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Status of the Coastal Pacific Whiting Resource in 1993

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ABSTRACT

This report assesses the status of the coastal Pacific whiting (Merluccius productus) resource in 1993. It reviews recent developments in the Pacific whiting fishery, tabulates and analyzes the 1992 catch statistics, reports on the 1992 triennial acoustic/midwater trawl and bottom trawl surveys of Pacific whiting, describes a stock synthesis model application using catch and survey data from 1965 to 1992, and presents yield options for 1994-96. The U.S. and Canadian harvest of Pacific whiting in 1992 was 295,189 metric tons (t). In 1993, the yield is expected to be 203,000 t. Assessment surveys conducted during summer of 1992 by the National Marine Fisheries Service (NMFS) and the Canada Department of Fisheries and Oceans resulted in estimates of population abundance considerably in excess of forecasts based on earlier surveys and models. Population biomass was estimated by the coastwide NMFS acoustic survey as 2.557 million t, more than double the acoustic estimate of 1.264 million t in 1989. The 1992 acoustic survey was conducted with a new echo-integration system and had a wider areal coverage than previous assessments. However, the population biomass estimates made with the new system still depend on the acoustic target strength of Pacific whiting, which continues to have a large amount of uncertainty associated with it. 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 in 1987 and has been declining steadily since that time. The biomass of age 3 and older fish in 1992 was estimated to be 3,055 million t. The recruitment abundance of the 1989 and 1990 year classes were estimated at 0.233 and 1.999 billion fish respectively, indicating that the 1989 year class is a weak year class, while the 1990 year class is close to the average 1977-92 recruitment of 2.170 billion age-2 fish. Indications from the 1992 assessment

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surveys and preliminary data from the 1993 fishery are that the 1991 year class is also average in size. The effect of uncertainty in the acoustic target strength estimate was examined by comparing stock synthesis runs using a target strength of -35 dB/kg (the standard value) and a more conservative target strength of -33.5 dB/kg. The estimated 1992 biomass for a target strength of -33.5 dB/kg is 2.317 million t, 25 % lower than the estimated biomass for a -35 dB/kg model. Recruitment estimates and fishery selectivity coefficients from the stock synthesis model were used with an age-structured simulation model to estimate sustainable yield. A deterministic version of the model was used to forecast yields for 1994-96. 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 set 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 1994, the potential total yield is calculated to be 325,000 t at a low harvest rate, 450,000 t at a moderate harvest rate, and 555,000 t at a high harvest rate. The dependence of our recommendations on one acoustic biomass estimate is an important consideration in setting short-term yields from the fishery. It seems reasonable to require at least two corroborating surveys before substantially increasing the potential yields for a fishery. For this reason, we recommend a low harvest rate for 1994-96. If recruitment remains near the 1960-92 median recruitment of 0.941 billion fish, the outlook for the immediate future is for a fairly rapid decline in annual yield in 1995 and 1996. The recruitment of a strong year class to the fishery would substantially increase the projected yields.

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INTRODUCTION

Surveys of Pacific whiting (Merluccius productus) conducted during summer of 1992 by the National Marine Fisheries Service (NMFS) and the Canada Department of Fisheries and Oceans (DFO) resulted in estimates of population abundance considerably in excess of forecast abundance based on earlier surveys and models. The acoustic survey by NMFS had a wider areal coverage, both offshore and to the north of earlier surveys. The Simrad EK-500 echo integration system used for this survey was better able discriminate less dense aggregations of fish, and could integrate echo sign closer to the bottom than previous systems. Acoustic estimates by DFO in the Canadian zone were generally consistent with biomass estimates by the NMFS surveys and were more than twice as high as any previous estimate of biomass in the Canadian zone. Despite these higher biomass estimates, survey and fishery age composition samples were consistent with a scenario that showed the population reaching a peak biomass in 1987 when the strong 1980 and 1984 year classes approached their maximum biomass, followed by a series of recruitments of weak or moderate year classes and a declining trend in population biomass. The primary objective of this assessment was to construct a model of the Pacific whiting population that was consistent with both the population abundance estimates of the 1992 surveys and information from earlier surveys and the commercial fishery.

The first major section of this report describes the 1992 coastal Pacific whiting fishery. The following section of this document describes the 1992 NMFS triennial trawl and acoustic surveys. The estimate of natural mortality is reconsidered in light of the new information gathered during the surveys. Additional sections of this report describe the application of a stock synthesis model for population assessment, reconstruct an historical time series of recruitment and population biomass estimates back to 1960, and present yield options for 1994 and forecast short-term trends in yield.

The 1992 Pacific Whiting Fishery in the U.S. Exclusive Economic Zone

The Pacific whiting fishery in the U.S. Exclusive Economic Zone (EEZ) continued its rapid evolution in 1992. As in 1991, all fishing and processing was done by American vessels or facilities. The offshore fleet of factory trawlers and motherships accounted for 73% of the U.S. catch in 1992. The most important development in 1992 was the expansion of shore-based processing capacity and landings, which accounted for 27 % of the total U.S. catch. An Acceptable Biological Catch (ABC) of 232,000 metric tons (t) was recommended for the coastal Pacific whiting stock in 1992. U.S. managers allocated 208,800 t or 90 % of the total ABC to the U.S. Pacific whiting fisheries, while Canadian managers allocated 90,000 t to Canadian Pacific whiting fisheries, so that 30% of the expected U.S. and Canadian harvest would go to Canadian fisheries. In the U.S. EEZ, the allocation was further divided into an allocation for at-sea processor vessels of 98,900 t, an allocation of 80,000 t for shore-side processors, and a 30,000 t reserve for use later in the season. To minimize Pacific salmon bycatch, at-sea processing was prohibited south of 42°N Lat. Additional regulations prohibited fishing between midnight and one-half hour after official sunrise and in the Kalamath and Columbia River Conservation zones. A trip limit of 2,000 pounds was also instituted for Pacific whiting caught inside the loo-fathom (fm) contour in the Eureka International North Pacific Fishery Commission (INPFC) region.

The offshore fishery, involving both factory trawlers and motherships, began on 15 April. Participation in the fishery consisted of 21 vessels with the ability to process catch. On a typical week, 12-15 vessels operated solely as catcher/processors, 3 operated solely as motherships, and 3-6 operated in both capacities. Aggregate weekly catches averaged 30-40,000 t. The offshore fishery closed on 5 May when the initial allocation was reached, for an opening of 21 days. Releases of

30,000 t in September and 25,000 t in October from the reserves allocation resulted in fisheries involving l0-15 vessels lasting for less than 2 weeks each.

The shore-based domestic fishery for Pacific whiting expanded substantially in 1992. The total shore-based domestic landings were 56,128 t, more than two times larger than the previous highest annual landings. The leading ports were Newport, Oregon (38,288 t); Astoria, Oregon (10,662 t); Crescent City, California (4,418 t); Ilwaco, Washington (1,954); and Eureka, California (512 t). The fishery based in Newport began in April and continued to October. Landings at Newport averaged 6,200 t per month from May to October. At Astoria, the monthly landings continued at a constant rate until the fishery closed in October. Farther south, at the northern California ports of Eureka and Crescent City, landings were high in May and June, but in, July the landings declined substantially and never recovered. Satellite images of sea surface temperature showed a residual mass of warm water from the 1992 El Nino between Cape Mendocino and Cape Blanco that persisted through most of the summer. Furthermore, fisherman reported difficulty in finding fish of acceptable size, suggesting that the bulk of the adult population had migrated farther north. The total U.S. catch in 1992 was 208,817 t, with Canadian fisheries adding another 86,370 t. The total yield of 295,187 t in 1992 was the third largest since the inception of the fishery (Table 1).

For 1993, U.S. and Canadian assessment scientists recommended a coastwide acceptable ABC of 178,000 t. In the absence of 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 142,000 t, 80% of the total ABC. Canadian managers set the Canadian allocation at 61,000 t, so that the Canadian allocation would make up 30 % of the combined U.S. and Canadian catch. Consequently, the combined U.S. and Canadian catch in 1993 is expected to exceed the ABC by approximately 14%.

Geographic Patterns of Fishing Activity

In April and May, fishing was concentrated in three areas: 1) in deep water offshore of Cape Blanco, 2) immediately to the south of Heceta Bank, and a band following the 200 m depth contour from the mouth of the Columbia River to Cape Flattery (Fig. 1). The concern that restricting offshore processing to north of 42°N latitude would adversely affect catches early in the year did not prove to be a problem. In September and October, fishing occurred farther north, mostly in waters offshore of Washington. Most of the catch in October came from the Vancouver INPFC region directly off the mouth of the Strait of Juan de Fuca. With openings lasting less than 2 weeks, Seattle-based catcher/processors and motherships did not have a strong incentive to search to the south for catches with desirable characteristics; for example, low bycatch rates of salmon and rockfish. An additional factor that may have contributed to the northern concentration of fishing in the fall openings is that the acoustic survey in August detected extremely dense aggregations of Pacific whiting in this area which may have persisted until September and October.

Information on fishing locations for the shore-based fleet is not yet available from all state agencies. However, the Oregon Department of Fish and Wildlife maintains an up-to-date logbook database which records trawl positions. Figure 2 shows the reported trawl locations for shore-based vessels targeting on Pacific whiting. Fishing tended to occur close to the ports of Newport and Astoria, where most of the fish was landed. The trawl positions tended to be concentrated near or inshore of the shelf break in somewhat shallower water than the offshore fleet typically operates. Since fishing by the offshore fleet occurred primarily to the north and south of the shore-based fleet, there was likely little interaction between the two fleets, though there is no certainty that this situation will continue in the future.

Age Composition by Area and Fishery

Estimates of catch at age for the offshore fleet in 1992 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 Eureka INPFC region, lat. 40°30'N to lat. 43°00'N (In 1992, fishing occurred only north of lat. 42°OO'N); 2) 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 3) 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. Temporal strata defined were 1) early (April-May) and 2) late (September-October). No spatial strata were defined for the second temporal strata because most of the catch occurred in the VNC region.

All foreign vessels in the Canadian whiting fishery carried fisheries observers in 1992. The Canadian catch at age statistics were compiled from random samples of otoliths collected by observers. The shore-based landings were sampled by port samplers. The average number of otoliths aged per year is approximately 3,000.

Figure 3 shows the estimated catch at age for Pacific whiting by the offshore fishery in the three spatial strata in the U.S. zone and the catch at age from the Canadian zone. The separate panels of Figure 3 show the estimated catch at age in the VNC area for the early time period (April-May) and the late time period (September-October). The general pattern of increasing age from south to north, noted in previous assessments, is again evident in the catch at age in 1992. The age-12 fish were considerably more abundant in the catch in the Canadian zone than in the areas in the U.S. zone to the south. A comparison of the early and the late catch in the VNC region reveals some unusual features. The relative magnitude of the 1987 and 1988 year classes is quite different, with the 1988 year class much more prominent in the catch late in the year. In addition, 2-year-old fish and a small number of l-year-old fish were present in the fall catch at age. Their relatively late arrival at this latitude suggests that their northward migration proceeded at a slower pace than the older fish in 1992, corroborating earlier analyses that identified a delayed northward migration of the younger fish (Dorn 1991).

The shore-based fishery was sampled by port samplers at Newport, Crescent City, and Eureka. A stratified random sampling design was used to estimate the age composition of the landed catch. Table 2 gives the Pacific whiting catch at age by sex and fishery in 1992. The 1984 year class (g-year-old fish) was the most common year class in the fishery, accounting for 37 % of the total catch in numbers. Presently, the 1980 year class is beginning to be displaced by the 1987 and 1988 year classes. The 1988 year class is roughly half as abundant as the 1987 year class in the catch (4- and 5-year-old fish). The presence of the l-year-old 1991 year class in the catch is encouraging since the catch of l-year-old fish typically occurs only when the year class is at above average abundance. 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 3 gives the estimated U.S. fishery catch at age for 1977-92 (Compiled from a database maintained by the U.S.. 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. con-n-nun., March 1993).

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 1992 estimates of mean length at age in the U.S. offshore fishery were compiled using the procedure described in Dorn and Methot (1990). Table 4 contains the 1992 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 1992). Also given in Table 4 are bias-corrected a and b coefficients of an exponential length-weight relationship of the form $w = \boldsymbol{a}\ l^{b}$ (Ricker 1975), estimated using linear regression.

A simple way to examine current trends in growth is to plot the growth trajectory of the strong 1980, 1984, and 1987 year classes (Fig. 4), which have dominated the catches in recent years. The 1984 and the 1987 year classes in 1992 were both larger than the 1980 year class at the same age. The 1987 year class was slightly larger than the 1984 year class at the same age, indicating that length at age has increased slightly in recent years.

1992 ASSESSMENT SURVEYS OF PACIFIC WHITING

Triennial Acoustic-Midwater Trawl Survey

Scientists at the AFSC conducted an echo integration-trawl survey of Pacific whiting aboard the NOAA ship Miller Freeman from 7 July to 19 August for a total of 42 sea days.

ended in Seattle, Washington. The area of operations extended along the west coast of North America from central California to the north end of Vancouver Island, British Columbia, Canada. Canadian scientists aboard the W.E. Ricker conducted a survey of the Pacific whiting population within their waters shortly before the Miller Freeman entered Canadian territory. Side-by-side operation conducted by the two vessels, near central Vancouver Island, to determine the comparability of the two acoustic data collection systems. The major objective of the survey was to obtain data for determination of the distribution, numbers, and biomass of Pacific whiting along the West Coast.

Acoustic Data Collection System

Acoustic data were collected with a Simrad EK-500, 38 KHZ echo sounder-echo integration system. Data were stored and later processed on a Sun workstation using a Simrad BI-500 echo integrator and target strength analysis system. All processed data were stored in an Ingress relational database. The echo sounder was equipped with a split beam transducer which is permanently housed on the ship in a retractable centerboard. The transducer was lowered during operation to about 3.7 m below the ship's keel (9.1 m total depth). This configuration allowed reliable data collection during operations such as trawling, running transects, or passively drifting. The acoustic data collection system was housed in a portable van mounted on the weather deck of the ship.

Acoustic System Calibration

Calibration was accomplished by suspending a standardized copper sphere with known backscattering characteristics below the transducer. Calibration consisted of adjustment of various system parameters to produce integration and target strength measurement values equivalent to the corresponding theoretical values for the standard sphere. The standard copper sphere (60.0 mm diameter; -33.6 dB target strength) calibrations were conducted in Port Susan, Washington, on 8 July and in Kendrick Inlet, Vancouver Island, on 13 August. The vessel was anchored fore and aft in both instances to minimize movement of the ship or the ball during data collection. Echo integration and split-beam target strength data were collected with the Simrad EK-500 system to normalize operation and to monitor long- and short-term drift. In addition, transducer directivity data were collected by moving the standard sphere throughout the main lobe of the beam to determine and monitor beam pattern characteristics. System calibrations were stable during this and several previous calibrations to within about + 0.2 dB. During the first week of the survey, a pre-processing algorithm problem was detected in a recently updated version of a manufacturer supplied EK-500 PROM (Programmable Read Only Memory). The PROM was replaced with the previous version on 15 July and an abbreviated sphere calibration was conducted in Drake’s Bay, California. No significant effect on the calibration of the system was observed.

Comparison of U.S. and Canadian Acoustic Systems

Side-by-side comparison of US and Canadian acoustic data collection systems, mounted on the Miller Freeman and the W.E. Ricker, respectively, were conducted during 10 August in an area near 48°45’N lat. 126°15 ‘W long., about 40 nmi west of Barkley Sound, Vancouver Island. Navigational instruments aboard the vessels were compared using radar range and bearing measurements to ensure that the position information was reliable. A total of 10 side-by-side transect pairs were run at vessel speeds of 8-9 knots. The leading position was alternated between the two ships. The trailing vessel maintained a position about 0.2 nmi astern and about the same distance to the side of the leading vessel. Transects ranged in length from 7-10 mni and were run east and west. Bottom depths ranged between 150 and 500 m. Pacific whiting abundance within the area ranged from moderately low to high densities. Results of the comparison indicated good agreement in estimated fish densities at most locations. Comparison of averaged fish densities along transects indicated that the Canadian equipment produced values somewhat higher than the U.S. system. The differences were inversely related to fish density and ranged from about 20-25 % at the lower values encountered during the experiment to nearly unity at the highest densities. A possible explanation for this relationship is that the Canadian system was more susceptible to noise than the U.S. system, resulting in a greater proportional error in low fish density areas. The Canadian system was calibrated prior to survey operations by measurement of system source level and receiving response using the facilities of an underwater acoustic calibration barge. No standard is available to simulate fish density, so it was not possible to determine the absolute accuracy of either system.

Survey` Design

The area surveyed for Pacific whiting (Fig. 5-6) extended along the North American west coast from 35°30’N lat. (San Luis Obispo, California) to 51° 15’N lat. (N. Vancouver Island, British Columbia). Acoustic data were collected in the Monterey INPFC area along a series of mixed zigzag and parallel tracklines and along parallel transects throughout the remainder of the area. Nominal transect spacing was 10 nmi except for the region between 48° and 49°N lat. where transect spacing was reduced to 5 nmi. More closely spaced transects were run within these boundaries in response to a request by Canadian scientists. The purpose of the closer transect spacing was to better define the distribution of Pacific whiting in the transitional area between U.S. and Canadian waters and also to more closely correspond to the survey pattern used by the Canadians. All transects were run between the 55 m (30 fm) and 457 m (250 fm) depth contours. Selected transects and those where fish sign was found at or near pre-determined transect outer end points were extended to deeper water. Survey operations were conducted during daylight hours to avoid contamination of Pacific whiting layers by other species which, during nighttime, move from near bottom or the surface into the water column. Ship speed was usually l0-12 knots. Echo sign could consistently be detected and echo integration data collected to within l-3 m of bottom, depending upon bottom depth and roughness.

Biological compositions of echo sign were identified and sampled using two gear types: a full-size midwater trawl for large fish and a bottom trawl for demersal and near-bottom fish. The midwater trawl was a modified Northern Gold 1200 midwater rope trawl (NET Systems, Inc.). It was constructed with ropes in the forward section and stretch mesh sizes ranging from 163 cm (64 inches) immediately behind the rope section to 8.9 cm (3.5 inches) in the cod end and was fitted with a 3.2 cm (1.25 inch) mesh cod end liner. Headrope and footrope lengths were 94.5 m (310 ft) between breastline attachment points. Tom weights (340 kg; 750 lb) were attached to the footrope 25 m (82 ft) to either side of its center point. The breastlines measured 79.4 m (260.5 ft). The net was fished in a bridleless configuration with the wings attached directly to the doors. Fish on or near bottom, and at times within the upper 100 m of the water column (fished in midwater), were sampled with a nylon Nor'eastern bottom trawl. Triple 54.8 m (180 ft) long dandylines were used. Net mesh sizes ranged from 12.7 cm (5 inches) in the body to 8.9 cm (3.5 inches) in the intermediate and codend; a 3.2 cm (1.25 inch) codend liner was used. Headrope and footrope lengths were 27.4 m and 32.0 m (90 ft and

105 ft), respectively, and the footrope was equipped with 36 cm (14 in) diameter roller gear. The rope trawl and the demersal trawl were fished using 1.8 m X 2.7 m (6 ft X 9 ft) steel V-doors weighing 1,000 kg (2,200 lb). Mouth openings and fishing depths of both trawl types were monitored with a (Furuno) headrope mounted, wireless net sounder system. Headrope to footrope openings while fishing averaged 26 m for the rope trawl and 7 m for the demersal trawl.

Trawl hauls were made on selected echo sign to provide information on Pacific whiting and to identify the biological composition of associated fish and other organisms. Standard catch sorting and enumeration procedures were used to process all catches. Each trawl catch was sorted in total unless it exceeded about It; representative splits of large catches were sorted. Total weights and numbers of individuals, by species, were determined for each catch. A subsample of manageable size (300-400 fish) was randomly selected from each catch for detailed examination, biological sampling, and data collection (e.g., size measurements, age structure collection, sexual maturity compositions, sex ratios, individual weights).

All survey operations pertaining to the assessment of Pacific whiting were conducted continuously during daylight hours (15 hours per day). Acoustic data, consisting of echo integrations and target strength measurements, were collected continuously throughout survey operations and during special studies. Echo integration data consist of measurements of the summed acoustic energy (echo intensity) reflected from fish detected within water volumes defined by the acoustic beam shape and consecutive depth layers throughout the water column. The measurements are automatically stored after each echo sounder ping (1 per second) in l-2 m depth bins. Post-processing of echo integration data, the selection of patches or layers of echo sign identified as representing target species, was accomplished to estimate the abundance (biomass/unit area) of Pacific whiting.

Post-processing of echo integration data was accomplished by use of a Simrad BI-500 analysis program operating in conjunction with an Ingress relational database. The database contains integration values for each echo sounder ping, stored within 500 contiguous depth cells of equal width, which extend over the particular depth range selected previously to data collection. In addition, the database stores 20 bottom locked cells which represent the 10 m of the water column nearest the seabed. The B1500 allows viewing of 5-mile sections of echo integration survey data as color echograms displayed on a workstation monitor. Portions of each segment of the integration data were selected by the user by drawing time and depth boundaries to enclose all echo sign judged to represent a target species. The selected data were then classified as a particular species and a threshold was adjusted to eliminate excessive backscattering from small organisms or noise. Echo integration values were then summed into cells representing average backscattering area (S_a) for 0.5 nmi distance segments along each transect. The data were saved into a table within the relational database from which various reports can be generated. All valid transect data were analyzed in this manner. Considerable quantities of small scatterers (non-whiting biomass) were encountered throughout much of the water column in the Monterey, Eureka, South Columbia, and North Columbia INPFC areas. The S_v (volume backscattering strength) threshold value selected for use within these four regions was -58.5 dB. The threshold value selected for all of the more northerly areas, where small scatterers were much less abundant, was -69.0 dB.

A pre-processing algorithm anomaly was detected in a recently updated version of a manufacturer supplied EK-500 PROM (Programmable Read Only Memory) set near the end of the first week of survey operations. The problem was temporarily solved, as suggested by the manufacturer, by re-installing the old EK-500 PROM set. Direct remediation of the effect of the algorithm error on data collected during the first week of survey operations (transect 1-12) is not possible. This would require re-analysis of the original high-resolution (0.1 m) echo intensity measurements, which are not available. However, an indirect method was used to effect the best possible correction of the data using the limited amount of information available. The EK-500 accomplishes two similar tasks in parallel; it calculates average echo intensity values for each depth stratum reported to the Simrad B1500 as well as a similar set of calculations for printing as short reports on the paper echogram. The two algorithms are very similar, but operate independently. Fortunately, the algorithm that generated echogram reports was not flawed. Thus, regression analyses were used to derive a correction factor for the flawed data by comparing the results of the two algorithms for selected segments of data throughout the affected survey area. Functional regression analyses (Ricker, 1975) indicate a slope coefficient of about 0.5 for the regression of echogram density values on Simrad BI-500 reported values. Estimated biomass for transect 1-12, the survey data over which the correction was applied, amounted to about 48% of that in the Monterey INPFC area.

The total Pacific whiting biomass along the West Coast was calculated as the sum of estimated biomasses within all survey area segments. The estimated biomass within each segment was calculated as the product of average fish density, derived from echo integration data, and the area of the segment. Further, estimates of age- and length-specific numbers and biomass of fish within each geographical area were calculated, based on an age-length key, the length compositions from trawl catch data and an appropriate length-weight relationship representative of the area. Biomass at length for each area was calculated as the product of three terms: proportionate numbers at length from trawl haul catches, the average weight at length (L-W equation) and the total estimated biomass for the area. Total numbers of fish at length were calculated as total biomass at length divided by the average weight at length. A similar series of calculations was used to estimate biomass and numbers of fish at age. The age-length key was used to determine the size compositions at age. Individual fish length measurements taken from trawl catches in each geographical area were used to determine an overall length composition representative of that particular area. Individual trawl hauls represent only a portion of the fish within a geographical area and are not necessarily representative of the whole area. Thus, size compositions from each haul were weighted by the proportion of the total area biomass represented by the subarea or aggregation from which each trawl catch was taken. When more than one haul was made within a group of fish, the weighting factor was calculated as the proportion of the total biomass within that group, divided by the number of trawl catches taken within its boundaries. Subareas were identified on the basis of similarity of size compositions of fish in trawl catches taken within identifiable geographical boundaries.

Survey Results

A total of about 2,900 nautical miles of transect lines were run while continuously collecting echo integration (fish density) data during the West Coast Pacific whiting survey. Forty-eight trawl hauls were made during daytime throughout the survey period to identify echo sign and to collect specimen and biological data. In addition, 14 trawl hauls were made during nighttime hours to identify the biological characteristics of fish in proximity to sites where target strength measurements were collected. Trawl catch data (i.e., CPUE) were not used to scale or verify echo integration data. The data were used only to identify and categorize the species and size compositions of fish represented by the various layers and groups of echo sign encountered during the survey.

