NOAA Technical Memorandum NMFS F/NWC-138

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

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ABSTRACT

This document provides a summary of the status of the Pacific whiting (Merluccius productus) stock in 1987 and recommendations for management in 1988. The current status of the Pacific whiting stock was evaluated on the basis of 1986 Northwest and Alaska Fisheries Center (NWAFC) bottom trawl and hydroacoustic survey data and information on the relative abundance of juveniles in 1984-86 California Department of Fish and Game juvenile survey data. The NWAFC survey data revealed several important findings. Analysis of the age structure of the stock revealed three strong year classes (1977, 1980, and 1984) are presently supporting the stock. In general, younger fish were concentrated in the southern International North Pacific Fisheries Commission areas of Eureka and Monterey, whereas older fish were primarily located north of the Columbia River. In areas where older and younger fish coexisted, the younger fish were concentrated in the offshore environment (> 55 fathoms (fm)), whereas the older fish were primarily located in the inshore environment (< 55 fm). The total biomass of the Pacific whiting stock in 1986 was 2.1 million metric tons (t). Preliminary information from juvenile whiting surveys indicated that the 1984 and 1986 year classes may be strong.

New estimates of offshore Pacific whiting fishery production were made using an age-structured simulation model. A-new management policy was imposed that constrained the spawner stock- biomass to previously observed levels with a high probability. Maximum long-term yield was estimated under both constant effort and variable effort scenarios using deterministic and stochastic versions of the simulation model. Estimates of maximum long-,term production from the Pacific whiting stock ranged from 165,000 to 196,000t. Estimates of yield were projected for the 1988-90 fishing seasons using the simulation

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INTRODUCTION

Commercially and ecologically, Pacific whiting (Merluccius productus) is one of the most important marine fish species off the west coast of North America. Francis and Hollowed (1985) summarize the history and management of the coastal fishery for whiting as follows. A small domestic fishery for whiting has existed since at least 1979. A large foreign fishery for whiting was initiated by the U.S.S.R. in 1966. During the period from 1973 to 1976, Poland, the Federal Republic of Germany (West Germany), the German Democratic Republic (East Germany), and Bulgaria joined the fishery.- Joint ventures for whiting developed in 1978 between foreign nations and the United States and Canada. In recent years (1980-86), joint venture operations have accounted for a substantial percentage of the whiting catch in U.S. and Canadian waters (Table 1). The estimated catches of whiting have ranged from 90,000 to 238,000 metric tons (t) since 1966 (Table 1). Catches peaked in 1976 and were subsequently reduced, due primarily to restrictions on foreign effort imposed after the implementation of the Magnuson Fisheries Conservation and Management Act (MFCMA) of 1976.

Table 2 compares commercial catch, Acceptable Biological Catch (ABC) and fishery quotas from 1977 to 1987. Combined U.S and Canadian catches have been below the recommended levels during the period from 1977 to 1986. The 1987 quota for the United States and Canada combined exceeded the ABC for the first time. Table 3 gives preliminary U.S. joint venture and foreign allocations of catch for the 1987 fishing season. Nineteen eighty-seven was the first year that applications for whiting allocations were made by the People's Republic of China and the -People's Republic of Korea. With the domestication of the U.S. fisheries in the 'Gulf of Alaska and the Bering Sea, foreign interest in Pacific whiting can be expected to increase in the next few years.

The fishery for whiting is tied closely to the migratory behavior of the population. Bailey et al. (1982) provided a detailed description of the life history of the stocks. Briefly, adult whiting spawn off the coasts of central, southern, and Baja California during the winter. In the spring adults migrate northward to summertime feeding grounds off the coasts of northern California, Oregon, Washington, and Vancouver Island. Larger individuals tend to make the longest northerly migrations. Large adults may migrate to waters off the coast of, Canada while juveniles remain off central and northern California. The. southward migration of adults begins in autumn and may be triggered by the shift of wind direction in the fall and the appearance of the Davidson Current.

The work of Bailey (1981) establishes a statistical link between year-class strength and environmental conditions at the time of spawning. An attempt to merge this environmental relationship into an age-structured management model was made by Swartzman et al. (1983) and Francis et al. (1984). Francis (1985) simplified this version of the model to evaluate the status of the whiting stock and to provide estimates of future levels of Acceptable Biological Catch (ABC) .

In 1987 research on the management and production of offshore whiting at the Northwest and Alaska Fisheries Center (NWAFC) focused on two areas: 1) estimation of production parameters incorporating data from the 1986 fishery and the 1986 NWAFC triennial trawl/hydroqcoustic survey, and 2) revision of management policy and procedures used to estimate production of the stock.

1986 SURVEY RESULTS

Since 1977, the NWAFC has conducted triennial acoustic/midwater trawl and bottom trawl surveys of important groundfish resources in the California to British Columbia region. These surveys were aimed primarily at providing information on the distribution, abundance, and biology of Pacific whiting, yellowtail rockfish (Sebastes flavidus), and canary rockfish (2. pinniger), but data from a wide variety of species are also routinely collected. The acoustic/midwater trawl survey and the bottom trawl survey are conducted independently, but concurrently, so results can be combined to more completely characterize whiting distribution and abundance. The following sections describe the 1986 surveys and summarize information obtained relative to the whiting resource.

Bottom Trawl Survey

The 1986 bottom trawl survey design was developed to provide improved estimates of yellowtail and canary rockfish abundance. Therefore, a 'large portion of the available samples were allocated to important rockfish grounds off Washington and Oregon. However, a minimal sampling density of 1 station per 29 square nautical miles (nmi^2) was maintained from 36°48' to 48°30' N latitude to obtain information on Pacific whiting and other species. Samples were allocated to two depth strata (55-183 m and 184-366 m) in proportion to stratum area. Station locations were selected using a stratified/random procedure. All trawl hauls were 30 minutes in duration and were conducted during daylight hours with a Nor'eastern trawl equipped with roller gear and a 3.18-cm liner in the codend. Horizontal and vertical net mouth dimensions averaged 13 and 7 m, respectively. Sampling _ conducted by two chartered stern trawlers from south to north, commencing in Monterey Bay, California, on

9 July and terminating off Cape Flattery, Washington, on 30 September. Thus, only the U.S. portion of the International North Pacific Fisheries Commission (INPFC) Vancouver area was sampled by bottom trawl. Catches were sampled for species composition by weight and numbers, length and age composition, sex ratios, state of maturity, and a variety of other biological data.

Successful trawl hauls were completed at 507 stations. Pacific whiting was the-most abundant species in the shallow stratum throughout most of the survey area. Most trawl hauls contained whiting and the catch per unit of effort (CPUE) was high over much of the survey area. The CPUE is grouped by three levels of magnitude and presented in Figure 1 on a haul-by-haul basis. The CPUE was greatest in INPFC statistical areas Monterey and Eureka where it averaged 107 and 781 kg/km trawled, respectively. A total of 239,153 t was estimated by the bottom trawl survey with 95% confidence limits of 179,111-299,195 t (Table 4, Fig. 2). Ninety-five percent of the total whiting biomass trawl surveys occurred in the 55- to 183-m zone. Juveniles (2- and 3-year-olds) comprised a larger proportion (51%) of the population in the 184- to 366-m zone than in the 55- to 183-m interval (41%). Forty percent of the total biomass was found in the Monterey area, 19% in the Eureka area, 34% in the Columbia area, and 7% in the U.S. portion of the Vancouver area.

Length and age compositions by INPFC area are presented in Figure 3. The most notable feature of the age compositions was the high variability in year-class size. The three most abundant year classes in the 1986 population were 1977, 1980, and 1984. These three year classes accounted for over 90% of the total population numbers,. Intervening year classes were considered to have been quite weak. Another important aspect of the age compositions is the latitudinal variation. The 1984 year class was predominant in the Monterey and Eureka areas and accounted for a major portion

(54%) of the population in those areas. Very few 2-year-olds of the 1984 year class were present in the Columbia area and no whiting less than 5 years old were in the U.S.-Vancouver area. In those northern areas, the population: was largely comprised of 6- and 9-year-olds of the 1980 and 1977 year classes, If this latitudinal pattern is consistent, in years when newly recruited year classes are of moderate or small sizes, a much smaller proportion of the total biomass tends to be found in the California-southern Oregon region. The converse may or may not be true, depending on environmental conditions. Even though a large 1980 year class was present in 1983, a large proportion of the younger fish were located off Oregon. This could have been related to northward extension of unusually warm water observed during the 1982-83 El Nino.

The latitudinal stratification by age results in increasing mean length from south to north. Mean fork length in the Monterey area was 39 cm while it was 48 cm in the U.S. portion of the Vancouver area. The length distributions in the southern areas are strongly bimodal. The left mode at about 34 cm was comprised almost entirely of 2-year-olds, and all of the other age groups fall into the right mode. The distribution in the U.S.-Vancouver area is unimodal due to the absence of juvenile fish.

Acoustic/Midwater Trawl Survey

An acoustic/midwater trawl survey sampled the pelagic component of the Pacific whiting stock in coastal waters (55-366 m) from San Francisco,, California (37°10'N), to Nootka Sound, Vancouver Island (49°30'N), between 30 June and 31 July 1986 (NWAFC 1986). The principal objective of the survey was to collect echo integrator and midwater trawl data necessary to determine the distribution, abundance, and biological composition of the off-bottom whiting stock.

The survey was conducted aboard the NOAA ship Miller Freeman, a 66-m stern trawler equipped for fisheries and oceanographic research. Acoustic data were collected using a computerized echo integration system installed in a cargo container mounted to the deck of the vessel. The system included a 38-kHz echo sounder used with a multi-beam transducer. The transducer was -housed in a deadweight body towed behind the vessel at a depth of 10-15 m. Echo data were processed using a Hewlett-Packard4/ 1000 computer. Echo sign was sampled using a 3/4 scale Norsenet rectangular midwater trawl and a Diamond 1000 midwater trawl.

Survey work began off the coast of California and proceeded northward. Echo integration data were collected along a zig-zag trackline placed roughly perpendicular to bottom depth contours with transect endpoint spacing at 15 nmi. Data collection along the trackline was confined to daylight hours (0600-2100 Pacific daylight time) because of the tendency of whiting schools to disperse and mix with other species at night. Density estimates were. computed at 1 -minute intervals for each l-m depth stratum from the transducer to within 3 m of the bottom. These l-m values were summed over the water column to provide estimates of surface density (kg/m^2) which were in turn averaged and multiplied by the area1 extent of a whiting aggregation to yield an estimate of biomass.

Midwater trawl hauls were made at selected locations to identify echo sign and provide biological samples. Standard catch sorting and biological sampling procedures were used to provide estimates of total weight and numbers by species, length composition data for abundant species, and individual weight measurements and otolith samples for Pacific whiting.

4/ Reference to trade names does not imply edorsement by the National Marine Fisheries Service,,NOAA.

The survey trackline consisted of 112 transects totalling 2,092 nmi (Fig. 4). Whiting were encountered along the entire coast with the densest concentrations just north of San Francisco, California, and off the Strait of Juan de Fuca, Washington (48°20'N). Point estimates and confidence intervals of biomass for 13 whiting aggregations are presented in Table 5. The midwater estimate of total biomass for the west coast whiting stock was 1.89 million t with a 95% confidence interval between 1.66 million and 2.12 million t. One of the larger aggregations of fish (aggregation 1) was found in the Monterey INPFC area and extended from Point Reyes, California (37°45'N), to Punta Gorda, California (40°05'N). Analysis of data south of aggregation 1 was inhibited because of dense concentrations of zooplankton in the water column. Two trawl catches just south (37°25'N) of the Farallon Islands contained significant quantities of whiting. However, a qualitative assessment of echograms collected during the bottom trawl survey indicates that few whiting were present in midwater in the area off Monterey Bay, California (36° 48'N)5/. Between Eureka, California (40°45'N), and the Columbia River (46°15'N), the survey encountered two extensive offshore aggregations (aggregations 3 and 5) and three smaller" inshore aggregations (aggregations 2, 4, and 6). North of the Columbia River, there were six small aggregations (aggregations 7, 8, 9, 11, 12, and 13) and one dense aggregation (aggregation 10) off the Strait of Juan de Fuca. The latter concentration accounted for 22% of the total coast-wide biomass. The proportion of the coastal midwater biomass in Canadian waters was 15%.

Forty-eight midwater trawl hauls provided the biological data used to derive age and size-specific estimates of biomass and population abundance.

5/ Mark Wilkins, Northwest and Alaska Fisheries Center, RACE, NOAA Bin C15700, Bldg. 4, 7600 Sand Point Way NE, Seattle WA 98115. Pers. commun., October 1986.

An examination of length composition data revealed an adult stock of large fish (average length = 45 cm) north of the Columbia River (Fig. 5). South of the Columbia River, juvenile. fish of mean length 34 cm were found in addition to adults. An examination of the inshore (<101 m) and offshore (.101 m) trawl catches south of the Columbia River revealed that 1) inshore, adults outnumbered juveniles approximately two to one, and 2) offshore, juveniles outnumbered adults approximately five to one (Fig. 6). Juveniles were also more prominent in bottom trawl samples from the deeper portions of the survey area. The reason for the habitat separation is unknown/but may be linked to feeding behavior.

Two year classes dominated the whiting midwater stock in 1986. The 1980 (6-year-olds) and 1984 (2-year-olds) year classes accounted for 79% of the total coastwide biomass (Fig. 7) and 87% of the total population numbers (Fig. 8). The exploitable adult stock was dominated by the 1980 year class. In the Monterey INPFC area, the juvenile 1984 year class accounted for 70% of the biomass. The relative absence of 3-, 4-, and 5-year-old fish reinforced the evidence that the 1981, 1982, and 1983 year classes were below average. With the exception of a single trawl haul in the Monterey INPFC area, no age-0 or age-l whiting were captured during the survey.

Attempts at assessing the size of a fisheries resource, whether it be via acoustic/midwater trawl survey or bottom trawl survey, are subject to both systematic (e.g., target strength, calibration, net catchability) and nonsystematic (e.g., sampling) errors (Traynor et al., in press). In acoustic/midwater trawl surveys, one potential source of bias is the fish target strength value used to scale echo integrator output to estimates of absolute abundance. The value currently used for whiting, -35 decibels(dB)/kg, was originally se1ected from a review of the fisheries acoustics literature as representing a consensus for "whiting-like" species. In situ dual beam data collected during the 1980 and 1983 surveys suggest that-33 dB/kg may be a more appropriate choice. A correction from -35 to -33 dB/kg would result in a 37% decrease in estimated biomass. However, the paucity of whiting target strength data combined with the fact that dual beam results have yet to be corroborated by the split beam system, make us hesitant to change from the historical value of -35 dB/kg.

