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STATUS OF THE PACIFIC WHITING RESOURCE AND RECOMMENDATIONS FOR MANAGEMENT IN 1987

by

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ABSTRACT

This paper describes the status of the resource and fishery for the coastal stock of Pacific whiting (Merluccius productus) in 1987. Preliminary information from juvenile whiting surveys indicate that the 1984 and 1986 year classes may be strong. New estimates of offshore whiting fishery production were made using an age-structured management model with three different egg-recruit relationships. The results show that maximum yield is attained at widely different effort levels depending on which egg-recruit relationship was used. Maximum yield ranged from 127,000 to 193,000 metric tons (t) at effort levels of 6,700 to 30,000 days, respectively. Because of the wide variability in the observed egg-recruit data, annual yield was restricted to a level of between 20 and 25% of the exploitable stock biomass. This exploitation level was chosen because preliminary analysis of world-wide whiting stocks showed that sustained exploitation rates greater than 30% generally resulted in a decline in the stock. Therefore, the recommended yield of Pacific whiting for the 1987 season was 264,000 t.

CONTENTS

INTRODUCTION

Commercially and ecologically, the coastal stock of Pacific whiting (*Merluccius productus*) is one of the most important marine fish species off the west coast of North America. Francis and Hollowed (1985) summarize the history of the coastal fishery for whiting as follows. A small-scale domestic fishery for whiting has existed since at least 1879. A large-scale foreign fishery for whiting was initiated by the Soviet Union in 1966. During the period between 1973 and 1976, Poland, the Federal Republic of Germany (West Germany), the German Democratic Republic (East Germany), and Bulgaria joined the fishery. Joint ventures for whiting developed in 1978 between foreign nations and the United States and Canada. The U.S. and Canadian joint venture operations have accounted for a substantial percentage of the whiting catch since 1980 (Table 1). Estimated catches have ranged from 90,000 to 238,000 metric tons (t) since 1966 (Table 1). Catches peaked in 1976 and were subsequently reduced due primarily to restrictions on foreign effort imposed subsequent to the implementation of the Magnuson Fisheries Conservation and Management Act (MFCMA) in 1977.

The fishery for whiting is tied closely to the migratory behavior of this species. Bailey et al. (1982) provide a detailed description of the life history of the Pacific whiting. Briefly, adult whiting spawn off the coasts of central, southern, and Baja California during the winter. In the spring, adults migrate northward to summer feeding grounds off the coasts of northern California, Oregon, Washington, and Vancouver Island. Larger individuals tend to make the longest northerly migrations. Large adults may migrate 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 and the appearance of the Davidson Current.

Table 1.--Annual catches of Pacific whiting (1,000 t) in U.S. and Canadian waters by foreign, joint venture (JV), and domestic fleets, (Lynde 1986).

	United States				Canada				Combined		
Year	Foreign	JV	Domestic	Total	Foreign	JV	Domestic	Total	Total	CPUE	Effort
1966	137.000	0.000	0.000	137.000	0.700	0.000	0.000	0.700	137.700	19.2	7.171
1967	168.699	0.000	8.963	177.658	36.713	0.000	0.000	36.713	214.371	36.0	5.951
1968	60.660	0.000	0.159	60.819	61.361	0.000	0.000	61.361	122.180	11.8	10.397
1969	86.187	0.000	0.093	86.280	93.851	0.000	0.000	93.851	180.131	18.5	9.726
1970	159.509	0.000	0.066	159.575	75.009	0.000	0.000	75.009	234.584	25.6	9.180
1971	126.485	0.000	1.428	127.913	26.699	0.000	0.000	26.699	154.612	17.5	8.842
1972	74.093	0.000	0.040	74.133	43.413	0.000	0.000	43.413	117.546	15.9	7.381
1973	147.441	0.000	0.072	147.313	15.125	0.000	0.001	15.126	162.439	23.8	6.752
1974	194.108	0.000	0.001	194.109	17.146	0.000	0.004	17.150	211.259	24.3	8.705
1975	205.654	0.000	0.002	205.656	15.704	0.000	0.000	15.704	221.360	19.0	11.646
1976	231.331	0.000	0.218	231.549	5.972	0.000	0.000	5.972	237.521	25.7	9.242
1977	127.013	0.000	0.489	127.502	5.191	0.000	0.000	3.453	130.955	30.9	4.244
1978	96.827	0.856	0.689	98.372	3.453	1.814	0.000	6.464	104.836	35.2	2.980
1979	114.909	8.834	0.937	124.680	7.900	4.233	0.302	12.435	137.115	26.0	5.276
1980	44.023	27.537	0.792	72.352	5.273	12.214	0.097	17.584	89.936	28.5	3.152
1981	70.365	43.556	0.839	114.760	3.919	17.159	3.283	24.361	139.121	28.3	4.915
1982	7.089	67.464	1.024	75.577	12.479	19.676	0.002	32.155	107.732	30.9	3.489
1983	0.000	72.100	1.050	73.150	13.117	27.657	0.000	40.774	113.924	-	-
1984	14.722	78.889	2.721	96.382	13.203	28.906	0.000	42.109	138.491	-	-
1985	49.853	32.033	4.636	86.522	10.533	13.237	1.192	24.962	111.484	-	-
MEAN				123.565				29.800	153.365		