Target Strength Data Collection

Conditions were suitable for the collection of Pacific whiting target strength measurements on seven different occasions; all measurements were made at night. Trawl hauls were made immediately before and after each set of data were collected to determine the biological composition (size and species) of the fish. The percentages of Pacific whiting in the catches ranged from 78 to 100% and consisted of adult fish ranging in length from 40 to 64 cm. Analysis of the target strength data collected during the cruise did not yield enough information to indicate a more appropriate value for use in echo integration data scaling than the value used for this survey (-35.0 dB/kg). This target strength value has been used to scale echo integration data for previous acoustic surveys of Pacific whiting along the West Coast.

Distribution. Size. and Abundance

Pacific whiting were encountered in all of the surveyed strata between Point Sur, California, and the northern end of Vancouver Island, Canada. The youngest and smallest fish were found from San Luis Obispo to Cape Mendocino, California. Average sizes and ages of the fish were found to be progressively greater in the more northerly geographical areas covered by the survey. The geographical boundaries of the strata used during analysis of survey data are listed in Table 5 and the areas and the estimated Pacific whiting biomass within each are listed in Table 6. The distribution of estimated biomass along each transect throughout the surveyed area is shown in Figures 7-8. Estimated age-specific biomass and abundance of Pacific whiting is given by geographical area in Tables 7 and 8. Estimated length-specific numbers are given by geographical area in Table 9.

Considerable biomass (2.6 x 10^6 t) of Pacific whiting was found within all INPFC areas between the southern and northern limits of the survey. This corresponds to approximately 5.0 x 10^9 fish.

Biomass estimates were lowest for the Monterey and Eureka INPFC areas, and reached maximum levels for the South Columbia and the Canada North INPFC areas. The large biomass for the South Columbia INPFC area was a result of its large area rather than a greater surface density value; the median surface density among INPFC areas was 29.9 t/km^2, the same as that found in South Columbia INPFC area. Only about 12% of the total biomass occurred in the Monterey and Eureka INPFC areas.

The youngest and smallest fish were abundant only in the Monterey and Eureka INPFC areas, whereas several older year classes were dominant in all of the more northern areas. Thus, in the Monterey INPFC area, l- and 2-year-old fish composed 83 % of the biomass and 94% of the total numbers, whereas less than 1% of these ages occurred north of the South Columbia INPFC area. The 8- and 12-year-old fish (1984 and 1980 year classes) were detectable in the Monterey INPFC area, and became strongly represented along with younger fish (< 6 years old) in the Eureka INPFC area, and together with the 5-year-old fish (1987 year class) dominated (about 79% by numbers and 82 % by weight) other year classes within all other areas.

Triennial Bottom Trawl Survey

The sixth triennial National Marine Fisheries Service (NMFS) groundfish survey of West Coast continental shelf groundfish resources was conducted in the summer of 1992 by the Resource Assessment and Conservation Engineering Division (RACE) of AFSC. This section summarizes the preliminary results of the survey as they relate to Pacific whiting. Triennial groundfish surveys are designed to describe and monitor the distribution, abundance, and population biology parameters of various groundfish stocks off the U.S. Pacific coast. Previous surveys in this series were conducted in 1977, 1980, 1983, 1986, and 1989 (Dark et al. 1980, Weinberg et al. 1984, Coleman 1986, Coleman

1988). The primary objectives of the 1992 survey were to assess the abundance of Pacific whiting and juvenile (age 1 +) sablefish (Anoplopoma fimbria). The survey for these two species maintaining the broader, multispecies assessment objectives of previous surveys. Accordingly, a background sampling intensity comparable to the low-density sampling in prior surveys was used for the entire survey area, with heavier sampling concentrated in four areas identified as high-density strata for juvenile sablefish: Juan de Fuca Canyon, Astoria Canyon, Half Moon Bay, and Morro Bay.

Survey Design

The survey was conducted aboard the chartered University of Washington research vessel Alaska between 20 August and 13 October 1992, and the commercial trawler Green Hope between 12 July and 5 October 1992. The vessels worked northward from Pt. Conception, California, to central Vancouver Island (Nootka Sound), British Columbia, Canada (34°30’ to 49°30’ N lat.), sampling predetermined stations between 55 and 366 m in depth (30 to 200 fm). Two commercial bottom trawl operators supervised the trawl operations. The research trawler R/V Alaska is 30.5 m long overall and powered by a single main engine with 855 continuous horsepower. The F/V Green Hope is 30.7 m long overall and powered by a single main engine with 565 continuous horsepower.

Both vessels used standardized polyethylene Nor’eastern high-opening bottom trawls equipped with bobbin roller gear. Gear specifications include a 27.2 m headrope with twenty-one 30 cm floats, and a 24.3 m long link chain fishing line attached to a 24.9 m footrope. The roller gear was 24.2 m long and constructed of 2 cm diameter galvanized wire rope, 36 cm rubber bobbins spaced 1.5 m apart and separated by a solid string of 10 cm rubber disks. Additionally, 5.9 m wire rope extensions with 10 cm and 20 cm rubber disks were used to span each lower flying wing section. Trawls were made of 12.7 cm stretched-mesh polyethylene web with a 0.6 cm mesh nylon liner in the codend. Nets were rigged with triple 54.9 m, 1.6 cm diameter galvanized wire rope dandylines. Steel V-doors (2.1 x 1.5 m) weighing approximately 567 kg each were used. The fishing dimensions of the trawl were measured aboard each vessel using a Scanmar net measurement system. Preliminary inspection of the data revealed that the net used on the Green Hope had a 12.55 m mean net width while that used aboard the Alaska had a 12.76 m mean net width.

The typical reduction in Pacific whiting and juvenile sablefish catch rates at depths from 165 m to 183 m served as the rationale for stratification at 183 m. Thus, the shallow stratum ranged from 55 to 183 m, and the deep stratum from 184 to 366 m. Tracklines were drawn across both depth strata at 18.5 km intervals. In the four high-density juvenile sablefish strata, additional tracklines were drawn midway between the 18.5 km tracklines, crossing only the 55 to 183 m depth stratum. Stations were randomly located along tracklines at the rate of one station per 7.4 km in the shallow stratum and one station per 9.3 km in the deep stratum. At least one trawl station was assigned to each depth stratum along each trackline. The two vessels fished alternate tracklines (alternate pairs in the high-density areas) to minimize and to assess the effects of between-vessel differences in fishing power.

A total of 601 pre-determined stations were established for this survey. Tows were 30 minutes in duration, allowing 3 to 10 minutes between setting the winch brakes and beginning the tow to allow the net to settle to the bottom. Efforts were made to maintain towing at a constant depth during each tow. Successful trawl hauls were achieved at 526 of the 569 survey stations attempted while 34 stations were abandoned because they were considered untrawlable, and 7 stations were not attempted due to time constraints. Catches were sorted, weighed and counted by species, and a variety of biological data (age, length, weight, and maturity of individual specimens) were taken.

Results: Distribution and Abundance

Pacific whiting had the highest mean CLUE of all species in the Columbia INPFC area and in the U.S. and Canadian portions of the Vancouver INPFC area, and was second in abundance in the Conception INPFC area, third in the Eureka INPFC area, and fourth in the Monterey INPFC area. In the three northernmost INPFC areas, the shallow stratum was dominated by Pacific whiting and the deep stratum was dominated by either sablefish, Pacific ocean perch (S. alutus), or Pacific whiting. The distribution of Pacific whiting catch per unit effort (CPUE) observations is shown in Figure 9 by individual haul, grouped by four levels of magnitude. Age-structured estimates of abundance by INPFC region for Pacific whiting is given in Table 10. These estimates were produced using standard area-swept methods (Weinberg 1984) to estimate total biomass by region. The biomass by region was further partitioned using the data from the biological samples (age, length, and weight) to produce the age-structured estimates of abundance and biomass. Since the Pacific whiting otoliths collected during the survey have not been read, these preliminary age composition estimates were calculated by applying the length-frequency information from the survey to age-length keys from the acoustic/midwater trawl survey. Methods are described in Weinberg (1984).

Analysis and Interpretation of Survey Results

Previous assessments have added the trawl and acoustic biomass estimates together and tuned assessment models to the combined estimates. Dorn and Methot (1992) examined models where the trawl and acoustic biomass time series were treated separately and found that the proportion of biomass double-counted when the two biomass estimates were added together was probably less than 10 % . This was because the age ranges vulnerable to the two surveys were different, and because the trawl survey biomass made up a fairly small fraction of the total biomass. They also suggested that a comparison between the depth distribution of fish density for the acoustic survey and the depth distribution of CPUE from the bottom trawl survey could provide useful information on the amount of overlap between the two surveys.

The justification for adding the biomass estimates for the trawl and acoustic surveys in the past has been that the lower limit of echo integration was as far above bottom as the headrope of the nets used in the trawl survey. It was assumed that the bottom component of the stock could be measured using bottom trawl CPUE and area-swept calculations. However, if there is significant lateral herding of fish, or vertical herding from above, then the total biomass would be overestimated. Nunnallee (1991) documented fish diving 15 m when a bottom trawl moved through a midwater spawning aggregation of Pacific whiting in Port Susan, Washington. The EK500 echo integration system has an improved bottom detection algorithm, and under ideal conditions integrates echo sign to within 0.5 m of the bottom. The lower limit of echo integration averages between 0.5 and 3 m above bottom, and depends on depth and bottom roughness. The net metering system used during recent trawl surveys has measured an average headrope height of 9-10 m above the footrope. With these factors in mind, we suggest that the rationale for adding the trawl and the acoustic biomass estimates be re-evaluated for the 1992 surveys.

Table 11 and Figures 10 and 11 show the distribution of vertically integrated density for the acoustic and the bottom trawl surveys by region and depth strata. For the acoustic survey, vertically integrated density for the bottom 10 m is reported separately. Several patterns can be observed in the table and figures. The bottom 10 m of integrated density from the acoustic survey is usually considerably smaller than the CPUE from the trawl survey in all area-depth strata. Consequently, it is not possible to account for the biomass measured by the trawl survey as the bottom 10 m of the acoustic survey biomass. Possible alternatives to account for the higher trawl biomass are 1) that there is a large increase in density within 0.5-3.0 m of the bottom, or 2) that the trawl gear herds fish vertically from above 10 m, or laterally.

The evidence is generally consistent with the hypothesis that most of the fish caught during the trawl survey would have been detected by the acoustic survey (with caveats for sampling error and potential shifts in depth distribution during the time between the two surveys). The estimated trawl density within an area-depth strata is usually less than the total density from the acoustic survey, suggesting that trawl gear is not sampling a component of the population near the bottom that is not sampled by the acoustic survey. The exception is the 50-100 m depth strata in the South Columbia INPFC region. This is an area where the bottom 10 m component of the acoustic density is the large fraction of the total (24%), indicating that most of the fish in these areas measured by the acoustic survey would be vulnerable to bottom trawl gear if significant vertical and lateral herding occurred. Trawl densities are high in the 50-150 m depth range when acoustic densities are also high in this depth range, but they are not high in other areas. With the information presented here, it is impossible to resolve the question of whether more error is caused by adding in the trawl biomass as an absolute estimate of the fish in the bottom 0.5-3.0 m, or by using the acoustic biomass estimate by itself. However, in view of documentation of diving behavior by Pacific whiting in Nunnllee (1991), it seems advisable to adopt the conservative approach of using the only the acoustic biomass until the presence of high densities of Pacific whiting close to the bottom can be demonstrated. An analysis of the bottom 10 m of acoustic biomass by 1 .0 or 0.5 m depth intervals should detect an increase in density toward the limit of integration if there are substantial increases in fish density near the bottom.

Detailed examination of transect layout of the earlier U.S. acoustic surveys in relation to fishery trawl locations and Pacific whiting aggregations found by exploratory surveys along the west coast of Vancouver Island by DFO research vessels revealed that Pacific whiting are frequently found outside the depth and latitudinal limits of the earlier U.S. survey transects. The presence of fish north of the earlier survey limits has been established by DFO research cruises (Mark Saunders, Pers. commun., March 1992). In 1986, exceptionally high salmon bycatch rates in shallower waters led the foreign fleet to prospect for fishable aggregations of Pacific whiting in deeper water. Figure 12 shows the haul locations for the foreign and joint venture fleets in 1986. The transects for the 1986 acoustic/midwater trawl survey are also given. It is not known whether the deepwater aggregations targeted by the 1986 fishery are present every year, although some fishing outside the limits of the acoustic survey has occurred in most years. The transect layout for the 1992 survey was designed to alleviate the concern that an offshore component of the stock was not being sampled adequately.

The depth distribution of biomass by region is shown in Figure 13 (Note that these are biomass estimates; Figure 10 show vertically integrated density, which is not weighted by the area within a depth strata.) There is a biomass maximum at 100-200 m in most areas that is consistent with the distribution of biomass found in the 1977 and 1980 acoustic surveys (Fig. 14). The biomass declines in most regions at depths of 300-400 m. However, in deeper water the biomass often increases again for some distance or remains relatively constant at low but detectable levels beyond 1,000 m. Figure 15 shows an estimate of what the biomass would have been had the 1992 survey stayed within the 55-366 m depth range of the earlier surveys. For reference, the biomass estimates for 1977-89 are given for the acoustic and the trawl surveys in Figure 15. The increases in biomass in the 1992 survey is apparently due to aggregations of fish in areas that were not surveyed during earlier years. The biomass north of the earlier survey limits (lat. 50° N) also contribute significantly to the higher biomass estimate. Other factors that would tend to increase the biomass relative to earlier acoustic estimates are the use of a lower -69 dB S_V threshold north of Oregon, and echo integration closer to the bottom.

The NMFS 1992 acoustic biomass estimate in the Canadian zone (931,000 t) compares favorably with the 1992 DFO acoustic biomass estimate of l,0ll,000 t, providing additional evidence for accepting it as the best estimate of total population biomass. However, it is difficult to reconcile the 1992 acoustic biomass estimate with the earlier acoustic estimates and age composition. The estimated age composition does not show a substantial increase in biomass due to new recruits, so for the relatively old population in 1992 to have an high biomass, the biomass must have been much higher during the earlier surveys. A rough approximation of biomass that may have been missed by the earlier surveys due to limited survey coverage can be obtained by calculating expansion factors based on the ratio of total biomass in 1992 to the biomass in the depth range covered by the earlier surveys. This was done by region to account for differences in the fraction of the population offshore. Table 12 shows the procedure used to expand the biomass estimates. The purpose here is not to revise the earlier acoustic estimates, but to determine whether these expanded biomass estimates are consistent with the 1992 acoustic biomass estimate. The expanded biomass in the U.S. zone averaged 2.2 times larger than the original estimates; the biomass in the Canadian zone 'averaged 2.1 times larger when the offshore expansion factor, then the northern factor were used to inflate the biomass in the Canadian zone. These revised biomass estimates should be regarded as having higher variability than the original biomass time series because of the potential error associated with the offshore expansion factor. An additional element of uncertainty with this procedure comes from the large offshore expansion factors calculated for the Eureka and the Monterey INPFC regions in 1992 when the biomass in these areas was anomalously low. These expansion factors were applied to years when the biomass in these areas was considerably higher (Fig. 16). For reference, the distribution of unexpanded biomass for each survey year by INPFC area is given in Table 13.

Re-evaluation of Natural Mortality Estimates

New estimates of the natural morality rate were obtained by examining the decline in abundance of a year class from one triennial survey to the next using the expanded biomass estimates for the acoustic survey before 1992. The total population size was assumed to be estimated by the expanded acoustic survey biomass. To reduce the possibility of misageing and sampling variability causing implausible estimates of the natural mortality rate, only the dominant year classes (1967, 1970, 1973, 1977, 1980, 1984, and 1987) were used in the calculations. The procedure assumes a constant exponential mortality rate between two surveys to estimate 2, then solves the Baranov catch equations to obtain an estimate of the fishing mortality rate. The natural mortality rate is obtained by subtraction:

$$Z = -\ln\left[\frac{N'}{N}\right] \quad ,$$

$$M = Z\left[1 - \frac{C}{N(1 - e^{-Z})}\right] \quad .$$

Where N is the starting abundance, N' is the ending abundance, and C is the aggregate catch. The estimated natural mortality rate is divided by three to obtain an annual rate.

Table 14 contains the natural mortality estimates for the dominant year classes using the revised acoustic estimates of abundance in 1977, 1980, 1983, 1986, 1989, and unaltered acoustic estimates for 1992. Figure 17 shows the estimates of natural mortality by ending survey year. There is a fairly consistent decline in the natural mortality from 1977 to 1992. The mean of the natural mortality estimates ending in 1986 and earlier was 0.36, estimates ending 1989 and 1992 averaged 0.16. An apparent shift in the natural mortality rate needs to be followed closely because of its important influence on population dynamics. The median estimate of natural mortality of 0.226 was considered most appropriate to use in assessment models because the very high and very low estimates are less reliable. The high natural mortality estimate for the 1970 year class from 1977 to 1980 was probably a result of ageing error; the low estimate for the 1987 year class between 1989 and 1992 is probably due to the partial vulnerability of the 2-year-old fish to the acoustic survey in 1992.

This estimate of natural mortality is probably not significantly different than the estimate of 0.237 by Dorn et al. (1991) used in assessment models from 1990 to 1992. However, the new estimate was obtained using all the available survey and catch information to 1992, and consequently was used in the assessment model. The close correspondence between the new estimate of natural mortality and the earlier estimate is probably a fortuitous coincidence. Hollowed et al. (1988) used a similar cohort decay method to obtain a natural mortality estimate of 0.2. Other earlier estimates of natural mortality include 0.45 (Francis 1983), 0.23 (Francis 1985), and variable age-specific natural mortality rate that increases with from 0.2 at age 3 to 0.9 at age 12 (Swartzman et al. 1987).

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 (1977-92), 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, 1991, and 1992, 6) age composition in the Canadian zone from DFO acoustic surveys. The fit to the expanded acoustic biomass estimates for 1977, 1980, 1983, 1986, and 1989 was examined, but these estimates were not used to constrain the model. Age compositions for the expanded acoustic biomass estimates were calculated by scaling up the age composition by region by the expansion factors and then summing across regions. This procedure would tend to increase the relative magnitude of the younger age classes because the expansion factors were largest in the southernmost regions where the younger fish are more abundant. Additional data sources were used to estimate the historical recruitments and population biomass back to 1960 and are described later.

As in previous assessments, the survey biomass estimates for the Canadian zone were expanded upwards to account for incomplete survey coverage. The new expansion factors were calculated from DFO acoustic surveys in 1990 and 1991, 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, 1991, and 1992 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: 1977-1.48, 1980-l .48, 1983-1.68, 1986-1.83, 1989-1.48. 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 as samples from the Canadian fishery off southwest Vancouver Island (Mark Saunders, Pers. commun., March 1992).

Configuration of the Geographic Stock Synthesis Model

The modeled population included 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 resulted in systematic overestimation of the abundance of the age 15 + fish. The small sample sizes used to estimate age composition 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 midwater trawls used to estimate age composition of the acoustic surveys. Because of the potential that this phenomenon could unduly 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 ageing 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, 8 in 1979, 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 produced 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 revised Canadian fishery age composition, an additional source of ageing 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 accumulate the younger fish to age 5 in 1985.

Systematic ageing 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 1 year in the same direction, and both were off by 2 years in the same direction. The probability that both agree and were off by more than 2 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 % agreement at age 2 and 75 % agreement at age 15 were obtained using linear regression constrained to pass through 1 .0 at age 2.

The model runs covered the years 1977-92. Two geographic areas, corresponding to the U.S. and Canadian management zones (EEZ), 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 1980s. Natural mortality was fixed at an age-invariant rate of 0.226 estimated in the previous section of this paper.

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, 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_l, p_2 , and p_3 in the migration function to vary from year to year. This represents a change from last year's assessment, when only the parameters p_1 and p_3 were allowed to vary interannually. 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

$$l_P = -\sum_i \left[\frac{p_i - p_i^*}{\sigma_{p_i^*}} \right]^2 ,$$

where p_i is the prior parameter estimate, and $\sigma_{p_i^*}$ 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 σ_{p_i} was set to the standard deviation of the annual migration coefficients during the survey years. The penalty likelihood component was given an emphasis level of 5 .0 in the basic model.

Treatment of Survey Time Series in the Synthesis Model

To assess the effect of the 1992 survey biomass estimate, several preliminary models were fit using the original time series of combined acoustic and trawl survey biomass as an absolute measure of population abundance. However, most model runs treated the bottom trawl and acoustic surveys separately. We modeled the biomass estimates from these surveys as an index of population abundance. The acoustic survey catchability (q) was assumed to be the same in both zones, while the model was configured with a different trawl survey catchability for each zone because of differences in the geographic coverage of the trawl survey. 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 50° N lat. was estimated using a threshold of -58 dB. In the Canadian zone, this total biomass was then expanded up by the northward expansion factor. The unrevised 1992 acoustic estimate was included with the expanded acoustic biomass estimates for the earlier years for an additional survey time series, but the final model was tuned only 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. To examine the effect of the target strength value for Pacific whiting on the model results, models were tuned to the 1992 acoustic biomass that results from a -35 dB/kg target strength value (the established value), and a more conservative -33.5 dB/kg target strength value.

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 Pacific whiting are between 4 and 6 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 a preliminary model run that was tuned to the 1992 acoustic biomass estimate plus the earlier expanded acoustic biomass estimates. This was necessary because a single year of data is probably 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 1 .0 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 also given 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 suspicion 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 three consecutive years, and since it covers only the Canadian zone, it is unable to act as constraint on the total population biomass. Inclusion of these surveys with nil emphasis allows examination of their patterns relative to the final population estimates.

Results of 1977-92 Geographic Model Runs

The effect of the 1992 biomass estimate on population trends can be seen in Figure 18, which shows the time trend of population biomass and biomass measured by surveys for two models, model A and model B. Model A is tuned to the original acoustic+ trawl biomass time series, but does not attempt to fit the 1992 biomass estimate. The predicted combined U.S. and Canadian zone survey biomass for 1992 is approximately 1 .0 million t, which is about one-third of the 2.9 million t estimated by the acoustic and trawl surveys combined. Model B is tuned to the original acoustic + trawl biomass plus the 1992 combined biomass estimate. This model is unable to obtain a good fit to either the original biomass time series or the 1992 estimate. The observed survey biomass is too low in 1983, 1986, and 1989, and too high in 1992. Both Model A and Model B used a fixed selectivity pattern for the U.S. zone that was estimated in the 1992 Pacific whiting assessment (Dorn and Methot 1992). Allowing the model to estimate the selectivity pattern for the survey in the U.S. zone resulted in a warped selectively curve with selectivity approaching 1 only for the oldest ages.

The stock synthesis estimation runs tuned to the 1992 acoustic biomass estimated using the standard -35 dB/kg target strength value typically converged rapidly to reasonable (or at least understandable) results. The model was able to reliably estimate all parameters except the age-2 abundance of the 1985 year class. This year class was rare in the age composition samples and one year younger than the strong 1984 year class. Consequently, with the ageing error included in the model, the few fish from this year class that were present in the age composition could be accounted for as misaged fish from the 1984 year class. In the final estimation run, this parameter was fixed at a low level (0.001 billion age-2 recruits).

Table 15 gives the contribution of each likelihood component to the total likelihood. The U.S. fishery age composition tended to fit better than the Canadian fishery age composition. The survey age compositions tended to fit better than the fishery age composition, as measured by the average log(likelihood) per annual age composition. Figure 19 shows the fit to the survey biomass estimates. The expected survey biomass is obtained by projecting the population abundance 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.

Figure 20 shows the estimated age-specific migration fractions for the basic model. Large departures from the mean conditions were observed in 1983, when a high proportion of the older fish were found in the Canadian zone, and 1980, when the proportion of older fish in the Canadian zone was low. 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 16. Table 17 gives the estimated population numbers at age for the years 1977-91 for the basic model described above. Table 18 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 1977-92.

Figure 21 shows the expected and observed mean age in the annual age composition for the U.S. and Canadian fisheries, and triennial surveys in the U.S. and Canadian zones. There is a satisfactory fit between the expected and observed mean age for each data component. In the U.S. zone, mean age generally declines from 1977 to 1984, then increases to 1992.

The general picture of the Pacific whiting population in previous assessments remains unchanged for this assessment. Population biomass peaked 1987 and has been declining steadily since that time. However, if one is willing to accept the 1992 biomass estimate with a target strength of -35 dB/kg as an unbiased estimate of current abundance, exploitation rates over the past decade have been considerably overestimated in previous assessments.

