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Martin W. Dorn and Richard D. Methot

Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE, BIN C15700, Bldg. 4
Seattle, Washington 98115

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ABSTRACT

This report evaluates the condition of the Pacific whiting (*Merluccius productus*) resource in 1989 and includes management recommendations for 1990. The harvest of Pacific whiting has increased in recent years and in 1989 the harvest was 309,000 metric tons (t). The fishery continues to be supported by the strong 1980 and 1984 year classes. However, there has been no evidence of strong recruitment to the population since the 1984 year class; as a consequence, the female spawning biomass will decline from 829,000 t in 1989 to an estimated 599,000 t in 1990 and will continue to decline through at least 1991. Yields in the immediate future will be much reduced from the levels of the past few years. In the 1989 assessment, the stock synthesis model is used to estimate age-structured population abundance, past levels of female spawning biomass, and recruitment for the 1959-86 year classes. In addition, differences in the selectivity patterns of U.S. and Canadian fisheries are investigated using this method. Recruitment estimates and fishery selectivity coefficients from the stock synthesis model are used with an age-structured simulation model to estimate sustainable yield under different harvesting strategies and levels of risk. Two harvesting strategies are explored: a constant effort strategy and a variable effort strategy, where effort for a particular year is proportional. to the level of female spawning biomass. Long-term average yield depends on the level of risk the managers are willing to accept. Risk is associated with the probability that the female spawning biomass will fall below a cautionary level of 398,000 t. Estimates of average yield ranged from 178,000 to 244,000 t for the constant effort strategy, and from 205,000 to 251,000 t for the variable effort

strategy over a reasonable range of risk levels. When a variable effort fishing strategy is applied to the projected numbers at age in 1990, the potential yield is calculated to be 180,000 t for a moderate risk strategy and 245,000 t for a high risk strategy. Based on the age structure of the population in 1990 and the estimated proportion of the stock in the U.S. management zone, the total yield should be split: 80% to the U.S. fisheries and 20% to the Canadian fisheries. Potential yields in the immediate future will continue to decline until a strong year class recruits to the fishery.

CONTENTS

INTRODUCTION

Ecologically and commercially the coastal stock of Pacific whiting (*Merluccius productus*) is one of the most important marine fish species on the west coast of North America. Francis and Hollowed (1985) summarize the history and management of the coastal fishery for Pacific whiting as follows. A small domestic fishery for whiting has existed since at least 1879. The Soviet Union initiated a foreign fishery for this species in 1966. Between 1973 and 1976, Poland, the Federal Republic of Germany (West Germany), the German Democratic Republic (East Germany), and Bulgaria entered the fishery. The estimated catches of Pacific whiting ranged from 118,000 to 238,000 metric tons (t) during this period of expansion (Table 1). Catches peaked in 1976 and were subsequently reduced, due primarily to restrictions on foreign effort imposed after implementation of the Magnuson Fisheries Conservation and Management Act (MFCMA) of 1976.

A joint venture fishery for Pacific whiting started in 1978 between foreign nations and the United States and Canada. In recent years (1980-88) this fishery, involving predominately Soviet and Polish processing vessels, has accounted for an increasing percentage of the whiting catch in the U.S. and Canadian management zones. At the same time, the foreign fishery has declined in importance (Table 1). In 1988 the foreign catch amounted to just 11% of the total whiting catch in the U.S. management zone, and in 1989 there was no foreign fishery for Pacific whiting. A new development in 1988 was the participation of a large Japanese surimi processor in the joint venture fishery. These vessels have greater processing capacity than the vessels participating in the whiting joint venture fishery in past years (350 t average daily processing weight, as compared to 50-60 t).

Table 2 contains acceptable biological catch (ABC) and fishery quotas from 1977 to 1989 (PFMC 1989). Combined U.S. and Canadian catches were below the recommended levels during the period from 1977 to 1986. With the domestication of the U.S. fisheries in the Gulf of Alaska and Bering Sea, foreign interest in Pacific whiting has increased in the last few years. In 1987 the combined quota for the United States and Canada exceeded the ABC for the first time. The coastal whiting resource is now fully utilized, and in 1989 the combined U.S. and Canadian catch of whiting was 309,000 t--the largest yield since the inception of the fishery in 1966.

The fishery for Pacific whiting is closely tied to the migratory behavior of the coastal population. Bailey et al. (1982) provides a detailed description of the life history of the population. Adult Pacific whiting spawn off the coasts of central, southern, and Baja California during the winter. In the spring, adults migrate north to summer feeding grounds off the coasts of northern California, Oregon, Washington, and Vancouver Island. The extent of this northward migration is highly age dependent and fluctuates from year to year. Older adults typically migrate as far north as Vancouver Island while juveniles remain off central and northern California. The southward migration of adults begins in autumn and may be triggered by the shift of wind direction in the fall and the appearance of the Davidson Current.

In 1989, research on the biology and management of the coastal Pacific whiting population at the Alaska Fisheries Science Center (AFSC) focused on 1) recompilation of catch-at-age and length-at-age statistics to obtain estimates by area-time strata for the years 1978-88; 2) implementation of the stock synthesis model to estimate the age-structured abundance of the population and fishery selectivity patterns; 3) analysis of the age-specific fraction of the population migrating into the Canadian management zone; and 4) assessment and revision of the population simulation model used to forecast sustainable and short-term yields from the resource.

CATCH ATTRIBUTES

Alongshore Distribution of the Catch

As a part of a cooperative research effort between U.S. and Canadian researchers to study the population dynamics, growth, and yield of Pacific whiting on finer geographic and temporal scales, we examined the spatial distribution of the whiting catch in U.S. waters. Our goal was to identify geographic strata based on the actual distribution of the stock. Figure 1 shows the alongshore distribution of the whiting catch for 1981-88 (Jerald Berger, U.S. Foreign Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115. Pers. commun., February 1989). Three persistent areas of high productivity were detected. Accordingly, we defined three spatial strata: 1) the area south of lat. 43°00’N containing the Eureka and Monterey International North Pacific Fisheries Commission (INPFC) regions, 2) the area from lat. 43°OO'N to Cape Falcon (lat. 46°45'N) in the Columbia INPFC region, and 3) the area from Cape Falcon to the U.S.-Canada border including the northern part of the Columbia INPFC region and the U.S. portion of the Vancouver INPFC region. In addition, we defined three temporal strata: 1) early (April-June), 2) middle (July-August), and 3) late (September-October).

Catch-at-age Estimates

Estimates of catch at age from 1978 to 1988 were recompiled using the procedure developed by Kimura (1989). With this method, the yield for a given substratum is distributed by age by applying the length frequency information from that substratum to age-length and weight-length keys compiled for the stratum of which it is an element. For this analysis the spatial and temporal strata defined above were used. A total of nine area-time strata were possible for a given year, and within each stratum, two substrata were possible, joint venture fishery or foreign fishery.

Since for most years approximately 3,000 Pacific whiting otoliths were read, using as many as nine age-length keys for a single year could potentially result in keys with large gaps, that is, length categories without any corresponding aged fish. To prevent this from occurring, we calculated a background age-length key using all the aged fish for a year. This key would assign ages to fish that fell into the gaps in the age-length keys used for each stratum. Table 3 contains the revised U.S. fishery catch at age for 1978-88 (Jerald Berger, U.S. Foreign Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115. Pers. commun., May 1989) and the Canadian catch at age for the corresponding years (Mark Saunders, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6. Pers. commun., May 1989)

GROWTH

Estimates of weight at age are required both by the stock synthesis model (Methot 1989) and by the population simulation model used to determine the long-term productivity of the resource. Although the population model is constructed with the assumption that weight at age is time-invariant, an earlier investigation of Pacific whiting growth demonstrated that a substantial decline in size at age occurred from 1977 to 1987 (Hollowed et al. 1988). The cause of this decline has not been identified. Some preliminary work suggests that a series of years with anomalously warm sea surface temperatures during this period, including but not limited to the 1983 El Nino, may be part of the explanation. Although difficult to study analytically, the potential for size-selective fishing mortality to alter the actual or measured growth characteristics of a population is another area of concern.

New length-at-age estimates were compiled for the years 1978-88. The identical strata and substrata identified earlier for the revised catch-at-age estimates were used. In addition, a delta method variance estimator was derived and implemented for these estimates of length at age. This estimator takes into account the two-stage sampling design used by the U.S. Foreign Fisheries Observer Program to sample the catch. This design can be described, briefly, as follows. The length and sex of a large initial sample of fish is recorded. For the second stage of sampling, a subsample of fixed size is selected for each combination of length category and sex. Otoliths are collected from each of these individuals, and the age is determined for each fish. Details of this estimator are available from the authors.

The analysis of Pacific whiting growth in Hollowed et al. (1988) was updated using the recompiled annual length-at-age estimates. Von Bertalanffy growth curves were fit separately to the males and females for the dominant year classes (1967, 1970, 1973, 1977, 1980, and 1984) using the nonlinear weighted least-squares algorithm PAR in the BMDP statistical package (Dixon 1983). The weights for each mean length at age were the inverse of the estimated variance, so that mean length-at-age estimates based on only a few observations would receive less weight than those based on many observations. As in the earlier analysis, we fit von Bertalanffy growth curves reparameterized to use L_1, the length at age one, to specify a particular solution to the governing differential equation, rather than using t_0, the theoretical age at which length is zero, as is the conventional practice. This curve has the general form

$$l_t = L_\infty + (L_1 - L_\infty)\exp(\,k(\,1 - t\,)).$$

For all year classes except 1984, L_1 values of 25.71 cm for males and 26.56 cm for females were used in the nonlinear least-square fits. These values were the average of the estimated L_1 values for the 1977 and 1980 year classes. These were strong year classes in which younger fish were well represented in the samples, For the 1984 year class, however, fish at age one were larger than those in previous year classes. Consequently, we used the 1984 year class length at age one for our L_1 values (males 30.3 cm, females 30.6 cm).

The growth curves for the dominant year classes show a striking and sustained reduction in length at age, confirming the earlier observations of a decline in growth rates (Fig. 2). The growth curves indicate that length at age for 8-year-old fish declined 10% for males and 7% for females from the 1970 year class to the 1980 year class. Since these curves are based entirely on fishery estimates of length at age, which are biased estimates of the actual population characteristics, they are best interpreted cautiously, as they give a only a qualitative picture of growth trends. Interestingly, though, the growth curve for the 1984 year class during the 4 years it has been present in the fishery shows a pattern similar to the 1980 year class, suggesting that size at age may have stabilized in recent years.

Because both ageing error and targeting of dominant year classes by the fishery can result in misleading estimates of length at age for the weak year classes, we used a simple procedure to obtain smoothed estimates for these year classes by interpolating from the von Bertalanffy growth curves for the adjacent strong year classes. This method consisted of estimating the mean length for a particular age by linearly interpolating from the von Bertalanffy curves for the preceding and following strong year classes. Since strong year classes have occurred once every 3 or 4 years during the time series of catch data, the distance between the interpolated values and the actual growth curves is never greater than 2 years. For year classes before 1967 and after 1984, the length-at-age estimates for the 1967 and 1984 year classes were simply extended outward to complete the length-at-age matrix. For the dominant year classes, the actual fishery estimates were used for the ages 2-11, since these ages would be well sampled in the fishery. For ages outside this range, the predicted values from the von Bertalanffy curves were used. These revised estimates of fishery length at age are given in Table 4.

Estimates of population length at age were obtained by assuming that a stratified estimate of length at age for the West Coast groundfish surveys (Weinberg et al. 1984; Nelson and Dark 1985; Coleman 1988; Neal Williamson, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN Cl5700, 7600 Sand Point Way NE., Seattle, WA 98115. Pers. commun., May 1989) was an unbiased estimate of length at age in the population. By comparing the survey estimates with the fishery estimates of length at age for the years 1977, 1980, 1983, and 1986, it was possible to correct for the influence of size selectivity by the fishery on the estimates of length at age.

Figure 3 illustrates the difference between the survey and the fishery estimates versus the fishery mean length for each age present during the survey years. The discrepancy between the survey and the fishery estimates tends to increase as the size of fish increases. To estimate mean length at age in the population for the nonsurvey years, the difference between the survey-estimated lengths and the fishery-estimated lengths was regressed on the fishery lengths. Only the dominant year classes present during the survey years were used in the regression since these estimates would be based on large sample sizes and would not be dependent on questionable corrections for ageing error. The results of regression are recorded in Figure 3. The population mean length at age is estimated by the equation

$$l_p = \alpha + (1+\beta) l_f,$$

where l_p is the mean length in the population and 1_f is the revised mean length in the fishery, and a and B are the regression coefficients.

Sex-specific coefficients for an exponential length-weight relationship of the form $w - a \cdot 1^b$ (Ricker 1975) were estimated for each year with nonlinear regression using data collected from the U.S. fishery (Table 5). The coefficients in the length-weight relationship were used to estimate weight at age for the males and females separately. These estimates were combined to obtain weight-at-age tables for the fishery and for the population (Table 6). These tables were used in the models for stock assessment.

POPULATION ASSESSMENT

The historical abundance and mortality of Pacific whiting was estimated by application of the stock synthesis model (Methot 1986, 1989) as described in an appendix to the 1988 status of stock report for Pacific whiting (Hollowed et al. 1988). The synthesis model is a separable catch-at-age analysis tuned to the survey estimates of biomass and age composition. The appendix to the 1988 report documents that the model yields estimates of abundance that are similar to those estimated by cohort analysis tuned to the observed abundance at age in the surveys. Subsequent, unpublished work indicated that a third tool, the CAGEAN computer program (Deriso et al. 1985), also yielded similar results. However, the synthesis model is more flexible than other analytical procedures in how the survey information can be used, and in how the fishery can be partitioned into zones. Here we explore three ways in which the two fisheries, U.S. and Canadian, can be modeled, First, the catch at age for the two fisheries can be combined and modeled as a single fishery. This is the approach that has been used in the past and will be used here to develop management recommendations. Second, the two fisheries can be treated as though they are competing gears, and the selectivity pattern for each fishery can be modeled relative to the entire stock. Third, the stock can be split into a northern and southern zone, and the selectivity for each fishery can be modeled relative to the portion of the stock in its zone. The latter two scenarios are explored in Appendix 2.

The synthesis model operates by simulating the dynamics of the population. Comparisons are made between the expected value of the observable characteristics of the population and the actual observations of the population from surveys and fishery sampling programs. The observations for Pacific whiting are catch biomass and age composition for the U.S. and Canadian fisheries, survey biomass, and survey age composition. The goodness of fit to these observations is evaluated in terms of log(likelihood). The total log(likelihood) is a weighted sum of the likelihood components for each type of data. The model assumes that fishing mortality can be separated into an age-specific component and a year-specific component. The parameters which the model estimates are population age composition in the first year, recruitment in each subsequent year, and age-specific selectivity by the U.S. fishery, the Canadian fishery, and the survey. The total number of parameters to be estimated can be reduced by specifying the age-specific availabilities as functions of age (Appendix 1). The year-specific fishing mortality factors are not estimated as parameters. Instead, they are tuned to the levels necessary to match the observed catch biomasses. The model parameters are estimated by an iterative process which involves numerical estimation of the first derivatives of total log(likelihood) with respect to each parameter, and the Hessian matrix of mixed partial derivatives. The inverse of the Hessian matrix postmultiplied by the vector of first derivatives indicates how the parameters should be changed.

The modeled population includes ages 2-14; age 14 is treated as an accumulator age, Most model runs covered the years 1973-88--the time period for which there was age composition data for the U.S. fishery. The parameters in these runs estimated fishery selectivity patterns, survey selectivity patterns, ageing error, age composition at the beginning of 1973, and year-class strength for the 1973-87 year classes. Selectivity patterns and ageing errors were fixed at the values estimated in these runs, and the time series was extended back to 1958 so that historical recruitments could be estimated. Body weights at age were set at year- and fishery-specific values for the years 1978-88. Fish from earlier years were assumed to have the same weight at age as those from 1978.

Ageing Imprecision

The model incorporates ageing imprecision by assuming that the standard deviation of observed age increases linearly with true age. The parameters which define this linear trend are the fraction misaged at age 2 and the fraction misaged at age 14. The model is able to estimate these parameters in the Pacific whiting model because the spillover of large year classes into adjacent poor year classes is readily apparent. The model estimates that 2% are misaged at age 2 and 31% at age 14.

In addition to symmetric ageing imprecision, the strong year classes in Pacific whiting allow us to detect three instances of ageing bias. First, the strong 1970 year class began to blur into the 1971 year class in 1978. This bias was accommodated by accumulating at age 7+ in 1978, 8+ in 1979, 9+ in 1980, etc. The estimated levels of the 1970 and 1971 year classes were 2.32 and 0.42 billion fish without the accumulation, and 2.64 and 0.15 billion with the accumulation. Second, previous analyses have noted that the strong 1977 year class appeared as 3-year-old fish in 1979 because of a small sample size in the age-length key for that year. Consequently, the data were adjusted before conducting the cohort analysis. Here, this problem was accommodated by accumulating the age-2 and age-3 fish in both the data and the model's estimate for the year 1979. Finally, the strong 1961 year class was prominent in the 1965-68 samples (Dark 1975); in 1969, the age composition was dominated by 7-year-old fish. We suspect that this age mode was actually the 1961 year class, misaged by one year. Therefore, we accumulated at age 7+ in the 1969 age composition sample.

