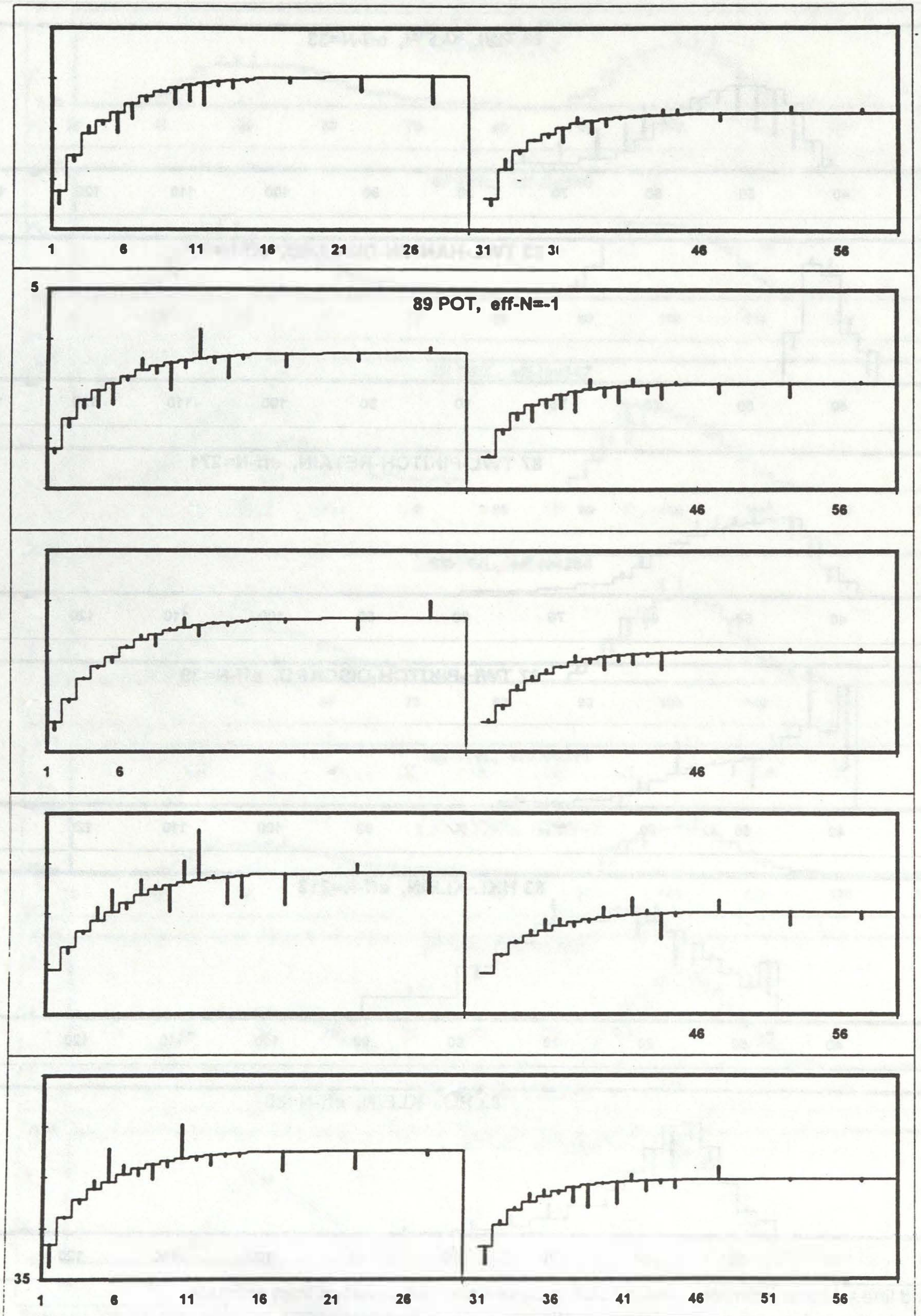
TRAWL FISHERY SIZE COMP.



Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 50



Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 50



Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.
Left distribution is females or combined sex; Right is males with offset of 30

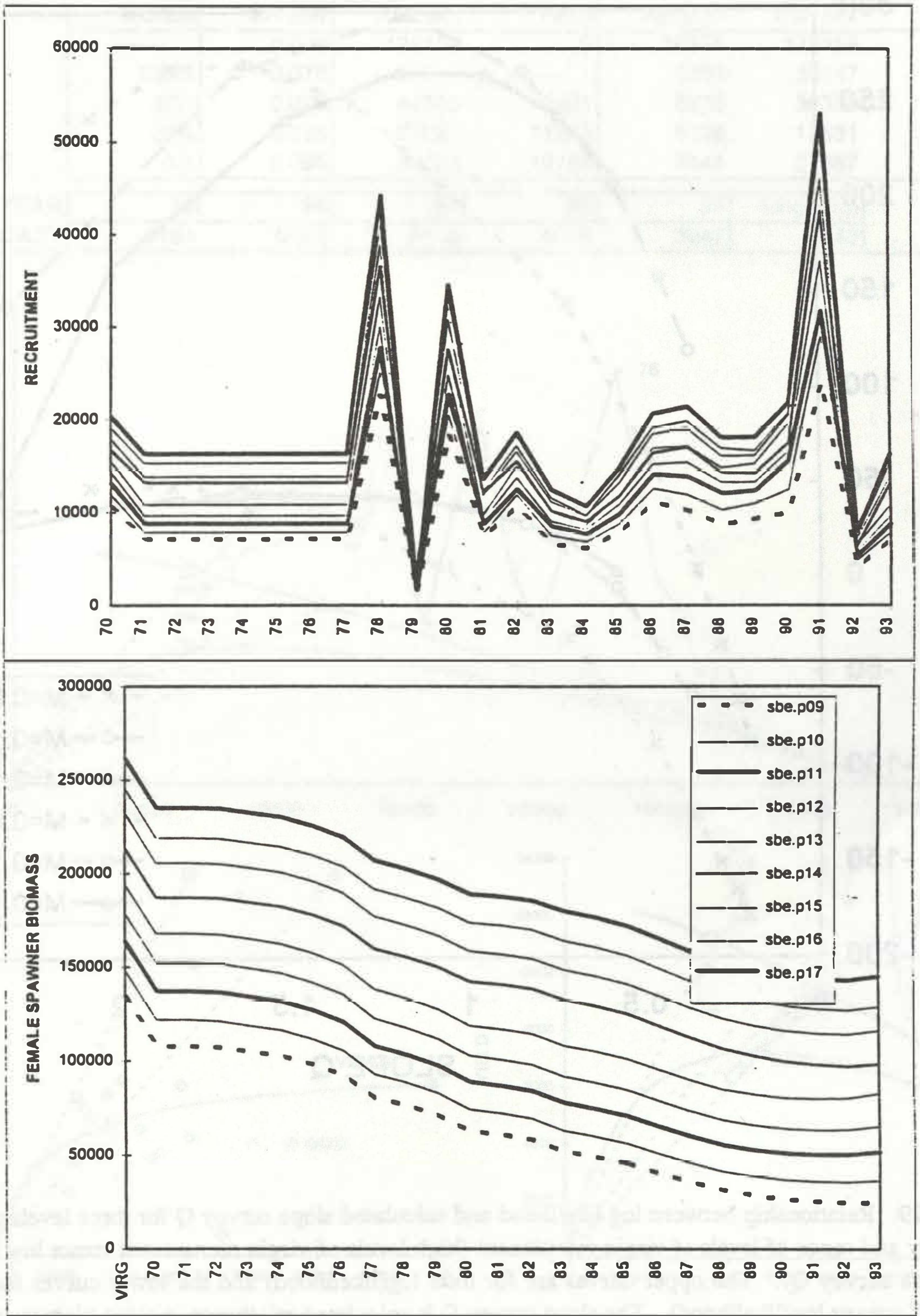


Figure 28. Estimated time series of recruitment and female spawning biomass for 9 levels of virgin recruitment in the third model configuration (10x emphasis on all trawl shelf surveys, nil on pot surveys).

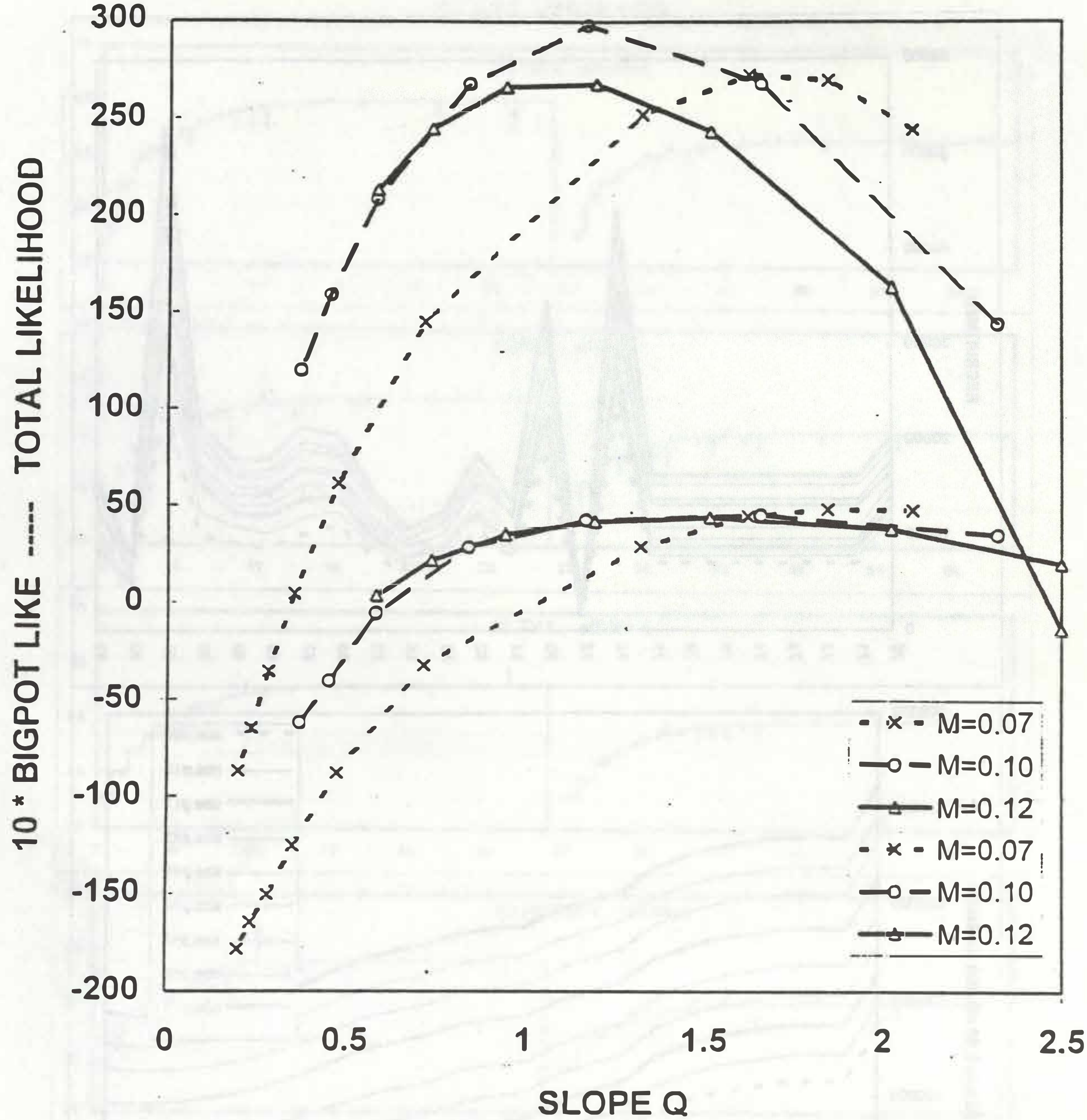


Figure 29. Relationship between log likelihood and calculated slope survey Q for three levels of natural mortality and range of levels of virgin recruitment (high levels of virgin recruitment create low estimates for slope survey Q). The upper curves are for total log(likelihood) and the lower curves for 10x the BIGPOT survey log(likelihood). The slope survey Q is calculated relative to a slope biomass of 42,937 mt for the 100-499 fathom depth range; about 36,000 mt of this biomass is in the Mon-Van area.

	ENTER CRITER.	EXPLOIT	CONSTANT RECR. F.SP.BIO.	CONSTANT RECR. YIELD	DEN.-DEP. RECRUIT. RECRUIT	DEN.-DEP. RECRUIT. F.SP.BIO.	DEN.-DEP. RECRUIT. YIELD
VIRGIN	——	0.000	135156	0	10775	135156	0
MSY	0.889	0.076	——	——	8263	36147	7221
SPR	35%	0.076	47305	9401	8275	36336	7218
SPR	20%	0.136	27031	11243	5336	13531	5556
YLD. SLOPE	0.1	0.095	39082	10188	7444	27087	7030

YEAR	95	96	97	98	99	long-term
FORECAST	6154	6163	6115	6018	5947	7943

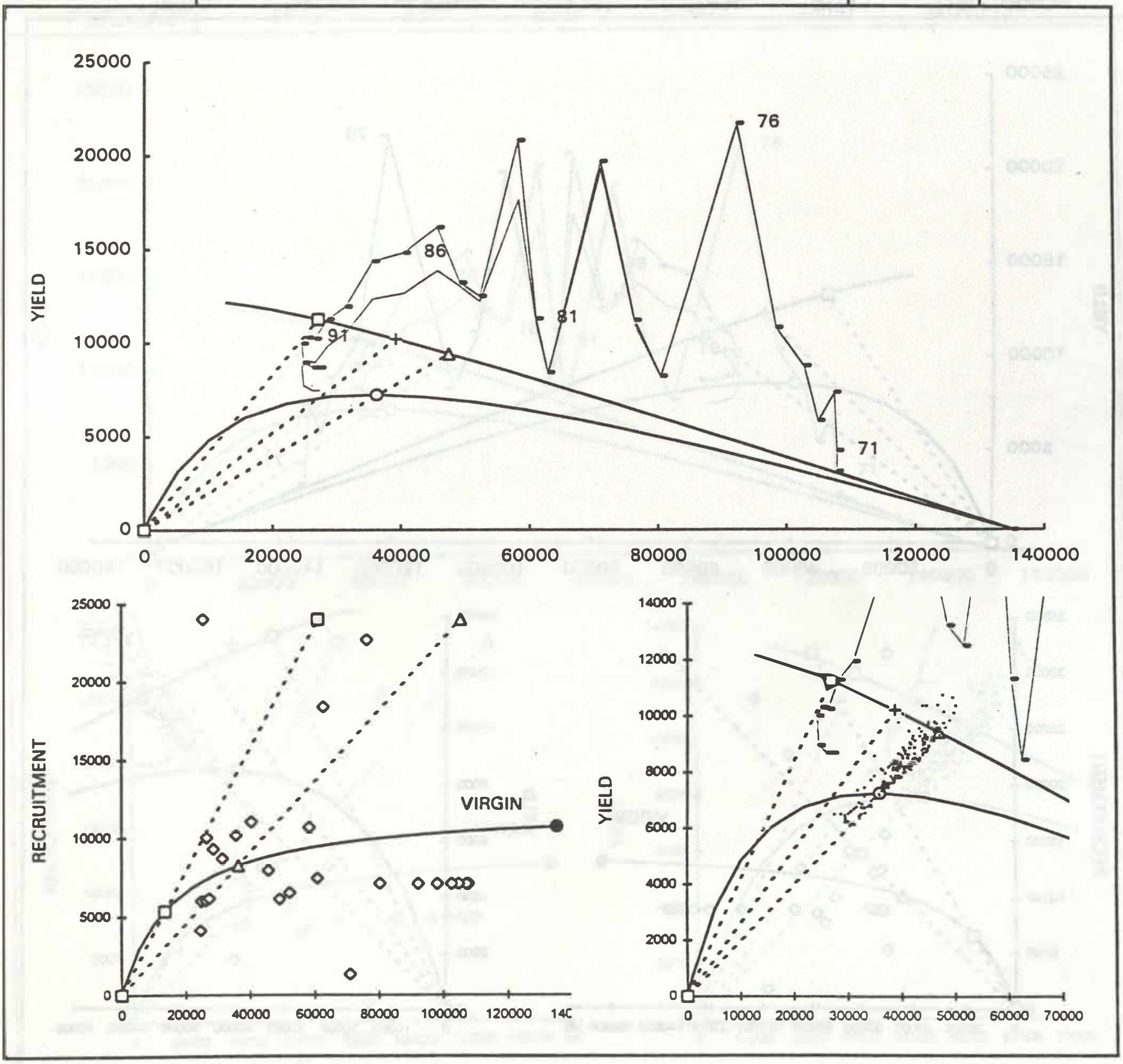


Figure 30. Summary of sablefish history, short-term and long-term projection for the conservative model run with nil pot survey emphasis, virgin recruitment equal to 10,775 thousand fish, and slope survey Q calculated to be 1.13 {0.97 relative to the Mon-Van area}. See text for description.

	ENTER CRITER.	EXPLOIT	CONSTANT RECR. F.SP.BIO.	YIELD	DEN.-DEP. RECRUIT. RECRUIT	F.SP.BIO.	YIELD
VIRGIN	——	0.000	164207	0	13169	164207	0
MSY	0.889	0.082	——	——	9746	39429	8534
SPR	35%	0.075	57472	11136	10090	44146	8521
SPR	20%	0.135	32841	13285	6529	16439	6574
YLD. SLOPE	0.1	0.098	45457	12241	8869	30630	8242

YEAR	95	96	97	98	99	long-term
FORECAST	11416	10977	10533	10098	9744	10458

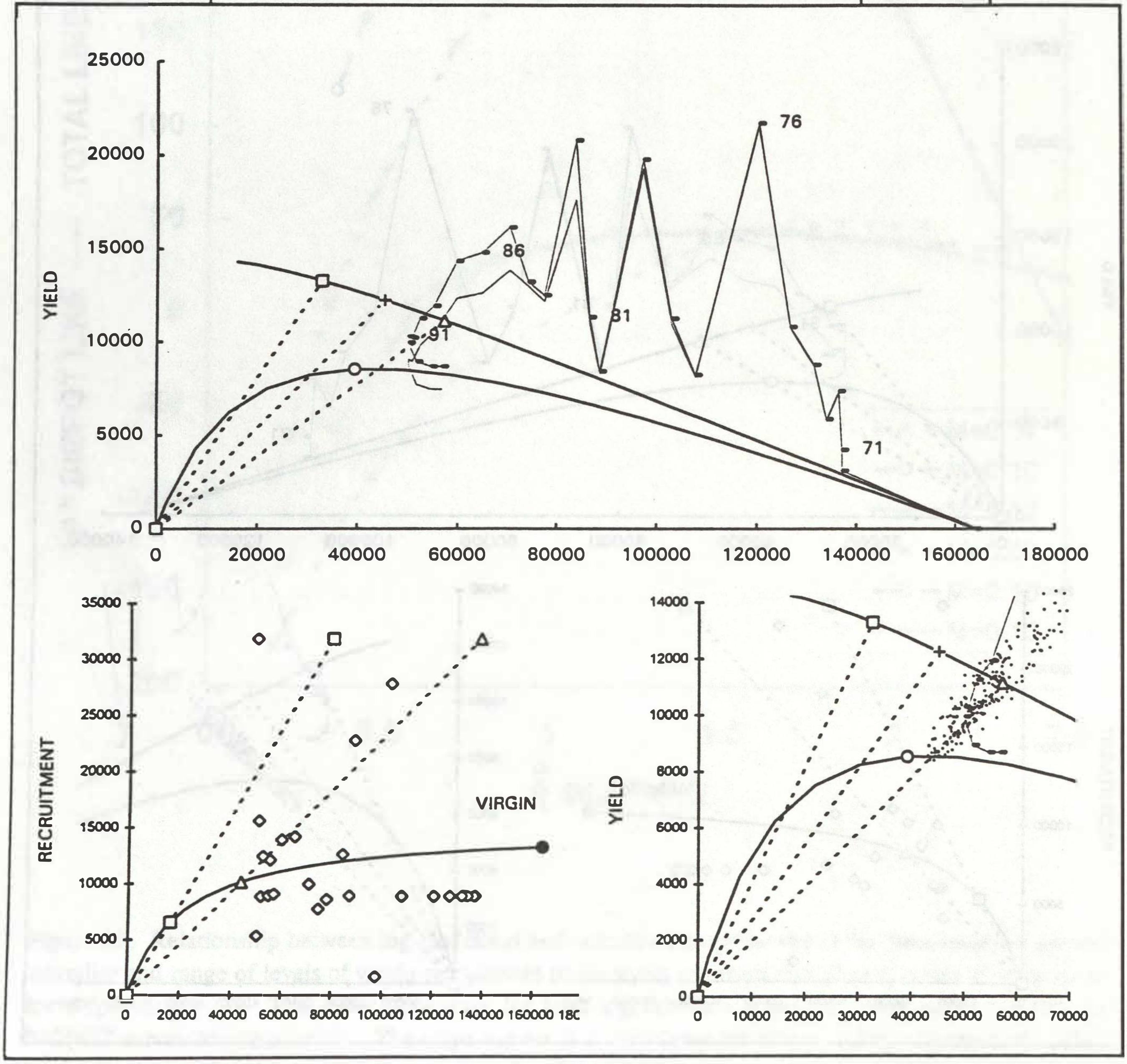


Figure 31. Equilibrium calculation for the optimistic model run with nil pot survey emphasis, virgin recruitment equal to 13,169 thousand fish, and slope survey Q calculated to be 0.64 {0.53 relative to the Mon-Van area}.

	ENTER CRITER.	EXPLOIT	CONSTANT RECR. F.SP.BIO.	CONSTANT RECR. YIELD	DEN.-DEP. RECRUIT. RECRUIT	DEN.-DEP. RECRUIT. F.SP.BIO.	DEN.-DEP. RECRUIT. YIELD
VIRGIN	——	0.000	148861	0	11972	148861	0
MSY	0.889	0.071	——	——	9377	42620	7839
SPR	35%	0.075	52101	10233	9176	40020	7834
SPR	20%	0.135	29772	12258	5928	14903	6056
YLD. SLOPE	0.1	0.097	41511	11240	8082	28108	7578

YEAR	95	96	97	98	99	long-term
FORECAST	8767	8571	8334	8069	7859	9426

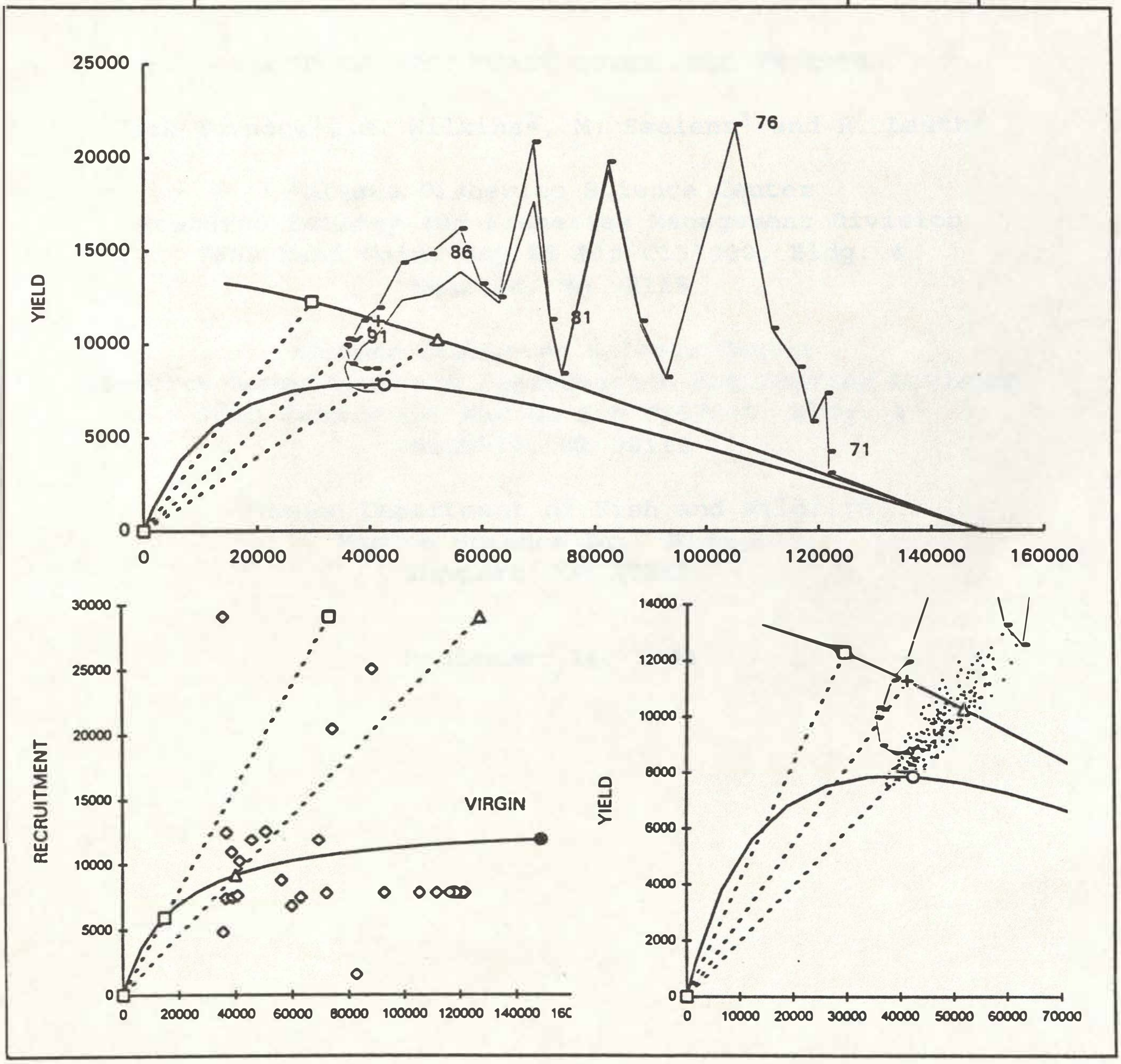


Figure 32. Equilibrium calculation for the intermediate model run with nil pot survey emphasis, virgin recruitment equal to 11,972 thousand fish, and slope survey Q calculated to be 0.82 {0.68 relative to the Mon-Van area}.

APPENDIX C
DOVER SOLE

STATUS OF WEST COAST DOVER SOLE IN 1994

Jack Turnock[1], M. Wilkins[2], M. Saelens[3] and R. Lauth[2]

[1]Alaska Fisheries Science Center
Resource Ecology and Fisheries Management Division
7600 Sand Point Way NE Bin C157000, Bldg. 4
Seattle, WA 98115

[2]Alaska Fisheries Science Center
Resource Assessment and Conservation Engineering Division
7600 Sand Point Way NE Bin C157000, Bldg. 4
Seattle, WA 98115

[3]Oregon Department of Fish and Wildlife
Marine Science Dr., Bldg 3
Newport, OR 97365

September 16, 1994

ABSTRACT

Size and age composition data from the INPFC Eureka and Columbia areas were analyzed by the length-based version of stock synthesis, a separable catch-at-age model. For both areas, separate fishery selectivities were estimated for several time periods to fit the changes in size, age and fraction female. In both areas the model was run at various levels of virgin recruitment to generate a range of fits to slope survey abundance estimates. Runs with the slope survey ratio (Q which equals the observed slope survey biomass divided by the population biomass after survey selectivities are applied) between 0.5 and 1.0 were taken as a plausible range of biomass levels. In the Eureka area, recent landed catches have declined to 3,062 mt in 1993. MSY, estimated under an assumed level of density-dependent recruitment is 3,176 to 5,779 mt for the low and high biomass scenarios respectively. The 1994 female spawning biomass is estimated to be below the F20% level for the low biomass scenario and just above the F20% level for the high biomass scenario. The recommended yield for 1995 is calculated by applying F35% (fishing mortality that reduces female spawning biomass per recruit to 35% of its unfished level) to the exploitable biomass. This results in a yield of 1,067 mt (landed catch 952 mt and discard 114 mt) to 3,797 mt (landed catch 3,475 mt and discard 322 mt) for 1995. The current quota in the Eureka area is 3,500 mt. In the Columbia area, MSY, estimated under an assumed level of density-dependent recruitment, is 2,948 mt and 3,894 mt for the low and high biomass runs respectively. The 1994 female spawning biomass is estimated to be at the target level (F35%) for the high biomass scenario and at the F20% level for the low biomass scenario. The low and high biomass range produce 1995 yields (applying F35%) of 1,670 mt (landed catch 1,561 mt and discard 109 mt) and 3,726 mt (landed catch 3,503 mt and discard 223 mt) respectively. The current quota for the Columbia area is 4,000 mt with a harvest guideline that steps down from 6,000 mt in 1993 to 4,000 mt in 1995. The lower recommended yields in the Columbia area for this assessment compared to the last assessment (Turnock and Methot, 1992) are mostly due to a lower estimate of biomass for the 1992-93 slope surveys that covered the entire Columbia area from previous surveys in 1988 and 1989. Previous surveys covered only the central Columbia area and were extrapolated to the entire area.

INTRODUCTION

The Dover sole (*Microstomus pacificus*) fishery has a long history with landings of over 5,000 mt per year coastwide in the 1950's to a high of 20,329 mt in 1985. In 1993 coastwide landed catch of Dover sole was 14,300 mt, down from the 1992 catch of 16,007 mt. Nearly all Dover sole are caught and landed by trawlers.

This assessment covers the Eureka and Columbia INPFC areas. The last assessment for both areas was in 1992 (Turnock and Methot 1992). Length data for 1992 and 1993 have been added for the Eureka area, and age and length data for 1992 are added in the Columbia area. No sampling for Dover sole was conducted in the Columbia area in 1993.

The changes in size and sex ratio of fish in the catch, possibly due to changes in the depth of fishing, were modeled by estimating additional parameters that change the fishery selectivities over time for both the Columbia and Eureka areas. Shelf survey abundance and size compositions were added to the model to represent small fish in the 30 to 200 fathom range not fully represented in the slope surveys. The slope surveys conducted in the Columbia area in 1992 and 1993 were combined to estimate biomass for the total Columbia area. The role of the slope surveys was changed from the 1992 assessment in the Columbia area, which will be discussed in the section on surveys.

CATCH BIOMASS

Columbia - US Vancouver

Figure 1 shows a map of the INPFC west coast assessment areas. Landed catch data for the Columbia and US Vancouver areas were obtained from the Pacific Marine Fisheries Commission (PMFC) Data series. This data source precedes the Pacific Fishery Information Network (PacFIN) data base which begins in 1981. Data from the PMFC data series was used in the assessments because its adjustments to area of catch are more accurate than the area of catch reported in PacFIN. The PMFC series uses logbook data for area adjustments for data from Oregon (not for California or Washington), and the PacFIN data series uses primarily port of landing. The PMFC series is limited to groundfish trawl gear only. Nearly all Dover sole are captured and landed by trawl, but small amounts are also caught by other gear types, particularly shrimp trawl.

In the Columbia area, landed catch was relatively stable from 1956 through 1977, averaging 1,940 mt (Table 1). The maximum landed catch during this period was 2,516 mt. In 1978 catch increased, reaching the highest levels in 1982 and 1983 at 7,223 and 6,732 mt. Landed catch declined somewhat during the 1984-87 period and in 1988 again exceeded 7,000 mt. Catch declined from a high of 9,016 mt in 1989 to 5,652 mt in 1993. Since 1966 118,803 mt have been harvested in the Columbia area and the average annual harvest during 1983-93 was 6,274 mt. No assessment was conducted for the Columbia area in 1993. The Acceptable Biological Catch (ABC) for 1992 and 1991 was 6,100 mt, which was lowered from the 1990 ABC of 11,500 mt. The ABC for the Columbia area in 1993 was lowered to 4,000 mt based on the 1992 assessment, however, a harvest guideline was recommended to step down the catch from 6,000 mt in 1993, 5,000 mt in 1994, to the ABC of 4,000 mt in 1995. The coastwide catch in 1993 was 14,300 mt which was lower than the coastwide ABC of 15,900 mt. The coastwide harvest guideline in 1993 was 17,900 mt.

In the US Vancouver area, landed catch was relatively minor between 1956-79 averaging about 450 mt annually. Beginning in 1976 landed catch began to increase and since 1979 catch has exceeded 1,000 mt each year. The record landed catch of 3,178 mt occurred in 1984. Landed catch was 1,499 mt in 1993, which was lower than the ABC of 2,400 mt.

Eureka - Monterey - Conception

Landed catch data for the Eureka, Monterey, and Conception areas also used the PMFC data series for the period 1955 - 1980. PacFIN data were used beginning in 1981. Pre-1981 CDFG landing statistics were adjusted to account for shipments of Dover sole between INPFC areas due to the previous method of accounting for shipments into a port. Total Eureka area landings were obtained by adding PMFC area 2A (California-Oregon border to Cape Blanco) values to the California values.

In the Eureka area, landed catch remained relatively stable from 1955 - 67, averaging 2,590 mt annually. Beginning in 1968, landed catch rose to highs of about 7,500 mt in 1975-76. Since 1976, landed catch has gradually declined to 3,062 mt in 1993. The cumulative catch since 1966 has been 143,017 mt and the average annual catch during 1983-93 was 4,403 mt. The ABC in the Eureka area was reduced from 4,900 mt to 3,500 mt for 1993 based on the 1992 assessment.

Dover sole landings in the Monterey area exhibit a pattern similar to the Eureka area. Catch was stable at a lower level during the 1950's through the late 1960's, followed by gradual growth through the 1970's, then moderate fluctuations in the most recent 10 year period. The largest annual catch was 4,850 mt occurring in 1977 and 1978. In 1993 catch was 2,874 mt, which is lower than the ABC of 5,000 mt. Average landings during 1983-93 have been about 3,718 mt.

The groundfish trawl fishery in the Conception area has historically been centered in the Morro Bay - Port San Luis area, with little groundfish trawling from more southerly ports. Table 1 indicates that landings were minimal until 1983, at which time a deep water trawl fishery began in winter as a result of an influx of trawlers from northern California and Oregon. Relatively virgin trawl grounds and an absence of market landing limits provided excellent fishing, thus landings increased dramatically. Since the development of this fishery, mean annual landings have been 1,565 mt (1983 to 1993). Currently, resident trawl vessels fish for Dover sole throughout the year. The ABC is 1,000 mt, which was lower than the 1993 catch of 1,213 mt.

SAMPLE DATA

Size and age composition of the catch in the Eureka area is based on port samples collected by the California Department of Fish and Game (CDFG). The catch by vessels fishing in the northern portion of the Eureka area and landing at Oregon ports is assumed to have the same characteristics as the catch landed at California ports. Only ages from 1981 to 1989 which were estimated from otoliths by the break and burn method were used in the analysis. Otoliths were read by personnel of the CDFG.

Size and age composition of the catch in the Columbia area is based on port samples collected by the Oregon Department of Fish an Wildlife (ODFW). Data for the northern (PMFC area 3A) and southern areas (PMFC areas 2B-2C) were combined for the analysis. A substantial proportion of the catch in area 3A is landed in Washington ports. Sample data from these landings has not been analyzed; all catch in the Columbia area is assumed to have the same characteristics as indicated by the Oregon samples. Age determinations in the Columbia area were made by ODFW personnel. Prior to 1985 age composition was determined by the scale reading method. These data greatly underestimate ages and have not been used in the analysis.

Sampling has been conducted using a fixed number of fish (usually 50 or 100). When several samples of fixed numbers from a given area/time strata are combined, the samples composed of larger fish make an excessive contribution to the total. Samples based on fixed sample biomass (not fixed numbers) are unbiased in this regard. The available sample data were adjusted by using a length-weight relationship to predict the total sample biomass from the length composition of the fixed number of fish, then weighting each sample's contribution to the total according to the ratio of a reference sample biomass to the predicted sample biomass.

Sex composition

In the Eureka area the sex ratio has varied considerably over time. During the early 1970s the fraction female was less than 0.45, during the late 1970s the fraction was 0.6-0.7, during the early 1980s the fraction declined again to less than about 0.4, and since 1984 the fraction has been near 0.5. In the Columbia area the fraction female was about 0.7 during 1966 - 1983. The fraction declined abruptly in 1984 to about 0.4-.45, then increased to 0.50 in 1992.

Size composition

Size composition data for 1966 to 1992 in Columbia area and for 1971 to 1993 in the Eureka area are presented in Figures 2 through 5.

Eureka

The mean size of male Dover sole landed in the Eureka area declined from about 40 cm in 1972 to about 39 cm in 1977-83 (Table 2). In 1985 the mean size dropped sharply to 35.4 cm, was 36-37 cm in 1986-89 then declined to 35 to 36 cm in 1990-93. The mean size of female Dover sole landed in the Eureka area declined from about 43 cm in 1972 to about 42.5 cm in 1976-82. In 1983 the mean size dropped sharply to 40 cm and was less than 39.5 cm in 1985-86. Mean size was about 40 cm in 1989-93. The sharp changes that occurred in the early 1980's are consistent with changes in the Eureka area market for Dover sole. In early 1983 the contract with the US Army for deep water Dover sole was terminated so the fishery probably reduced its level of effort directed at larger Dover sole. Also through this time period the minimum market limit was reduced from 13.5 inches (34.3 cm) to 13 inches (33.0 cm)(Larry Quirollo, pers. comm.) so the fishermen may have increased retention of small fish, and perhaps increased targeting on areas containing smaller fish. Also, there has been an increased use of roller gear and nets with less than 4.5" mesh. However, logbook data indicating the depth of fishing activity does not corroborate this pattern. The depth of catch in the Eureka area has gradually shifted into deeper water, which will be discussed in a later section.

Columbia

The mean size of male Dover sole in the Columbia area has been smaller than their mean size in the Eureka area, declining from about 38-39 cm during the late 60's-early 1970s to about 36 cm by 1980, then dropping to about 33-35 cm during the mid-1980s to 1992 (Table 2). The mean size of female Dover sole in the Columbia area was about 41-42 cm during the late 60's-early 70's , then fluctuated during the 1970's, but seemed to drop from about 41 cm in the 70's to 40 cm by 1980, then dropped to about 37-39 cm in 1984-92. Demory et al. (1984) present data indicating that the mean size of female Dover sole in the PMFC area 3A (northern Columbia area) was nearly 45 cm during the early 1950s. Discard studies in the Columbia area (see below) indicate that the size at 50% retention dropped by about 2-3 cm between 1974 and 1985-87. This change would affect the mean size of retained Dover sole, and the time series of mean size indicates that the change in retention probably occurred fairly rapidly in about 1984. Interestingly, the mean depth of fishing effort (from logbooks) and the mean depth at which Dover sole are captured (from logbooks) increased by about 50 fathoms during the early 1980s (see below). This shift in the depth of fishing should have increased, not decreased, the mean size of Dover sole.

Age composition

Eureka

Age compositions in the Eureka area are relatively flat with appreciable numbers of age 5-7 fish and about 8% at least 25 years old (Figures 6a and 6b). Mean age has ranged from 13.5 to 17.1 years (except for the anomalous year 1983)(Table 3).

Columbia

In the Columbia area the age distributions are generally more peaked than in the Eureka area (Figures 7a and 7b). However, the low number of age 5-7 fish during 1985-1988 may be partially due to a difference in aging criteria between the CDFG and ODFW readers for these young fish. In 1989 and 1991 there were more young fish in the Columbia area samples and there probably was a convergence in aging criteria between the two states at this time. In 1990 the age composition was very flat with a mean age of 14.6 for females and 15.5 for males. The mean age declined in 1991 and 1992 to near the 1989 values of 12.7 and 13.3 for females and males respectively.

Discard

Size-specific retention and aggregate retained biomass has been determined in several voluntary observer programs conducted in Oregon. In 1974 the size at 50% retention was 32.6 cm for males and 33.3 cm for females (ODFW, unpubl. data) (Table 4). By 1985-87, the size at 50% retention had declined to 30.3 - 30.4 cm (Pikitch, unpubl. data). This increase in the retention of small Dover sole is mirrored in the Eureka area where the minimum size accepted by processors declined from 14 inches (35.6 cm) to 13 inches (33.0 cm) over a similar time period (L. Quirollo, unpubl. data).

Total discard biomass was reported as 11% during 1950-53 and 20% during 1959-61 (Herman and Harry, 1963). A small sample in 1974 indicated discard of 17% (ODFW, unpubl. data). By 1982, discard had fallen to 7% (Barss and Demory, 1985), and during a large study in 1985-87 (Pikitch et al. 1988) the level of discard was only 5% (Pikitch, unpubl. data).

Retention of fish is modeled as a logistic function of size with two parameters estimated by the synthesis model, the size at 50% retention and the slope. To fit the observed fishery size and age composition data, the synthesis model first applies the selectivity function then applies the retention function. The discard biomass is estimated by partitioning the catch at age numbers into landed and discarded components from the retention at age, and then applying the weight at age. The retention at age is estimated from the retention at size and the size at age for fish selected by the fishery. In the Eureka area the retention function changes in 1982 to a lower length at 50% retention. In the Columbia area there are three different retention function: 1966 to 1981, 1982-1986, and 1987 to 1994.

In the Columbia area the size composition of the discarded fish from the 1985-1987 study (Pikitch et al. 1988) was included as an observation (Figure 8). The likelihood for the fit to the discard size composition data is added into the fishery size composition likelihood. The estimated size composition of discarded fish is estimated by comparing the fish that are selected and the fish that are retained. This puts some constraint on the fishery selectivities to fit the observed discard size composition. Also, the time series of discarded biomass from (Barss and Demory 1985) for 1966 to 1981 was input as data to the model. From 1982 to 1994, the discard was estimated to be 5% of the landed catch based on the 1985-87 study (Pikitch et al. 1988). This results in a likelihood component for catch in the model resulting from the fit to the observed discards. In the Eureka area discard was assumed to be 10% of landings for the period 1970 to 1981 and 5% from 1982 to 1994.

Migration

Our ability to conduct area-specific assessments of Dover sole is dependent on the observation that Dover sole do not make long migrations. Tag recoveries typically are from within the INPFC area of tagging, and indicate there may be three groups of Dover sole in the Columbia area separated by major terrain features such as the Astoria Canyon and Cape Blanco (Demory, et al. 1984). Adult Dover sole, particularly females, undertake offshore migrations beginning in late fall and extending through the spawning season (Demory, et al. 1984). Females return to shallower waters in the spring. Westrheim, et al. (1992) summarized analyses on tagging experiments for the west coast from California to British Columbia and concluded that little north-south movement of adults occurs and that seasonal migrations are as observed by Demory, et al. (1984). However, intermingling of larvae from different stocks may be extensive as the pelagic larval stage of Dover sole may average about 21 months (Markle, Harris and Toole 1992).

Maturation

Harry (1959) estimated size at 50% mature to be 38 cm and size at 100% mature 42 cm in 1948-50. Using the same criteria as Harry (1959), Yoklavich and Pikitch (1989) found all fish greater then 32 cm to be mature by visual inspection from samples taken in 1985-86 in the Columbia area. This may indicate a decline in size at maturity or errors in determining whether fish were immature or spent in the study by Harry (1959). Very few fish were sampled at less than 32 cm by Yoklavich and Pikitch (1989) so size at 50% mature could not be estimated. Hunter et al. (1992) estimated maturity for Dover sole using various criteria from just prior to spawning and during the spawning season for Oregon and Central California samples. The size at 50% mature varied from 25 cm to 42 cm depending on the criteria used and the time of sampling. For Oregon and California data combined, the size at 50% mature was 33.2 cm prior to spawning and 38.9 cm during spawning. Hunter et al. (1992) reports 33.6 cm for the Oregon data and 29.8 cm for the Central California data as the best estimate of size at 50% mature. Here, we use estimates from studies during the spawning seasons of 1980-81 in the northern Columbia area that indicate a size at 50% maturity of 34.4 cm with a logistic slope of 0.36 (calculated from unpubl. data provided by W. Barss, ODFW). Since these samples were taken during the spawning season, size at 50% mature may be overestimated, however, 34.4 cm is close to the best estimate of 33.6 cm for the Oregon data reported by Hunter et al. (1992).

Length-Weight

The length-weight relationship used in this analysis is:

$$\text{weight (kg)} = .0000064 \ \text{length (cm)}^{3.1076}$$

as determined from samples collected in the Columbia area fishery.