Reconstruction of Historical Abundance and Recruitment

Prior to 1977, there are fewer sources of information on the coastal population of Pacific whiting. U.S. fishery age composition for the years 1973-76 is available from sampling conducted by Polish researchers (Morski Instytut Rybacki 1977). Dark (1975) provides estimates of age composition for the years 1965-69 obtained primarily from research cruises off the southern coast of Washington. Finally, a time series of yield in biomass for U.S. and Canadian waters extends back to the inception of the large-scale fishery in 1966 (Bailey et al. 1982). These yields were reported by the foreign nationals conducting the fishery and were not subject to independent verification.

To model these data we begin by assuming that the population had an equilibrium age composition in 1957. The model uses the mean age-2 recruitment for the years 1957-92 (1.630 billion) for the equilibrium age-2 recruitment value. The abundance of equilibrium population at the start of the time series will affect the estimated magnitude of the recruitment in the early years, however this effect degrades rapidly (Dorn and Methot 1990). The age composition data from Dark (1975) came primarily from the southern coast of Washington, and so we expect them to represent a selectivity pattern different from that of the current coastwide U.S. surveys. We modeled these data as a qualitative survey, because no biomass estimates are available, and we used a fixed selectivity pattern estimated by

Dorn and Methot (1991) for the U.S. fishery in the Vancouver/N. Columbia INPFC region, Preliminary models that attempted to estimate the selectivity pattern for the 1965-69 data gave a strongly peaked selectivity pattern that did not correspond to the age-specific distribution of the population of the southern Washington coast. To prevent the assumed equilibrium age composition from influencing the fit to the 1965-69 data, we truncated the 1965 samples at age 9, the 1966 samples at age 10, and so on. The 1969 age composition was accumulated at age 7 because of an apparent bias in the ageing of the 8-year-old 1961 year class.

Population abundance and recruitment prior to 1977 were estimated by fixing the parameters of the model at values estimated using only the data for 1977 and later. Fishery and survey selectivity curves were fixed, as were estimates of recruitment abundance for 1977 and later. The migration between the U.S. and Canada was modeled using a single curve with no interannual variation rather than to attempt to model interannual variation in migration in the earlier years. Although we estimated recruitment beginning with the 1956 year class, we do not support the estimates for the 1956 and 1957 year classes because of their dependence on the assumed initial population level and the short duration they were observed as age 8-9 fish in 1965-66.

Preliminary runs of the model revealed that the Polish age composition data in 1975 was not consistent with the fishery selectivity pattern of other years. Most of the lack of fit was due to a much higher catch of age-2 fish than expected. In 1975, the fishery operated south of its normal range, with approximately 70% of the U.S. catch coming from the Monterey INPFC area. In our final model, we estimated a separate double logistic selectivity curve for the U.S. fishery in 1975. The selectivity of the age-2 fish was estimated as 0.26, as compared to a selectivity of 0.05 for the other years.

The reconstructed time series of recruitment (Table 19, Fig. 22) shows the same pattern of strong and weak year classes as the previous estimates of the extended recruitment time series (Dorn et al. 1991). However the absolute magnitude of the strong year classes differs significantly from previous estimates. The 1961 year class is slightly larger (3.8 billion vs. 3.5 billion in Dorn et al. (1991)). The 1970, 1973, and 1977 year classes are approximately 1.6 times larger than in Dorn et al. (1991). The larger size of the more recent year classes can be easily be explained by the higher survey biomass estimates used to tune the model. As has been noted in previous assessment, the year classes from the late 1960s appear to have been less variable than those of the late 1970s and 1980s. Another possible explanation is that less precise ageing during the early 1970s caused the early year classes to appear more similar in size. Biomass levels appear to have been near equilibrium levels in the 1960s and 1970s dropped to low levels in the early 1980s then increased substantially as the 1980 and 1984 year classes recruited to the population.

The Effect of the Target-Strength Estimate on Assessment Results

In abundance estimation using acoustic methods, the target strength value converts echo-integrator output to population biomass, and consequently plays a central role in determining the absolute level of biomass. The -35 dB/kg target strength value that is currently used for Pacific whiting was chosen based on a comparison of target strength estimates of gadoid species similar in size and shape to Pacific whiting (Dark et al 1980). Williamson and Traynor (1984) estimated the target strength of 50-55 cm Pacific whiting using in situ methods at -36 dB/kg. Since a scaling argument indicates that target strength should decrease with increasing fish length, fish of mean length of 42-48 cm, the mean size of fish from midwater trawls during acoustic surveys, should have a higher target strength. Table 20 shows estimates of target strength of Pacific whiting and related species. To put these data in perspective, it should be noted that a 1 dB/kg decrease in the target strength (i.e. from -35 dB/kg to -36 dB/kg) increases the resulting biomass by 26 % , while an 1 dB/kg increase in target strength decreases the biomass by 20%. Hollowed et al (1988) note that in situ dual beam target strength data collected during the 1980 and 1983 surveys suggests that -33 dB/kg may be an appropriate target strength for Pacific whiting. Although it is impossible to put confidence limits on the -35 dB/kg target strength estimate, the limited amount of information presented here indicates that there is no evidence to exclude a target strength in the range of -33.5 dB/kg to -36 dB/kg from being an appropriate value for Pacific whiting.

To investigate the consequences of higher target strength on the assessment model, the 1992 biomass estimate was scaled to correspond to a -33.5 dB/kg target strength. This reduces the 1992 acoustic biomass estimate from 2.58 million t to 1.82 million t, or about 29% Table 15 shows the fit to the data sources used to tune the model. The fit to U.S. and Canadian fisheries age composition degrades slightly, as does the fit to the acoustic time series index. Fits to acoustic survey age composition improve slightly. The total likelihood decreases from -643.0 to -653.0, indicating that a better fit overall can be achieved with the higher biomass resulting from a -35 dB/kg target strength. This result depends on the relative emphasis levels of the likelihood components, and a different set of emphasis levels could give a different result. It should also be noted that the changes in the likelihood components are monotonic over a fairly wide range of ending biomass levels. For example, a model with a 1992 acoustic biomass estimated using a target strength of -36 dB/kg gave a 1992 population biomass estimate of 3.7 million t, and a total likelihood of -640.5, indicating a better fit than the -35 dB/kg model. This analysis suggests that the age composition and survey index information is insufficient to establish an upper bound on the total abundance of Pacific whiting.

ESTIMATING SUSTAINABLE YIELD AND FORECASTING SHORT-TERM YIELDS

Sustainable Yield

An age-structured population simulation model was used to estimate long-term average yield and to forecast yields for 1994-96. We again used the bootstrap method from previous assessments (Dorn and Methot 1991) to simulate a recruitment time series. The recruitment estimates for the year classes 1958-90 (33 years) from the stock synthesis model form the sample space. This procedure gives the simulated recruit 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, if there is significant autocorrelation in the recruitment time series, the bootstrap procedure would not reproduce it.

The model divided the population numbers at age between the U.S. and Canadian zones using the mean migration function estimated by the synthesis model. Within each zone, the Baranov catch equations modeled the effect of the fishery on the population, and an exponential mortality model updated the population numbers at age to the start of the following year. Based on the analysis of survey and catch data described earlier, the natural mortality rate was assumed to be constant with respect to age at 0.226. Separate weight-at-age vectors for the U.S. fishery, the Canadian fishery, and for the population were used. These were estimated by averaging weight at age for the years 1978-92 separately for each source. Since there has been a large decline in weight at age over the past 12 years, this resulted in weights at age that are larger than currently observed in the fishery, but smaller than 12 years ago.

Age-specific fishing mortality rates were modeled as the product of an annual fishing mortality rate and an age-specific selectivity coefficient. Separate vectors of selectivity coefficients, estimated by the stock synthesis model, were used for the U.S. and Canadian fisheries. The annual control variable in this parameterization is the full recruitment fishing mortality in the U.S. zone, $F_{US}(y)$. We set the fishing mortality rate in the Canadian zone so that the percentage of the total yield harvested by the Canadian fishery would be equal to the percentage of the mature biomass expected to migrate into Canadian waters. This was calculated using the mean fraction of mature fish at age in each zone as estimated by the stock synthesis model. To estimate the split in mature biomass for a particular year, the projected numbers of mature fish at age for that year were split between the two regions using the mean migration curve, converted to biomass using zone-specific body weights at age, then summed over all ages to get the estimated total mature biomass in each zone. This procedure was adopted simply because some algorithm for dividing the catch between the U.S. and Canada is necessary to simulate the dynamics of the population. Previous modeling has established that the total yield is relatively insensitive to a broad range of allocation procedures. The estimated catch at age in each zone was multiplied by the fishery-specific weight at age and summed over age to give the total yield. Table 21 gives the age-specific biological characteristics of Pacific whiting used to simulate the population dynamics.

Sustainable yield was estimated by averaging 20 replicate l000-year simulations. To remove the effect of initial conditions, all simulations were run for 50 years before beginning to tabulate the summary statistics. For each harvest strategy, we present three harvest rates (low, moderate, and high) to bracket viable alternatives and to provide a middle course. Table 22 gives the sustainable yields that can be obtained assuming an acoustic target strength of -35 dB/kg. To show how uncertainty in target strength influences sustainable yield, Table 23 shows the yield obtainable with a target strength of -35.5 dB/kg. It is important to bear in mind that the labels of low, medium, and high are relative designations, and are not intended to imply judgments about which rate is best. The harvest 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_y 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 each harvest strategy, three harvest rates were determined by the probability that female spawning biomass drops below a cautionary spawning biomass level, the 0.1 percentile of female spawning biomass of an unfished population (Fig. 23). The cautionary spawning biomass was obtained by determining the 0.1 percentile of spawning biomass in 20 replicate 1 ,000-year simulations of an unexploited population. A more complete discussion of the cautionary spawning biomass is in Dorn et al. (1991)

The low harvest rate is defined so 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. For reference, we also show in Tables 22 and 23 the fishing mortality rate that lowers the mean female spawning biomass to 35% of its pristine level.

Since many West Coast stocks are managed at the $F_{35\%}$ level, it may be useful to relate the harvest rates based on the cautionary biomass level to the F_{35}% harvest strategy. Since a stock-recruit relationship is not used in the simulation model, the equivalent to a $F_{35\%}$ harvest strategy would be a fishing rate that reduced the mean spawning biomass to 35 % of its pristine value. The cautionary spawning biomass level of 632,000 t occurs at 29% of the mean pristine spawning biomass level of 2,163,000 t for the -35 dB/kg target strength scenario. For the -33.5 dB/kg target strength scenario, the cautionary level occurs at 30% of the mean pristine spawning biomass. These values are close to the mean spawning biomass level at $F_{35\%}$. The alternative harvest rates presented above are based on the lower 10, 20, and 30 percentiles of the distribution of spawning biomass rather than the mean. This extra protection for the population is required because of the extreme variability of Pacific whiting recruitment, and the fact that they mature several years before they recruit to the fishery.

The estimates of sustainable yield for the different harvest strategies for a target strength of -35 dB/kg are about 50% larger than the estimates in Dorn et al. (1991). For example, in the 1991 assessment the moderate rate hybrid harvest strategy, which was used to set yields in 1991-93, was estimated at 221,000 t. In this assessment, we estimate the sustainable yield for this harvest strategy as 336,000 t. The primary reason for this change is the increase in mean historical recruitment (1.875 billion vs 1.230 billion) because of the 1992 acoustic survey results. Estimates of sustainable yield for the -33.5 dB/kg target strength scenario averaged about 11% lower than the -35 dB/kg target strength scenario.

Yield Forecasts for 1994-96 and 1994 Acceptable Biological Catch

We used a deterministic version of the population simulation model with the information in Table 24 to forecast the yield for 1994-96. Weight at age vectors for these projections were estimated by averaging the weight at age for the years 1990-1992 and are intended to represent the weight at age currently being observed in the various fisheries and in the population. The yield forecasts were based on the assumption of median recruitment for the years 1993-95. The median recruitment was set at 0.974 billion age-2 fish, the median recruitment for years 1960-92. It should be recognized, however, that if a strong year class recruits during 1993 or 1994, the yield would be much higher than projected for 1995 and 1996. Conversely, poor recruitment during1993 and 1994 would tend to decrease the projected yields for 1995 and 1996. Population abundance at the start of 1992 (estimated by the synthesis model) was projected forward to the start of 1994 by removing the estimated 1992 catch and the expected catch for 1993. In the forecasts for 1994-96, 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. This method of calculating the yield was also used in the simulations to estimate sustainable yield.

Table 25 gives the projected yields for a -35 dB/kg target strength scenario for 1994-96 under the constant F, the variable F, and hybrid policy for the different harvest rates discussed in the previous section. The yield for 1994 ranged from 245,000 t to 631,000 t. The harvest rate contributes about 200,000 t of the range, and the F strategy contributes about 190,000 t. These yield projections are significantly higher than the projected yields for 1994 given in last year's assessment. For example, in the 1992 assessment, the hybrid F-moderate harvest rate, on which the 1993 ABC was based, predicted a yield of 125,000 t in 1993. In Table 25 of this paper the yield for this harvest policy is 450,000 t, about 3.6 times as large. The 1992 survey result dominates all other factors in accounting for this increase over previous projections. For comparison, Table 26 gives the projected yields for 1994-96 for a -33.5 dB/kg target strength scenario under the constant F, the variable F, and hybrid policy for the different harvest rates. The yield for 1994 ranged from 198,000 t to 463,000 t. In general, yields from low harvest rates for the -35 dB/kg target strength scenario are higher than the yields from high harvest rates for the -33.5 dB/kg target strength scenario.

The stock synthesis estimate of age-2 recruitment of the 1990 year class is 1.999 billion, indicating that it is an average year class comparable to 1987 and 1988 year classes. The abundance of the l-year-old 1991 year class in the 1992 triennial acoustic survey was approximately the same magnitude as the 1990 year class, suggesting that it also is of average size. Preliminary data from the 1993 fishery (Fig. 24) shows these two year classes as a prominent mode in the samples from the southern portion of the summer range of the population. These smaller fish were not conspicuous in the length frequency data from the offshore fishery, which operated mostly north of the Columbia River's mouth. This evidence suggests that moderately sized year classes are continuing to recruit to the fishery. There is no evidence of recruitment of a strong year class like those which dominated the Pacific whiting population in the 1970s and 1980s.

In 1992, the Groundfish Management Team recommended that the 1993 ABC be based on a moderate harvest rate, hybrid strategy. The moderate harvest rate, hybrid strategy specifies a total yield of 450,000 t for 1994, while the low and high harvest rate hybrid strategies specify a total yield of 325,000 t and 555,000 t, respectively. The yield projections for 1995 and 1996 tended to be much lower than the yield in 1994. 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.

The dependence of our recommendations on the 1992 acoustic biomass estimate is an important consideration in setting short-term yields from the fishery. In addition, the decision with respect to harvest strategies should be made with a 3-year time horizon since there will likely be little new information on Pacific whiting population biomass levels or target strength until the next triennial surveys in 1995. It seems reasonable to require at least two corroborating surveys before substantially increasing yields from a fishery. For this reason, we recommend a low harvest rate for 1994-96. Since even the low harvest rates result in a substantial increase in yield from 1993 to 1994, followed by a rapid decline, we also projected the stock forward under a constant catch for 1994-96 of 270,000 t, the 1994-96 mean yield under the low hybrid harvest rate. The projected spawning biomass under this harvest strategy for 1997 was 840,000 t, nearly identical to a projected 1997 spawning biomass of 850,000 if the low hybrid harvest rate were followed in each year.

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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, 1966-91.

	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	8.834	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
Mean 1966-91				139.530				43.628	183.159

Sources: 1966-80 from Bailey et al. 1982; 1981-92 from Pacific Fishery Information Network (PacFIN), Pacific Fishery Management Council, Metro Center, Suite 170, 2000 SW. First Avenue, Portland, OR 97201; Canadian catches reported by Mark Saunders, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6, Pers. commun., April 1993.

Table 2.--Pacific whiting catch at age (millions of fish) by sex and fishery in 1992.

	Shore-based		Offshore		Canada		Total	
Age	Males	Females	Males	Females	Males	Females	Males	Females
1	0.00	0.56	0.18	0.23	0.00	0.00	0.18	0.79
2	6.76	6.99	2.45	2.32	0.00	0.00	9.22	9.32
3	1.84	2.01	3.36	2.73	0.34	0.34	5.54	5.07
4	8.62	5.40	17.76	20.17	3.41	4.22	29.79	29.79
5	15.83	11.14	45.32	37.30	7.36	10.44	68.51	58.88
6	2.34	0.65	3.04	4.24	1.87	1.67	7.25	6.56
7	1.32	0.74	1.22	1.81	0.13	0.27	2.68	2.82
8	24.97	11.36	55.48	40.13	27.18	29.65	107.63	81.14
9	0.69	0.88	1.77	1.51	0.13	0.13	2.59	2.52
10	0.00	0.00	2.05	0.34	0.00	0.00	2.05	0.34
11	0.00	0.00	0.47	0.32	0.07	0.07	0.53	0.39
12	8.15	3.98	17.50	12.42	14.66	16.13	40.31	32.54
13	0.00	0.32	0.10	0.21	0.07	0.00	0.17	0.53
14	0.00	0.00	0.18	0.02	0.07	0.07	0.24	0.08
15+	0.33	0.08	0.61	0.86	0.34	0.87	1.28	1.80
Total	70.85	44.11	151.50	124.59	55.63	63.86	277.97	232.56

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 1993.

Table 3.--Catch at age (millions of fish) for the Pacific whiting fisheries, 1977-92. 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.

	Age															
Year	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
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
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

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 1993.

Table 4.-U.S. and Canadian mean length at age (cm) for the offshore fishery and coefficients of a length-weight relationship (cm to g) for Pacific whiting in 1992.

	Males		Females	
Age	U.S.	Canada	U.S.	Canada
		Length at age		
2	34.3	---	34.6	---
3	39.1	---	39.1	---
4	42.3	---	42.9	---
5	43.6	---	44.5	---
6	44.3	---	45.5	---
7	45.5	Not available	46.6	Not available
8	45.9	---	47.0	---
9	45.2	---	47.1	---
10	45.8	---	46.3	---
11	46.0	---	47.0	---
12	47.0	---	49.1	---
13	52.3	---	52.0	---
14	43.0	---	54.0	---
15+	49.2	---	53.6	---
		Length-weight coefficients		
a	0.0072	0.2677	0.0058	0.1288
b	2.9502	2.0289	3.0067	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. cormnun., April 1993.

Table 5. Geographical boundaries used during analysis of West Coast Pacific whiting survey, MF-92-08.

REGION	FROM	TO
MONTEREY	35° 00´ N. Lat.	40° 30´ N. Lat.
EUREKA	40° 30´ N. Lat.	43° 00´ N. Lat.
SOUTH COLUMBIA	43° 00´ N. Lat.	45° 46´ N. Lat.
NORTH COLUMBIA	45° 46´ N. Lat.	47° 30´ N. Lat.
U.S. - VANCOUVER	47° 30´ N. Lat.	U.S.-CANADA BORDER
CANADA SOUTH	U.S.-CAN BORDER	49° 00´ N. Lat.
CANADA NORTH, SECT A	49° 00´ N. Lat.	49° 15´ N. Lat.
CANADA NORTH, SECT B	49° 15´ N. Lat.	49° 30´ N. Lat.
CANADA NORTH, SECT C	49° 30´ N. Lat.	50° 00´ N. Lat.
CANADA NORTH, SECT D	50° 00´ N. Lat.	51° 15´ N. Lat.
CANADA NORTH	49° 00´ N. Lat.	51° 15´ N. Lat.

Table 6. Surveyed areas and estimated biomass, by geographical area, for West Coast Pacific whiting survey, MF-92-08.

INPFC AREA	NMFS acoustic survey Surveyed area nm^2	NMFS acoustic survey Surveyed area km^2	NMFS Biomass (t)	DFO acoustic survey Surveyed Area nm^2	DFO acoustic survey Surveyed Area km^2	DFO Biomass (t)
MONTEREY	4416.1	15146.8	88233.1			
EUREKA	3209.4	11007.9	212006.7			
SOUTH COLUMBIA	5929.1	20336.2	607948.9			
NORTH COLUMBIA	3291.7	11290.2	327708.3			
U.S. - VANCOUVER	2135.2	7323.5	416066.1			
NORTH COLUMBIA AND U.S.- VANCOUVER COMBINED	5426.9	18613.8	743774.4			
ALL US COMBINED	18981.5	65104.7	1651962.8			
CANADA SOUTH	2374.8	8145.3	364031.0	2212.5	7588.7	397325.0
CANADA NORTH, SECT A	545.3	1870.3	24811.9	260.5	893.5	42730.0
CANADA NORTH, SECT B	458.5	1572.6	36351.6	408.0	1399.4	101790.0
CANADA NORTH, SECT C	784.0	2689.0	86115.0	1299.6	4457.5	237310.0
CANADA NORTH, SECT D	1856.7	6368.3	394160.2	1137.9	3902.9	286589.0
CANADA NORTH, SECT A-D COMBINED	3644.5	12500.3	541438.7	3111.2	10671.1	668419.0
QUEEN CHARLOTTE SOUND	157.5	540.2	26190.1	550.6	1888.5	35584.0
ALL CANADA (+QCS) COMBINED	6176.8	21185.8	931659.8	5874.3	20148.3	1101328.0
Totals =	25158.3	86290.6	2583622.6			

Table 7. Estimated biomass (1,000 t) of Pacific whiting at age, by geographical area (defined in Table 5), for the West Coast Pacific whiting survey, MF-92-08. Queen Charlotte Sound is not included.

AGE	MONTEREY	EUREKA	S COL	N COL	US VAN	CAN (S)	CAN (N)	ROW SUMS
1	35.64	17.47	0.15	0.	0.	0.	0.	53.26
2	37.55	32.20	37.85	0.04	0.	0.	0.	107.63
3	4.83	9.93	12.45	3.71	2.25	0.	2.46	35.63
4	0.46	37.66	72.04	30.02	23.38	14.51	36.38	214.45
5	0.83	26.48	144.95	88.58	86.95	67.75	70.54	486.07
6	0.24	0.	11.72	11.12	11.56	15.38	7.02	57.02
7	0.	0.	3.05	0.79	1.65	3.94	12.34	21.77
8	3.67	41.90	259.62	154.47	220.32	161.69	254.04	1095.70
9	0.70	0.	2.10	0.94	0.76	10.01	18.04	32.55
10	0.	1.32	6.39	1.52	1.95	2.38	5.57	19.33
11	0.	0.28	3.05	0.	0.	2.10	2.85	8.29
12	4.13	41.25	52.93	33.91	61.03	77.69	116.08	387.02
13	0.	2.63	1.65	0.61	2.12	3.43	9.66	20.10
14	0.	0.	0.	0.	0.	0.	0.	0.
15	0.20	0.91	0.	0.84	1.20	5.16	6.46	14.75
16	0.	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	1.17	2.90	0.	0.	4.07
Totals	88.23	212.01	607.95	327.71	416.07	364.03	541.44	2557.43

Table 8. Estimated population (millions) of Pacific whiting at age, by geographical area (defined in Table 5), for the West Coast Pacific whiting survey, MF-92-08. Queen Charlotte Sound is not included.

AGE	MONTEREY	EUREKA	S COL	N COL	US VAN	CAN (S)	CAN (N)	ROW SUMS
1	388.22	117.35	0.94	0.	0.	0.	0.	506.51
2	232.21	148.76	142.25	0.13	0.	0.	0.	523.34
3	20.82	24.68	31.57	7.73	4.71	0.	4.80	94.31
4	0.95	87.44	153.25	57.41	44.47	25.81	60.42	429.75
5	1.51	53.69	291.81	158.44	151.99	117.47	113.20	888.10
6	0.42	0.	23.83	19.59	19.70	25.19	10.49	99.21
7	0.	0.	6.08	1.15	2.30	5.85	17.91	33.30
8	6.53	76.89	456.13	252.98	334.48	244.05	362.08	1733.13
9	1.31	0.	3.26	1.72	1.43	15.82	24.26	47.81
10	0.	2.32	11.26	2.48	3.10	3.33	7.30	29.78
11	0.	0.42	4.28	0.	0.	2.82	4.48	12.00
12	6.71	74.97	89.30	54.27	86.33	106.62	147.76	565.95
13	0.	5.23	2.85	0.85	2.75	5.12	12.87	29.67
14	0.	0.	0.	0.	0.	0.	0.	0.
15	0.29	1.51	0.	1.30	1.79	7.03	7.60	19.51
16	0.	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	1.83	3.75	0.	0.	5.58
Totals	658.97	593.23	1216.81	559.87	656.79	559.10	773.17	5017.94
Thousand fish/square nmi								
	149.2	184.8	205.2	170.1	307.6	235.4	212.1	

Table 9. Estimated Pacific whiting population (millions) at length, by geographical area, for West Coast Pacific whiting survey MF-92-08. Queen Charlotte Sound is not included.