Emphasis on Survey Biomass Likelihood

The emphasis placed on each component of the total log(likelihood) function determines how closely the model's estimates will approach the observations of that type. If all of the processes and error structures built into the model matched their true counterparts, then all emphasis levels should be set at 1.0. Because the true model is not known, the emphasis factors allow correction for the model's tendency to fit some types of data more or less closely than is reasonable. If the variance of a particular type of observation were known, the emphasis factors could be set so that the deviations between the model's predictions and the observations are consistent with this level of measurement error. Of course, if the various types of data are highly consistent with each other, the emphasis factors will have little effect; fitting one type of data will automatically produce a good fit to the other types of data. By varying the emphasis factors one is able to detect inconsistencies among the types of data. Here we explore the sensitivity of the results to the emphasis on the likelihood component for survey biomass (Table 7). The model tends to 1) match the 1977 and 1986 survey biomass values very closely, 2) suggest these values are less than the biomass measured in 1980, and 3) suggest they are greater than the biomass measured in

1983. Basically, any decrease in biomass from 1980 to 1983 is inconsistent with a strong 1980 year class. As shown in Table 7, an increase in the emphasis on the likelihood component for survey biomass causes changes in the estimated strengths of the large year classes. These changes improve the fit to the survey biomasses, but degrade the fit to the U.S. fishery age composition, the Canadian fishery age composition, and to the survey age composition (Fig. 4). We selected an emphasis level of 5.0 to provide a reasonable compromise between the fits of the various types of data.

Survey Selectivity

Examination of the survey age composition indicates that the fish older than about age 11 are not as common as expected. Either their availability to the survey is reduced or the older fish have higher natural mortality than younger fish. Selectivity of the survey for younger fish is difficult to estimate because most surveys have occurred when the youngest large year class was 3 or 4 years old. Only the 1986 survey encountered a large 2-year-old year class. We assume that fish become fully available to the survey at age 2, but we also investigate the consequences of reduced selectivity at younger ages. Patterns in age-specific selectivity are modeled as a four-parameter function which is the product of two logistic curves (Appendix 1). Table 8 describes three scenarios for survey selectivity and natural mortality. In the first scenario, only the descending side of the selectivity curve is estimated. In the second scenario, the ascending side is also estimated. In the third scenario, all ages are assumed to be fully available and a linear increase in natural mortality is estimated for the older ages, The goodness of fit is best in the second scenario, but the increase in likelihood is not great when one considers that two additional parameters are included in the model. The higher ending biomass also found in this scenario is due primarily to an increase in the estimated size of the 1984 year class which is estimated to be not fully surveyed in 1986. The third scenario produces a plausible increase in the natural mortality (from 0.2 at age 10 to 0.55 at age 14), and a small degradation in the goodness of fit. At this time we do not have sufficient information to deviate from the null model described in scenario one. A second observation of the 1984 year class in the 1989 survey will allow better evaluation of scenario two. A northerly extension of this survey may allow some evaluation of scenario three.

Fishery Selectivity and Vulnerability

When the catch at age for the U.S. and Canadian fisheries is combined, as has been done in the past, the resulting age-specific selectivity coefficients increase from age 2 to age 8, and decline thereafter (Table 9). This pattern is very different than the average age-specific catchability coefficients (Q) estimated by the previous cohort analysis. We have examined the age- and year-specific Q values in last year's cohort analysis. Many of the Q values for weak year classes were large, especially as these year classes aged. These large values probably represent a bias due to a small level of misageing from the adjacent strong year classes. The synthesis model is less susceptible to this sort of bias, and we note that the cohort analysis estimate of average Q for strong year classes (Table 9) is similar to the age-specific selectivity pattern estimated by synthesis. The change in selectivity pattern from the previous estimate may influence the management model because the fishery will now be modeled to concentrate its efforts more on younger ages. Although the selectivity pattern for the combined fishery is the pattern used in the management model, Appendix 2 describes an initial exploration of alternative descriptions of the fishery selectivity patterns.

Long Time Series

Extension of the time series back through the 1960s is possible because age composition data for the years 1965-69 is available (Table 10; Dark 1975). The year-class index of Bailey (1981) utilizes the percentage at age 4-6 in these data. Here we examine the percentage at ages 4-9 and treat these data as the age composition of the entire U.S. fishery during this period. However, because these data are primarily from the southern coast of Washington, we expect them to represent a selectivity pattern different from that of the current coastwide U.S. fishery. A double logistic function (Appendix 1) was used to model the selectivity pattern of these data, Also, all ages were determined by surface reading of otoliths, whereas the current methodology uses a combination of surface readings. and break-and-burn readings. Age compositions were accumulated at age 9 because older fish may not have been accurately aged. The 1969 age composition was accumulated at age 7, as noted above, because of an apparent bias in the ageing of the 8-year-old 1961 year class.

Rather than attempt to estimate the population age composition at the beginning of 1965, we have extended the time series back to 1958 and assumed that the population had an equilibrium age composition in 1957. The abundance of this assumed equilibrium population affects the estimated magnitude of the early recruitments, but the effect degrades rapidly (Table 11). We select a high level of virgin, equilibrium recruitment (900 million at age 2) so that the estimated female spawning biomass is near constant during the early part of the time series. We estimate recruitments beginning with the 1956 year class, but 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.

The long time series of estimated recruitment (Table 12) is similar to that previously estimated by calibration to the year-class index (Hollowed et al. 1987). The 1961 year class is estimated to be very large, similar in magnitude to the 1980 and 1984 year classes. Year classes from the late 1960s appear to have been less variable than those of the late 1970s and 1980s. While this may be true, it is also possible that less precise ageing during the early 1970s caused a blurring of the early year classes.

The long time series of estimated female spawning biomass differs from that previously estimated by cohort analysis and calibration to the year-class index (Hollowed et al. 1987). The female spawning biomass during the late 1960s is now estimated to be relatively high, rather than dipping to historical low levels. In hindsight, the previous estimate is inconsistent with the presence of a very large 1961 year class. The previous procedure was able to produce low estimates of female spawning biomass during this period because the female spawning biomass of ages 3-10 was estimated in relation to the estimate of age 3-7 female spawning biomass produced by the cohort analysis. However, the age 3-7 female spawning biomass does not include the large 1961 year class, so the expansion to age 3-10 underestimates the female spawning biomass during the late 1960s. This change in the estimated time series of female spawning biomass -removes the rationale for treating 319,000 t as a cautionary level of female spawning biomass. An alternative procedure for defining cautionary female spawning biomass will be defined in the management section.

ESTIMATION OF THE AGE-SPECIFIC FRACTION MIGRATING INTO THE CANADIAN ZONE

Sources of Data

There are two primary sources of information on the geographic distribution of Pacific whiting: the triennial acoustic surveys conducted in 1977, 1980, 1983 and 1986 (Nelson and Dark 1985, Neal Williamson, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115. Pers. commun., May 1989), and the West Coast bottom trawl surveys conducted in the same years (Dark et al. 1980, Weinberg et al. 1984, Coleman 1986, Coleman 1988). These surveys took place in mid- to late summer, when the coastal population of Pacific whiting is at the northern limit of its feeding migration (Francis 1983). The two survey methods sample different components of the population--the acoustic survey sampling the mid-water component and the trawl survey sampling the demersal component of the population. In 1977 and 1986, the bottom trawl survey did not extend above the U.S.-Canada border, limiting the usefulness of this source of information.

In the regression analysis that follows, we use only the acoustic information on the geographic distribution of Pacific whiting. Table 13 gives the estimated total abundance and the proportion in the Canadian exclusive economic zone (EEZ) for the acoustic surveys (Neal Williamson, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115. Pers. commun., May 1989). In 1980 and 1983, when the trawl survey did extend into Canada, the trawl survey abundance estimates were less than 3% of the total estimated abundance in the Canadian zone. Nevertheless, since the trawl survey captures a much higher proportion of the older individuals (age 8+), its omission is indeed consequential, The situation is further complicated by the sharp decline in the demersal biomass as estimated by the trawl survey in the Canadian portion of the Vancouver INPFC region when compared to the U.S. portion, a drop that is not found in the acoustic estimates (Table 14).

Logistic Regression Methods

Logistic regression is a common method of analyzing data in the form of proportions, that is, the number of successes out of n trials. In this application, success is defined as migration into the Canadian zone, whereas number of trials is the total number of Pacific whiting of a particular age. In logistic regression, the logistic transformed proportions are equated with a linear predictor containing explanatory variables (see McCullagh and Nelder 1983). The error assumption of logistic regression is independent binomial error, although with large sample sizes it is often found that there is more residual variability than would be expected with binomial error. Overdispersion, as this is called, is encountered in this application, and requires that the significance levels and standard errors be adjusted.

Another difficulty that prevents this analysis from being a straightforward application is that logistic regression gives more weight to the binomial proportions with more trials. Consequently, the younger ages, which are much more abundant, would dominate the regression. This would degrade the fit to the older fish, whose geographic distribution is more important from the standpoint of allocation. We circumvented difficulty by re-scaling all the proportions so that they represent the number of fish out of 1,000 migrating into the Canadian zone.

The analysis was done using GLIM, an interactive statistical program for fitting a general class of regression models using an iterative re-weighted least squares algorithm (NAG 1987).

Logistic Regression Results

A preliminary step in the analysis was to fit a full model and use the deviance of the observations from that model (divided by the degrees of freedom) as an estimate of the residual error. For data without extra-binomial variability, this estimate of residual error should be near one. For overdispersed data, it will be larger than one. We fit a cubic polynomial of age for each survey year separately as a full model. The deviance for this model was 686.7 with 36 degrees of freedom, giving an estimate of the scale parameter of 19.075.

Table 15 gives an analysis of deviance for the age-specific proportion of the population migrating into the Canadian zone. The first four terms in the model fit a single cubic function of age for all the survey years. The temperature variable is mean August sea surface temperature (°C) from ships of opportunity from lat. 40°N to lat. 50°N and from the coast west to long. 130°W. Adding the temperature variable increases the R-square value from 52 to 81%. (N.B. R-square is the percent of the null deviance explained by the model.) Year-class abundance, as measured by estimates of age-3 recruitment abundance from the stock synthesis program, was also tested in the model, However, the addition of the term measuring recruitment abundance caused only a minor reduction in the deviance and was not significant. This suggests that year-class strength is not a primary factor in determining the age-specific fraction of Pacific whiting migrating into Canada. The p-values were obtained by comparing the statistic (change in deviance/change in degrees of freedom)/scale parameter to an F reference distribution. The correctness of this test depends on asymptotic arguments that are not likely to have been met in this application. Figure 5 shows the proportion at age estimated by the logistic regression model for each of the survey years.

Since it is difficult to forecast sea surface temperature, this model would have limited use for predicting the future distribution of Pacific whiting for the purpose of allocation. Consequently, we fit another model without the temperature time series and excluding the anomalous 1983 El Nino survey results. Table 16 gives the estimated age-specific fraction migrating into Canada for this model. (See also Figure 6.)

ESTIMATION OF SUSTAINABLE YIELD

The age-structured simulation model of Francis (1985) used in previous stock assessments to investigate the productivity of the coastal Pacific whiting population was completely rewritten for this year's stock assessment, and some different approaches were implemented in our analysis. In this section we identify the changes from previous assessments and provide a rationale for them. We also summarize recent research on the recruitment of Pacific whiting. Finally, we evaluate the potential yield under various exploitation strategies and under different levels of risk using the revised simulation model.

Population Dynamics

The fundamental equations for the dynamics of the Pacific whiting population are identical to that of earlier versions of the model: the age-structured Baranov catch equations model the effect of the fishery on the population, and a simple exponential mortality model updates population abundance. Based on previous analyses, the natural mortality rate was assumed to be constant with respect to age at 0.2 (Hollowed et al. 1987). In the past, a single weight-at-age vector was used for the U.S. fishery, the Canadian fishery, and for the population. Since we have found large differences in weight at age between these different sources, the model was generalized to use separate weight-at-age vectors for each. These were estimated by averaging weight at age for the years 1978-88 separately for each source. Since there has been a substantial decline in weight at age for the past decade, this gave compromise estimates of weight at age that are larger than currently observed in the fishery, but smaller than 10 years ago. To obtain the total yield in biomass, the estimated catch at age was divided between the U.S. and the Canadian fisheries according to the age-specific proportion by number in the respective national zones as estimated by the acoustic surveys. Multiplying by the characteristic weight at age for each fishery and summing over age gave the total yield.

In order to directly utilize the parameters from the stock synthesis model, the age-specific fishing mortality rates were modelled as the product of a full-recruitment fishing mortality rate and an age-specific selectivity coefficient. A single vector of selectivity coefficients was used in the simulations, representing the combined characteristics of the U.S. and Canadian fisheries. The annual control variable in this parameterization is the full recruitment fishing mortality, f(t). This is a change from the previous version, which modelled fishing mortality as a product of an age-specific catchability coefficient and effort, where effort was assumed to be proportional to fishing mortality.

Recruitment

The factors governing the recruitment of Pacific whiting continue to be the focus of much research. Research on the effect of the ocean environment on recruitment began with the work of Bailey (1981), who found a significant correlation between Pacific whiting recruitment and the intensity of wind-driven Ekman transport on the spawning grounds in the Los Angeles Bight during spawning. To explain this correlation, he proposed a transport mechanism whereby strong upwelling causes an offshore drift of the eggs and larvae away from favorable rearing habitat. Sea surface temperature is inversely correlated with the intensity of Ekman transport. Consequently, mean January-March sea surface temperature in the Los Angeles Bight, which can be accurately and inexpensively measured, is used as a predictor of recruitment success. The significance level of the correlation between Ekman transport and recruitment has eroded since Bailey published his findings (Hollowed and Bailey 1989). Nevertheless, the relationship between temperature and recruitment is still significant (rank order correlation two-tailed p-value < 0.05) when using the recruitments from the stock synthesis model for the year classes 1959-86.

Other hypotheses about the causes of recruitment success in Pacific whiting are currently being investigated. One hypothesis, based on the observation that strong year classes have never occurred consecutively, proposes that juvenile cannibalism on larvae and young-of-the-year is an important factor in determining the strength of a year class. Another hypothesis, an elaboration of Bailey's transport hypothesis, proposes that conditions are favorable for recruitment success when weak offshore transport during either January or February is followed by a period of strong upwelling in March (Hollowed and Bailey 1989).

Although establishing a stock-recruit relationship is an important element of assessing the productivity of the resource, the observed pattern of the relationship between the spawning biomass of female whiting and recruitment (Fig. 7) does not lend itself to description by a parametric curve with a log-normal error assumption. Hollowed and Bailey (1989) use the time series methods of Welch (1987) to filter density independent variability from the recruitment time series of Pacific whiting. The resulting scatterplot of filtered recruitment versus egg production (proportional to female spawning biomass) shows a flat relationship over the range of historical levels of egg production. From this analysis they conclude that, at the observed levels of stock abundance, the occurrence of strong year classes cannot be directly attributed to stock abundance and may be linked to factors independent of population density such as environmental conditions.

In earlier versions of the simulation model, recruitment was assumed to be driven by temperature at the time of spawning. Years of cold water temperatures (average Jan. -March temperature in the second quadrant of Marsden square 120 < 15.0°C) were assumed to be years with low mean recruitment, and years of warm temperature (> 15.0°C) were assumed to be years with higher, though more variable recruitment. To simulate recruitment for a 1,000-year run of the simulation model, temperatures for the years 1931-82 were cycled through the model repeatedly. A log-normal random variate was generated with a mean and variance equivalent to the observed cold or warm temperature recruitment according to whether the year was cold or warm.

We considered this procedure to be unsatisfactory for several reasons. First, reliable recruitment estimates are available only for the 1959-86 year classes. By cycling through the longer temperature time series, it is possible to obtain a different mean and variance for the simulated recruitment than has been historically observed. Second, by driving the simulation exclusively by temperature, the possible influence of other environmental variables is neglected. Third, it gives the simulated recruitment time series a particular autocorrelation (since temperature is positively autocorrelated) that is not supported by the recruitment data. A final objection concerns the use of a log-normal random variate. Although the assumption of log-normal variability in recruitment is virtually ubiquitous in simulation models of this type, the atypically high coefficient of variation of Pacific whiting recruitment (1.36) can produce a simulated recruitment that is three to four times larger than any historically observed recruitment when log-normal variability is assumed. From a biological perspective, such a recruitment is unrealistic.

A suitable method to simulate the recruitment process should have the following properties: 1) simulated recruitment should be independent of female spawning biomass over the range of historical levels; 2) the recruitment time series should have the same statistical properties as the observed recruitment, particularly the same mean and variance; and 3) strong assumptions about the pattern of variability in recruitment that are not supported by the data should be avoided. Consideration of these requirements leads us to adopt a procedure similar to iterative resampling statistical procedures (e.g., bootstrap). We propose to sample with replacement from the observed recruitment time series. For such a scheme to have smooth behavior, a moderately long time series of recruitment must be available. The stock synthesis model allowed us to extend our estimates of age-2 recruitment back to the 1959 year class, making available 28 years of recruitment estimates for a sample space,

Harvest Strategies and Risk

Without knowledge of the effect of harvesting on ability of the Pacific whiting population to produce successful recruitments in a highly variable ocean environment, we incur a risk of population collapse by taking a harvest. We assess this risk by focusing on the female spawning biomass. This is defined as

$$SB = \Sigma\ POPN(a) \cdot MATURE(a) \cdot PROPFEM(a) \cdot WEIGHT(a),$$

where POPN(a) is population number of an age group, MATURE(a) is the fraction of sexually mature females of an age group, PROPFEM(a) is the female proportion of total biomass of an age group, and WEIGHT(a) is the population weight at age. Figure 8 shows a frequency histogram for 10 replicate 1,000-year simulations of an unexploited Pacific whiting population using the recruitment resampling method described earlier. When an annual harvest is taken from the population, the distribution of female spawning biomass will be shifted towards lower mean levels of female spawning biomass, The risk is the possibility that harvesting might lower the female spawning biomass to such low levels that it could no longer produce recruitment to sustain population abundance even when conditions are favorable for larval survival.