Transducer source level is another of the parameters used to scale echo integrator output. To monitor performance and provide the necessary scaling factors, the acoustic system is calibrated before and after each survey. During 1986, the post-cruise system calibration revealed a 1.7 dB drop in source level from pre-cruise measurements. It was impossible to determine if this change in source level occurred at some point during or after the survey, or represents a gradual decline. The pre-cruise value of source level was used in our calculations because it yielded a more conservative, and in our opinion, more realistic estimate of biomass. For example, the annual total mortality estimates for the 1980 year class between 1983 and 1986 using 1986 pre and post cruise abundance estimates were 0.20 and 0.07 respectively. The value of 0.07 was unreasonably low, whereas the value of 0.20 is much closer to the average value of total mortality for ages 3-5 (0.26) (see pages 14 and 15). Application of the post-cruise value in analysis would result in a 48% increase in estimated biomass.

Once the biomass estimate was derived, it was partitioned into the different year classes using the age and length data collected from midwater trawl catches. Errors in ageing biological samples directly influence estimates of year class abundance (Lai and Gunderson 1987). We have evidence of ageing errors from past whiting surveys, and so this possibility cannot be dismissed. Since ageing errors are typically + 1 year, estimates of year-class strength for cohorts that are adjacent to strong year classes are especially vulnerable to this bias.

Combined Survey Results

Biological data from the acoustic/midwater trawl and bottom trawl surveys were similar, but some area differences do exist.' Results of the bottom trawl survey show the presence of large numbers of whiting in the Eureka area which were 30-38 cm in length, a length group which was not so, prominent in the acoustic/midwater trawl samples from the area. This might be explained by the fact that only two midwater trawl hauls were made in the Eureka area. Perhaps the size composition observed in these two tows was not representative of the population. Conversely, a considerably higher proportion of small fish were observed by the acoustic/midwater trawl survey in the Columbia area than by the bottom trawl survey. Overall, the acoustic/midwater trawl survey sampled a slightly higher proportion of small fish. than did the bottom trawl survey. Both sets of data show a total population length distribution which is bimodal with modes at about 34 and 44 cm.

Age compositions derived by the two surveys reflect the area differences discussed above. The 2- and 6-year-olds of the 1984 and 1980 year classes were prominent in both data sets. Nine-year-olds of the large 1977 year class were still notable in the bottom trawl samples, but were less important in the acoustic/midwater trawl samples. Differences in age and length composition based on bottom and midwater trawl samples may be due to sampling variability, gear selection, or vertical statification of the population, but the relative importance of these factors is unknown.

The biomass estimates derived from the 1986 bottom trawl and acoustic/midwater surveys were combined and compared with estimates for 1977, 1980, and

1983 in Figure 9 and Table 6. Estimates from the two surveys were assumed to be additive. In 1980 and 1983 when the bottom trawl and acoustic/midwater trawl surveys sampled the same area, the bottom component averaged about 12% of the total. Biomass in the Monterey area tends to vary more annually than in the more northern areas as occasional strong year-classes occur. Biomass estimates in the Columbia and Vancouver areas were more constant between years. There has been an increasing trend with total biomass rising from 1.2 million t in 1977 to 2.1 million t in 1986. This trend should not be expected to continue over long periods because biomass levels are subject to large changes due to variable recruitment. The 1986 biomass estimate exceeded the long-term average (1.55 million t) due largely to the presence of the three large year classes previously mentioned. Because the 1980 year class will' be a prominent component of the population for another year and the 1984 year class is not yet fully recruited to the exploited population, the outlook is for abundance to remain at a relatively high level for the near future.

CURRENT STATUS OF THE RESOURCE

Age Composition

Figure 10 illustrates the relative age frequencies of whiting catches for 1985 and 1986 in U.S. and Canadian waters. In both years, most of the catches were comprised of strong year classes (1977, 1980, and 1984). It is interesting to note that the Canadian fishery is primarily supported by older fish, whereas younger fish comprise a major portion of the U.S. fishery.

Year-Class Strength

Since the fishery is predominantly supported by a small number of strong year classes, it is useful to forecast the relative strength of recruitment based on pre-recruit abundance. Figure 11 shows histograms of three indices of year-class strength. The first two indices give a measure of relative abundance of O-age whiting. They correspond to the CPUE and percent occurrence of O-age whiting in mid-water trawl surveys conducted by the California Department of Fish and Game (CDFGG) off the California coast (south of Point Conception) over the last 20 years (updated from Bailey et al. 1986). Annual indices of juvenile abundance from surveys conducted in spring, summer, autumn, and early winter are given. The last index is a measure of the abundance of 3-year-olds (i.e., the age of recruitment to the fishery) obtained from cohort analysis. Clearly, the strong year classes of 1967, 1970, 1973, 1977, and 1980 , which have historically supported the fishery, were identifiable in the O-age survey. Also, both pre-recruits and recruit indices indicate that the 1981 to 1983 year classes were complete failures and should not be expected to significantly contribute to the fishery:'

The O-age surveys can be used to forecast the relative strength of the 1984 to 1986 year classes for which recruitment estimates from cohort analysis can not yet be obtained. Estimates from the O-age- surveys conducted during those years suggested that the 1984 and 1986 year classes were above average (Fig. 11). Catch-at-age data from the 1985 and -1986 fishing seasons and the results of the 1986 NWAFC trawl/hydroacoustic survey show large catches of l- and 2-year-olds respectively, which tends to support other indications that the 1984 year-class strength is above average (Figs. 8 and 10).

Growth

Estimates of annual mean length-at-age and mean weight-at-age by sex were calculated using 1975-86 data from the National Marine Fisheries Service (NMFS) U.S. Foreign Fisheries Observer Program. Examination of mean annual weight-at-age reveals sharp decreases in **1978** and **1983** (Fig. 12). The drop in weight-at-age observed in 1983 may reflect the influence of the El Nino phenomenon. The graphs of mean weight-at-age and length-at-age show a general decline in average size of fish age 8 and above between 1976 and 1986 (Figs. 12 and 13). A similar decline has been observed in the Straight of Georgia Pacific whiting stock (Sandy Mcfarlane, Pacific Biological Station, Nanaimo, B.C., Canada, V9R 5K6. Pers. Commun., March 1988).

Examination of annual mean length and mean weight-at-age data also revealed extremely low values of mean weight and length for 3-year-old fish in 1979 (Figs. 12 and 13). Comparison of the individual length frequency distribution of 2- and 3-year-olds and their combined length frequency in 1979 with the corresponding general distributions for 1975 to 1986 showed clear differences.' This suggested that members of the strong 1977 year-class were incorrectly assigned to the age-3 group. Therefore, the relative frequency of 2- and 3-year-old fish in 1979 was corrected using a method' developed by Dan Kimura (NWAFC, 7600 Sand Point Way NE, Seattle, WA, 98115. Pers. Commun., April 1987). First, the distribution of length -at-age for ages 2 and 3 was determined for all years except 1979 (i.e., 1976-77, 1978-86). Then, the length-at-age distribution of 2- and 3-year-old fish combined was divided into age 2 and age 3 classes based on the expected length-at-age distribution for ages 2 and 3 for all other years. Using this method, 97% of the combined 2- and 3-year-old fish in 1979 were classified as age 2. Since there is some degree of interannual variability of length-at-age, we assumed a slightly more conservative classification of 90% age 2 and 10% age 3. Kimura's method was only applicable in cases of mis-ageing young age groups where a clear distinction of length-at-age was possible. Therefore, Kimura's method could not be used to correct the ageing errors in older fish.

ESTIMATES OF FISHERY PRODUCTION

With inclusion of the 1986 fishery data as well as the abundance estimates from the 1986 triennial NWAFC trawl/hydroacoustic survey, new estimates of natural mortality (M), catchability (q), and initial population (N) were derived.

Catch-at-Age Estimates

Estimates of catch-at-age in numbers from the 1986 fishing season were determined by a procedure developed by Kimura (In press). Using this method, the yield for a given substratum was distributed by age using randomly sampled length frequencies from a given stratum applied to age-length and weight-length keys. For this analysis the following substrata were used: quarter, INPFC area, and fishery type (i.e., joint venture or foreign directed).In addition, the estimated catch-at-age for 1979 was revised because of the modification in the age composition of the catch described above. Catch-at-age for 1973-78 and 1980-85 are from Hollowed and Francis (1986).

Natural Mortality Estimates

Age-specific natural mortality was derived using a modified form of the method described in Francis (1985). Total mortality (2) was estimated by following the decay of abundance' of cohorts using data from the 1977, 1980, 1983, and 1986 triennial NWAFC surveys. Total mortality was partitioned into natural (M) and fishing (F) mortalities by incorporation of catch information.

Following the decay of individual cohorts using the current estimates of catch and abundance-at-age revealed instances where the number of fish in a cohort at the end of a decay period (1977-80; 1980-83; 1983-86') exceeded the initial number in the cohort. To investigate this problem, the decay of strong year classes of Pacific whiting was examined. This exercise revealed instances when some fish were apparently mis-aged by plus or minus 1 year. To 'overcome this ageing problem, we followed the decay of three groups of cohorts consisting of fish ages 3 to 5, 6 to 8, and 9 to 11. The annual natural mortality estimates for each age category were averaged over all three decay periods (Table 7).

It was possible that the estimates of M for the younger' fish. (ages 3 to 5) were underestimated and the estimates for the older age groups were over-estimated. The estimate of M for the younger fish (ages 3 to 5) may be under-estimated because these fish are only partially recruited to the fishery.' Furthermore, in some years the triennial survey did not adequately sample the southern range of the whiting population. This southern portion of the range was typically dominated by the younger immature fish. The values of M for ages 9 to 11 were most likely overestimated because the behavior of the older fish may make them partially unavailable to both the commercial and survey gears. Therefore, we assumed that average estimate of M (0.2) for ages 6 to 8 (the youngest ages fully recruited to the fishery) represented the most realistic estimate for the entire stock. This value of natural mortality was the same as that estimated for the Puget Sound whiting stock using Gunderson and Dygert's (1987) relationship between relative reproductive effort and natural mortality (Goni 1988). Ths value of M was also similar to an estimate of natural mortality (m = 0.25) based on the Beverton and Holt (1959) relationship between natural mortality and maximum age (20 yrs).

Population Estimates

Age-specific catchabilities (q) and 1973-86 population abundance were estimated from the cohort analysis method developed by Francis (1983). This cohort analysis uses the analytic formulation of Pope (1972) and Tomlinson

(1970). The analysis was performed in such a way to fit the estimated numbers-at-age from the cohort analysis to the numbers-at-age derived from the 1977, 1980, 1983, and 1986 NWAFC triennial trawl-hydroacoustic surveys. We assumed that the survey estimates of abundance of whiting at, ages 6 to 8 provided the most reliable estimates of M, within the range of ages of 3 to 11. Accordingly, the fit of the cohort estimates was done focusing mainly on those ages, but also minimizing the overall sum of squares across the 4 years considered in the analysis. Catch data used to perform the cohort analysis, estimated fishing mortality, numbers-at-age observed from the surveys, and estimated numbers-at-age from the cohort analysis are given in Table 8.

Recruitment

Data and estimates that form the basis of a stock-environment-recruitment relationship used in the management model are presented in Table 9. The second column gives the year class index (BI) developed by Bailey (1981). This index represents the mean contribution of a cohort at ages 4, 5, and 6 based on survey and commercial catch data. The third column gives an analog of Bailey's YCI based on estimates of numbers-at-age from the cohort analysis for the 1967-82 year classes. The YCI for the 1960-66 year classes was derived from a linear regression of BI (based on survey data) on the YCI (based on cohort analysis) for the 1967-75 year classes.

The fourth column of Table 9 gives estimates of recruitment at age 3. Recruitment was estimated from the cohort analysis for the 1970-83 year classes and predicted for the 1960-69 year classes from a linear regression of R3 on YCI (based on the 1970-82 data).

The fifth column of Table 9 shows the estimates of female spawning stock biomass. The spawning biomass was calculated from the cohort analysis for 1973-86 year classes, and derived from a reconstructed stock of 3- to 7-year-olds for the 1967-72 year classes. The stock of fish ages 3 to 7 was reconstructed from the initial estimates of recruitment by accruing natural and fishing mortality via a Beverton Holt type analysis. The total spawner biomass was estimated based on the linear regression of the total spawner biomass on the spawner biomass of the 3- to 7-year-olds.

Maximum Sustainable Yield

Estimates of offshore whiting fishery production were made using a modified form of the age-structured simulation model described in Francis (1985). The model has both a deterministic and a stochastic form. Stochastic variability is associated with variations in recruitment. The simulations were made over a 1,000-year time period to provide a long-term evaluation of potential yield from the whiting stock under various fishing scenarios and management options.

Recruitment in the simulation model was assumed to be a function of temperature at the time of spawning. Bailey (1981) showed whiting recruitment to be inversely -correlated to wind-driven Ekman transport on the spawning ground in early winter. He found that offshore transport was positively correlated with ,-the level of upwelling, and negatively correlated with sea surface temperature. Therefore, years of "cold" water temperatures on the spawning ground were assumed to be years of low larval survival, and years of "warm" water temperatures were assumed to be years of higher, although more variable, larval survival (Fig. 14).

Figure 15 gives the 1930-86 time series of average January-March sea surface temperatures in the Los Angeles Bight, the approximate center of whiting spawning range. As described in Francis et al., (1984), temperatures above and below 15°C were considered warm and cold temperatures, respectively.

The temperature time series was used as a driving variable for runs of the age-structured model. In order to make the 1,000-year runs, the temperatures from years 1943 to 1982 were cycled through. the model 25 times. This time period appeared to capture two cycles of warm and cold temperatures (Fig. 15).

Figure 16 shows recruitment levels corresponding to spawner biomass for the years 1967 to 1983. No apparent relationship between recruitment and level of spawner biomass exists in the range of the available information. Therefore, recruitment was considered to be a function of temperature alone and density dependent effects on recruitment were not considered.