LENGTH	MONTEREY	EUREKA	S COL	N COL	US VAN	CAN (S)	CAN (N)	ROW SUMS
20	0.	0.	0.	0.	0.	0.	0.	0.
21	1.50	0.	0.	0.	0.	0.	0.	1.50
22	10.94	0.	0.	0.	0.	0.	0.	10.94
23	51.57	0.	0.	0.	0.	0.	0.	51.57
24	124.62	0.39	0.	0.	0.	0.	0.	125.00
25	128.59	0.96	0.	0.	0.	0.	0.	129.55
26	81.69	4.81	0.	0.	0.	0.	0.	86.50
27	25.25	22.27	0.44	0.	0.	0.	0.	47.96
28	23.75	45.00	1.45	0.	0.	0.	0.	70.20
29	21.16	49.11	1.36	0.	0.	0.	0.	71.63
30	25.30	29.71	1.80	0.	0.	0.	0.	56.81
31	41.37	21.16	5.29	0.	0.	0.	0.	67.82
32	41.05	19.46	9.23	0.	0.	0.	0.	69.74
33	31.10	23.80	33.34	0.	0.	0.	0.	88.23
34	17.80	27.73	42.42	0.26	0.	0.	0.	88.21
35	11.00	10.16	32.17	0.	0.	0.	0.	53.33
36	2.88	7.75	17.43	0.	0.	0.	0.	28.06
37	0.91	16.47	7.18	0.51	0.	0.	0.	25.07
38	0.	1.34	6.63	0.25	0.	0.	0.	8.22
39	0.22	3.15	7.87	0.	0.	0.	0.	11.24
40	0.	1.15	26.98	2.85	0.	0.63	0.	31.61
41	0.57	26.49	49.81	11.86	6.87	1.36	2.47	99.42
42	0.91	45.35	96.87	33.34	18.48	9.04	9.71	213.70
43	0.57	57.21	143.51	62.97	51.51	28.00	21.02	364.79
44	2.30	52.28	189.72	87.92	72.78	57.27	53.17	515.44
45	3.08	50.40	198.88	111.59	122.72	87.69	99.72	674.08
46	2.94	44.05	162.65	114.94	113.90	114.00	127.67	680.16
47	2.73	24.11	98.71	72.55	100.32	106.24	123.15	527.81
48	2.38	5.59	48.92	38.02	75.94	69.88	109.93	350.66
49	1.73	2.93	22.65	14.42	46.80	42.02	79.07	209.63
50	0.43	0.20	8.55	6.70	27.66	19.39	57.22	120.16
51	0.22	0.	1.47	1.10	8.84	8.55	36.37	56.56
52	0.	0.	0.	0.29	4.09	4.64	18.45	27.47
53	0.22	0.	1.47	0.29	5.24	2.64	14.33	24.20
54	0.	0.20	0.	0.	0.	2.01	7.51	9.72
55	0.22	0.	0.	0.	0.	1.30	4.16	5.68
56	0.	0.	0.	0.	0.82	1.63	4.40	6.85
57	0.	0.	0.	0.	0.	1.08	0.34	1.42
58	0.	0.	0.	0.	0.	0.31	2.39	2.70
59	0.	0.	0.	0.	0.82	0.39	0.87	2.08
60	0.	0.	0.	0.	0.	0.35	0.85	1.19
61	0.	0.	0.	0.	0.	0.19	0.39	0.58
62	0.	0.	0.	0.	0.	0.16	0.	0.16
63	0.	0.	0.	0.	0.	0.23	0.	0.23
64	0.	0.	0.	0.	0.	0.08	0.	0.08
65	0.	0.	0.	0.	0.	0.	0.	0.
Totals	658.97	593.23	1216.81	559.87	656.79	559.10	773.17	5017.94
	Mean individual fish length (cm) by geographical area.							
	27.5	37.8	43.2	45.2	46.2	46.5	47.4	(42.1)

Table 10.--Estimated numbers at age (millions of fish) for Pacific whiting by International North Pacific Fisheries Commission (INPFC) area for 1992 west coast bottom trawl survey. These estimates were produced using standard area-swept methods (Weinberg 1984).

	INPFC Areas						
Age	Conc.	Mont.	Eureka	Scol.	NCol.- U.S. Van.	Can. Van.	Total
0	0.125	0.063	1.810	0.116	0.000	0.000	2.114
1	22.847	34.823	6.258	3.001	0.004	0.000	66.933
2	2.517	17.196	5.373	46.939	0.398	0.000	72.423
3	0.046	1.604	0.241	9.745	1.155	0.000	12.791
4	0.041	0.641	0.152	14.861	6.803	0.000	22.498
5	0.053	1.161	0.401	28.175	22.393	5.550	57.733
6	0.000	0.094	0.033	2.489	1.698	0.000	4.314
7	0.000	0.000	0.000	0.000	0.000	2.923	2.923
8	0.037	4.686	1.741	90.575	95.593	41.721	234.353
9	0.000	0.035	0.050	2.506	3.070	0.131	5.792
10	0.000	0.010	0.010	1.009	0.510	0.000	1.539
11	0.000	0.094	0.015	0.696	0.942	0.000	1.747
12	0.012	2.201	1.386	73.096	78.485	24.360	179.540
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.026	0.006	0.000	0.032
15	0.000	0.533	0.167	4.151	6.577	3.155	14.583
Total	25.678	63.141	17.637	277.385	217.634	77.840	679.315

Conc. = Conception.
Mont. = Monterey.
Scol. = Southern portion of Columbia.
Ncol.-U.S. Van. = Northern portion of Columbia and U.S. Vancouver.
Can. Van. = Canadian portion of Vancouver area, up to lat. 49°35´N.

Table 11. Surface density (kg/ha) for the acoustic survey (entire water column and the 0-10 m from bottom fraction) and the bottom trawl survey by geographic strata and depth bins.

Depth	Conception			Monterey		
	Acoustic	Bot. 10 m	Trawl	Acoustic	Bot. 10 m	Trawl
35+	---	---	---	0.0	0.0	
50+	---	---	0.0	0.0	0.0	2.8
100+	---	---	1.2	16.4	9.1	7.6
150+	---	---	10.5	49.6	34.0	7.6
200+	---	---	2.9	130.7	26.4	9.5
250+	---	---	21.1	252.5	18.1	42.3
300+	---	---	14.3	193.3	6.5	28.0
350+	---	---	---	41.7	0.0	---
400+	---	---	---	47.3	0.0	---
500+	---	---	---	54.3	0.0	---
600+	---	---	---	125.2	0.0	---
700+	---	---	---	3.0	0.0	---
800+	---	---	---	11.0	0.0	---
900+	---	---	---	54.8	0.0	---
1000+	---	---	---	308.8	0.0	---

Depth	Eureka			S. Columbia		
	Acoustic	Bot. 10 m	Trawl	Acoustic	Bot. 10 m	Trawl
35+	0.0	0.0	---	5.6	0.0	---
50+	0.0	0.0	4.5	46.6	11.4	105.4
100+	13.7	0.0	5.8	233.9	46.4	133.1
150+	326.9	0.0	0.4	577.8	9.7	176.8
200+	339.5	0.0	19.2	665.5	8.9	83.8
250+	475.8	0.0	55.0	631.1	0.0	66.2
300+	82.4	0.0	31.7	412.4	0.0	23.9
350+	319.6	0.0	---	381.3	0.0	---
400+	244.7	0.0	---	404.2	0.0	---
500+	132.2	0.0	---	244.3	0.0	---
600+	145.9	0.0	---	229.5	0.0	---
700+	441.3	0.0	---	237.7	0.0	---
800+	308.1	0.0	---	205.4	0.0	---
900+	193.0	0.0	---	362.5	0.0	---
1000+	237.7	0.0	---	369.3	0.0	---

Table 11 -- Continued.

Depth	N. Columbia/ U.S. Van.			Canada S.		
	Acoustic	Bot. 10 m	Trawl	Acoustic	Bot. 10 m	Trawl
35+	1.8	0.0	---	0.0	0.0	---
50+	266.8	86.2	171.6	53.2	13.7	2.1
100+	451.6	76.3	99.9	344.7	53.9	99.4
150+	533.0	19.5	59.6	1404.3	33.5	32.6
200+	1199.8	1.0	29.2	867.6	7.9	21.0
250+	1131.5	0.0	3.7	1147.5	0.0	18.3
300+	1015.8	1.6	3.7	917.6	0.0	13.1
350+	916.3	0.0	---	627.4	0.0	---
400+	646.2	0.0	---	974.6	0.0	---
500+	546.8	0.0	---	483.9	0.0	---
600+	419.8	0.0	---	594.1	0.0	---
700+	291.7	0.0	---	253.6	0.0	---
800+	354.8	0.0	---	281.3	0.0	---
900+	453.5	0.0	---	71.9	0.0	---
1000+	262.1	0.0	---	91.1	0.0	---

Depth	Canada N.		
	Acoustic	Bot. 10 m	Trawl
35+	---	---	---
50+	5.1	0.9	---
100+	118.8	5.6	---
150+	483.3	22.0	---
200+	916.0	8.9	---
250+	670.7	37.6	---
300+	355.0	8.5	---
350+	884.1	0.0	---
400+	1344.4	0.0	---
500+	1055.8	0.0	---
600+	563.4	0.0	---
700+	1230.1	0.0	---
800+	647.2	0.0	---
900+	764.2	0.0	---
1000+	350.6	0.0	---

Table 12. Calculation of offshore expansion factors for the 1977-1989 acoustic surveys based on the offshore distribution of biomass in the 1992. Differences in the expansion factor for different surveys are due to the differences in the reported depth coverage by the earlier surveys and by differences in the northern extent of the survey.

A. Unadjusted biomass by region.

		Survey year				
Strata	Strata No.	1977	1980	1983	1986	1989
Mont.	1	108.087	579.841	56.203	770.292	209.437
Eureka	2	360.944	182.783	252.265	192.205	360.454
S. Col.	3	274.138	82.113	303.477	273.846	303.690
N. C./Van	4	194.741	338.295	330.198	367.099	254.378
Canada	5	191.382	162.402	258.725	284.316	104.603
	Total	1129.292	1345.434	1200.868	1887.758	1232.564

B. Expansion factors based on survey coverage

		Survey year				
Strata	Strata No.	1977	1980	1983	1986	1989
Inshore limit		91 m	55 m	55 m	55 m	55 m
Offshore limit		457 m	457 m	366 m	366 m	366 m
Mont.	1	2.00	2.00	2.19	2.19	2.19
Eureka	2	2.96	2.96	4.19	4.19	4.19
S. Col.	3	1.33	1.33	1.63	1.63	1.63
N. Col./Van	4	1.42	1.42	1.48	1.48	1.48
Canada	offshore	1.36	1.36	1.22	1.22	1.45
	northern	1.48	1.48	1.68	1.83	1.48

C. Expanded biomass estimates

		Survey year				
Strata	Strata No.	1977	1980	1983	1986	1989
Mont.	1	216.174	1159.682	123.085	1686.939	458.667
Eureka	2	1068.394	541.038	1056.990	805.339	1510.302
S. Col.	3	364.604	109.210	494.668	446.369	495.015
N. C./Van.	4	276.532	480.379	488.693	543.307	376.479
US total		1925.704	2290.309	2163.435	3481.954	2840.463
Ratio old/new		48.70%	51.65%	43.55%	46.05%	39.71%
Canada	offshore	1.36	1.36	1.22	1.22	1.45
	northern	1.48	1.48	1.68	1.83	1.48
Canada		385.214	326.883	530.283	634.764	224.478
Ratio old/new		49.68%	49.68%	48.79%	44.79%	46.60%
Coastwide total		2310.918	2617.192	2693.718	4116.718	3064.941

Table 13.--Estimates of Pacific whiting biomass (1,000 t) by region from the NMFS bottom trawl and acoustic surveys in 1977, 1980, 1983, 1986, 1989 and 1992. The trawl survey estimates of biomass in the Canadian zone in 1977 and 1986 were interpolated by multiplying the acoustic biomass in 1977 and 1989 by the ratio of the aggregate trawl biomass for the Canadian Vancouver International North Pacific Fisheries Commission (INPFC) area for the surveys in 1980, 1983, and 1989 to the aggregate acoustic biomasses for the same years. The expansion factor used to account for the unsurveyed biomass north of survey grid has not been used to adjust these biomass estimates. The acoustic survey estimates were obtained using a target strength of -35 db/kg. BT-bottom trawl estimate, ACO-acoustic estimate, TOT-total.

		INPFC Areas					
Year	Estimate	Mont.	Eureka	Columb.	U.S. Van.	Canada	Total
1977	BT	17.707	10.153	31.548	6.523	10.376	76.307
	ACO	108.087	360.944	316.44	152.439	191.382	1129.292
	TOT	125.794	371.097	347.988	158.962	201.758	1205.599
1980	BT	140.948	11.338	19.858	11.770	4.385	188.299
	ACO	579.841	182.783	260.477	159.931	162.402	1345.434
	TOT	720.789	194.121	280.335	171.701	166.787	1533.733
1983	BT	19.164	43.559	56.665	8.068	1.352	128.808
	ACO	56.203	252.265	397.168	236.507	258.725	1200.868
	TOT	75.367	295.824	453.833	244.575	260.077	1329.676
1986	BT	95.953	45.228	78.568	19.403	15.414	254.566
	ACO	770.292	192.205	402.469	238.476	284.316	1887.758
	TOT	866.245	237.433	481.037	257.879	299.730	2142.324
1989	BT	91.073	20.415	224.055	21.503	22.764	379.810
	ACO	241.130	360.454	420.665	137.405	104.603	1264.257
	TOT	332.203	380.869	644.720	158.908	127.367	1644.067
1992	BT	13.749	4.971	237.913	38.564	57.342	352.539
	ACO	88.233	212.007	935.657	416.066	931.660	2583.623
	TOT	101.982	216.978	1173.570	454.630	989.002	2936.162

Mont. = Conception and Monterey.
Columb. = Columbia.
U.S. Van. = U.S. Vancouver.

Table 14. --Natural mortality estimates for Pacific whiting using expanded estimates of abundance for the 1977-1989 triennial acoustic/midwater trawl surveys and the unrevised 1992 acoustic estimate. Only the dominant year classes (1967, 1970, 1973, 1980, 1984, and 1987) were used to estimate natural mortality. Starting abundance, ending abundance and aggregate catch are in millions of fish.

Year class	Mean age (years)	Years surveyed	Age range (years)	Starting abundance	Ending abundance	Aggregate catch	Fishing mortality	Natural mortality
1973	5.5	1977-80	4-7	1119.929	504.146	134.484	0.058	0.208
1970	8.5	1977-80	7-10	1174.686	143.345	103.154	0.070	0.631
1967	12	1977-80	10-13	63.045	23.992	4.689	0.039	0.283
1977	4.5	1980-83	3-6	2642.064	535.385	241.323	0.061	0.471
1973	8.5	1980-83	7-10	504.146	88.848	64.598	0.090	0.489
1970	12	1980-83	10-13	143.345	25.938	38.217	0.185	0.384
1980	4.5	1983-86	3-6	5996.005	2950.128	451.235	0.035	0.201
1977	7.5	1983-86	6-9	535.385	306.057	86.248	0.070	0.116
1973	12	1983-86	10-13	88.848	16.418	13.123	0.102	0.461
1984	3.5	1986-89	2-5	6045.414	3176.041	674.983	0.050	0.164
1980	7.5	1986-89	6-9	2950.128	1016.455	603.107	0.111	0.244
1977	11	1986-89	9-12	306.057	80.234	59.060	0.117	0.330
1987	3.5	1989-92	2-5	931.411	833.560	109.339	0.041	-0.004
1984	6.5	1989-92	5-8	3176.041	1714.925	611.546	0.086	0.119
1980	11	1989-92	9-12	1016.455	552.367	303.887	0.133	0.070
1977	14	1989-92	12-15	80.234	28.483	22.392	0.149	0.196
							Average	0.273
							Median	0.226

Table 15.--Log-likelihood components for the basic geographic stock synthesis model. The 1992 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. Results are presented for a models tuned to 1992 biomass estimates for a target strengths of -35 dB/kg and a -33.5 dB/kg.

Likelihood component	Emphasis level	-35 dB/kg TS Likelihood	-33.5 dB/kg TS Likelihood
U.S. catch (age composition)	1.0	-234.589	-238.103
Canadian catch (age composition)	1.0	-281.228	-282.009
U.S. zone acoustic (survey index)	5.0	9.025	8.084
U.S. zone acoustic survey (age composition)	1.0	-96.492	-94.671
Canadian zone acoustic (survey index)	5.0	5.051	4.625
Canadian zone acoustic survey (age composition)	1.0	-102.060	-99.326
1992 U.S. zone (acoustic biomass)	5.0	2.041	1.568
1992 U.S. zone acoustic (age composition)	0.001	-98.657	-99.593
1992 Canadian zone (acoustic biomass)	5.0	0.999	1.028
1992 Canadian zone (age composition)	0.001	-102.053	-99.326
DFO acoustic survey (biomass)	0.001	-77.957	-84.682
DFO acoustic survey (age composition)	0.001	-111.899	-115.782
U.S. zone trawl (survey index)	0.001	-50.395	-57.079
U.S. zone trawl survey (age composition)	0.001	-236.933	-240.971
Canadian zone trawl (survey index)	0.001	-61.778	-63.260
Canadian zone trawl survey (age composition)	0.001	-321.527	-313.696
Penalty component	5.0	-2.994	-3.060
Total likelihood	---	-643.090	-653.950
1992 biomass (t)		3,055,139.0	2,317,714.0

Table 16.--Estimated selectivity at age for the Pacific whiting fisheries and surveys estimated using the basic geographic model with a target strength of -35 dB/kg for the 1992 acoustic survey biomass estimate. The "U.S. zone acoustic index" selectivity applies to the NMFS acoustic biomass triennial survey data from the U.S. zone, while the "Canadian zone acoustic index" selectivity applies to the NMFS triennial survey acoustic data in the Canadian zone. The "U.S. zone trawl index" selectivity applies to the NMFS trawl biomass triennial survey data from the U.S. zone, while the "Canadian zone trawl index" selectivity applies to the NMFS triennial survey acoustic data in the Canadian zone. The U.S. and Canadian fisheries were modeled using the double logistic selectivity function. 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 Canadian acoustic survey selectivities were fixed at unity.

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	0.45	1.00	0.54	1.00	1.00	0.17	0.17
3	0.21	0.44	0.61	1.00	0.80	1.00	1.00	0.24	0.24
4	0.56	0.49	0.76	1.00	1.00	1.00	1.00	0.33	0.33
5	0.86	0.55	0.86	1.00	1.00	1.00	1.00	0.43	0.43
6	0.98	0.62	0.92	1.00	1.00	1.00	1.00	0.54	0.54
7	1.00	0.70	0.96	1.00	1.00	1.00	1.00	0.65	0.65
8	1.00	0.78	0.98	1.00	1.00	1.00	1.00	0.74	0.74
9	0.98	0.87	0.99	1.00	1.00	1.00	1.00	0.82	0.82
10	0.92	0.95	0.99	1.00	1.00	1.00	1.00	0.88	0.88
11	0.81	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.92
12	0.60	0.94	1.00	1.00	1.00	1.00	1.00	0.95	0.95
13	0.36	0.71	1.00	1.00	1.00	1.00	1.00	0.98	0.98
14	0.17	0.41	1.00	1.00	1.00	1.00	1.00	0.99	0.99
15	0.07	0.19	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Survey catchability			0.526	0.526	1.000	1.000	1.000	0.149	0.019

Table 17. Numbers at age (millions of fish) for the coastal population of Pacific whiting as estimated by the stock synthesis model, 1977. 1992. 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	515.8	359.7	1,337.3	268.4	219.8	1,139.7	154.5	103.3	41.7	37.9	29.5	15.4	0.0	0.0
1978	235.9	408.4	276.6	937.5	162.4	124.8	699.0	111.8	89.5	41.5	40.9	33.3	17.9	0.0
1979	4,044.0	186.0	310.1	189.2	582.8	107.9	91.7	534.7	86.4	69.5	32.4	32.3	26.6	14.5
1980	380.4	3,208.6	145.6	237.5	147.8	477.8	88.7	74.6	432.6	70.0	56.7	26.8	27.1	35.1
1981	419.5	301.4	2,479.6	102.9	142.4	82.3	284.7	57.3	49.9	293.0	47.7	39.0	18.7	44.1
1982	12,208.1	328.7	220.4	1,537.3	59.9	95.1	62.2	223.8	45.4	39.6	234.0	38.6	32.1	52.8
1983	144.3	9,429.5	220.0	104.4	635.2	25.9	41.8	27.4	98.5	20.0	17.5	104.3	17.4	39.2
1984	117.0	114.2	7,287.3	166.5	93.2	678.8	28.9	46.8	30.7	110.0	22.3	19.7	119.1	66.1
1985	203.8	92.8	88.6	5,276.8	112.7	67.0	511.1	22.0	35.6	23.3	83.5	17.1	15.3	146.6
1986	9,709.5	160.4	70.0	59.0	3,003.1	65.6	42.3	331.3	14.3	23.2	15.2	54.7	11.3	108.5
1987	0.1	7,666.8	122.0	47.6	37.0	2,165.3	55.0	37.5	297.2	12.9	20.9	13.9	50.8	114.2
1988	435.1	0.1	5,859.6	85.3	31.1	26.4	1,653.5	42.7	29.1	230.9	10.0	16.5	11.2	137.3
1989	2,657.4	342.2	0.1	3,774.3	48.5	19.0	17.4	1,116.3	28.9	19.7	156.6	6.9	11.6	108.3
1990	1,336.2	2,012.2	223.8	0.0	1,953.5	29.3	12.4	11.6	741.7	19.2	13.1	106.3	4.8	86.7
1991	232.3	1,053.9	1,537.1	162.4	0.0	1,528.9	23.3	9.9	9.2	589.5	15.4	10.7	88.6	79.1
1992	1,988.2	180.0	755.9	956.0	99.7	0.0	1,140.1	17.6	7.5	7.0	450.5	12.0	8.6	140.3
						Canadian zone								
1977	1.8	3.3	30.3	14.4	26.9	296.1	75.4	79.7	42.6	44.6	37.1	20.0	0.0	0.0
1978	0.3	2.6	7.9	104.4	48.3	58.2	372.1	61.4	49.5	23.0	22.7	18.4	9.9	0.0
1979	7.4	1.7	12.7	28.7	201.5	50.8	46.7	276.9	44.9	36.2	16.9	16.8	13.8	7.5
1980	0.2	6.3	1.1	6.7	13.6	103.3	29.2	28.4	171.4	28.0	22.7	10.8	10.9	14.1
1981	0.3	1.3	56.6	10.7	43.9	40.2	156.3	32.2	28.2	165.5	27.0	22.0	10.6	24.9
1982	28.2	4.7	16.9	394.1	24.7	43.5	29.0	104.4	21.2	18.5	109.2	18.0	15.0	24.7
1983	0.7	302.9	42.9	79.2	836.7	38.3	62.9	41.4	148.6	30.1	26.4	157.3	26.3	59.1
1984	0.2	1.1	369.4	36.0	46.7	440.7	19.8	32.4	21.2	76.1	15.5	13.6	82.4	45.8
1985	0.2	0.5	2.5	679.6	42.6	39.6	337.8	14.8	24.1	15.8	56.7	11.6	10.4	99.6
1986	27.4	2.1	3.9	12.4	1,625.2	54.8	40.2	324.8	14.1	22.9	15.0	54.1	11.2	107.3
1987	0.0	64.8	5.3	8.7	16.3	1,291.6	35.1	24.2	192.4	8.3	13.6	9.0	32.9	74.0
1988	0.6	0.0	198.0	11.6	10.8	13.1	898.9	23.6	16.2	128.6	5.6	9.2	6.2	76.4
1989	5.8	4.1	0.0	875.5	24.2	12.1	11.7	755.5	19.6	13.3	106.2	4.7	7.9	73.4
1990	13.0	99.8	46.2	0.0	1,450.5	23.7	10.2	9.5	611.8	15.8	10.8	87.7	4.0	71.5
1991	0.6	14.7	102.0	39.2	0.0	952.4	15.3	6.5	6.1	391.5	10.2	7.1	58.9	52.5
1992	10.5	4.3	70.5	251.4	44.0	0.0	617.7	9.6	4.1	3.8	247.0	6.6	4.7	76.9
						Total population								
1977	517.6	363.0	1,367.6	282.8	246.7	1,435.8	229.9	183.0	84.3	82.5	66.6	35.5	0.0	0.0
1978	236.2	411.0	284.5	1,041.9	210.6	183.0	1,071.1	173.2	139.0	64.5	63.6	51.7	27.9	0.0
1979	4,051.4	187.7	322.8	217.9	784.3	158.7	138.4	811.6	131.3	105.7	49.3	49.1	40.4	22.0
1980	380.6	3,214.9	146.7	244.2	161.4	581.1	117.9	102.9	604.0	98.0	79.4	37.5	38.0	49.2
1981	419.8	302.7	2,536.1	113.6	186.3	122.5	441.0	89.5	78.1	458.6	74.7	61.0	29.2	69.0
1982	12,236.3	333.4	237.3	1,931.4	84.7	138.5	91.2	328.2	66.6	58.1	343.2	56.6	47.1	77.5
1983	145.0	9,732.4	262.9	183.6	1,471.9	64.2	104.7	68.8	247.1	50.1	43.9	261.5	43.7	98.3
1984	117.2	115.3	7,656.7	202.6	139.9	1,119.5	48.7	79.2	51.9	186.1	37.8	33.4	201.5	111.9
1985	204.0	93.3	91.1	5,956.4	155.4	106.6	849.0	36.8	59.7	39.0	140.2	28.7	25.7	246.2
1986	9,737.0	162.5	73.9	71.4	4,628.3	120.4	82.5	656.1	28.4	46.0	30.2	108.9	22.5	215.7
1987	0.1	7,731.6	127.3	56.3	53.3	3,457.0	90.1	61.6	489.6	21.2	34.5	22.8	83.8	188.2
1988	435.7	0.1	6,057.6	96.9	41.9	39.5	2,552.4	66.3	45.3	359.5	15.6	25.7	17.4	213.7
1989	2,663.2	346.3	0.1	4,649.8	72.8	31.1	29.1	1,871.8	48.4	33.0	262.8	11.6	19.5	181.7
1990	1,349.2	2,112.0	270.0	0.0	3,404.0	53.0	22.6	21.1	1,353.4	35.0	24.0	194.1	8.7	158.3
1991	232.9	1,068.6	1,639.0	201.6	0.0	2,481.3	38.5	16.4	15.3	981.0	25.5	17.8	147.5	131.6
1992	1,998.7	184.3	826.4	1,207.3	143.7	0.0	1,757.8	27.2	11.6	10.8	697.5	18.5	13.3	217.2

Table 18.--Time series of estimated biomass, recruitment, and utilization for 1977-92 for the -35 dB/kg target strength 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	3.285	1.505	0.518	3.88%	0.16%	4.04%
1978	2.664	1.415	0.236	3.69%	0.20%	3.89%
1979	2.583	1.125	4.051	4.83%	0.48%	5.31%
1980	3.487	1.381	0.381	2.08%	0.50%	2.58%
1981	3.140	1.405	0.420	3.65%	0.78%	4.43%
1982	2.737	1.375	12.236	2.76%	1.17%	3.94%
1983	5.091	2.096	0.145	1.44%	0.80%	2.24%
1984	5.025	2.131	0.117	1.92%	0.84%	2.76%
1985	4.911	2.415	0.204	1.74%	0.51%	2.25%
1986	3.908	2.210	9.737	3.97%	1.42%	5.39%
1987	5.928	2.354	0.000	2.71%	1.24%	3.95%
1988	5.139	2.267	0.436	3.13%	1.76%	4.89%
1989	4.744	2.237	2.663	4.45%	2.10%	6.55%
1990	4.253	2.161	1.349	4.32%	1.80%	6.12%
1991	4.062	1.730	0.233	5.35%	2.57%	7.92%
1992	3.055	1.562	1.999	6.83%	2.83%	9.66%
Avg. 1977-92	4.001	1.836	2.170	3.54%	1.20%	4.74%

Table 19. Estimated time series of Pacific whiting age 3 + population biomass, spawning biomass, and age-2 recruitment (billions), 1960-1992, for the -35 dB/kg target strength model.