To assess this risk we used the empirical distribution of female spawning biomass for an unexploited population as a benchmark against which we gauged the magnitude of the disruption that occurs when an annual harvest is taken from the population. We designated the 0.1 percentile of female spawning biomass as a cautionary level of female spawning biomass. This occurs at 398,000 t of female spawning biomass, which is 25% of the mean unfished female spawning biomass (Fig. 8). We assess the risk of a particular harvest strategy by determining the probability that female spawning biomass drops below this level, and seek to develop harvesting strategies where yield from the fishery is maximized subject to the constraint that this probability is at a selected level. Low risk harvest strategies are those where the probability of dropping below this cautionary level is low, and high risk strategies are those where the probability is high.

We acknowledge that the 0.1 percentile of unexploited female spawning biomass is an arbitrary level, and we do not argue that the probability of recruitment failure increases rapidly below this level, although we do note that it must increase rapidly below some level. The fact that the Pacific whiting population persists in an unexploited state at some stable level of mean abundance suggests that the distribution of unexploited female spawning biomass is sufficient to maintain the population through all but the most extraordinary of circumstances. The 0.1 percentile is a level below which the female spawning biomass has not dropped during our 32 years of observation. Our confidence in the assumption that recruitment is unaffected by female spawning biomass erodes rapidly below this point--hence the term cautionary level.

We consider two classes of harvest strategies, a constant effort strategy, and the variable effort algorithm originally promoted by Shuter and Koonce (1985) to manage the Lake Erie walleye (Stizostedion vitreum vitreum) fishery. The use of the term "effort" may be somewhat misleading here since the annual fishing mortality is the control variable. For the variable effort algorithm, fishing mortality in a given year is calculated by

$$f_t = f_{opt}(SB_t/SB_{opt}),$$

where f_{opt} is the optimum level of fishing mortality, SB_t is the current female spawning biomass level, and SB_{opt} is the mean female spawning biomass for the optimal constant effort strategy.

The variable effort harvest strategy has been used to manage the Pacific whiting resource since 1985. It is considered superior to constant effort strategies because in simulations it gives a higher mean yield for a given level of risk. It is able to achieve this higher yield despite cutting back on the fishing mortality rate at low female spawning biomass levels because it greatly increases harvest when female spawning biomass is high. A disadvantage of this strategy is that it makes yield from the fishery extremely variable, and this variability necessarily includes large declines in the yield from one year to the next when a strong year class moves out of the fishery. The economic and political consequences of the variable effort strategy have not been confronted in the past simply because before 1988 the yield from the fishery was far below the recommendations, In this year's assessment, we tamed some of the more extreme behavior of the algorithm by establishing a 500,000 t upper limit on the potential yield from the fishery. In addition, the very large biomass levels generated by the previous log-normal recruitment model do not occur in the resampling model.

Table 17 gives the parameters used to simulate the dynamics of the Pacific whiting population. Estimates of sustainable yield for constant effort and variable effort harvesting strategies are given in Table 18. The table entries were estimated by averaging 10 replicate 1,000-year simulations. To remove the effect of initial conditions, the simulation was run for 50 years before beginning to tabulate the summary statistics. For each harvest strategy we present three levels of risk (low, moderate, and high) to bracket viable alternatives and to provide a middle course. It is important to bear in mind that the labels of low, medium, and high risk are relative designations, and are not intended to imply judgments about which strategy is most reasonable.

The risk categories were defined as follows. Under a low risk strategy the probability of falling below the cautionary female spawning biomass level is 0.05; for moderate risk it is 0.15; and for high risk it is 0.25. Although the definitions of these categories are arbitrary, they result in fishing mortality rates that span the biological reference points commonly used to guide fisheries management decisions (Sissenwine and Shepherd 1987). The low risk options are near a strategy where fishing mortality equals natural mortality (F - M). Under moderate risk harvesting strategies, the mean female spawning biomass is between 42 and 47% of mean unexploited female spawning biomass --slightly lower than the 50% that a surplus production model would predict for maximum sustainable yield. The high risk strategies reduce mean female spawning biomass to 38-41% of the unexploited level and correspond more closely to a $F_{0.1}$ strategy, although the situation is more complex than a yield per recruit analysis would indicate. A yield per recruit analysis assumes a fixed age-specific selectivity pattern for the fishery. If, as the exploitation rate increases, the fishery were to move south to target on the younger, more abundant age groups, the selectivity curve for the fishery would shift. This would change the shape of the yield curve and, thus, change the location of the $F_{0.1}$ point.

We note also that recent scientific advice to management has advocated an exploitation rate near our high risk option (Hollowed et al. 1988). It is important to recognize that, because of the lack of interest in the Pacific whiting resource, these high fishing mortality rates did not occur until last year. For 1989, the projected yield was based on a variable effort strategy with f - 0.53 (although parameterized in terms of catchability). However, these projections assumed that the yield in 1988 was 50,000 t greater than what actually occurred, so the actual fishing mortality rate in 1989 was much lower --closer to our moderate risk variable effort strategy of F - 0.35. For the variable effort strategy, Figures 9 and 10 give a graphical analysis of risk and yield as a function of the fishing mortality rate.

Finally, note that these estimates of sustainable yield assume a fixed pattern of age-specific selectivity similar to that which has been observed in the past. One of the characteristics of the Pacific whiting population is its strong age stratification along the coast. Consequently, an alongshore shift in the center of fishing activity, whether by management design or due to some other factor, would change the selectivity pattern of the fishery, and may result in significantly different estimates of sustainable yield.

YIELD FORECASTS FOR 1990-92 AND 1990 ACCEPTABLE BIOLOGICAL CATCH

Since 1967, the Pacific whiting fishery has been supported by strong year classes occurring every 3 or 4 years. The 1984 year class is the most recent strong year class observed in the fishery. In 1988 it constituted 57% of the total U.S. fishery catch of whiting by number, with most of the remaining catch contributed by the strong 1980 year class. The 1984 year class will contribute even more to the harvest in 1989.

The age-2 abundance of the 1985 and 1986 year classes, estimated by the stock synthesis model (0.017 and 0.100 billion, respectively), are both below the median. Although these figures unquestionably include some estimation error, they should be accurate enough to fix the order of magnitude of these year classes. We base our conclusion that the 1987 year class is also weak on the information presented in Figure 11. The strongest evidence comes from a comparison between the length-frequency histograms for 1985 and 1986, when the 1984 year class was 1 and 2 years old, and the histograms for 1988 and 1989, when the 1987 year class would have been 1 and 2 years old. The strong 1984 year class was evident as a distinct mode in the length-frequency histogram from the U.S. fishery at both 1 and 2 years old, These modes are absent in the histograms for 1988 and 1989. Thus, the evidence is strong that the worst case scenario presented in last year's stock assessment (median recruitment in 1986 and 1987) has turned out to be the most correct one.

In 1988, both the U.S. and the Canadian fisheries were very active, harvesting an aggregate of 251,000 t. An estimated harvest of 309,000 t was removed from the population biomass by the 1989 fisheries. All these factors

--the aging of the strong 1984 year class, the lack of significant recruitment since then, and the high yields of the past 2 years--have combined to reduce the projected female spawning biomass at the start of 1990 to the lowest levels observed since the start of the fishery (Fig. 12). The substantially reduced yields that we forecast for 1990-92 are a consequence of this rapidly changing situation.

One initial concern was that the changes in methodology between this year's and last year's stock assessments had an effect on our yield projections for 1990. We investigated the switch between the asymptotic catchabilities from cohort analysis and the dome-shaped selectivity coefficients from the stock synthesis model, the difference in final year population numbers at age estimated using cohort analysis and stock synthesis, and the use of the recalculated weight-at-age vectors. None of these alterations affected our yield projections for 1990 by more than 7%.

The differences between the forecasts for last year and this year result largely from our assessment of risk. As was mentioned earlier, this year's high risk variable effort strategy corresponds to the single risk category presented in previous assessments. Our analysis demonstrates that this level of exploitation is on the same end of the spectrum as an exploitation rate based on a yield per recruit analysis, and thus must be regarded as a high risk strategy in view of the minimal protection it gives to the female spawning biomass.

Most of the indeterminacy in the yield projections for 1990-92 is due to our uncertainty of the year-class sizes for 1988-90. Our ignorance is most crucial with respect to the timing of the next strong year class. We consider four alternative recruitment scenarios. In scenario A, the 1988 year class is strong, followed by weak year classes in 1989 and in 1990. In scenario B, the 1988 year class is weak, the 1989 year class is strong, and the 1990 year class is weak. In scenario C, a strong year class does not occur until 1990. Scenario D represents the worst case: weak year classes in all 3 years. A strong year class is operationally defined as the mean of the top 25% of the historical recruitments (age-2 abundance 3.178 billion), and a weak year class as the mean of the historical recruitments below the 50th percentile (age-2 abundance 0.137 billion).

Although these recruitment scenarios are intended to represent plausible alternatives, we do not argue that they are equally likely. A preliminary tabulation of the length frequency for the 1989 U.S. fishery shows no sign of a mode of small fish less than 30 cm that would indicate a strong 1988 year class (Fig. 11). Also, 1988 and 1989 were cold years (J. G. Norton, Pacific Fisheries Environmental Group, P. O. Box 831, Monterey, Ca 93942. Pers. commun., May 1989), and a strong year class has never been observed during a cold year. However, in 1989 the U.S. joint venture fishery closed in late June, much earlier than the traditional closing in late September or early October. Consequently the fast-growing one-year-old Pacific whiting may have been missed by the 1989 fishery.

We used a deterministic version of the population simulation model with the information in Table 19 to forecast the yield for 1990-92. The population abundance for the beginning of 1988 (estimated by the stock synthesis model) was updated to the start of 1990 by removing the yield for 1988 (251,000 t) and 1989 (309,000 t). For the 1987 year class, age-2 recruitment was set to 0.137 billion, reflecting our conclusion that it was a weak year class. The weight-at-age vectors given in Table 19 for the U.S. catch, the Canadian catch, and the Pacific whiting population are averages of the smoothed estimates for 1987 and 1988 and the projected weights at age for 1989 based on an extension of von Bertalanffy growth curves for the dominant year classes. These vectors represent the weight at age currently observed in the stock rather than the long-term average.

Table 20 gives the projected yields for 1990-92 under the different harvest strategies and risk levels discussed in the previous section. The, yield for 1990 ranged from 114,000 to 273,000 t. The risk level contributes about 100,000 t of the range, the recruitment scenario contributes about 20,000 t, and the effort strategy contributes about 12,000 t. The fishing mortality rate projected for 1990 using the variable effort strategy with high risk, moderate risk, and low risk options is shown in Figure 13. The low risk scenario provides greater stock protection than seems necessary thus is not recommended. The moderate risk, variable effort strategy specifies a total yield of 180,000 t for recruitment scenarios B, C, and D, which assume that the 1988 year class is weak. The high risk variable effort strategy specifies a total yield of 245,000 t for the same situations. We propose a range of 180,000 to 245,000 t for the total ABC in 1990. The U.S. proportion is estimated to be 80% based on the projected population numbers at age for 1990, the age-specific fraction migrating into the Canadian zone estimated using the logistic regression model already presented, and the fishery-specific weight at age.

In 1991, the yield projections ranged from 67,000 to 224,000 t. Under the optimistic recruitment scenario A, which assumes a strong 1988 year class, the yield for 1991 will still be close to the 1990 yield. A strong 1988 year class will not have a great deal of influence on the female spawning biomass or the recruited biomass until 1991 and later. Under the less optimistic scenarios B, C, and D the yield for 1991 will drop below the yield for 1990. Because of the high level of uncertainty concerning the 1989 and 1990 year classes, forecast of the yield for 1992 is purely speculative. However, it is unlikely to exceed 266,000 t, and may be as low as 50,000 t.

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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, 1966-89.

	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	3.453	130.955
1978	96.827	0.856	0.689	98.372	3.453	1.814	0.000	6.464	104.836
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	32.155	107.732
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	203.577	7.418	-	31.589	66.256	-	-	-
Mean 1966-88				128.101				35.471	163.572

Sources : 1966-80 from Bailey et at. 1980, 1981-89 from Pacific Fishery Information network (PacFIN), Pacific Marine Fisheries Commission, Metro Center, Suite 170, 2000 SW. First Avenue Portland, OR 97201: Canadian catches reported by Mark Saundars, Pacific Biological Station Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6, Pers. commun., January 1990.

Table 2.--Annual catches, quotas and acceptable biological catch (ABC) recommendations for Pacific whiting (1,000 t) in U.S. and Canadian management zones.

	U.S.			Canada			U.S. and Canada combined		
Year	Catch	Quota	ABC	Catch	Quota	ABC	Catch	Quota	ABC
1977	127.502	150.000	-	3.453	20.000	-	130.955	170.000	-
1978	98.372	130.000	-	6.464	23.000	-	104.836	153.000	-
1979	124.680	198.000	-	12.435	24.700	-	137.115	222.000	-
1980	72.352	175.000	-	17.584	31.500	-	89.936	206.500	-
1981	114.760	175.000	-	24.361	31.000	-	139.121	206.000	-
1982	75.577	175.000	-	32.155	30.500	-	107.732	205.500	-
1983	73.150	175.000	-	40.774	42.000	-	113.924	217.000	-
1984	96.382	175.000	-	42.109	40.000	-	138.491	215.000	270.000
1985	85.439	175.000	145.000	24.962	33.400	67.000	110.401	208.400	212.000
1986	154.964	227.500	300.000	55.653	70.000	105.000	210.617	297.500	405.000
1987	160.448	195.000	206.000	73.699	90.000	58.000	234.147	285.000	264.000
1988	160.698	232.200	232.200	90.491	98.000	93.000	251.189	330.200	327.000
1989	-	225.000	225.000	-	98.000	98.000	-	323.000	323.000
Mean 1977-88	112.027			35.3452			147.372		

Sources: Pacific Fishery Management Council 1989, Canadian statistics reported by Mark Saunders. Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6, Pers. commun., January 1990

Table 3.- -Revised catch at age (millions of fish) for the Pacific whiting fisheries, 1978-88. Separate tables are given for the U.S. fisheries, the Canadian fisheries and the combined fisheries. These numbers include the foreign, joint venture and domestic fisheries. The catch at age estimates for the U.S. fishery were revised using the procedure described in the text.

	Age															
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
U.S. fisheries																
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
Canadian fisheries																
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
Combined fisheries																
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

Source: Jerald Berger, U.S. Foreign Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOM, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115, Parr. co-., May 1989. Canadian statistics reported by Mark Saunders, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6, Pars. commun., May 1989

Table 4.--Revised estimates of U.S. fishery length at age (cm) for Pacific whiting. Values for the dominant year classes are as observed. Values for the other year classes were interpolated from the estimated length at age from growth curves fit to the dominant year classes.

	Age														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
								Males							
1978	25.71	34.26	39.67	43.33	46.17	47.49	48.62	49.50	51.42	52.64	53.54	53.44	53.44	53.44	53.44
1979	25.71	32.76	39.75	43.30	45.85	47.24	48.84	49.68	50.94	51.85	52.80	53.44	53.44	53.44	53.44
1980	25.71	33.96	40.70	43.27	45.69	47.55	49.21	49.80	50.44	50.87	52.16	52.92	53.44	53.44	53.44
1981	25.71	33.53	39.14	43.22	45.53	47.27	48.69	49.79	50.48	51.00	51.65	52.39	53.01	53.44	53.44
1982	26.86	33.44	38.46	42.40	45.31	46.99	48.31	49.47	50.54	50.96	51.41	51.87	52.57	53.07	53.44
1983	28.01	33.78	37.77	41.57	44.46	46.60	47.94	49.01	49.99	51.14	51.30	51.71	52.13	52.70	53.12
1984	29.15	34.45	38.16	40.37	43.54	45.74	47.31	48.54	49.46	50.34	51.52	51.54	51.92	52.32	52.79
1985	30.30	35.12	38.54	40.94	42.98	44.77	46.56	49.40	48.94	49.77	50.58	51.38	51.72	52.08	52.46
1986	30.30	35.70	38.92	41.14	42.71	43.77	45.55	47.06	48.78	49.20	49.97	50.74	51.51	51.84	52.20
1987	30.30	35.79	39.39	41.34	42.79	43.82	44.61	46.05	47.39	48.60	49.36	50.11	50.85	51.60	51.93
1988	30.30	35.79	39.30	41.51	42.88	43.85	44.53	45.14	46.36	47.59	48.35	49.47	50.20	50.93	51.66
1989	30.30	35.79	39.30	41.54	42.97	43.87	44.51	44.98	45.33	46.55	47.71	48.83	49.54	50.26	50.98
								Females							
1978	26.56	35.12	40.34	43.93	46.88	48.10	49.32	50.53	52.18	53.55	54.65	55.53	56.18	56.72	57.16
1979	26.56	33.07	40.58	44.01	46.60	48.51	49.80	50.83	52.35	53.35	54.52	55.53	56.18	56.72	57.16
1980	26.56	35.24	41.25	44.09	46.48	48.47	50.15	51.09	52.03	53.18	54.31	55.31	56.18	56.72	57.16
1981	26.56	35.09	40.53	43.85	46.35	48.14	49.78	50.80	52.07	52.99	53.81	55.10	55.96	56.72	57.16
1982	27.57	33.62	40.24	43.76	46.18	47.82	49.28	50.70	52.57	52.83	53.76	54.88	55.74	56.49	57.16
1983	28.58	35.21	38.35	43.34	45.72	47.53	48.78	50.05	51.35	52.64	53.41	54.37	55.52	56.27	56.93
1984	29.59	35.47	39.88	40.87	45.21	46.92	48.17	49.40	50.58	51.81	52.96	53.86	54.86	56.04	56.70
1985	30.60	35.74	39.81	42.74	43.68	46.34	47.65	50.35	49.81	50.95	52.13	53.35	54.21	55.26	56.47
1986	30.60	35.73	39.74	42.55	44.50	44.57	47.03	48.10	50.02	50.09	51.20	52.36	53.55	54.48	55.58
1987	30.60	36.00	39.92	42.36	44.29	45.58	45.44	47.44	48.37	49.52	50.27	51.38	52.53	53.70	54.69
1988	30.60	36.00	39.68	42.10	44.08	45.40	46.25	46.05	47.69	48.53	49.41	50.39	51.50	52.64	53.80
1989	30.60	36.00	39.68	42.18	43.87	45.21	46.11	45.08	47.00	47.84	48.63	49.41	50.48	51.59	52.73

Source: Jerald Berger, U.S. Foreign Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115, Pers. commun., February 1989.