Because density dependent recruitment has not been observed in the range of observed spawning biomasses, a prudent management policy is to maintain spawning biomass in this range. The above consideration about recruitment led us to develop constant and variable effort management policies which, with a high probability, constrained the spawning biomass to previously observed levels. Spawner biomass was constrained as follows: spawner biomass was allowed to drop below the lowest observed level (SB_{min} = 0.319 million t, Table 9) only 10% ,of the time in a 1 ,000-year run of the model. We defined the model parameter fopt as: 1) the, level of effort which maximized the long-term catch subject to the above constraint in the constant effort scenario, and 2) the value about which effort is varied in the variable effort scenario, which maximized the long-term catch subject to the constraint above. In the variable effort case, effort in a given year was calculated as follows:

f_i = effort in year i

$= f_{opt} (SB_i/SB_{opt})$,

Where SB_{opt}= optimum spawner biomass level set equal to the mean observed spawner biomass at the beginning of year (0.6373 million t). The parameters used in the 1,000-year runs appear in Table 10.

Runs were made using both the deterministic and stochastic versions of the model. Stochasticity was incorporated in recruitment as a log-normal random variable with mean equal to the corresponding cold or warm year mean recruitment and standard deviation equal to product of the mean recruitment and the observed coefficient of variation in recruitment for the respective temperature condition. Log normal random variates were generated using the method decribed in Naylor et al. (1966). In the stochastic cases, the estimates of long-term production represented the average of 10 1,000 -year runs, each with different seed values for the random number generator. In the deterministic cases, 1 run of 1,000 years was made with coefficient of variation of recruitment set equal to zero.

Table 11 gives the results from the 1 ,000-year optimal variable and constant effort runs of both the deterministic and stochastic versions of the model. The maximum average annual surplus production of the stock under the variable and constant effort options was 196,000 and 185,000 t using the deterministic version of the model, and 182,000 and 165,000 t using the stochastic version. We believe that the stochastic version more accurately represented the inherent variability in the recruitment of the whiting population. The stochastic version also produced slightly lower estimates of average yield, from substantially lower values of fopt.

PROJECTIONS OF 1988 ABC

Estimates of whiting yields were projected for the 1988-90 fishing seasons using the deterministic version of the model. Runs of the model were made incorporating the best estimates of stock abundance and recruitment levels for the upcoming fishing seasons. In these runs, fishing was initiated at the beginning of 1986. Effort was then set to remove the observed catches for 1986 and expected catches for 1987 (209,000 and 285,000 t, respectively). Initial numbers-at-age in 1986 were from the result of the cohort analysis.

Projections of yield in 1988-90 were based on the assumptions that: 1) the 1984 and 1986 year classes were strong (i.e., mean warm year recruitment = 0.971 billion), and 2) the 1985 and 1987 year classes were average strength (i.e., the mean recruitment for warm years excluding the strong year classes = 0.339 billion). The first assumption was based on the fact that the results of the 1986 NWAFC trawl/hydroacoustic survey and the 1984-86 CDF&G juvenile surveys indicate that the 1984 and 1986 year classes were strong. We assumed that the 1985 year class was average strength because the 1985 CDF&G juvenile survey indicated that the 1985 year class was average. We. assumed that the 1987 year class was average, despite the fact that temperature conditions on the spawning grounds were warm, because two sequential strong year classes of Pacific whiting have rarely been observed.

The results of our 1988-90 catch projections under various. policy options are shown in Table 12. The first two projections were produced from the application of the constant effort and variable effort policies derived using the optimum fishing effort determined in the 1,000-year runs of the stochastic version of the model Under both of these options there was a significant decrease in catch over the 3-year time period. As a result we made two runs that implemented constant effort and constant catch policies and gave the same spawning stock protection over the 3-year period as the variable effort algorithm (i.e., reducing the spawning stock biomass to no lower than 596,000 t by the beginning of 1991). It was interesting to note that the trade-off in mean catch around 1988-90 was minimal when comparing the variable effort algorithm (341,000 t/year) with the constant effort (336,000 t/year) and constant catch (325,000 t/year) which gave the same spawning stock protection at the beginning of 1991.

We recommend that the ABC for the total Pacific whiting stock in 1988 should be set at 325,000 t. The results of our modeling exercise indicated that this yield could be sustained over the next 3 years without imposing any significant damage to the stock. The yield-at-age projected from the model for the 1988 season can be allocated between the U.S. and Canadian fisheries based on a smoothed estimate of the proportion-at-age of available biomass in the- corresponding zones as determined by the 1986 NWAFC hydroacustic survey. Using this method, the 1988 ABC for the U.S. Pacific whiting fishery would be 232,000 t. The higher than average Canadian proportion of the total yield (29%) reflected the fact that 89% of the expected yield at age in 1988 is comprised of older fish (age 8 and above).

ACKNOWLEDGMENTS

We thank Kevin Bailey, Richard Methot, and Al Tyler for their constructive review of this manuscript.

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Table 1 .--Annual catches of Pacific whiting (1,000 t) in U.S. and Canadian waters by foreign, joint venture (Jv), and domestic fleets.

	U.S.				Canada				Combined		
Year	Foreign	J-V	Domestic	Total	Foreign	JV	Domestic	Total	Total	CPUEZ	Effort*
1966	137.000	0.000	0.000	137.000	0.700	0.000	0.000	0.700	137.700	19.2	7.171
1967	168.699	0.000	8.963	177.658	36.713	0.000	0.000	36.713	214.371	36.0	5.951
1968	60.660	0.000	0.159	60.819	61.361	0.000	0.000	61.361	122.180	11.8	10.397
1969	86.187	0.000	0.093	86.280	93.851	0.000	0.000	93.851	180.131	18.5	9.726
1970	159.509	0.000	0.066	159.575	75.009	0.000	0.000	75.009	234.584	25.6	9.180
1971	126.485	0.000	1.428	127.913	26.699	0.000	0.000	26.699	154.612	17.5	8.842
1972	74.093	0.000	0.040	74.133	43.413	0.000	0.000	43.413	117.546	15.9	7.381
1973	147.441	0.000	0.072	147.313	15.125	0.000	0.001	15.126	162.439	23.8	6.752
1974	194.108	0.000	0.001	194.109	17.146	0.000	0.004	17.150	211.259	24.3	8.705
1975	205.654	0.000	0.002	205.656	15.704	0.000	0.000	15.704	221.360	19.0	11.646
1976	231.331	0.000	0.218	231.549	5.972	0.000	0.000	5.972	237.521	25.7	9.242
1977	127.013	0.000	0.489	127.502	5.191	0.000	0.000	3.453	130.955	30.9	4.244
1978	96.827	0.856	0.689	98.372	3.453	1.814	0.000	6.464	104.836	35.2	2.980
1979	114.909	8.834	0.937	124.680	7.900	4.233	0.302	12.435	137.115	26.0	5.276
1980	44.023	27.537	0.792	72.352	5.273	12.214	0.097	17.584	89.936	28.5	3.152
1981	70.365	43.556	0.839	114.760	3.919	17.159	3.283	24.361	139.121	28.3	4.915
1982	7.089	67.464	1.024	75.577	12.479	19.676	0.002	32.155	107.732	30.9	3.489
1983	0.000	72.100	1.050	73.150	13.117	27.657	0.000	40.774	113.924	(30.9)	(3.687)
1984	14.722	78.889	2.721	96.382	13.203	28.906	0.000	42.109	138.491	(30.9)	(4.482)
1985	49.853	32.033	4.636	86.522	10.533	13.237	1.192	24.962	111.484	(30.9)	(3.608)
1986	69.861	81.640	3.463	154.964	23.743	30.136	0.000	53.879	208.843	(30.9)	(6.759)
MEAN				125.053				29.800	156.007		

*Effort for 1983-86 based on the assumption of constant CPUE equal to that observed in 1982.

Table 2.--Annual catches of Pacific whiting (1,000 t) in U.S. and Canadian waters by foreign, joint venture (JV), and domestic fleets compared to fishery quotas and Acceptable Biological Catch (ABC).

Year	U.S.			Canada			Combined		
	Catch	Quota	ABC	Catch	Quota	ABC	Catch	Quota	ABC
1977	127.502	150.000	-	3.453	20.000	-	130.955	170.000	-
1978	98.372	130.000	-	6.464	23.000	-	104.836	153.000	-
1979	124.680	198.000	-	12.435	24.700	-	137.115	222.700	-
1980	72.352	175.000	-	17.584	31.500	-	89.936	206.500	-
1981	114.760	175.000	-	24.361	31.000	-	139.121	206.000	-
1982	75.577	175.000	-	32.155	30.500	-	107.732	205.500	-
1983	73.150	175.000	-	40.774	42.000	-	113.924	217.000	-
1984	96.382	175.000	-	42.109	40.000	-	138.491	215.000	270.000
1985	86.522	175.000	145.000	24.962	33.400	67.000	111.484	208.400	212.000
1986	154.964	227.500	300.000	53.879	70.000	105.000	208.843	297.500	405.000
1987		195.000	206.000		90.000	58.000		285.000	264.000
MEAN 77-86	102.426			25.818			128.244		

Table 3.--Preliminary 1987 foreign allocations of Pacific whiting by the United States.

	Joint venture	Directed
U.S.S.R.	45,000	0
People's Republic of China	5,000	7,500
People's Republic of Korea	2,500	2,500
Poland	53,750	53,750
Total	106,250	63,750

Table 4.--Pacific whiting biomass estimates and 95% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and depth stratum based on bottom trawl survey data.

	Depth (m)	Biomass* (t)	95% Confidence interval
INPFC Monterey			
	55-183	91,124	58,132 - 124,116 (± 36%)
	184-366	4,829	15 - 9,643 (± 100%)
	55-366	95,953	62,724 - 129,181 (± 35%)
INPFC Eureka			
	55-183	42,325	27,177 - 57,473 (± 36%)
	184-366	2,903	72 - 5,734 (± 98%)
	55-366	45,228	29,868 - 60,588 (± 34%)
INPFC Columbia			
	55-183	77,147	45,372 - 108,922 (± 41%)
	184-366	1,421	868 - 1,974 (± 39%)
	55-366	78,568	46,788 - 110,348 (± 40%)
U.S. portion of INPFC Vancouver			
	55-183	18,070	6,471 - 29,669 (± 64%)
	184-366	1,335	632 - 2,038 (± 53%)
	55-366	19,404	7,784 - 31,024 (± 60%)
Total survey area			
	55-183	228,666	168,967 - 288,302 (± 26%)
	184-366	10,487	2,787 - 18,188 (± 73%)
	55-366	239,153	179,111 - 299,195 (± 25%)

*Differences in totals may exist due to rounding.

Table 5.--Biomass estimates for the 13 Pacific whiting aggregations delineated during the 1986 acoustic/ midwater trawl survey. Subtotals by INPFC area and a total for the west coast are presented.

Aggregation	Biomass (t)	Standard Error	95% confidence interval	Area (nmi^2)	Density (kg/m^2)	INPFC area
1	770,292	82027	60951 - 931065 (± 21%)	1283	0.175	MONTEREY
2	76,290	17669	41658 - 110922 (± 45%)	195	0.114	
3	115,915	16127	84306 - 147524 (± 27%)	490	0.069	
	192,205	23922	145317 - 239093 (± 24%)	685	0.082	EUREKA
3	96,366	32409	32844 - 159888 (± 66%)	271	0.104	
4	36,374	2903	30684 - 42064 (± 16%)	200	0.053	
5	197,654	34936	129180 - 266128 (± 35%)	783	0.073	
6	27,235	5961	15552 - 38918 (± 43%)	81	0.098	
7	24,273	944	22424 - 26122 (± 8%)	49	0.144	
8	20,567	4651	11451 - 29683 (± 44%)	62	0.097	
	402,469	48346	307710 - 497228 (± 24%)	1446	0.081	COLUMBIA
9	32,238	5456	21544 - 42932 (± 33%)	70	0.134	
10	206,309	46401	115362 - 297256 (± 44%)	225	0.264	
	238,547	46721	146974 - 330120 (± 38%)	295	0.233	VANCOUVER (USA)
10	216,136	36490	144616 - 287656 (± 33%)	247	0.252	
11	29,744	7668	14714 - 44774 (± 51%)	110	0.079	
12	27,490	16479	0 - 59789 (±117%)	79	0.101	
13	10,875	5329	430 - 21320 (± 96%)	105	0.030	
	284,245	41113	203664 - 364826 (± 28%)	541	0.152	VANCOUVER (CAN)
	1,887,758	116237	1659933 - 2115583 (± 12%)	4250	0.129	WEST COAST

Table 6.--Pacific whiting biomass estimates based on bottom trawl and hydrocoustic surveys in 1977, 1980, 1983, and 1986.

		International North Pacific Fisheries Commission Area.				
Year		Monterey	Eureka	Columbia	Vancouver	Total
1977	BT	17,707	10,153	31,548	5,791*	65,199
	H	108,087	360,944	316,440	343,821	1,129,292
	T	125,794	371,097	347,988	349,612	1,194,491
1980	BT	140,948	11,338	19,858	16,155	188,299
	H	578,841	182,783	260,477	322,335	1,344,436
	T	719,789	194,121	280,335	350,260	1,532,735
1983	BT	19,165	43,559	56,665	9,420	128,809
	H	56,203	252,265	397,168	495,231	1,200,867
	T	75,368	295,824	453,833	512,719	1,329,676
1986	BT	95,953	45,228	78,568	19,404*	239,153
	H	770,292	192,205	402,469	522,792	1,887,758
	T	866,245	237,433	481,037	542,195	2,126,911

BT = bottom trawl; H = hydroacoustic; T = total

*U.S. portion of Vancouver area only

Table 7.--Summary of natural mortality coefficients by cohort decay period.

Ages	3-year Fishing mort. coefficient	3-year Total, mort. coefficient	3-year Natural Mort. coefficient	Exploitation rate	Annual natural mort. coefficient
1977-80					
3-4-5	0.4153	0.4232	0.0079	0.3386	0.0026
6-7-8	0.3081	0.6920	0.3839	0.2224	0.1280
9-10-11	0.1704	1.1064	0.9360	0.1031	0.3120
1980-83					
3-4-5	0.3229	1.5203	1.1974	0.1653	0.3992
6-7-8	0.5421	1.5301	0.9880	0.2776	0.3293
9-10-11	0.5511	2.7413	2.1902	0.1881	0.7301
1983-86					
3-4-5	0.1867	0.3984	0.2118	0.1540	0.0706
6-7-8	0.3644	0.7829	0.4185	0.2527	0.1395
9-10-11	0.5259	1.5787	1.0528	0.2644	0.3509
Average					
3-4-5					0.1575
6-7-8					0.1989
9-10-11					0.4643

Table 8a--Catch-at-age data for the cohort analysis and observed mean numbers at age from surveys and derived from the cohort analysis.