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	3.737	1.740	0.518
1978	2.974	1.586	0.236
1979	2.842	1.243	4.051
1980	3.708	1.493	0.381
1981	3.297	1.483	0.420
1982	2.848	1.430	12.236
1983	5.099	2.103	0.145
1984	5.082	2.158	0.117
1985	4.987	2.452	0.204
1986	3.916	2.213	9.737
1987	5.953	2.367	0.000
1988	5.176	2.284	0.436
1989	4.716	2.240	2.663
1990	4.176	2.086	1.349
1991	4.038	1.726	0.233
1992	3.063	1.565	1.999
Average 1960-92	4.215	1.920	1.875

Table 20. Target-strength measurements of selected gadoid species.

Species	Length (cm)	Target strength (dB/kg)	Source	Measurement technique	Frequency
Blue whiting	31	-33.5	Robinson (1982)	Indirect in situ	29.3kHz
(*Micromesistius poutassou*)	33	-33.0	Robinson (1982) based on Nakken and Olsen (1977)	Tethered fish (adjusted)	38 kHz
Atlantic cod	30	-33.5	Anon. (1978) based on Nakken and Olsen (1977)	Tethered fish (adjusted)	38 kHz
	50	-34.5	Anon. (1978) based on Nakken and Olsen (1977)	Tethered fish (adjusted)	38 kHz
Saithe	30	-33.0	Anon. (1978) based on Nakken and Olsen (1977)	Tethered fish (adjusted)	38 kHz
	50	-34.0	Anon. (1978) based on Nakken and Olsen (1977)	Tethered fish (adjusted)	38 kHz
Combined gadoids (includes Atlantic cod,	30-40	-28.5	Forbes et al. (1982)	Caged, free-swimming fish	38 kHz
saithe, blue whiting and haddock	40-50	-28.2	Forbes et al. (1982)	Caged, free-swimming fish	38 kHz
(*Melanogrammus aeglefinus*))	50-60	-28.6	Forbes et al. (1982)	Caged, free-swimming fish	38 kHz
Pacific whiting (*Merluccius productus*)	51.4	-35.0	Traynor (1975)	Dual beam in situ (night-time)	120 kHz
	50-55	-36.0	Williamson and Traynor (1984)	Dual beam in situ (night-time)	38 kHz
Walleye pollock (*Theragra chalcogramma*)	47	-29.9 -32.7	Traynor and Williamson (1983)	Dual beam in situ (daytime) (night-time)	38 kHz

Table 21 .--Parameter values for the revised age-structured simulation model used to estimate long-term Pacific whiting yield.

Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
USWT	0.278	0.392	0.481	0.555	0.603	0.649	0.694	0.729	0.760	0.814	0.871	0.931	0.938	1.021
CANWT	0.290	0.504	0.604	0.679	0.741	0.780	0.837	0.877	0.906	0.966	1.023	1.065	1.092	1.150
POPWT	0.253	0.386	0.496	0.594	0.657	0.716	0.767	0.811	0.848	0.902	0.934	0.982	1.026	1.064
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
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
POPINIT	1.999	0.184	0.826	1.207	0.144	0.000	1.758	0.027	0.012	0.011	0.697	0.019	0.013	0.217
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

USWT = United States fishery weight at age (g).
CANWT = Canadian fishery weight at age (g).
POPWT = Population weight at age (g).
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.
USCAN = Proportion of fish migrating into Canadian zone.
POPINIT = Initial population vector (billions).
NMORT = Natural mortality rate.

Table 22.--Sustainable yield for different harvesting strategies for Pacific whiting for a total population biomass consistent with an acoustic target strength of -35 dB/kg. SB_{opt} used in the variable F and combination 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.

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 23.--Sustainable yield for different harvesting strategies for Pacific whiting for a total population biomass consistent with an acoustic target strength of -33.5 dB/kg. SB, opt used in the variable F and combination 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.

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	0.16	234	49.4	---	1,199	46.5	60.1	9.5
Moderate	0.23	283	51.7	---	1,020	50.2	51.1	20.6
High	0.30	320	53.8	---	902	53.3	45.2	30.6
35% prist. spawn. biom.	0.45	359	58.5	---	712	59.3	35.7	50.5
Variable F strategy								
Low	0.22	280	80.6	1,020	1,022	40.0	51.2	9.8
Moderate	0.30	320	81.1	1,020	902	41.7	45.2	20.1
High	0.39	338	81.3	1,020	819	42.4	41.1	29.2
35% prist. spawn. biom.	0.56	359	83.7	1,020	715	44.4	35.8	44.2
Hybrid F strategy								
Low	0.22	266	60.1	1,020	1,100	46.3	55.1	10.0
Moderate	0.30	293	64.6	1,020	954	46.8	47.8	19.2
High	0.40	323	68.5	1,020	854	47.7	42.8	29.3
35% prist. spawn. biom.	0.63	360	75.3	1,020	709	48.9	35.5	48.0

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

CV = coefficient of variation

Table 24.--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	0.271	0.368	0.450	0.511	0.534	0.569	0.590	0.582	0.579	0.619	0.659	0.757	0.722	0.845
CANWT	0.271	0.562	0.597	0.645	0.691	0.734	0.764	0.804	0.839	0.872	0.915	0.972	1.025	1.093
POPWT	0.240	0.359	0.459	0.538	0.570	0.623	0.652	0.661	0.672	0.760	0.735	0.800	0.865	0.923
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
1992 AC	1.999	0.184	0.826	1.207	0.144	0.000	1.758	0.027	0.012	0.011	0.697	0.019	0.013	0.217
1993 AC	0.941	1.582	0.142	0.604	0.850	0.101	0.000	1.223	0.019	0.008	0.008	0.500	0.014	0.180
1994 AC	0.941	0.746	1.227	0.105	0.434	0.608	0.072	0.000	0.868	0.013	0.006	0.006	0.376	0.153

1992 estimated yield: U.S.-208,800 t Canada-86,300 t
1993 expected yield: U.S.-142,000 t Canada- 61,000 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
1992 AC = 1992 initial age composition (billions)
1993 AC = 1993 initial age composition (billions)
1994 AC = 1994 initial age composition (billions)

Table 25.--Summary of the 1994-96 potential annual yields for a population biomass consistent with a -35 dB/kg acoustic target strength. Yield and biomass projections are in millions of tons. All projections are based on median recruitment of 0.941 billion age-2 fish for 1993-1996.

Management strategy	Harvest rate	Year	Fishing mortality	Total yield	Spawn. biomass	Age-2+ biomass
Constant F	Low	1994	0.17	0.245	1.257	2.855
		1995	0.17	0.219	1.164	2.602
		1996	0.17	0.191	1.006	2.305
	Moderate	1994	0.24	0.338	1.257	2.855
		1995	0.24	0.287	1.117	2.512
		1996	0.24	0.242	0.933	2.167
	High	1994	0.31	0.426	1.257	2.855
		1995	0.31	0.346	1.071	2.426
		1996	0.31	0.280	0.866	2.041
Variable F	Low	1994	0.26	0.358	1.257	2.855
		1995	0.23	0.268	1.106	2.492
		1996	0.19	0.195	0.933	2.169
	Moderate	1994	0.38	0.514	1.257	2.855
		1995	0.31	0.333	1.026	2.339
		1996	0.26	0.226	0.835	1.983
	High	1994	0.49	0.631	1.257	2.855
		1995	0.38	0.365	0.966	2.225
		1996	0.30	0.238	0.770	1.860
Hybrid F	Low	1994	0.23	0.325	1.257	2.855
		1995	0.23	0.278	1.123	2.525
		1996	0.20	0.208	0.943	2.186
	Moderate	1994	0.33	0.450	1.257	2.855
		1995	0.32	0.355	1.059	2.402
		1996	0.26	0.235	0.852	2.014
	High	1994	0.42	0.555	1.257	2.855
		1995	0.39	0.394	1.005	2.299
		1996	0.31	0.248	0.787	1.892

Table 26.--Summary of the 1994-96 potential annual yields for a population biomass consistent with a -33.5 dB/kg acoustic target strength. Yield and biomass projections are in millions of tons. All projections are based on median recruitment of 0.876 billion age-2 fish for 1993-1996.

Management strategy	Harvest rate	Year	Fishing mortality	Total yield	Spawn. biomass	Age-2+ biomass
Constant F	Low	1994	0.16	0.154	0.834	2.002
		1995	0.16	0.146	0.811	1.920
		1996	0.16	0.137	0.743	1.794
	Moderate	1994	0.23	0.216	0.834	2.002
		1995	0.23	0.196	0.779	1.859
		1996	0.23	0.177	0.692	1.696
	High	1994	0.30	0.275	0.834	2.002
		1995	0.30	0.238	0.749	1.801
		1996	0.30	0.208	0.645	1.608
Variable	Low	1994	0.18	0.172	0.834	2.002
		1995	0.17	0.155	0.802	1.903
		1996	0.16	0.133	0.731	1.770
	Moderate	1994	0.25	0.229	0.834	2.002
		1995	0.23	0.192	0.772	1.846
		1996	0.20	0.156	0.688	1.689
	High	1994	0.32	0.290	0.834	2.002
		1995	0.28	0.224	0.741	1.786
		1996	0.25	0.175	0.646	1.610
Hybrid	Low	1994	0.18	0.172	0.834	2.002
		1995	0.17	0.155	0.802	1.903
		1996	0.16	0.133	0.731	1.770
	Moderate	1994	0.25	0.229	0.834	2.002
		1995	0.23	0.192	0.772	1.846
		1996	0.20	0.156	0.688	1.689
	High	1994	0.33	0.297	0.834	2.002
		1995	0.29	0.227	0.738	1.780
		1996	0.25	0.177	0.642	1.601

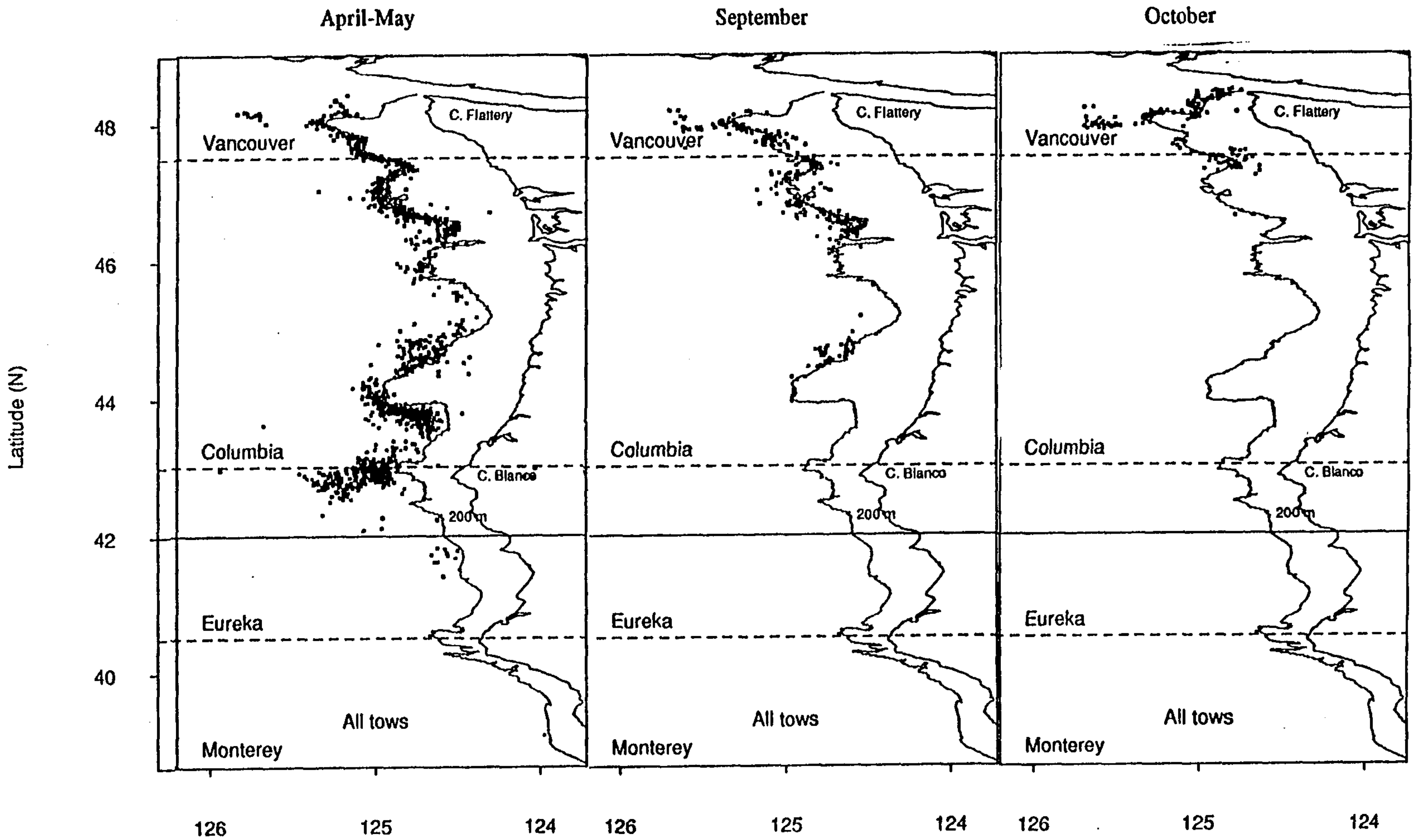


Figure 1 .--Trawl positions of factory trawlers and catcher boats participating in the 1992 offshore fishery for Pacific whiting during April-May, September, and October. The 200 m depth contour is shown in the figure. The latitudinal scale is compressed on the plots.

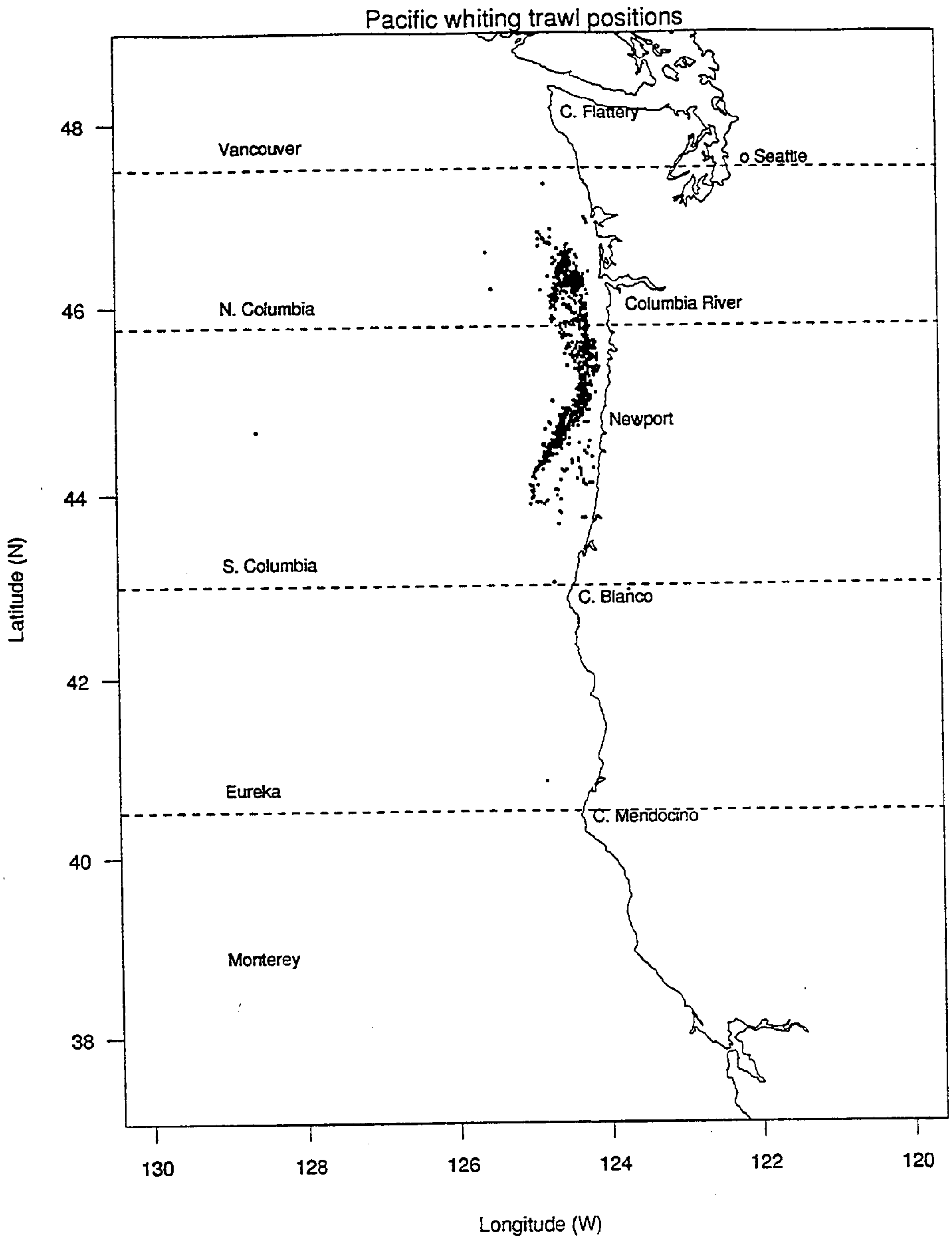


Figure 2.--Trawl positions shore-based boats participating in the 1992 fishery for Pacific whiting. Position data is for landings in Oregon ports only.

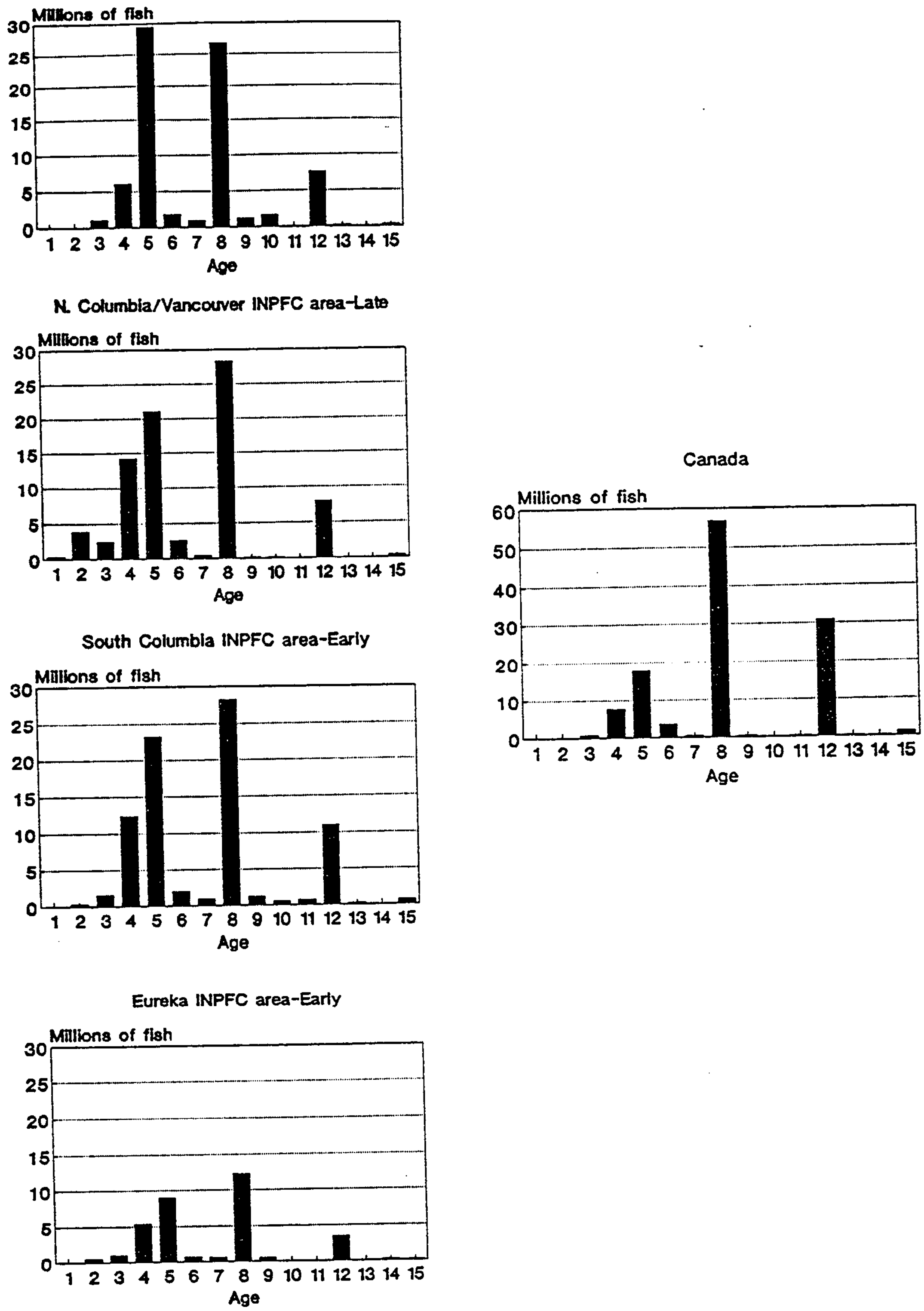


Figure 3.--Catch at age of Pacific whiting by geographic region in millions of fish for the offshore fleet in the U. S . and Canadian zones in 1992. A separate. panel shows the catch at age in the North Columbia/Vancouver region early in the season (April-May) and late in the season (September-October).