Growth

Mean size at age data from fishery samples are presented in Figure 9. Age 10 females are about 3 cm larger than age 10 males. The size at age for younger fish is larger in the Eureka area than in the Columbia area, however, the curves are similar for the older fish. Size at older ages does not have an obvious asymptote. The growth curve fit by the synthesis model will utilize these size at age data. The growth curve was constrained to pass through 20.5 cm at age 3 (as determined from research trawl collections with fine mesh). The L_{inf} and K parameters were estimated by the model. The coefficient of variation of size at age was estimated from the fishery size-age data as 9% for age 5, and 8% for age 25.

Size at age in the Eureka area was anomalously high in 1983. Also, few old fish were observed in that year. Mean age decreased sharply, but mean size remained high. The cause of this anomaly is not certain. The extreme warm water of the ENSO may have altered the depth distribution of the fish. Also, the fishery lost a major contract for deep water Dover sole, but an increase in the mean depth of fishing was not obvious. Whatever the cause of this anomaly, we do not use the Eureka age composition and size at age data in 1983.

Natural mortality

Natural mortality was estimated using the maximum age method (Hoenig, 1983). The maximum observed age of a Dover sole is 45 years giving an estimate of M of 0.10. This is the value used in the 1991 and 1992 assessments, and in this assessment. Demory, et al. (1984) used values of 0.184 and 0.15 due to the underestimation of longevity by the scale aging method. Natural mortality has been estimated at 0.15 for Dover sole in Canadian waters (Jeff Fargo, pers. comm.), however, this value seems high considering the longevity of the fish.

Aging imprecision

Cross-reading of otoliths by ODFW and CDFG otolith readers occurred in September 1989 and February 1990. The results of the September 89 workshop indicate a moderate level of aging imprecision. The standard deviation of the 3 readings was linearly related to the mean of the 3 readings (zero intercept, slope = 0.141, r-square = 0.45).

Unfortunately, some aging bias was detected for Dover sole with ages less than about 15. For the 21 otoliths with at least one reader assigning an age less than or equal to 10, the mean of the ODFW ages was 2 years greater than the mean age assigned by the CDFG readers. Plots of one reader age versus the other reader ages indicate no substantial, and certainly no important, bias for older Dover sole. These differences may explain the size-at-age data presented above, where size-at-age for young (age <15 years) Dover sole in the Columbia area seems to lag about 3.5 years behind the size-at-age trend in the Eureka area. Size at older ages converges for the two areas. However, the size at age data for 1990 in the Columbia area (after the 1989 reader comparison was done) is similar to previous years, indicating that aging bias may not be the cause of the difference in size at age between areas.

Catch and effort by depth

Eureka

The distribution of trawl effort and catch by depth and year was calculated from logbook data from all bottom trawls. In the Eureka area in 1978-85 about half of the effort occurred shallower than 200 fathoms (Tables 5 and 6 and Figures 10 and 11). In 1986-91 effort decreased in depths less than 200 fathoms and increased in depths greater than 400 fathoms.

Catch has generally declined in all strata from 1978 to 1991, except in depths greater than 500 fm (Table 6 and Figure 11). In depths greater than 500 fm catch increased in the mid-eighties, then declined. The highest fraction of the catch in recent years is from the 200-299fm depth range.

Columbia

The depth distribution of bottom trawl effort in the Columbia area (Table 8) is 60-70 fathoms shallower than in the Eureka area in the early 80's. The mean depth increased from 94 fm in 1980 to 229 fm in 1990. The effort in >300 fm increased from about 3-7% of the total in the early 80's to about 33% of the total in 1990.

The mean depth of the catch has increased from 139 fm in 1980 to 241 fm in 1990 (Table 9). In 1980 about 50% of the catch came from less than 100 fm and about 7.5% from greater than 300 fm. In 1990 only 14% of the catch came from less than 100 fm while 31% of the catch came from greater than 300 fm.

Fishery CPUE

CPUE in the Eureka area declines by about 50 to 60% from 1978 to 1991 (Table 7 and Figure 12). In the Columbia area CPUE for all depths combined is flat, showing no trends (Table 10). CPUE in depths greater than 400 fm declined sharply in the late 80's, in both the Eureka and Columbia areas. The effort in both areas, in greater than 400 fm, increased dramatically in the late 80's. The shifts in CPUE are more likely due to changes in fishing strategy, e.g. increased targeting on thornyheads and arrowtooth flounder, than on a sudden loss of Dover sole fishable biomass. Thus, we do not consider a quantitative analysis of the catch per effort data to be reasonable.

SURVEY DATA

Slope survey

Eureka

A NMFS bottom trawl survey in November, 1990, estimated the biomass of Dover sole for the Eureka area at 18,368 mt. The survey covered depths from 100 to 700 fathoms. About 50% of the biomass is in depths from 300 to 500 fathoms, with about 24% in <300 fathoms and 26% >500 fathoms (Figure 13). Trawl sites were selected at random within each 100 fm depth strata along systematically placed track lines 9 nm apart approximately perpendicular to the depth contour lines (Raymore and Weinberg 1990). Trawls were towed for 30 minutes along the depth contour attempting to maintain the same depth throughout the tow. A modified Nor'eastern bottom trawl was used for all tows. Biomass estimates were made using the "area swept" method described by Alverson and Pereyra (1969).

The size composition for all depths for the 1990 Eureka survey indicates possibly two modes for females, one at about the same size as the mode for males (31 to 36 cm) and the other at sizes 43 to 47 cm (Figure 14g). The size of both males and females and the fraction female increases with depth (Figures 14a through 14h).

The 300-400 fathom depth range was surveyed in 1991 in the Columbia and Eureka areas (Table 11), as a check on the relative biomass between the Columbia and Eureka areas. The 1990 Eureka biomass estimate (18,368 mt) seemed low compared to the Columbia area slope survey estimates in 1988 and 1989 (when expanded to the total Columbia area: 47,215 mt and 53,978 mt respectively). The total area of the Columbia INPFC area is about twice that of the Eureka area. However, the cpue for the 300-400 fathom range was the same in 1991 in the Eureka area (47.8 kg/km) as in the 1990 Eureka survey (48.7 kg/km). The cpue was lower in the 300-400 fm strata Columbia area in 1991 (30.2 kg/km) than in 1989 (46.1 kg/km) or 1988 surveys (36.1 kg/km), but similar to the 1984 Columbia cpue (29.6 kg/km). The seemingly low biomass estimate for the 1990 Eureka area compared to the Columbia area could be due to using less wire out (scope) in the 1990 Eureka survey, which would make the net lighter on the bottom possibly allowing Dover sole to escape under the net.

<u>Columbia</u>

Surveys conducted by ODFW in 1973-76 (Demory et al. 1976; Barss et al. 1977), estimated biomass for the entire INPFC Columbia area. These surveys covered the entire Columbia area, although the entire area was not surveyed in a single year. The depth range surveyed was 10 to 300 fathoms off Washington and 10 to 400 fathoms off Oregon. Results were extrapolated to 500 fathoms by Demory et al. (1984). The greatest limitation with regard to interpretation of these survey data is the low amount of sampling in deeper water, and the use of roller gear (with an escapement factor of 3.90 relative to chain-disk gear) to collect these deep water samples. Demory et al. (1984) also expressed two concerns common to all trawl surveys: extrapolation of the results into untrawlable habitat, and assumed catchability of 1.0 when some preliminary Scottish studies indicated that a trawl catches only about half of the flatfish in its path. The estimate of biomass for the Columbia area was 6,500 mt for the 10-49 fathom depth stratum, 27,700 mt in 50-99 fathoms, and 62,000 mt in 100-499 fathoms for a total of 96,163 mt. The estimate of 62,000 mt for 100-499 fm depth range is used in 1975 for the ODFW trawl survey abundance estimate.

The recent slope surveys conducted by the NMFS occurred in 1984 (Raymore and Weinberg, 1990), 1988, 1989, 1992 and 1993 (Weinberg, unpubl. data) using similar methods as the 1990 Eureka survey. The 1984 survey covered the depth range 60 - 500 fathoms, and the 1988, 1989, 1992 and 1993 surveys covered 100 -

700 fathoms. The central Columbia area (2C) was surveyed in 1984, 1988, 1989 and 1993. In 1992 the northern (3A) portion of the Columbia area was surveyed and in 1993, the southern area (2B) was surveyed. The biomass estimates for the 2C area in 1993, the 2B area in 1992 and 3A area in 1993 were combined to give an estimate of the total Columbia area of 30,437 mt. In previous assessments the estimates of biomass from the central Columbia (2C) area were expanded to the total Columbia INPFC area. The unexpanded biomass estimates for the 2C area were 7,291 mt in 1984, 21,101 mt in 1988, 23,468 mt in 1989 and 9,698 mt in 1993. The biomass estimates in the central Columbia area indicate that the biomass increased in the 80's then declined sharply in the 90's. However, we do not use the 1984 survey because of its unreasonably low biomass estimate, especially for the 200-300 fathom depth range (Figure 15). A biomass that was that low could not have supported the increased catches that occurred during the late 1980s. All of the recent surveys were conducted with similar gear, all were in autumn (1989 was earliest and 1988 was latest). The 1984 survey tow speed was 3 kts, faster than the 2 kts used in the subsequent surveys. The net would be lighter on the bottom at a faster speed possibly allowing Dover sole to escape under the net.

The size of Dover sole and the fraction female in the 1988 and 89 surveys increased with depth (Figures 16a through 16h and 17a through 17h). An abrupt increase in size occurs at greater than 300 fathoms.

Shelf surveys

Shelf surveys were conducted by NMFS every three years from 1977 to 1992 on the west coast (Tables 11 and 12). The gear used was not the same as the slope survey gear and was not optimal for flatfish. The cpue in the 100-200 fathom range was generally about 25% of the cpue for the slope surveys in the 100-200 fm range for the Columbia area (Tables 12 and 13). This difference in the cpue for the slope and shelf surveys is similar to the differences found from comparing roller and disc gear of 1/3.9 (Barss et al, 1977. The shelf surveys used roller gear and the slope surveys disc gear. For the Eureka area the cpue in the 100-200 fm range increases over time to near the slope survey cpue in the 100-200 fm range. These surveys are included as a relative measure of abundance of small fish in shallow waters not covered by the slope trawl survey. In the Eureka area the biomass shows an increasing trend from 1977 to 1986 then decreasing to 1992. In the Columbia area the trend in biomass is flat.

STOCK SYNTHESIS ASSESSMENT MODEL CONFIGURATION

In the Eureka area the model was set up to run from 1971 through 1994. The configuration was the same as the 1992 assessment (Turnock and Methot 1992), except that a different selectivity function was used for the fishery. The population at the beginning of 1971 was assumed to be in equilibrium with the mean landed catch observed during 1956-70. In the Columbia area the model was run from 1966 through 1994 and was assumed to be in equilibrium with the mean catch observed from 1955 to 1965. The Columbia area runs started earlier because fishery size data are available beginning in 1966. The age at recruitment was age 5, and age 25 was set as the accumulator age. Age composition data were grouped into 13 bins: individual bins for ages 5 through 14, ages 15-19, 20-24, and ages 25 and older. Size composition data were grouped into 2 cm bins from 24 to 56 cm, with 58 and larger an accumulator bin. In both the Columbia and Eureka areas the selectivity function for the fishery was changed from the 1992 assessment to attempt to fit the age composition data better. In this assessment, the likelihood values for the male size composition, the female size composition, and the sex ratio data were calculated separately. The male and female data have always been separate in the Dover sole assessment, however, the fit to the size composition data and the sex ratio were not separated. This configuration separates the fitting of the female size composition, male size composition, and the sex ratio data.

Abrupt drops in mean size of landed fish suggest a change in the retention and/or selectivity patterns in the early 1980's. We assume here that the size-specific retention did change at about this time. In the Eureka area the retention function was estimated separately for two time periods (1970-1981 and 1982-1992). In the Columbia area three time periods were used (1966-1981, 1982-1986, and 1987-1992).

Selectivity curves

The fishery selectivity curve is composed of two logistic functions, an ascending and a descending function. The ascending side of the curve is the same for males and females and is based on length. The descending side however, is separate for males and females, and is based on age instead of length. A separate parameter is estimated that scales the male relative to the female curve on the descending side. The size at which the ascending and descending curves meet is estimated by another parameter separately for males and females.

Selectivity curves for various time periods were estimated by letting the model estimate parameters that fit changes in the fishery data. This resulted in changes to the selectivity curves that fit the changes in the fishery size and age data, which is assumed to be due the changes in markets and the depth of fishing and not in the population structure. In the Eureka area five selectivity time periods were used: 1971-74, 75-82, 83-85, 86-87 and 88-94. In the Columbia area seven time periods were used: 1966-72, 73-74, 75-77, 78, 79-81, 82-85, 86-94. The number of time periods was selected subjectively based on first estimating a selectivity curve for each year in the model and then combining the time periods where the selectivity curves were similar.

The selectivity curve for the slope and shelf surveys is the product of two logistic functions, one function for small fish and another for large fish. One selectivity curve was estimated for both males and females. The slope selectivity curves were fixed to be asymptotic in both the Eureka and Columbia areas. In the Eureka area the slope survey selectivity curve estimated by the synthesis model was linear starting at 0 at 24 cm and increasing to 1.0 at 58 cm. This resulted in a population biomass that was about three times the survey biomass(before selectivities were applied) with an estimated catchability of 1.0 for the survey. This seemed unreasonable, so the selectivity curve was fixed to be the same as the curve estimated by the model for the Columbia area 1993 slope survey. The fixed curve results in a lower ending biomass and a more conservative scenario than when the model is allowed to estimate the survey selectivity curve.

In previous assessments in the Columbia area the slope surveys in the central Columbia area and the ODFW survey were used together as one time series (Turnock and Methot 1992). This assumes that all the surveys had a similar Q and that the expansion of the central Columbia biomass estimates to the whole Columbia area was unbiased. In this assessment the 1975 ODFW survey is allowed to have it's own Q. The central Columbia area surveys in 1984, 88, 89 and 1993 have their own Q and are used as a trend indicator, not as absolute biomass. The combined biomass estimate for the whole Columbia area is used as absolute biomass in 1993.

In the Eureka area virgin recruitment was fixed at 7 levels: 17.5, 20.1, 28.8, 30.9, 34.0, 36.6, and 47.1 million age 5 recruits. This resulted in a range of estimated 1990 slope survey Q's from 1.04 to 0.35. In the Columbia area virgin recruitment was fixed at 6 levels: 21.25, 22.5, 25, 26.25, 30, 32.5, 35 and 37.5 million age 5 recruits. This resulted in a range of Q for the 1993 slope survey biomass from about 2.46 to 0.35.

Recruitment Assumptions

At the beginning of the time series the population is assumed to be in equilibrium with a specified level of virgin recruitment. In this assessment, the virgin recruitment level is fixed and all subsequent recruitments were estimated by the model for the Columbia and Eureka areas, except that recruitments in 1993 and 1994 were fixed at the median recruitment since there is insufficient data for their estimation by the model.

ASSESSMENT RESULTS

Eureka

The figures presented for the fits to the data are for the VR=30.86 million run (estimated 1990 slope survey Q=0.75), the fits for the Q=1.0 and Q=0.49 runs were very similar to this run. Fishery selectivities are higher for males than for females for the whole time period(Figures 18a and b). Selectivities for younger fish increase from the early to the late time periods.

The slope survey selectivity curve estimated by the model for the Columbia area increases sharply from 0 at 24 cm to about 1.0 at 34 cm with 50% selectivity at about 27 cm (Figure 19). The Eureka slope survey selectivities were fixed at the values for the 1993 Columbia slope survey. The estimated selectivity curve for the Eureka area (not used here) had a 50% selectivity at 44 cm. The fit to the female slope survey size composition shows too many small female fish, as would be expected by increasing the selectivities of small fish, and not enough males (Figure 20). The emphasis level on the slope survey size composition data was set low, so that the model did not try to fit the data, since the selectivities were fixed.

The shelf survey abundance estimates for the 30 to 200 fathom depth range show an increasing trend in the Eureka area from 1980 to 1986 then declines in 1989 and 1992(Figure 23). The biomass estimates from the synthesis model do not fit this trend but show declining abundance throughout the time period. The increase in shelf survey abundance may be an indication of changes in recruitment since this survey is in shallow water mainly catching small fish.

The best fit in the Eureka area was at VR=34.0 with a Q of 0.59 (Table 14), however, there is little change in the total likelihood between Q=0.86 and Q=0.35 runs. All emphasis values for the likelihood components shown in Table 14 were equal and set to 1.0. The fit to all likelihood components degrades as biomass levels decrease, except the fishery catch likelihood, which declines, but then improves again at the lowest biomass level (Q=1.04). The fishery catch likelihood is the measure of fit to the discard time series. The fit to the slope survey abundance is not shown, because it does not change since the Q is adjusted to fit it and it is only one observation, resulting in no deviation. The shelf abundance fits best at the highest biomass level(Q=0.35) and the shelf length composition fits best at Q=0.86 to Q=0.59. The age composition data show two peaks, with the highest likelihood occurring at Q=0.35. The lower peak occurrs at Q=0.86 to Q=0.75. The size composition data fit best at Q=0.59, and the size at age data at Q=0.75.

Columbia

The figures presented for the fits to the data are for the VR=31.4 million run (estimated Q=0.72), the fits for the Q=1.0 and Q=0.48 runs were very similar to this run. The decline in mean size are fit well by the model (Figure 33). The majority of the catch is female from 1966 to 1983 and then male through 1992, and about even in 1994 (Figure 32). The fraction female increases with depth for the slope survey data (Figures 16a through 17h). This indicates that the selectivities and or retention has changed over time, because it would be expected that the fraction female would remain high as fishing moved into deeper water. In the current model small fish are discarded. Due to market shifts for larger deepwater Dover sole, discarding may be occurring for the larger, older fish in deeper water, which may be mostly female. At this time no information is available on whether this type of discard is occurring.

The selectivity curves generally show an increasing selectivity of younger fish from the early years to the late years, and an increase in the selectivity of males relative to females(Figures 27a and 27b). The selectivity curves reflect the changes in size and sex ratio in the catch. The selectivity of young fish increases from the first period (1966-72) to the second period (1973-74) then declines for 1975-77. In the mid-80's the selectivity for females is less relative to males, reflecting the change in sex ratio to mostly males in 1987-1991.

The selectivity curve for the 1993 slope survey rises steeply from 0 at 22 cm to 1.0 at about 34 cm, with 50% selected at about 27 cm (Figure 28). The shelf survey selects smaller fish and occurs in shallower water where smaller fish are found, however, the slope and shelf selectivities overlap. The shelf selectivities decline at larger sizes while the slope selectivities are fixed at 1.0 for larger fish. The central Columbia slope survey abundance declines by more than 50% from 1988-89 to 1993 (Figure 34). The estimated trend does not decline as much as the data indicate. The estimated shelf survey biomass decreases slightly from 1977 to 1986 then declines in 1992 (Figure 35). The observed shelf survey trend is variable but mostly flat from 1977 to 1992. The 1993 slope survey size composition estimates too many small females and not enough males (Figure 29). The discard size composition data are fit reasonably well, but also estimates too many small females and not enough males (Figure 30).

The population biomass decreases for all runs throughout the time series (Table 15 and Figure 36). The trends in recruitment are the same for all runs with some high recruitments in the late 70's and early 80's then decline to near the virgin recruitment level.

The total likelihood continues to increase as biomass declines over a range of 1993 slope survey Q's from 2.46 to 0.35 (Table 16). Q is the ratio of the survey biomass to the population biomass after survey selectivities have been applied. A higher Q translates to a lower population biomass. The fishery size composition likelihood is highest at a Q of 0.72. The fishery age composition likelihood is best at the lowest biomass (Q=2.46). The size at age likelihood is variable but is highest at Q=0.48. The 1993 slope survey size composition data and the shelf survey size composition data likelihoods are highest at the lowest biomass (Q=2.46). The central Columbia slope survey trend and size composition have highest likelihoods at near the lowest biomass (Q=1.6). The shelf abundance likelihood fits best at the highest biomass level.

Yield and spawning biomass per recruit

The Eureka area fishing mortality rate that reduces spawning biomass per recruit to 35% of its unfished level (SBPR-35%) is 0.233 to 0.310 for a range of Q=1.0 to 0.49 (Table 18). Note that these fishing mortality rates apply to the age/sex that has maximum selectivity. The selectivity (therefore the fishing mortality) for other ages will be less. The maximum selectivity for females is less than that for males so their fishing mortality will be less also. Applying an F of 0.233 to the 1995 population in the Eureka area produces a yield of 1,067 mt (952 mt landed catch and 114 mt of discard) for the low biomass scenario (Q=1.0). The high biomass scenario(Q=0.49) F35% is 0.310, which produces a 1995 yield of 3,797 mt (3,475 mt landed catch and 322 mt of discard). The estimated 1995 landed catch for the high biomass scenario is at the current ABC of 3,500 mt for the Eureka area. Female spawning biomass (FSB) is just above the F20% level for the high biomass scenario and below F20% for the lower biomass scenarios (Figures 38, 39 and 40).

In the Columbia area F35% for the lower biomass scenario (Q=1.0) was estimated as 0.176 (Table 19). This produces a yield of 1,670 mt (landed catch 1,561 mt and 109 mt discard) in 1995. The high biomass scenario F35% is 0.187 which produces a 1995 yield of 3,726 mt (landed catch 3,503 mt and 233 mt discard). The current quota for the Columbia area is 4,000 mt with a harvest guideline that has stepped down from 6,000 mt in 1993 to 4,000 mt in 1995. The FSB is at the F35% level in 1994 for the high biomass scenario and at the F20% level for the low biomass scenario (Figures 41, 42 and 43). The 1995 F35% yields estimated here are lower than previous recommended yields (Turnock and Methot, 1992) mainly due to the lower estimate of biomass for the 1992-93 slope surveys in the Columbia area. Previous biomass estimates were higher than the 1992-93 estimate and had been expanded to the total area from data in the central Columbia area only. The 1992-93 slope survey covered the entire Columbia INPFC area. The addition of the estimate of biomass in the central Columbia area in 1993 indicates a steeply declining trend in biomass from the late 80's to 1993 (Figure 34).

Equilibrium yield overview

Yield curves as presented in Figures 39 through 43 display much information on the history, status, and future for the stocks. The jagged line on the right displays the trajectory along which the stock has been fished down. The yield levels displayed here are landed yield only. The left-most point is the projected F35% yield for 1995 and is labeled 1995. The trajectory begins on the right at the virgin spawning biomass. The second point is the initial equilibrium in 1971 (Eureka) or 1966 (Columbia). This equilibrium is calculated under the assumption of constant virgin recruitment, a historical catch level of 2,396 mt (Eureka) or 1,960 mt (Columbia) and a selectivity pattern equal to that of the subsequent fishery.

Two equilibrium yield curves are shown with solid lines. The upper line occurs if recruitment is constant at the virgin level. The lower line occurs if recruitment is 90% of virgin when spawning biomass is 50% of virgin. Tic marks along these yield curves indicate the fishing mortality rates at which the curves were evaluated. Generally we used steps of 0.01 for these calculations. The dotted line indicates the level of constant fishing mortality that produces SBPR-35%. The intersection of this line with the lower yield curve indicates that it is an excellent proxy for Fmsy if the density-dependence in recruitment is as assumed by the lower yield curve. The long-term potential for the stock is probably close to this F35% line somewhere between where it intersects the upper and lower yield curves. The ABC for 1995 can be approximated by interpolating (or extrapolating) along the F35% line to where it intersects the estimated spawning biomass for 1995. A more precise calculation of ABC requires examination of the age composition of the stock projected to the beginning of 1995. The dotted line with the steeper slope represents the fishing mortality that produces SBPR-20%. This is the fishing mortality rate defined as overfishing.

The F35% fishing mortality levels (dotted line in Figures 38 through 43) relative to the equilibrium yields at two levels of recruitment density- dependence (solid lines with tic marks) provide information with regard to standard levels of fishing mortality. The F35% line intersects the lower, density-dependent yield curve to the left of the maximum for this curve, so F35% is higher than Fmsy if the level of density-dependence assumed in the lower yield curve is true.

Equilibrium yield - Eureka area

The MSY is 3,176 mt and 5,779 mt for the low and high biomass scenarios (Table 18). The equilibrium yield at F35% and constant recruitment is 4,132 mt to 7,495 mt for the low and high scenarios.

Equilibrium yield - Columbia area

The MSY is 2,948 mt and 3,891 mt for the low and high biomass scenarios (Table 19). The equilibrium yield at F35% and constant recruitment is 3,835 mt and 5,067 mt.

The differences in yields for the Eureka and Columbia areas may be due to the differences in fishery selectivities and in the size at age. The fishery selectivities estimated by the synthesis model in the Columbia area declined at older ages while the selectivities in the Eureka area stayed high at older ages. There seems to be more older fish (> 20 years) in the Eureka area than in the Columbia area. From 1987 to 1989 the fraction of fish > 14 years and especially the fraction greater than 24 years has increased in the Eureka area. Fish between 12 and 14 years appear more abundant in the Columbia than the Eureka area, and fish less than 10 years more abundant in the Eureka area. These differences in the age compositions could cause the differences in the selectivities between the Eureka and Columbia areas. In the Eureka area the model needs more older fish to fit the age data so the selectivities on the older fish is higher. The larger selectivities on older fish would increase potential yields in the Eureka area over the Columbia area. The population in the Eureka area is at a lower level relative to the virgin level so projected yields using F35% are lower than in the Columbia area.

Mean size at age is greater in the Eureka area than in the Columbia area for both females and males from age 5 to 14 yr (Figure 9). Mean size at age is similar in the two areas at ages greater than 15 yr. This difference in growth could be due to differences in aging criteria between the two areas. Since the older fish are bined by 5 year intervals no difference in growth is evident. The growth model fit by synthesis, estimates mean size to be 1 to 2 cm less in the Columbia area than the Eureka area through the 20-24 year age bin. At the oldest ages the mean size in the Columbia area is larger than the mean size in the Eureka area for females and is estimated to be the same size in both areas for males. The productivity in the Eureka area is larger than in the Columbia area due to the larger mean size at age for most fish in the Eureka area.

ACKNOWLEDGMENTS

We would like to thank Bob Demory, Frank Henry, Brenda Irwin, Becky Ota, Larry Quirollo and Claire Wood for providing data on Dover sole.

REFERENCES

Barss, W.H., R.L. Demory and N. TenEyck. 1977. Marine resource surveys on the continental shelf off Washington, 1975-76. Oregon Dept. Fish and Wildl., Completion rept. 34 p.

Barss, W.H. and R.L. Demory. 1985. Observations on retention and discard of groundfish from a limited sampling of Oregon trawl vessels in 1982. ODFW Informational Report 85-7.

Demory, R.L., J.T. Golden and E.K. Pikitch. 1984. Status of Dover sole (*Microstomus pacificus*) in INPFC Columbia and Vancouver areas in 1984. Status of Pacific Coast Groundfish Fishery and recommendations for Management in 1985. Pacific Fishery Management Council. Portland, Oregon 97201.

Hagerman, F.B. 1952. The biology of the Dover sole, *Microstomus pacificus* (Lockington), Calif. Dept. Fish & Game, Fish Bull. 85, 48 p.

Herman, R.B. and G. Y. Harry. 1963. Results of a sampling program to determine catches of Oregon trawl vessels. PMFC Bull. No. 6.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82(1):898-903.

Hunter, J.R., B.J. Macewicz, N. Chyan-huei Lo and C. A. Kimbrell. 1992. Fecundity, spawning, and maturity of female Dover sole, *Microstomus pacificus*, with an evaluation of assumptions and precision. Fishery Bulletin, U.S. 90:101-128.

Markle, D.F., P.M. Harris and C.L. Toole. 1992. Metamorphosis and an overview of early-life-history stages in Dover sole *Microstomus pacificus*. Fishery Bulletin 90:285-301.

Methot, R.D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. National Marine Fisheries Service unpub report, 17pp.

Methot, R.D., R.D. Demory, F. Henry and J. Turnock. 1990. Assessment of west coast Dover sole in 1990 and recommendations to management in 1991. Status of the Pacific coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991. Pacific Fishery Management Council, Portland, Oregon.

Pikitch, E.K., D.L. Erickson and J.R. Wallace. An evaluation of the effectiveness of trip limits as a management tool. Northwest and Alaska Fisheries Center Processed Report 88-27.

Raymore P.A. and K.L. Weinberg. 1990. 1984 spring and autumn surveys of pacific west coast upper continental slope groundfish resources. NOAA Technical Memorandum NMFS F/NWC-179.

Turnock, J. and R. D. Methot. 1991. Assessment of west coast Dover sole in 1991 and recommendations to management in 1992. Status of the Pacific coast groundfish fishery through 1991 and recommended acceptable biological catches for 1992. Pacific Fishery Management Council, Portland, Oregon.

Turnock, J. and R.D. Methot. 1992. Assessment of west coast Dover sole in 1992 and recommendations to management in 1993. Status of the Pacific coast groundfish fishery through 1992 and recommended acceptable biological catches for 1993. Pacific Fishery Management Council, Portland, Oregon.

Westrheim, S.J., W.H. Barss, E.K. Pikitch and L.F. Quirollo. 1992. Stock Delineation of Dover Sole in the California-British Columbia Region, Based on Tagging Studies Conducted during 1948-1979. North American Journal of Fisheries Management 12:172-181.

Yoklavich, M.A. and E. Pikitch. 1989. Reproductive status of Dover sole, *Microstomus pacificus*, off Northern Oregon. Fishery Bulletin 87:988-995.

Table 1. Landed catch (mt) of Dover sole by INPFC area from 1955 to 1993.

Year	Conception	Monterey	Eureka	Columbia	U.S. Van	Coastwide
55	0	903	2365	-	-	3268
56	0	1335	2300	1242	988	5865
57	0	1076	2429	1701	385	5591
58	0	1266	2247	1289	468	5270
59	0	974	2213	2203	525	5915
60	0	1225	2887	2343	860	7315
61	0	1101	2332	1845	655	5933
62	39	1185	3055	2005	470	6754
63	0	1346	3014	2399	658	7417
64	68	1690	2500	2365	266	6889
65	46	1724	3184	1502	148	6604
66	0	1747	3048	1417	225	6437
67	0	1141	2101	1543	118	4903
68	0	681	3264	1714	407	6066
69	0	859	5362	2096	450	8767
70	10	1778	5259	2262	454	9763
71	0	1838	4837	2281	515	9471
72	22	2721	7385	2516	340	12984
73	13	3155	7216	1743	323	12450
74	19	2660	6312	2242	195	11428
75	69	2888	7499	2012	269	12737
76	78	3706	7460	2095	627	13966
77	63	4843	5840	1876	510	13132
78	50	4850	4715	3841	598	14054
79	31	4151	6683	5828	1245	17938
80	53	3151	5472	4282	1128	14086
81	60	3474	6285	4815	1545	16179
82	107	4468	5838	7223	2439	20075
83	356	4012	5507	6732	3074	19681
84	1263	4326	5056	5235	3178	19058
85	2826	4278	5899	4755	2571	20329
86	1011	4758	4932	3906	1587	16194
87	2451	3739	5038	5492	1301	18021
88	1661	2581	4342	7154	1992	17730
89	-	4469[1]	3789	9016	1519	18793
90	-	3485[1]	3887	7290	1564	16226
91	1474	3285	3405	8120	1914	18198
92	1834	3575	3524	5665	1409	16007
93	1213	2874	3062	5652	1499	14300
ABC 1993	1,000	5,000	3,500	4,000[2]	2,400	15,900[3]
sum 1966-93	14664	81539	143017	118803	32996	398973
average 1983-93	1565	3714	4403	6274	1964	17685

[1] includes Conception area

[2] Harvest Guideline 6,000 mt

[3] Harvest Guideline 17,900 mt

Table 2. Mean size(cm) of dover sole by sex for the Eureka, Columbia and Vancouver areas.

	Eureka		Columbia		Vancouver	
Year	Female	Male	Female	Male	Female	Male
71	41.0	39.4			50.0	43.7
72	42.8	40.3	42.4	39	50.2	44.8
73	43.4	39.7	39	37.2	49.2	42.8
74	43.0	39.8	39.6	36.2	48.7	42.9
75	43.3	39.2	40.3	37.8	46.8	41
76	42.5	38.5	41.6	37.2	49.3	41.5
77	no data		41.7	37.8	47.5	42.6
78	42.1	38.7	38	35.4		
79	42.2	38.8	41.8	38.6		
80	40.7	38.1	40.1	37.2		
81	42.5	38.8	40.7	35.8		
82	42.9	39.0	39.9	34.2		
83	40.1	38.6	39.6	36.3		
84	40.3	37.8	37.6	33.1		
85	39.2	35.4	37.6	35.2	47.6	40.2
86	39.2	36.8	37.9	33.8	46.4	40.1
87	40.0	36.3	36.9	32.8	47.3	41
88	41.0	36.0	37.2	34.1	46.9	40.7
89	40.8	36.2	37.5	34.4	46.4	40.9
90	39.9	35.1	39.0	35.2		
91	39.9	35.7	38.0	34.1		
92	39.6	34.8	37.4	33.2		
93	40.4	35.8				

Table 3. Observed mean age of Dover sole in fishery samples.

	Eureka		Columbia		Vancouver	
Year	female	male	female	male	female	male
81	16.9	17.1				
82	15.1	14.8				
83	10.0	12.3				
84	14.8	16.7				
85	13.7	14.1	13.9	16.0	19.3	17.1
86	13.5	16.0	13.8	14.3		
87	14.6	14.5	14.0	14.6		
88	15.5	14.0	13.5	13.7	18.6	16.9
89	16.8	15.8	12.7	13.3		
90			14.6	15.5		
91			12.9	13.3		
92			12.6	13.2		

Table 4. Size-specific fraction of Dover sole retained by trawlers. Estimated by observers on vessels in the Columbia area (Demory, unpubl. data). Fraction retained by weight was 83.3% in the 1974 study, and 94.8% in the 1985-87 study.

	1974		1985-87	
Length	Male	Female	Male	Female
25	.000	.000	.000	.000
26	.040	.000	.043	.000
27	.037	.000	.138	.063
28	.186	.095	.197	.346
29	.101	.063	.322	.250
30	.217	.162	.433	.351
31	.273	.305	.578	.618
32	.362	.307	.736	.746
33	.505	.352	.861	.811
34	.673	.510	.956	.892
35	.828	.742	.997	.968
36	.925	.917	.991	1.00
37	.992	.972	1.00	1.00
38	1.00	1.00	1.00	1.00
L50	32.6	33.3	30.3	30.4
slope	.594	.614	.655	.631

Table 5. Eureka area hours of effort for 1978 to 1991 by 100 fm depth strata from California Fish and Game logbook data.

	Depth							
Year	0-99	100-199	200-299	300-399	400-499	500-599	>600	Grand Total
78	6781	2904	2715	2478	991	191	0	16060
79	12014	4868	4901	6358	1453	324	14	29932
80	7541	2921	3233	2656	913	284	71	17619
81	8125	3962	5242	4600	1848	773	12	24562
82	9572	3514	4045	3763	2616	837	44	24389
83	8563	4394	4035	3582	2646	361	24	23605
84	9422	4241	4212	3327	3390	828	6	25427
85	9089	5172	3321	2386	3651	2065	19	25702
86	3556	2236	3818	2642	4057	2179	20	18508
87	3523	2311	2416	1397	2350	1591	421	14009
88	3378	3658	3264	1547	5814	6485	485	24631
89	2082	2323	3334	1338	7275	6485	199	23036
90	1683	3069	4651	1586	5806	6770	196	23761
91	1007	3410	6949	3623	5484	3150	195	23818
Grand Total	86337	48984	56135	41283	48293	32322	1705	315059

Table 6. Eureka area catch for 1978 to 1991 by 100 fm depth strata from California Fish and Game fishery logbook data

	Depth							
Year	0-99	100-199	200-299	300-399	400-499	500-599	>600	Grand Total
78	733	715	795	819	306	33	0	3401
79	1285	923	1270	1968	366	85	3	5899
80	878	505	795	717	198	59	68	3220
81	923	731	1453	1568	755	229	6	5665
82	836	506	890	1810	1463	362	9	5876
83	595	488	704	951	855	120	6	3719
84	726	481	700	581	680	219	0	3388
85	850	661	504	417	632	387	3	3454
86	261	366	1023	588	617	304	5	3164
87	323	380	520	327	372	174	43	2140
88	305	565	654	301	627	516	40	3007
89	146	303	656	234	523	427	13	2303
90	104	378	851	270	376	264	9	2252
91	38	346	821	490	349	75	5	2125
Grand Total	8003	7348	11637	11042	8119	3255	208	49612

Table 7. Eureka area cpue for 1978 to 1991 for 100 fm depth strata from California Fish and Game fishery logbook data

Year	0-99	100-199	200-299	300-399	400-499	500-599	>600	all depths
78	0.108	0.246	0.293	0.331	0.309	0.173	0.000	0.212
79	0.107	0.190	0.259	0.310	0.252	0.262	0.176	0.197
80	0.116	0.173	0.246	0.270	0.217	0.209	0.962	0.183
81	0.114	0.185	0.277	0.341	0.409	0.296	0.462	0.231
82	0.087	0.144	0.220	0.481	0.559	0.433	0.203	0.241
83	0.070	0.111	0.174	0.266	0.323	0.332	0.250	0.158
84	0.077	0.113	0.166	0.175	0.201	0.265	0.064	0.133
85	0.094	0.128	0.152	0.175	0.173	0.188	0.153	0.134
86	0.073	0.164	0.268	0.223	0.152	0.139	0.251	0.171
87	0.092	0.165	0.215	0.234	0.158	0.109	0.101	0.153
88	0.090	0.154	0.200	0.194	0.108	0.080	0.082	0.122
89	0.070	0.130	0.197	0.175	0.072	0.066	0.065	0.100
90	0.062	0.123	0.183	0.170	0.065	0.039	0.047	0.095
91	0.038	0.102	0.118	0.135	0.064	0.024	0.024	0.089

Table 8. Effort (hours) from trawl logbook data by 100 fathom depth intervals in the Columbia INPFC area.

depth	mean depth	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
<100	57.5	40882	38620	47928	50362	47935	36915	23879	23749	23759	28908	23156
101-200	150	9013	8225	18355	25325	15763	18023	12372	12937	14644	16563	14597
201-300	250	3816	3992	8592	6327	11789	11861	10449	11042	12440	17663	14429
301-400	350	1421	1507	2917	3257	3580	5143	2766	2823	4726	7075	9600
>400	450	49	33	320	44	205	1913	449	436	1554	5925	16593
total		55181	52377	78112	85315	79272	73855	47702	53200	57123	76134	78375
mean depth		94	96	113	112	120	147	146	140	158	180	229

Table 9. Catch of Dover sole from log book data for the INPFC Columbia area by 100 fathom depth intervals from 1980 to 1990.

	YEAR										
depth (fm)	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
<100	2248	2178	2814	2222	1880	1601	969	1254	1076	1303	866
100-200	904	983	1655	1748	878	1009	1018	1481	1469	1372	1079
201-300	857	846	2069	2001	1717	1283	1613	2264	2563	3002	2289
301-400	272	786	587	746	736	704	330	478	969	1306	1548
>400	8	22	99	14	25	184	49	75	165	272	330
total	4288	4815	7222	6731	5235	4779	3978	5551	6242	7255	6112
mean depth	139	164	166	176	181	189	189	192	214	222	241

Table 10. Catch(mt) per hour of Dover sole from log book data for the INPFC Columbia area by 100 fathom depth intervals from 1980 to 1990.

	YEAR										
depth (fm)	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
<100	0.05	0.06	0.06	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.04
100-200	0.10	0.12	0.09	0.07	0.06	0.06	0.08	0.11	0.10	0.08	0.07
201-300	0.22	0.21	0.24	0.32	0.15	0.11	0.15	0.21	0.21	0.17	0.16
301-400	0.19	0.52	0.20	0.23	0.21	0.14	0.12	0.17	0.21	0.18	0.16
>400	0.16	0.67	0.31	0.32	0.12	0.10	0.11	0.17	0.11	0.05	0.02
All depths	0.08	0.09	0.09	0.08	0.07	0.06	0.08	0.10	0.11	0.10	0.08

Table 11. Shelf survey biomass estimates (mt) for the Columbia and Eureka areas 1977 to 1992.

year	Eureka	Columbia
1977	1211	8486
1980	1060	4890
1983	2902	9283
1986	4677	10332
1989	2923	6965
1992	1767	8198

Table 12. Catch per unit effort (kg/km^2) of dover sole by depth shelf surveys.

		shelf survey cpue by depth		
Year	area	30-100	100-200	all depths
77	Columbia	6.2	12.1	7.9
77	Eureka	1.9	10.9	4.7
77	Monterey	3.5	18.8	7.0
77	U.S. Vancouver	2.7	15.1	6.4
80	Columbia	2.9	5.2	3.3
80	Eureka	2.1	7.9	3.8
80	Monterey	2.2	10.0	3.4
80	U.S. Vancouver	2.3	17.6	6.2
83	Columbia	4.2	14.5	6.3
83	Eureka	3.0	24.9	7.6
83	Monterey	3.4	26.6	7.1
83	U.S. Vancouver	2.7	10.8	4.8
86	Columbia	6.2	9.8	6.9
86	Eureka	7.6	26.6	11.6
86	Monterey	7.7	28.8	11.0
86	U.S. Vancouver	2.3	8.7	3.9
89	Columbia	3.9	2.3	3.6
89	Eureka	4.8	8.8	5.7
89	Monterey	2.6	10.6	4.0
89	U.S. Vancouver	2.5	9.7	4.3
92	Columbia	1.0	10.0	4.3
92	Eureka	<.1	12.7	3.4
92	Monterey	<.1	8.4	1.6
92	U.S. Vancouver	2.0	15.1	5.3

Table 13. Catch per unit effort (kg/km) of dover sole by depth for slope surveys.

		Slope survey cpue by depth							
	area	10-100	100-200	200-300	300-400	400-500	500-600	600-700	all depths
75	Vancouver ODFW[2]	16.1	40.1	40.1	-	-	-	-	18.2
75	Columbia ODFW[2]	25.2	76.6	76.6	-	-	-	-	37.8
84	Columbia	16.5[1]	15.1	17.3	29.6	23.9	8.4	-	18.2
88	Columbia	-	23.1	100.3	36.1	24.9	19.7	3.0	47.0
89	Columbia	-	51.8	90.6	46.1	28.5	7.2	0.3	54.6
90	Eureka	-	26.2	36.6	47.1	35.6	27.5	12.4	31.3
91	Monterey	-	19.7	87.7	48.7	33.2	26.9	9.8	37.7
91	Columbia	-	-	-	30.2	-	-	-	-
91	Eureka	-	-	-	47.8	-	-	-	-
92	Columbia	-	38.8	26.9	35.0	11.0	3.8	3.0	24.5
92	US Vancouver	-	42.9	58.0	15.6	3.8	0.5	-	21.8
93	N.Columbia	-	48.2	78.1	16.4	4.7	1.7	9.8	25.1
93	S.Columbia	-	73.0	64.2	32.8	23.1	16.9	15.5	43.7

1 depth range in 1984 was 60-100 fathoms

2 cpue was estimated for the combined 100-300 fathom depth range in 1975

Table 14. Likelihoods and biomass values for Eureka area. Highest likelihoods are highlighted with a box border.

1990 slope survey Q	1.04	1.00	.86	.75	.59	.49	.35
Virgin recruit(million 5 yr fish)	17.52	20.14	28.77	30.86	34.00	36.61	47.07
FISH CATCH	-5.1	-6.3	-4.8	-5.1	-4.1	-4.9	-5.1
AGECOMP 81-89	-206.2	-175.2	-134.0	-134.0	-134.6	-136.5	-130.6
FISH SIZECOMP	-431.2	-386.5	-334.9	-331.7	-330.8	-331.6	-336.5
FISH SIZE@AGE	78.6	87.2	101.0	101.3	100.2	99.6	97.5
SHELF ABUND	-18.9	-18.6	-18.1	-16.0	-13.5	-11.8	-8.8
SHELF SIZECOMP	-63.6	-62.1	-60.5	-60.5	-60.5	-61.0	-64.4
Total likelihood	-645.9	-561.0	-450.8	-445.6	-442.8	-445.9	-447.5
1994 Biomass	11,813	12,809	16,174	21,944	28,451	38,064	80,287
1994 Female SPB	5,278	5,621	8,013	10,010	14,307	18,319	36,987

Table 15. Biomass and recruitment time series for the Eureka area for 1990 slope survey Q=1.0 and 0.49.