Table 5.- -Coefficients for an exponential length-weight relationship for Pacific whiting estimated with nonlinear regression using data from the U.S. fishery and estimated weights (g) for selected lengths.

Year	Coefficients a	Coefficients b	Estimated weight at length 30 cm	40 cm	50 cm
Males					
1976	0.008	2.944	186.2	434.4	837.9
1977	0.055	2.449	227.9	461.0	796.1
1978	0.082	2.326	223.4	436.2	733.0
1979	0.033	2.585	218.9	460.6	820.1
1980	0.052	2.463	224.1	455.2	788.6
1981	0.032	2.579	209.2	439.3	781.2
1982	0.030	2.589	201.6	424.6	756.7
1983	0.058	2.389	196.9	391.4	667.0
1984	0.067	2.374	214.0	423.7	719.6
1985	0.046	2.489	218.8	447.7	780.2
1986	0.047	2.469	210.4	428.2	743.0
1987	0.017	2.728	186.3	408.4	750.7
1988	0.020	2.695	192.0	416.9	760.7
Females					
1976	0.034	2.582	218.6	459.4	817.3
1977	0.009	2.903	183.2	422.3	807.3
1978	0.004	3.085	154.1	374.4	745.4
1979	0.012	2.841	194.1	439.6	828.7
1980	0.008	2.960	180.9	423.9	820.7
1981	0.011	2.865	188.0	428.7	812.3
1982	0.006	3.019	169.7	404.3	792.9
1983	0.004	3.095	148.5	361.8	721.7
1984	0.010	2.880	178.4	408.5	776.7
1985	0.012	2.844	191.2	433.3	817.3
1986	0.003	3.209	152.0	382.7	783.1
1987	0.007	2.952	170.3	398.2	769.5
1988	0.005	3.075	166.3	402.8	800.0

Source: Jerald Berger, U.S. Foreign Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115, Pers. commun., February 1989.

Table 6.- -Estimates of combined sex weight at age (g) for the U.S. Pacific whiting fishery and the total population.

	Age														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
							U.S. fishery mean weight at age								
1978	118.7	264.0	407.1	513.9	610.1	655.7	695.7	743.4	812.4	879.8	956.1	993.3	1065.4	1092.8	1125.3
1979	142.7	264.4	455.5	570.5	667.3	733.8	792.6	831.1	905.2	943.9	1016.1	1088.3	1155.7	1071.4	1207.8
1980	141.2	297.8	469.7	558.9	646.0	722.0	790.2	825.5	866.5	898.5	995.0	1045.6	1049.9	1040.0	1158.8
1981	136.5	286.5	428.7	546.9	631.7	696.6	760.2	809.0	858.4	888.1	933.6	999.9	1055.1	1075.5	1175.8
1982	142.6	253.2	395.7	508.5	605.3	668.6	730.2	787.5	856.5	877.4	900.9	975.6	1052.5	1060.8	1016.2
1983	149.8	252.7	328.4	446.5	525.5	589.1	636.5	680.3	721.2	790.9	806.3	849.6	878.2	1005.0	999.4
1984	187.4	293.1	387.2	433.8	550.4	607.2	658.2	712.0	752.5	797.8	863.3	905.7	934.4	952.2	1113.2
1985	213.3	321.2	412.2	490.9	544.8	618.8	678.9	795.5	776.8	831.0	919.8	960.9	1023.5	1003.7	1110.6
1986	192.1	293.9	386.4	463.8	517.9	538.0	616.6	663.1	735.4	754.6	815.7	876.5	919.3	928.3	1093.8
1987	186.7	296.7	393.8	460.0	517.0	546.5	563.0	627.1	681.2	719.5	748.2	834.2	856.1	892.6	975.3
1988	197.3	302.8	395.1	465.9	520.4	570.4	571.5	595.6	641.5	702.1	733.4	802.8	873.6	886.2	954.6
1989	188.3	300.3	395.4	467.6	520.1	558.6	584.9	608.1	622.4	665.5	711.2	757.1	805.1	840.2	919.3
Avg. 1978-88	166.4	285.5	404.6	493.9	571.4	625.4	673.2	723.2	769.2	812.4	866.6	924.1	972.4	987.4	1070.8
							Population mean weight at age								
1978	91.3	243.4	389.6	515.9	634.1	690.6	746.2	799.4	891.8	964.8	1024.3	1054.2	1079.1	1100.0	1117.4
1979	98.1	223.8	437.8	574.7	691.1	773.9	850.1	902.5	984.1	1043.0	1111.0	1166.5	1191.0	1211.6	1228.7
1980	96.7	260.4	456.6	562.8	668.8	762.7	850.6	894.1	940.8	990.7	1064.4	1122.0	1170.1	1191.7	1209.8
1981	94.2	249.1	411.7	549.9	654.8	739.1	817.9	874.9	932.1	975.5	1020.0	1085.6	1134.1	1175.1	1192.2
1982	100.6	215.3	377.2	512.0	624.5	702.7	773.3	843.2	930.5	949.9	994.0	1047.2	1098.5	1141.8	1179.2
1983	110.0	220.2	306.4	443.3	538.4	617.8	674.0	729.1	786.1	849.3	877.9	918.9	968.5	1008.2	1042.5
1984	144.3	259.1	371.2	420.1	558.3	637.3	698.2	755.6	807.6	862.5	924.2	953.9	996.3	1046.7	1081.4
1985	169.9	284.0	396.2	491.1	547.3	643.7	713.8	853.2	826.8	880.1	936.7	996.5	1034.4	1081.1	1135.7
1986	148.9	262.3	367.2	455.3	524.9	545.6	641.3	701.5	796.1	807.7	861.8	920.1	982.2	1026.2	1079.6
1987	145.9	264.4	374.6	451.5	517.4	566.0	578.6	656.9	711.0	771.2	811.2	863.0	918.4	976.9	1020.1
1988	146.3	267.1	374.8	457.6	525.6	575.4	610.7	618.1	687.6	739.5	783.4	841.4	896.0	954.3	1016.0
1989	146.3	267.1	374.8	459.8	522.6	571.3	606.6	630.8	646.8	696.1	745.4	795.2	845.8	900.5	958.6
Avg. 1978-88	122.4	249.9	387.6	494.0	589.6	659.5	723.1	784.4	845.0	894.0	946.3	997.2	1042.6	1083.1	1118.4

Table 7.--Impact of the emphasis on the log(likelihood) for Pacific whiting survey biomass. All other runs of the model were made with the emphasis set at a level of 5.0. Less negative values of the log(likelihood) indicate better fit to that type of data. Survey biomass standard error is the root mean square of the deviations between measured and modeled survey biomass.

Emphasis	0.1	1.0	5.0	10.0	25.0	100.0
Numbers at age 3 by year class						
1970	3.65	2.87	2.61	2.59	2.60	2.74
1973	1.24	1.02	0.95	0.93	0.94	0.99
1977	1.62	1.45	1.46	1.52	1.67	2.15
1980	3.88	3.70	3.69	3.59	3.35	2.97
1984	2.65	2.85	3.31	3.48	3.82	4.43
Log(likelihood) components						
U.S. fish. age	-363.0	-364.0	-369.0	-378.0	-415.0	-546.0
Can. fish. age	-269.0	-271.0	-270.0	-272.0	-275.0	-324.0
Survey age	-45.0	-52.0	-61.0	-65.0	-104.0	-147.0
Survey biomass	-39.0	-8.0	-0.0	2.0	5.0	10.0
Survey biomass standard error	0.301	0.215	0.169	0.153	0.122	0.060
Age 3+ biomass (million t) in 1989*	1.46	1.36	1.49	1.53	1.62	1.85

*This is the biomass of ages 3 and older at the beginning of 1989.

Table 8.- -Effect of assumptions regarding Pacific whiting survey selectivity and age-specific natural mortality. Survey selectivity was defined as the product of two logistic functions of age, where two parameters specify the ascending function and two parameters specify the descending function. When a trend in natural mortality was estimated, one parameter specified the inflection age and one parameter specified the natural mortality rate at age 14.

Ascend: Descend: Nat.Mort:	Constant Fitted Constant		Fitted Fitted Constant		Constant Constant Fitted	
Age	Sel.	M	Sel.	M	Sel.	M
2	1.00	0.20	0.63	0.20	1.00	0.20
3	1.00	0.20	0.69	0.20	1.00	0.20
4	1.00	0.20	0.76	0.20	1.00	0.20
5	1.00	0.20	0.82	0.20	1.00	0.20
6	1.00	0.20	0.88	0.20	1.00	0.20
7	1.00	0.20	0.93	0.20	1.00	0.20
8	1.00	0.20	0.97	0.20	1.00	0.20
9	1.00	0.20	1.00	0.20	1.00	0.20
10	0.97	0.20	0.98	0.20	1.00	0.20
11	0.84	0.20	0.79	0.20	1.00	0.27
12	0.46	0.20	0.37	0.20	1.00	0.36
13	0.12	0.20	0.10	0.20	1.00	0.45
14	0.02	0.20	0.02	0.20	1.00	0.55
Number of fitted parameters:						
Survey	2		4		0	
Mortality	0		0		2	
Model output:						
Log(likelihood) of fit to survey age composition	-61.0		-48.0		-69.0	
Std. error of fit to log(survey biomass)	0.169		0.158		0.167	
Age 2+ Biomass in 1989	1.49		2.24		1.37	

Table 9.--Selectivity pattern for combined Pacific whiting fisheries as estimated by the current synthesis model and the 1988 cohort analysis. All selectivity patterns were scaled to be 1.0 at age 8. The average selectivity pattern for the cohort analysis is calculated according to the averaging procedure developed by Francis et al. (1985), and as the simple mean of the catchabilities for the strong year classes.

Age	1989 Synthesis	1988 Cohort strong year class	1988 Cohort
2	0.089	---	---
3	0.195	0.175	0.043
4	0.564	0.556	0.196
5	0.688	0.759	0.262
6	0.874	0.888	0.554
7	0.925	0.994	0.604
8	1.000	1.000	1.000
9	0.749	0.775	1.055
10	0.739	1.116	1.291
11	0.280	1.156	1.291
12	0.237	---	---
13	0.053	---	---
14	0.025	---	---

Table 10.--Fit to early Pacific whiting age composition data (Dark 1975) in the long time series runs. The expected age composition (Exp.) is compared to the observed age composition (Obs.) for the years 1965-69. The last value in each column accumulates values for all older ages. Age-specific selectivity coefficients are also given for each age.

		1965		1966		1967		1968		1969	
Age	Select.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
4	0.055	0.197	0.187	0.018	0.003	0.012	0.021	0.013	0.021	0.015	0.001
5	0.301	0.216	0.239	0.418	0.453	0.046	0.049	0.057	0.025	0.070	0.078
6	0.872	0.255	0.252	0.289	0.279	0.614	0.583	0.077	0.088	0.155	0.174
7	1.132	0.095	0.085	0.159	0.153	0.211	0.211	0.612	0.636	0.759	0.746
8	1.000	0.112	0.115	0.045	0.051	0.076	0.081	0.173	0.156		
9	0.710	0.125	0.121	0.071	0.061	0.041	0.055	0.069	0.074		
10	0.411										
11	0.201										
12	0.089										
13	0.038										
14	0.015										

Table 11.- -Influence of the assumed level of virgin equilibrium recruitment on the estimated recruitment for the 1956-62 Pacific whiting year classes. Recruitment levels are in billions of age-3 fish. Female spawning biomass (SB, million t) for 1965 is also given.

	Assumed virgin recruitment		
Year class	0.30	0.60	0.90
1956	0.03	0.03	0.03
1957	0.31	0.39	0.43
1958	0.14	0.17	0.18
1959	0.56	0.63	0.67
1960	1.11	1.19	1.25
1961	3.99	4.11	4.21
1962	0.10	0.11	0.11
Virgin SB	0.41	0.86	1.31
1965 SB	1.22	1.47	1.69

Table 12.--Time series of abundance and fishing mortality for Pacific whiting. Catch and fishing mortality are for the combined U.S. and Canadian fisheries. Abundance is in millions of tons of age-2 and older fish, and is presented at the beginning of the year and the mean within the year. Recruitment is presented as billions of age-2 fish at the beginning of the year. Survey deviations are the $\log_e$(observed/expected).

Year	Beginning biomass	Mean biomass	Beginning spawning biomass	Recruitment (billions)	Catch (1,000 t)	Fishing mortality
1958	2.849	2.582	1.310	0.036	0.200	0.000
1959	2.708	2.454	1.246	0.547	0.200	0.000
1960	2.504	2.269	1.179	0.227	0.200	0.000
1961	2.434	2.206	1.074	0.835	0.200	0.000
1962	2.603	2.359	1.039	1.533	0.200	0.000
1963	3.734	3.384	1.082	5.160	0.200	0.000
1964	3.961	3.590	1.486	0.131	0.200	0.000
1965	4.077	3.695	1.696	0.895	0.200	0.000
1966	4.067	3.615	1.863	0.768	137.700	0.118
1967	3.732	3.271	1.682	0.692	214.371	0.127
1968	3.388	3.007	1.510	0.786	122.180	0.076
1969	3.259	2.860	1.402	1.110	180.131	0.141
1970	3.035	2.629	1.317	0.636	234.584	0.181
1971	2.650	2.323	1.190	0.315	154.612	0.130
1972	3.135	2.782	1.079	3.597	117.546	0.118
1973	3.067	2.698	1.216	0.169	162.439	0.161
1974	2.831	2.459	1.216	0.306	211.259	0.181
1975	2.773	2.400	1.182	1.432	221.359	0.204
1976	2.403	2.055	1.060	0.139	237.520	0.241
1977	2.013	1.758	0.911	0.220	130.954	0.143
1978	1.718	1.503	0.825	0.094	104.836	0.129
1979	1.964	1.709	0.771	1.716	137.114	0.185
1980	1.859	1.640	0.763	0.035	89.936	0.133
1981	1.605	1.384	0.706	0.145	139.121	0.215
1982	2.265	2.000	0.625	4.604	107.732	0.175
1983	2.052	1.805	0.735	0.022	113.924	0.184
1984	1.995	1.742	0.836	0.042	138.491	0.146

Table 12.- -Continued.

Year	Beginning biomass	Mean biomass	Beginning spawning biomass	Recruitment (billions)	Catch (1,000 t)	Fishing mortality
1985	1.918	1.685	0.929	0.183	110.401	0.107
1986	2.566	2.225	0.715	4.221	210.617	0.223
1987	2.342	2.012	0.845	0.017	234.147	0.269
1988	1.997	1.688	0.833	0.101	251.189	0.244
1989	1.620	1.315	0.788	(0.100)	303.000	0.385

	Survey biomass (million t)		
Year	Observed	Expected	Deviate
1977	1.195668	1.345248	-0.118
1980	1.532735	1.301007	0.164
1983	1.329676	1.523491	-0.136
1986	2.131030	2.004613	0.061
Root mean squared dev.			0.145

Table 13 .--Estimates of the midwater component of the Pacific whiting population and the age-specific proportion in the Canadian exclusive economic zone (EEZ) from the west coast triennial acoustic surveys (millions of fish).