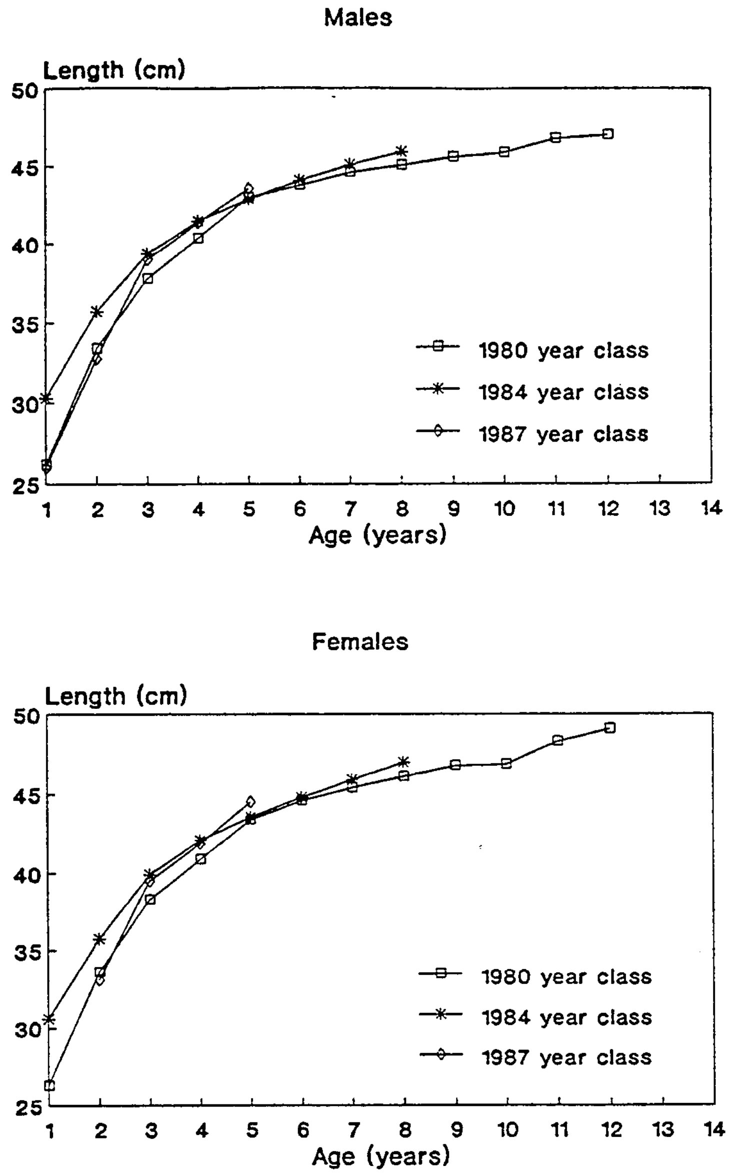


Figure 4.--A comparison of the growth trajectory of the 1980, 1984, and 1987 year classes. Mean length at age is estimated from samples of the offshore U.S. fishery for Pacific whiting.

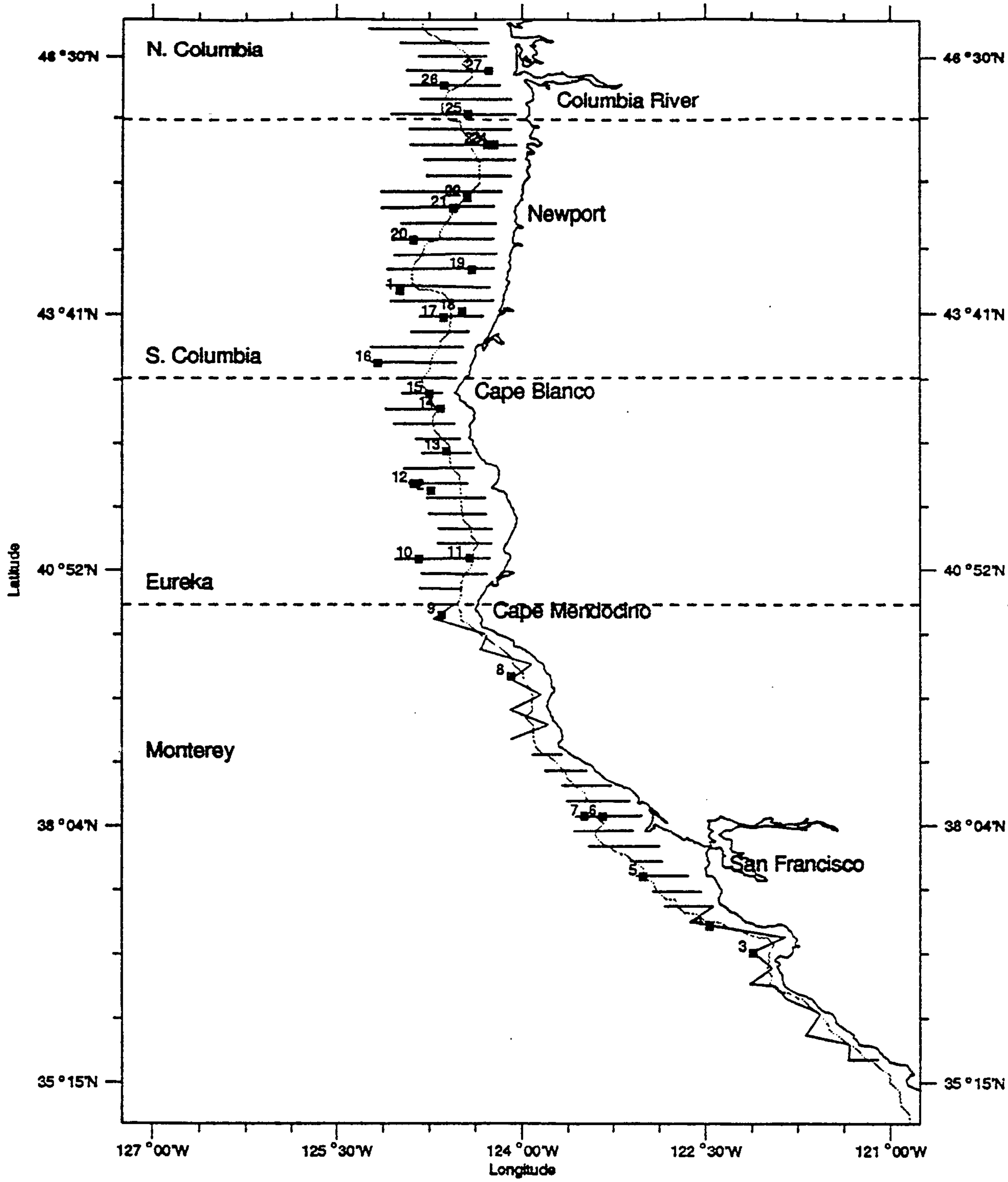


Figure 5.--The transect and trawl haul locations occupied in the southern portion of 1992 Pacific whiting acoustic/midwater trawl survey. Dashed lines represent INPFC area boundaries.

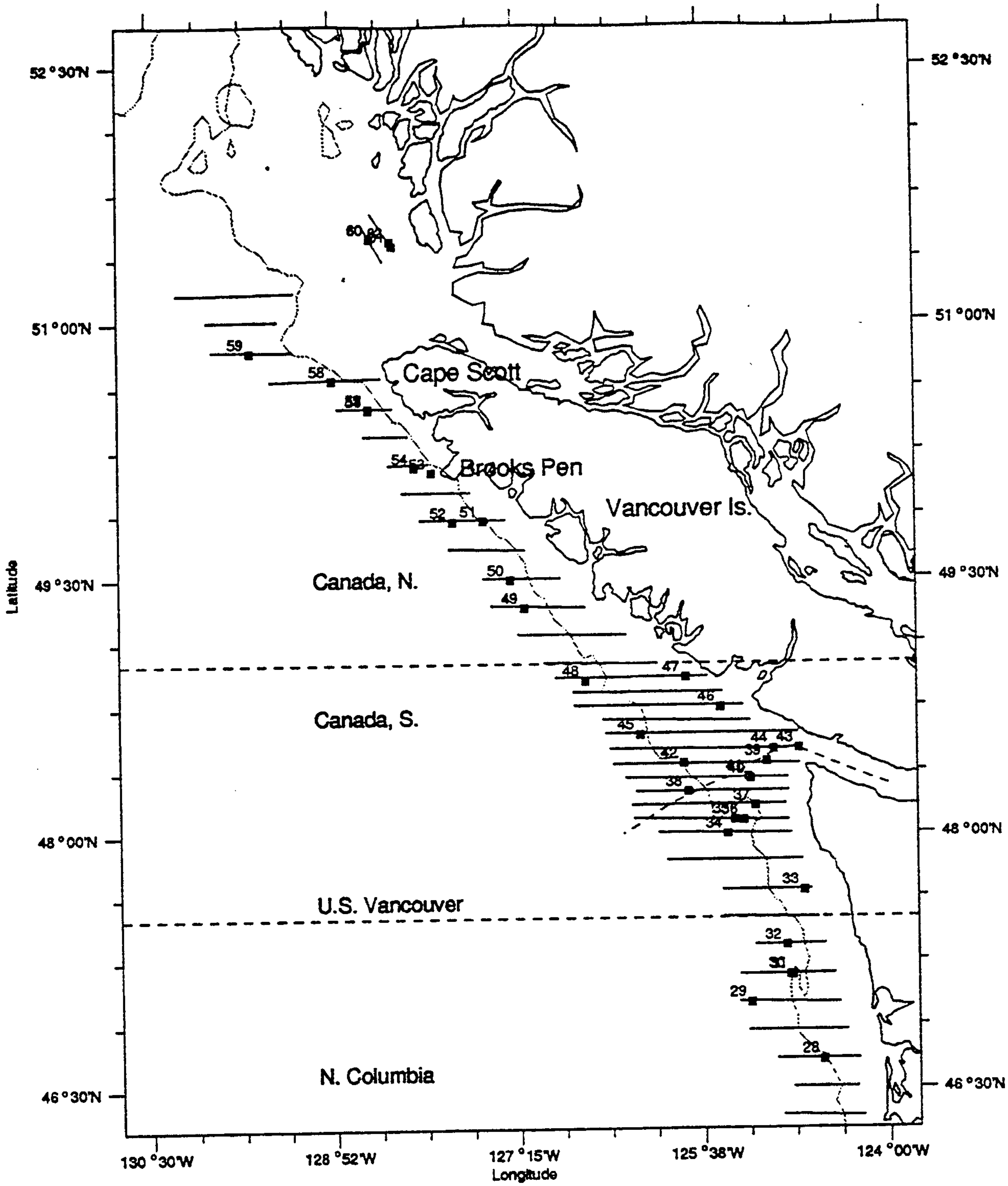


Figure 6.--The transect and trawl haul locations occupied in the northern portion of 1992 Pacific whiting acoustic/midwater trawl survey. Dashed lines represent INPFC area boundaries.

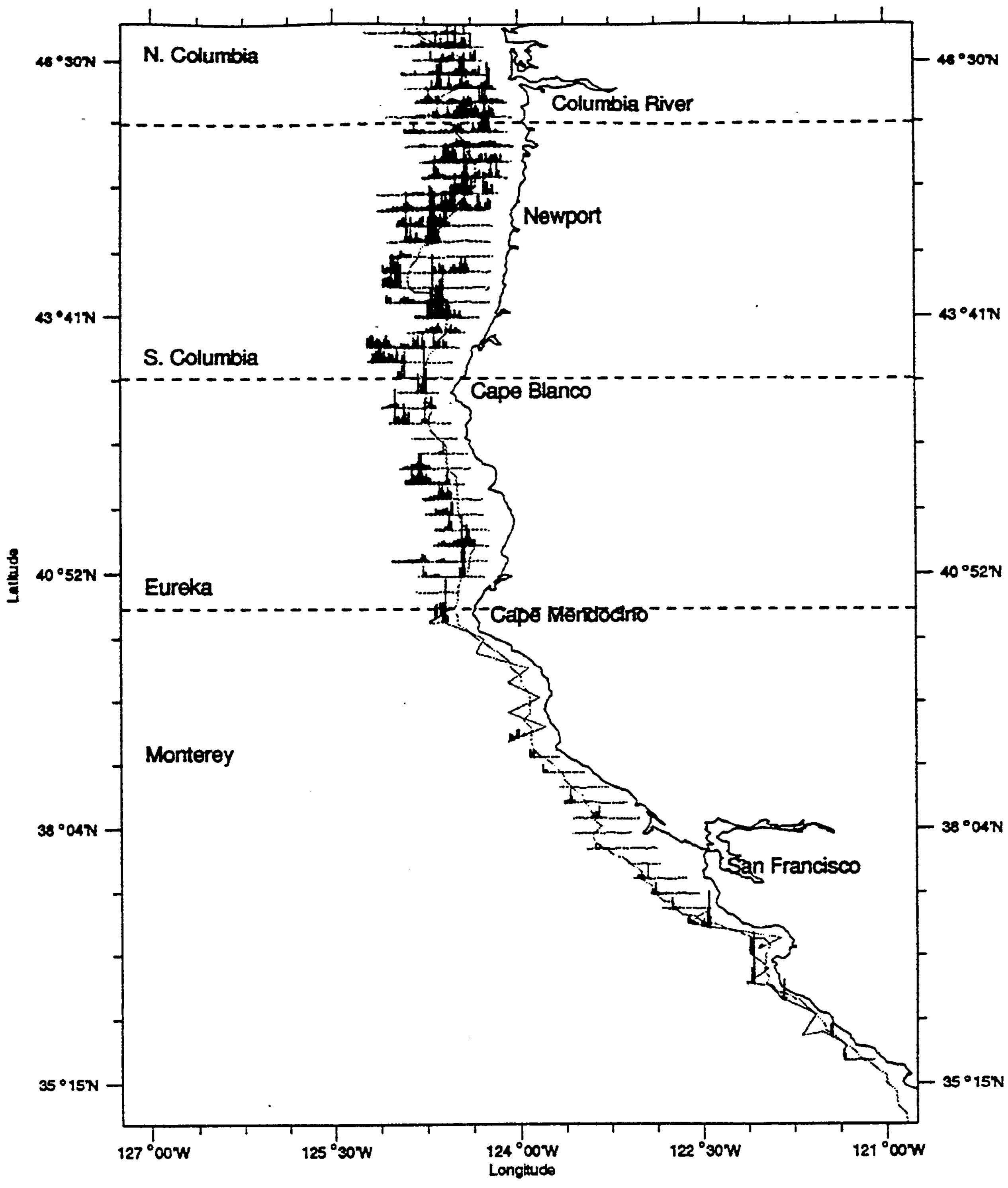


Figure 7.--Distribution of Pacific whiting surface densities along transects for the southern portion of West Coast acoustic survey cruise. A bar height of 1^{o} latitude corresponds to an area backscattering value (S_a) of 10,000 m^2 nmi^{-2} and surface fish density of 0.7 kg m^{-2}. Note that the apparent fish density is dependent on transect spacing.

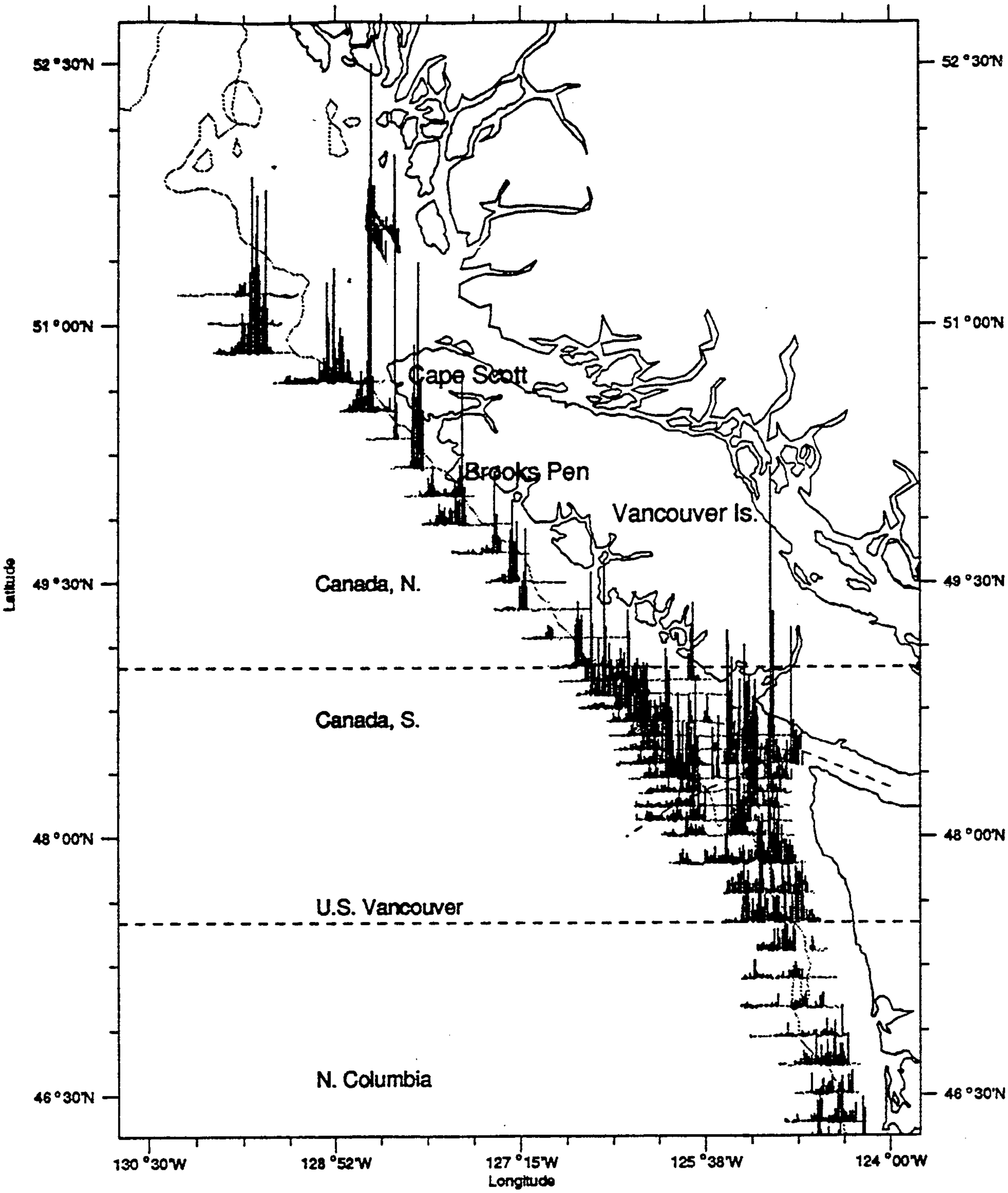


Figure 8.--Distribution of Pacific whiting surface densities along transects for the northern portion of West Coast acoustic survey cruise. A bar height of 1° latitude corresponds to an area backscattering value (S_a) of 10,000 m^2 nmi^{-2} and surface fish density of 0.7 kg m^{-2}. Note that the apparent fish density is dependent on transect spacing.

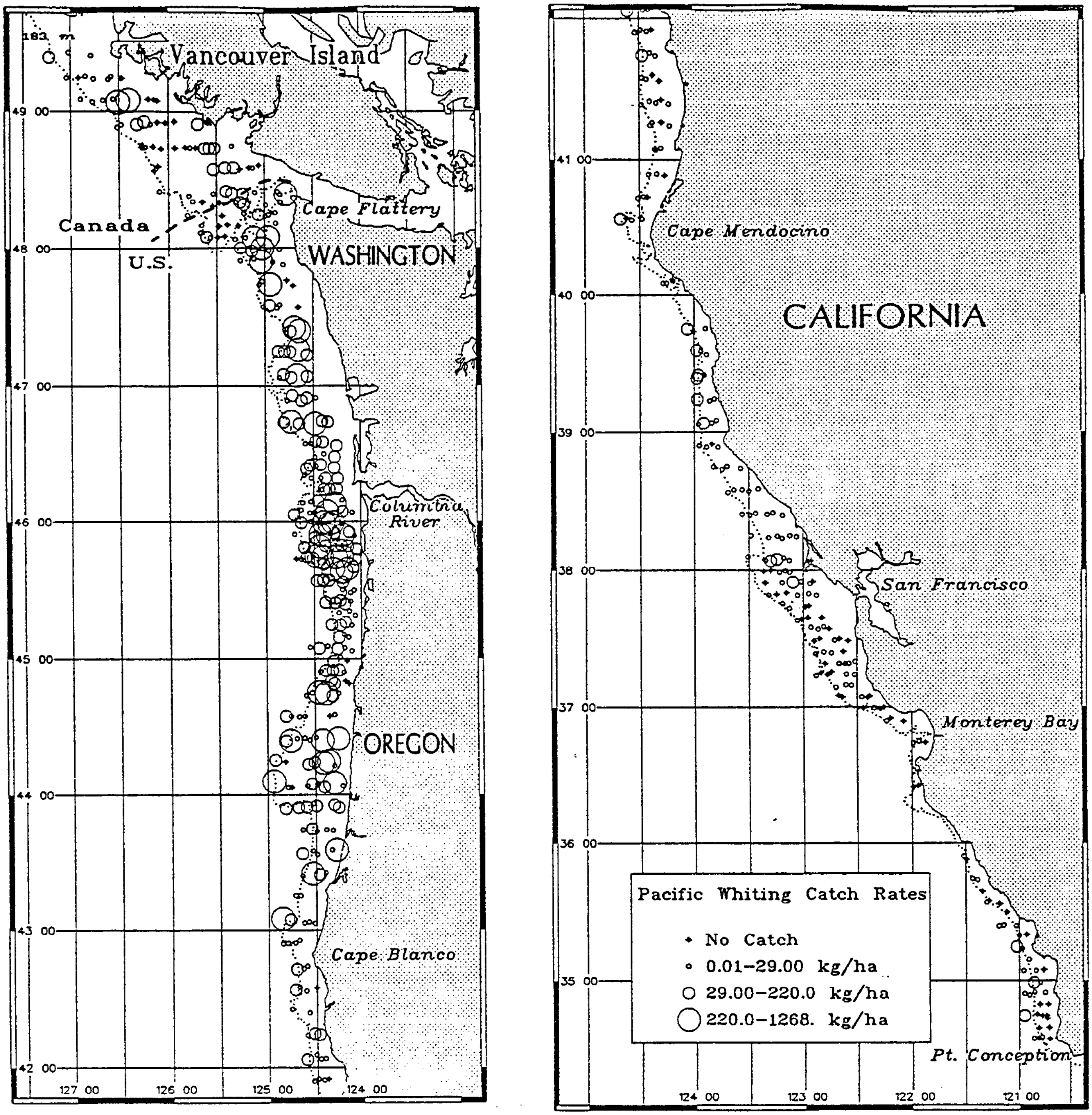


Figure 9.--The distribution of Pacific whiting catch per unit effort (kg/ha) by haul position for the 1992 West Coast bottom trawl survey.