	Q=1.0			Q=0.49		
Year	Mid Year Biomass	Female spawn Biomass	Age 5 recruits X .001	Mid Year Biomass	Female spawn Biomass	Age 5 recruits X .001
Virgin	102019	50145	20136	178045	85663	36611
Equil	71746	32531	20136	148190	71573	36611
71	84710	33032	106299	145694	71523	28016
72	80875	32660	6398	137569	70350	7971
73	76428	31572	9703	128299	67838	9703
74	72566	30844	12361	121059	64992	20487
75	73511	30618	45503	121021	62374	66960
76	69971	30016	19545	111108	59304	4270
77	65589	29096	9728	101854	56211	3111
78	62315	28620	10450	96634	53712	20934
79	56847	28251	1648	87983	51405	1894
80	53569	26633	19123	82180	48061	21875
81	52745	25268	33122	79214	45135	36379
82	47066	23281	1494	71486	41793	3674
83	41982	21440	3604	64250	38700	2748
84	41484	20218	30802	63712	36552	41141
85	36448	18937	2041	57177	34445	1351
86	33341	17206	13990	53996	32073	21697
87	28686	15730	1829	48272	29950	2167
88	25535	14079	8688	45279	27786	16131
89	23377	12563	11386	43452	25673	18779
90	20500	11036	6354	41325	23726	15421
91	17017	9461	840	37392	21830	1782
92	15630	8100	13499	38718	20413	33885
93	14054	6700	10010	38166	19114	18200
94	12809	5621	10010	38064	18319	18200

Table 16. Likelihoods and biomass values for Columbia area runs.

VR(million 5 yr old)	20.9	23.5	27.5	31.4	3.66	41.8
Q 1993 slope survey	2.46	1.60	1.00	0.72	0.48	0.35
FISH CATCH	-7.0	-6.7	-7.3	-7.4	-7.7	-7.2
FISH GOOD AGES	-132.2	-141.6	-148.5	-154.2	-154.4	-163.3
FISH SIZECOMP	-586.1	-580.3	-576.0	-575.3	-580.3	-576.9
FISH SIZE@AGE	121.3	118.1	122.3	121.3	124.5	122.0
SLOPE ABUND	1.2	1.2	1.2	1.2	1.2	1.2
SLOPE SIZEC	-30.6	-32.5	-36.0	-36.9	-38.7	-38.5
SHELF ABUND	-1.6	0.1	2.2	3.3	4.2	4.8
SHELF SIZECOMP	-83.2	-90.2	-90.2	-90.6	-89.8	-89.6
CCOL ABUND	3.1	3.4	3.2	3.0	2.6	2.2
CCOL SIZEC	-91.1	-88.0	-92.3	-93.6	-97.1	-96.4
ODFW ABUND	1.2	1.2	1.2	1.2	1.2	1.2
Total Likelihood	-806.0	-816.1	-820.7	-828.6	-835.0	-841.4
1994 Mid year Biomass	14,512	21,527	35,100	47,607	71,590	97,374
1994 Female SB	4,841	7,024	11,798	15,236	27,333	38,474

Table 17. Biomass and recruitment time series for the Columbia area for 1993 slope survey Q= 0.48 and Q=1.0.

	Q=1.0			Q=0.48		
Year	Mid Year Biomass	Female spawn biomass	Age 5 recruits	Mid Year Biomass	Female spawn biomass	Age 5 recruits
virgin	122733	60052	27458	162791	78766	36611
Equil	94018	38137	27458	134400	57167	36611
66	91409	38078	4474	130404	57080	2521
67	90841	38358	21670	129267	57313	27566
68	93418	38543	48196	132248	57434	62173
69	91827	38511	14371	129202	57271	12600
70	92462	38220	35483	130133	56822	48766
71	90870	37772	17091	127657	56176	20213
72	89809	37324	23211	125437	55474	24476
73	90894	36780	39506	126160	54654	47657
74	91467	36885	34325	126219	54466	40973
75	89644	36701	14256	124292	53962	23871
76	88331	36545	17682	122165	53486	21119
77	88753	36380	31806	122133	53003	38356
78	94734	36510	86773	129313	52861	106451
79	91230	35625	20637	125308	51711	24941
80	85501	33511	875	118529	49332	947
81	89900	32592	80464	124871	48256	105379
82	86011	31520	18623	120431	47038	21528
83	82516	29814	29534	117135	45229	39151
84	80073	28393	30000	114794	43793	38755
85	76740	27683	15315	111166	43113	20665
86	73838	27088	17086	107867	42478	22692
87	68825	26925	3301	102001	42391	4375
88	65464	26090	29610	99238	41700	42140
89	60131	24131	28186	94532	39713	41902
90	52179	21077	2697	86466	36664	8675
91	44189	18705	1436	77920	34222	4665
92	41336	15684	37555	77417	31152	64987
93	38135	13728	21787	74451	29232	29050
94	35100	11798	21787	71590	27333	29050

Table 18. Equilibrium yields and 1995 yield projections for the Eureka area.

1990 slope survey Q	1.0	0.75	0.49
Virgin recruitment (X .001)	20,236	30,858	36,611
<u>Equilibrium</u>			
F 35%	0.233	0.299	0.310
FSPB 35%	17,551	25,513	29,982
Yield F35%	4,132	6,328	7,495
Discard F35%	206	316	375
F20%	0.430	0.545	0.558
FSPB F20%	10,029	14,579	17,133
Yield F20%	4,717	7,199	8,497
Discard F20%	236	359	425
F MSY	0.203	0.291	0.291
FSPB MSY	15,691	20,198	24,697
Yield MSY	3,176	4,870	5,779
Discard MSY	159	243	289
<u>Projections</u>			
1995 Biomass	12,802	22,368	37,899
1995 FSPB	4,682	9,257	17,811
1995 Yield F35%	1,067	2,023	3,797
1995 Landed Catch	952	1,827	3,475
1995 Discard	114	196	322

Table 19. Equilibrium yields and 1995 yield projections for the Columbia area.

1993 Slope survey Q	1.0	0.72	0.48
Virgin recruitment(X .001)	27458	31381	36611
Equilibrium			
F 35%	0.176	0.179	0.187
FSPB 35%	21018	23730	27568
Yield F35%	3835	4326	5067
Discard F35%	192	216	253
F20%	0.301	0.305	0.316
FSPB F20%	12010	13560	15753
Yield F20%	4671	5285	6177
Discard F20%	234	264	309
F MSY	0.187	0.187	0.187
FSPB MSY	14799	17059	21177
Yield MSY	2948	3327	3891
Discard MSY	147	166	195
Projections			
1995 Biomass	34730	47607	68146
1995 FSPB	9984	15236	25443
1995 Yield F35%	1670	2396	3726
1995 Landed catch	1561	2249	3503
1995 Discard	109	149	223

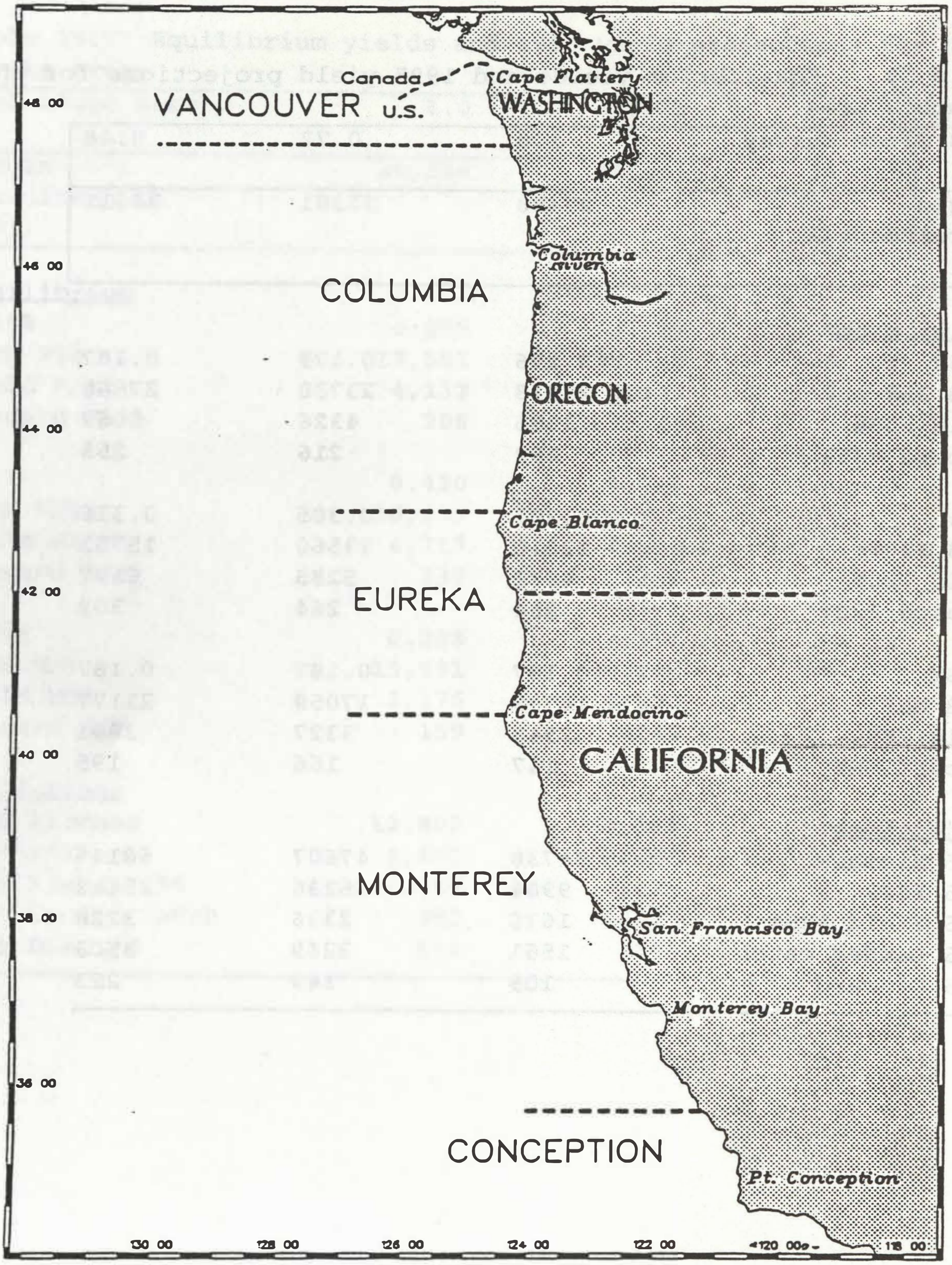


Figure 1. Map of the west coast assessment areas.

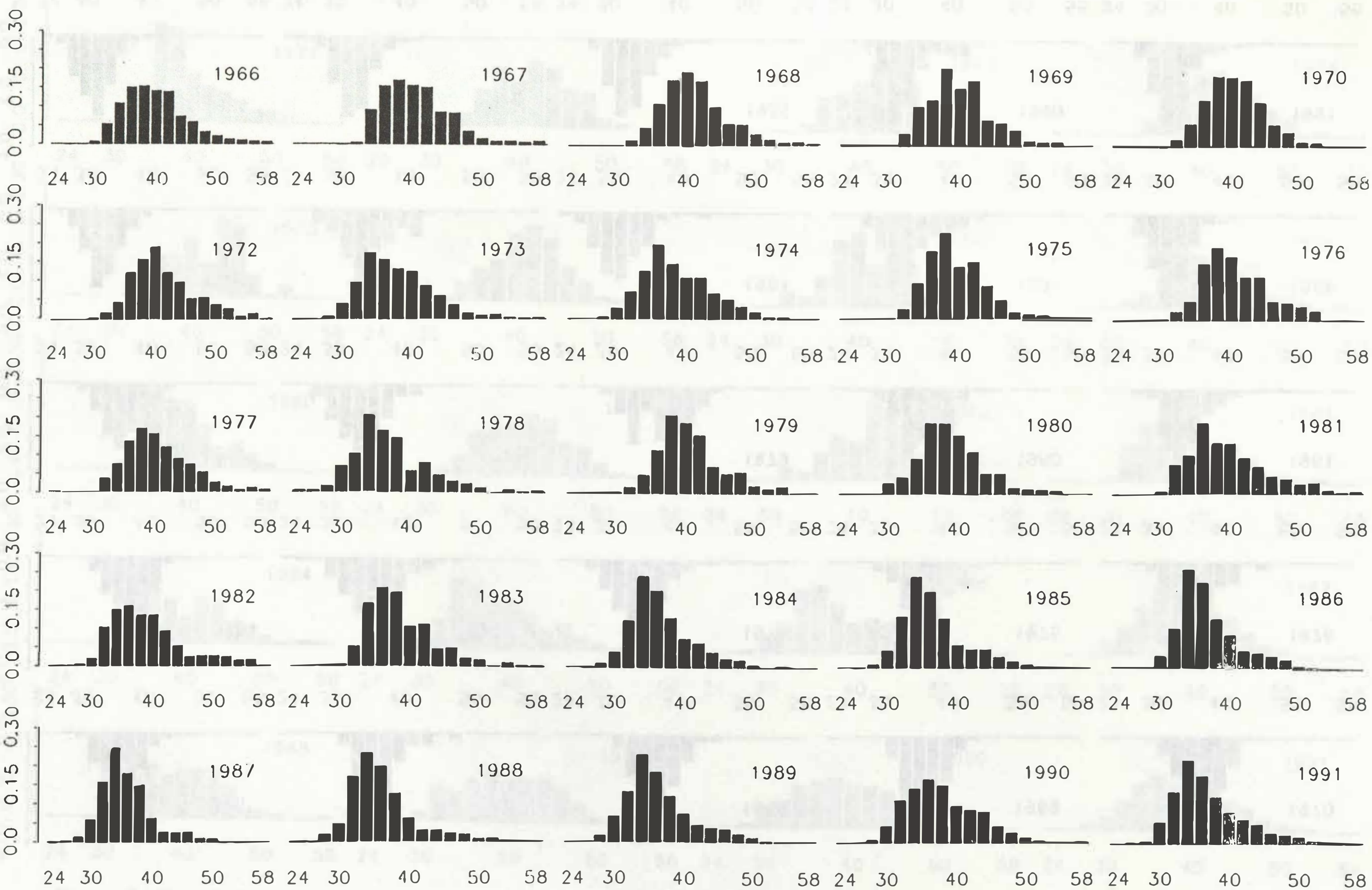


Figure 2. Female fishery size composition data in the Columbia area.

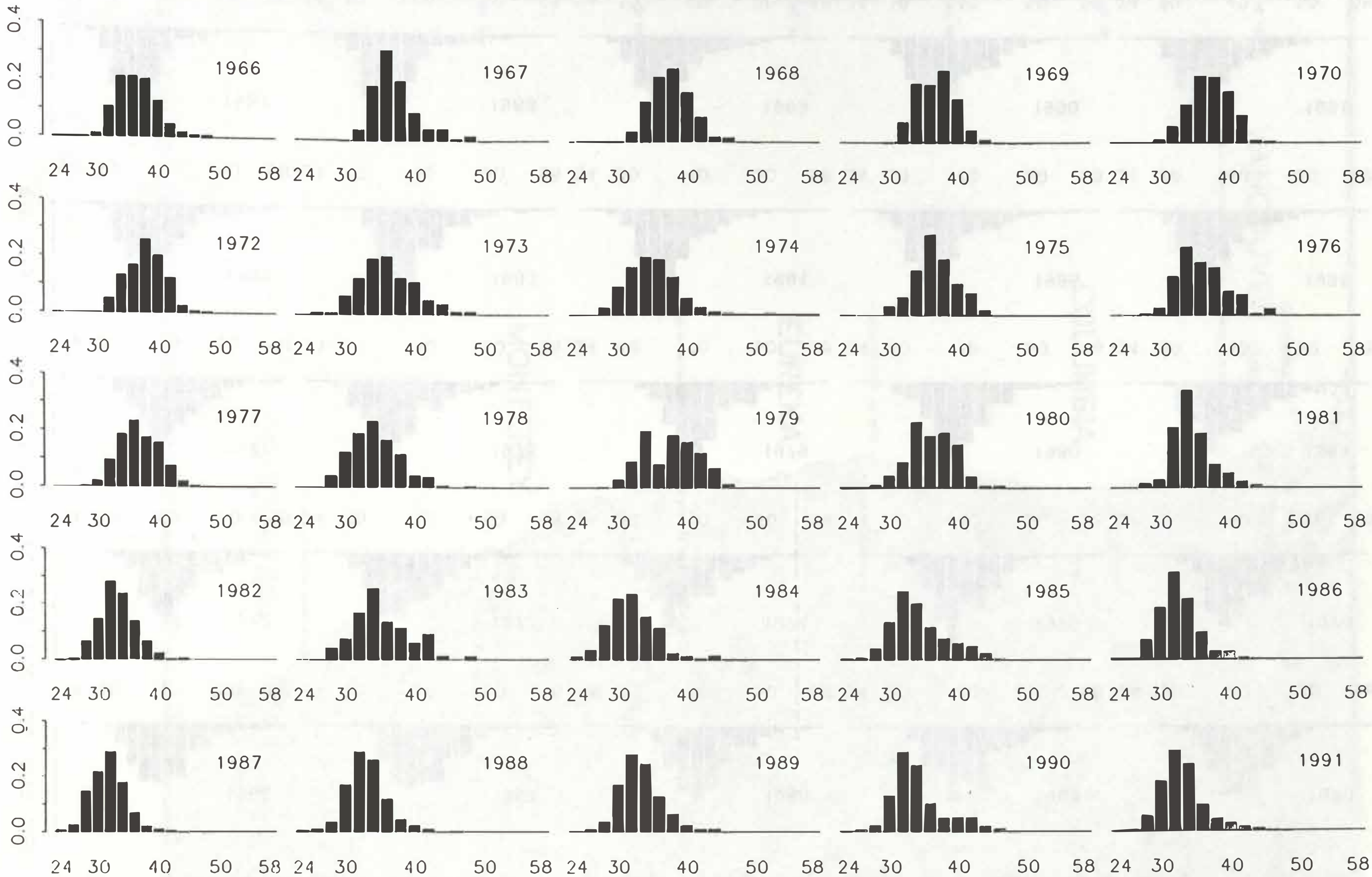


Figure 3. Male fishery size composition data in the Columbia area.

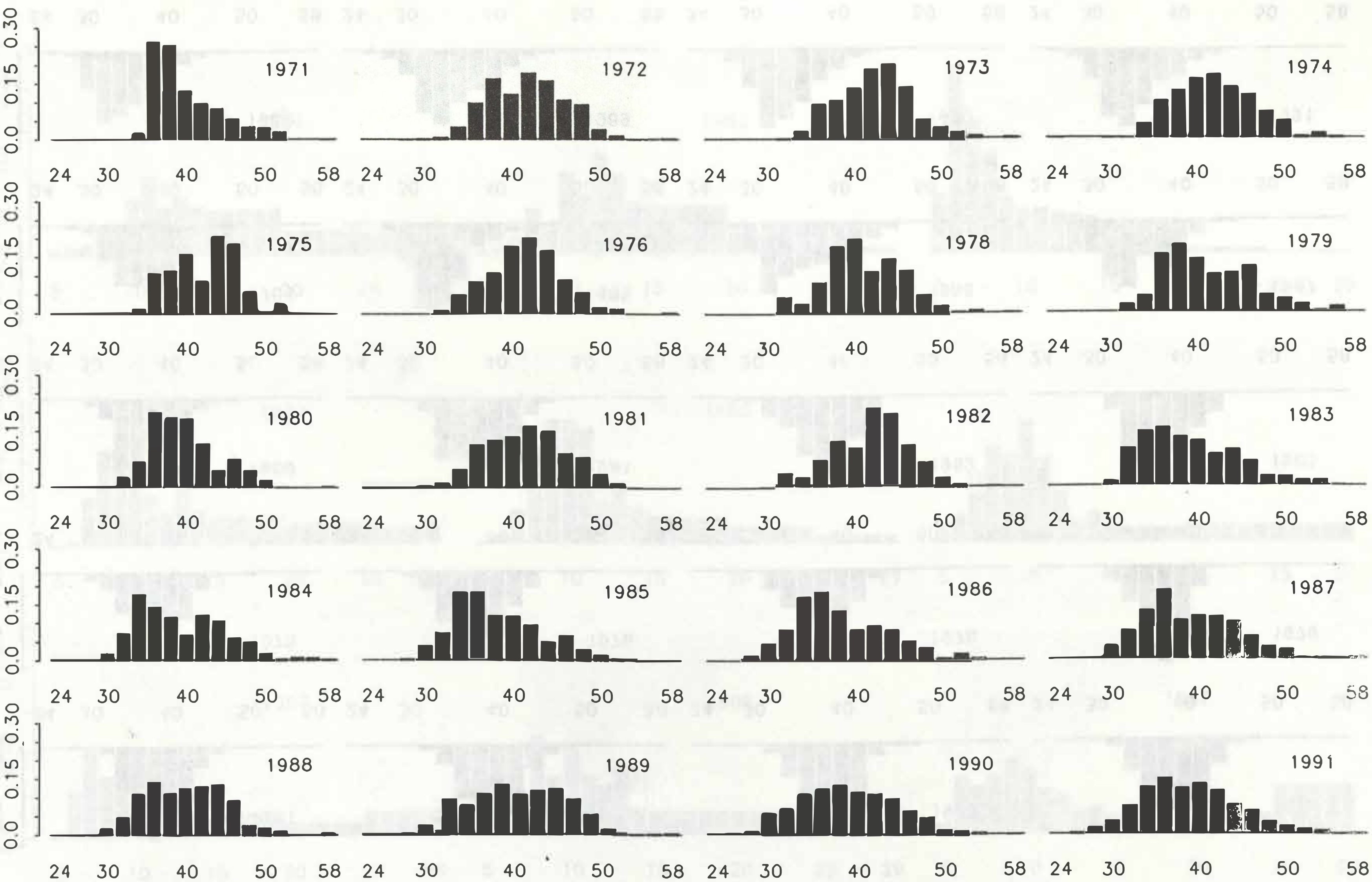


Figure 4. Female fishery size composition data in the Eureka area.

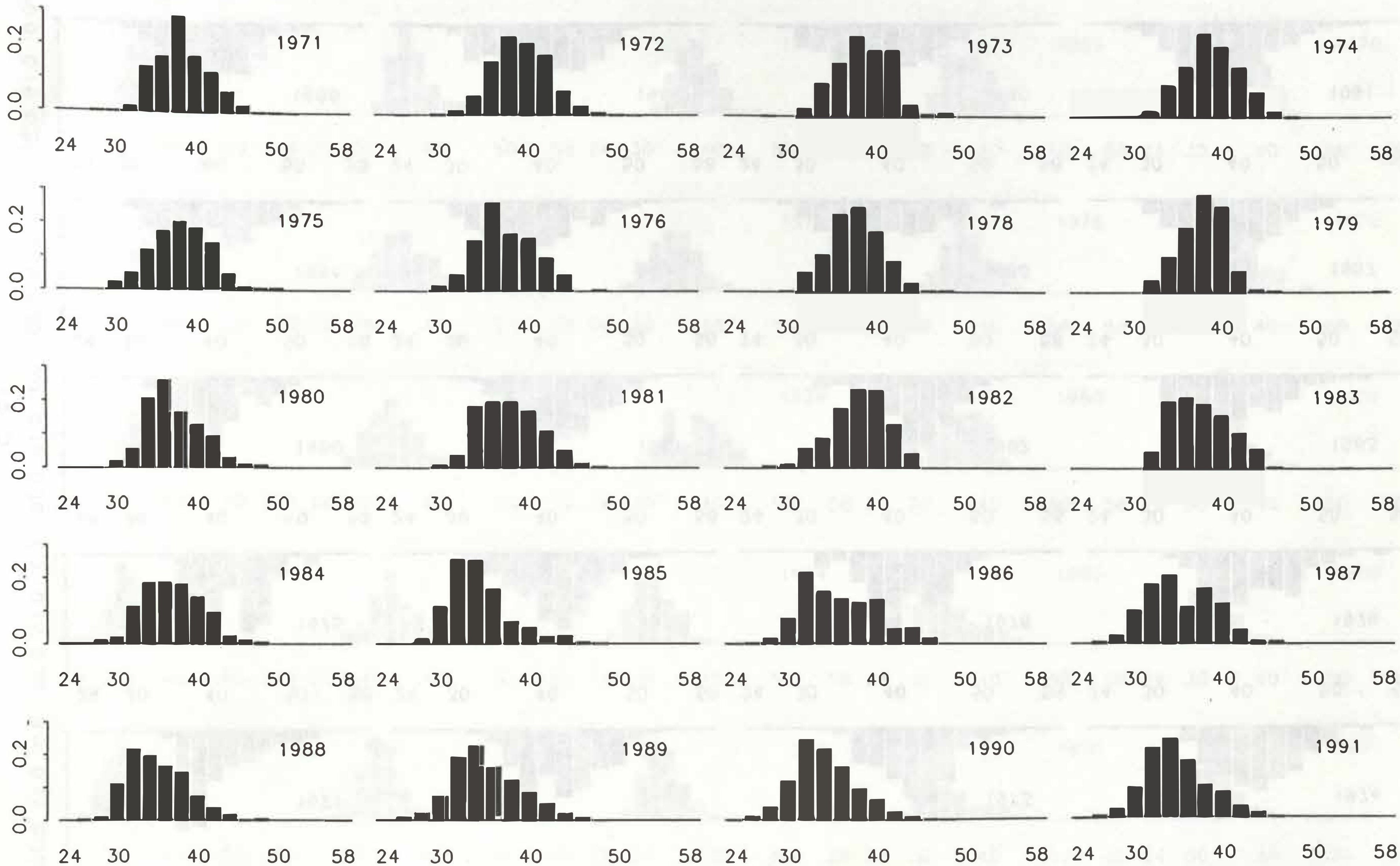


Figure 5. Male fishery size composition data in the Eureka area.

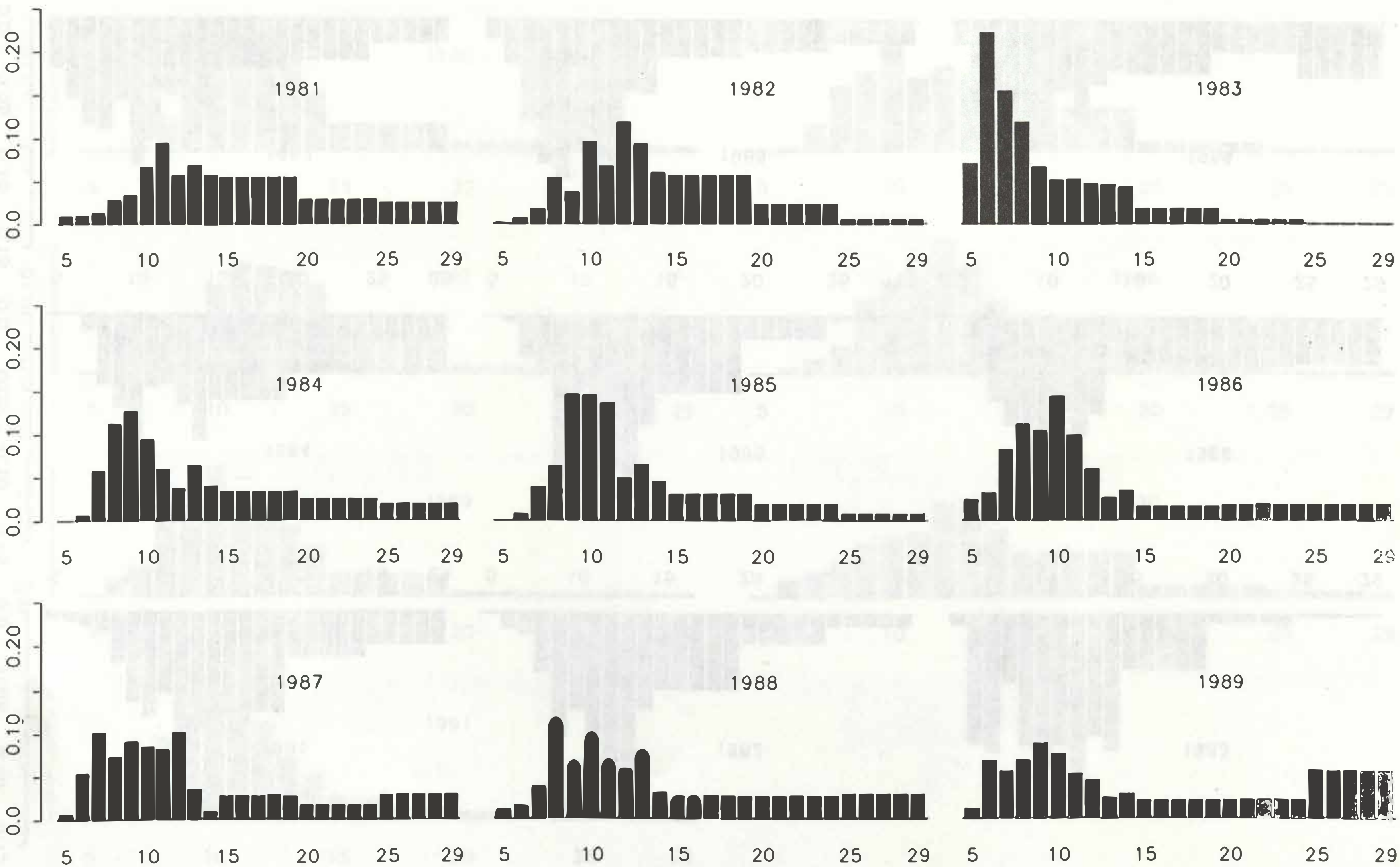


Figure 6a. Fishery female age composition data in the Eureka area.

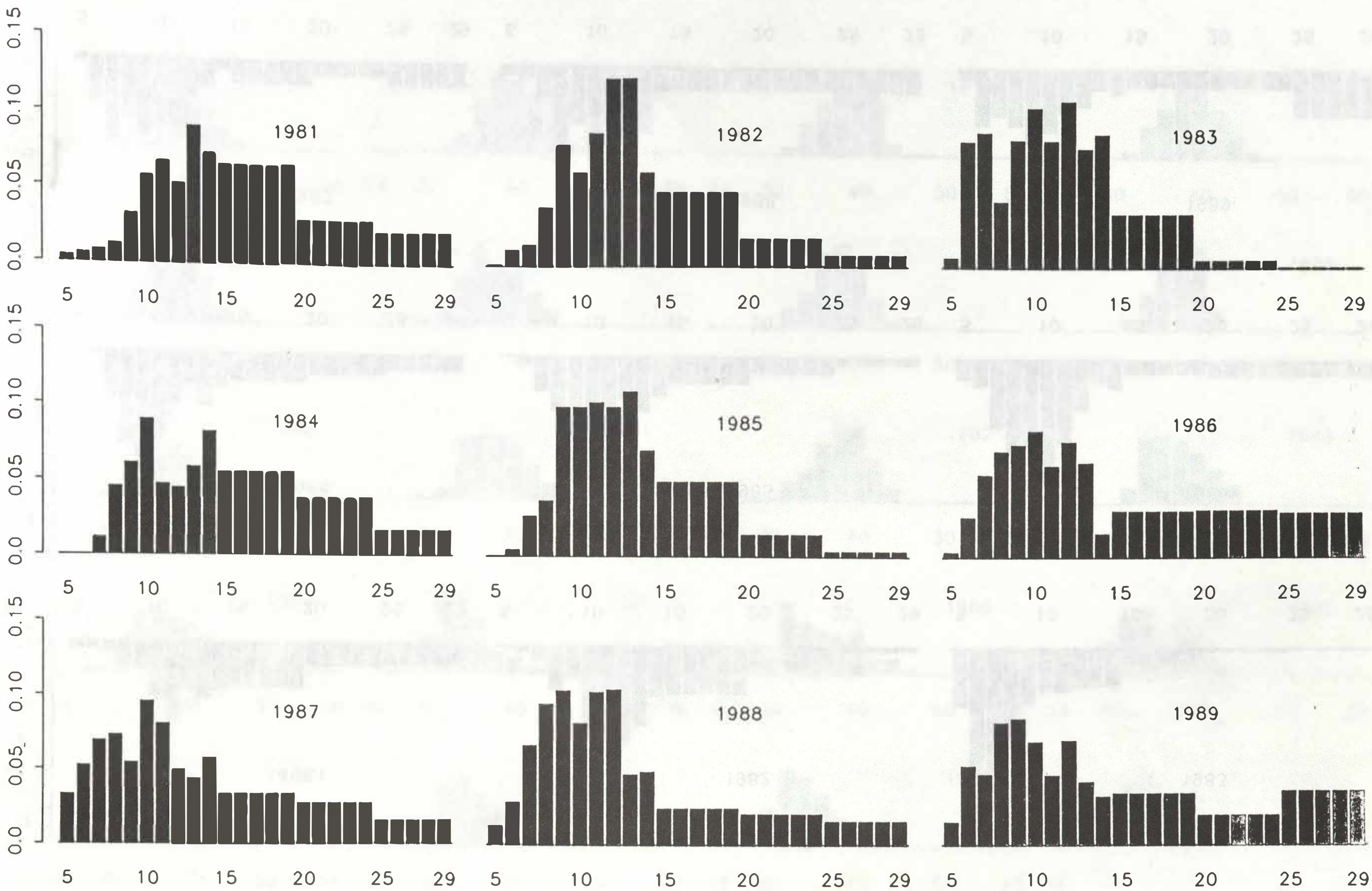


Figure 6b. Fishery male age composition data in the Eureka area.

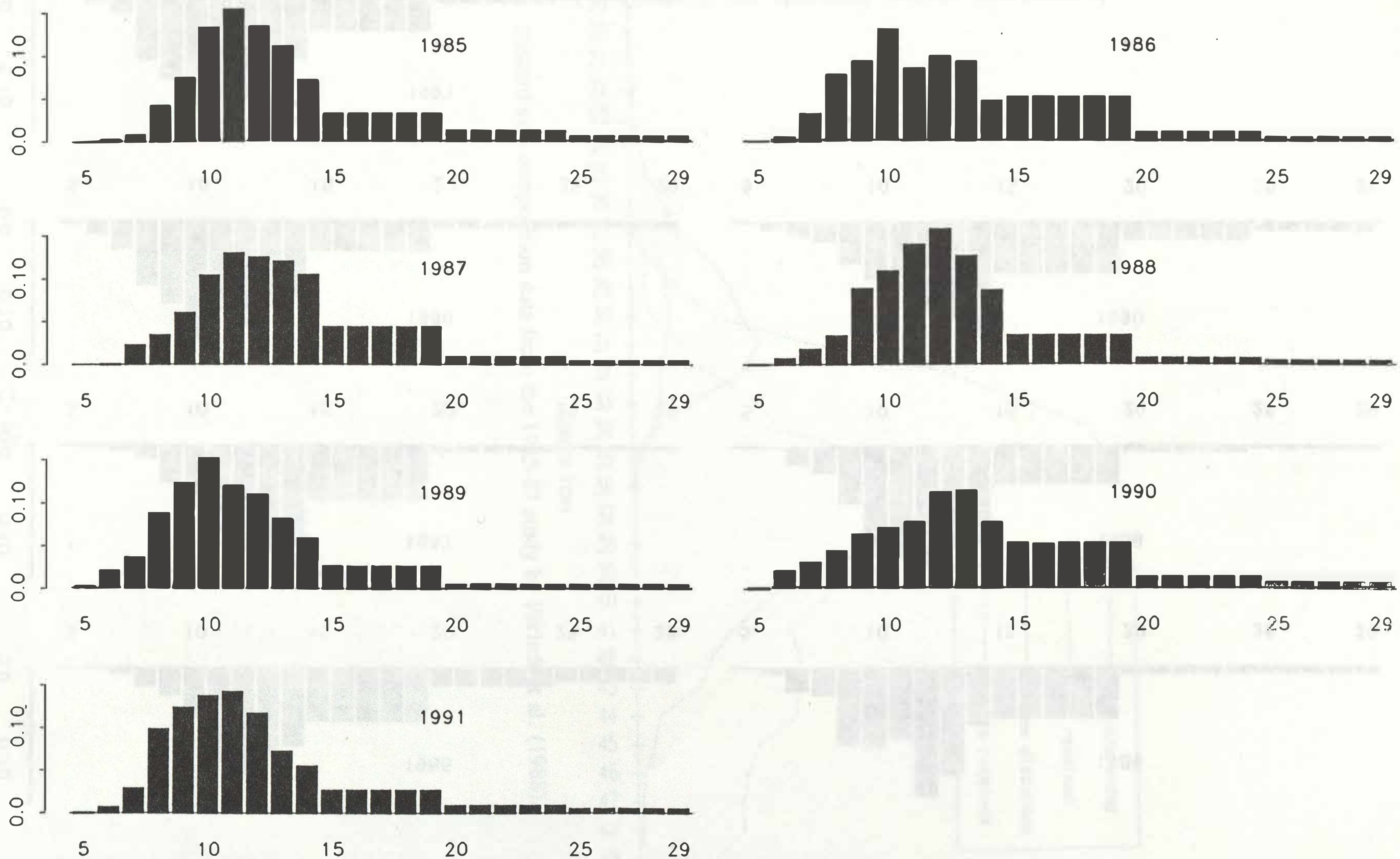


Figure 7a. Fishery female age composition data in the Columbia area.

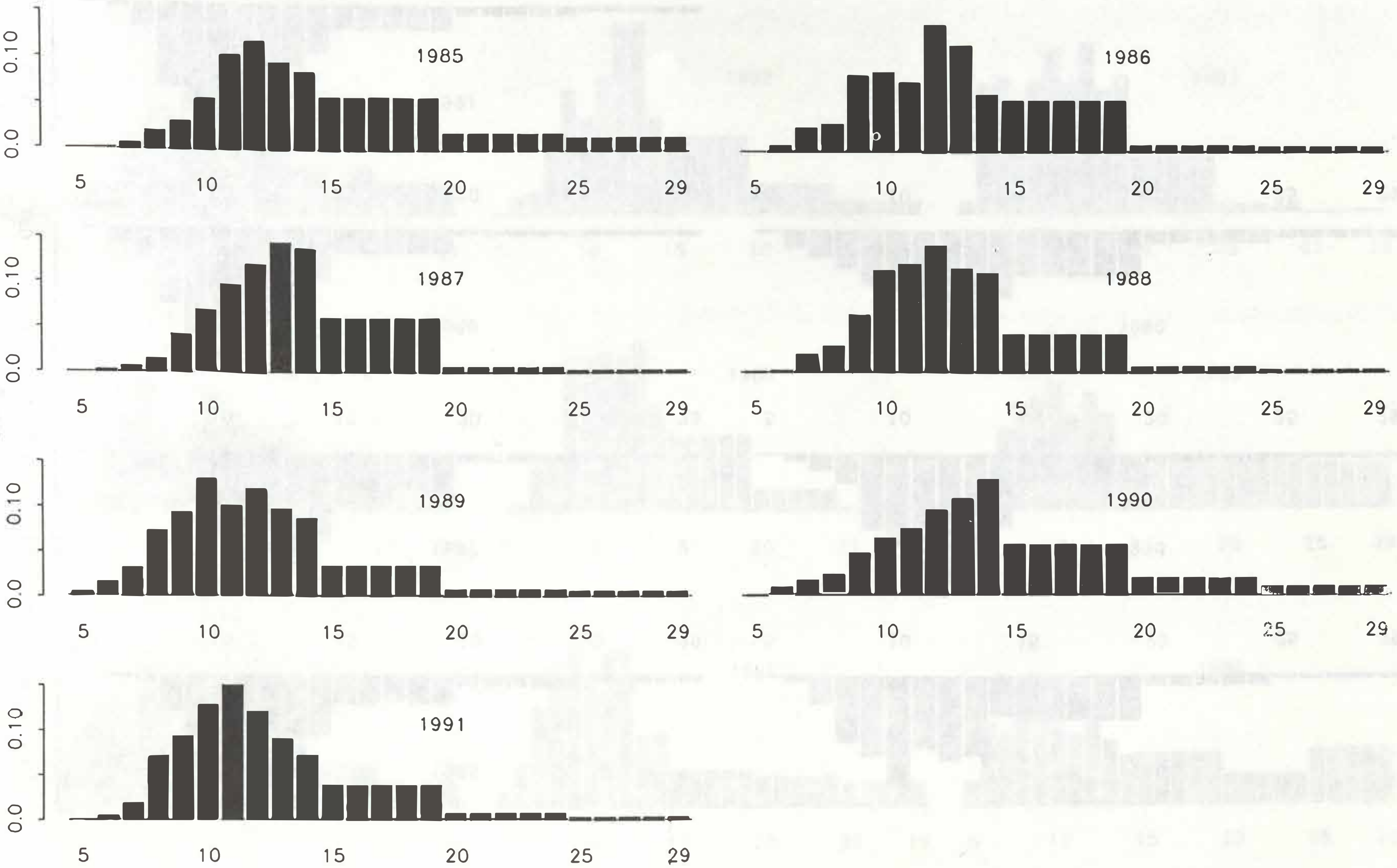


Figure 7b. Fishery male age composition data in the Columbia area.

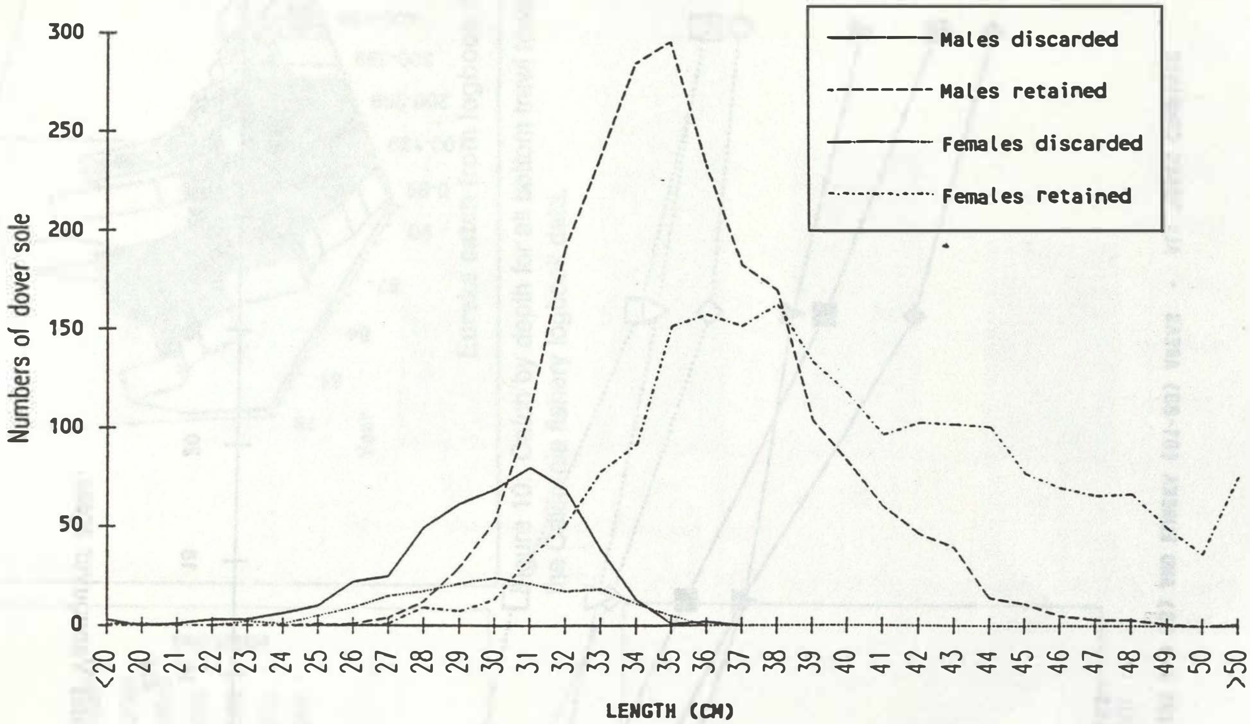


Figure 8. Discard size composition data from the 1985-87 study by Pikitch et al. (1988).