Age	Total pop. size	No. in Canada	Proportion in Canada	Total pop. size	No. in Canada	Proportion in Canada
	1977			1980		
2	45.70	0.01	0.00	36.30	0.23	0.01
3	53.63	0.14	0.00	1,349.61	0.00	0.00
4	443.52	10.74	0.02	119.25	0.00	0.00
5	40.82	1.79	0.04	79.71	6.07	0.08
6	62.86	6.85	0.11	62.58	3.65	0.06
7	614.38	96.22	0.16	242.52	39.26	0.16
8	79.57	21.15	0.27	61.34	6.10	0.10
9	52.23	18.87	0.36	188.78	45.08	0.24
10	36.19	12.36	0.34	75.89	22.92	0.30
11	26.09	9.62	0.37	52.48	18.40	0.35
12	12.99	5.42	0.42	13.11	4.83	0.37
13	4.72	2.33	0.49	11.14	4.28	0.38
14+	1.74	0.73	0.42	4.71	1.76	0.37
	1983			1986		
2	18.98	0.01	0.00	2,947.10	0.83	0.00
3	2,526.13	100.27	0.04	73.99	0.19	0.00
4	37.19	9.68	0.26	16.95	1.96	0.12
5	24.33	10.18	0.42	131.02	12.25	0.09
6	295.72	190.19	0.64	1,402.07	314.81	0.22
7	23.90	16.06	0.67	135.50	36.25	0.27
8	25.05	17.66	0.71	99.87	17.58	0.18
9	20.62	14.89	0.72	123.29	40.59	0.33
10	33.45	24.33	0.73	14.05	3.39	0.24
11	11.52	8.44	0.73	14.75	3.08	0.21
12	8.60	6.42	0.75	5.02	0.47	0.09
13	6.37	4.72	0.74	9.44	3.26	0.35
14+	1.24	0.93	0.75	2.67	0.30	0.1

Source: Neal Williamson, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115, Pers. commun., May 1989.

Table 14.- -Pacific whiting survey biomass estimates (1,000 t) in the Vancouver International North Pacific Fisheries Commission (INPFC) region. The trawl biomass estimates for the Canadian sector in 1977 and 1986 were estimated by applying the average of the 1980 and 1983 ratio of trawl biomass between the U.S. and Canadian sectors of the Vancouver INPFC region to the years 1977 and 1986.

	U.S.	Canada	Total
1977			
Acoustic survey	152.439	191.382	343.821
Trawl survey	6.523	1.762	8.285
Total	158.962	193.144	352.106
1980			
Acoustic survey	159.931	162.402	322.333
Trawl survey	11.770	4.385	16.155
Total	171.701	166.787	338.488
1983			
Acoustic survey	236.507	258.725	495.232
Trawl survey	8.068	1.352	9.420
Total	244.575	260.077	504.652
1986			
Acoustic	238.476	284.316	522.792
Trawl	19.403	5.240	24.643
Total	257.879	289.556	547.435

Sources: Dark et al. 1980, Weinberg et al. 1984, Nelson and Dark 1985, Coleman 1986, Coleman 1988, Neal Williamson, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115. Pers. commun., May 1989.

Table 15.--Analysis of deviance table for the age-specific proportion of Pacific whiting migrating into the Canadian exclusive economic zone (EEZ).

Parameters in model	Deviance	Change in dev.	d.f.	Change in d.f.	p-value
Constant	16461.0	---	51	---	---
+ Age	10509.0	5952.0	50	1	<.001
+ Age^2	8764.2	1744.8	49	1	<.001
+ Age^3	8463.6	300.6	48	1	<.001
+ Temp.	2886.2	5577.4	47	1	<.001

Scale Parameter = 19.075   d.f. = 36

$R^2 = 0.82$

Parameter Estimates:

Parameter	Estimate	Standard error
Constant	-30.54	1.785
Age	2.366	0.3969
Age^2	-0.2107	0.04704
Age^3	0.006288	0.001751
Temp.	1.415	0.0911

Table 16.--Logistic regression estimates of the age-specific proportion of Pacific whiting migrating into the Canadian exclusive economic zone (EEZ) for a model without the anomalous results of the 1983 surveys and without temperature as a covariate.

Age	Proportion
2	0.004
3	0.012
4	0.032
5	0.070
6	0.122
7	0.180
8	0.234
9	0.275
10	0.302
11	0.317
12	0.324
13	0.330
14+	0.338

Parameter estimates:

Parameter	Estimate	Standard error
Constant	-8.9310	1.6370
Age	1.9310	0.5944
Age^2	-0.1532	0.0682
Age^3	0.0041	0.0025

$R^2 = 0.76$

Table 17.--Parameter values for the 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
USWT	285.5	404.6	493.9	571.4	625.4	673.2	723.2	769.2	812.4	866.6	924.1	972.4	1,029.1
CANWT	309.5	489.1	618.0	703.0	767.3	803.6	871.7	928.8	949.2	1,015.8	1,075.0	1,108.4	1,117.0
POPWT	249.9	387.6	494.0	589.6	659.5	723.1	784.4	845.0	894.0	946.3	997.2	1,042.6	1,083.1
SELECT	0.089	0.195	0.563	0.688	0.874	0.925	1.000	0.749	0.739	0.280	0.237	0.053	0.024
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
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
USCAN	0.004	0.012	0.032	0.070	0.122	0.180	0.234	0.275	0.302	0.317	0.324	0.330	0.338
POPINIT	0.100	0.013	2.635	0.081	0.013	0.004	0.727	0.015	0.002	0.099	0.004	0.008	0.165
NMORT	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200

USWT - United States fishery weight at age (kg)
CANWT - Canadian fishery weight at age (kg)
POPWT - Population weight at age (kg)
SELECT - Combined fishery selectivities estimated by the stock synthesis model
MATURE - Proportion of sexually mature females
PROPFEM - Proportion by weight of females in the population
USCAN - Proportion of fish in the Canadian zone
POPINIT - Initial population vector (billions)
NMORT - Natural mortality rate

Table 18.--Sustainable yield for different management policies estimated by averaging the results of 10 replicate simulations of the Pacific whiting fishery of 1,000 years each. SB_{opt} used in the variable effort algorithm is defined as the mean female spawning biomass level at constant effort strategy where the probability is 0.15 that the female spawning biomass goes below the cautionary level of female spawning biomass (SB_{caut}) of 398,000 t.

	F_{opt}	Total yield (kt)	CV	U.S. yield (kt)	CV	SB_{opt} (kt)	Spawn. biom. (kt)	CV	% years below SB_{caut}	% years at yield cap
					Constant effort policy					
Low risk	0.18	178	48.9	150	50.3	---	949	41.3	5.0	0.2
Mod. risk	0.27	214	50.7	184	52.3	---	767	46.7	15.0	1.9
High risk	0.36	244	50.2	213	51.5	---	666	49.8	25.0	4.8
					Variable effort algorithm					
Low risk	0.21	205	68.0	177	70.1	767	817	40.3	5.0	8.0
Mod. risk	0.35	237	64.3	207	66.5	767	687	43.3	15.0	12.8
High risk	0.50	251	63.1	221	65.2	767	615	47.2	25.0	16.2

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

kt - 1,000 metric tons

CV - coefficient of variation

Yield cap - maximum annual yield (set at 500,000 t)

Table 19.--Summary of information used for the short-term yield forecasts of the Pacific whiting resource.

I. Beginning of the year population abundance (billions of fish) by age

Year/Age	2	3	4	5	6	7	8	9	10	11	12	13	14
1988	0.100	0.013	2.635	0.081	0.013	0.004	0.727	0.015	0.002	0.099	0.004	0.008	0.165
1989	0.137	0.080	0.010	1.885	0.056	0.009	0.003	0.468	0.010	0.001	0.076	0.003	0.141
1990	---	0.108	0.061	0.007	1.188	0.033	0.005	0.001	0.288	0.006	0.001	0.057	0.117

II. Current weight at age (kg)

Year/Age	2	3	4	5	6	7	8	9	10	11	12	13	14
U.S.	0.300	0.395	0.465	0.519	0.558	0.573	0.610	0.648	0.696	0.731	0.798	0.845	0.873
Canada	0.314	0.457	0.566	0.643	0.692	0.706	0.768	0.801	0.827	0.877	0.919	0.943	0.940
Popul.	0.266	0.375	0.456	0.522	0.571	0.599	0.635	0.682	0.736	0.780	0.833	0.887	0.944

1988 estimated yield: 251,000 t
1989 expected yield: 303,000 t

1989 beginning of year spawning biomass: 829,000 t
1990 beginning of year spawning biomass: 599,000 t

Table 20.--Summary of the 1990-92 potential annual yields. Yield and biomass projections are in thousands of tons. Recruitment scenarios are described in Item VII.

I. Variable effort, low risk strategy (F = 0.21)

Recruit. scenario	Year	Yield	Spawn. biomass	Age 2+ biomass
A	1990	126	599	1,998
	1991	129	711	1,887
	1992	171	731	1,678
B	1990	114	599	1,189
	1991	76	481	1,776
	1992	106	638	1,748
C	1990	114	599	1,189
	1991	67	481	967
	1992	58	407	1,634
D	1990	114	599	1,189
	1991	67	481	967
	1992	50	407	825

II. Constant effort, low risk strategy (F = 0.18)

Recruit. scenario	Year	Yield	Spawn. biomass	Age 2+ biomass
A	1990	137	599	1,998
	1991	118	706	1,876
	1992	154	731	1,680
B	1990	123	599	1,189
	1991	101	476	1,767
	1992	105	622	1,716
C	1990	123	599	1,189
	1991	88	476	958
	1992	88	392	1,606
D	1990	123	599	1,189
	1991	88	476	958
	1992	75	392	797

III. Variable effort, moderate risk strategy (F = 0.35)

Recruit. scenario	Year	Yield	Spawn. biomass	Age 2+ biomass
A	1990	200	599	1,998
	1991	184	676	1,815
	1992	228	673	1,661
B	1990	180	599	1,189
	1991	106	448	1,713
	1992	144	595	1,663
C	1990	180	599	1,189
	1991	92	449	904
	1992	76	365	1,555
D	1990	180	599	1,189
	1991	92	449	904
	1992	63	365	746

IV. Constant effort, moderate risk strategy (F = 0.27)

Recruit. scenario	Year	Yield	Spawn. biomass	Age 2+ biomass
A	1990	198	599	1,998
	1991	163	677	1,817
	1992	207	683	1,583
B	1990	179	599	1,189
	1991	138	449	1,714
	1992	139	581	1,633
C	1990	179	599	1,189
	1991	118	449	905
	1992	114	352	1,531
D	1990	179	599	1,189
	1991	118	449	905
	1992	94	352	722

Table 20 .--Continued.

V. Variable effort, high risk strategy (F - 0.50) | IV. Constant effort, high risk strategy (F - 0.36)

Recruit. scenario	Year	Yield	Spawn. biomass	Age 2+ biomass	Recruit. scenario	Year	Yield	Spawn. biomass	Age 2+ biomass
A	1990	273	599	1,998	A	1990	257	599	1,998
	1991	224	642	1,745		1991	201	650	1,761
	1992	266	622	1,458		1992	249	640	1,496
B	1990	245	599	1,189	B	1990	230	599	1,189
	1991	127	416	1,652		1991	168	423	1,666
	1992	170	557	1,589		1992	164	545	1,561
C	1990	245	599	1,189		1990	230	599	1,189
	1991	107	416	834		1991	142	423	857
	1992	85	329	1,487		1992	132	318	1,466
D	1990	245	599	1,189		1990	230	599	1,189
	1991	107	416	834		1991	142	423	857
	1992	70	329	678		1992	106	318	657

VII. Recruitment scenarios

	Year class	Annual recruitment
A.	1988	strong
	1989	weak
	1990	weak
B.	1988	weak
	1989	strong
	1990	weak
C.	1988	weak
	1989	weak
	1990	strong
D.	1988	weak
	1989	weak
	1990	weak

Note: Strong - 3.178 billion (mean of top 25 percent historical recruitment)
Weak recruitment - 0.137 billion (mean of historical recruitment below median)

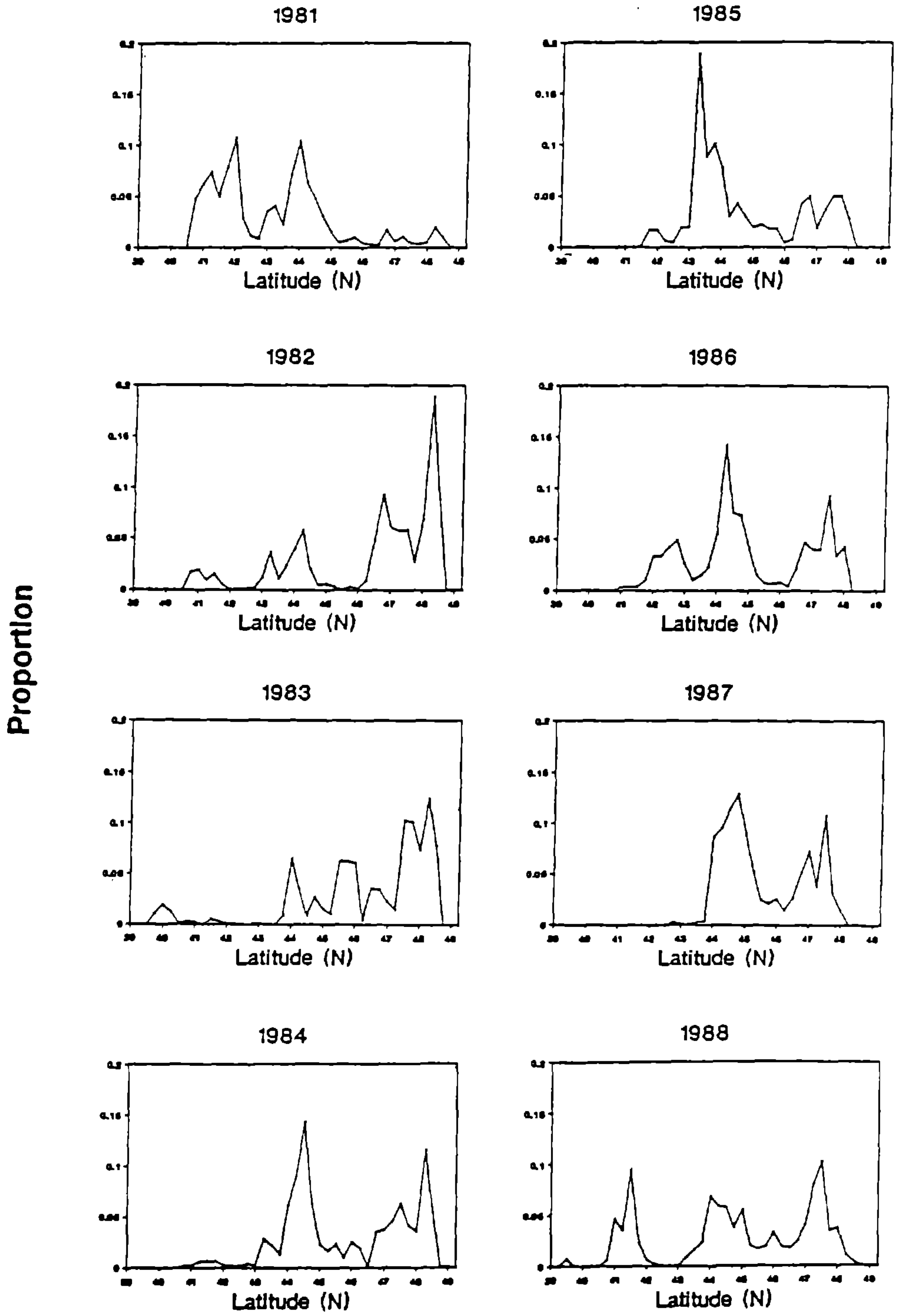
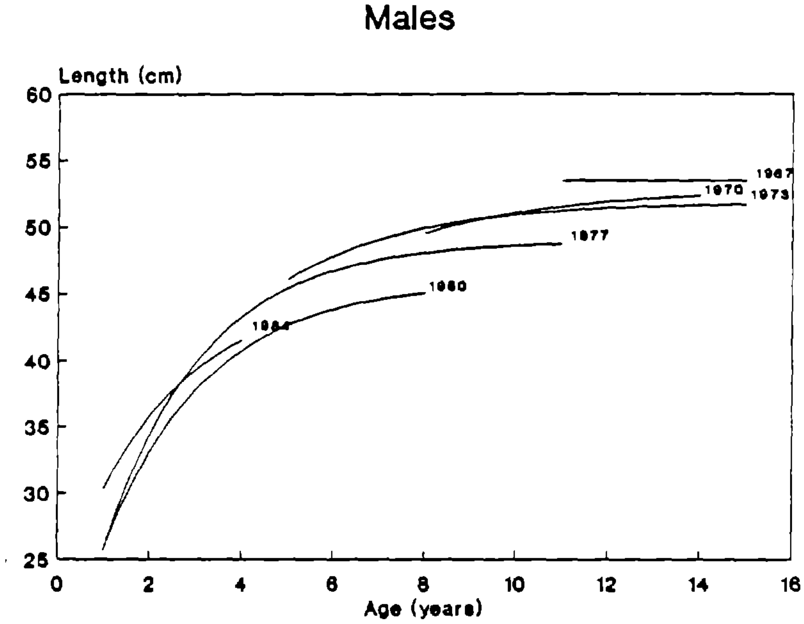


Figure 1. --The alongshore distribution of the Pacific whiting catch in the U.S. management zone, 1981-88. The persistence of three areas of high fishing productivity is evident in the plots. Source: Jerald Berger, U.S. Foreign Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115, Pers. commun., February 1989.