Age	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Catch At Age Data (Millions)														
3	55.89	0.98	2.69	36.82	3.82	4.15	1.44	15.20	1.78	1.94	103.12	2.20	0.39	9.53
4	9.68	150.14	3.67	29.26	54.60	8.10	17.70	8.95	107.52	2.07	4.71	155.03	12.87	1.98
5	21.71	20.52	128.11	29.59	11.32	48.58	10.97	9.11	10.44	71.53	4.58	8.84	116.96	16.49
6	40.20	35.50	21.86	185.10	20.23	9.40	51.75	10.16	12.18	5.79	64.76	14.40	11.69	217.08
7	25.15	44.29	23.54	27.62	69.94	19.85	16.51	23.12	6.48	7.55	5.03	41.00	8.17	23.32
8	23.00	25.73	38.00	13.81	11.58	38.45	31.67	10.65	27.79	6.75	6.30	6.08	17.58	13.44
9	21.50	11.40	17.15	4.93	6.30	5.85	23.31	8.68	7.53	16.98	5.17	5.84	1.76	25.58
10	10.32	3.58	7.40	0.99	3.13	2.90	3.70	22.87	6.46	3.43	15.30	4.12	0.71	2.58
11	4.51	1.63	3.70	0.31	3.13	2.90	1.92	2.37	14.33	3.49	2.54	8.72	1.01	1.56
Fishing Mortality Coefficients														
3	.02957	.00280	.00912	.05182	.02544	.02068	.00998	.01452	.00477	.00467	.02915	.00907	.01543	.06759
4	.03456	.10352	.01303	.12944	.10119	.06911	.11489	.07929	.13483	.00682	.01396	.05582	.06710	.10139
5	.10318	.09542	.12064	.13678	.06762	.12295	.12584	.07968	.12513	.12477	.01865	.03274	.05435	.11490
6	.19621	.24407	.13945	.25586	.13056	.07352	.18635	.16431	.14536	.09459	.15886	.07500	.05523	.13519
7	.21381	.34396	.25339	.26198	.14481	.18279	.17853	.11869	.14986	.12612	.11136	.14291	.05554	.14870
8	.62177	.35265	.55967	.23156	.16676	.11059	.49231	.16731	.20426	.23013	.14725	.19062	.08396	.12166
9	.72353	.73595	.42131	.12758	.15697	.11884	.09061	.24061	.17103	.18528	.27683	.19787	.07745	.16898
10	.88207	.24561	1.87848	.03773	.11161	.10051	.10261	.12054	.28370	.10955	.25344	.37143	.03317	.15546
11	.33760	.32208	.40390	.34195	.16127	.14304	.08969	.08826	.10321	.24423	.11061	.22410	.14432	.09463

Table 8b.--Mean numbers at age from surveys and derived from the cohort analysis.

	1977		1980		1983		1986	
	EST	OBS	EST	OBS	EST	OBS	EST	OBS
3	150	90	1047	1581	3538	2728	141	82
4	540	508	113	128	337	45	20	19
5	167	41	114	90	245	26	144	142
6	155	61	62	73	408	330	1606	1607
7	483	573	195	265	45	31	157	158
8	69	70	64	79	43	32	110	114
9	40	44	36	206	19	29	151	146
10	28	28	190	88	60	45	17	16
11	19	19	27	58	23	17	16	17
SUM OF SQUARES	37550		332666		796639		3523	
TOTAL	1170380							

1977 data from surveys. All other data estimated from cohort analysis.

EST = estimated, OBS = observed.

Table 9.--Summary of estimates of year class indices[a]/, recruitment at age 3 from cohort analyses and spawner biomass for Pacific whiting.

Year class	b/ Bailey's YCI (BI)	c/ YCI	d/ Recruitment at age 3 (Billions)	e/ Spawner biomass (million t)	f/ Total temp. index
1960	54	(71.0)	(1.062)	-	Warm
1961	130	(176.7)	(2.884)	-	Warm
1962	14	(15.4)	(0.104)	-	Cold
1963	19	(22.3)	(0.223)	-	Warm
1964	20	(23.7)	(0.247)	-	Warm
1965	8	(7.0)	(0.000)	-	Cold
1966	20	(23.7)	(0.247)	-	Warm
1967	34	36.6	(0.469)	(0.8492)	Warm
1968	28	24.5	(0.260)	(0.6329)	Warm
1969	29	26.5	(0.296)	(0.3194)	Warm
1970	78	147.4	2.115	(0.3460)	Warm
1971	18	33.0	0.386	(0.3673)	Cold
1972	14	29.6	0.327	(0.3860)	Cold
1973	86	86.1	0.804	0.5803	Warm
1974	16	19.4	0.167	0.6569	Cold
1975	30	24.6	0.224	0.6893	Cold
1976	-	14.9	0.159	0.6740	Cold
1977	-	93.0	1.162	0.6012	Warm
1978	-	28.7	0.412	0.5621	Warm
1979	-	20.7	0.460	0.4919	Cold
1980	-	211.3	3.958	0.5163	Warm
1981	-	20.0	0.269	0.5445	Warm
1982	-	0.8	0.028	0.4879	Cold
1983	-	-	0.161	0.8665	Warm
1984	-	-	-	1.0399	Warm
1985	-	-	-	1.1162	Cold
1986	-	-	-	1.0179	Warm

Mean warm year recruitment.= 0.971, CV = 117.5%; Mean cold year recruitment = 0.206, CV = 76.7%; Mean spawner biomass = 0.6373, CV = 36.7%; Minimum spawner biomass = 0.3193.

a/ Values in parentheses are estimated from linear regression.

b/ BI = Pct. contribution of 4, 5, and 6 year old fish calculated from commercial catch and survey data (Bailey 1981).

c/ YCI = Year Class Index percent contribution of 4, 5, and 6 year old fish to the total population calculated from the cohort analysis.

$$YCI = -4.1 + 0.0139 * BI \quad (r^2 = 0.812)$$

d/ R = Recruitment

$$R = -0.161 + 1.723\ YCI \quad (r^2 = 0.942)$$

e/ SB) = Spawner biomass ages 3 to 11
N = Numbers at age in beginning of year
W = Average weight at age
C = Proportion mature at age
PCTF = Female percent of at age

$$SB(3-11) = \sum^{11} N_i * C_i * \overline{W_i} * PCTF_i \quad (1973-1986)$$

$$SB(3-11) = 0.223 + 0.852\ SB(3-7) \quad (r^2 = 0.912)$$

f/ Temperature on the spawning grounds 1960-86.
Warm = Mean January-March temperatures >15°c
Cold = Mean January-March temperatures <15°c

Table 10.--Parameter values used in l,000-year simulation runs of an age structured model for Pacific whiting.

Parameter	7 %												
	3	4	5	6	7	8	9	10	11	12	13	14	15
Q	0.00360	0.01417	0.02012	0.03154	0.03756	0.08877	0.07864	0.07888	0.07888	0.07888	0.07888	0.07888	0.07888
C	0.50	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
W	0.4098	0.5190	0.6105	0.6991	0.7898	0.8952	0.9683	1.0315	1.1162	1.2050	1.2190	1.2330	1.2360
I	0.520	0.446	0.354	0.282	0.224	0.178	0.141	0.112	0.089	0.071	0.056	0.045	0.036
PCTF	0.508	0.506	0.514	0.519	0.522	0.539	0.549	0.558	0.583	0.583	0.583	0.583	0.583

Q = Age specific catchability coefficient
C = Proportion of mature females
W = Average weight at age (kg)
I = Initial numbers at age used for management runs (billions)
PCTF = Percentage of weight represented by females

Note:

N	number of age classes	13
R	number of years that recruitment is delayed after spawning	3
SB_{opt}	optimum spawner biomass level (million t) set at mean observed spawner biomass	0.6373
SB_{min}	minimum spawning biomass (million mt)	0.3193
RW	average warm year recruitment (billions)	0.971
RC	average cold year recruitment (billions)	0.206
M	Natural mortality coefficient	0.2

Table 11 .--Summary of results from 1,000-year runs of the deterministic and stochastic versions of the model under constant recruitment management policy.

Management Policy	Y(CV) (1,000 t)	f(CV) (1,000 d)	CPUE (t/d)	B(CV) (1,000 t)	% years SB<Scrit	Minimum Biomass (1,000 t)	fopt (1,000 d)
Variable effort							
Det	196 (36.0)	8.4 (25.2)	23.3	923 (27.1)	10%	436	11.000
Stoch	182 (70.2)	5.2 (42.9)	34.9	1,083 (47.3)	10%	376	5.830
Constant effort							
Det	185 (29.3)	6.3 (0.0)	29.3	1,048 (31.0)	10%	404	6.300
Stoch	165 (50.8)	3.9 (0.0)	42.6	1,263 (53.0)	10%	311	3.862

Det = Deterministic run
Stoch = Stochastic run
Y = Yield
f = average effort

fopt = optimum effort level

CPUE = Catch Per Unit Effort in tons per boat day
B = Total biomass
SB = Spawner biomass
Scrit = Minimum observed spawner biomass

Table 12.--Summary of the 1988-90 potential yields.

Management Policy	Year	Yield (1,000 t)	Effort (1,000 d)	Average Biomass (1,000 t)	Spawner Biomass (1,000 t)	Percent Exploitation
Observed	1986	209	2.96	1,770	1,069	12%
Expected	1987	285	4.36	1,749	986	16%
Constant effort Algorithm	1988	327	3.86	1,479	878	22%
	1989	228	3.86	1,462	803	16%
	1990	188	3.86	1,300	726	14%
	1991	-	-	-	717	-

	Mean 1988-90	248				
Variable effort Algorithm	1988	587	8.03	1,333	878	44%
	1989	255	6.07	1,218	664	21%
	1990	182	5.39	1,078	589	17%
	1991	-	-	-	596	-

	Mean 1988-90	341				
Constant effort 1988 - 1990	1988	490	6.32	1,389	878	35%
	1989	294	6.32	1,282	716	23%
	1990	224	6.32	1,096	614	20%
	1991	-	-	-	596	-

	Mean 1988-90	336				
Constant catch 1988 - 1990	1988	325	3.84	1,479	878	22%
	1989	325	5.82	1,412	803	23%
	1990	325	8.30	1,143	675	28%
	1991	-	-	-	596	-

	Mean 1988-90	325				

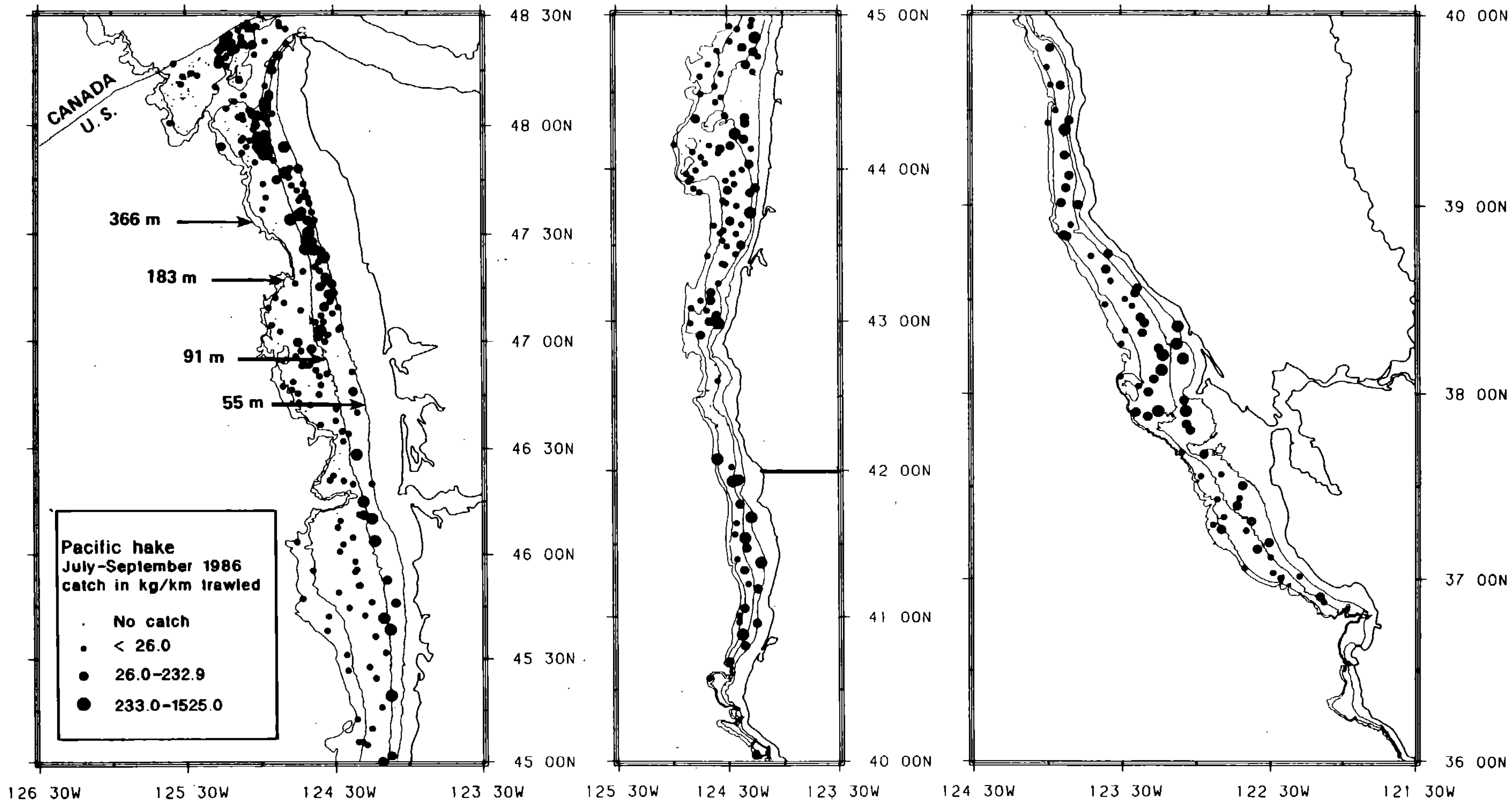

Figure 1 .--Pacific whiting distribution and abundance as measured by catch rates during the 1986 bottom trawl survey.