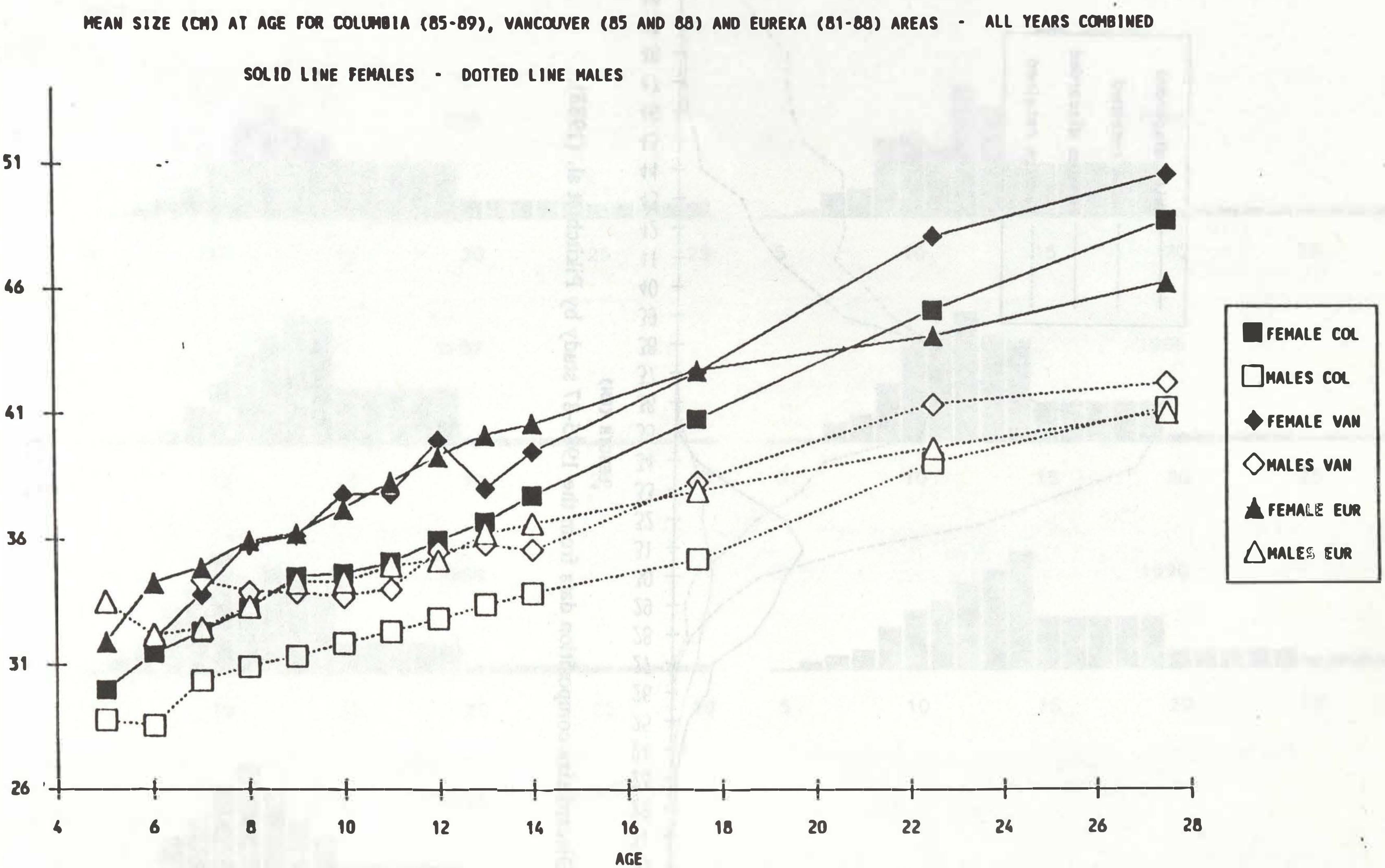


Figure 9. Mean size at age for the Eureka, Columbia and Vancouver areas.

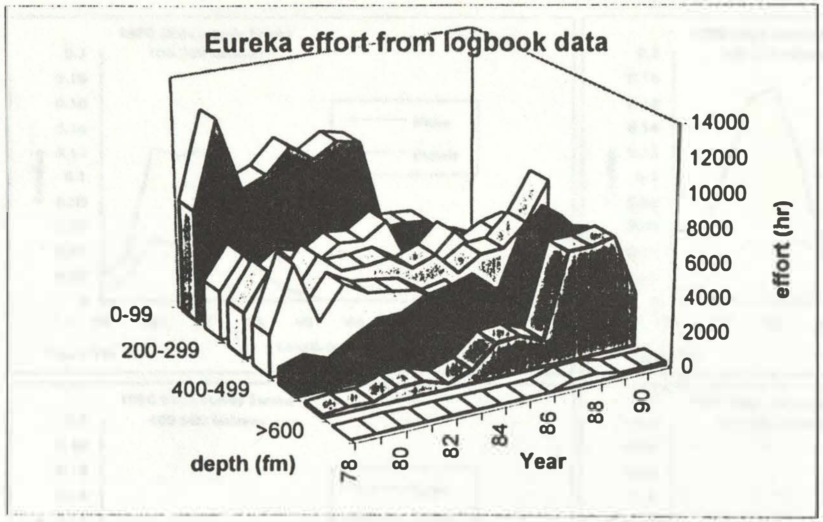


Figure 10. Effort by depth for all bottom trawl tows from the California fishery logbook data.

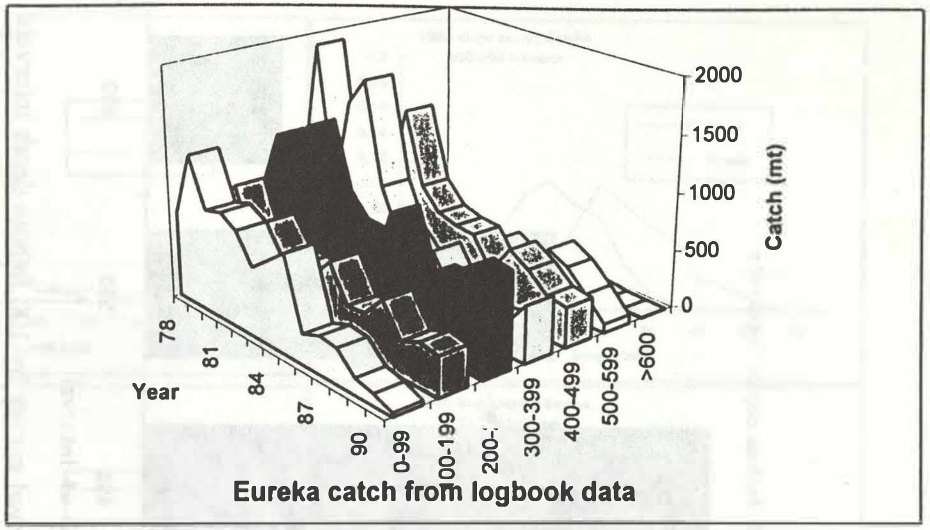


Figure 10. Catch by depth for all bottom trawl tows from the California fishery logbook data.

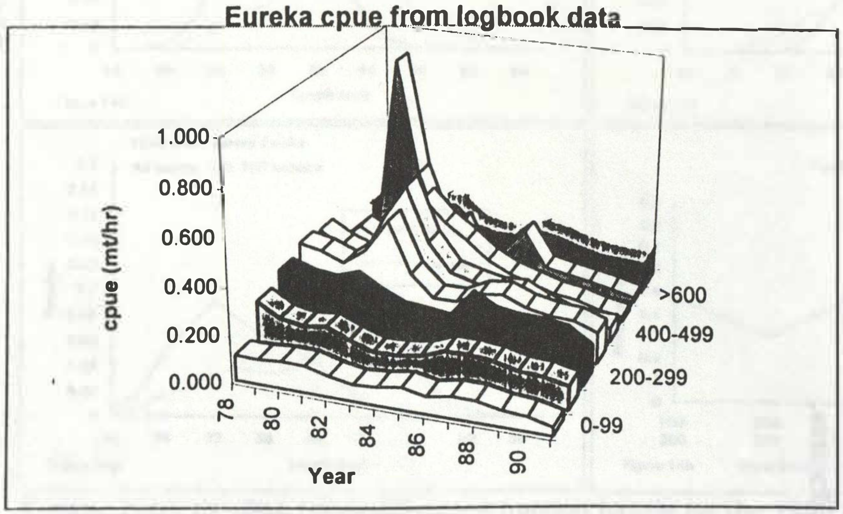


Figure 10. CPUE(mt/hr) by depth for all bottom trawl tows from the California fishery logbook data.

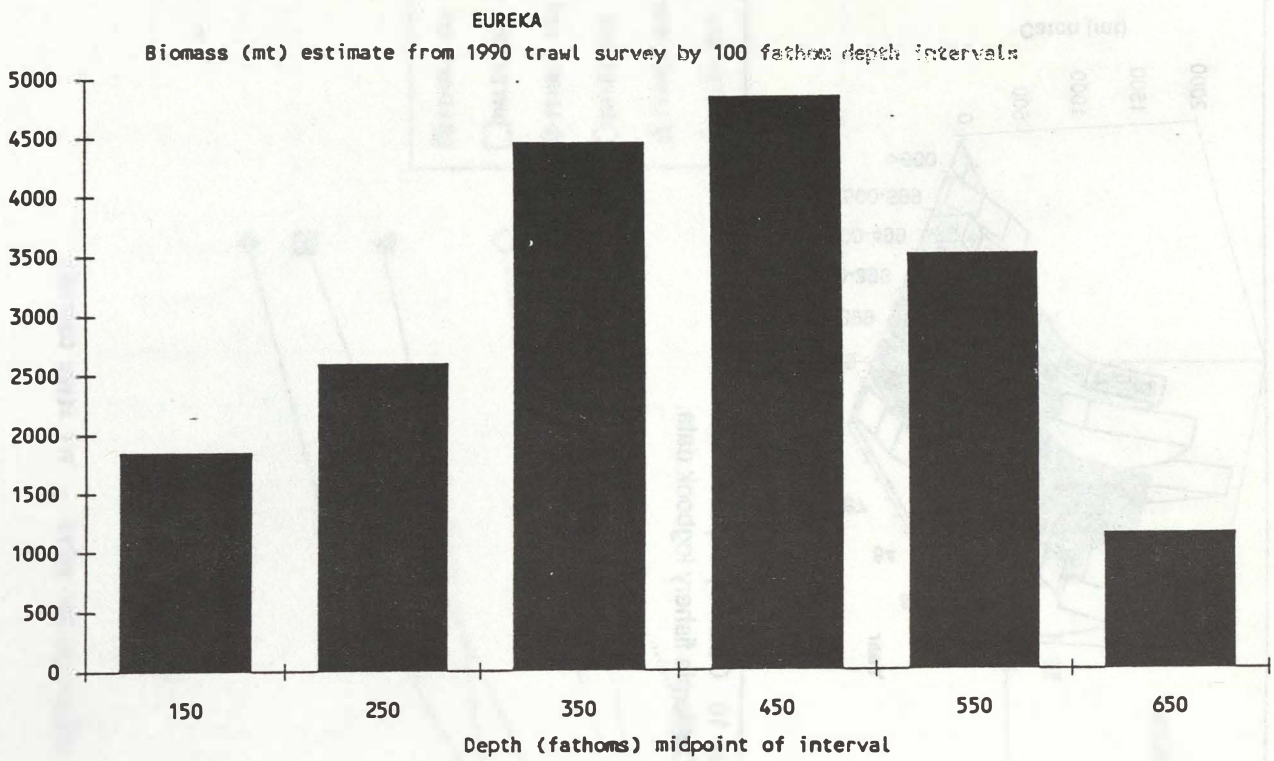
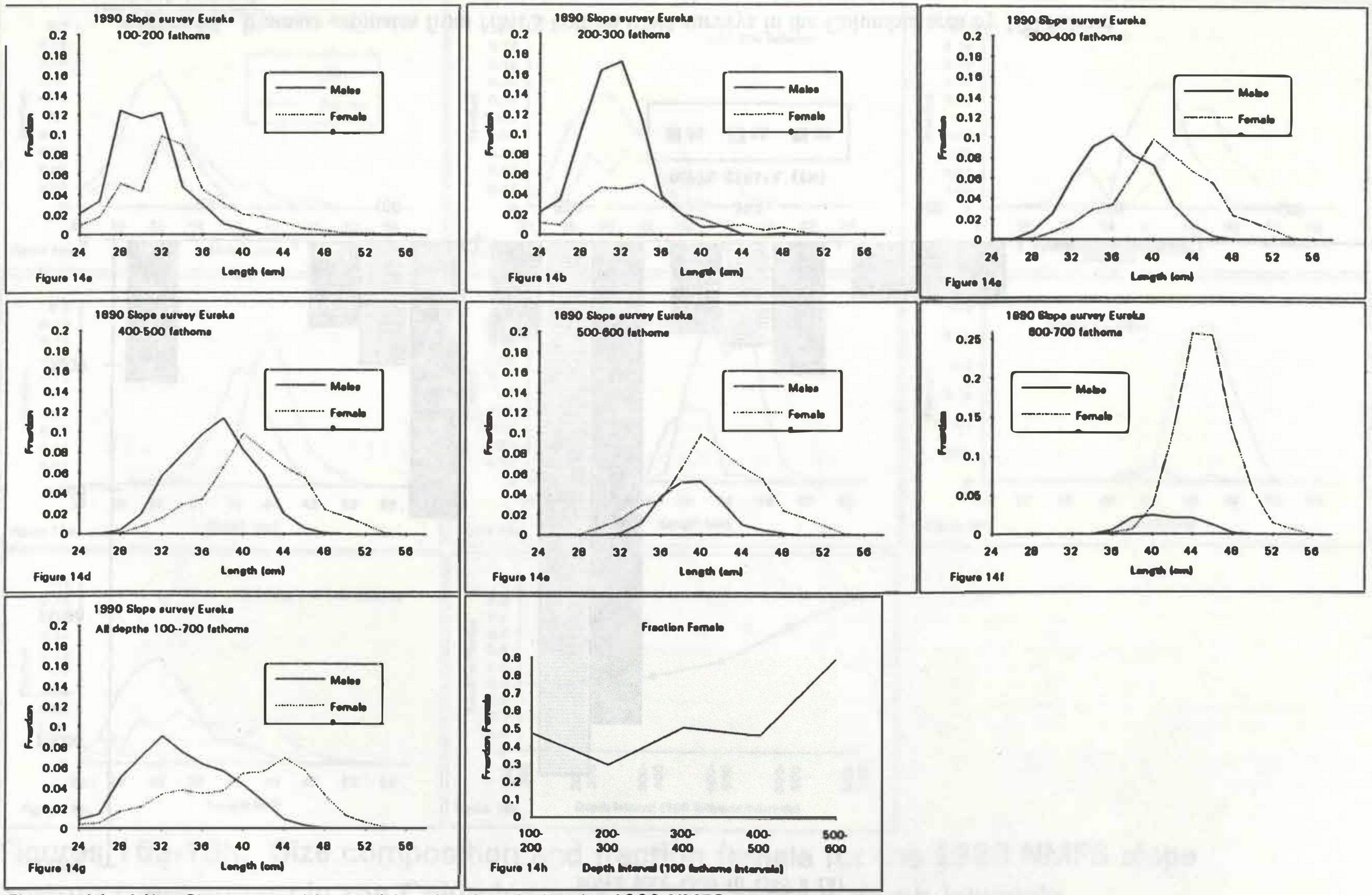


Figure 13. Biomass estimate for the 1990 NMFS bottom trawl survey by 100 fathom depth intervals in the Eureka area.



Figures 14a-14h. Size composition and fraction female for the 1990 NMFS slope bottom trawl survey in the Eureka area by 100 fathom depth intervals.

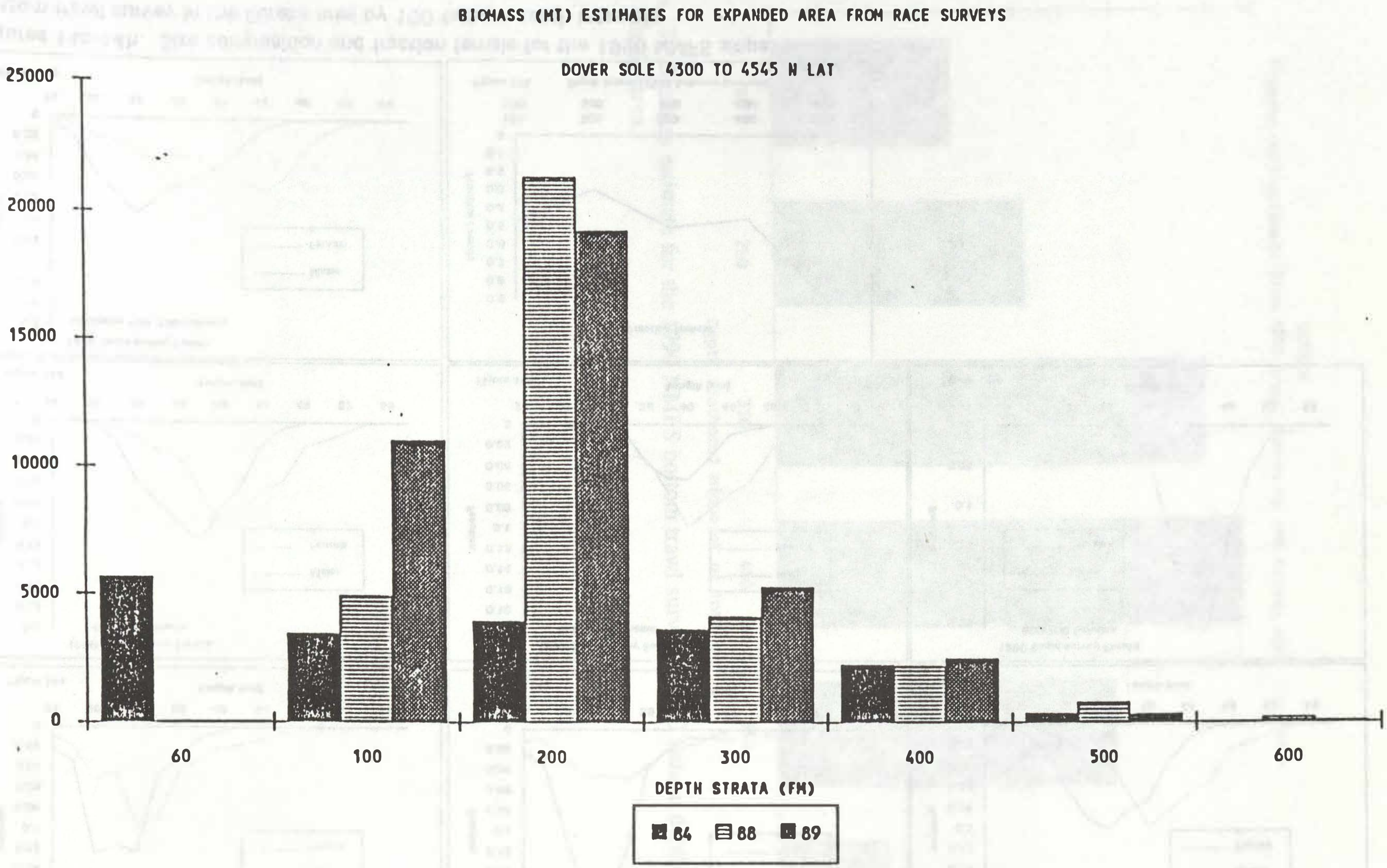
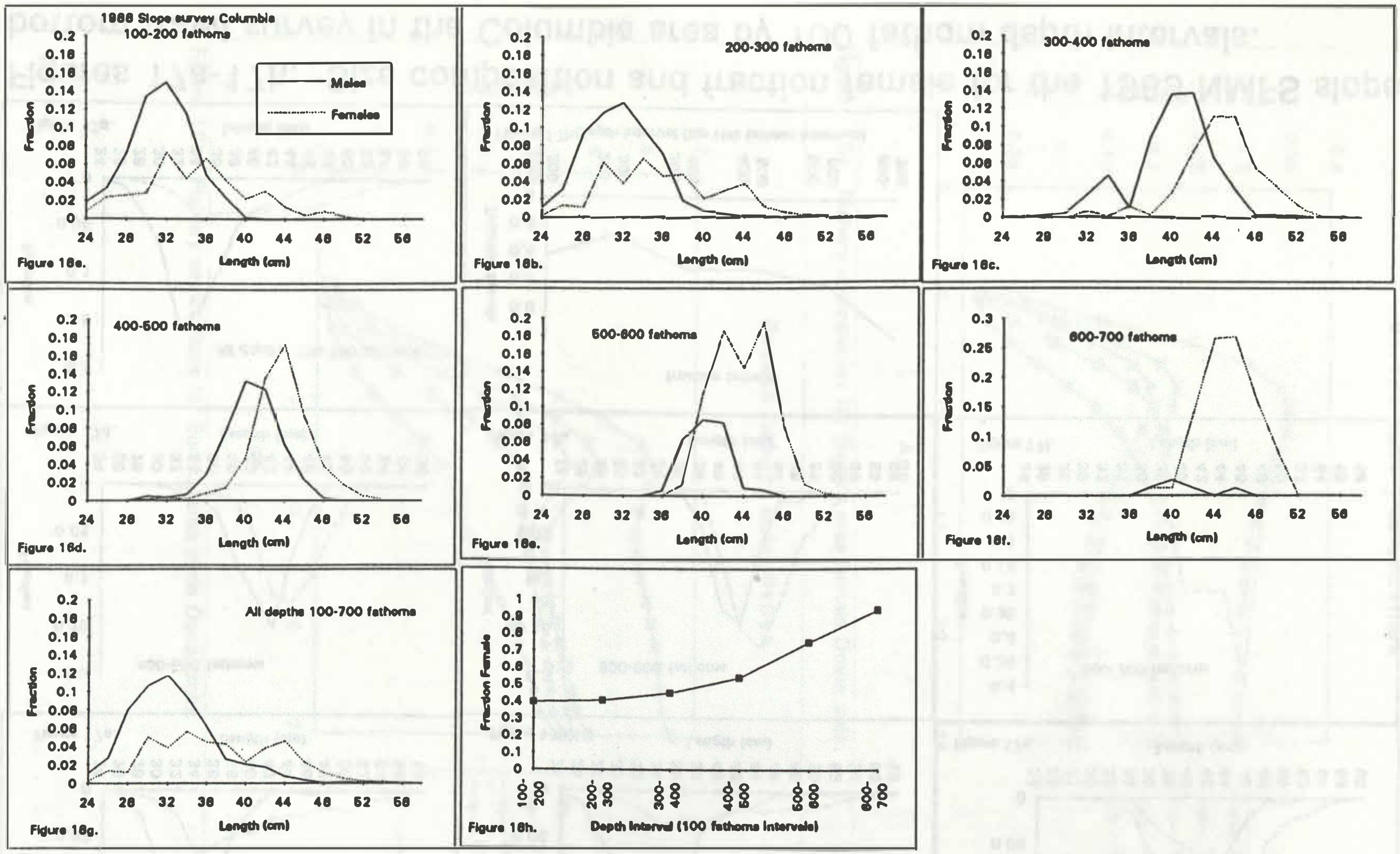
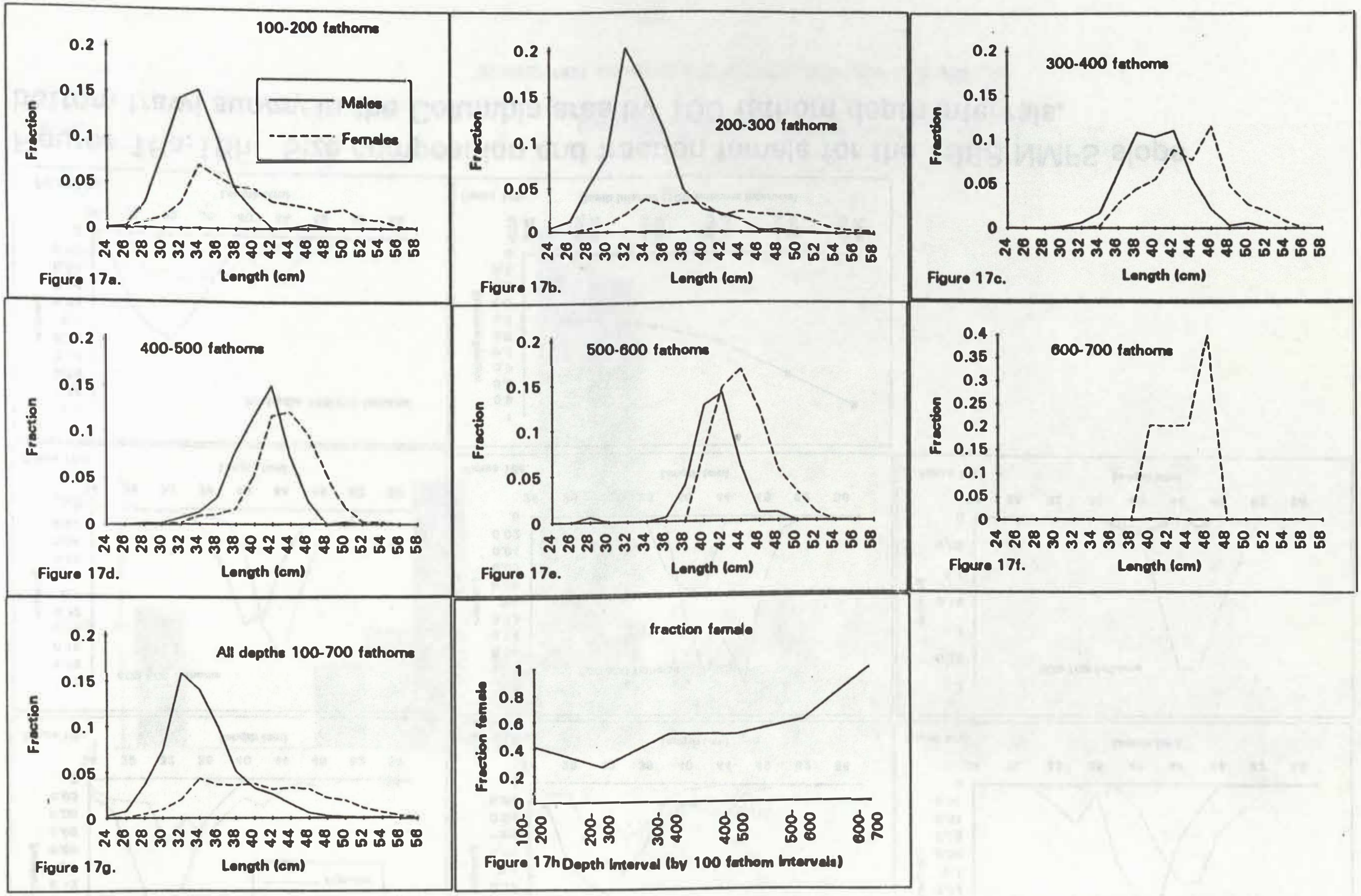


Figure 15. Biomass estimates from NMFS bottom trawl surveys in the Columbia area by 100 fathom depth intervals.



Figures 16a-16h. Size composition and fraction female for the 1988 NMFS slope bottom trawl survey in the Columbia area by 100 fathom depth intervals.



Figures 17a-17h. Size composition and fraction female for the 1989 NMFS slope bottom trawl survey in the Columbia area by 100 fathom depth intervals.

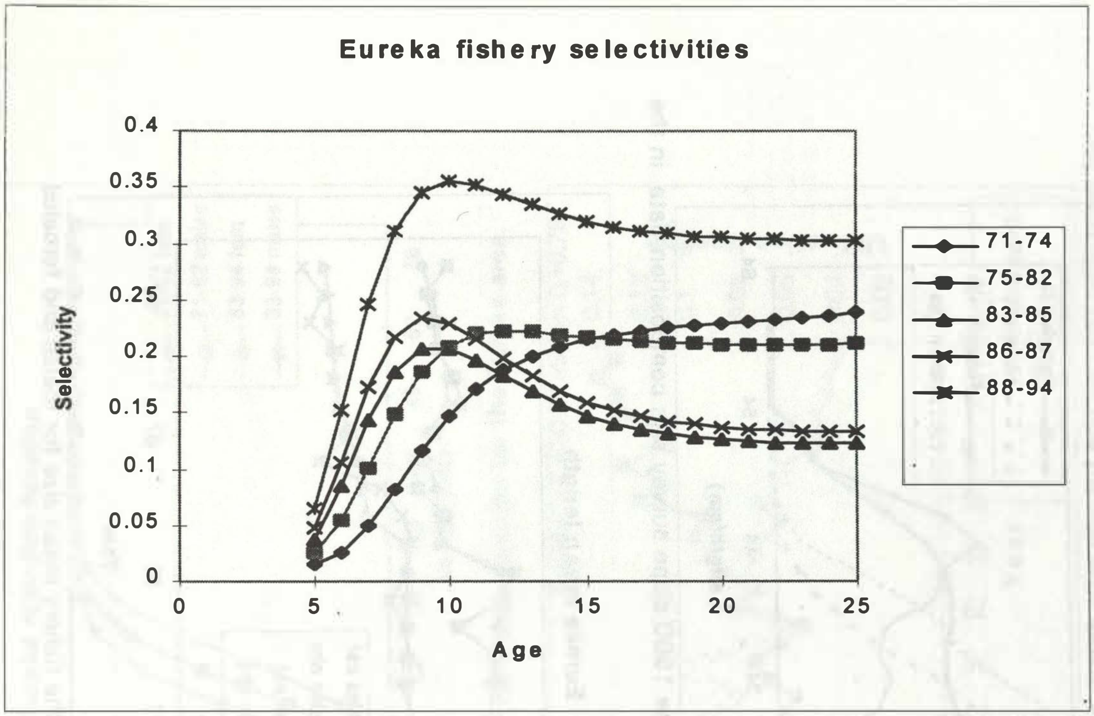


Figure 18a. Fishery selectivities for Eureka area female Dover sole.

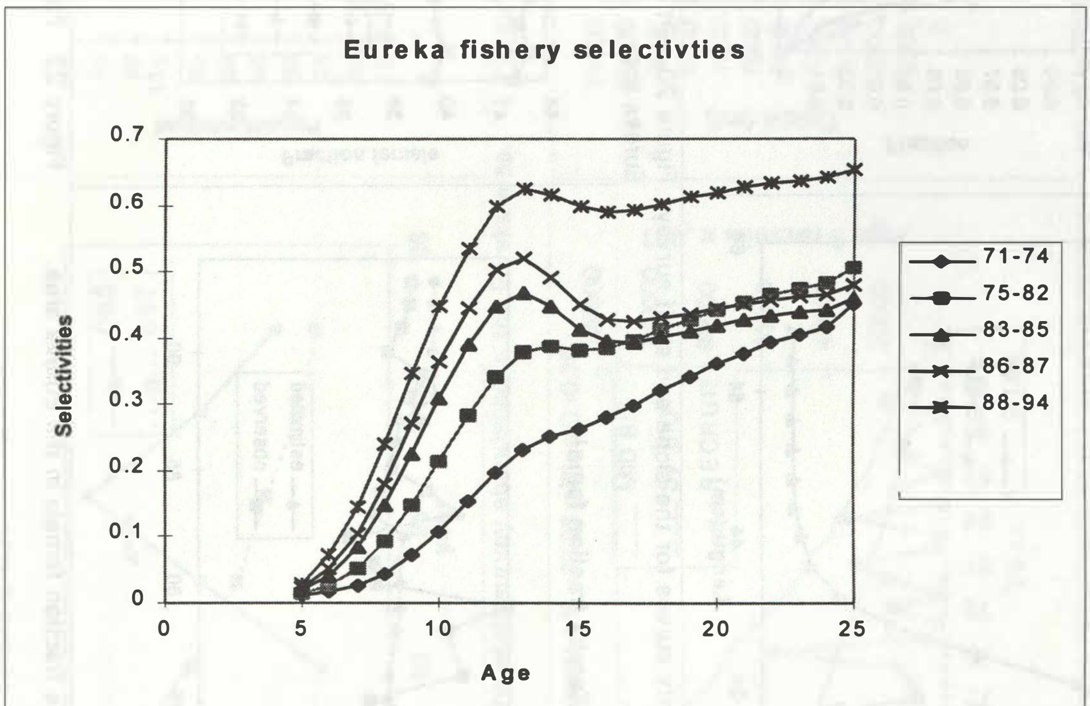


Figure 18b. Fishery selectivities for Eureka area male Dover sole.

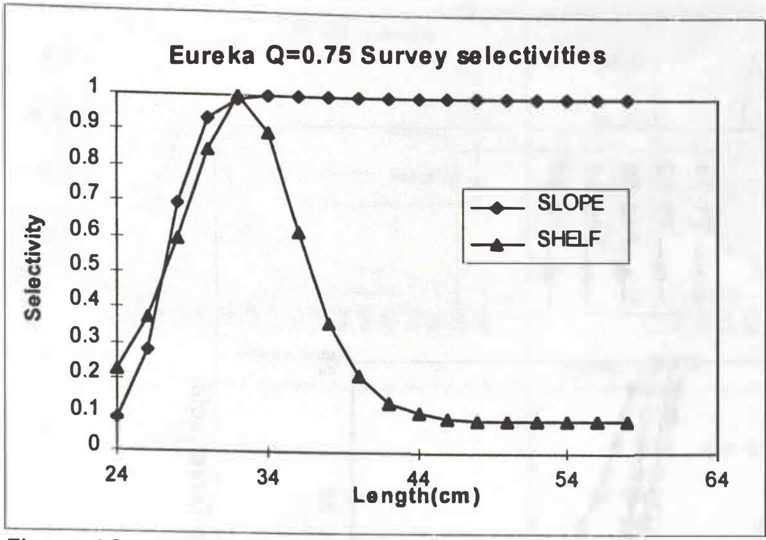


Figure 19. Selectivity curves for the slope and shelf surveys for the Eureka area.

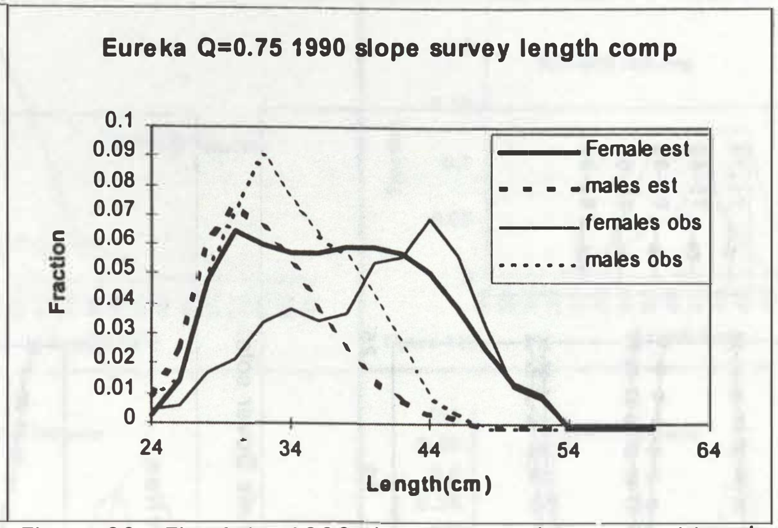


Figure 20. Fit of the 1990 slope survey size composition data in the Eureka area.

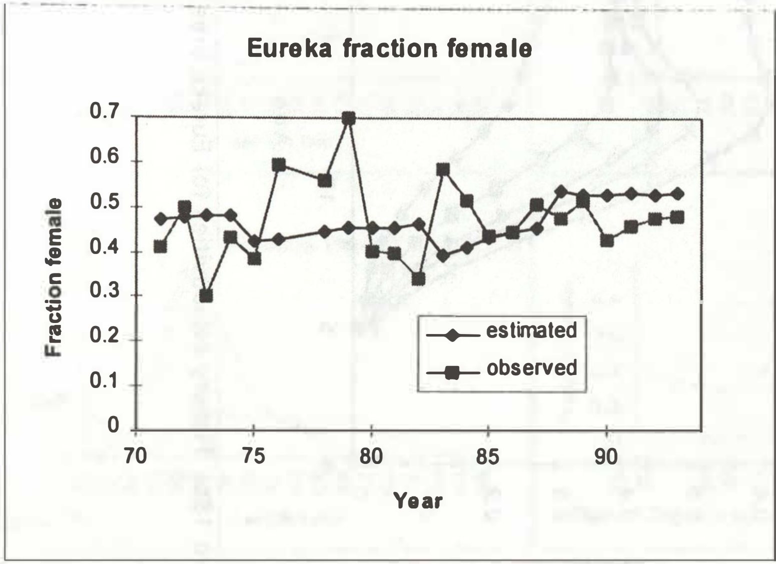


Figure 21. Fit to the fraction female in the Eureka area.

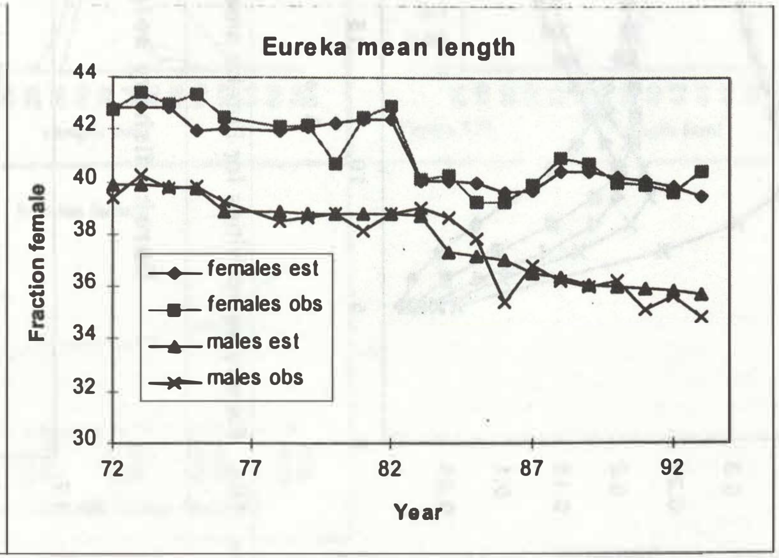


Figure 22. Fit to the fishery mean size for males and females

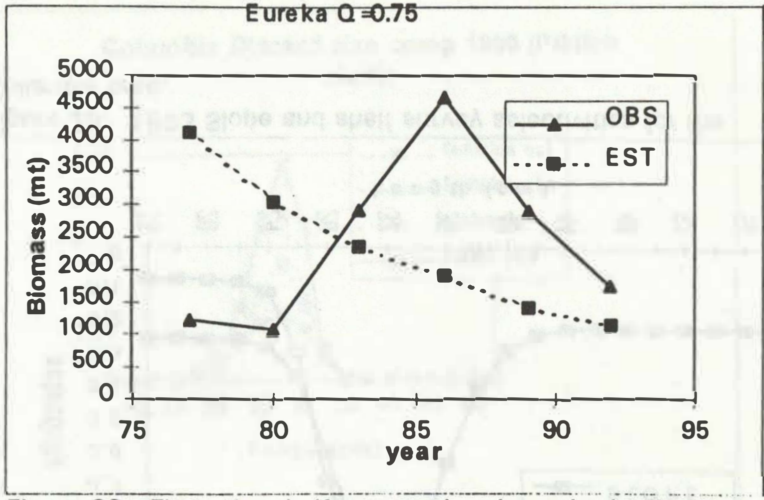


Figure 23. Fit to the shelf survey abundance in the Eureka area.

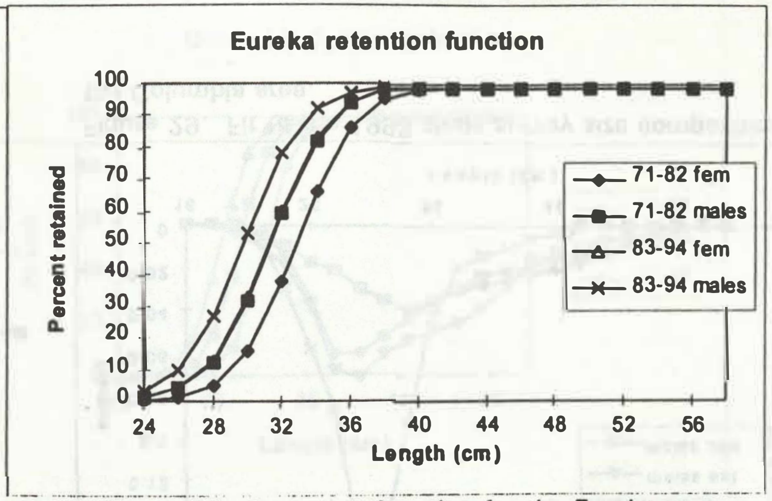


Figure 24. Retention function for the Eureka area.

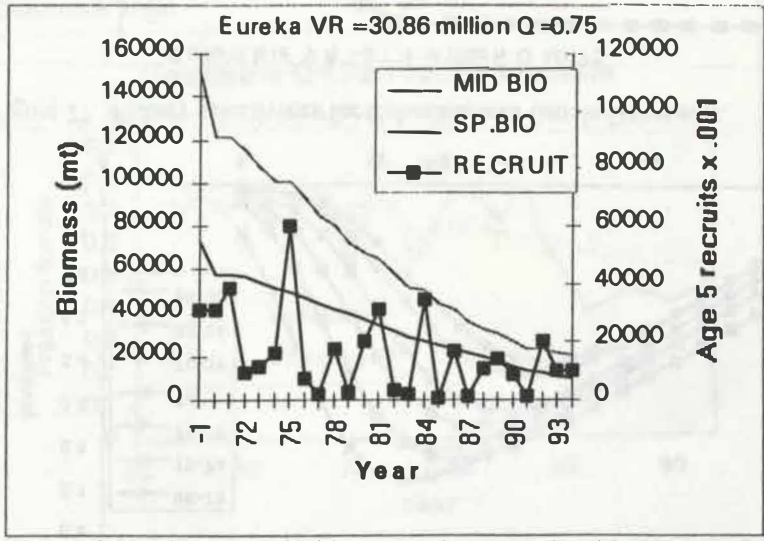


Figure 25. Biomass(mid bio), female spawning biomass (fsb) and age 5 recruits from virgin levels to 1994.

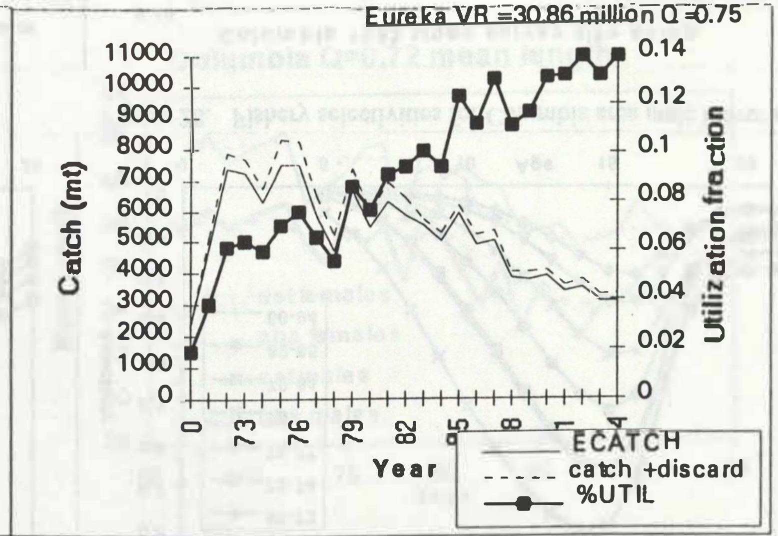


Figure 26. Catch, catch plus discard and percent utilization for the Eureka area.