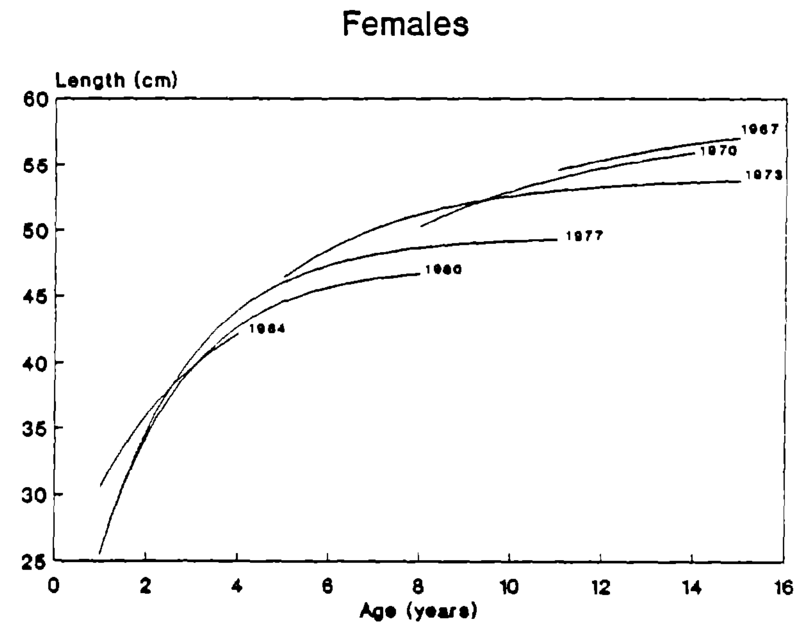


Figure 2.--Von Bertalanffy growth curves fit to the dominant Pacific whiting year classes from 1967 to 1984 using length-at-age data from the U.S. fishery with nonlinear weighted least squares. We used a reparameterized form of the von Bertalanffy growth curve such that length at age one is an unestimated parameter.

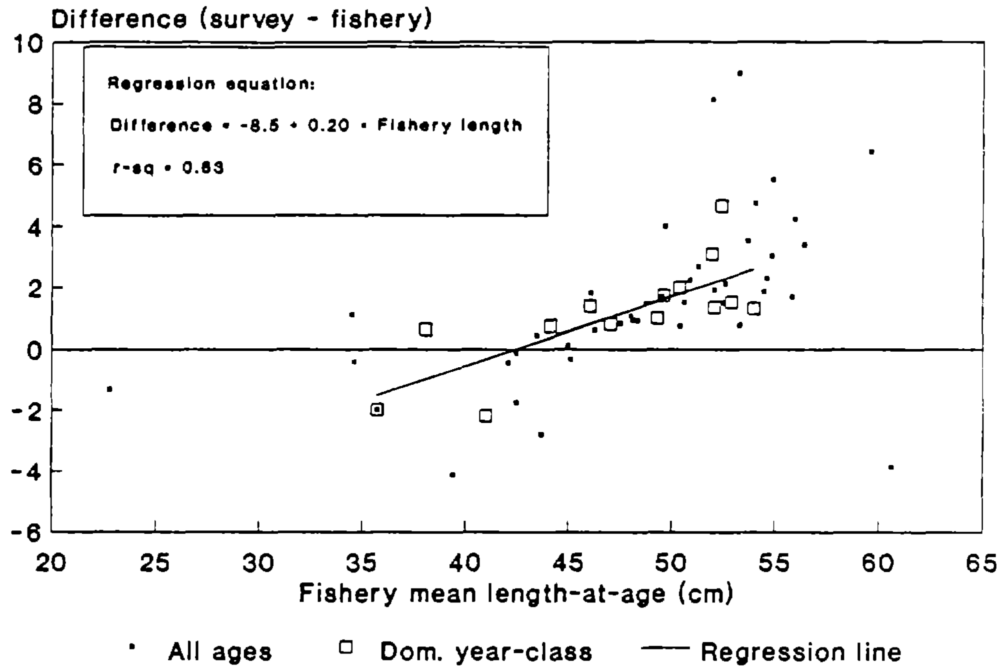


Figure 3. --Relationship between U.S. fishery mean length at age for Pacific whiting and the difference between survey and U.S. fishery length at age during the survey years 1977, 1980, 1983, 1986. This relationship was employed to obtain estimates for population weight at age for years in which no survey took place. Regression line represents dominant year classes only. Sources: Jerald Berger, U.S. Foreign Fishery Observer Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115, Pers. commun., February 1989; Weinberg et al. 1984; Nelson and Dark 1985; Coleman 1988; Neal Williamson, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, BIN C15700, 7600 Sand Point Way NE., Seattle, WA 98115, Pers. commun., May 1989.

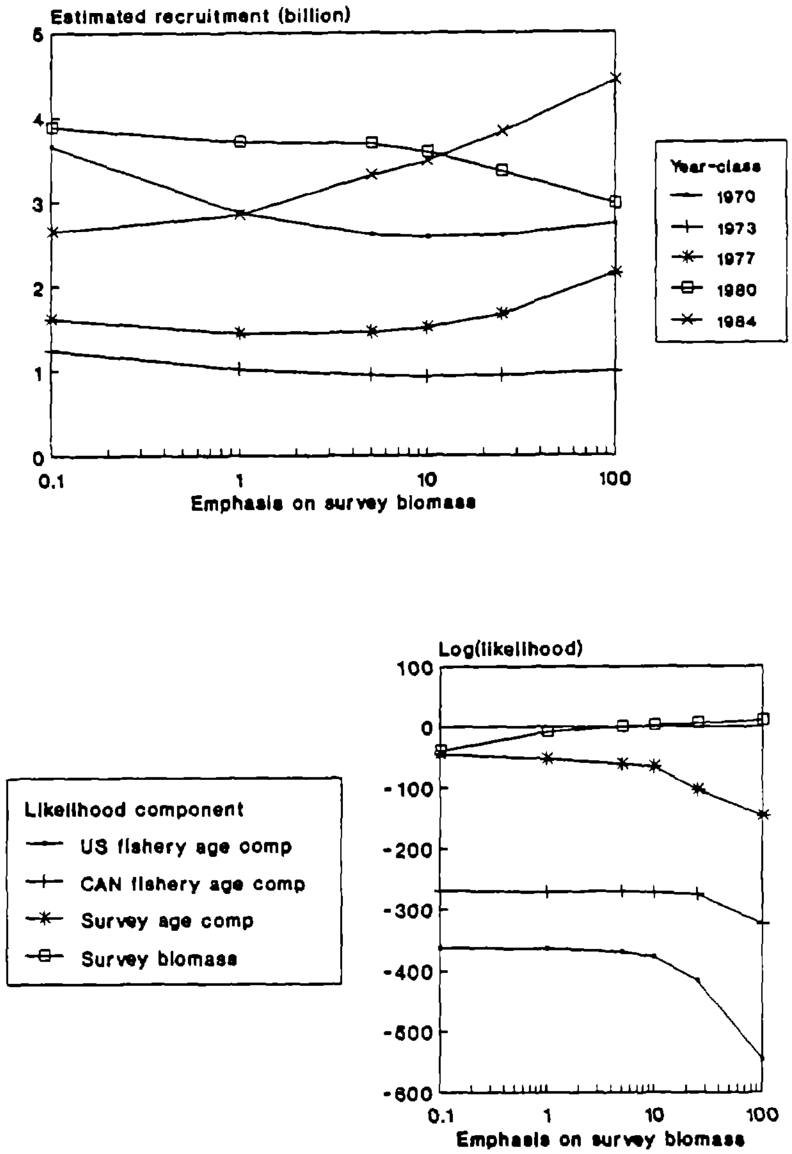


Figure 4. --The effect of changing the emphasis factor for the survey biomass log(likelihood) on recruitment estimates for the dominant Pacific whiting year classes 1970, 1973, 1977, 1980, and 1984 (top panel), and on the likelihood components for the different sources of information used to fit the synthesis model (bottom panel). A less negative value for an information source indicates a better fit of the model to the data from that source.

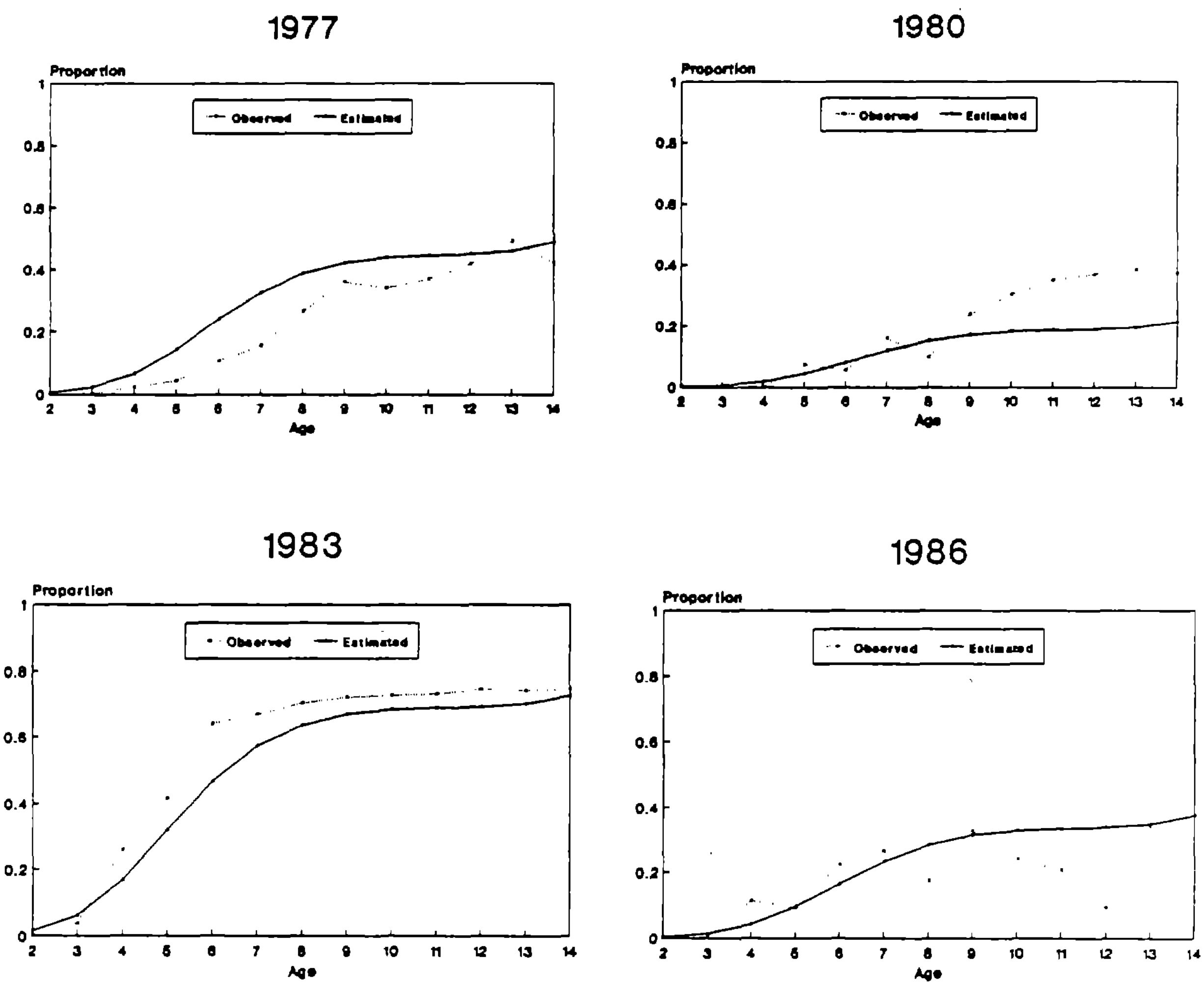


Figure 5. --Observed and predicted age-specific fraction of the Pacific whiting population in the Canadian exclusive economic zone (EEZ) during the survey years 1977, 1980, 1983, and 1986 using logistic regression. The model used a linear predictor consisting of a cubic function of age and mean August sea surface temperature (°C).

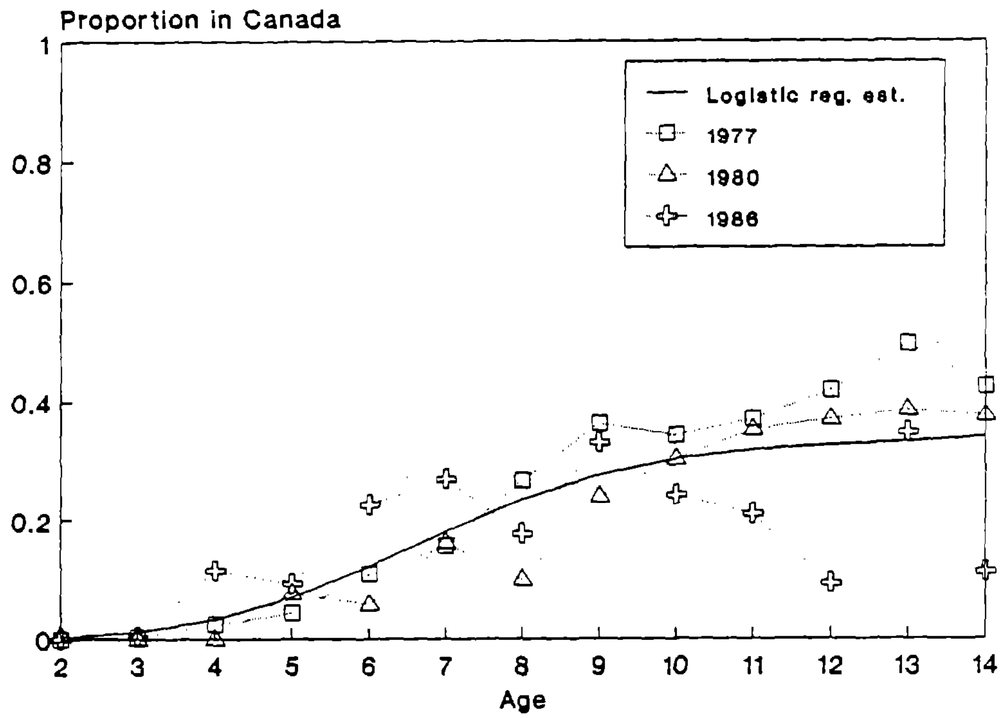


Figure 6. --Observed and predicted age-specific fraction of the Pacific whiting population in the Canadian zone during the survey years 1977, 1980, and 1986 using logistic regression. The model used a linear predictor consisting of only a cubic function of age. The 1983 surveys were omitted in this analysis because the 1983 El Nino produced an atypical spatial distribution of whiting during this year.

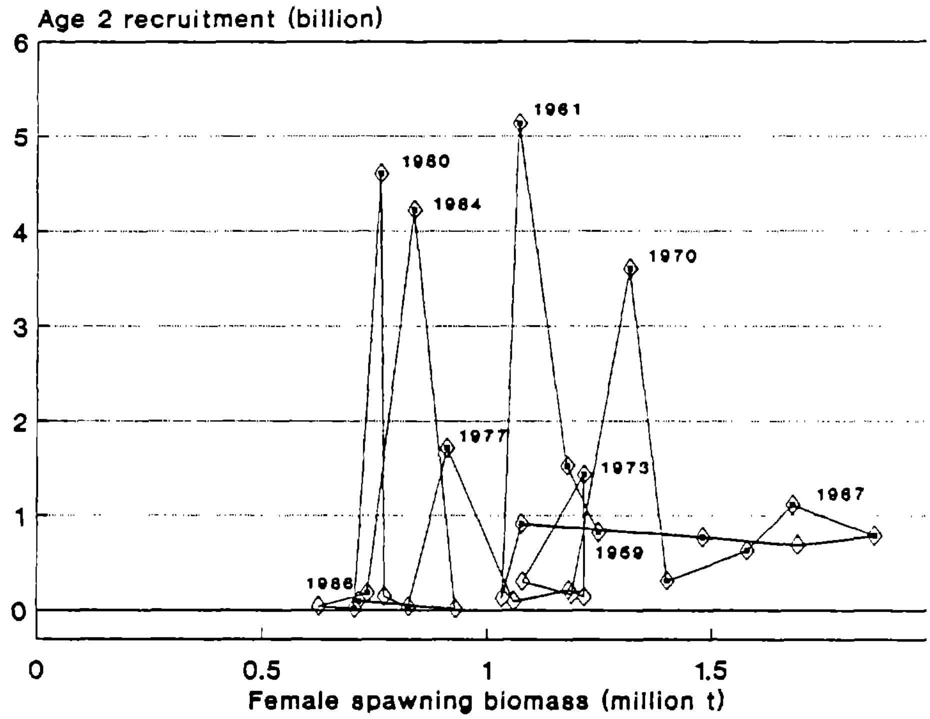


Figure 7. --Female spawning biomass versus recruitment graph for Pacific whiting. Dotted diamonds indicate warm (> 15.0°C) years, the unfilled diamonds the cold (< 15.0°C) years.