Managers of the whiting stock endeavor to develop management models to account for the extreme variations in stock abundance resulting from variations in year-class strength. The work of Bailey (1980, 1981, 1982) establishes a statistical link between year-class strength and environmental conditions at the time of spawning. An attempt to merge these relationships into an age-structured management model was made by Swartzman et al. (1983) and Francis et al. (1984). Francis (1985) simplified the management models of Swartzman et al. (1983) and Francis et al. (1984). This simplified model was used to evaluate the status of offshore whiting production in 1986 and to provide estimates of the future catch for effective management of the whiting stock. Research in 1986 at the Northwest and Alaska Fisheries Center (NWAFC) on offshore whiting production and management has focused on re-estimation of production parameters based on new fishery (1984-85) data. This paper describes the condition of the coastal stock of Pacific whiting as evaluated in 1986, and presents a suggested allocation of catch for the 1987 fishing season.

CURRENT STATUS OF THE RESOURCE

Table 1 gives recently updated estimates of whiting catches since the initiation of the fishery in 1966. Figure 1 illustrates the relative age frequencies of the 1984 and 1985 catches in U.S. and Canadian waters. It is interesting to note that in both 1984 and 1985 most of the Canadian whiting catches in numbers were comprised of the strong 1977 and 1980 year classes, whereas most of the U.S. catches were comprised of the 1980 year class alone.

Since the fishery is predominantly supported by a small number of strong year classes, it is important to attempt to forecast the relative strengths of pre-recruit year classes. Figure 2 gives histograms of three indices of year class abundance. The first two (percent occurrence, standard number per

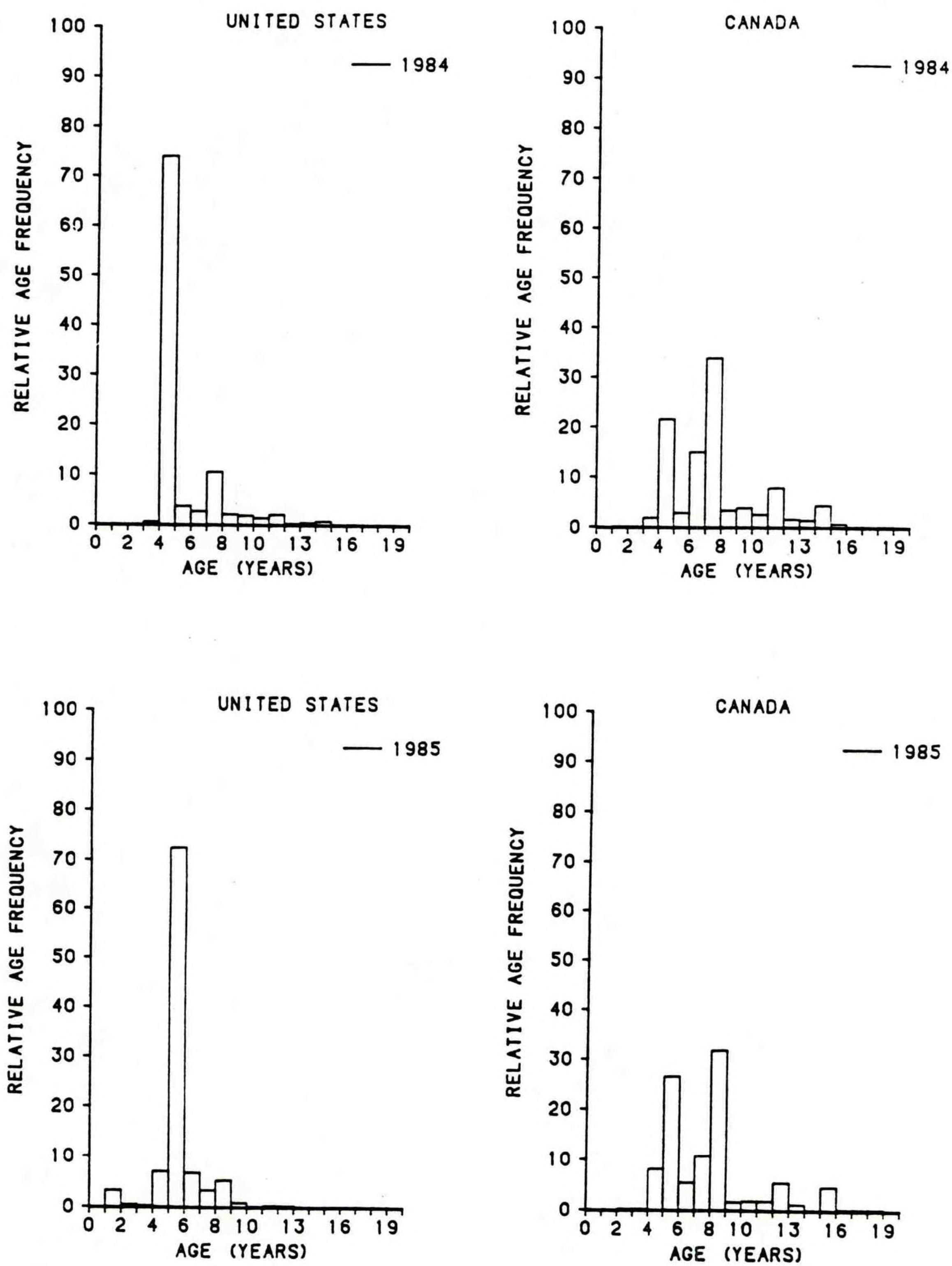


Figure 1.--Relative age frequency of Pacific whiting catches in U.S. and Canadian waters, 1984-85.