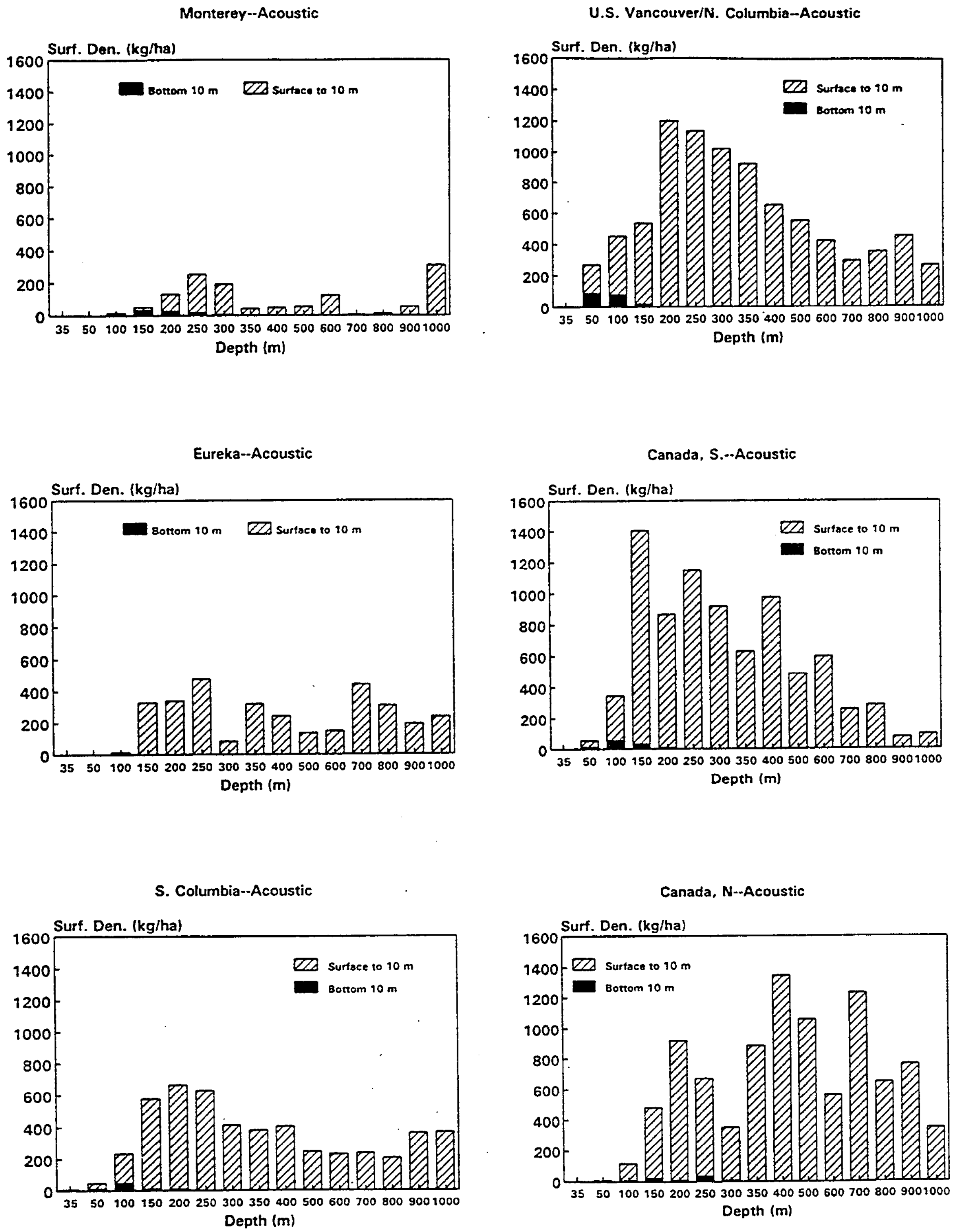


Figure 10.--Pacific whiting surface density (kg/ha) by region and depth interval for the 1992 acoustic/midwater trawl survey of Pacific whiting.

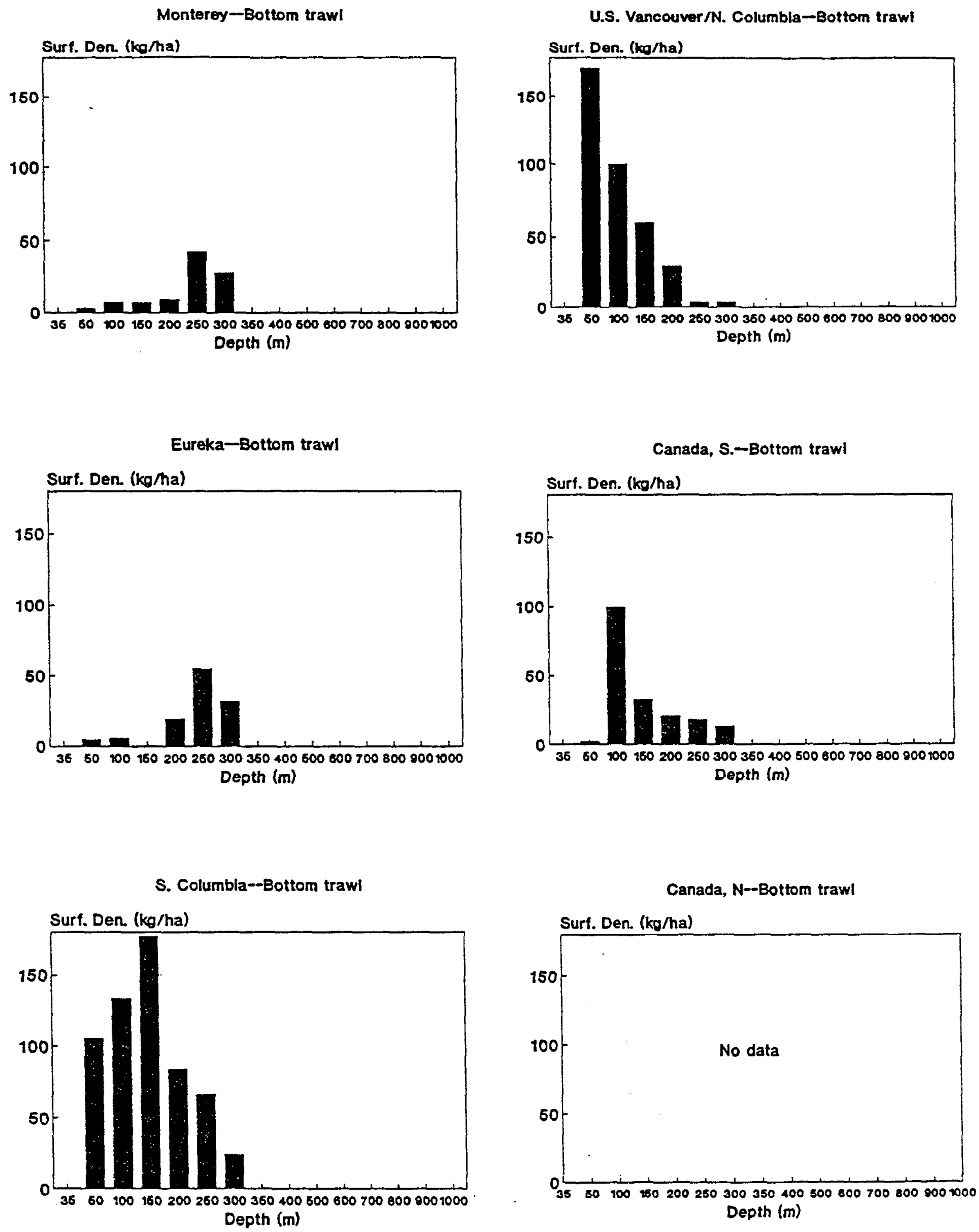


Figure 11.--Pacific whiting surface density (kg/ha) by region and depth interval for the 1992 bottom trawl survey of Pacific whiting.

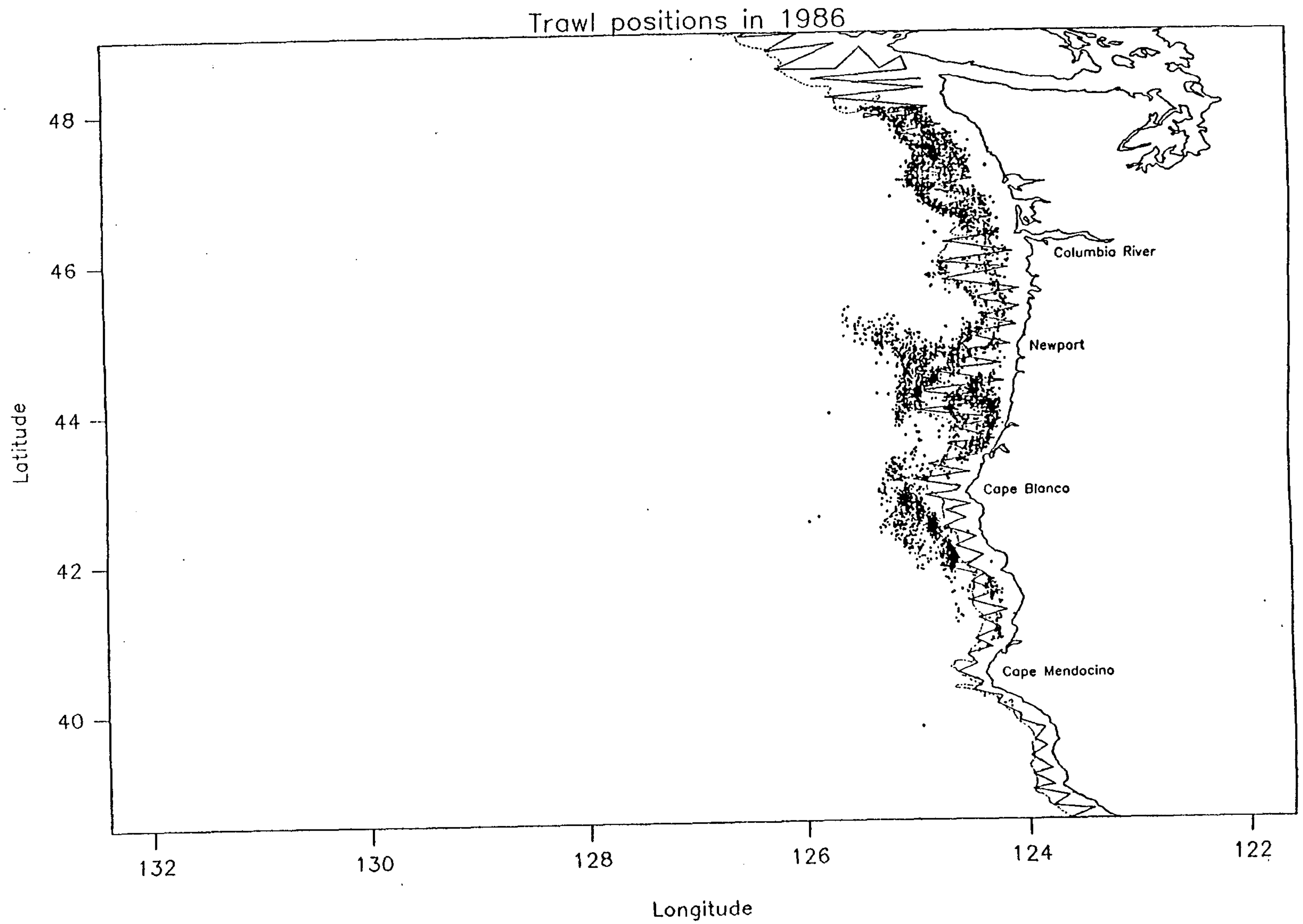


Figure 12.--Joint-venture and foreign fishery reported haul positions in 1986. The 1986 acoustic survey transects are also shown. The dotted line is the 300 m depth contour

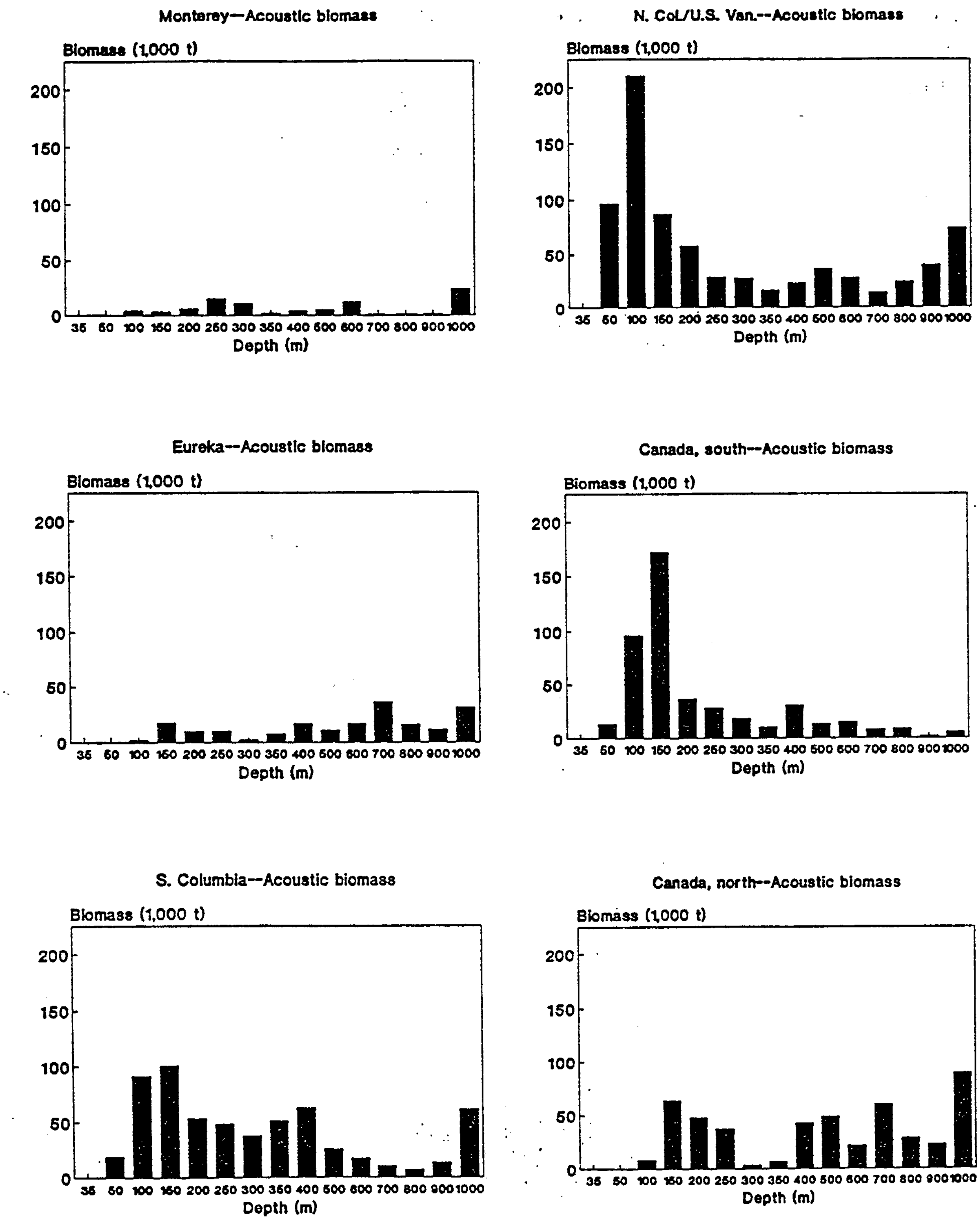


Figure 13.--Pacific whiting biomass by region and depth interval as estimated by the 1992 acoustic/midwater trawl survey.

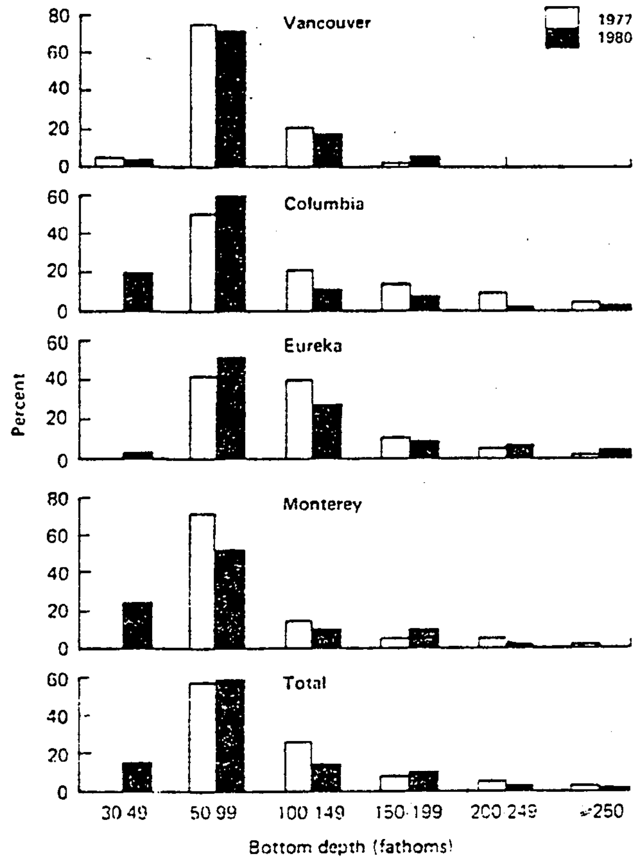
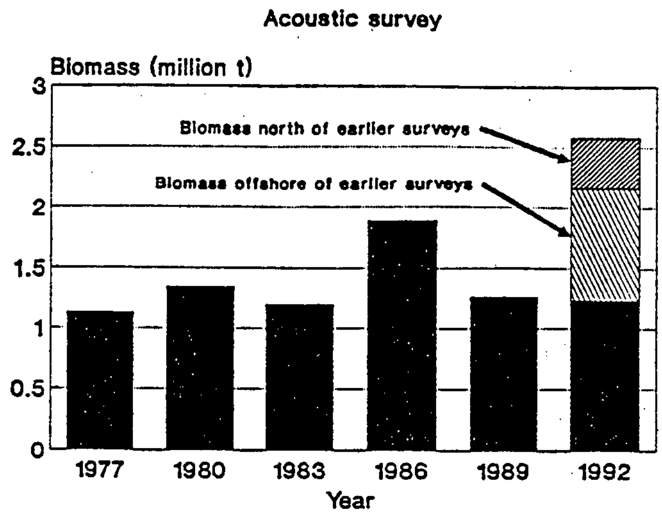


Figure 14.--Pacific whiting biomass by region and depth interval as estimated by the 1977 and 1980 acoustic/midwater trawl surveys (from Nelson and Dark 1985).



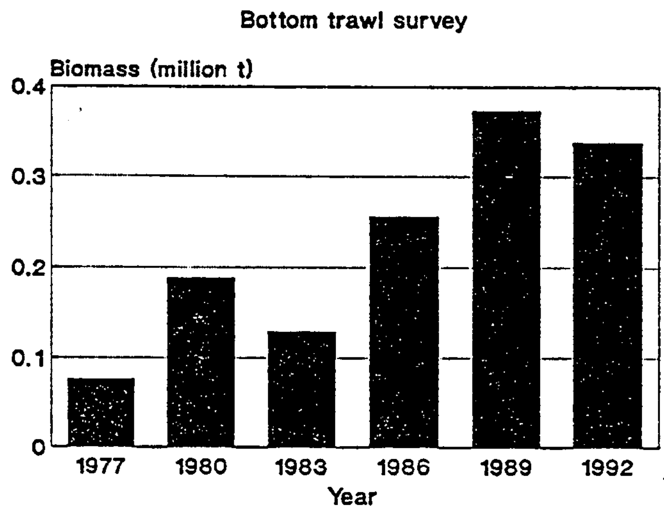


Figure 15.--Time trend of Pacific whiting population biomass estimated by the triennial acoustic and trawl surveys. The acoustic biomass for 1992 is partitioned into three components 1) biomass inshore of 366 m and south of latitude 50° N, 2) biomass offshore of 366 m and south of latitude 50° N, biomass north of latitude 50° N.

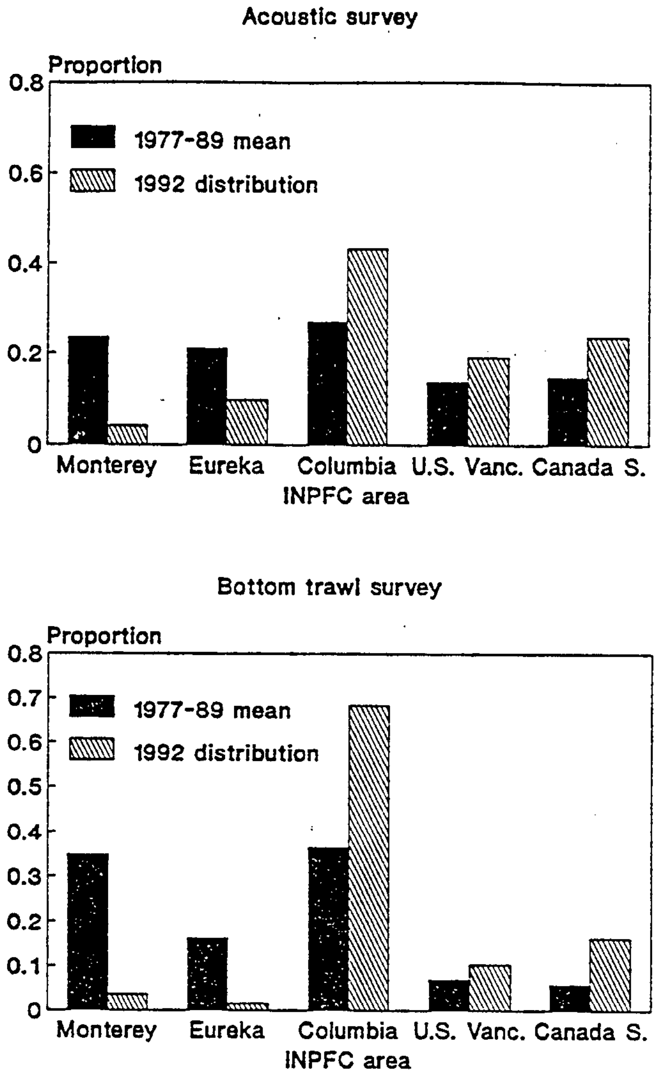


Figure 16.--Proportional distribution of biomass by INPFC area for the triennial acoustic and trawl surveys in 1992. For comparison, the mean distribution for the 1977-89 surveys is also shown.

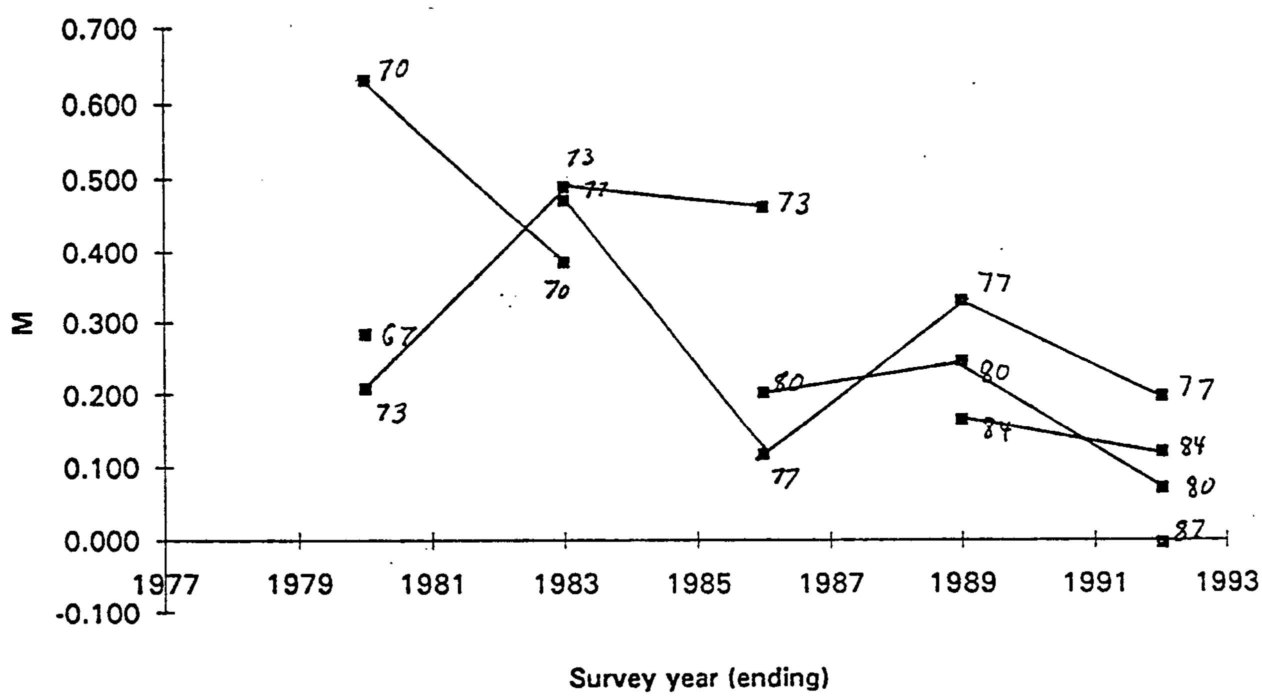


Figure 17.--Estimated natural mortality (m) for the strong year classes between West Coast triennial surveys.