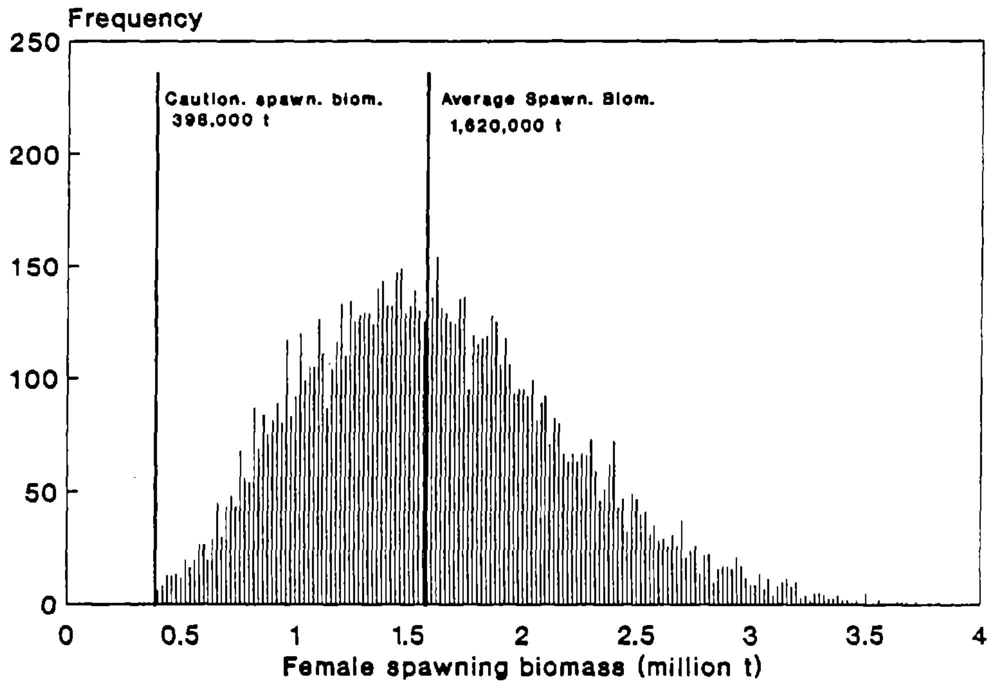


Figure 8. --Frequency histogram of female spawning biomass (million t) resulting from 10 replicate 1,000 year simulations of an unexploited Pacific whiting population. Recruitments to drive the model were obtained by resampling from the observed recruitments 1959-86. A cautionary level of female spawning biomass of 398,000 t was identified as the 0.1 percentile of the empirical distribution of female spawning biomass for an unexploited population.

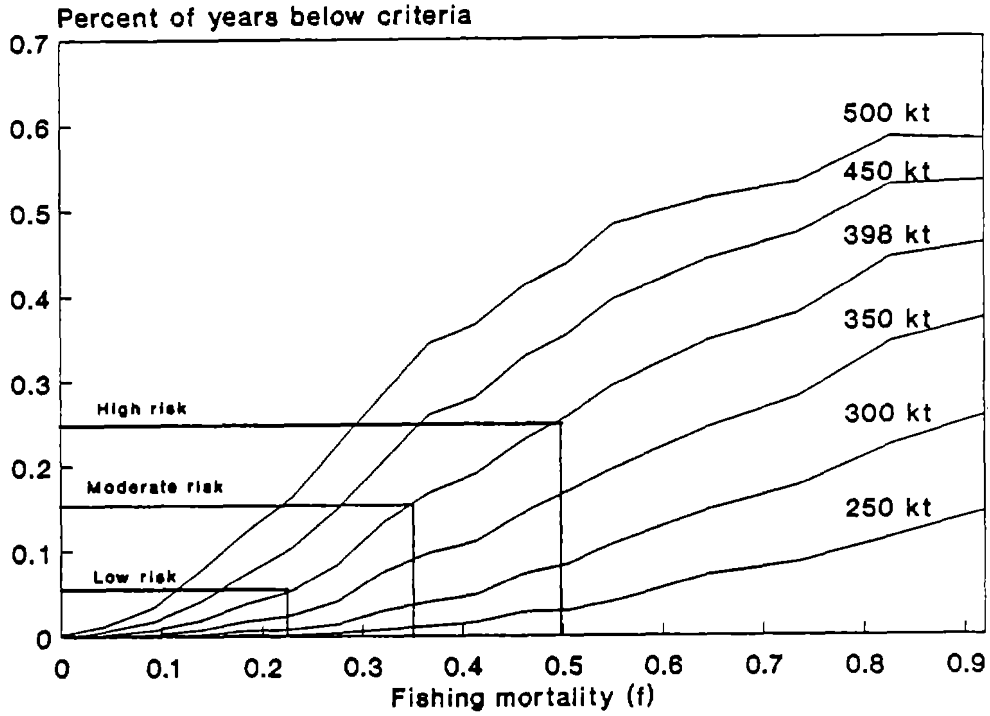


Figure 9. --Probability that the female Pacific whiting spawning biomass (SB) drops below various levels between 250,000 t and 500,000 t as a function of fishing mortality for the variable effort algorithm. For a cautionary spawning biomass of 398,000 t, three rates of fishing mortality, corresponding to low risk, moderate risk, and high risk long-term harvesting strategies, are identified. (Low risk: probability (SB < 398,000 t) - 0.05, moderate risk: probability (SB < 398,000 t) - 0.15, high risk: probability (SB C 398,000 t) - 0.25.)

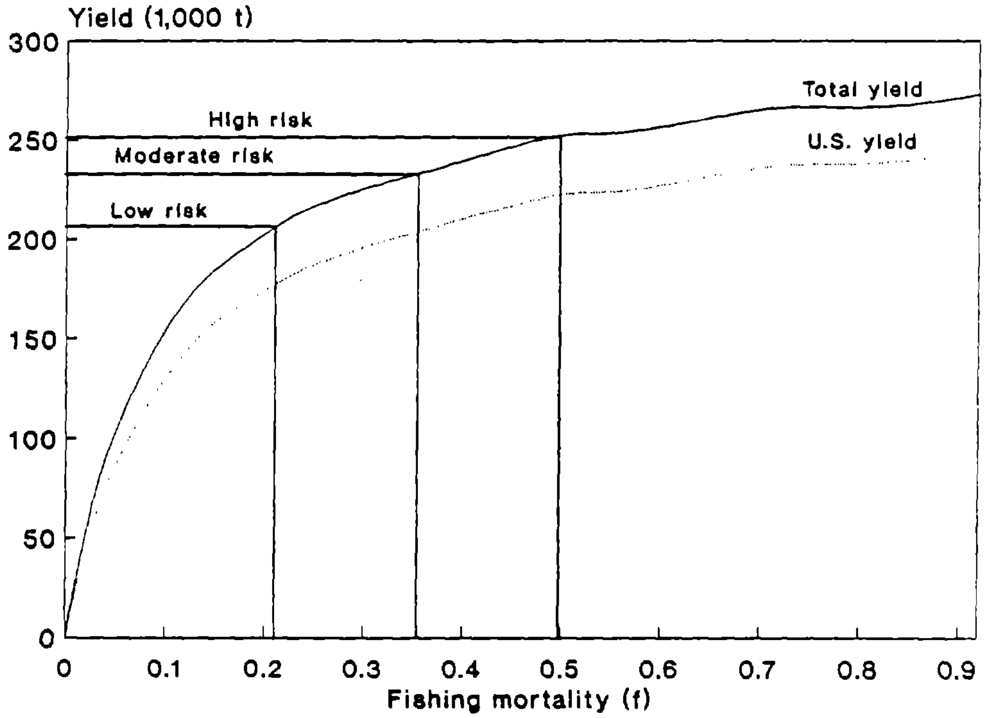


Figure 10. --Total yield and U.S. yield as a function of fishing mortality for the variable effort algorithm. U.S. yield was obtained by dividing the catch at age between the U.S. and the Canadian Pacific whiting fisheries according to the average proportion by number in respective national zones and multiplying by the characteristic weight at age for each fishery. The three long-term harvest strategies shown in the graph correspond to those identified in Figure 9.

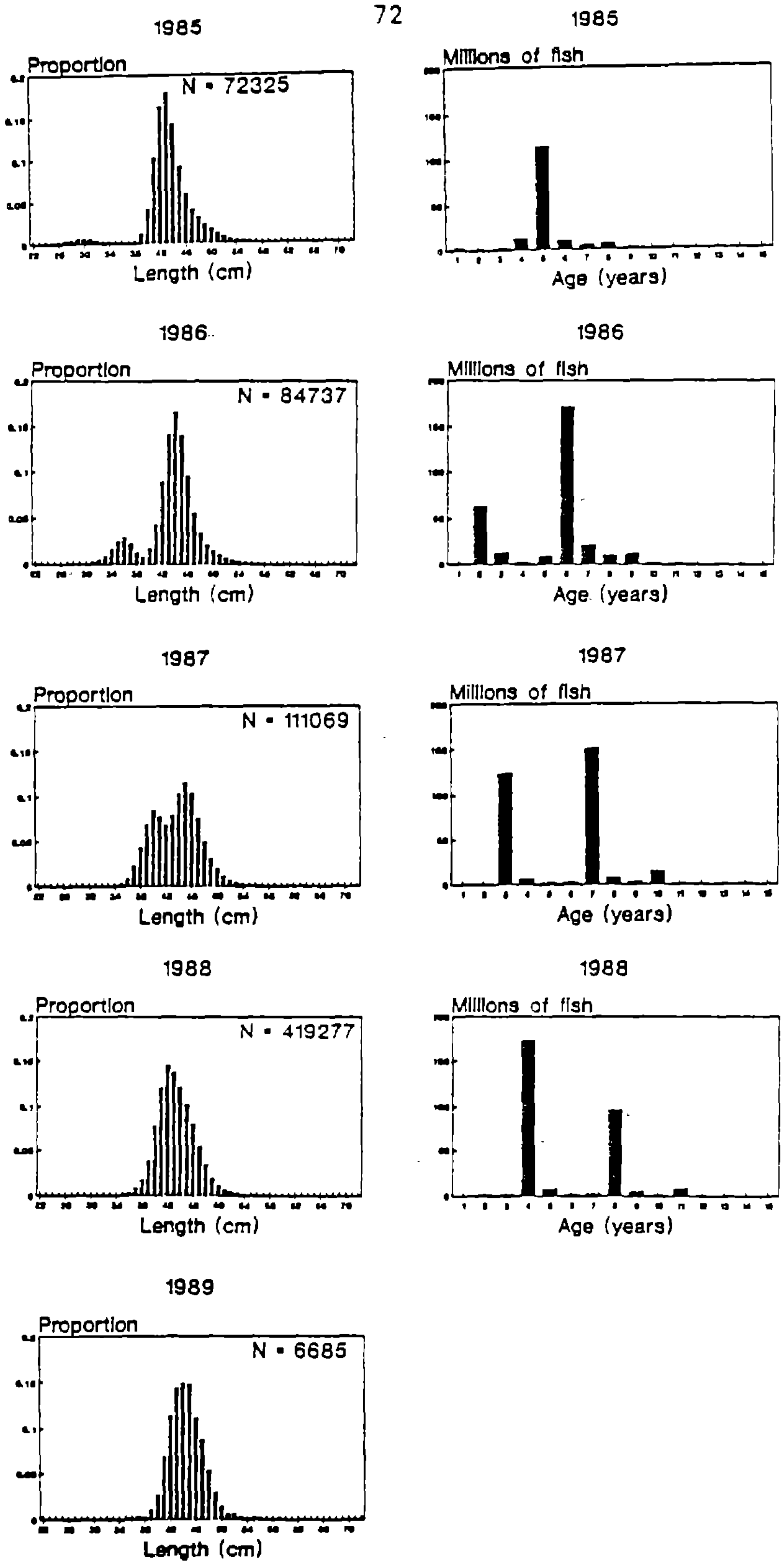


Figure 11. --Length frequency and catch at age of Pacific whiting in the U.S. management zone including the foreign, joint venture, and domestic fisheries. The length-frequency histogram for 1989 is based on a preliminary tabulation of a small subsample of the available data.

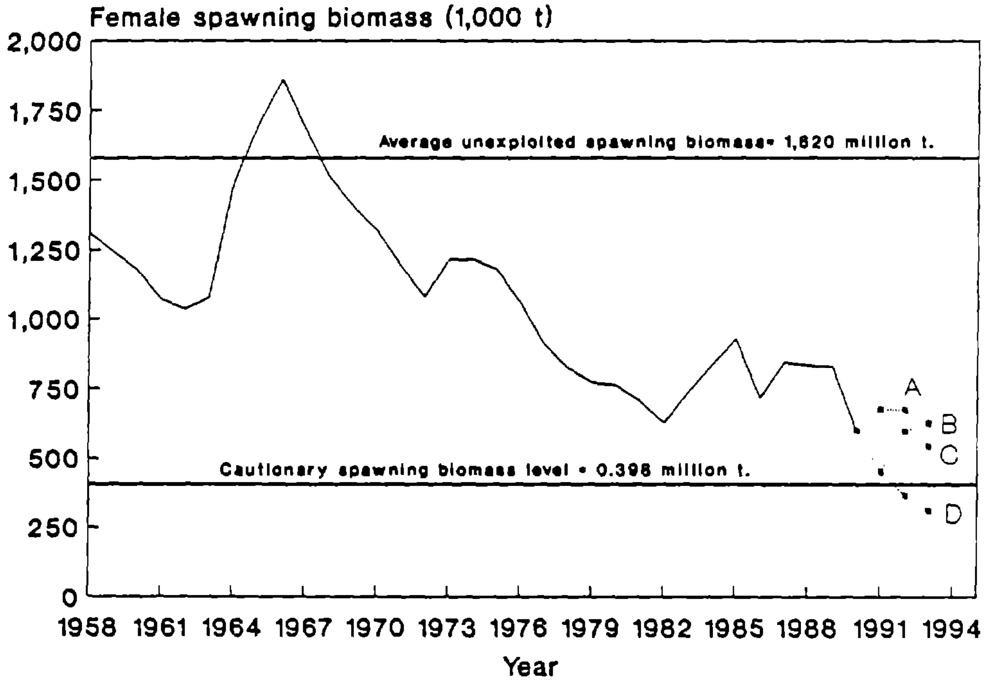


Figure 12. --Time trend of Pacific whiting female spawning biomass (million t) for 1958-90. The two horizontal lines in the graph locate the average unexploited female spawning biomass level and the cautionary female spawning biomass level used in the analysis to define risk. The average female spawning biomass from 1958 to 1990 was 1.097 million t. Trajectories A, B, C, and D represent the projected female spawning biomass for 1991-93 with a moderate risk variable effort harvesting strategy (VF - 0.35) under recruitment scenarios A, B, C, and D. (See Table 20 for a description of the different recruitment scenarios.)

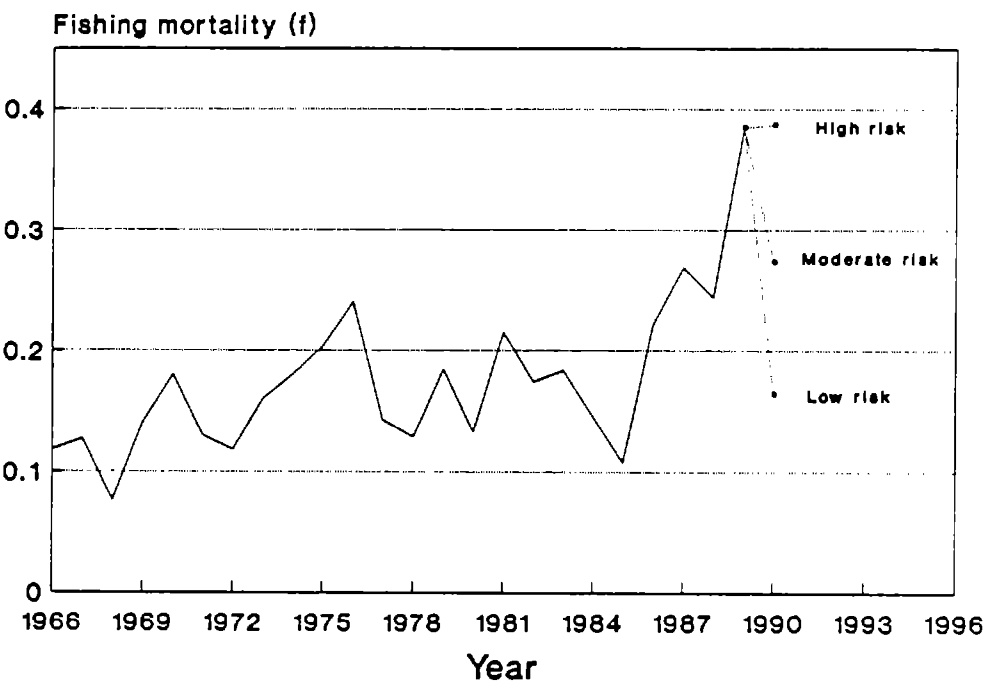


Figure 13.--Time trend of full recruitment fishing mortality (f) for the coastal Pacific whiting population. The high risk, moderate risk, and low risk alternatives for 1990 are for a variable effort strategy based on a beginning female spawning biomass projection for 1990 of 599,000 tons, a decline of 28% from the female spawning biomass in 1989.

APPENDIX 1

Double Logistic Selectivity Function

The use of a functional form to describe age-specific patterns in selectivity can greatly reduce the number of parameters which must be estimated (Fournier and Archibald 1982). This approach links the selectivity of adjacent age groups without making the restrictive assumption that a range of ages has full and equal selectivity. Various functional forms have been proposed, including a two-parameter gamma function with a third parameter describing offset along the age axis (Methot and Hightower 1988). The problem with functions with few parameters is that the ascending side of the selectivity curve is coupled to the descending side of the curve. Here we utilize a four parameter function (S), which is the product of two logistic curves (S_1,S_2) :

$$S_1(a) = 1/(1+e^{(-p2(a-p1))})$$

$$S_2(a) = 1 - 1/(1+e^{(-p4(a-p3))})$$

$$S(a) = S_1(a) \cdot S_2(a)/max$$

where:

p1 is the inflection age for the first curve

p2 is the slope of the first curve

p3 is the inflection age for the second curve

p4 is the slope of the second curve

a is age

max is the maximum of the product of S1 and S2

over the range of ages.