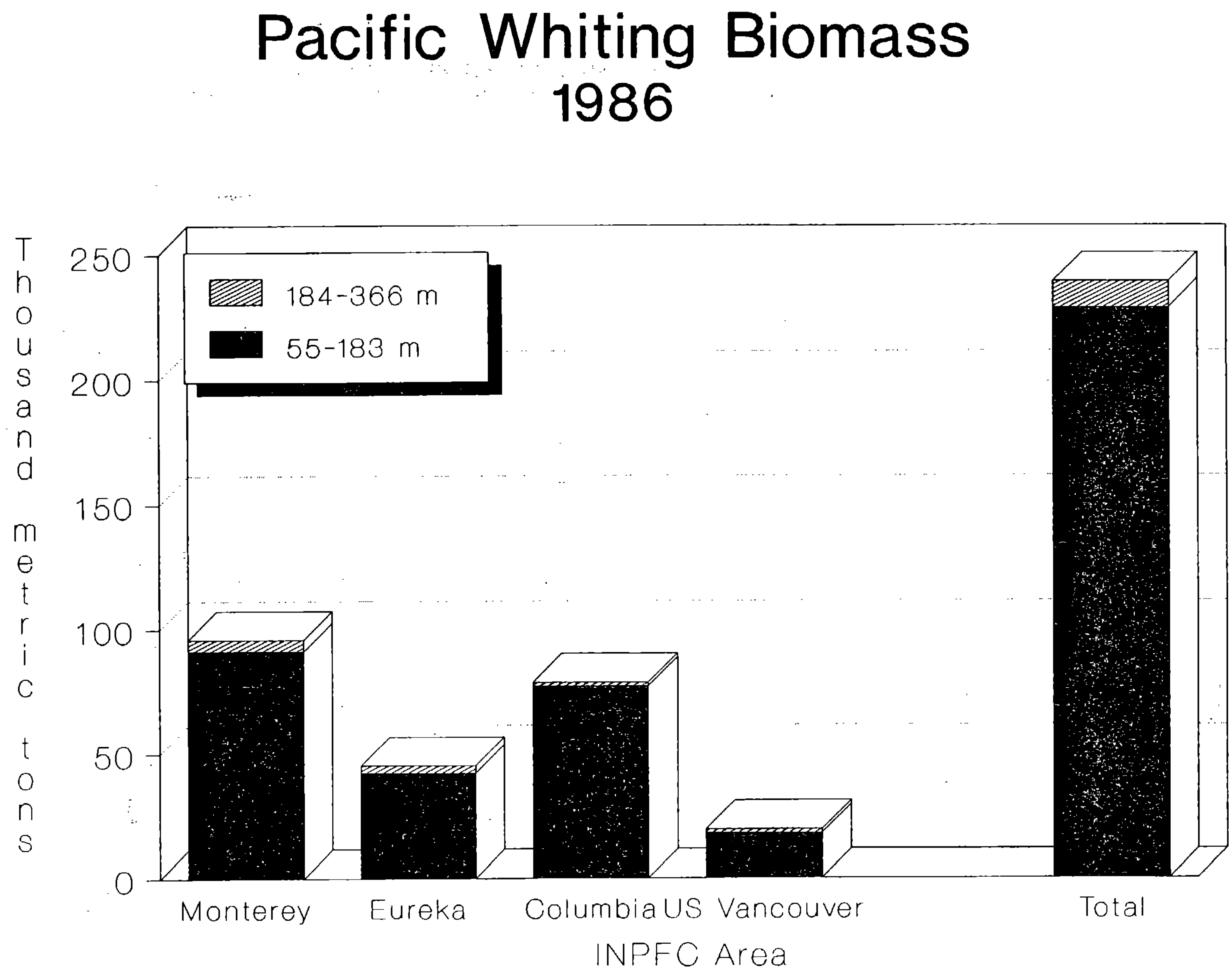

Figure 2. --Estimated Pacific whiting biomass by INPFC area and depth stratum based on 1986 bottom trawl survey data.

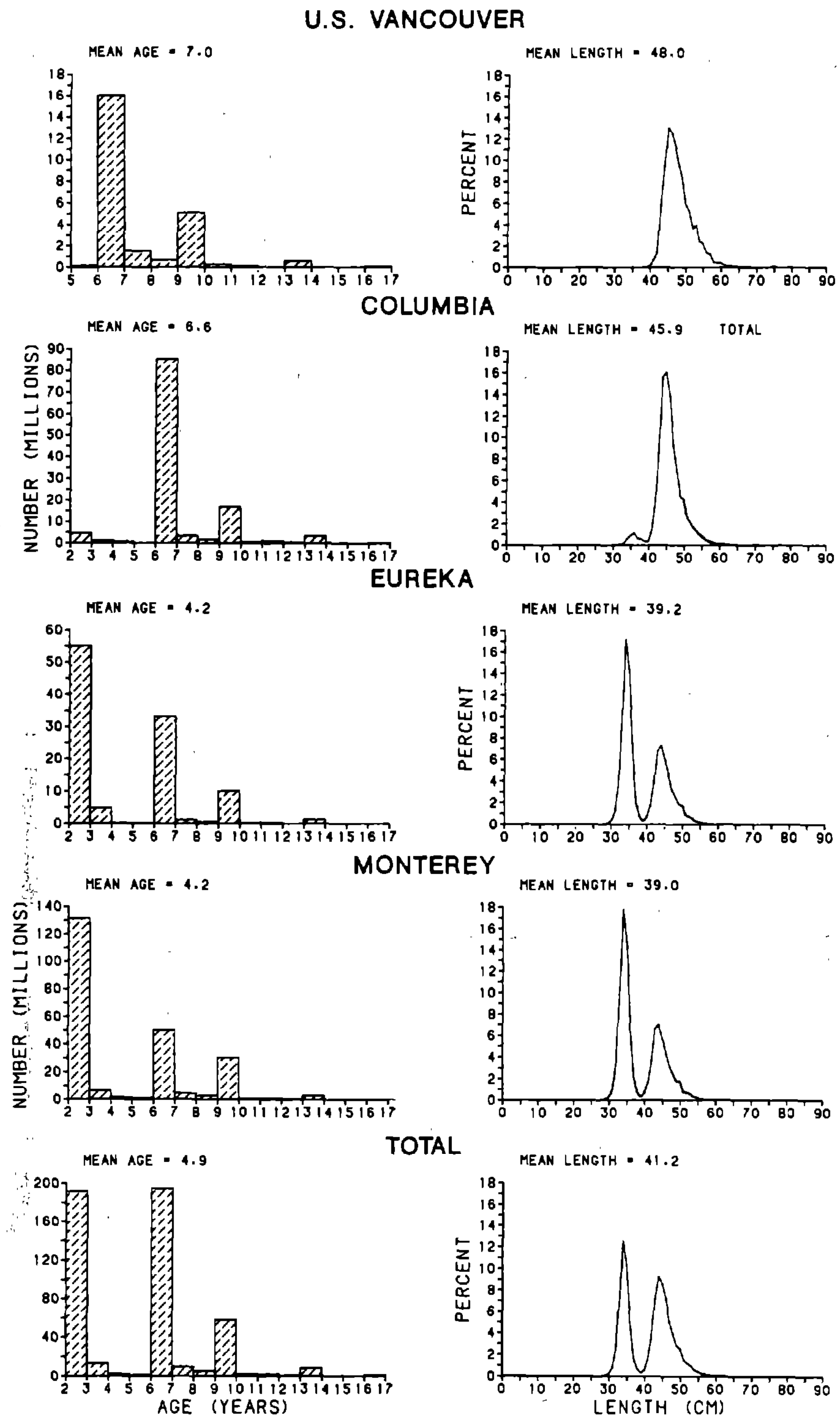

Figure 3.--Estimated Pacific whiting,population age and length compositions by INPFC area based on 1986 bottom trawl survey data.

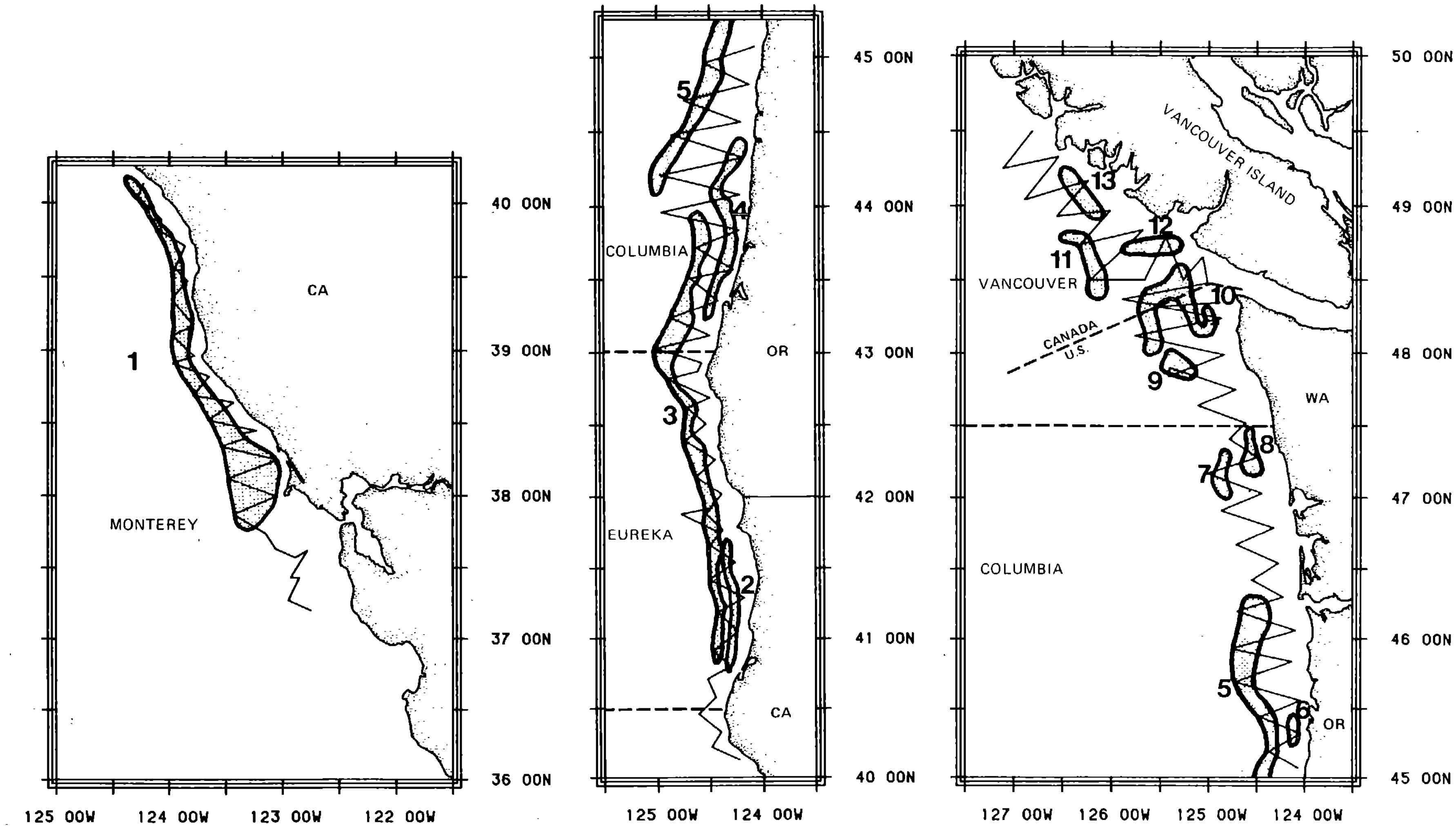

Figure 4.--Geographic distribution of Pacific whiting aggregations (outlined and shaded areas), determined from the 1986 acoustic/midwater trawl survey.

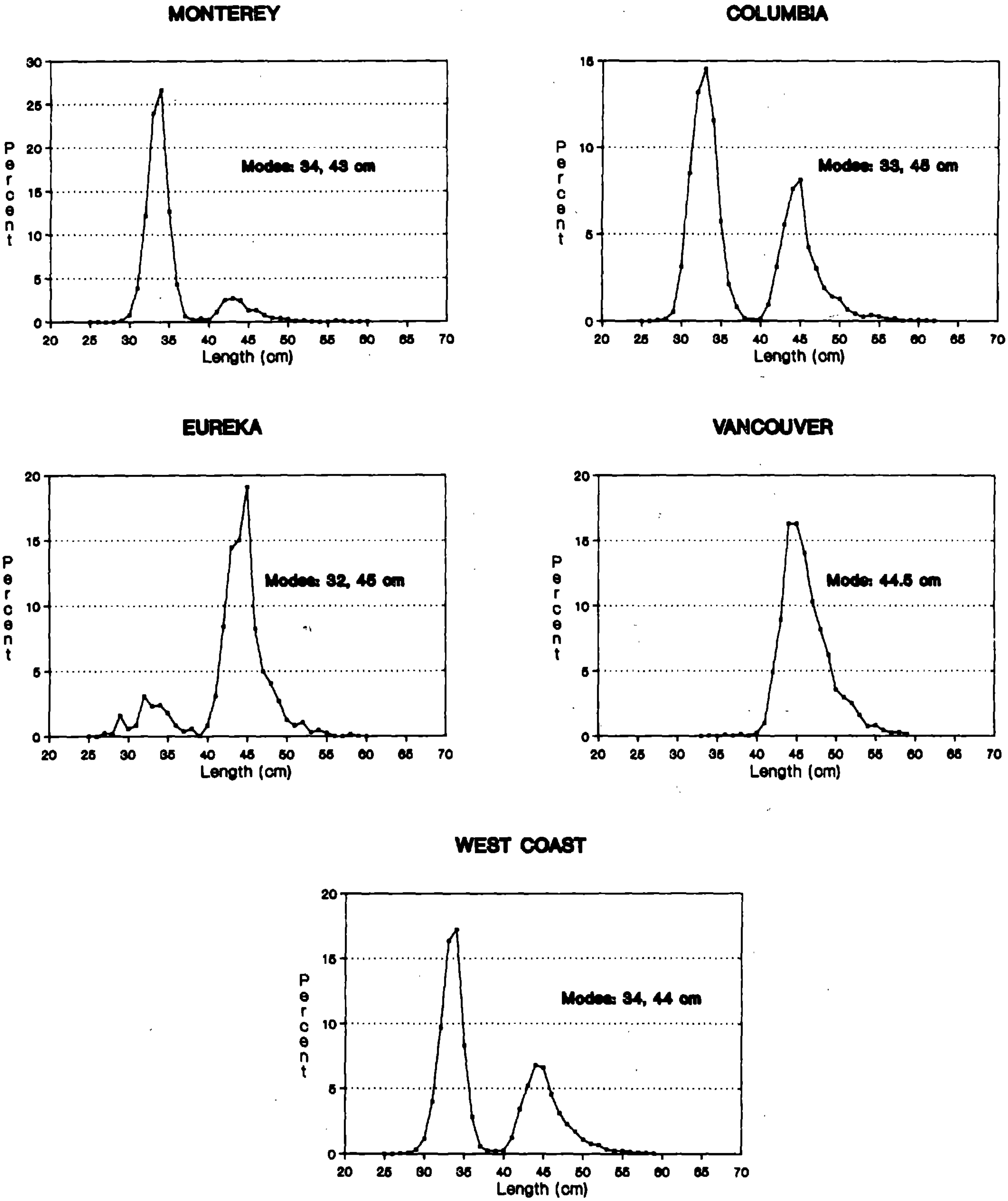

Figure 5.--Pacific whiting size compositions (sexes combined) by International North Pacific Fisheries Center area and summarized for the entire west coast, estimated from the 1986 acoustic/midwater trawl survey.