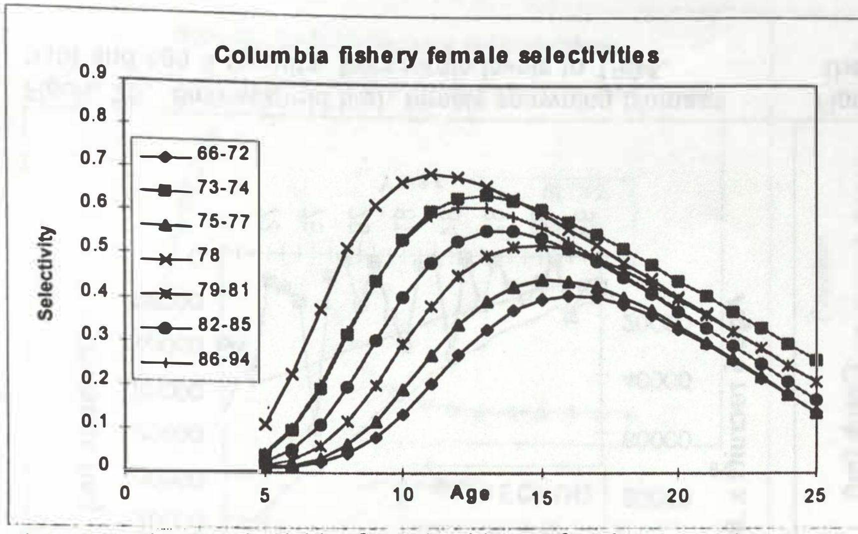


Figure 27. Fishery selectivities for Columbia area female Dover sole.

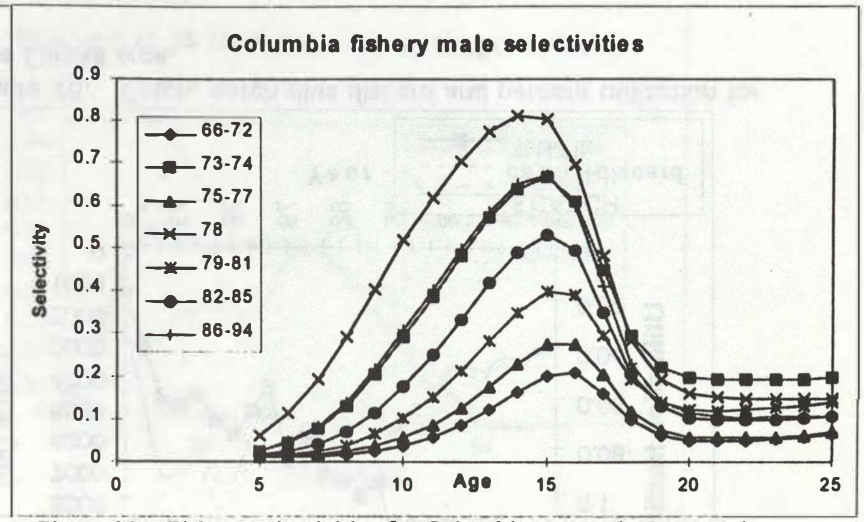


Figure 28. Fishery selectivities for Columbia area male Dover sole.

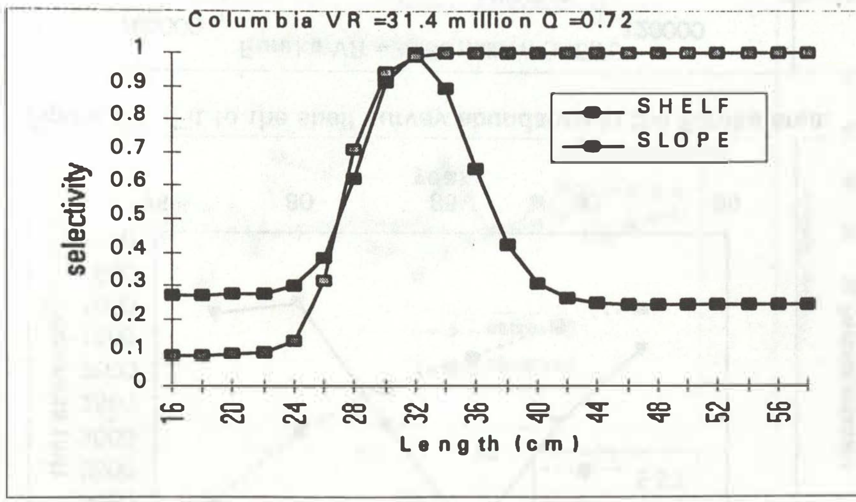


Figure 28. 1993 Slope and shelf survey selectivities for the Columbia area.

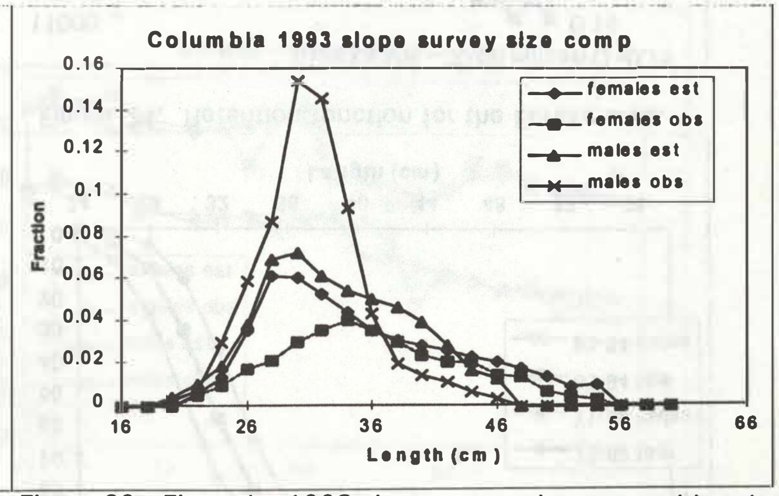


Figure 29. Fit to the 1993 slope survey size composition data for the Columbia area.

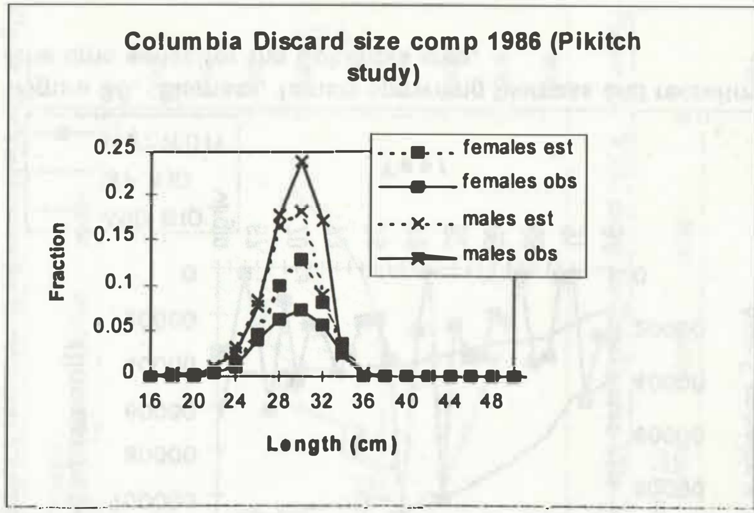


Figure 30. Fit to the descard size composition data in the Columbia area.

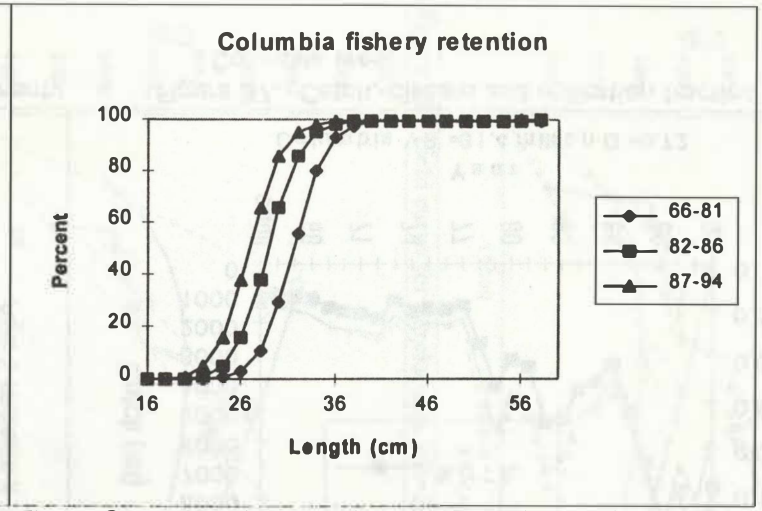


Figure 31. Retention function for three time periods, 66-81,82-86, 87-94.

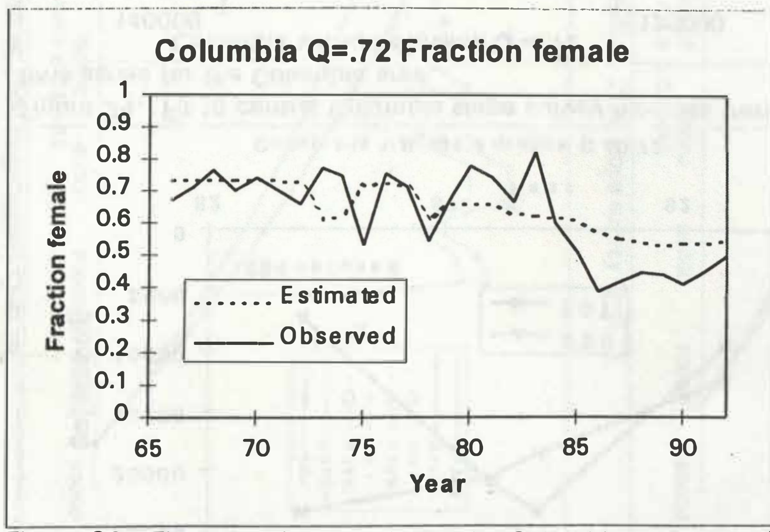


Figure 32. Fit to fraction female for the Columbia area.

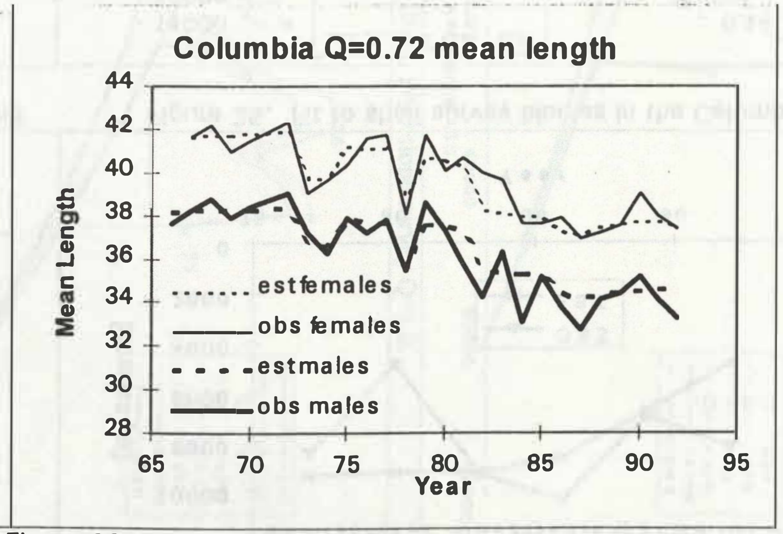


Figure 33. Fit to mean size for the Columbia area males and females.

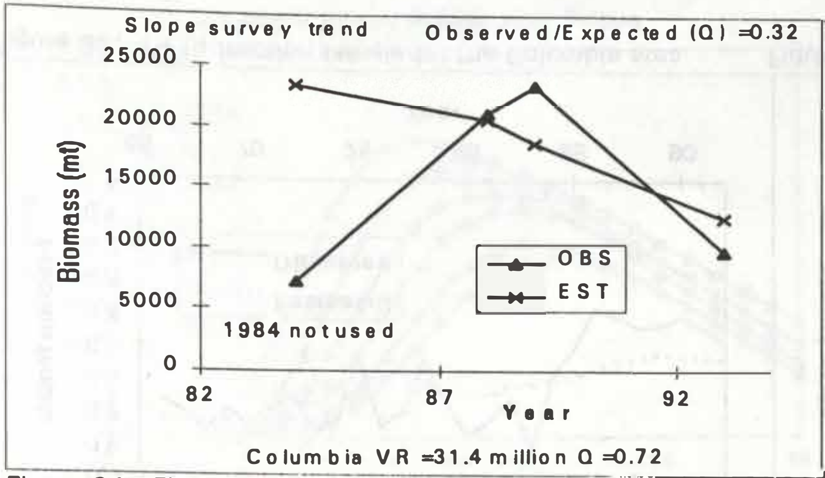


Figure 34. Fit to central Columbia slope survey biomass trend time series for the Columbia area.

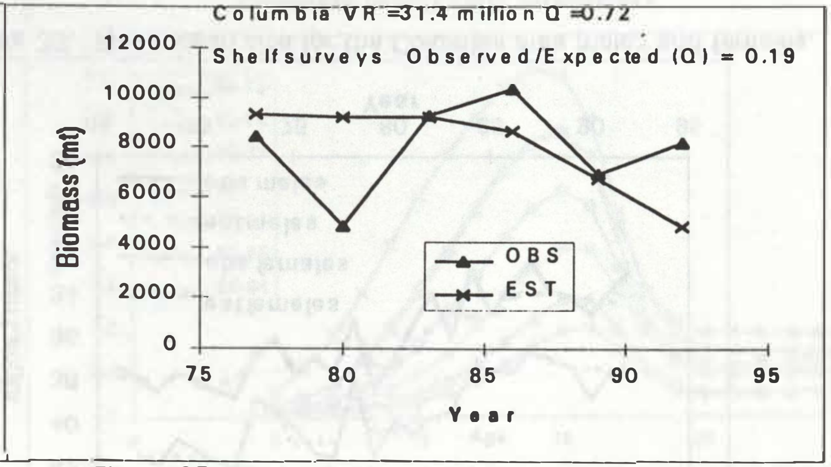


Figure 35. Fit to shelf survey biomas in the Columbia area.

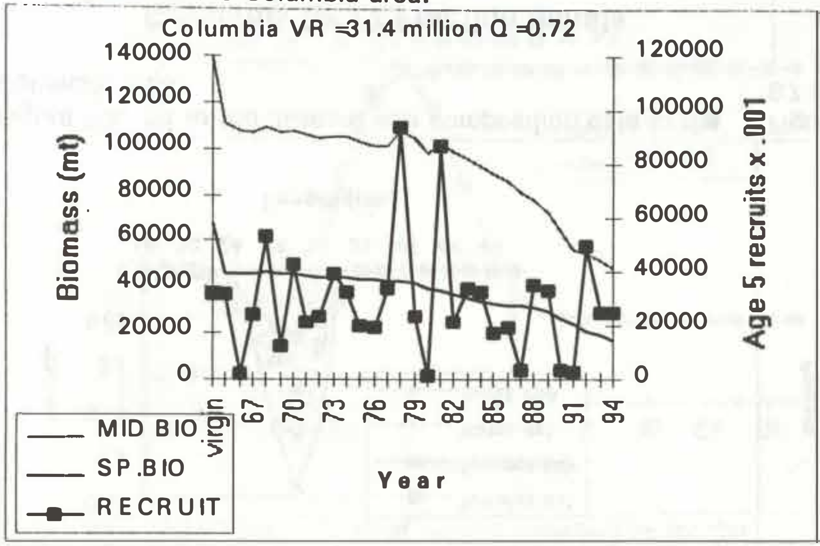


Figure 36. Biomass, female spawning biomass and recruitment the time series for the Columbia area.

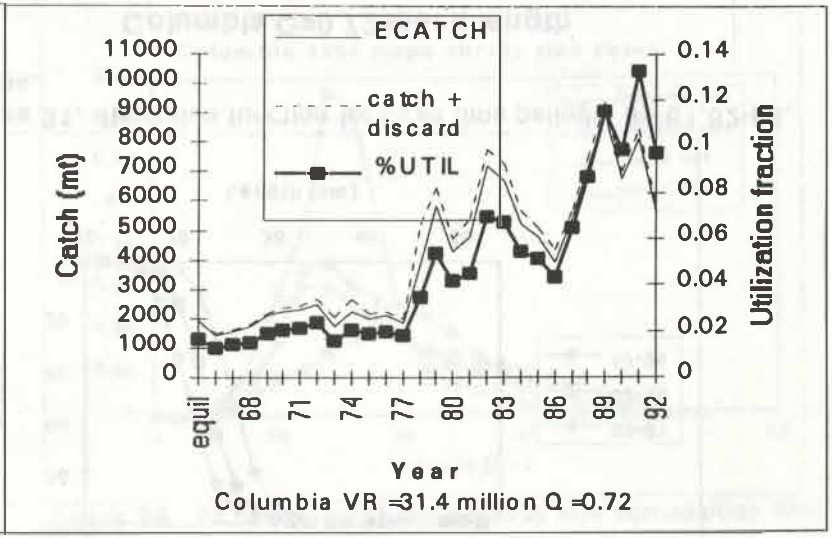


Figure 37. Catch, discard and utilization fraction time series for Columbia area.

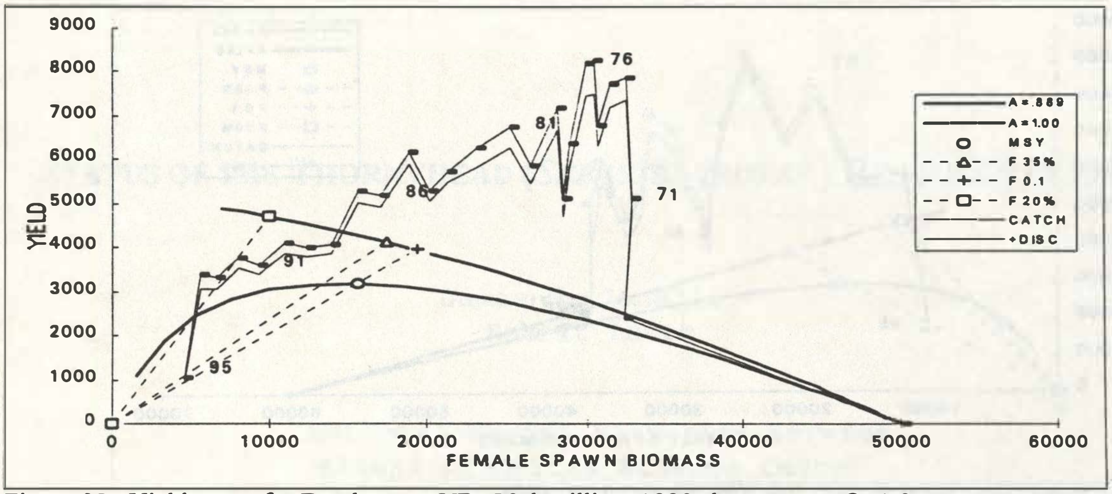


Figure 38. Yield curve for Eureka area VR=20.1 million, 1990 slope survey Q=1.0.

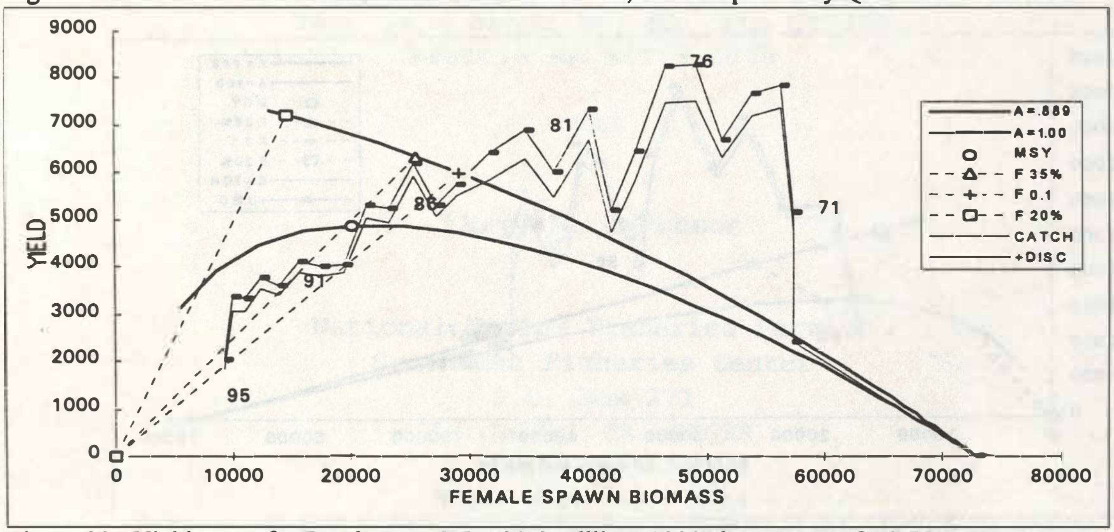


Figure 39. Yield curve for Eureka area VR= 30.9 million, 1990 slope survey Q=0.75.

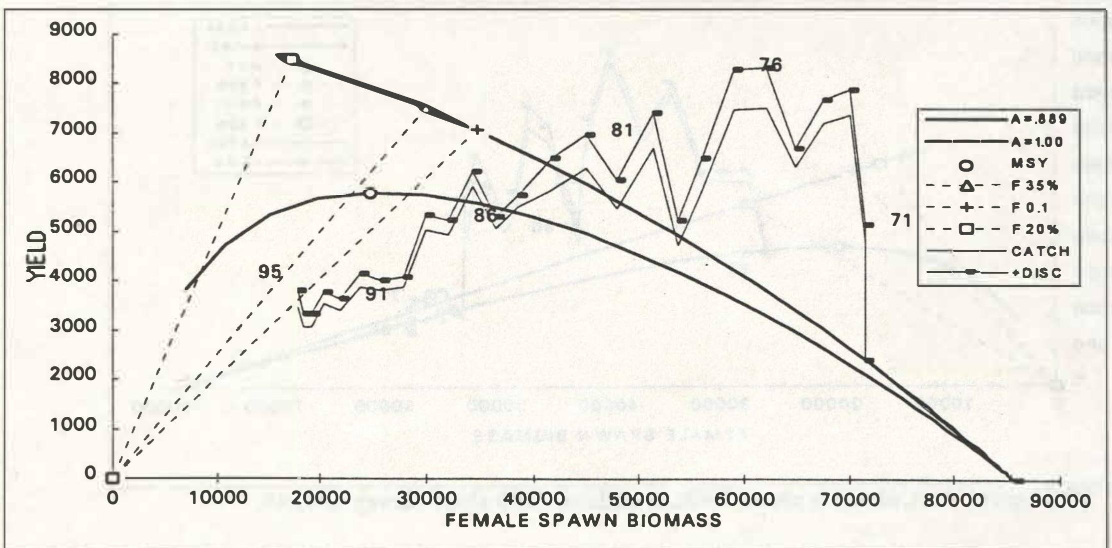


Figure 40. Yield curve for Eureka area VR=36.6 million, 1990 slope survey Q=0.49.

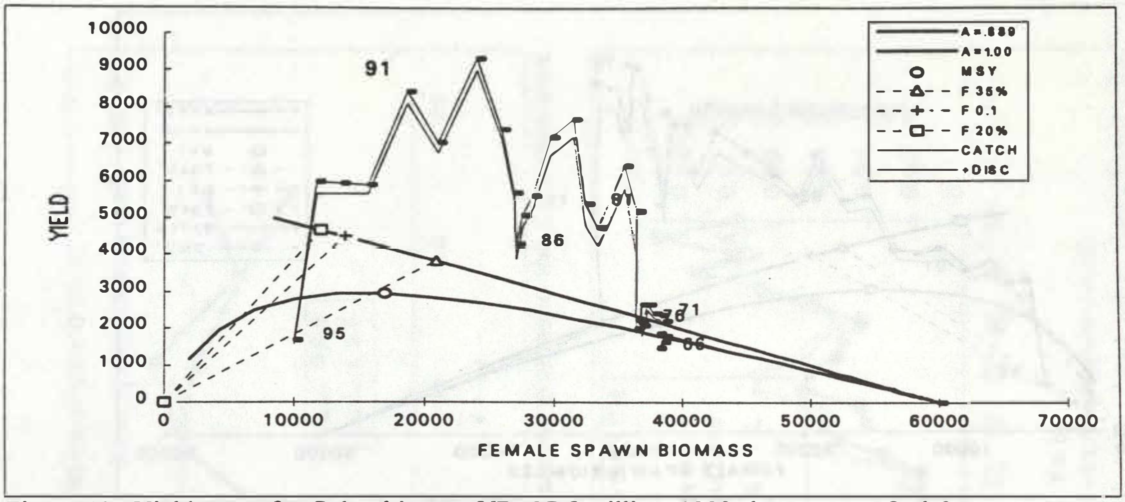


Figure 41. Yield curve for Columbia area VR=27.5 million, 1993 slope survey Q=1.0.

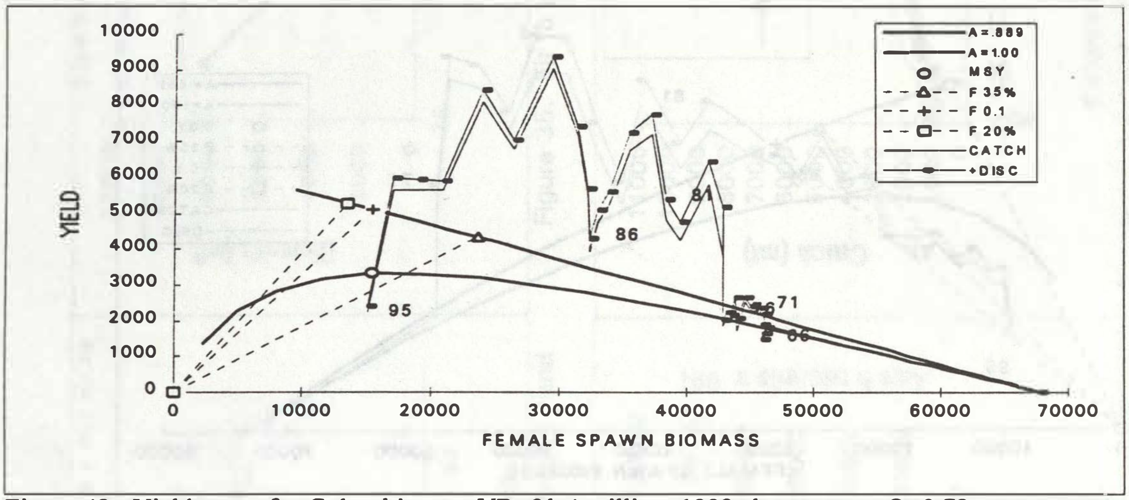


Figure 42. Yield curve for Columbia area VR=31.4 million, 1993 slope survey Q=0.72.

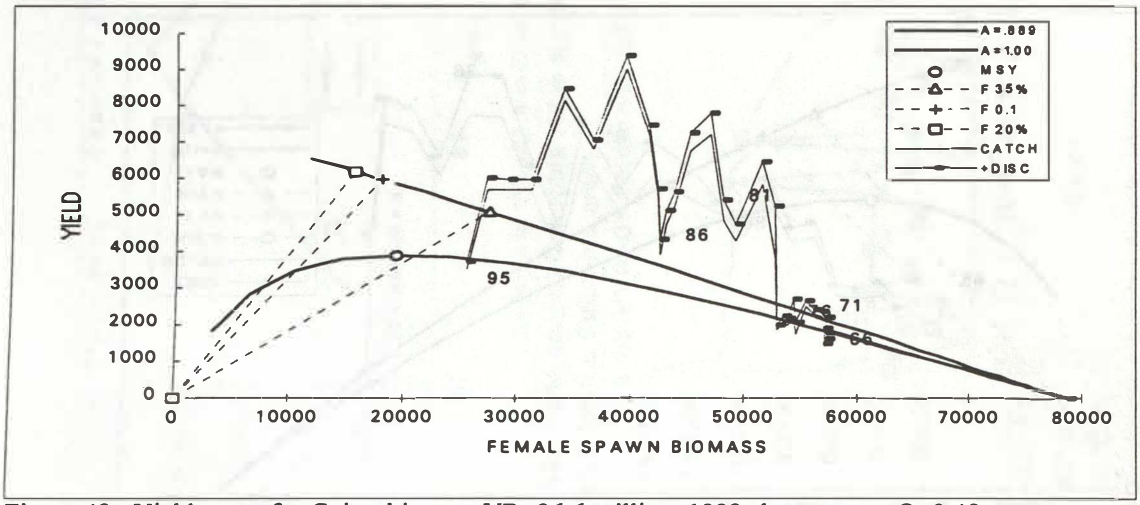


Figure 43. Yield curve for Columbia area VR=36.6 million, 1993 slope survey Q=0.48.

STATUS OF THE THORNYHEAD (*SEBASTELOBUS SP.*) RESOURCE IN 1994

James N. Ianelli,
Robert Lauth

National Marine Fisheries Service
Alaska Fisheries Science Center
Resource Ecology and Fisheries Management
7600 Sand Point Way NE, Bin C15700
Seattle WA 98115-0070

and

Larry D. Jacobson

National Marine Fisheries Service
Southwest Fisheries Center
P.O. Box 271
La Jolla, CA 92038

September 16, 1994

ABSTRACT

The market value of thornyheads has increased in recent years, particularly for small individuals. With this market expansion, interest in the fishery has increased with higher total landings. In this assessment, a unique approach to using NMFS survey data was taken in an effort to attain a coast-wide biomass estimate. Trends in this biomass index were investigated and indicated a slight decline for both longspine and shortspine thornyheads. Additionally, market sample data were analyzed for maturity and length composition information and logbook data was analyzed for catch-rate analyses. Using a combination of survey and fishery data, an attempt to estimate pre-market discard rates was made.

The preferred habitat of longspine thornyheads is in deeper water than for shortspine thornyheads. Longspine thornyheads appear to be more abundant than shortspine thornyheads although their individual size is smaller. Shortspine thornyheads appear to move into deeper water as they grow, whereas the size distribution of longspine thornyheads is relatively uniform with depth. We use the fact that, based on fishery logbook data, the average fishing depth has increased over time to modify (increase) the effective selectivity of larger shortspine thornyheads. This is reflected in our assessment of the $F_{35\%}$ and other benchmark fishing mortality rates.

For shortspine thornyheads, a large amount of ambiguity remains over the interpretation of the relationship between age and increments counted on their otoliths. Recent analyses using radiometric methods suggest that previous age determinations may have been over-estimated. However, more study in this area of research is needed to support or refute this proposition. In this analyses, we make assumptions about the average maximum size of shortspine thornyheads and their size at an early age and attempt to determine their growth rate independently. Results indicated that the growth rate was highly dependent on assumptions of natural mortality rate. However, given the available data, the likelihood of natural mortality having values less than 0.05 for shortspine thornyheads was low. A similar analysis for longspine thornyheads indicated that a natural mortality of about 0.1 was appropriate, given current information about their age and growth.

INTRODUCTION

This is an assessment of shortspine (*Sebastolobus alascanus*) and longspine thornyheads (*S. altivelis*) stocks along the Pacific Coast of Washington, Oregon and California. Several new analyses have been conducted on the stock since Jacobson (1991). In particular, the NMFS west coast slope survey estimates of biomass were used to derive a coast wide abundance index. This index was compared with a re-analysis of CDF&G logbook data for the years 1978-1991. In addition, a population analysis which reflects uncertainty in maximum age of shortspine thornyheads (and the subsequent effect on natural mortality estimates) was developed and tuned to the new abundance indices.

FISHERY DATA

Landings

Landings and exvessel price data (by port, area, month, year, etc.) for 1981 to 1993 are available from the PACFIN database. Landings from earlier years were estimated from landings reported in the California Department of Fish and Game's (CDFG) trawl reports and extend to 1964. PACFIN landings data do not distinguish between shortspine and longspine thornyheads which comprise the thornyhead "market category". Species composition data (based on port samples) for 1978 to 1993 were available from CDFG, and Oregon Department of Fish and Wildlife (ODFW). Length composition data for 1978 to 1993 (also based on port samples) are also available from CDFG and ODFW for shortspine and longspine thornyheads.

Thornyhead landings coastwide have increased five-fold since 1981 (Table 1 and Figure 1). Coastwide thornyhead landings during 1981 were less than 2,000 mt; during the four years since 1990, annual landings have averaged about 8,500 mt. Landings during 1981 to 1993 were greatest in the Eureka area, followed by the Monterey and Columbia areas. On average, 43% of annual coastwide thornyhead landings are from the Eureka area, 19% are from the Monterey area, 30% are from the Columbia area, 4% are from the Conception area, 4% are from the Vancouver area and less than 1% are from unknown areas (Table 1 and Figure 1). The reported landings from the Conception area have increased in recent years.

There continues to be some inconsistencies in species composition data used to separate thornyhead landings into shortspine and longspine components. For example, official reports indicate that only shortspine thornyheads were landed in Washington during 1981 to 1989. Reports for fish taken off the Washington coast but landed in Oregon during the same period, however, suggest that both shortspine and longspine thornyheads were available to fishermen along the Washington coast. Landings data for shortspine and longspine thornyheads should, because of the inconsistencies, be regarded as a useful but not completely reliable index of species composition for the thornyhead market category. Since 1990, longspine thornyheads have comprised the largest component of the total catch (Figure 2). The proportion of longspine thornyheads in coastwide thornyhead landings increased from 13% during 1981 to 33% during 1989 and was 60% in recent years.

Management History

The fishery management activities with respect to the deepwater complex have increased in recent years. A summary of the Pacific Fishery Management Council's actions is presented below:

Effective Date	Management Action
1-Jan-89	Coastwide trawl trip of 1,000 lbs or 45% of deepwater (DW) complex (sablefish, dover sole, arrowtooth flounder (ATF) and thornyheads (TTH))
26-Apr-89	Weekly trip limit on DW complex of only 1 landing above 4,000lbs, not to exceed 30,000 lbs.
10-Oct-89	Removed overall trawl poundage and trip freq. limits for DW complex, but retained separate trip limit for sablefish at 25% or 1,000lbs, whichever is greater.
31-Jan-90	Coastwide trawl trip limit of 1,000 lbs or 25% of deepwater complex (sablefish, Dovers sole, ATF and TTH)
3-Oct-90	15,000 lb trip limit on DW complex
1-Jan-91	Weekly trawl trip limit for DW complex of 27,500lbs, no more than 7,500lbs of thornyheads
31-Jul-91	Increased weekly trip limit for thornyheads to 12,500 lbs, DW complex remained at 27,500lbs
1-Jan-92	Established a cumulative landing limit per specified 2-week period of 55,000 lbs for DW complex, of which no more than 25,000 lbs may be thornyheads.
29-Jul-92	Reduced the cumulative 2-week landing limit for thornyheads from 25,000 lbs to 20,000 lbs
7-Oct-92	Reduced the cumulative 2-week landing limit for thornyheads from 20,000 lbs to 15,000 lbs and the DW limit from 55,000 to 50,000
1-Jan-93	Established a cumulative landing limit per specified 2-week period of 45,000 lbs for DW complex, of which no more than 20,000 lbs may be thornyheads.
21-Apr-93	Reduced the 2-week cumulative trip limit for DW complex from 45,000 per 2-week period to 60,000 lbs per 4 week period, also reduced the thornyhead trip limit from 20,000 lbs cumulative per 2-week period to 35,000 lbs per 4-week period
18-Jun-94	Effective July 1, 1994, reduced the thornyhead trip limit from the cumulative 35,000 lbs per 4-week period to 8,000 lbs.

Fleet Characteristics

In many fisheries, a relatively few vessels often catch a large share of the total catch. This can influence analyses of catch rate data and can be useful to select vessels that are concentrating their effort in a particular fishery. Results from analysis of the CDFG logbook data from the Eureka area indicated that the fleet is fairly homogeneous with respect to catching thornyheads. This conclusion was based on the fact that differences in total reported landings among vessels were relatively minor (Fig. 3).

Catch and Effort Data

Logbook data (including information about catch and fishing effort) are collected by all three states. The use of commercial catch rates (catch per unit-effort or CPUE) data as an index of relative biomass for thornyheads was assessed by Jacobson (1990) using bottom trawl logbook data provided by CDFG for fishing in the Eureka area during 1978 to 1987. In this analysis, we extend this data to 1991 and include all CDFG areas to arrive at estimates of standardized relative catch rates (mt/hr) for thornyheads. Preliminary analyses using general linear models indicated that depth strata, as reported by Jacobson (1991), was the most significant factor affecting catch rates (Fig. 4). The distribution of effort increased to deeper waters over this period, perhaps reflecting the market development for the smaller (longspine) thornyheads (Fig. 5). With the effect of depth taken into account, the standardized catch rates increased during the late 1980s and then declined (Fig. 6). This pattern may be due to discards being unaccounted for during the early part of the fishery. Because of this potential, the standardized annual average CPUE's from the logbook data are given little emphasis in the stock assessment model.

Estimation of Discards

This year we attempted to estimate discards in the historical fishery using surveys in conjunction with CDFG logbook data, both of which were post-stratified by 100-fathom depth categories. During the early period of the fishery, the market for thornyheads was primarily domestic and marketed with other rockfish under a variety of common names (e.g., channel rockfish, ocean catfish, hardhead rockfish). During the latter part of the 1980s the market in Japan developed as a similar species (*S. machrochir)* was becoming less abundant off of Japan. With this development, the landings of longspine thornyheads (which are generally smaller than shortspine thornyheads) increased (Fig. 2) Currently, all sizes of thornyheads are marketable (Pete Leipzig, pers. comm.). To estimate discards, species specific catch rate data from before and after market development were compared.

The proportion by weight of thornyheads relative to the biomass of dover sole from the NMFS surveys (described below) was compared to similar quantities from the logbook data. From the surveys, the proportion of thornyheads increases with depth to the 500-599 fathom strata and then declines slightly with deeper water. This pattern closely matches the logbook data for the recent period (1988-91) but the early logbook data indicates that the proportion of thornyheads caught was considerably lower (Fig 7). In this analysis we assume that the difference between the early logbook data and the more recent data is due to the effect of discards. Other factors such as differential declines in abundance of dover sole may play a role, however, the survey data suggest that the magnitude of thornyheads relative to dover sole in the recent logbook data are similar. Carrying this result further, the average discard rate relative to the reported logbook landings for the period 1978-1987 can be estimated as:

C_{ij} = Recorded catch of dover sole in depth strata i in year j

T_{ij} = Recorded thornyhead catch in depth strata i in year j

$\hat{T}_j$ = Expected thornyhead catch in year j

$$p_i = \frac{\sum_{j=1988}^{1991} T_{ij}}{\sum_{j=1988}^{1991} C_{ij}} \quad \text{(the ratio of thornyheads to dover sole)}$$

$$\hat{T}_j = \sum_{i=1}^{nstrata} C_{ij} p_i$$

$$D = \text{Average Discard rate 1978 - 87} = \frac{\sum_{j=1978}^{1987} \left(\hat{T}_j - T_j\right)}{\sum_{j=1978}^{1987} T_j}$$

The overall discard rate for the early fishery was estimated to be about 70% of the estimated total harvest of longspine thornyheads and about 16% for shortspine thornyheads during this period. These estimates are consistent with the species proportion of the catch that should have been caught given the depth of fishing. A summary of estimated landings and discards is presented in Table 2.

Because direct observation on discards are not available, estimating the rate requires making several assumptions. For the procedure presented above, the following assumptions apply:

- changes in relative abundance between these species over time are minor;
- the fishery has limited ability to target on these species within a depth strata;
- the reported landings data are not affected by changes in regulation and discard behavior for the species other than thornyheads;
- species identification abilities of port-samplers has not changed over time; and
- the affect of changes in gear on relative proportions of species caught was minor.

As an independent check of these calculations, the relative abundance-at-depth data from NMFS surveys was compared with the reported hours fished at depth. The expected proportion of longspine thornyheads in the catch based on the number of hours reportedly fished at different depths show that after 1987 the predicted is close to the observed (Fig. 8). Barring unquantifiable effects due to changes in gear type and species identification abilities by port samplers, this supports the conclusion that discard rates for longspine thornyheads have declined drastically since the mid-1980s. As will be shown below, the effect of including discards as estimated above and not including them has little bearing on the current status of the longspine thornyhead stock and harvest recommendations.

SURVEY DATA

"Swept area" estimates of biomass, abundance and other biological data (i.e., sex, weight, maturity, etc.) are available for shortspine and longspine thornyheads from a number of research cruises conducted by the National Marine Fisheries Service (NMFS). This year an alternative approach to estimating total biomass of shortspine and longspine thornyheads in the Columbia, Eureka and Monterey areas was attempted. Previously, the biomass estimates were calculated for each species and tabulated using strata based on: 30 to 250, 250 to 550 and 550 to 700 fathoms. In the present study, biomass estimates were recalculated using 100-199, 200-299, 300-399, 400-499, 500-599, and >600 fathoms. These depth strata were chosen because the abundance of thornyheads is low in shallow areas and changes between species relatively rapidly through these depths. Also, expanding a catch per swept area in the strata from 30 to 250 fathoms may be misleading because of the large surface area this strata represents in some regions of the coast. The results of biomass estimates within these strata for longspine and shortspine thornyheads are given in Table 3. These biomass estimates summarized by area and time show that the surveys are sparse (Fig. 9). In this assessment, we attempt to fit a smooth surface to these data to "fill in the gaps." The dimensions to the surface were depth-strata, area, and time. We used a general linear model (GLM, Chambers and Hastie 1991) of the form:

$$U_{ijt} = \mu + d_i + a_j + \beta x_t + \varepsilon_{ijt} \qquad \varepsilon_{ijt} \sim Poisson(\mu)$$

where U_{ijt} is the catch rate in kilograms per hectare in depth strata i and area j in year t. Factors included in the model are d_i for depth strata and a_i for area. These observations were weighted by the inverse of their variances (within time, area, and depth strata). Time, represented by years (x_t) is treated as a continuous variable with slope β. Because longspine and shortspine thornyheads are relatively longlived species, we felt that a smooth trend over the short period of surveys was most appropriate. Models with year as a factor were also performed (with other variables out of the model or represented in smooth fashion) but explained relatively small fractions of the variance. The form of this model was selected initially to guarantee non-negative values and because the rate of catching fish can be considered as a poisson process. Alternative error assumptions were investigated and gave similar results. We calculated the total hectares within each area - depth strata to derive a coastwide (Conception - US Vancouver) estimate of longspine and shortspine thornyhead biomass. The results of this excercise are presented in Table 4. The coefficients of variation for the biomass estimates range from 6% to 27% among areas and years (Table 5).

As an alternative, a "coastwide" biomass estimate similar to that used for sablefish was estimated as a simple sum of the subareas presented in Table 4 but grouped over years from 1990-1993 (plus the 1988 estimate for the Conception area). This gives values of 85,892 t for longspines and 31,380 t for shortspines. Note that these values are very close to the coastwide values from the GLM model in 1993.

In either usage of the survey data, the question remains as to the potential bias of the survey gear. Specifically, are the estimates consistently over- or under-estimating the true population density? Currently, this topic is highly debated on a species-specific basis. Based on submersible observations, it does not appear that thornyheads exhibit any burrowing behavior and, additionally, their primary habitat is in trawlable areas (i.e., they do not aggregate in high densities over untrawlable rock outcroppings). This suggests that they are probably not underestimated, unless they are able to avoid the gear in some other way. The effect of "herding" by the trawl bridles may result in consistent over-estimates of abundance. To our knowledge, no data exist to support or refute this possibility. As a consequence, we explored the effect of different levels of bias in the absolute survey biomass relative to the available data and other uncertainties as described in the section titled Assessment Model.

BIOLOGICAL DATA

Information about growth, mortality, maturity, fecundity, diet, and yield per recruit for shortspine thornyheads captured off Cape Ommaney in southeastern Alaska is available (Miller 1985). Thornyheads in Alaskan waters are assessed annually on the basis of catch rates from longline and trawl surveys, swept area biomass estimates, and yield per recruit analysis (Anon. 1989). Information about early life history of shortspine and longspine thornyheads along the continental west coast is available from Moser (1974). In this study, results from some new data collections in the Oregon market sampling program were analyzed in addition to data presented in previous assessments.

Size at Age

Shortspine thornyheads samples were taken during a 1988 NMFS research cruise off California in addition to large specimens taken by port samplers from commercial landings in Oregon for analyses of size at age. A preliminary subset of the data for longspine and shortspine thornyheads were used by Jacobson (1990). The current status of these data are summarized in the following sections.

Longspine thornyheads

Age data for a sample of longspine thornyheads from otolith sections (provided by J. Butler, Southwest Fishery Science Center, NMFS) were used to estimate length at age for longspine thornyheads. The criteria used for ageing longspine thornyheads have not been validated, however, are considered easier to age than shortspine thornyheads because "annual" marks were fewer and more widely spaced. The relationship between total length and estimated age from these data is given in Fig. 9.