Some examples of the flexibility of this function are illustrated in Appendix Figure 1.

APPENDIX 2

Fishery Specific Selectivity Patterns

First we investigated the patterns of selectivity under the assumption that the entire stock is vulnerable to both fisheries. While this is clearly not correct, at low levels of fishing mortality it is difficult to distinguish between fish that are not at all vulnerable and fish that simply have a low selectivity. The catch equations for this situation are

$$C(a,y,t) = N(a,y) \frac{F(y,t)\ S(a,t)}{Z} (1-e^{-Z})$$

$$Z = M + F(y,1)\ S(a,1) + F(y,2)\ S(a,2)$$

$$N(a+1,y+1) = N(a,y)\ e^{-Z}$$

where: a = age, y = year, t = type (U.S. or Canadian)

C is catch at age

N is numbers at age in the entire stock

F is fishing mortality

S is age-specific selectivity

M is natural mortality

Z is total mortality.

The estimated age-specific patterns of selectivity to the separate U.S. and Canadian Pacific whiting fisheries are as expected; young fish are much more available to the U.S. fishery (Appendix Figure 2). The U.S. pattern is still similar to that of the combined fishery because the U.S. fishery has harvested most of the total catch. A poor fit to the age composition in Canada occurred in 1983 when the Canadian fishery captured many young fish. The survey in 1983 also indicated that an anomalous large fraction of the young fish had moved north. When a separate, double logistic selectivity pattern is used for the 1983 Canadian fishery (4 additional parameters), the improvement in goodness of fit is substantial (15 units per parameter), although statistical tests of significance have not been conducted. When a double logistic pattern is used to estimate selectivity for each fishery, the number of estimated parameters is reduced from 23 to 8, and the likelihood for the fishery age composition degrades by only 2 units per parameter (Appendix Table 1). This double logistic formulation obviously provides an adequate description of the data and will be used in much of the model exploration.

The above patterns of selectivity combine several phenomena, including latitudinal variation in age composition and targeting behavior by the fishery. These phenomena can be separated by independently defining the magnitude of latitudinal variation in age composition, The vulnerable fraction of the stock is defined as those fish having a positive probability of being captured by a unit of effort. Here we define the age-specific fraction vulnerable to the Canadian fishery as the fraction found north of the U.S.-Canada border during late summer. The fraction vulnerable to the U.S. fishery is the complement of the Canadian vulnerabilities. These vulnerabilities are only an approximation because fish move through the U.S. fishery en route to Canadian waters, and an aggregation of fish is commonly found straddling the border. The following equations describe this situation:

$$C(a,y,t) = N(a,y)\ V(a,t)\ \frac{F(y,t)\ S(a,t)}{Z(a,y,t)}\ (1-e^{-Z})$$

$$Z(a,y,t) = M + F(y,1)\ S(a,t)$$

$$N(a+1,y+1) = N(a,y)\ [V(a,1)\ e^{-Z(a,y,1)} + V(a,2)\ e^{-Z(a,y,2)}]$$

where: a = age, y = year, t = type (U.S. or Canadian)

C is catch at age

N is numbers at age in the entire stock

V is the fraction vulnerable to this fishery

F is fishing mortality

S is age-specific selectivity

M is natural mortality

Z is total mortality.

If the vulnerabilities are set equal to the geographic distribution measured by the acoustic survey (Appendix Table 2), one finds that the selectivity patterns within each zone are similar, especially on the ascending side (Appendix Table 2). This indicates that much of the difference in age composition between the two fisheries can be explained on the basis of the geographic partitioning of the stock.

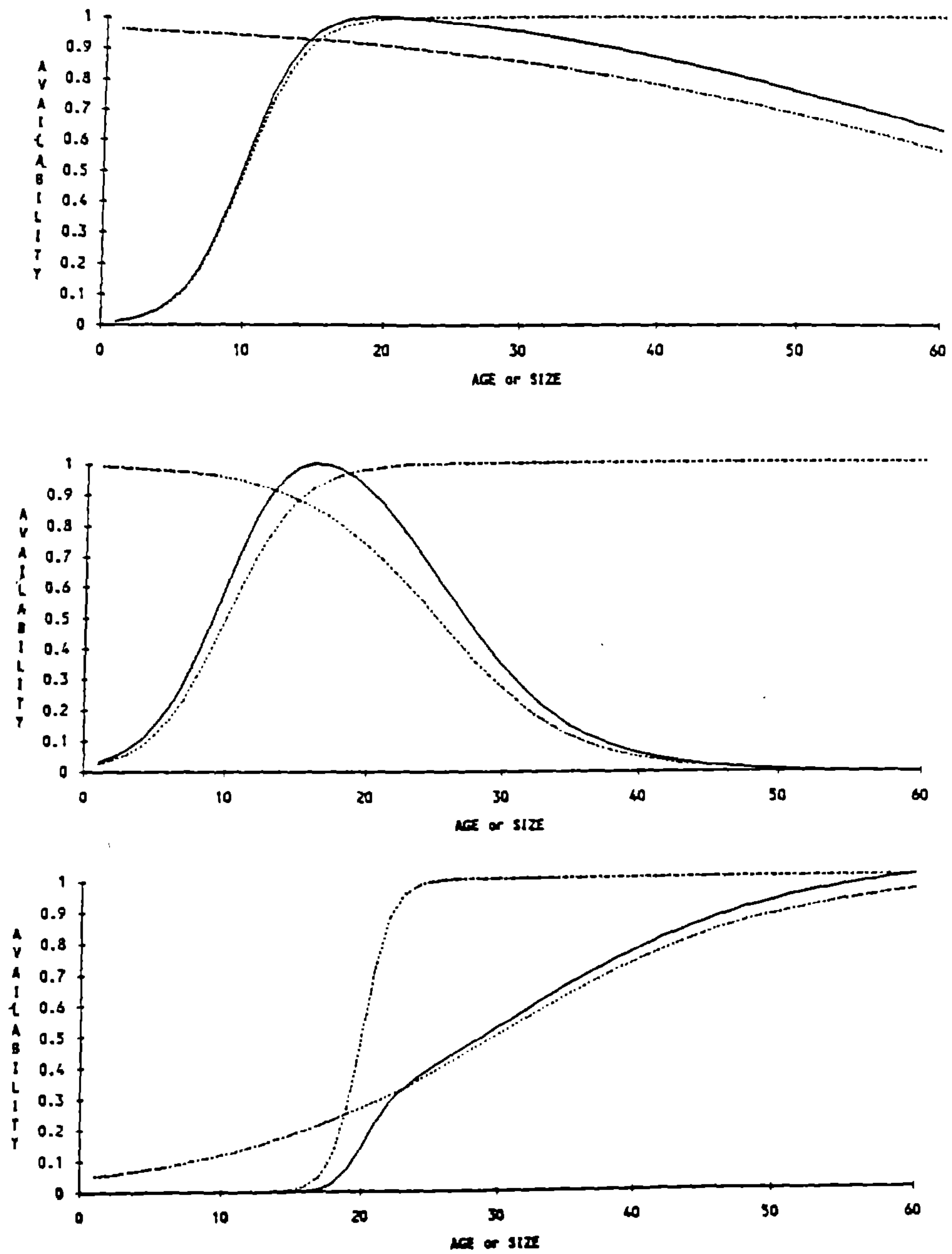
Finally, we explore a hypothetical situation in which the survey adequately estimates the distribution of young fish, but underestimates the fraction of older fish that are vulnerable to the Canadian fishery. We consider the question: What must the vulnerability pattern be in order to make the selectivity pattern the same for each fishery? The survey data indicated that about 34% of the oldest fish are in Canadian waters. If this level is increased to about 65% (Appendix Table 2), then the selectivity patterns within each zone are very similar. Use of geographic vulnerabilities in the model causes no change to the estimate of population abundance or to the fit to the age composition of the U.S. fishery. The fit to the Canadian fishery is improved slightly (-270 without vulnerabilities in Appendix Table 1, -252 with vulnerabilities estimated from the survey, and -260 with adjusted vulnerabilities), and the estimates of recent fishing mortality rates imposed by the Canadian fishery are greatly increased (F is 0.161 relative to the entire stock and 0.828 relative to the fraction of the stock estimated to be vulnerable to that fishery). The implications of these alternative fishery selectivity patterns will be a subject of future investigation.

Appendix Table 1. --Patterns of Pacific whiting selectivity to the U.S. and Canadian fisheries. The four scenarios are distinguished by whether or not the double logistic selectivity function (Appendix 1) was used, and by whether or not the year 1983 was singled out as having a distinct selectivity pattern in Canada. In all scenarios the selectivity is defined relative to the entire stock, not relative to the portion of the stock in the national zone. The following codes were used to distinguish between the different scenarios. Each: a separate parameter was used to. define the selectivity at each age, except age 8 which was defined to have a selectivity of 1.0. Log: selectivity at age was defined by the product of two logistic functions of age; this product was scaled to be 1.000 at age 8. Can-83: special selectivity pattern used for the Canadian fishery only in year 1983 when warm water caused more young fish to move into range of the Canadian fishery.

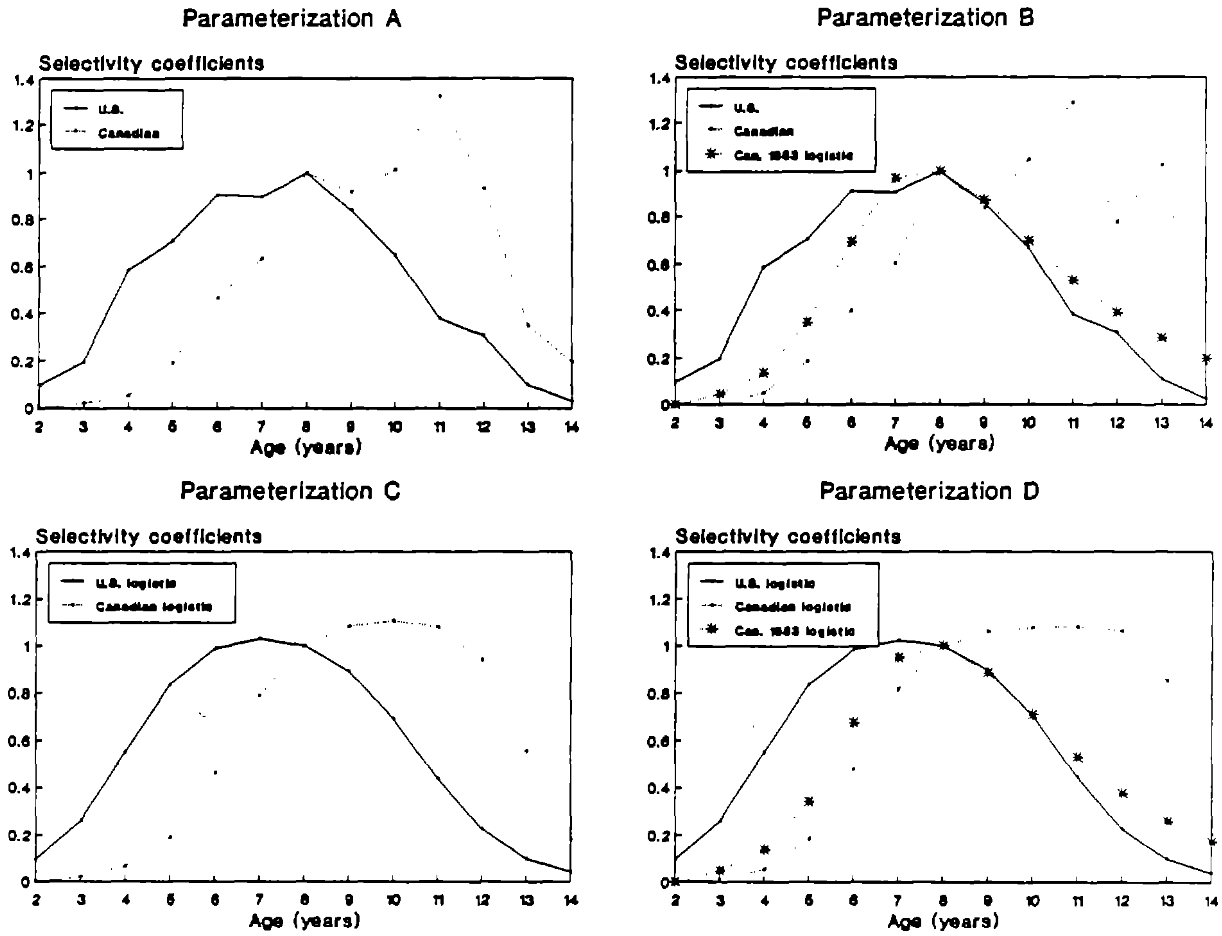
Age	Each U.S.	Each Can.	Each U.S.	Each Can.	Log Can-83	Log U.S.	Log Can.	Log U.S.	Log Can.	Log Can-83
2	0.096	0.000	0.097	0.000	0.000	0.096	0.000	0.096	0.000	0.000
3	0.198	0.020	0.198	0.002	0.047	0.261	0.020	0.261	0.015	0.047
4	0.583	0.054	0.585	0.052	0.136	0.551	0.065	0.552	0.054	0.135
5	0.706	0.190	0.706	0.187	0.348	0.836	0.192	0.835	0.184	0.342
6	0.903	0.465	0.908	0.398	0.692	0.990	0.461	0.985	0.478	0.676
7	0.894	0.633	0.907	0.602	0.967	1.031	0.789	1.027	0.817	0.950
8	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
9	0.834	0.915	0.855	0.833	0.871	0.893	1.085	0.900	1.062	0.886
10	0.646	1.012	0.668	1.046	0.696	0.692	1.107	0.705	1.079	0.711
11	0.378	1.322	0.385	1.289	0.530	0.438	1.082	0.446	1.082	0.532
12	0.304	0.931	0.307	0.774	0.391	0.224	0.940	0.226	1.066	0.378
13	0.098	0.347	0.111	1.024	0.283	0.099	0.557	0.097	0.851	0.259
14	0.030	0.196	0.026	0.178	0.201	0.041	0.180	0.039	0.206	0.172
Log(likelihood)	-356.0	-303.0	-351.0	-241.0		-375.0	-313.0	-369.0	-270.0	
1989 biomass	1.479			1.503		1.471			1.488	

Appendix Table 2. --The effect of geographic segregation on estimated fishery selectivity. All selectivity patterns were estimated as the product of two logistic functions and are relative to the fraction of the Pacific whiting stock found within each fishing zone. The age-specific fraction of the population found north of the U.S. -Canada border during late summer (% North) in the first case was estimated from the hydro-acoustic survey data. In the second case the vulnerability coefficients from age 8 to age 14 were adjusted manually to produce a similar age-specific selectivity pattern within each zone. Also given is the fishing mortality multiplier necessary to obtain the 1988 catch biomass, the log(likelihood) of the age composition data (less negative implies better fit), and the estimated biomass of ages 3 and older at the beginning of 1989.

	Survey distribution				Tuned vulnerability			
Age	% North	U.S.	Can.	Can. 83	% North	U.S.	Can.	Can. 83
2	0.004	0.080	0.000	0.000	0.004	0.081	0.000	0.000
3	0.012	0.210	0.090	0.950	0.012	0.209	0.096	1.082
4	0.032	0.452	0.356	1.200	0.032	0.446	0.401	1.394
5	0.070	0.729	0.757	1.357	0.070	0.720	0.814	1.577
6	0.122	0.913	0.947	1.364	0.122	0.904	0.975	1.549
7	0.180	0.990	0.992	1.225	0.180	0.984	1.004	1.323
8	0.234	1.000	1.000	1.000	0.234	1.000	1.000	1.000
9	0.275	0.952	1.001	0.756	0.275	0.966	0.973	0.686
10	0.302	0.810	1.000	0.540	0.375	0.861	0.894	0.439
11	0.317	0.552	0.998	0.371	0.450	0.654	0.714	0.268
12	0.324	0.278	0.905	0.248	0.525	0.387	0.438	0.159
13	0.330	0.110	0.556	0.163	0.600	0.179	0.198	0.093
14	0.338	0.038	0.144	0.105	0.650	0.071	0.073	0.053
1988 fishing mortality multiplier		0.199	0.828	---	---	0.199	0.787	---
Log (likelihood)		-371.0	-252.0	---	---	-368.0	-260.0	---
Age 3+ Biomass in 1989 (million t)			1.506				1.561	



Appendix Figure 1. --Double logistic selectivity patterns. The solid line is the product of the two dotted lines, an ascending logistic curve and a descending logistic curve, scaled to have a maximum of 1.0. Note in the third example that a change in sign for the slope parameter will cause both functions to be ascending.



Appendix Figure 2. --Some alternative parameterizations of the selectivity coefficients for Pacific whiting in the U.S. and Canadian fisheries. In parameterization A, separate coefficients were estimated for each age for both the U.S. and Canadian fisheries. Parameterization B was identical to A except that a separate double logistic function was used to estimate the selectivity curve for the Canadian fishery in 1983, when warm water caused more young fish to move into the range of the Canadian fishery. In parameterization C, the double logistic function was used to estimate selectivity curves for both the U.S. and Canadian fisheries. Parameterization D was identical to C except that a separate double logistic selectivity curve was estimated for the Canadian fishery in 1983. In all cases, the selectivity of the age 8 fish was fixed at 1.0.