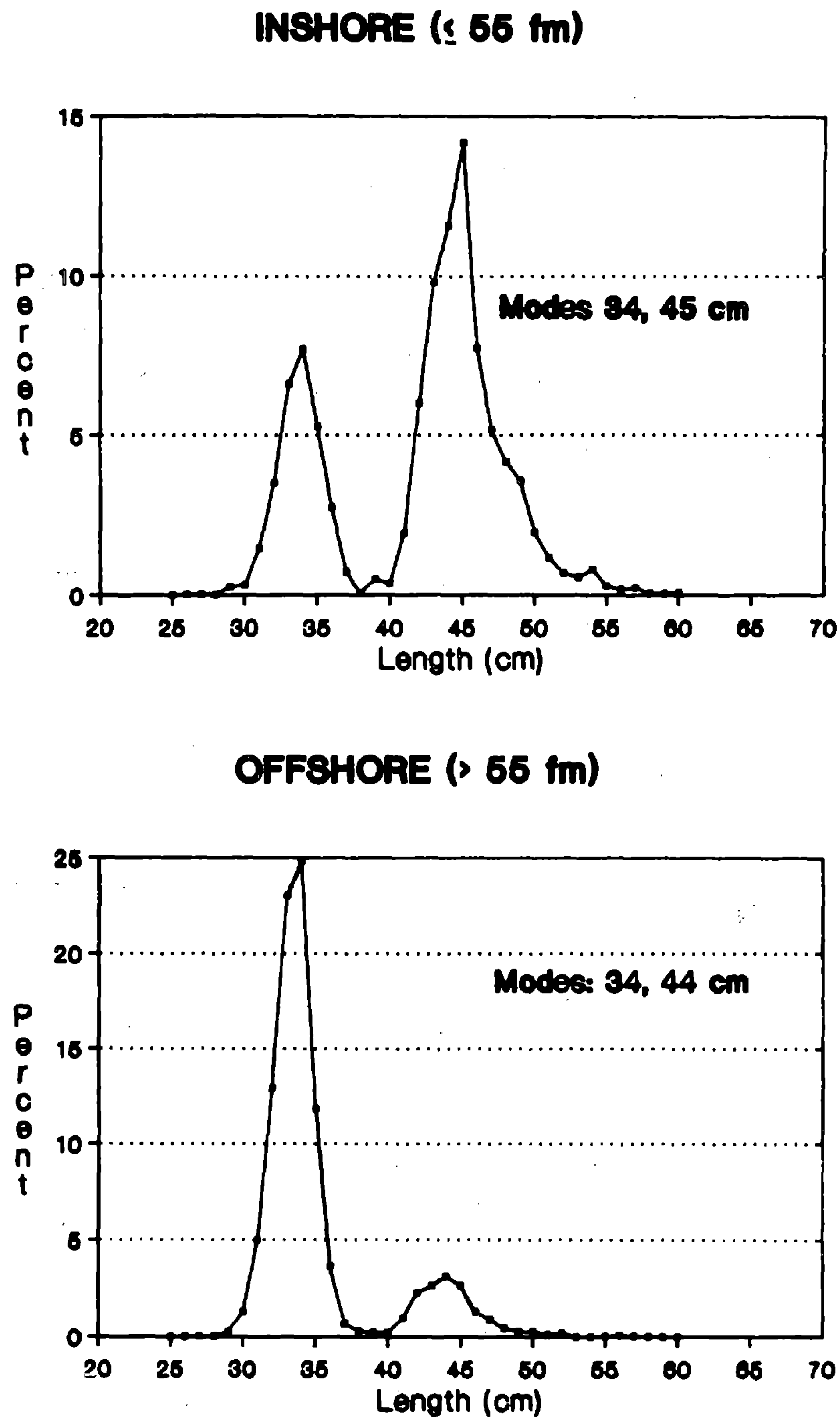

Figure 6. --Pacific whiting size compositions (sexes combined) for inshore (<55 fathoms) and offshore (>55 fathoms) fish south of the Columbia River, estimated from the 1986 acoustic/midwater trawl survey .

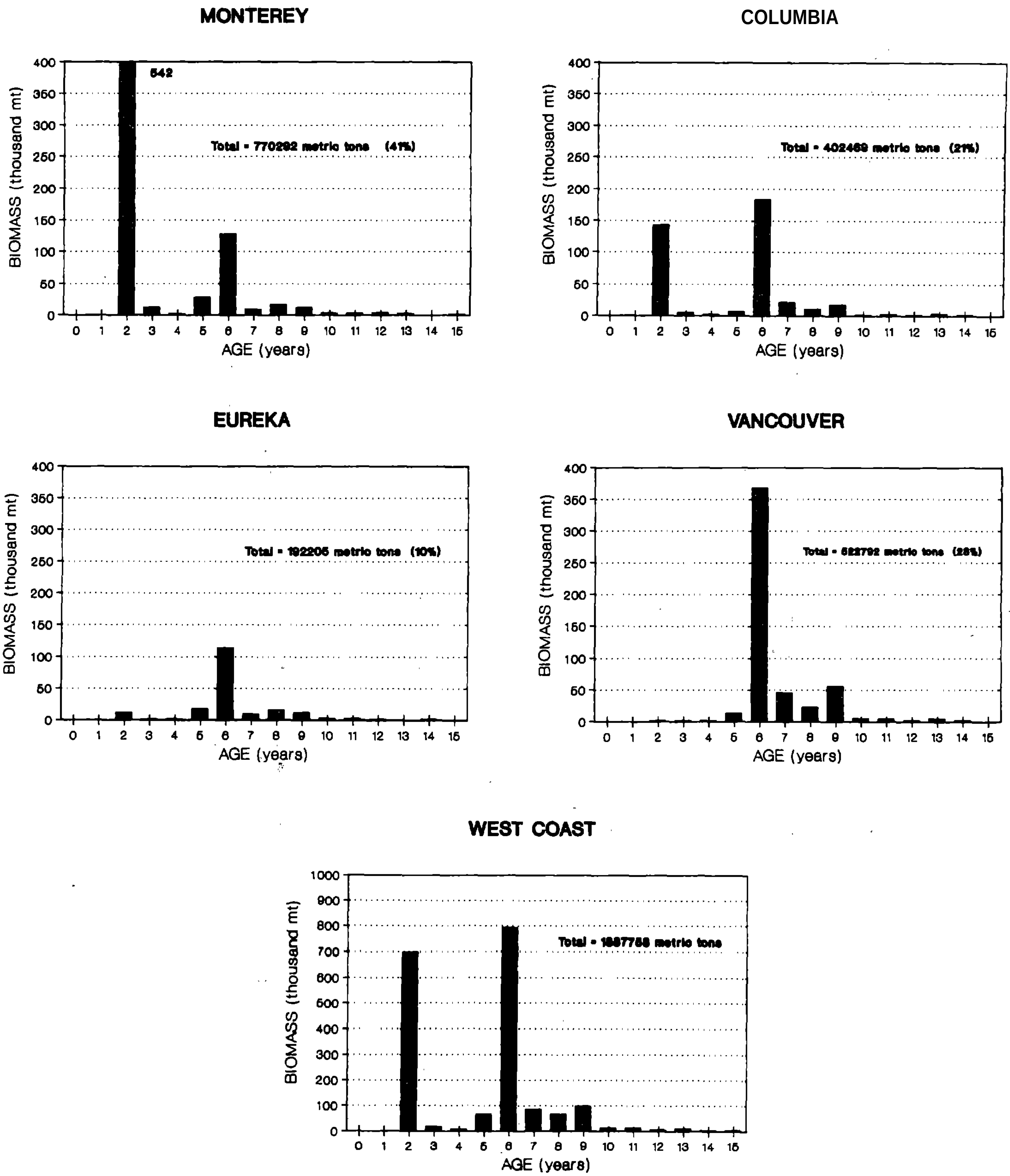

Figure 7.--Pacific whiting biomass/age compositions by International North Pacific-Fisheries Center area and summarized for the entire west coast, estimated from the 1986 acoustic/midwater trawl survey.

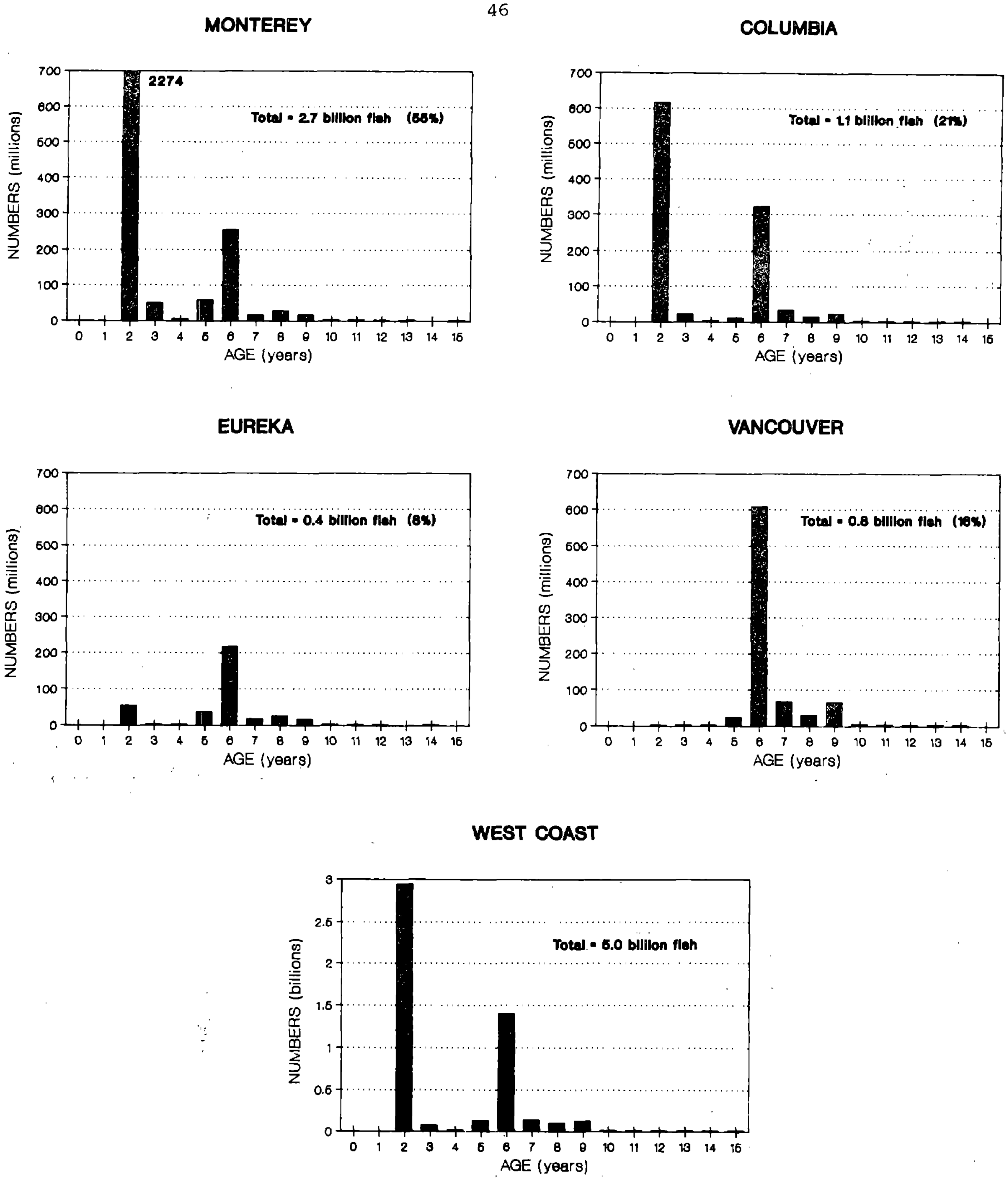

Figure 8.--Pacific whiting population numbers-at-age compositions by International North Pacific Fisheries Center area and summarized for the entire west coast, estimated from the 1986 acoustic/midwater trawl survey.