Shortspine thornyheads

As in Jacobson (1991), age determinations for shortspine thornyheads used in this study were provided by J. Butler. There has been general agreement among independent readers indicating that shortspine thornyheads are probably long lived (Fig. 11). Recently, shortspine thornyhead otolith samples have been aged using radiometric methods (Bennett et al. 1982) and preliminary results indicate that the oldest fish is probably in the range of 50-100 years old. Because of the small number of samples that have been done using this method, the data are inconclusive as a means of validating conventional, otolith increment-count data. Currently, NMFS is considering the feasibility of tagging shortspine thornyheads and using otolith marking techniques for developing a direct age-validation method. In this assessment, we attempt to analyze plausible growth scenarios using yet another source: fishery and survey size-composition information.

Natural Mortality, Longevity

In previous assessments of these species, a linear regression model relating oldest observed age and mortality was used to estimate the natural mortality rate (M), for shortspine and longspine thornyheads (Hoenig 1983). Because of the uncertainty in determinations of the oldest-aged shortspine thornyhead, this method was used only as a cross-check of the range determined from modelling efforts detailed in this report. Also, Pascual and Iribarne (1993) show that there are often statistical problems with using functional relationships to "predict" related variables such as natural mortality.

Longspine thornyheads

The oldest longspine thornyheads observed in the sample used for this analysis was 45 years which according to Jacobson (1990) corresponds to a natural mortality rate of about 0.1 yr^{-1}. In this study, natural mortality is evaluated with respect to several different data types in the framework of a stock assessment model. As presented below, the natural mortality rate most likely lies in the range from 0.08 to 0.12. This supports the range used by Jacobson (1991).

Shortspine thornyheads

It was pointed out in Jacobson (1991) that conventional age estimates may be twice the actual age based on radiometric studies. Using Hoenig's method, the natural mortality rate corresponding to a maximum age of about 120 years is about 0.04 whereas for a maximum age of about 60 gives M=0.07. Miller (1985) estimated shortspine thornyhead natural mortality rate in the Gulf of Alaska at $M = 0.07\ yr^{-1}$. The oldest age observed in Miller's (1985) sample of shortspine thornyheads was 62 years. As will be shown below, another estimate of natural mortality was attained using the fishery and survey data in the context of the stock synthesis model. The values giving the maximum likelihood were higher than the above estimates. As a consequence, three models were run with values of M = 0.05, M=0.07, and M=0.09.

Spawning and maturity

The month of peak spawning for shortspine thornyheads is thought to be April (Moser 1974) and the month of peak spawning for longspine thornyheads is thought to be February (Wakefield 1990).

In the previous assessment, data from Wakefield (1990) were used to describe the relationship between maturity and total length for female longspine thornyhead. Jacobson (1991) estimated maturity at size for shortspine thornyheads based on data taken during the 1988 research cruise aboard the R/V David Starr Jordan. In this assessment, additional data collected by ODFW over the period 1990-1993 were compiled and analyzed for size at maturity information.

The ODFW supplied data from 10,839 samples of longspine thornyheads and 2,926 samples of shortspine thornyheads. All fish were sexed and categorized by maturity codes given in Table 6. The size composition for fish in each of these stages is presented in Fig. 12. The number of females used for maturity estimation was 3,738 and 940 longspine and shortspine thornyheads, respectively.

Logistic regression and maximum likelihood were used to fit the model

$$\text{Proportion Mature}_i = \frac{1}{1+e^{-(b \cdot length_i - a)}} + \varepsilon_i$$

to maturity data for female thornyheads (Figure 13). The statistical error ε in was assumed to be binomial. The model fit indicates that 10% of female longspine thornyheads are mature at about 19 cm, 50% are mature at about 21.5 cm and 90% are mature at about 25 cm (Fig. 13, upper panel). For shortspine thornyheads, the model fit indicates that 10% of female shortspine thornyheads were sexually mature at about 17 cm, 50% are mature at about 22 cm and 90% are mature at about 27 cm (Fig. 13, lower panel). The parameter estimates for the logistic maturity model (standard errors in parentheses) and sample sizes are as follows:

Species	a	b	N
Shortspine thornyheads	9.028 (1.186)	0.410 (0.047)	940
Longspine thornyheads	16.910 (0.647)	0.766 (0.028)	3,738

Length-weight relationship

The parameter estimates of the model $W=aL^b$ (where W is round weight in grams and L total length in mm) from Jacobson (1990) used in this assessment are:

	Shortspine	Longspine
a[1]	2.651×10^{-6}	1.794×10^{-6}
SE for ln(a)	0.04064	0.1051
b	3.264	3.352
SE for b	0.006993	0.02035
r^2	0.99	0.99
N	1721	289
min-max L	24-740 mm	69-308 mm
min-max W	9-6662 g	3-377 g

[1]Corrected for bias due to log transformation

ASSESSMENT MODEL

Separate length-based assessment models were performed for both thornyhead species using the stock synthesis program (Methot 1990). Several alternative model scenarios were examined for each species. In particular, the relationship between assumptions about natural mortality, and the effective "area swept" nature of the survey biomass estimates were explored extensively for the more abundant species, longspine thornyheads. Initial runs found that the assessment model could not provide a reasonable means to evaluate trawl survey effectiveness given the available data and uncertain biological assumptions about this species. Consequently, we assumed that the trawl surveys estimated the absolute abundance of longspine thornyheads with a Q of 1.0. The same assumption was necessary for shortspine thornyheads. However, the issues of ageing uncertainty and the implication for natural mortality were explored for shortspine thornyheads.

Data

The fishery data included the catch and discards (as specified below) and estimates of the size composition. The size composition data are presented in Figs. 14 and 15 for California and Oregon, respectively. The distribution of size by depth category is presented in Fig. 16. The survey biomass data were used in the two forms as presented above. The size composition data used in the assessment model for these surveys are shown in Fig. 17. A summary of the data sources and availability by time is given in Table 7.

Assumptions

The nature of the data are such that much is open to interpretation regarding its application. This assessment does not present an exhaustive set of plausible model scenarios. The scenarios that are examined reflect biases that the authors have developed in processing the different databases, observing survey operations, and in conducting assessments of other species. To direct the readers attention to these potential biases, the following presents a subjective score of data quality based on the opinion of the authors (arbitrary scale, 10 being the best, i.e., reliable, and 1 being highly uncertain):

Data / assumption	Score
Fishery catch data	4
Fishery discard rate	6
Fishery size composition data	5
Fishery species composition data	6
Raw survey biomass data	6
Integrated survey biomass results	8
Survey size composition data	4
Size at age data longspine thornyheads :	7
Size at age data shortspine thornyheads:	3
Maturity at size data	8
Natural mortality	3
Weight-length data	10

From the above table it is clear that considerable skepticism exists on the reliability of several aspects critical to this thornyhead stock assessment. Nonetheless, these relative scores helped to design sensitivity analyses and provide guidance in selecting models for providing harvest recommendations. Some key assumptions in configuring a population dynamics model to fit our observations included:

- survey and fishery selectivity is based on size and is monotonic, increasing to an asymptote;
- the statistically fitted survey biomass estimates are a reasonable approach to attain a time-series of coast-wide biomass estimates,
- the estimation of discard rates is reasonable as presented above,
- growth between ages 5 and 30 years is reasonable represented by age-length data presented in previous assessments (i.e., Jacobson 1990, 1991) for longspine thornyheads,

- relative abundance between longspine and shortspine thornyheads has remained constant over the short history of the fishery, and

- the assumption of a "unit stock" for the coastwide fishery is not unreasonable in terms of providing harvest guidelines.

- the underlying stock-recruitment relationship is largely due to process error—i.e., annual recruitment "anomalies" are estimated relative to a fixed stock-recruitment curve. For all of the models investigated below, a fixed Beverton-Holt model as parameterized by Kimura (1988) was selected with parameter values that imply a 90% reduction in recruitment as spawner biomass levels is reduced to 20% of the average, unfished biomass.

Sensitivity analyses/Model selection methods

Three levels of sensitivity analyses were completed for longspine thornyheads. These dealt with uncertainties in discard amounts, our treatment of the survey data (i.e., whether there is a discernable time trend or not), and our assumptions of natural mortality. We identified three model configurations, where for Model 1, catches were used exactly as reported to PACFIN and a background discard rate of 8% was assumed. In this model we chose a single point estimate for absolute biomass as the sum across survey areas and years. In Model 2, we used the estimate of discards as presented above. Finally, Model 3 was the same as Model 2 but the integrated time series of survey biomass was used. The three models are summarized as follows:

Longspine models

Model	Discards	Survey
Model 1	set to background of 8% of PACFIN landings	simple sum, set as if it were a coastwide 1993 estimate
Model 2	set to estimated rates (presented above)	simple sum, set as if it were a coastwide 1993 estimate
Model 3	set to estimated rates (presented above)	integrated coastwide treatment with moderate trend

For longspine thornyheads we assumed that our size at age data was measured with error, but that it was unbiased. Likelihood profiles over alternative values for natural mortality were run for each of the three models. This allowed us to evaluate the effect of uncertainties in discard rates and our treatment of survey biomass levels on estimates of natural mortality.

The assessment of shortspine thornyheads presented a different set of problems. In this case we chose to fix Q at 1, and to deal with the problems of size at age and its related uncertainty on natural mortality. Because of the ambiguities surrounding the age relationship, we attempted to evaluate the growth rate using data other than from the radiometric methods and the conventional age readings. To do this, we fixed the average maximum size to values of 65, 70, and 75 cm with the size at age 5 fixed at 15 cm. This left the von Bertalanffy growth parameter, K, to be freely estimated given the population model data. Intuitively, the value of K will be confounded with M so a grid of model runs were conducted for different fixed values of these parameters to define the feasible parameter space. This space was then compared with values attained from conventional age reading data and the recent radiometric data. To select a final model.

Additionally, the stock synthesis model for shortspine thornyheads was configured to have selectivity vary as a function of depth of fishing. This was done to account for the fact that the mean length of shortspine thornyheads increases with depth (Fig. 18).

Results

Model Selection

For longspine thornyheads the selection of a single model among the uncertain parameters and model configurations was not clear-cut. The likelihood profile was comparatively flat for different values of natural mortality and had slightly different shapes depending on model configuration (Fig. 19). Because we feel Model 1 discard rates almost certainly underestimate historical values, and that Model 2 may not reflect the apparent downward trend in abundance, we chose Model 3 as the basis of our recommendations. Within this model configuration, we ran three values for natural mortality: M=0.08, 0.10, 0.12 based on a likelihood profile under different fixed values of M:

Longspine thornyheads
Log-Likelihood component value

Natural Mortality	Fishery Size Composition	Survey Abundance	Survey Size Composition	Survey Size at Age	Total Likelihood
0.01	-514.1	6.9	-789.6	-30.7	-1327.6
0.02	-384.7	10.0	-440.1	-20.7	-835.4
0.03	-379.0	12.0	-276.1	-20.9	-664.0
0.04	-354.3	12.8	-223.6	-21.6	-586.7
0.05	-335.2	13.3	-147.9	-15.3	-485.1
0.06	-313.8	13.6	-148.7	-13.6	-462.4
0.07	-307.8	13.8	-132.3	-16.5	-442.8
<u>0.08</u>	**-301.6**	**13.8**	**-122.5**	**-15.1**	**-425.3**
0.09	-296.9	13.9	-115.5	-13.4	-411.9
<u>0.10</u>	**-289.7**	**13.7**	**-114.9**	**-13.0**	**-403.9**
0.11	-287.0	13.7	-115.1	-13.8	-402.1
<u>0.12</u>	**-284.5**	**13.7**	**-117.2**	**-16.0**	**-404.0**
0.13	-280.6	13.4	-125.1	-16.8	-409.1
0.14	-279.1	13.3	-132.9	-22.0	-420.7
0.15	-276.7	13.0	-144.3	-27.0	-435.1
0.16	-274.2	12.8	-157.7	-34.2	-453.4
0.17	-273.2	12.3	-167.7	-43.4	-472.0
0.18	-278.2	11.6	-169.8	-74.4	-510.8
0.19	-271.7	10.8	-207.1	-81.3	-549.3
0.20	-270.4	9.5	-190.2	-84.5	-535.6

Additionally, we examined the impact our discard estimation had on our assessment of longspine thornyheads. The historical biomass estimates of age 5 and older and female spawners followed by key management parameters using low historical discard rates and using our estimated discard rates were:

	Biomass 5+		Female Spawner Biomass		%Equilibrium SpawnerBiomass	
	Low Discards	Est. Discards	Low Discards	Est. Discards	Low Discards	Est. Discards
Equil.	110,616	130,385	35,771	42,336	100%	100%
64	110,593	130,187	35,761	42,255	100%	100%
65	110,512	130,007	35,736	42,183	100%	100%
66	110,384	129,710	35,708	42,100	100%	100%
67	110,242	129,407	35,691	42,048	100%	99%
68	110,111	129,174	35,683	42,022	100%	99%
69	109,957	128,904	35,661	41,957	100%	99%
70	109,722	128,427	35,618	41,830	100%	99%
71	109,489	127,922	35,565	41,677	99%	99%
72	109,553	127,544	35,481	41,438	99%	98%
73	109,707	126,941	35,360	41,100	99%	97%
74	109,915	126,322	35,239	40,772	99%	96%
75	110,286	125,915	35,103	40,412	98%	96%
76	110,664	125,302	34,940	39,987	98%	95%
77	111,084	124,687	34,780	39,573	97%	94%
78	111,552	124,140	34,648	39,220	97%	93%
79	111,998	123,735	34,534	38,853	97%	92%
80	112,178	122,774	34,490	38,561	97%	91%
81	112,299	122,064	34,544	38,390	97%	91%
82	112,102	121,046	34,668	38,183	97%	90%
83	111,629	119,529	34,871	37,950	98%	90%
84	110,952	117,868	35,135	37,754	98%	89%
85	110,123	116,105	35,350	37,373	99%	88%
86	108,916	113,583	35,450	36,710	99%	87%
87	107,424	110,651	35,333	35,857	99%	85%
88	105,179	107,387	34,533	34,744	97%	82%
89	101,053	103,849	32,946	33,184	93%	79%
90	96,033	99,556	30,862	31,153	87%	74%
91	90,564	94,979	28,855	29,222	82%	70%
92	87,059	92,764	26,761	27,235	77%	66%
93	82,475	89,528	24,486	25,107	71%	61%
94	78,714	87,233	22,341	23,151	65%	57%
95	75,354	85,481	21,501	22,630	63%	55%

Quantity	Low Discards	Est. Discards
$F_{35\%}$	0.249	0.247
$F_{20\%}$	0.566	0.555
1995 ABC	7,523	7,823
1995 Over-Fishing	15,470	15,997

Legend: Est. Discards = Discards were included in the model as estimated, Low Discards = discard of longspine thornyheads were set to 8% of total harvest (default trip-limit level).

The difference between alternative assumptions on discards on current conditions is relatively minor. However, when the higher discard values are used, a greater percentage reduction in female spawner biomass was apparent but the projected 1995 ABC was slightly higher than if the lower historical discard values were used.

Results from the shortspine thornyheads analysis show a positive correlation in the likelihood surface between growth rate and natural mortality for different fixed values of maximum size (Fig. 20). Because this is a "catch-curve" type of analysis and given that there remains some uncertainty on the species identification, an additional run was made with fish smaller than 30 cm dropped from the model (Fig. 21). This avoids the potential influence of longspine thornyheads being mis-identified as shortspine thornyheads for the size composition data. Plotted in two dimensions, the likelihood profile with respect to natural mortality is relatively flat for values greater than about 0.07 (Fig. 22). For the basis of our harvest recommendations, we chose to evaluate results using natural mortality rates of 0.05, 0.07, and 0.09 for shortspine thornyheads. We felt these rates reflect the range of reasonable values given our current knowledge.

Model fits to the observed survey and trawl fishery size composition data are presented in Addendum tables D1 - D4. These represent models where M=0.10 and M=0.07 for longspine and shortspine thornyheads, respectively.

Model estimates of selectivity, biomass, recruitment and fishing mortality

The estimated selectivity for the surveys and fisheries for longspine and shortspine thornyheads differed under different assumed values of natural mortality (Table 8). The time series of biomass, recruitment, and fishing mortality rates from 1964-1994 show the biomass for longspine thornyheads has decreased to about 56% of the estimated unfished level (Table 9). For shortspine thornyheads the decline in spawner biomass ranges from 26-31%, depending on the natural mortality rate assumed (Table 10). Recruitment was more variable for the shortspine thornyheads than longspine thornyheads (Tables 9 & 10). This may reflect the longer larval settlement period for longspine thornyheads as reported by Moser (1974). The full selection fishing mortality rate for longspine thornyheads has been relatively low and currently is at the highest level observed (Table 9). Shortspine thornyheads have been harvested at a high rate for the past decade (Table 10).

Target fishing mortality rates and 1995 yields

The estimation of historical fishing mortality rates depend on the measures of absolute biomass and the level of removals. As there is uncertainty in both these quantities, the fishing mortality reported here should be viewed with caution. Depending on the natural assumption, the 1995 ABC using the $F_{35\%}$ rate ranges from 5,997-10,099 t and 601-1,542 t for longspine and shortspine thornyheads, respectively (Table 11). The overfishing ranges for these two species are 11,940-20,764 t and 1,044-2,826.

To evaluate the effect of uncertainty in natural mortality has on the recommended harvest rate, a simple simulation was performed. We began with the assumption that the natural mortality rate was some value between 0.03 and 0.11 and each (small) value was equally likely to be true. Then with the estimated selectivity, growth and maturation, if the stock was fished at the $F_{35\%}$ mortality rate determined from M=0.07, the distribution of the percent reduction in spawner biomass level per recruit was monitored. The results show that fishing at the $F_{35\%}$ rate with M=0.07 did not result in a drop below the $F_{20\%}$ rate, which is commonly used as the overfishing definition (Fig. 23). This suggests that the recommended rate presented here would not likely result in overfishing, even given uncertainties in natural mortality. Of course, the assumption in this aspect of the analysis requires that absolute biomass is measured with negligible error—a condition that is unlikely to be true.

Projections

Projecting the $F_{35\%}$ harvest into the future reveals the contrast in the current status of these two species of thornyheads along the westcoast of the continental US. Longspine thornyheads, a relatively lightly exploited species shows a continued decline indicating that the current stock size is above what the expected sustainable level is (Table 12). Shortspine thornyheads, on the other hand, shows the rebuilding effect of the $F_{35\%}$ rate (Table 12). This indicates that the shortspine thornyhead stock has been heavily fished and is expected to increase under management.

SUMMARY

The estimates of coastwide biomass for longspine and shortspine thornyheads include the Conception (South to Point Conception) and the Vancouver INPFC areas. Previously these areas were not included. In 1993, the recommended coastwide ABC was 1,900 tons for shortspine thornyheads and 10,100 tons for longspine thornyheads. Based on this assessment, the projected coastwide $F_{35\%}$ yield for 1995 is about 981 tons for shortspine thornyheads and 7,785 tons for longspine thornyheads. The overfishing rates ($F_{20\%}$) corresponds to yields of 1,757 and 15,925 tons, respectively. To the extent possible, fishing in deeper water would be beneficial because a) the more abundant longspine thornyheads can be targetted and b) the shortspine thornyheads are generally larger, and hence would have had more spawning opportunities.

ACKNOWLEDGMENTS

John Butler, Cathy Dahlin and Angel Rodriguez (NMFS/SWFSC) provided age data. Brenda Erwin (CDFG) provided bottom trawl logbook and port sampling data. Don Pearson (NMFS/SWFSC) assisted with extracting California logbook data pertinent to this study. Mark Saelens and Kathy Murphy (ODFW) provided species composition and maturity data for Oregon landings. Larry Quirollo (CDFG) provided information about the commercial fishery. Tom Jagielo, Jean Rogers, Martin Dorn, and Rick Methot provided several suggestions on earlier drafts.

REFERENCES

Anon. 1989. Stock assessment and fishery evaluation report for the 1990 Gulf of Alaska groundfish fishery. North Pacific Fishery Management Council. Anchorage, Alaska.

Bennett, J.T., G.W. Boehlert, and K.K Turekian. 1982. Confirmation of longevity in *Sebastes diploproa* (Pisces: Scorpaenidae) from 210Pb/226Ra measurements in otoliths. Mar. Biol. 71:209-215.

Butler, J. L., C. A. Kimbrell, W. C. Flerx, and R. D. Methot. 1989. The 1987-88 demersal fish surveys off central California (34° 30' N to 36° 30' N). NOAA Tech. Mem. NMFS NOAA-TM-NMFS-SWFC-133.

Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci. 48: 734-750.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

Jacobson, L. D. 1990. Thornyheads--stock assessment for 1990. Appendix D. _In:_ Status of the pacific coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991. Pacific Fishery Management Council. Portland, Oregon.

Jacobson, L. D. 1991. Thornyheads--stock assessment for 1991. Appendix D. _In:_ Status of the pacific coast groundfish fishery through 1990 and recommended acceptable biological catches for 1992. Pacific Fishery Management Council. Portland, Oregon.

Kimura, D. K. 1988. Stock-recruitment curves as used in stock-reduction analysis model. J. Cons. Cons. Int. Explor. Mer 44:253-258.

Miller, P. P. 1985. Life history study of the shortspine thornyhead, _Sebastolobus alascanus,_ at Cape Ommaney, Southeastern Alaska. Master's thesis, University of Alaska, Juneau.

Moser, H. G. 1974. Development and distribution of larvae and juveniles of Sebastolobus (Pisces; family Scorpaenidae). Fish. Bull. 72: 865-884.

Pascual, M.A. and O.O. Iribarne. 1993. How good are empirical predictions of natural mortality? Fish.Res. 16:17-24.

Wakefield, W. 1990. Patterns in the distribution of demersal fishes on the upper continental slope off central California with studies on the role of ontogenetic vertical migration in particle flux. Ph.D. dissertation, Univ. of California, San Diego.

TABLES

Table 1. Landings (metric tons) of thornyheads by area and year. Sources: 1964-1976 from extrapolated CDFG trawl reports; 1977-1980 from extrapolated CDFG landings bulletins; 1981-93 from PACFIN.

Year	Conception	Monterey	Eureka	Columbia	Vancouver	Unident.
1964	3	89	107	27	3	
1965	5	156	186	46	4	
1966	5	141	168	42	4	
1967	2	66	79	20	2	
1968	2	66	79	20	2	
1969	6	197	235	59	6	
1970	9	280	334	83	8	
1971	9	291	348	87	8	
1972	18	554	663	165	16	
1973	20	619	741	184	18	
1974	17	524	627	156	15	
1975	23	708	846	211	20	
1976	24	754	901	224	22	
1977	23	715	855	213	20	
1978	21	647	774	193	19	
1979	29	905	1,082	269	26	
1980	0	651	838	140	7	
1981	5	1,160	1,109	55	16	0
1982	9	879	1,138	166	43	0
1983	96	726	1,000	656	32	1
1984	312	867	1,070	628	43	0
1985	399	1,247	1,502	855	64	0
1986	98	1,284	1,670	505	54	1
1987	44	1,373	1,660	559	30	14
1988	2	985	3,844	706	76	0
1989	11	1,732	4,292	1,750	128	13
1990	6	2,199	4,142	3,417	146	8
1991	518	660	2,119	2,905	166	0
1992	1,086	1,077	2,466	3,447	576	2
1993	803	1,017	2,514	3,493	1,187	30

Table 2. Estimated landings and discards by species. Units are metric tons. LSP= longspine thornyheads, SSP= shortspine thornyheads.

	Longspine thornyheads		Shortspine thornyheads		Combined	
Year	Landed	Discarded	Landed	Discarded	Harvest	Discard %
1964	41	89	187	36	353	35%
1965	71	156	327	63	617	35%
1966	64	141	295	57	557	35%
1967	30	66	139	27	262	35%
1968	30	66	139	27	262	35%
1969	90	197	413	79	779	35%
1970	128	280	587	112	1,107	35%
1971	133	291	610	117	1,151	35%
1972	253	556	1,163	223	2,194	35%
1973	283	621	1,300	249	2,452	35%
1974	239	525	1,099	211	2,074	35%
1975	323	709	1,485	284	2,801	35%
1976	344	756	1,582	303	2,984	35%
1977	326	717	1,500	287	2,830	35%
1978	295	649	1,358	260	2,562	35%
1979	413	907	1,898	364	3,582	35%
1980	292	642	1,344	257	2,535	35%
1981	391	684	1,954	298	3,327	30%
1982	438	985	1,797	353	3,572	37%
1983	439	1,008	2,071	414	3,932	36%
1984	407	933	2,513	502	4,354	33%
1985	697	1,599	3,371	674	6,341	36%
1986	809	1,856	2,803	561	6,029	40%
1987	1,447	1,660	2,232	446	5,786	36%
1988	3,485	303	2,128	185	5,670	8%
1989	4,663	405	3,262	284	8,004	8%
1990	5,514	479	4,404	383	10,017	8%
1991	4,308	375	2,061	179	6,432	8%
1992	5,656	492	2,998	261	8,740	8%
1993	5,294	460	3,751	326	9,135	8%

Table 3. Biomass estimates (metric tons) from NMFS surveys by area, year, and depth strata for longspine and shortspine thornyheads. Also included are the new estimates of bottom surface area in hectares by area and depth strata.

Longspine thornyheads								
		Stratum (Fthms)						
Area	Year	100	200	300	400	500	600	Total
S. Monterey &	87	-	175	1,823	6,082	5,013	1,459	14,552
N. Conception	88	11	1,484	3,080	5,597	3,371	500	14,043
N. Monterey	91	0	306	2,540	5,711	5,434	1,670	15,661
Eureka	90	0	117	4,208	6,064	8,368	4,181	22,938
Columbia (south)	84	6	19	696	796	-	-	1,517
Columbia (south)	93	0	91	1,579	1,005	1,924	924	5,523
Columbia (mid)	84	0	122	1,493	3,467	-	-	5,082
Columbia (mid)	88	0	392	2,224	6,092	3,521	1,883	14,112
Columbia (mid)	89	0	46	3,275	6,870	2,521	1,682	14,394
Columbia (mid)	93	0	260	1,085	1,620	1,636	1,306	5,907
Columbia (north)	92	0	215	1,883	3,644	5,490	3,200	14,432
Vancouver	92	0	151	517	2,643	3,032	790	7,133
Shortspine thornyheads								
		Stratum (Fthms)						
Area	Year	100	200	300	400	500	600	Total
S. Monterey &	87	60	1,695	2,820	3,104	3,534	821	12,034
N. Conception	88	35	2,008	1,248	1,408	1,398	294	6,391
N. Monterey	91	196	383	752	404	1,278	1,187	4,200
Eureka	90	180	336	1,358	493	1,441	1,768	5,576
Columbia (south)	84	680	486	445	176	-	-	1,787
Columbia (south)	93	448	502	611	53	186	340	2,140
Columbia (mid)	84	1,747	3,152	1,238	657	-	-	6,794
Columbia (mid)	88	2,817	4,115	2,437	843	662	427	11,301
Columbia (mid)	89	2,685	4,543	1,618	712	468	449	10,475
Columbia (mid)	93	1,516	2,335	522	142	104	232	4,851
Columbia (north)	92	743	822	587	260	430	387	3,229
Vancouver	92	729	297	238	343	431	133	2,171

Bottom Surface Area (Hectares)	**Stratum** (Fthms)	100	200	300	400	500	600
S. Monterey & N. Conception		185,215	309,034	334,759	244,895	283,310	227,403
N. Monterey		111,129	92,607	107,699	116,617	127,592	136,510
Eureka		107,699	110,443	167,036	171,838	195,162	139,940
Columbia (south)		105,641	74,772	62,767	43,217	53,507	56,593
Columbia (mid)		165,321	209,224	93,979	76,487	61,052	74,086
Columbia (north)		131,708	90,206	104,612	115,931	123,820	108,728
Vancouver		117,989	41,159	51,792	61,052	66,883	52,821

Table 4. Modelled coastwide biomass estimates (metric tons) from NMFS surveys by area and year, and the fit to the survey biomass for longspine and shortspine thornyheads. Note that the survey biomass numbers for 1984 did not include all the depth strata. The modelled biomass estimates were expanded to include all estimates.

Longspine thornyheads

Modeled Survey	Conception	Monterey	Eureka	S Columbia	C Columbia	N Columbia	Vancouver	Total
84	16,567	19,399	27,015	5,329	12,591	17,386	9,049	107,337
85	16,131	18,887	26,303	5,188	12,259	16,928	8,810	104,506
86	15,705	18,389	25,609	5,051	11,936	16,482	8,578	101,750
87	15,291	17,904	24,934	4,918	11,621	16,047	8,352	99,067
88	14,888	17,432	24,277	4,788	11,314	15,624	8,132	96,455
89	14,495	16,972	23,636	4,662	11,016	15,212	7,917	93,911
90	14,113	16,525	23,013	4,539	10,726	14,811	7,708	91,435
91	13,741	16,089	22,406	4,420	10,443	14,420	7,505	89,023
92	13,378	15,665	21,815	4,303	10,167	14,040	7,307	86,676
93	13,026	15,252	21,240	4,190	9,899	13,670	7,114	84,390

Surveys	Conception	Monterey	Eureka	S Columbia	C Columbia	N Columbia	Vancouver
84				1,517	5,082		
85							
86							
87	14,552						
88	14,043				14,112		
89					14,394		
90			22,938				
91		15,661					
92						14,432	7,133
93				5,523	5,907		

Residuals	Conception	Monterey	Eureka	S Columbia	C Columbia	N Columbia	Vancouver
84				-3,812	-7,509		
85							
86							
87	-739						
88	-845				2,798		
89					3,378		
90			-75				
91		-428					
92						392	-174
93				1,333	-3,992		

Note: Residuals do not reflect model corrections for depth strata.

Table 4. (cont'd)

Shortspine thornyheads

Modeled Survey	Conception	Monterey	Eureka	S Columbia	C Columbia	N Columbia	Vancouver	Total
84	11,341	5,608	7,468	2,958	10,558	5,436	3,484	46,853
85	10,714	5,298	7,055	2,795	9,974	5,135	3,292	44,263
86	10,122	5,005	6,665	2,640	9,423	4,851	3,110	41,816
87	9,562	4,728	6,297	2,494	8,902	4,583	2,938	39,505
88	9,034	4,467	5,949	2,356	8,410	4,330	2,776	37,321
89	8,535	4,220	5,620	2,226	7,945	4,091	2,622	35,259
90	8,063	3,987	5,309	2,103	7,506	3,865	2,477	33,310
91	7,617	3,767	5,016	1,987	7,091	3,651	2,340	31,469
92	7,196	3,558	4,738	1,877	6,699	3,449	2,211	29,729
93	6,798	3,362	4,477	1,773	6,329	3,259	2,089	28,086

Surveys	Conception	Monterey	Eureka	S Columbia	C Columbia	N Columbia	Vancouver
84				1,787	6,794		
85							
86							
87	12,034						
88	6,391				11,301		
89					10,475		
90			5,576				
91		4,200					
92						3,229	2,171
93				2,140	4,851		

Residuals	Conception	Monterey	Eureka	S Columbia	C Columbia	N Columbia	Vancouver
84				-1,171	-3,764		
85							
86							
87	2,472						
88	-2,643				2,891		
89					2,530		
90			267				
91		433					
92						-220	-40
93				367	-1,478		

Note: Residuals do not reflect model corrections for depth strata.

Table 5. Coefficients of variation for biomass estimates from each area by year for longspine and shortspine thornyheads.

Year	Conception	Monterey	Eureka	S Columbia	C Columbia	N Columbia	Vancouver
Longspine thornyheads							
84				27%	15%		
88	14%				8%		
89	17%				10%		
90			6%				
91		9%					
92						9%	11%
93				7%	9%		
Shortspine thornyheads							
84				18%	12%		
88	13%				13%		
89	13%				12%		
90			10%				
91		11%					
92						11%	15%
93				18%	9%		

Table 6. Female maturity classification codes for longspine and shortspine thornyheads developed by Bill Barss, ODFW, Marine Science Drive, Bldg. 3, Newport OR 97365. Note that code 5 is not included because it is for eyed stage eggs—a condition not applicable to thornyhead rockfish.

Maturity	Code	Description
Immature	1	Very small, translucent, pink
	2	Maturing. Small, translucent, pink. Only for fish which have not spawned previously
Mature	3	Ova developing. Large, translucent or opaque, pink; ova are small white and opaque.
	4	With jelly. Large, white eggs surrounded by jelly, and jelly often partially extruded.
	6	Spent. Large, flaccid, red, often with a few eggs being absorbed at the posterior end
	7	Resting. Ovary is moderate to large size, opaque, translucent, or pink with no visible ova.
	8	Mature (no description).

Table 7. Summary of data availability by area and time.

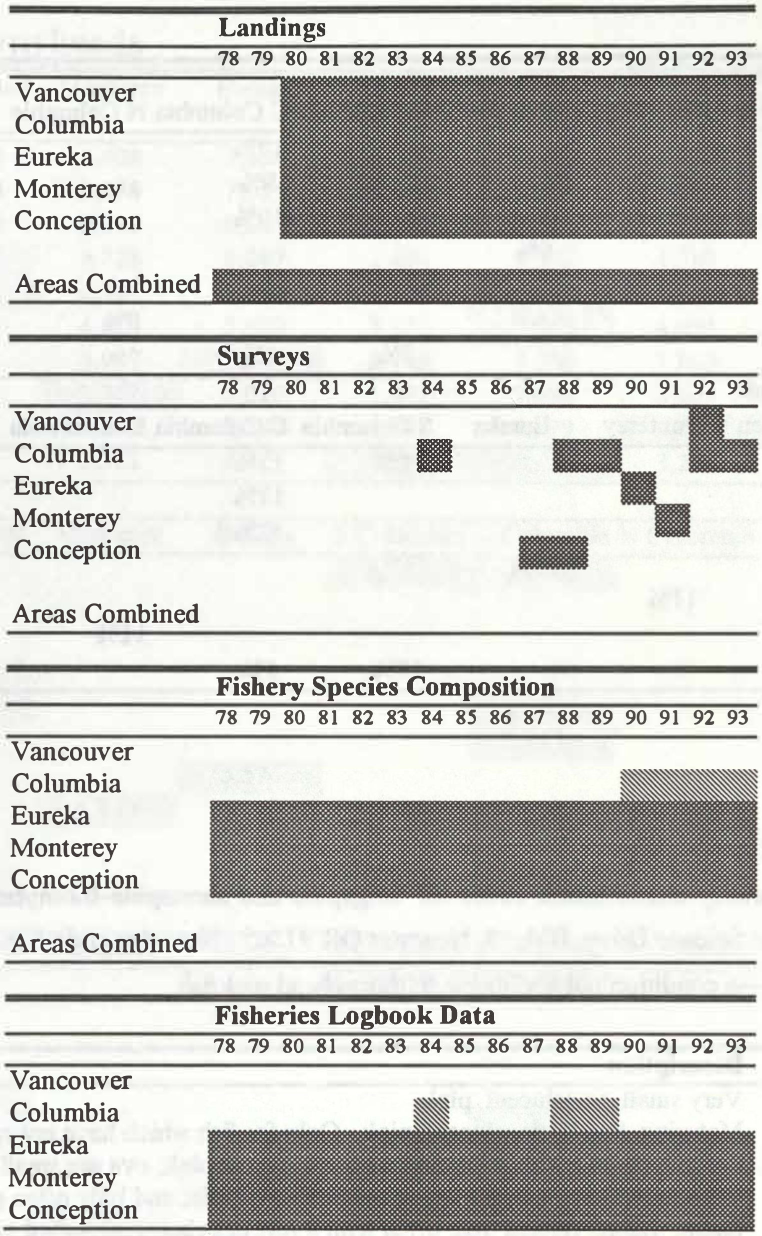


Table 8. Survey and current trawl fishery size-selectivity estimates for longspine and shortspine thornyheads under different assumptions about natural mortality rate (M).

Longspine thornyheads

Lower limit of length group (cm)	Survey M=0.08	Survey M=0.10	Survey M=0.12	Trawl Fishery M=0.08	Trawl Fishery M=0.10	Trawl Fishery M=0.12
5	0.00	0.00	0.00	0.00	0.00	0.00
6	0.11	0.08	0.06	0.00	0.00	0.00
7	0.23	0.16	0.11	0.00	0.00	0.00
8	0.34	0.23	0.17	0.00	0.00	0.00
9	0.44	0.31	0.22	0.00	0.00	0.00
10	0.53	0.38	0.28	0.00	0.00	0.00
11	0.62	0.45	0.33	0.01	0.00	0.00
12	0.69	0.51	0.39	0.01	0.00	0.00
13	0.75	0.57	0.44	0.01	0.01	0.00
14	0.80	0.63	0.49	0.02	0.01	0.01
15	0.84	0.68	0.54	0.03	0.01	0.01
16	0.88	0.73	0.59	0.04	0.02	0.01
17	0.91	0.77	0.63	0.05	0.03	0.02
18	0.93	0.81	0.68	0.08	0.05	0.04
19	0.95	0.84	0.72	0.11	0.08	0.06
20	0.96	0.87	0.76	0.16	0.11	0.09
21	0.97	0.90	0.80	0.22	0.17	0.14
22	0.98	0.92	0.84	0.31	0.25	0.22
23	0.99	0.94	0.88	0.41	0.36	0.32
24	0.99	0.96	0.91	0.54	0.49	0.46
25	0.99	0.98	0.94	0.69	0.65	0.63
26	1.00	0.99	0.97	0.84	0.83	0.81
27	1.00	1.00	1.00	1.00	1.00	1.00
28	1.00	1.00	1.00	1.00	1.00	1.00
29	1.00	1.00	1.00	1.00	1.00	1.00

Shortspine thornyheads

Lower limit of length group (cm)	Survey M=0.05	Survey M=0.07	Survey M=0.09	Current Fishery M=0.05	Current Fishery M=0.07	Current Fishery M=0.09
5	0.00	0.00	0.00	0.00	0.00	0.00
10	0.34	0.19	0.28	0.00	0.00	0.00
12	0.80	0.62	0.65	0.00	0.00	0.00
14	0.97	0.92	0.90	0.00	0.00	0.00
16	1.00	0.99	0.98	0.01	0.01	0.01
18	1.00	1.00	1.00	0.02	0.02	0.02
20	1.00	1.00	1.00	0.06	0.07	0.07
22	1.00	1.00	1.00	0.18	0.18	0.21
24	1.00	1.00	1.00	0.45	0.45	0.48
26	1.00	1.00	1.00	0.86	0.87	0.77
28	1.00	1.00	1.00	1.00	1.00	0.92
30	1.00	1.00	1.00	1.00	1.00	0.98
32	1.00	1.00	1.00	1.00	1.00	0.99
34	1.00	1.00	1.00	1.00	1.00	1.00
36	1.00	1.00	1.00	1.00	1.00	1.00
38	1.00	1.00	1.00	1.00	1.00	1.00
40	1.00	1.00	1.00	1.00	1.00	1.00
42	1.00	1.00	1.00	1.00	1.00	1.01
44	1.00	1.00	1.00	1.00	1.00	1.03
48	1.00	1.00	1.00	1.00	1.00	1.06
52	1.00	1.00	1.00	0.86	0.97	1.09
56	1.00	1.00	1.00	0.53	0.77	1.12
60	1.00	1.00	1.00	0.53	0.76	1.15
64	1.00	1.00	1.00	0.53	0.76	1.18
68	1.00	1.00	1.00	0.53	0.76	1.21

Table 9. Biomass, full selection fishing mortality rate, female spawner biomass, and estimated recruitment for longspine thornyheads. These results are based on Model 3.

Longspine thornyheads

	Age 5+ Biomass			Full Selection F			Spawner Biomass			Age 5 Recruits		
	M=0.08	M=0.10	M=0.12	M=0.08	M=0.10	M=0.12	M=0.08	M=0.10	M=0.12	M=0.08	M=0.10	M=0.12
64	124,253	130,187	139,055	0.002	0.002	0.002	43,340	42,255	41,777			
65	124,098	130,007	138,860	0.003	0.003	0.004	43,266	42,183	41,706			
66	123,839	129,710	138,543	0.003	0.003	0.003	43,180	42,100	41,626			
67	123,589	129,407	138,214	0.001	0.002	0.002	43,125	42,048	41,578			
68	123,425	129,174	137,947	0.001	0.002	0.002	43,096	42,022	41,555			
69	123,240	128,904	137,639	0.004	0.004	0.005	43,027	41,957	41,493			
70	122,858	128,427	137,123	0.006	0.006	0.007	42,895	41,830	41,370			
71	122,374	127,922	136,651	0.006	0.007	0.007	42,739	41,677	41,222	220,296	379,973	580,989
72	121,994	127,544	136,597	0.011	0.012	0.013	42,500	41,438	40,987	293,812	423,733	793,949
73	121,360	126,941	136,215	0.013	0.014	0.015	42,165	41,100	40,654	291,137	397,245	480,718
74	120,683	126,322	135,874	0.011	0.012	0.013	41,845	40,772	40,331	217,565	314,514	448,008
75	120,219	125,915	135,753	0.015	0.016	0.017	41,497	40,412	39,980	215,919	305,406	449,901
76	119,553	125,302	135,416	0.016	0.018	0.019	41,084	39,987	39,571	202,625	291,736	445,382
77	118,891	124,687	135,043	0.015	0.017	0.018	40,677	39,573	39,188	213,669	315,559	466,923
78	118,314	124,140	134,697	0.014	0.015	0.016	40,316	39,220	38,891	200,700	303,986	453,649
79	117,815	123,735	134,396	0.020	0.022	0.023	39,920	38,853	38,618	177,278	340,375	450,476
80	116,897	122,774	133,527	0.014	0.016	0.017	39,569	38,561	38,463	143,095	161,824	325,871
81	116,271	122,064	132,802	0.016	0.018	0.019	39,317	38,390	38,458	141,455	203,417	315,174
82	115,396	121,046	131,673	0.022	0.024	0.025	39,021	38,183	38,418	133,672	202,933	296,691
83	114,091	119,529	129,972	0.023	0.025	0.026	38,706	37,950	38,327	141,678	206,061	309,729
84	112,672	117,868	128,080	0.021	0.023	0.024	38,453	37,754	38,238	150,432	240,169	360,788
85	111,285	116,105	125,987	0.037	0.040	0.042	38,043	37,373	37,922	169,449	179,721	251,875
86	109,030	113,583	123,182	0.043	0.047	0.050	37,369	36,710	37,293	228,176	382,931	540,475
87	106,394	110,651	119,965	0.052	0.057	0.059	36,522	35,857	36,450	156,808	219,499	346,311
88	103,387	107,387	116,448	0.065	0.071	0.074	35,427	34,744	35,327	160,247	239,271	355,156
89	99,980	103,849	112,784	0.091	0.099	0.103	33,895	33,184	33,750	272,940	410,145	592,354
90	95,676	99,556	108,506	0.114	0.125	0.130	31,894	31,153	31,703	301,430	438,628	621,999
91	90,828	94,979	104,159	0.095	0.104	0.108	29,992	29,222	29,760	259,940	458,214	682,261
92	88,075	92,764	102,463	0.133	0.147	0.152	28,029	27,235	27,771	616,351	854,018	1,169,153
93	84,150	89,528	99,838	0.135	0.149	0.155	25,894	25,107	25,669			
94	81,020	87,233	98,250	0.146	0.163	0.168	23,893	23,151	23,768			

Table 10. Biomass, full selection fishing mortality rate, female spawner biomass, and estimated recruitment for shortspine thornyheads under different assumed values of natural mortality rate.