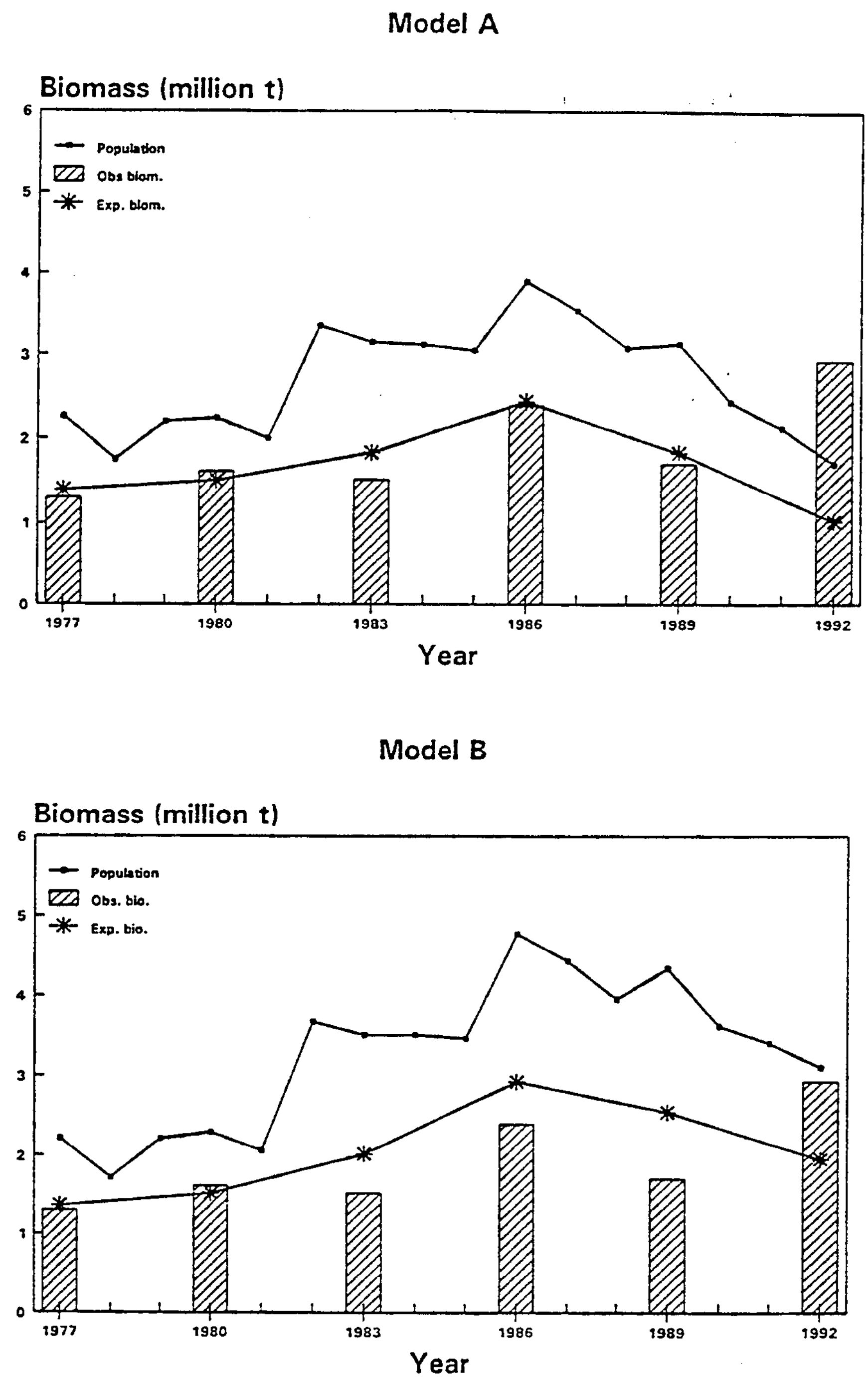


Figure 18.--Population biomass and predicted and observed survey biomass for two models showing the influence of the 1992 biomass estimate on population trend. Model A does not fit the 1992 survey biomass estimate, Model B fits the 1992 biomass as given.

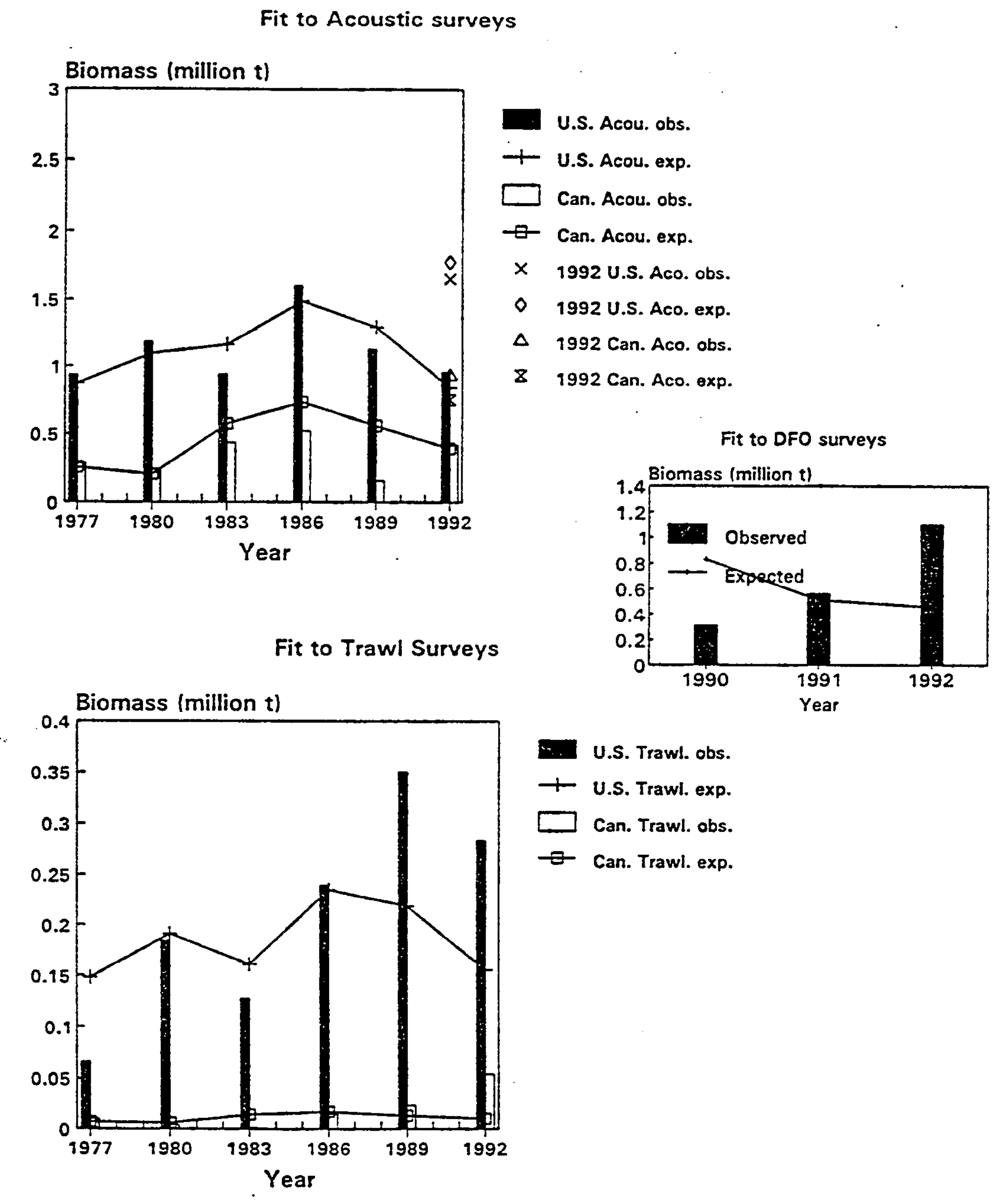


Figure 19--Observed and predicted survey biomass estimates for a stock synthesis model tuned to a -35 dB/kg target strength for the 1992 acoustic survey biomass.

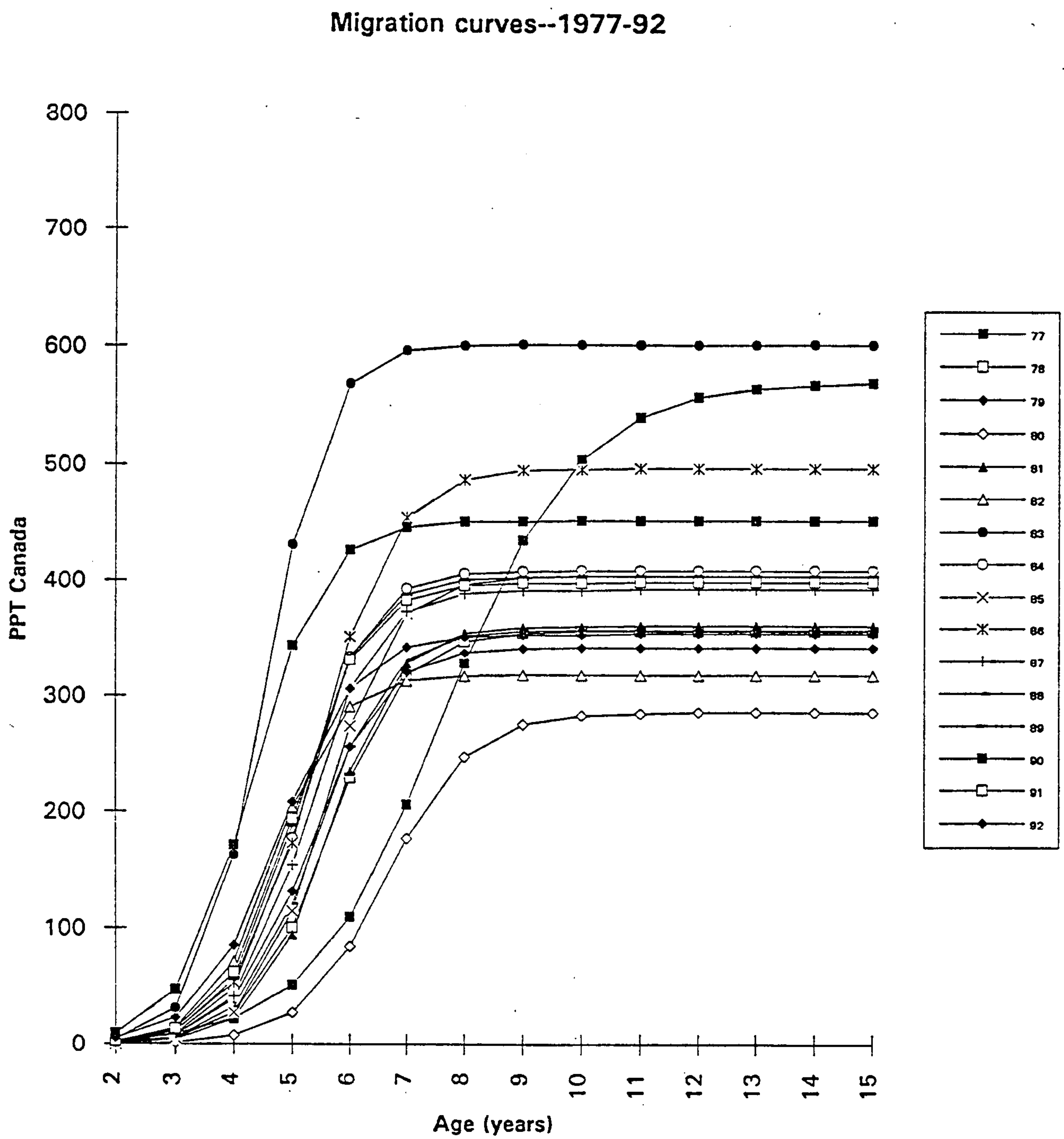


Figure 20.--Annual migration functions estimated using a geographic version of the synthesis model tuned to a -35 dB/kg target strength for the 1992 acoustic survey biomass. These curves represent the annual age-specific fraction of the population migrating into Canadian waters.

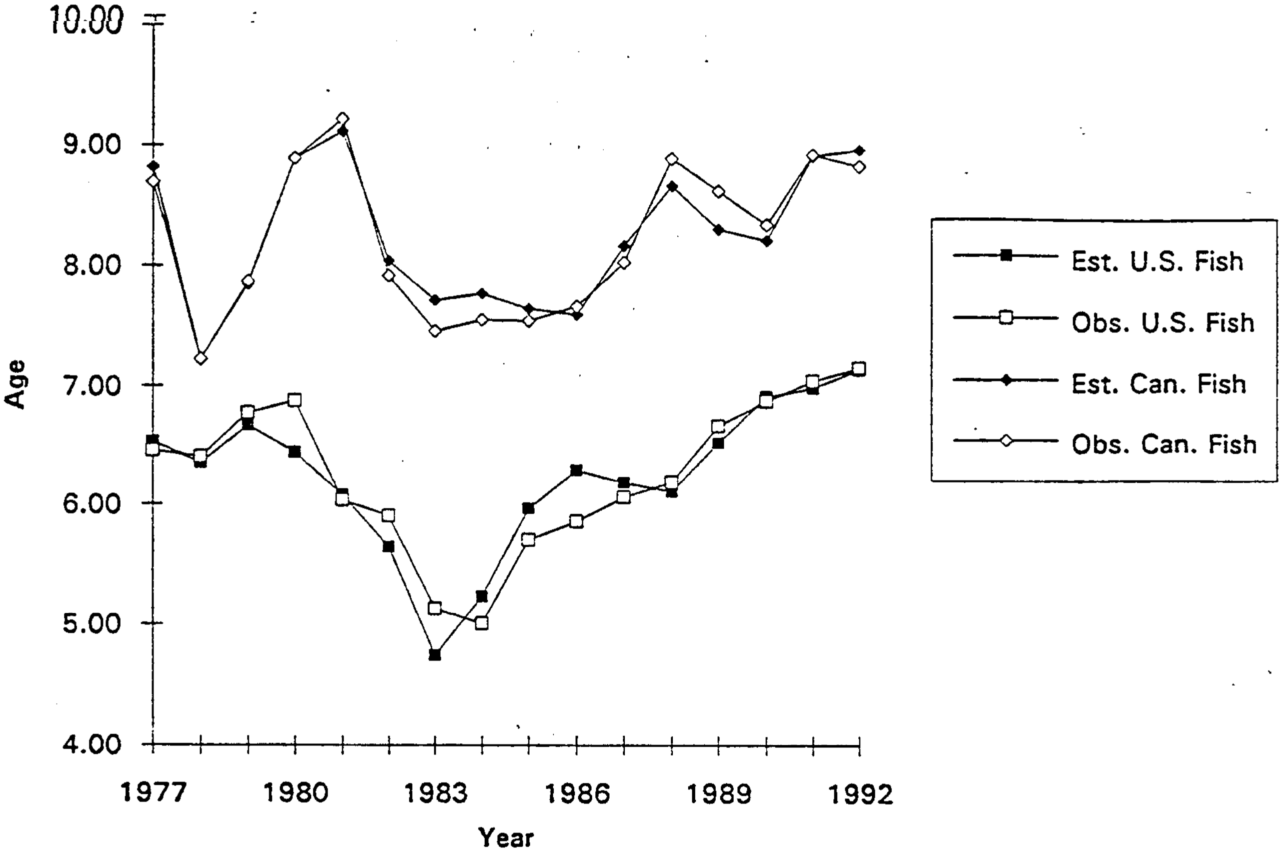


Figure 21.--Estimated and observed mean age for the age composition data from the U.S. and Canadian fisheries. The mean age was estimated by a stock synthesis model tuned to a -35 dB/kg target strength for the 1992 acoustic survey biomass.

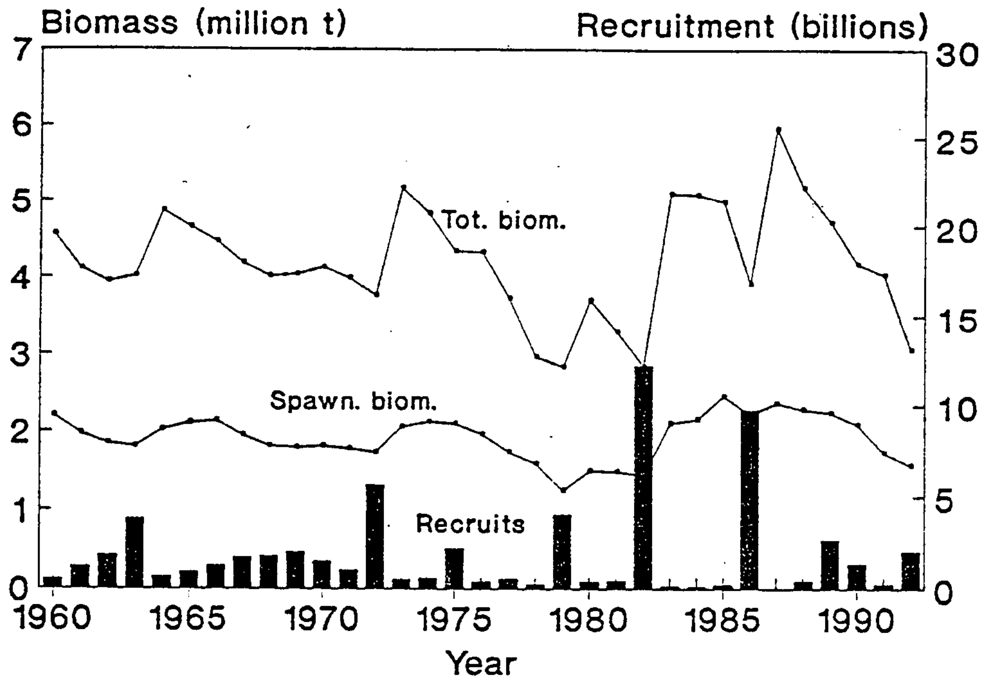


Figure 22.--Estimated time series of Pacific whiting total biomass and female spawning biomass (million t) and age-2 recruitment (billions of fish) for 1960-92. The time series was estimated by a stock synthesis model tuned to a -35 dB/kg target strength for the 1992 acoustic survey biomass.

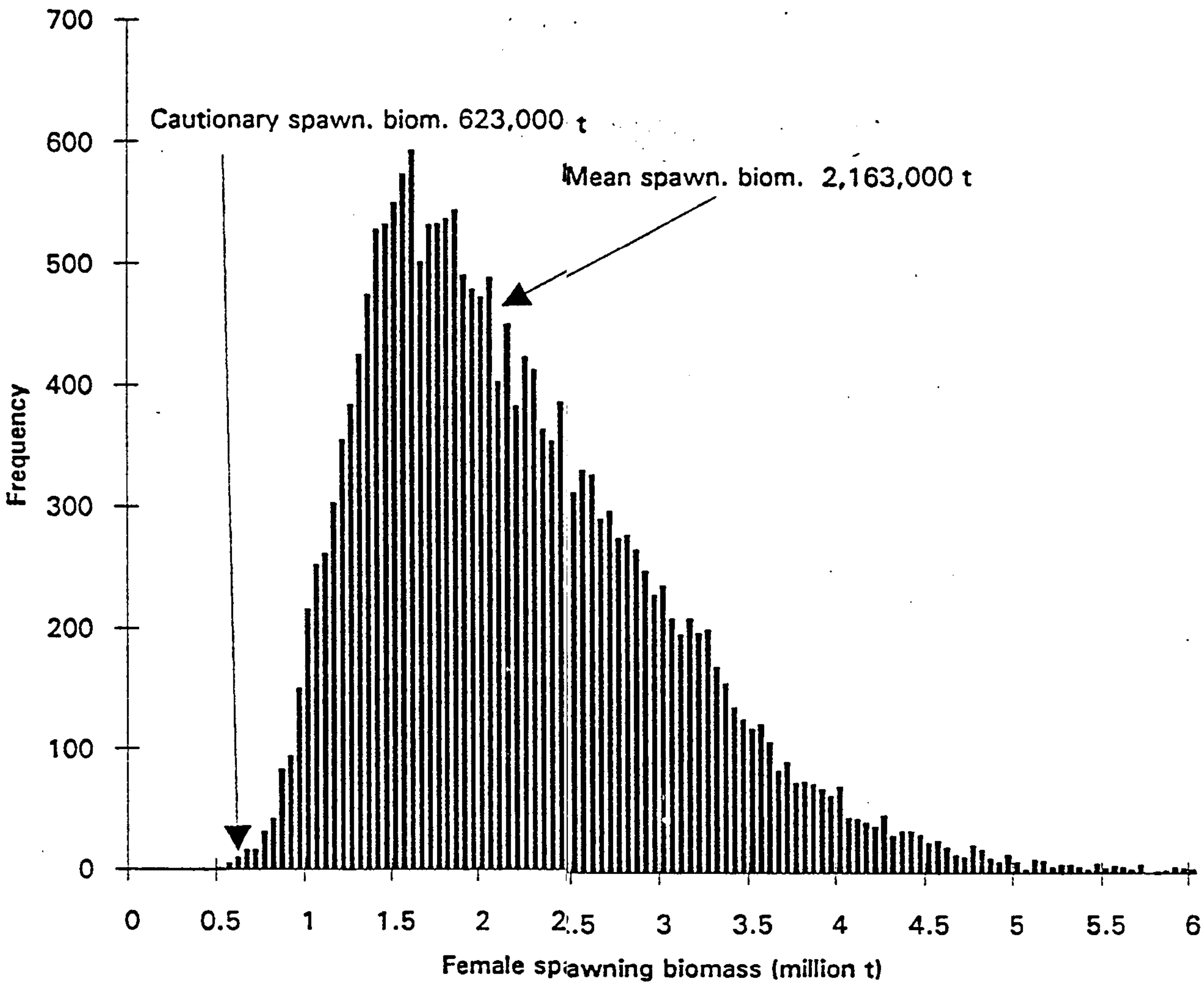


Figure 23.--Frequency distribution of female spawning biomass (million t) resulting from 20 replicate 1,000 year simulations of an unexploited Pacific whiting population. Recruitments to drive the model were obtained by resampling from the observed recruitment for 1958-90 year classes. A cautionary level of female spawning biomass of 623,000 t was identified as the 0.1 percentile of the empirical distribution of female spawning biomass for an unexploited population.

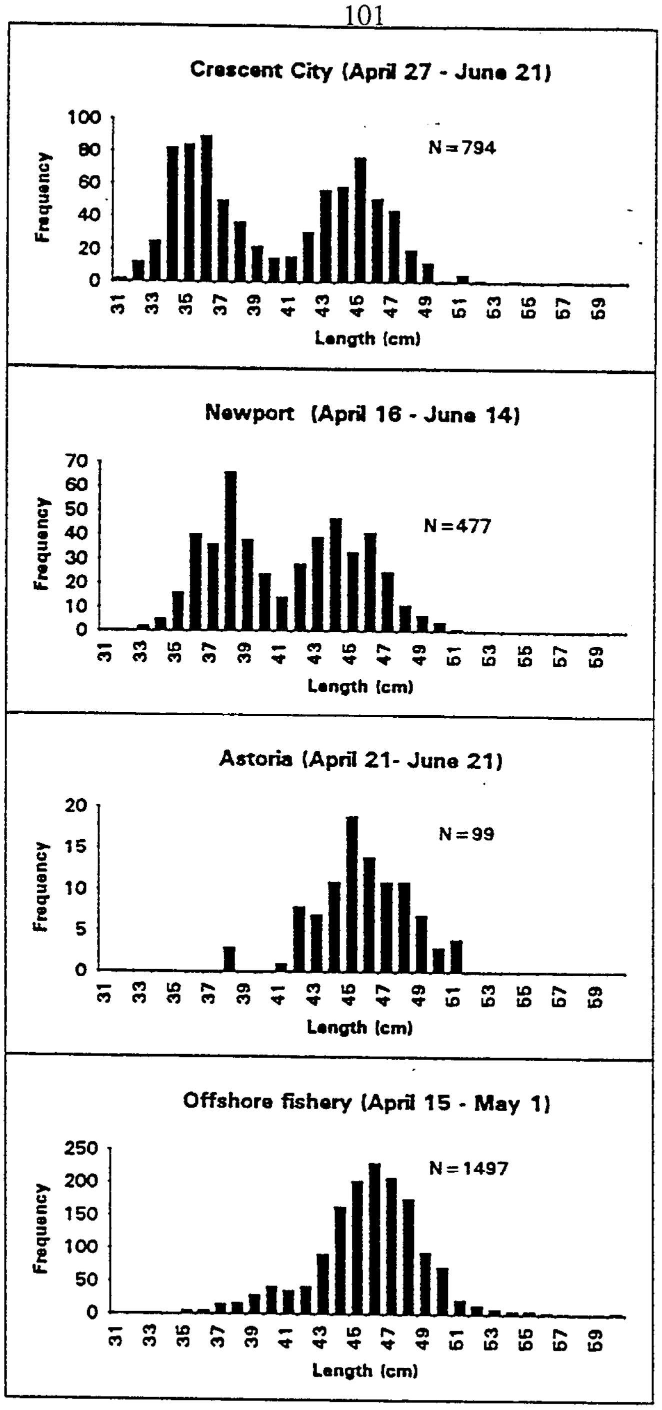


Figure 24.--Length-frequency samples of Pacific whiting in a) 1993 Crescent City shore-based fishery, b) 1993 Newport shore-based fishery, c) 1993 Astoria shore-based fishery, d) 1993 offshore fishery (Shore-based data provided by Larry Quirollo, California Department of Fish and Game, 619 2nd Street, Eureka, California, 95501, and William Barss, Oregon Department of Fish and Wildlife, Marine Science Drive, Building 3, Newport, OR 97365, Pers. commun., July 1993).