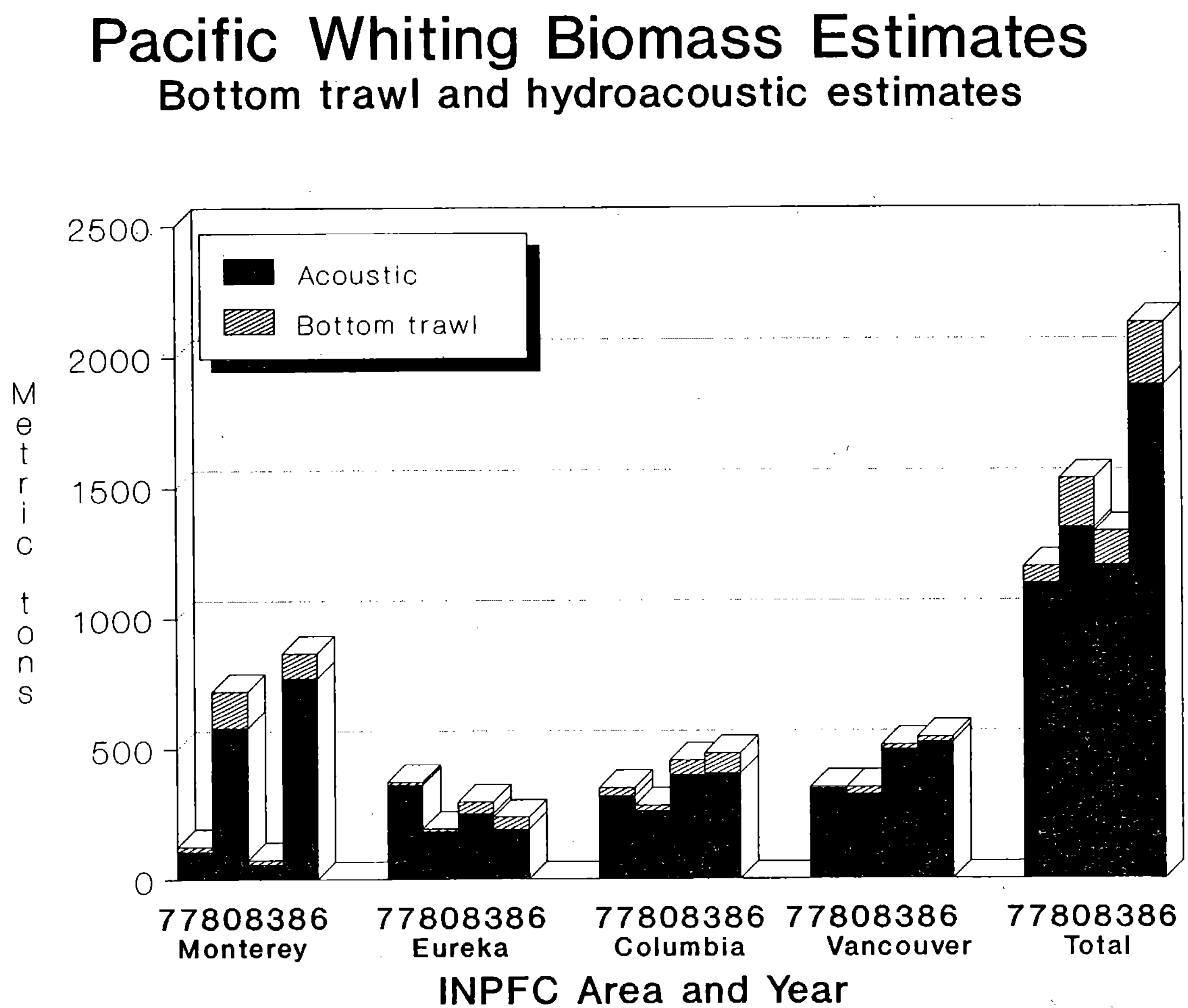

Figure 9.--Estimated total Pacific whiting biomass by year and INPFC areas (estimates based on bottom trawl surveys in the International North Pacific Fisheries,Center (INPFC) area in 1977 and 1986 are for the U.S. portion only).

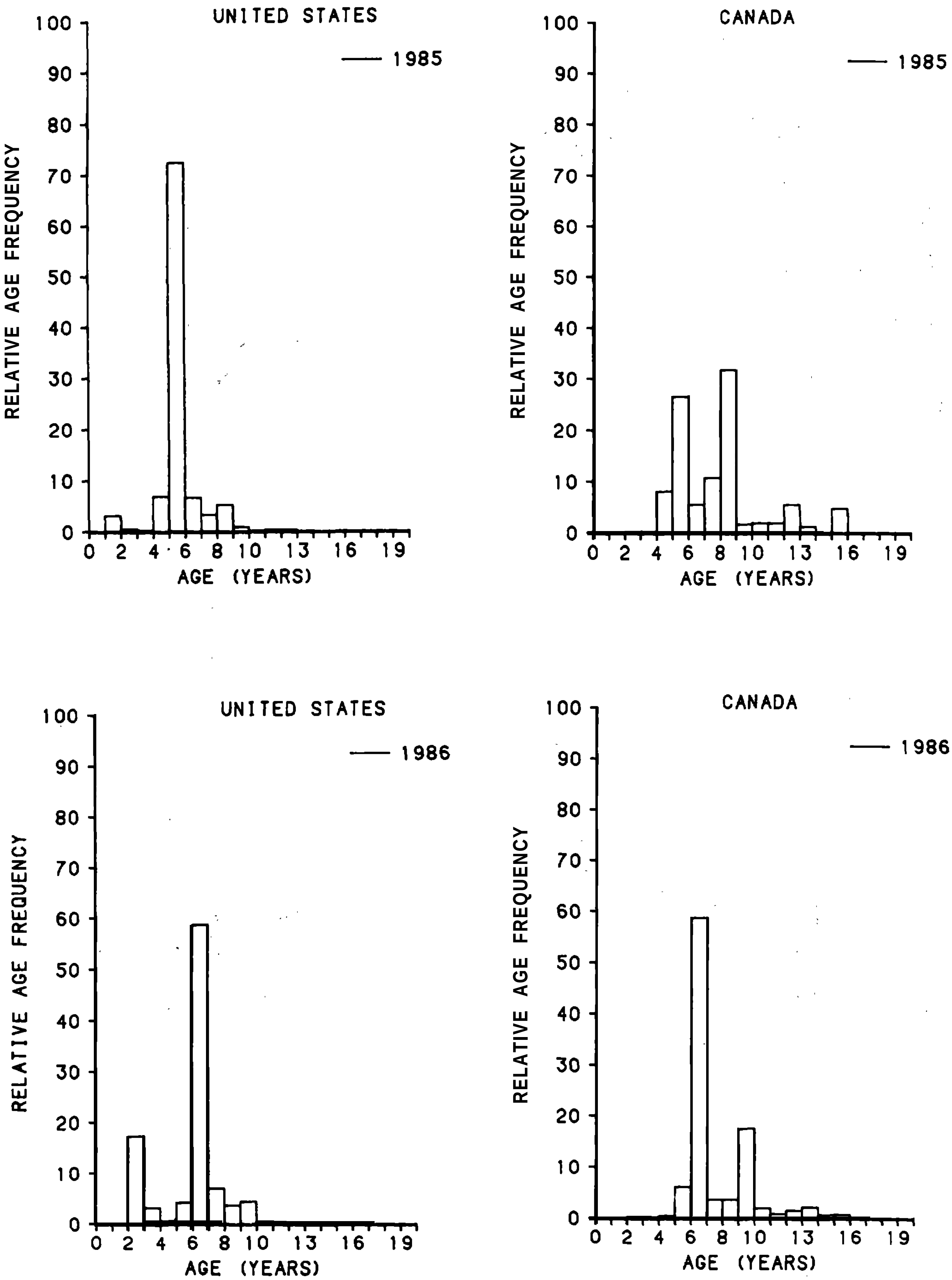

Figure 10.-- Percent of catch at age of Pacific whiting in U.S. and Canadian waters, 1985-86

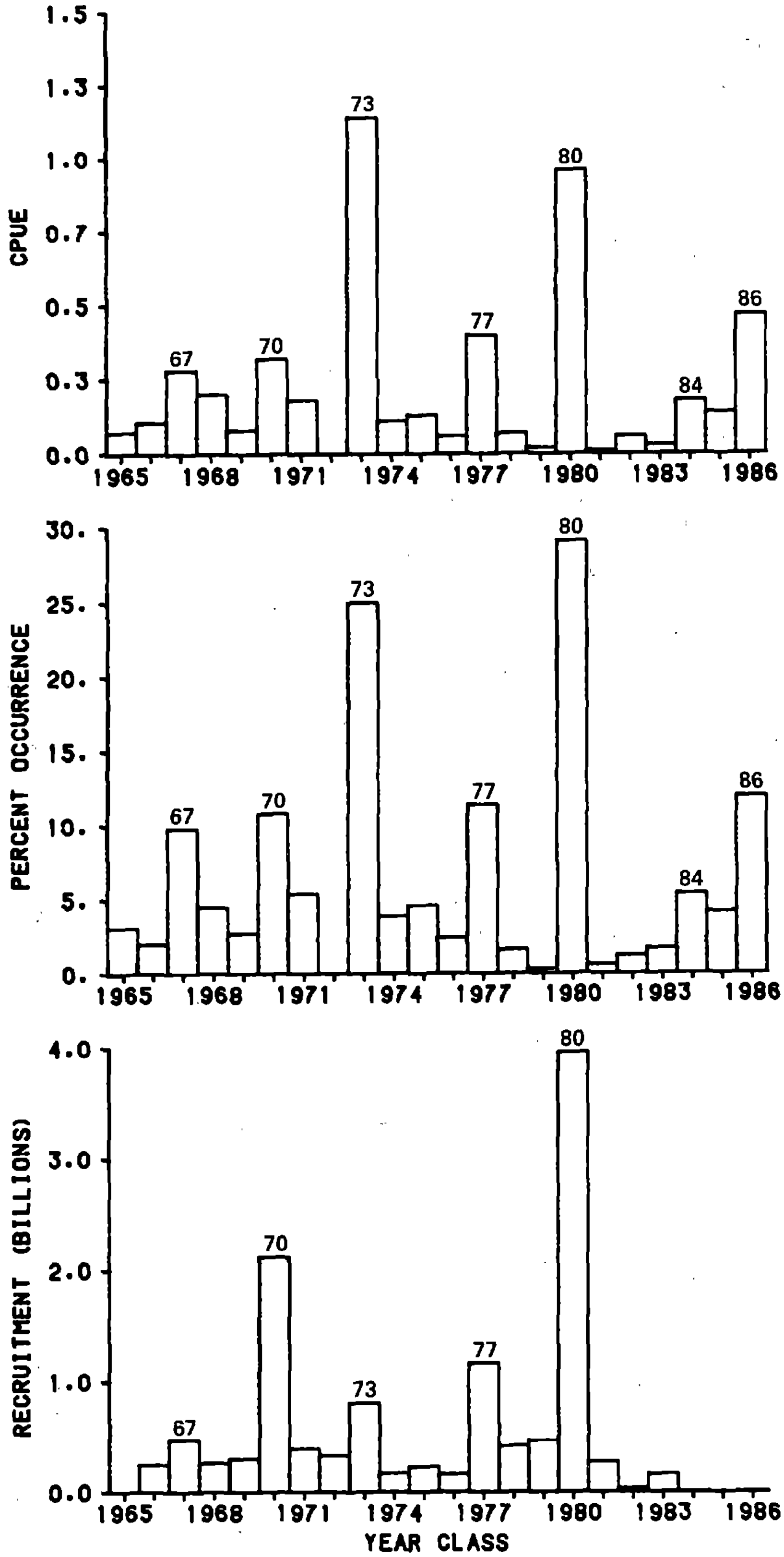

Figure 11 .--Indices of Pacific whiting year-class strength from age-0 surveys and the adult fishery.

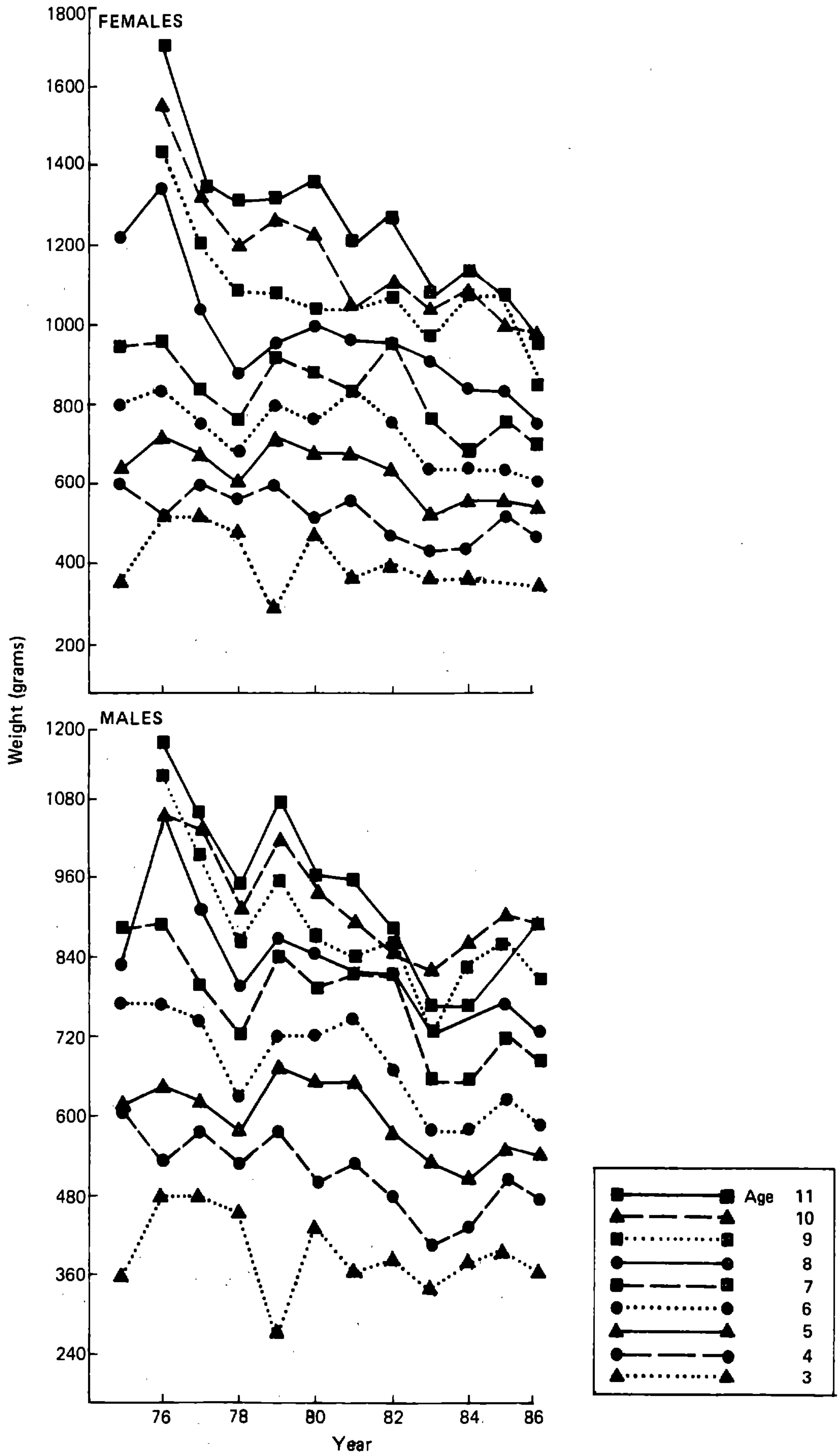

Figure 12. --Annual mean weight-at-age for male and female Pacific whiting 1975-86 based on samples from U.S. waters only.