Shortspine thornyheads

	Biomass age 5+			Full Selection F			Spawner Biomass			Age 5 Recruits		
	M=0.05	M=0.07	M=0.09	M=0.05	M=0.07	M=0.09	M=0.05	M=0.07	M=0.09	M=0.05	M=0.07	M=0.09
64	81,263	82,755	79,508	0.004	0.003	0.003	39,931	40,354	38,679			
65	81,034	82,528	79,284	0.007	0.006	0.006	39,796	40,221	38,548			
66	80,633	82,133	78,896	0.006	0.005	0.005	39,600	40,029	38,360			
67	80,269	81,780	78,553	0.003	0.003	0.003	39,443	39,877	38,213			
68	80,085	81,584	78,379	0.003	0.003	0.003	39,356	39,795	38,137			
69	79,896	81,376	78,196	0.009	0.008	0.007	39,228	39,671	38,021			
70	79,367	80,819	77,674	0.013	0.011	0.011	38,947	39,393	37,753			
71	78,618	80,037	76,934	0.014	0.012	0.011	38,580	39,026	37,398			
72	77,803	79,173	76,133	0.026	0.022	0.021	38,112	38,550	36,940			
73	76,295	77,625	74,652	0.030	0.025	0.024	37,363	37,789	36,207			
74	74,585	75,865	73,020	0.026	0.022	0.021	36,573	36,979	35,436			
75	73,096	74,291	71,586	0.036	0.030	0.029	35,802	36,181	34,687			
76	71,115	72,196	69,643	0.040	0.033	0.032	34,825	35,174	33,745			
77	68,990	69,937	67,544	0.039	0.033	0.031	33,799	34,111	32,764			
78	66,972	67,746	65,492	0.036	0.030	0.029	32,817	33,079	31,825	6,193	6,033	7,621
79	65,124	65,759	63,578	0.052	0.044	0.042	31,801	32,000	30,837	6,426	10,520	8,636
80	62,599	63,085	61,016	0.039	0.033	0.031	30,617	30,743	29,662	5,430	8,134	11,078
81	60,755	61,050	59,102	0.056	0.048	0.044	29,597	29,636	28,622	5,803	6,021	10,304
82	58,295	58,415	56,520	0.056	0.048	0.044	28,348	28,303	27,341	8,581	10,457	9,301
83	55,937	55,915	54,103	0.068	0.058	0.053	27,105	26,979	26,065	6,466	10,256	12,907
84	53,283	53,123	51,382	0.087	0.074	0.067	25,683	25,486	24,619	7,792	10,027	11,105
85	50,115	49,846	48,229	0.125	0.106	0.095	23,944	23,694	22,883	6,783	9,259	13,511
86	46,001	45,691	44,213	0.111	0.094	0.083	21,945	21,664	20,923	10,768	14,855	16,968
87	42,591	42,309	41,063	0.094	0.079	0.069	20,327	20,037	19,384	5,923	11,265	17,557
88	39,906	39,622	38,658	0.079	0.067	0.058	19,072	18,793	18,251	3,898	3,989	8,954
89	38,137	37,987	37,260	0.128	0.108	0.092	17,909	17,664	17,263	25,325	34,592	35,359
90	35,051	35,042	34,725	0.192	0.162	0.137	16,205	16,028	15,812	3,777	5,798	12,271
91	30,926	31,190	31,357	0.102	0.086	0.073	14,451	14,382	14,397	8,260	15,736	22,346
92	29,281	29,845	30,513	0.159	0.132	0.110	13,490	13,555	13,836	8,689	14,690	18,157
93	26,732	27,717	29,034	0.224	0.183	0.149	12,130	12,370	12,955			
94	23,548	25,128	27,217	0.260	0.207	0.164	10,540	10,998	11,909			

Table 11. Approximate 1995 yield and full selection fishing mortality rates for longspine and shortspine thornyheads under different assumption for natural mortality (M) and harvest rates.

Longspine thornyheads

	Approximate 1995 Yield			Full Selection Fishing Mortality		
	M=0.08	M=0.10	M=0.12	M=0.08	M=0.10	M=0.12
$F_{20\%}$	11,940	15,925	20,764	0.355	0.556	0.795
$F_{30\%}$	7,410	9,714	12,656	0.210	0.315	0.438
$F_{35\%}$	5,997	7,785	10,099	0.167	0.247	0.340
$F_{40\%}$	4,903	6,305	8,138	0.150	0.197	0.268

Shortspine thornyheads

	1995 Yield			Full Selection F		
	M=0.05	M=0.07	M=0.09	M=0.05	M=0.07	M=0.09
$F_{20\%}$	1,044	1,757	2,826	0.077	0.103	0.132
$F_{30\%}$	711	1,171	1,854	0.052	0.068	0.085
$F_{35\%}$	601	981	1,542	0.044	0.056	0.070
$F_{40\%}$	511	828	1,293	0.037	0.048	0.058

Table 12. Projected yield and female spawner biomass under the $F_{35\%}$ harvest rate for different assumptions about natural mortality for longspine and shortspine thornyheads. The mean observed recruitment was assumed.

Longspine thornyheads

	Yield			Female Spawner Biomass		
Year	M=0.08	M=0.10	M=0.12	M=0.08	M=0.10	M=0.12
95	5,997	7,785	10,099	21,920	20,891	21,105
96	5,490	6,860	8,524	20,132	18,685	18,350
97	5,078	6,144	7,397	18,704	17,068	16,506
98	4,741	5,608	6,609	17,593	15,985	15,410
99	4,467	5,231	6,121	16,787	15,392	14,965

Shortspine thornyheads

	Yield			Female Spawner Biomass		
	M=0.05	M=0.07	M=0.09	M=0.05	M=0.07	M=0.09
95	601	981	1,542	9,416	10,083	11,264
96	618	1,001	1,567	9,477	10,264	11,550
97	635	1,029	1,614	9,573	10,568	11,954
98	654	1,072	1,682	9,701	10,987	12,391
99	675	1,136	1,749	9,851	11,467	12,772

FIGURES

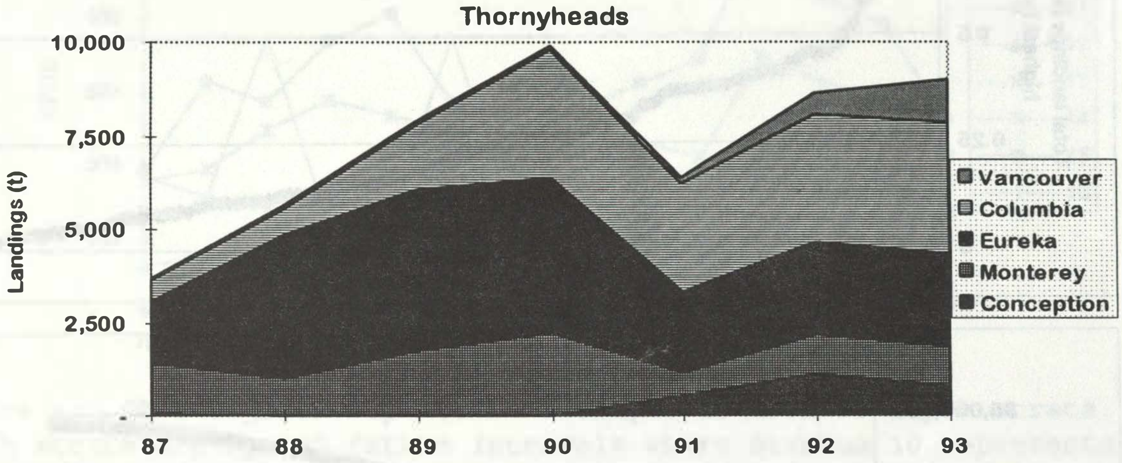


Figure 1. PACFIN reported landings by recent years and areas.

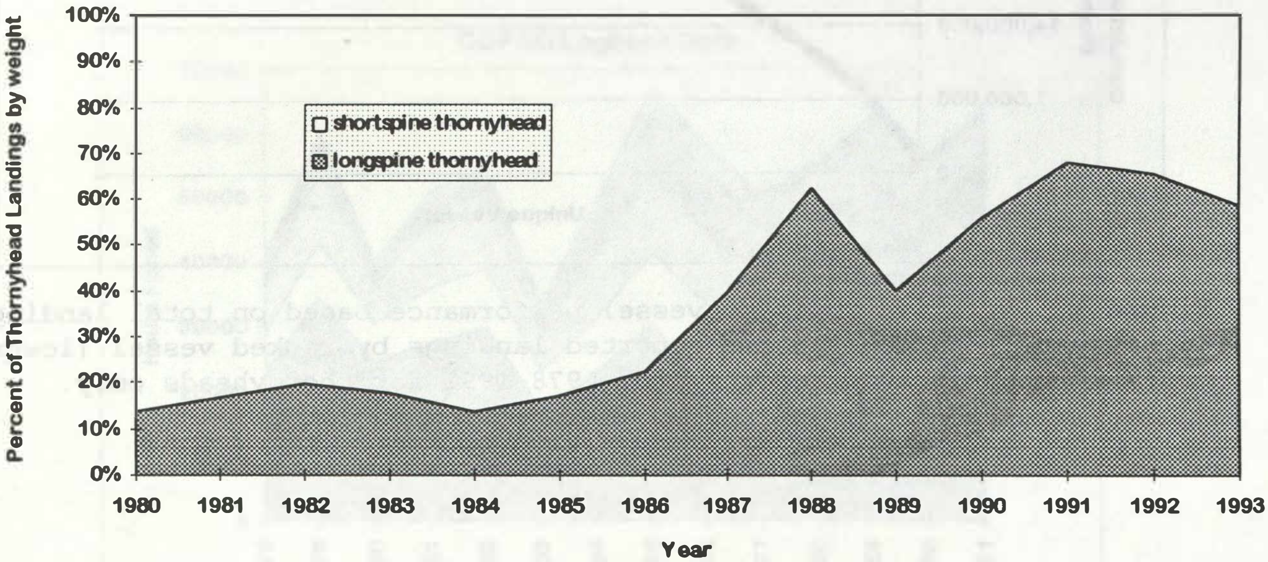


Figure 2. CDFG market samples of species composition landings. NOTE: because of an apparent mis-identification problem between longspine and shortspine thornyheads in the 1989 samples, the actual proportion of longspine thornyheads in 1989 was computed as the average of 1988 and 1990, not the value as shown.

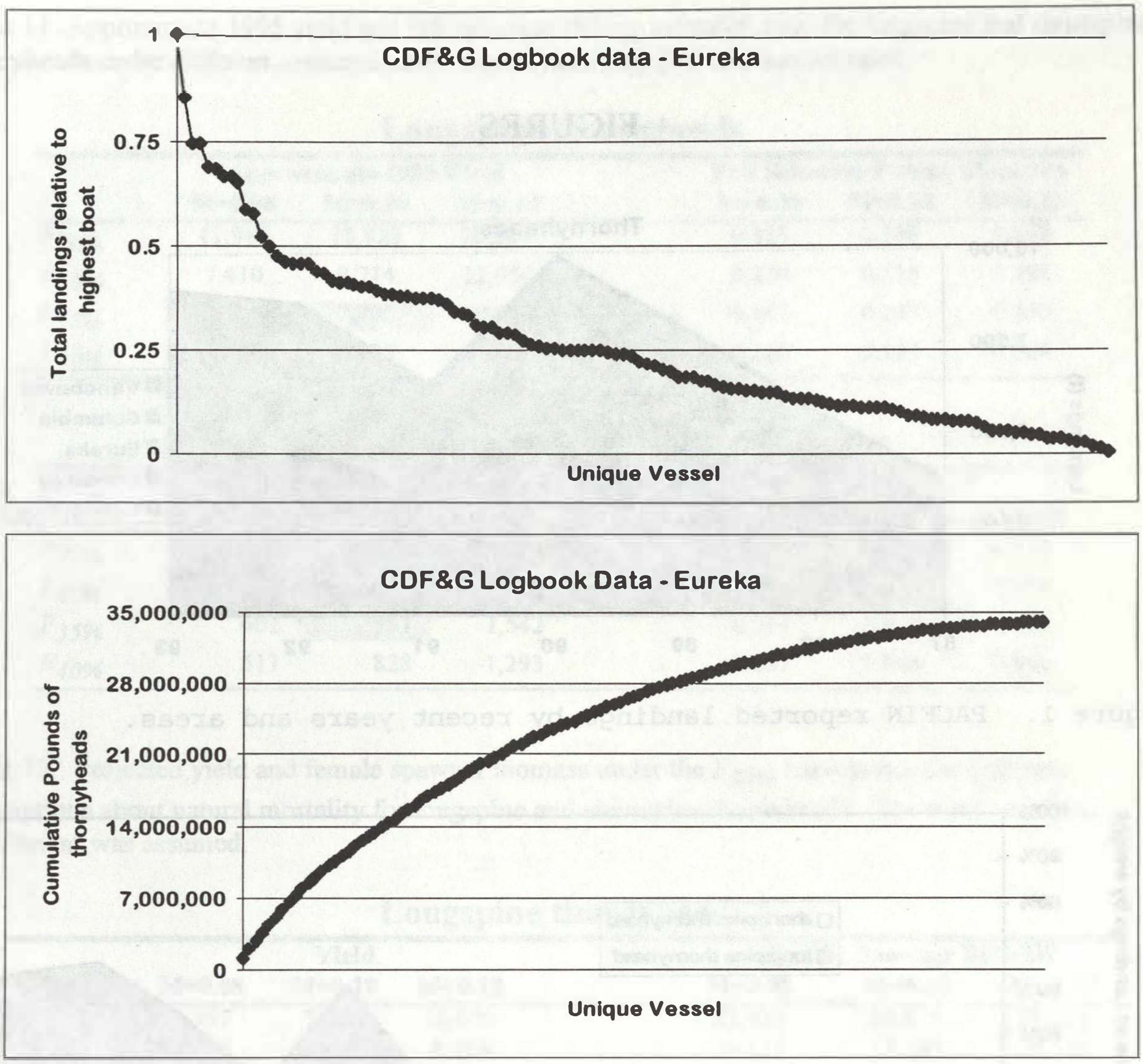


Figure 3. Relative reported vessel performance based on total landings (upper panel) and cumulative reported landings by ranked vessel (lower panel). Data include reports from 1978-1991 for thornyheads only.

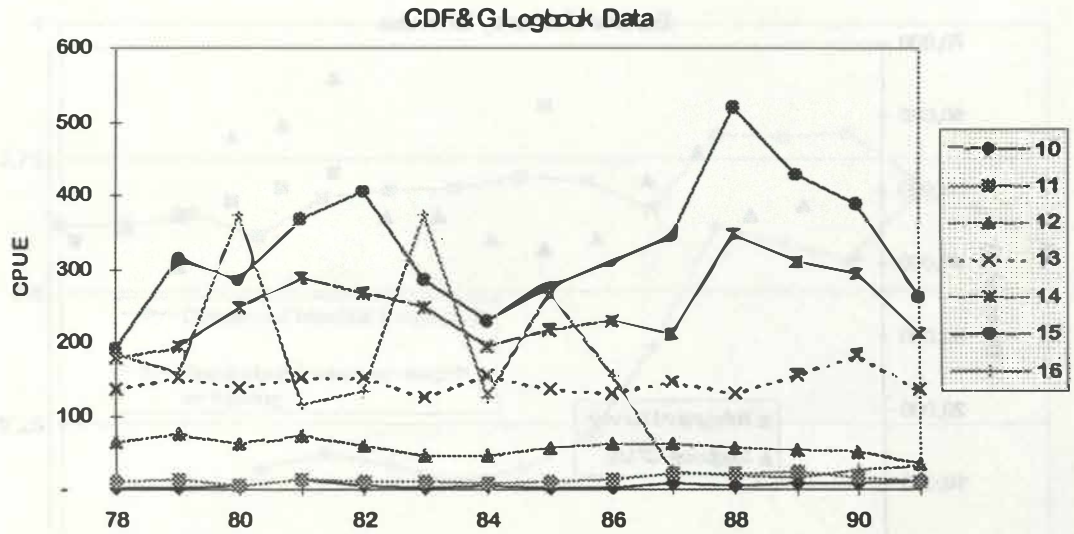


Figure 4. CDFG logbook reports of thornyheads CPUE vs depth strata. Depth strata are by 100 fathom intervals where stratum 10 represents 0-99 fathoms, stratum 11 represents 100-199 fathoms etc.

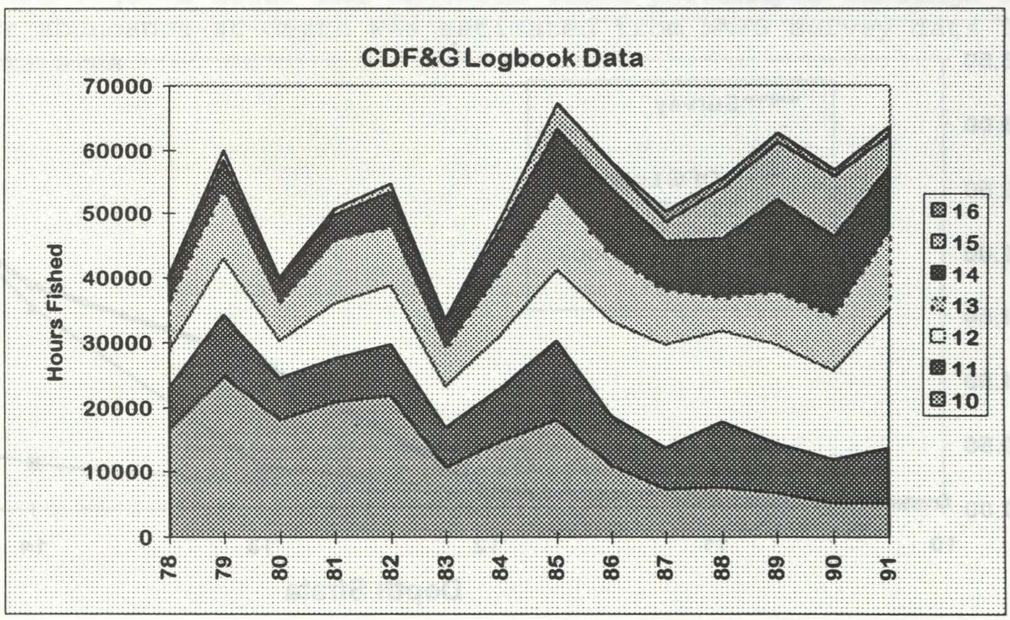


Figure 5. CDFG logbook reports of deepwater complex (thornyheads, sablefish, and dover sole) effort by depth strata and year. Depth strata are by 100 fathom intervals where stratum 10 represents 0-99 fathoms, stratum 11 represents 100-199 fathoms etc.

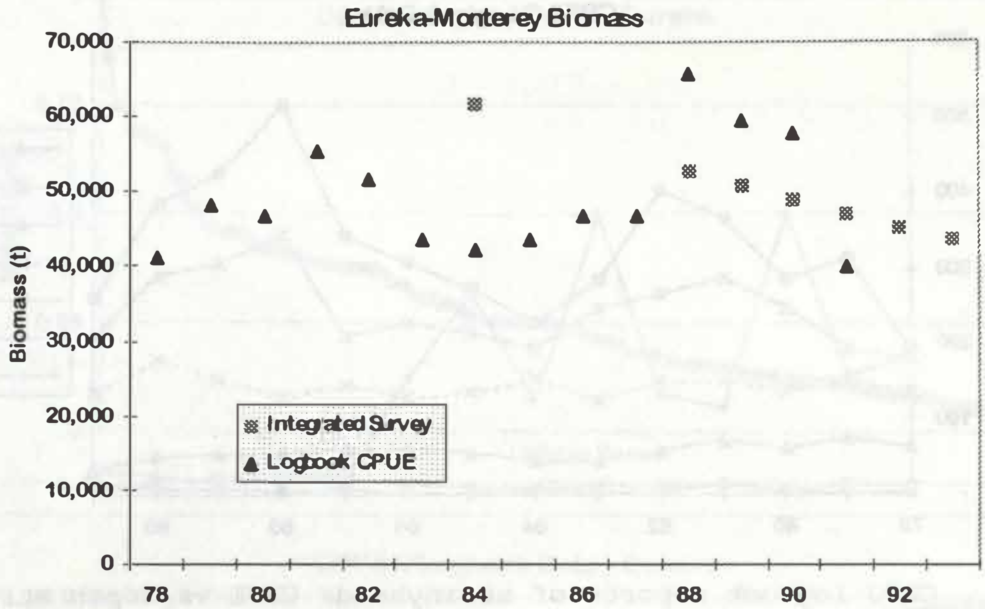


Figure 6. CDFG logbook reports of standardized CPUE by year relative to the integrated survey biomass trend.

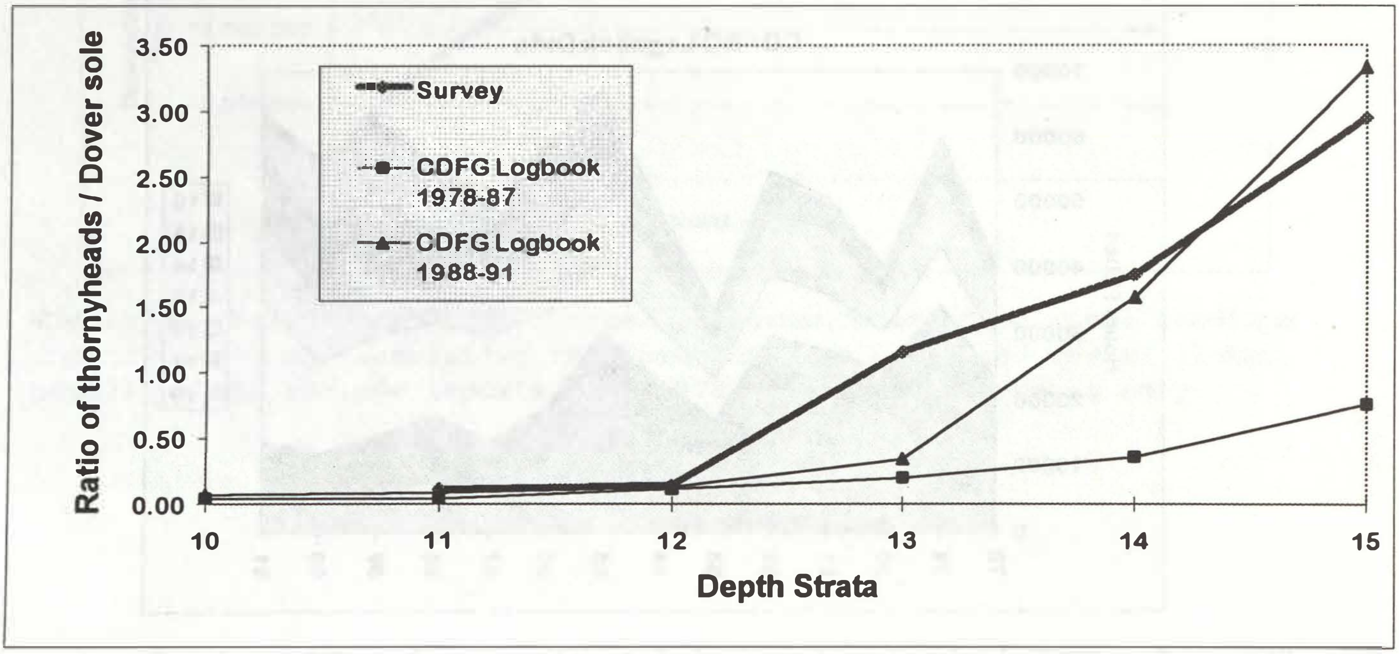


Figure 7. Apparent abundance of thornyheads relative to dover sole for NMFS surveys, and pre- and post- market development periods from CDFG logbook data by depth strata.

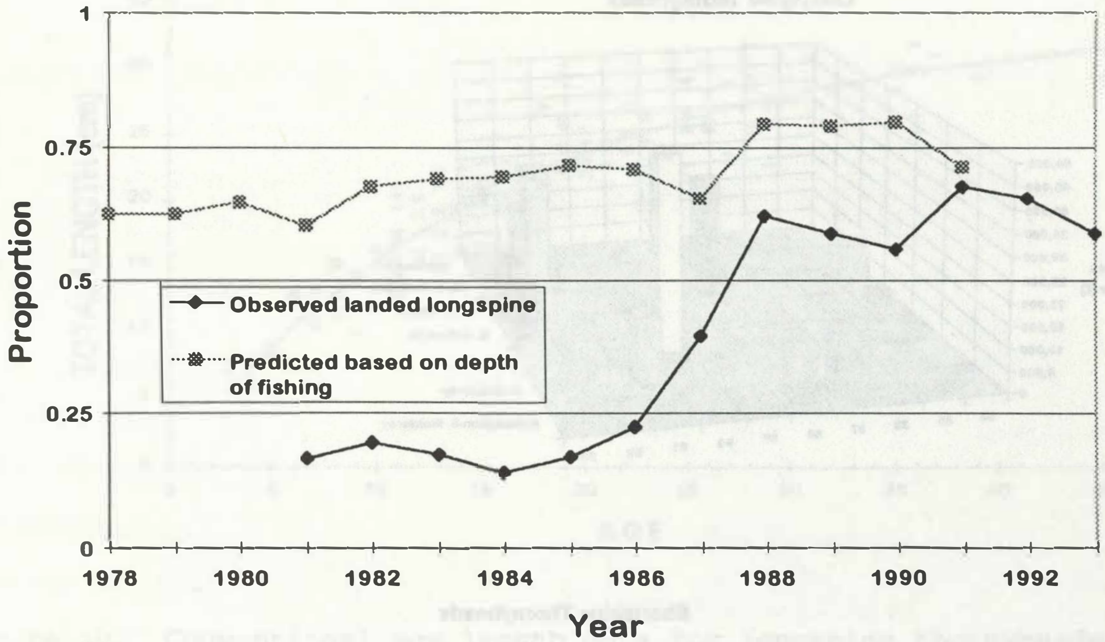
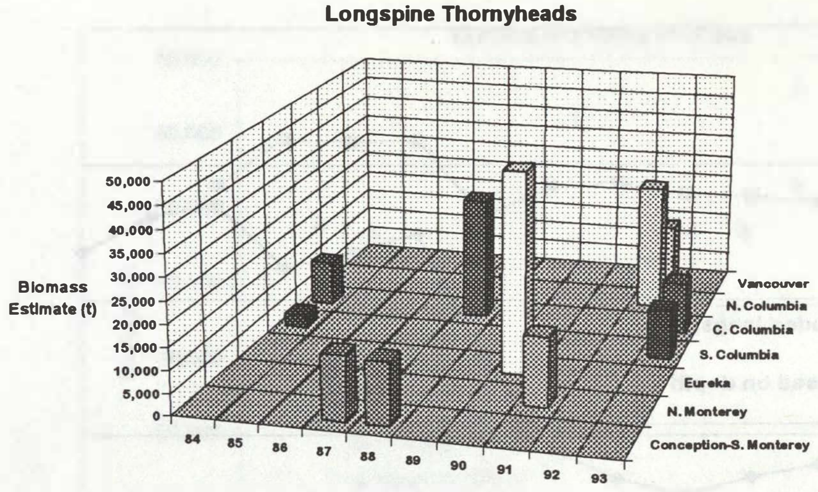


Figure 8. Proportion of longspine expected based on the hours fished at depth (CDFG logbook data) and observed (CDFG portsample landings data). Relative abundance-at-depth was estimated from NMFS survey data from the Eureka area.



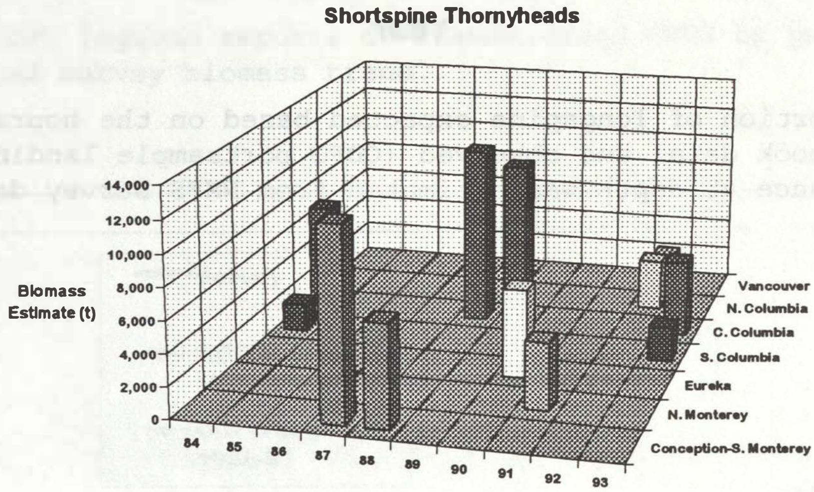


Figure 9. Survey biomass estimates by area and year for longspine and shortspine thornyheads. Note that in 1984, not all depth strata were sampled, hence the biomass estimates for this year is not directly comparable without adjusting for depth strata differences.

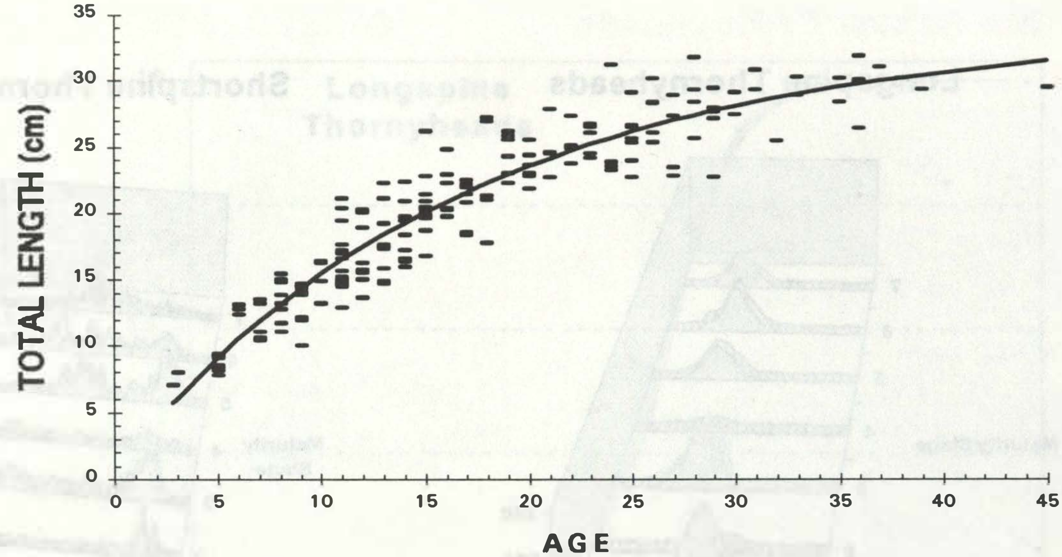


Figure 10. Conventional age length data for longspine thornyheads as presented in Jacobson (1991).

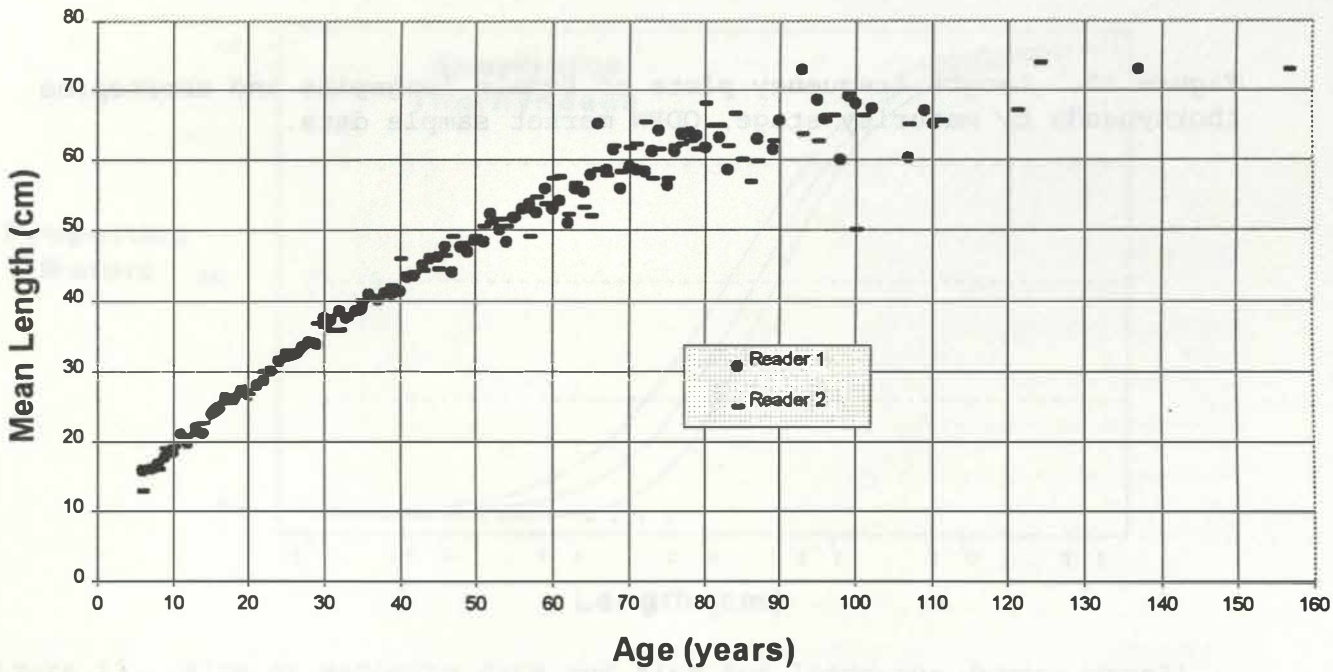


Figure 11. Conventional age length data for shortspine thornyheads showing agreement between readers.

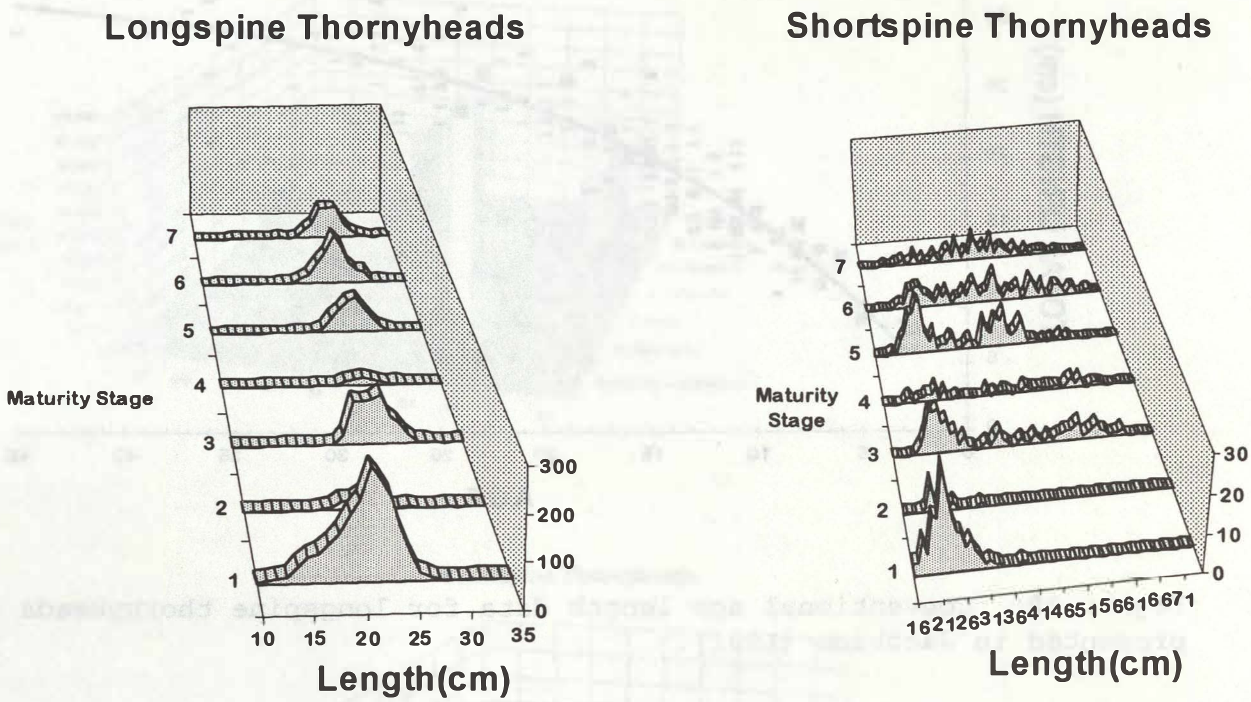


Figure 12. Length frequency plots of female longspine and shortspine thornyheads by maturity stage, ODFW market sample data.

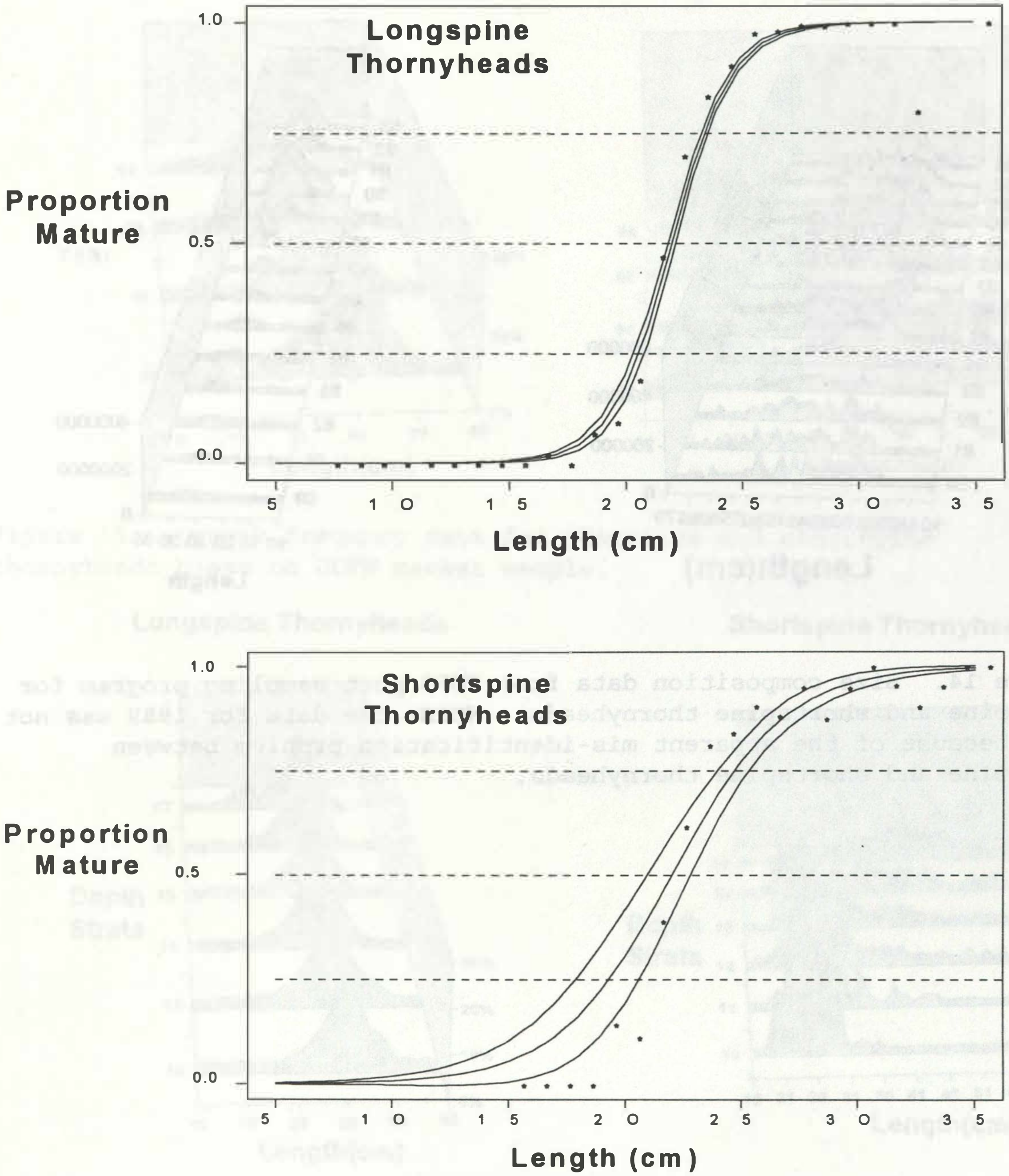


Figure 13. Size at maturity data and fits for longspine (upper panel) and shortspine (lower panel) thornyheads used in this analysis. Points represent mean proportion mature, lines represent the model fit and the respective 95% confidence bands.

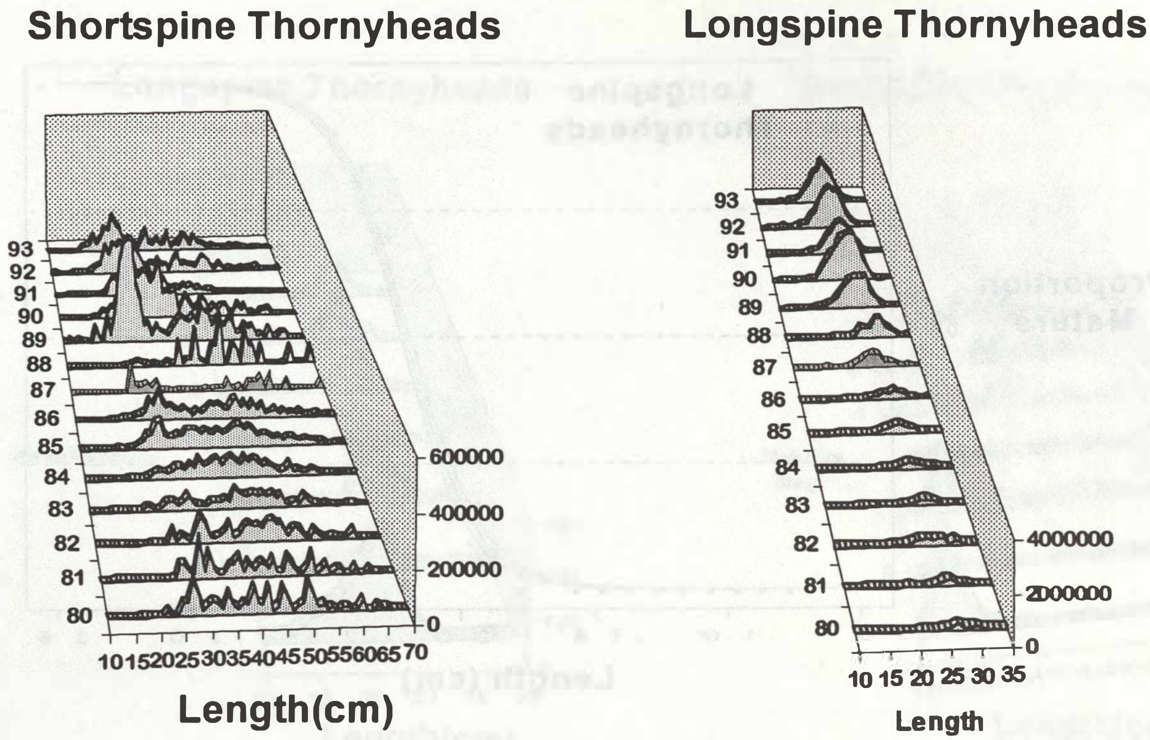


Figure 14. Size composition data from CDFG port sampling program for longspine and shortspine thornyheads. NOTE: the data for 1989 was not used because of the apparent mis-identification problem between longspine and shortspine thornyheads.

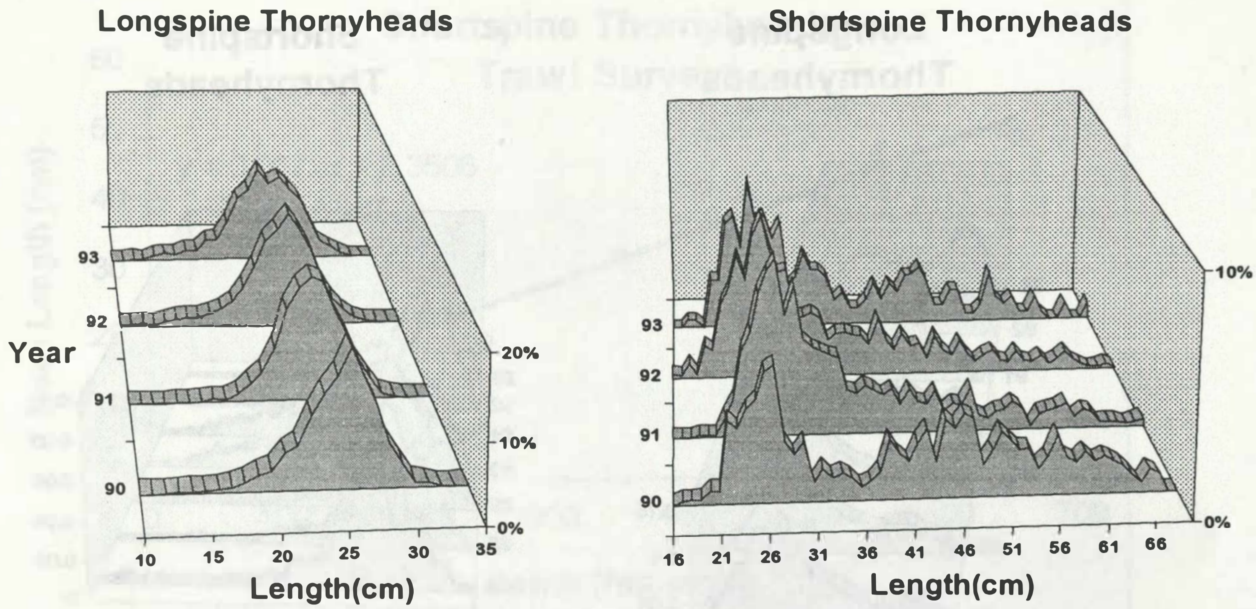


Figure 15. Length frequncy data for longspine and shortspine thornyheads based on ODFW market sample.

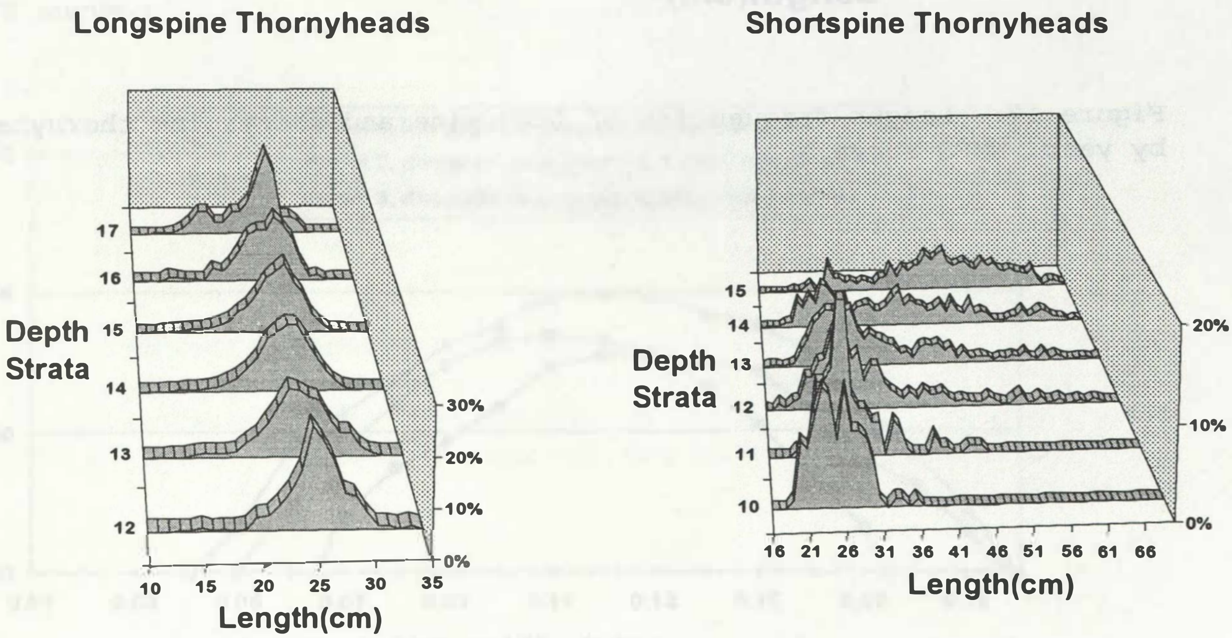


Figure 16. Length frequencies of longspine and shortspine thornyheads by depth strata, ODFW market sample data. Depth strata are by 100 fathom intervals where stratum 10 represents 0-99 fathoms, stratum 11 represents 100-199 fathoms etc.

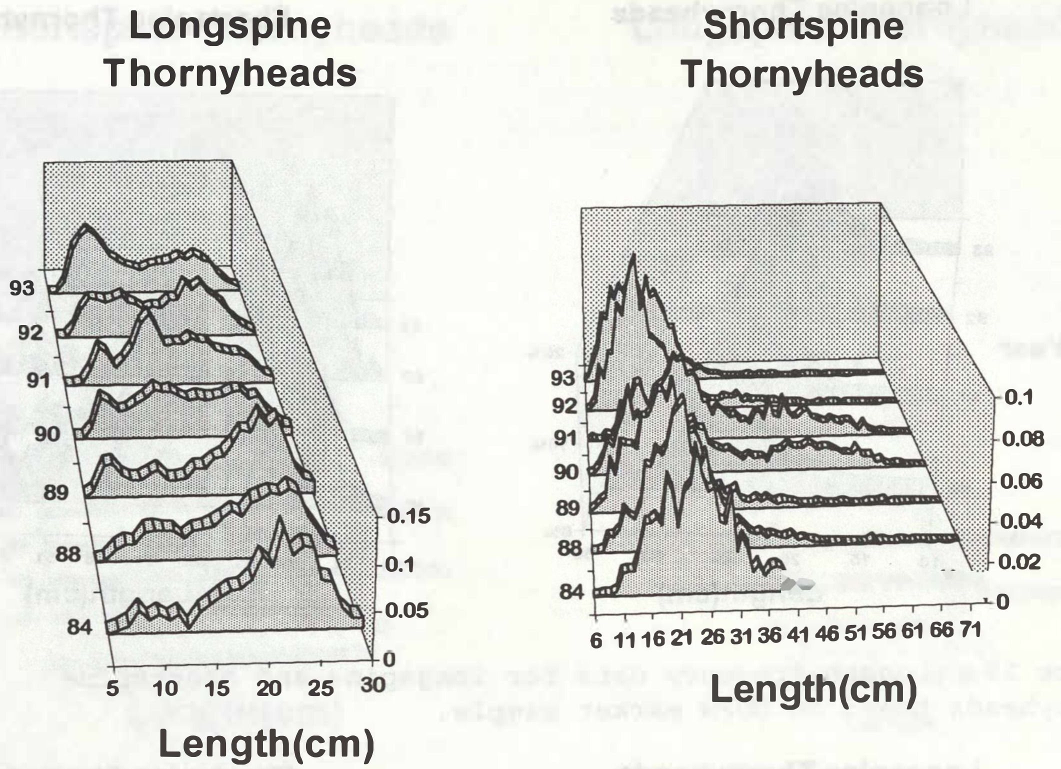


Figure 17. Length frequencies of longspine and shortspine thornyheads by year, NMFS surveys.

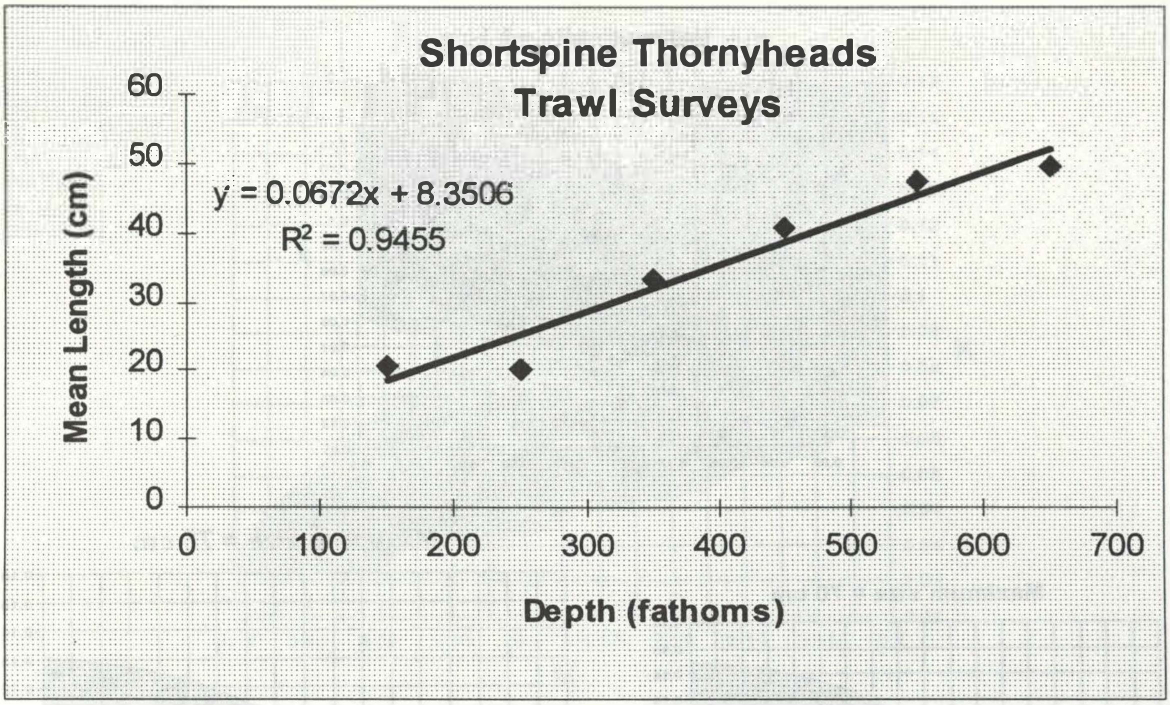


Figure 18. Mean length of shortspine thornyheads by depth strata based on NMFS surveys.

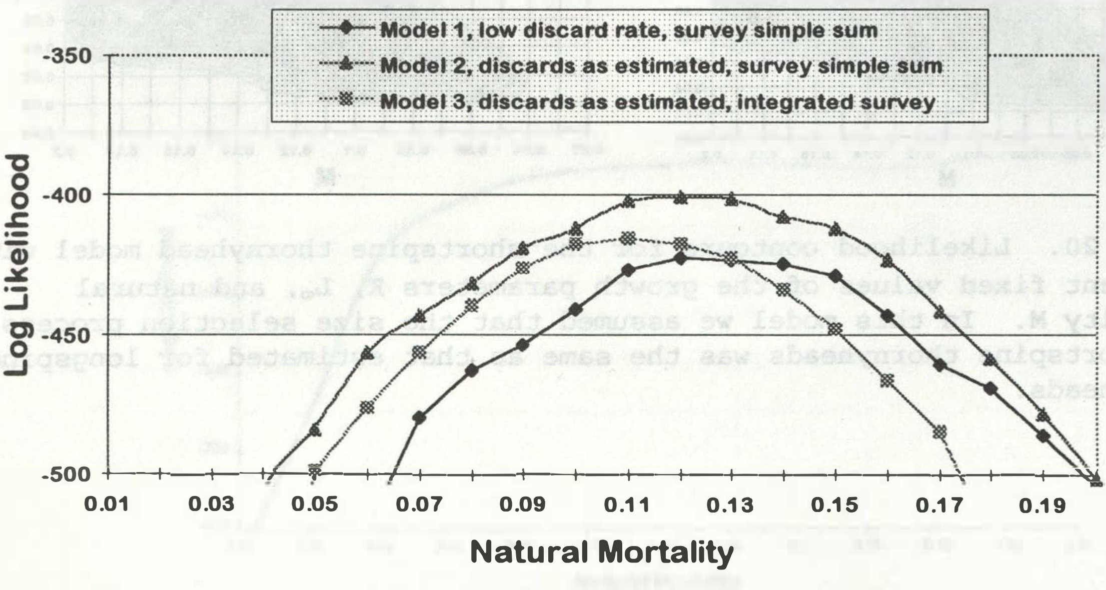


Figure 19. Plot showing the likelihood profile for different fixed natural mortality values for longspine thornyheads.

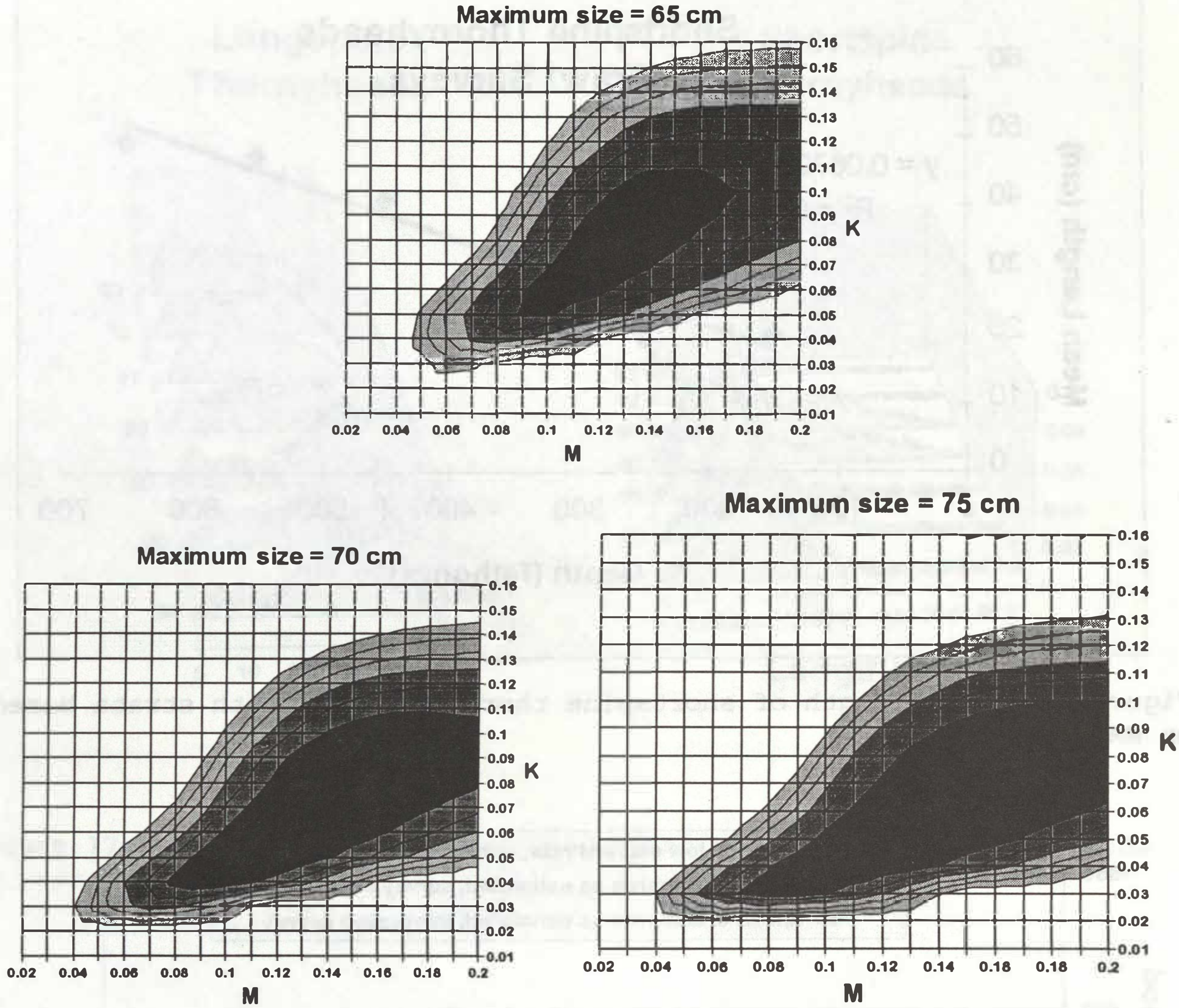


Figure 20. Likelihood contours for the shortspine thornyhead model with different fixed values of the growth parameters K, L_∞, and natural mortality M. In this model we assumed that the size selection process for shortspine thornyheads was the same as that estimated for longspine thornyheads.

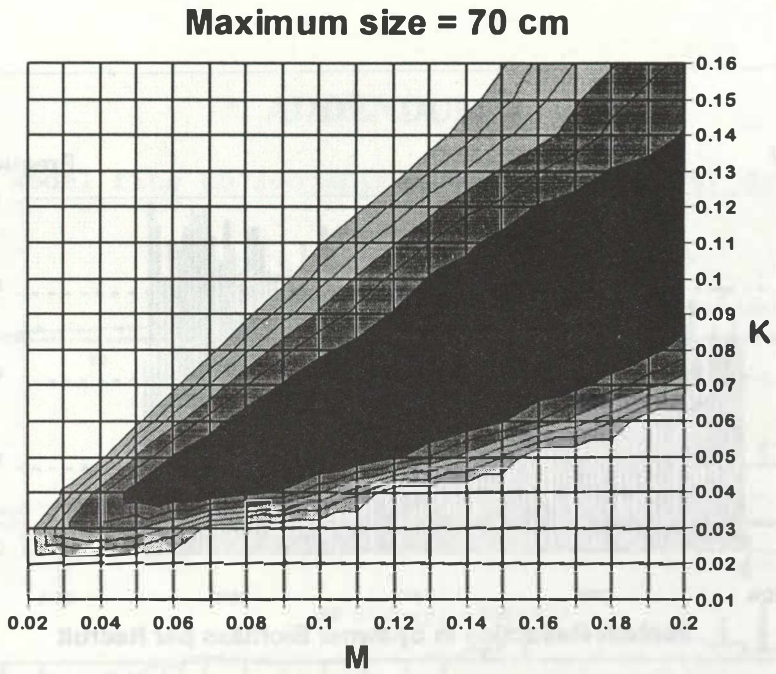


Figure 21. Likelihood contours for the shortspine thornyhead model with different fixed values of the growth parameter K and natural mortality M. This is the same as Fig. 18 but with the data on fish smaller than 30 cm were omitted.

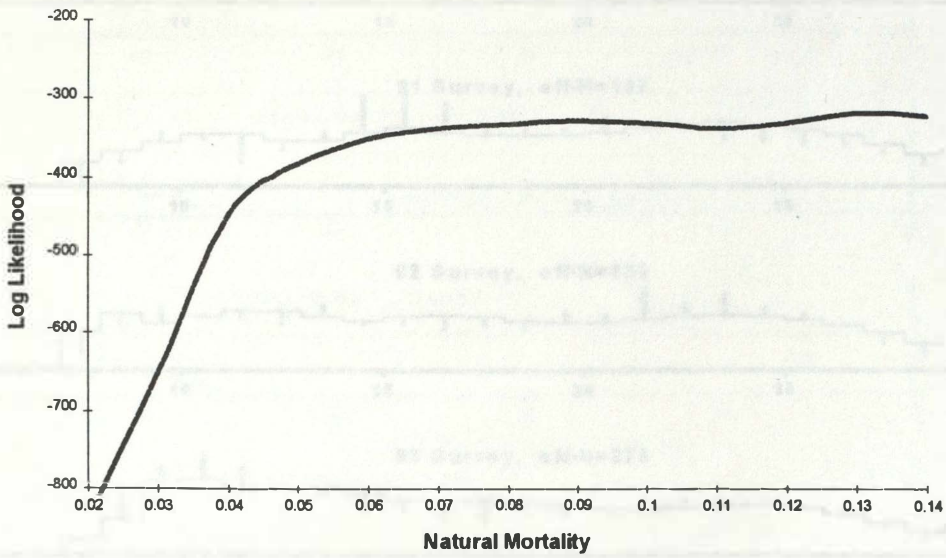


Figure 22. Likelihood profile for the shortspine thornyhead model with respect to alternative natural mortality assumptions. Note that values of M=0.05, 0.07, and 0.09 were used in the assessment.

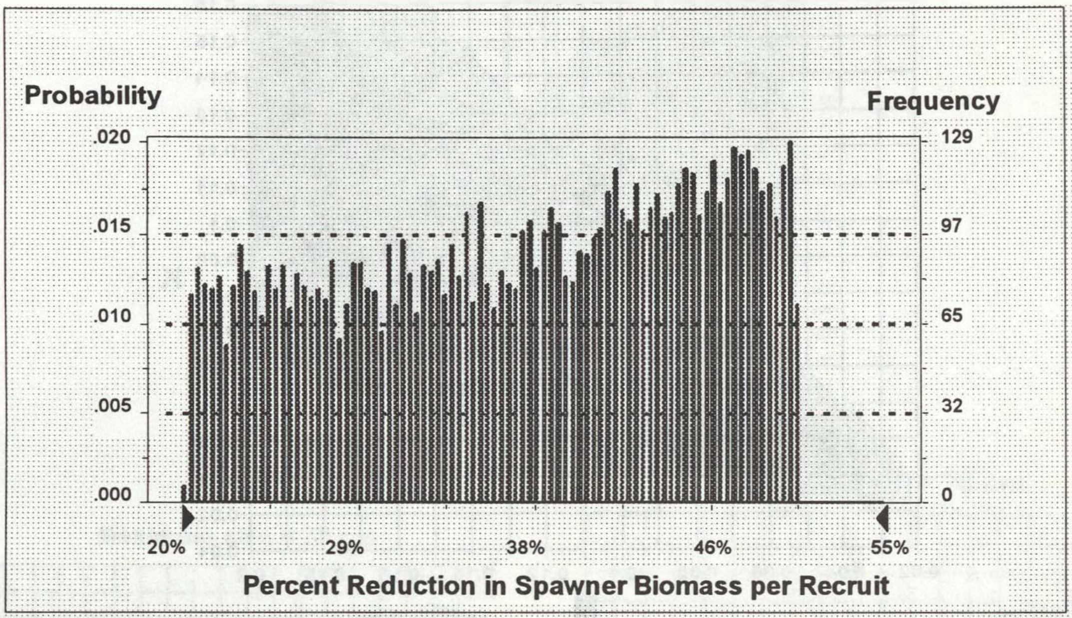
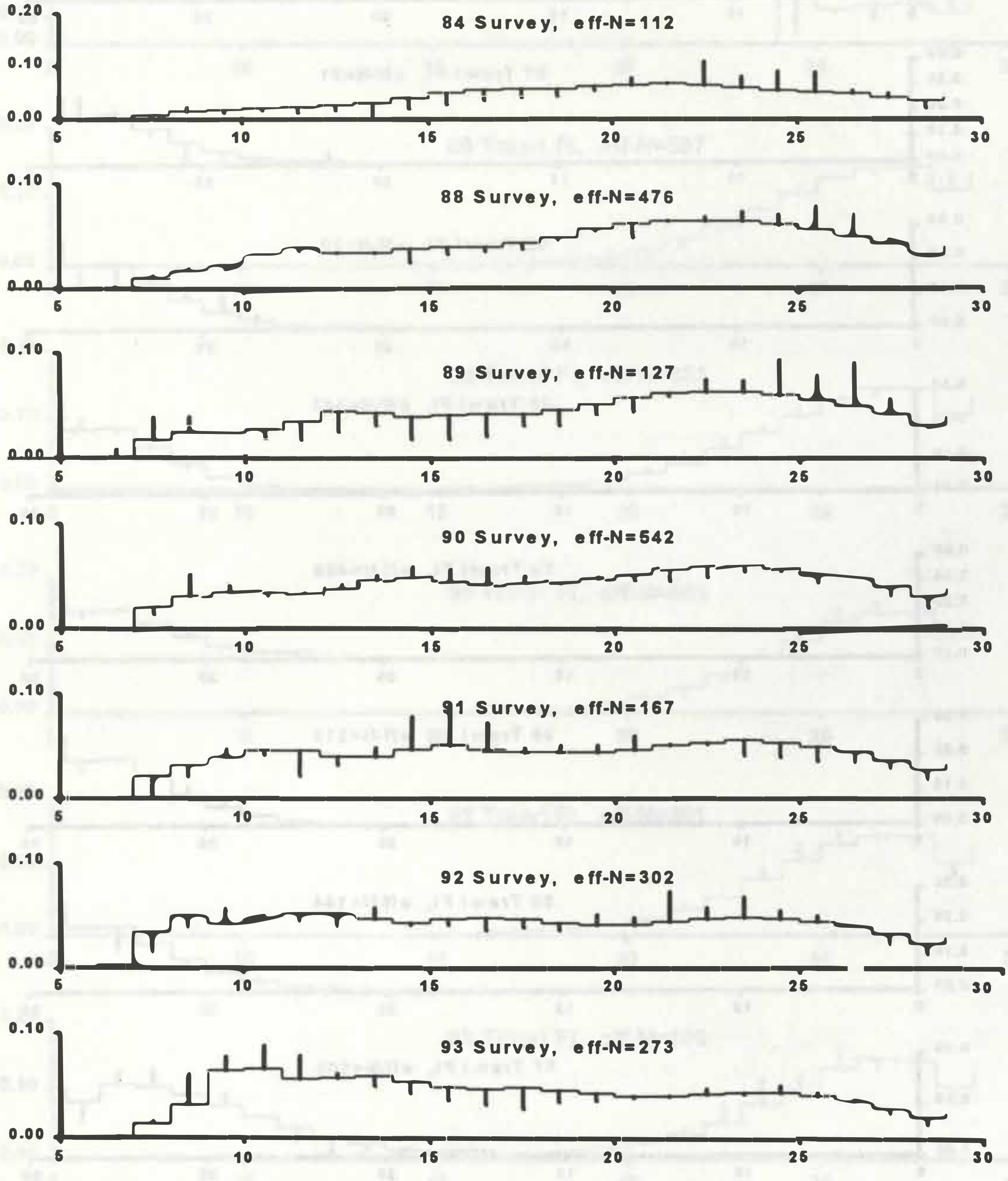


Figure 23. Distribution of percent reduction in spawner biomass per recruit using the estimated $F_{35\%}$ rate with natural mortality treated as a Monte Carlo random variable with a uniform distribution on the interval of 0.03 - 0.11. A total of 8,000 simulations were performed.

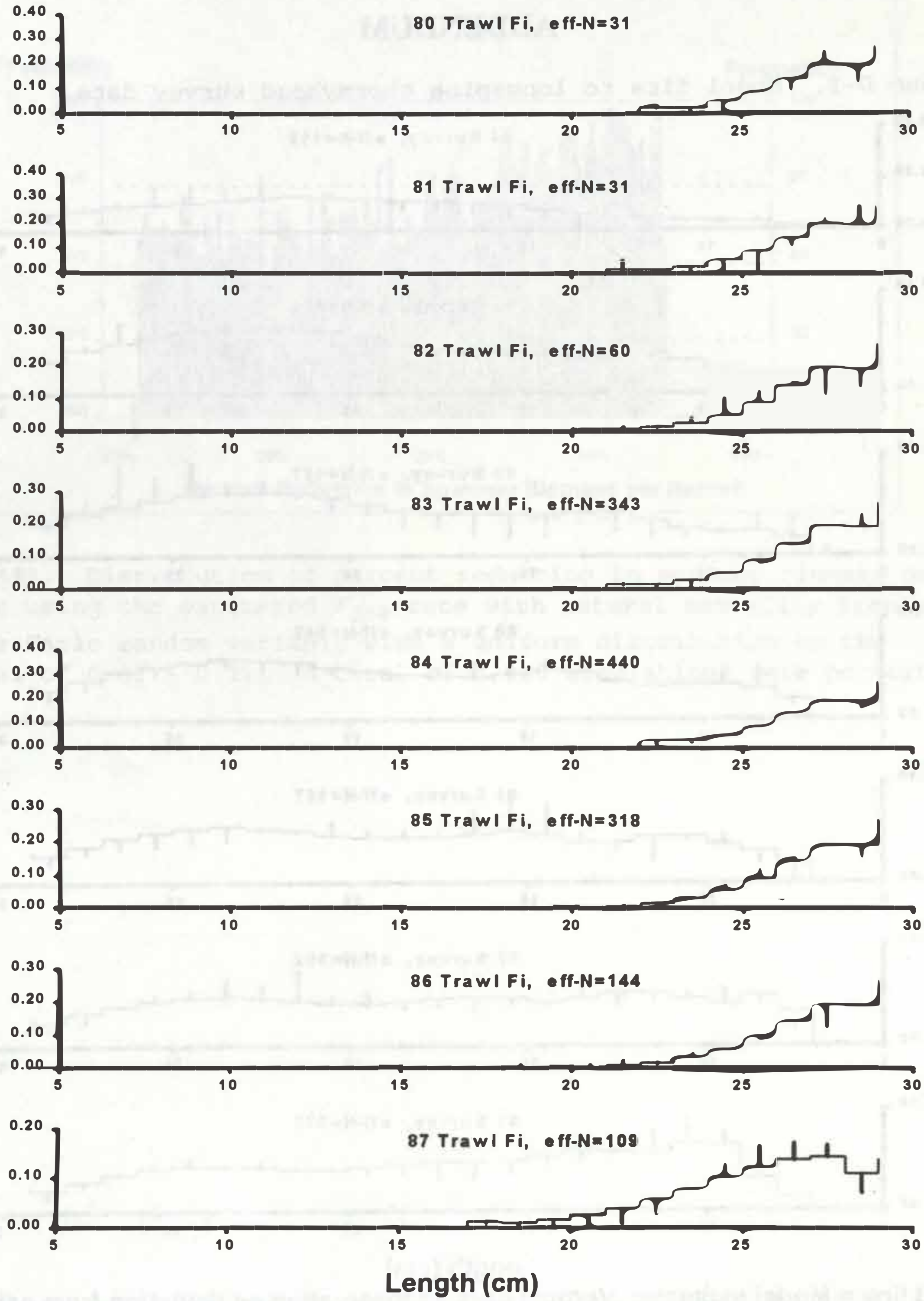
ADDENDUM

Addendum D-1. Model fits to longspine thornyhead survey data.



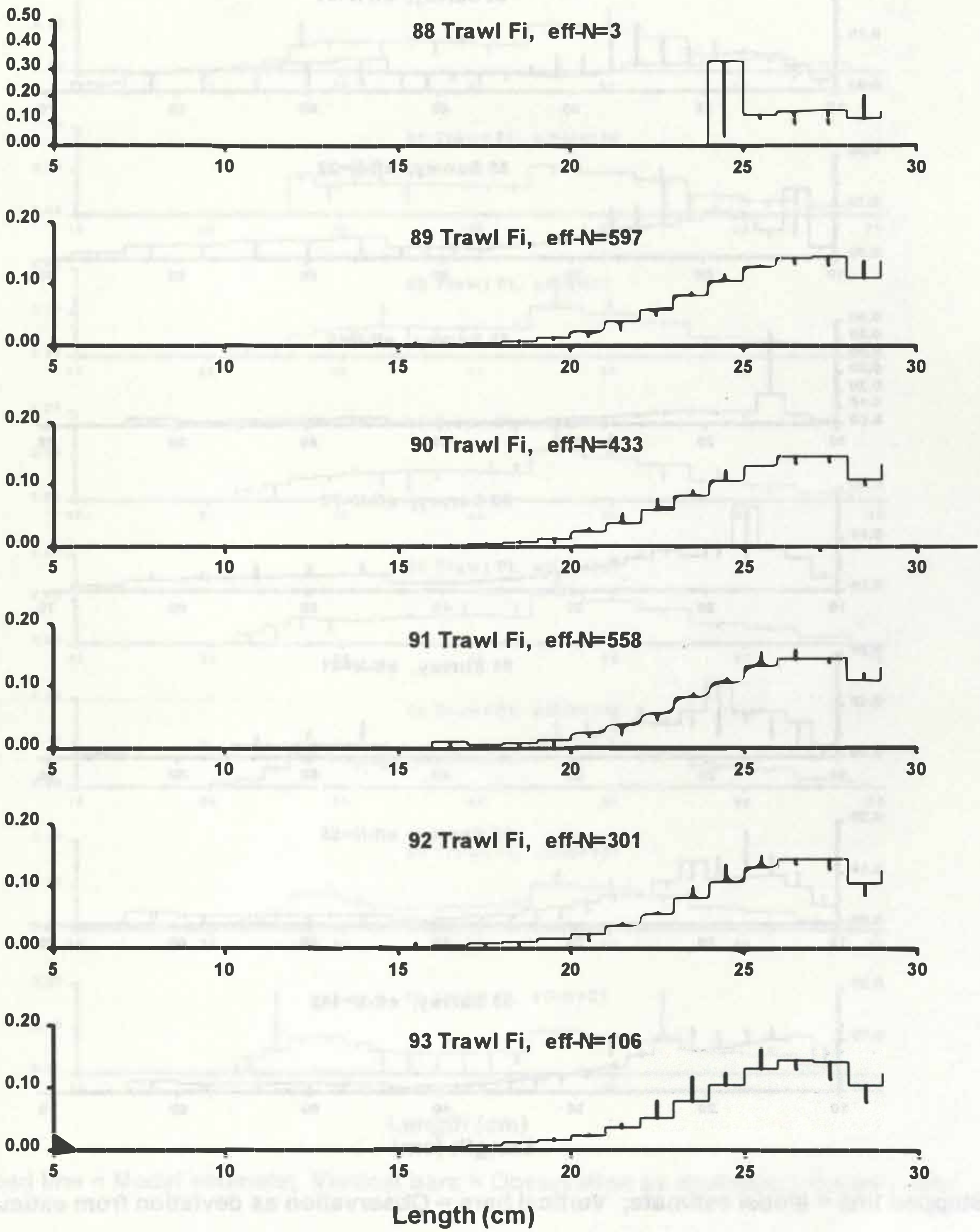
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.

Addendum D-2. Model fits to longspine thornyhead trawl fishery data.



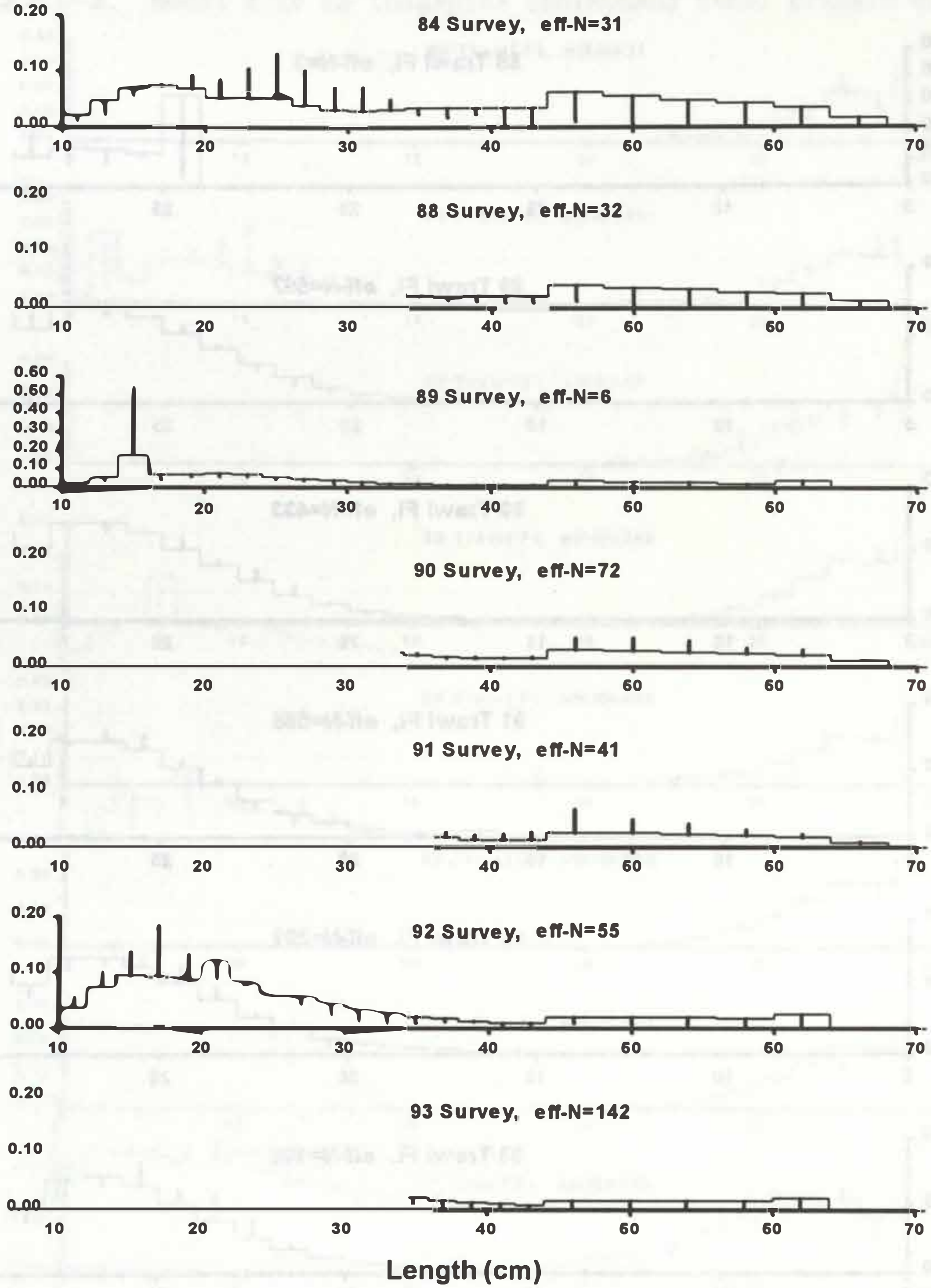
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.

Addendum D-2 (cont'd). Model fits to longspine thornyhead trawl fishery data.



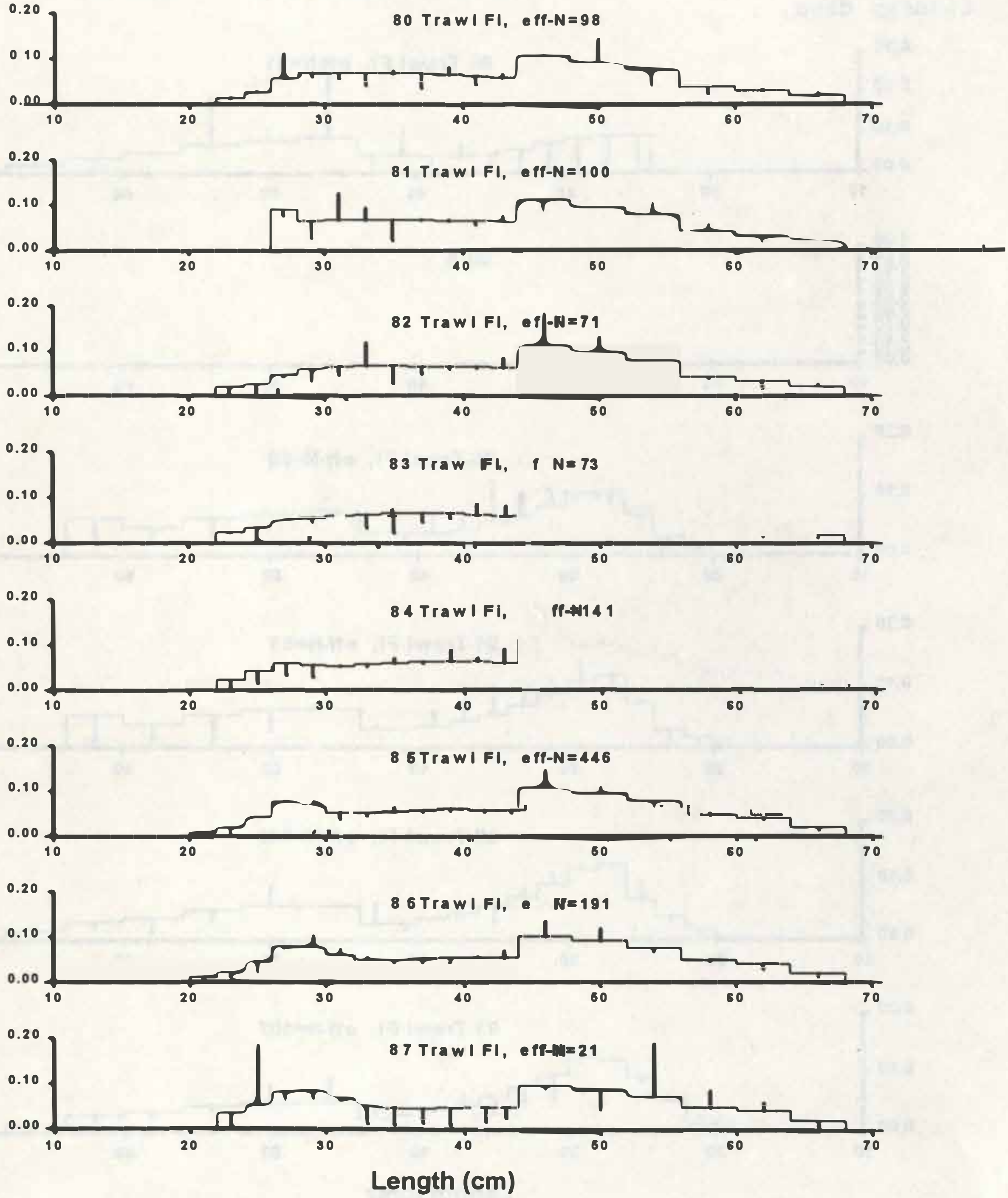
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.

Addendum D-3. Model fits to shortspine thornyhead survey data.



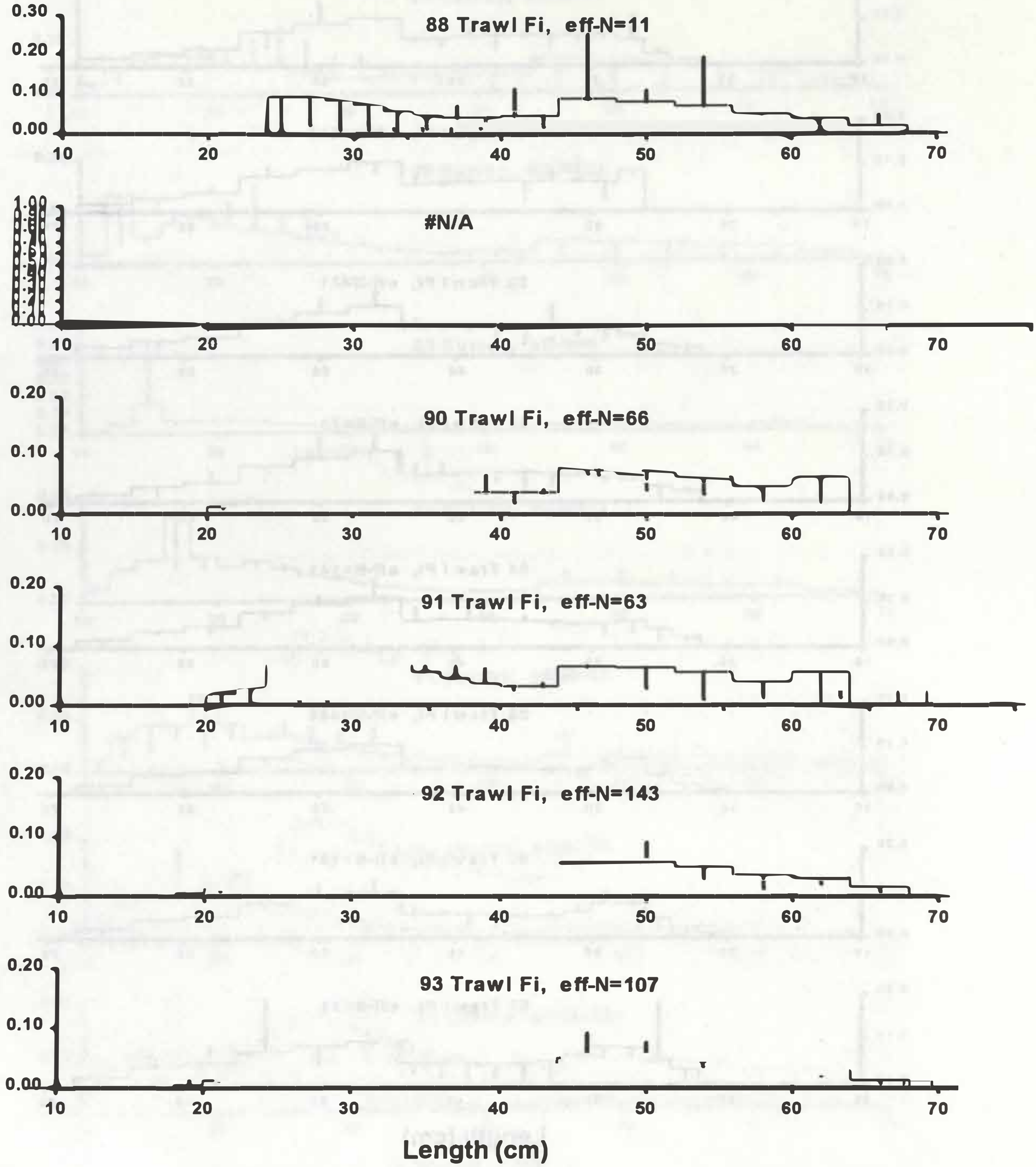
Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.

Addendum D-4. Model fits to shortspine thornyhead trawl fishery data.



Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.

Addendum D-4 (cont'd). Model fits to shortshortspine thornyhead trawl fishery data.



Stepped line = Model estimate; Vertical bars = Observation as deviation from estimate.