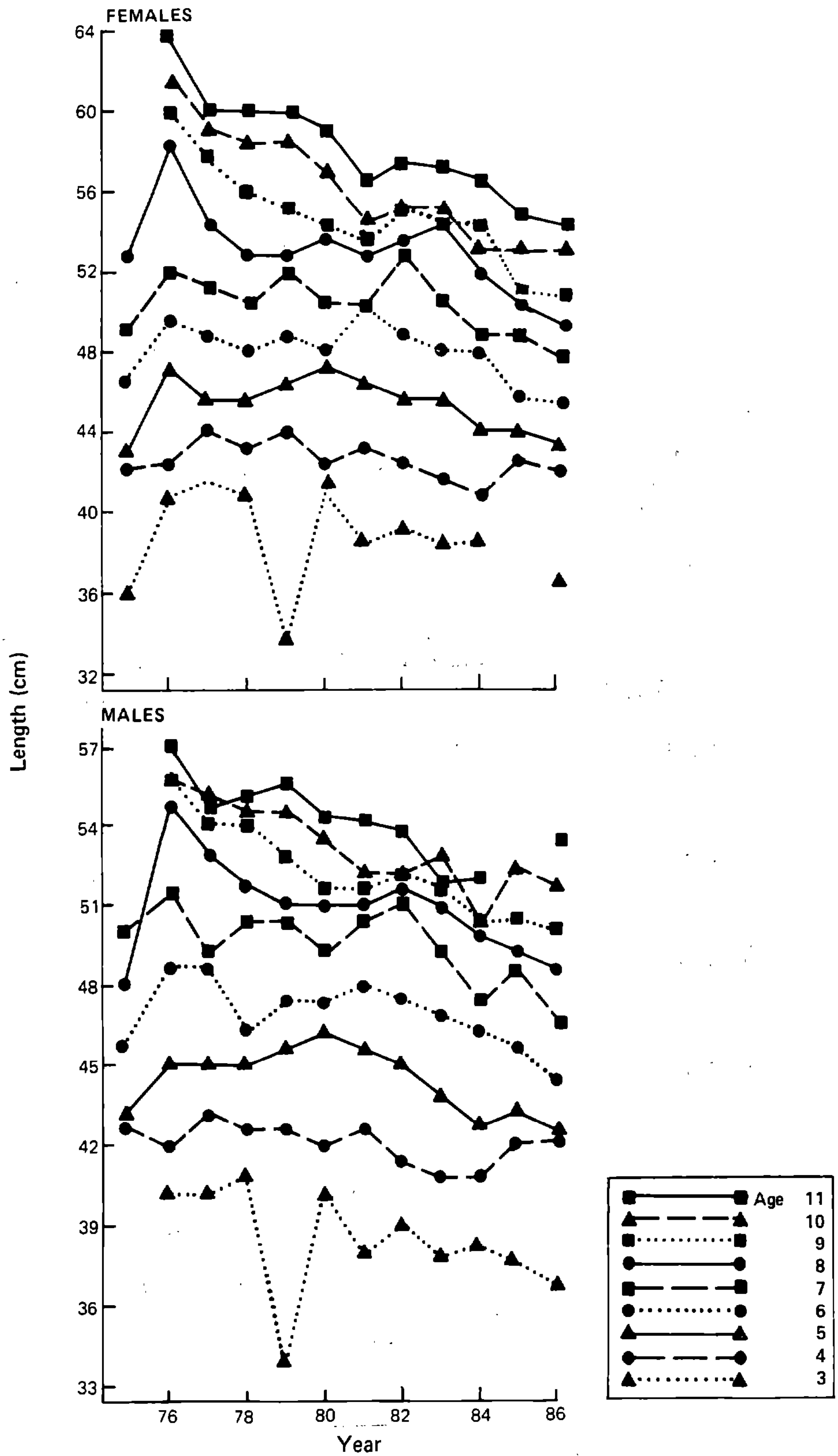

Figure 13.--Annual mean length-at-age for male and female whiting 1975-1986 based on samples from U.S. waters only.

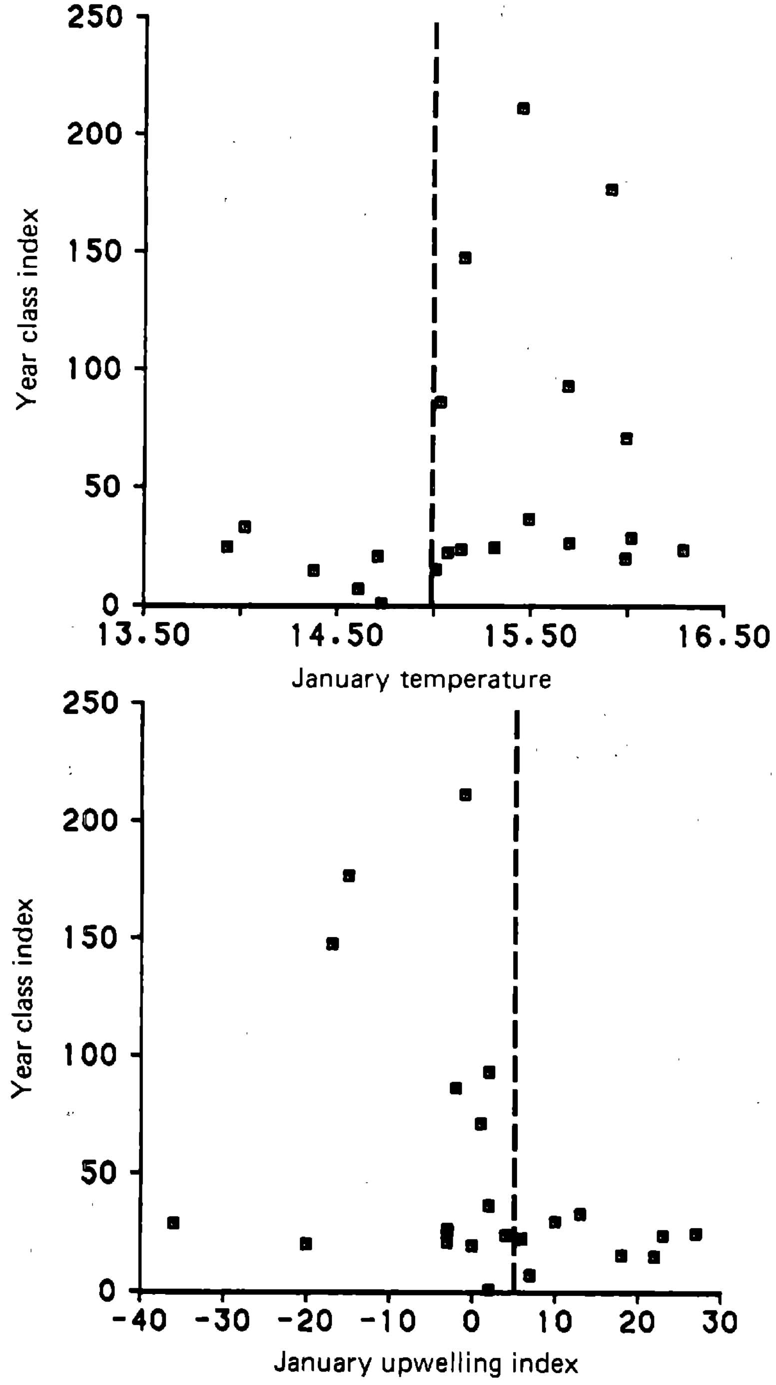

Figure 14. --Pacific whiting year-class index (1960-82) as related to upwelling and temperature indices at the time of spawning 36°N lat., January.

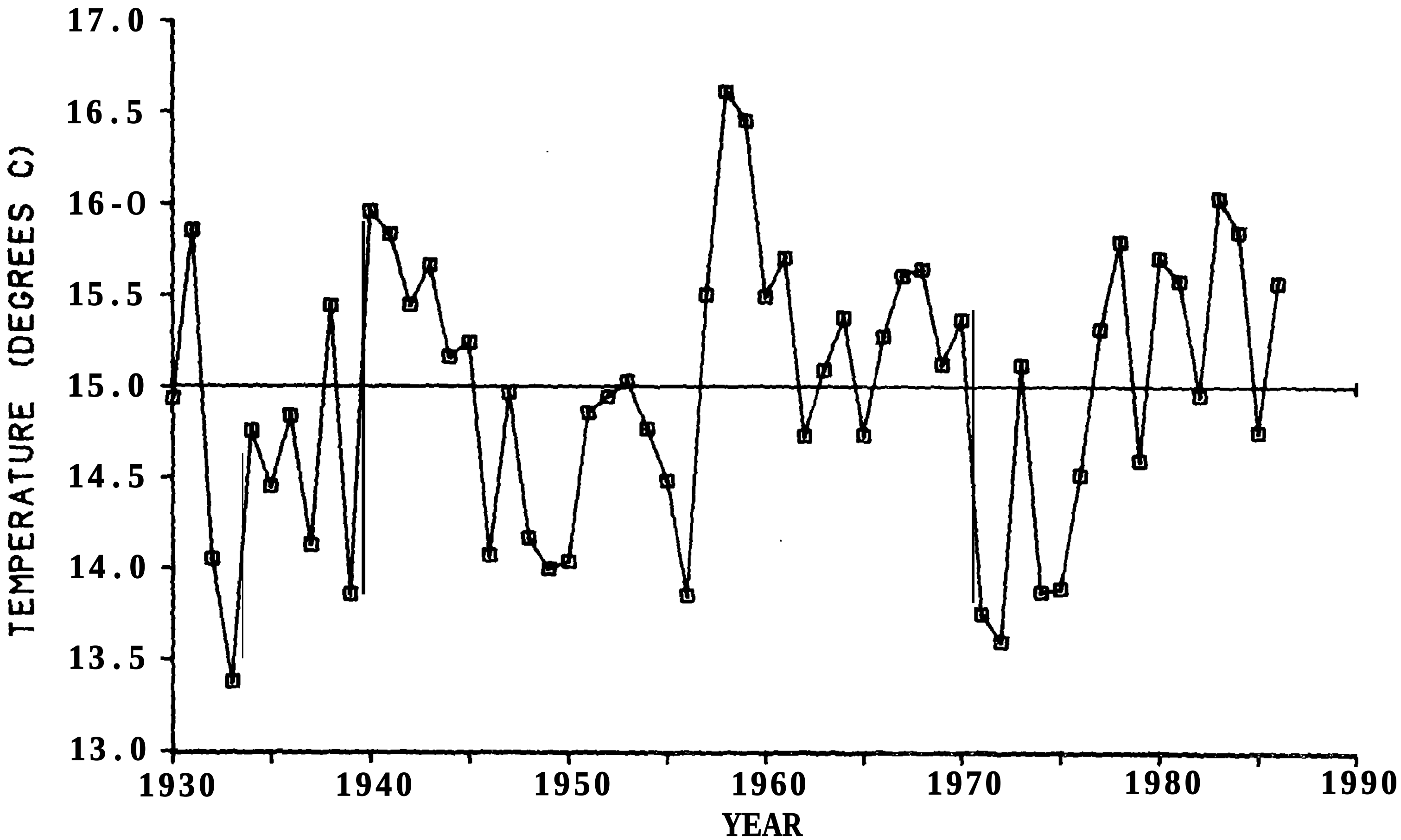

Figure 15. --The 1931-85 mean January through March sea surface temperature in Los Angeles Bight.

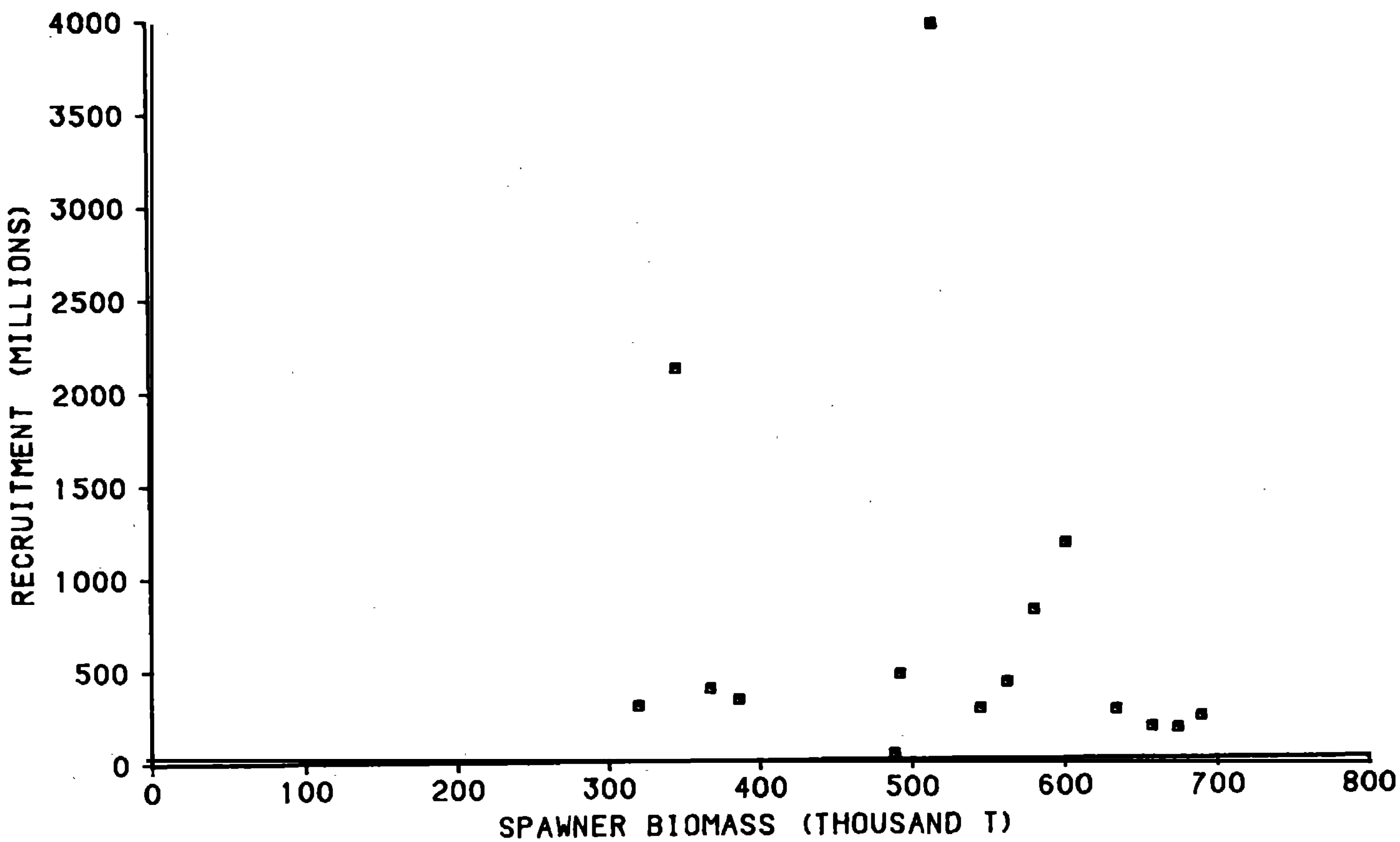

Figure 16.--Recruitment per spawner biomass of Pacific whiting,1967