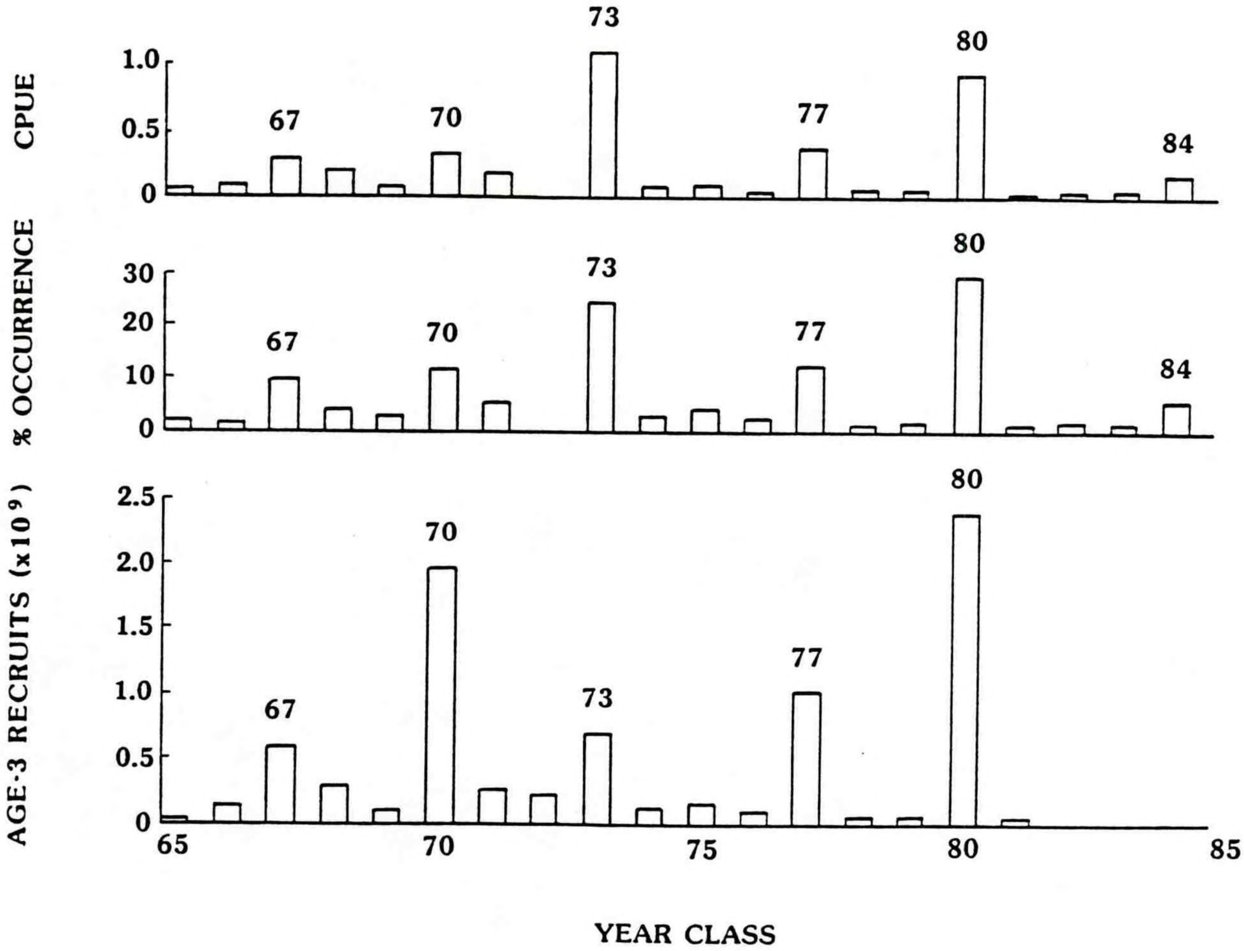


Figure 2.--Indices of whiting year-class strength from age-0 surveys and the adult fishery.

tow) are measures of relative abundance of 0-age whiting from California Department of Fish and Game midwater trawl surveys conducted off the California coast (south of Point Conception) over the last 20 years. The indices are annual averages from spring, summer, autumn, and early winter surveys of 0-age fish. The last index of Figure 2 is an index of recruitment at age 3 from a cohort analysis performed on the 1973-84 catch-at-age data. There is no question that the strong year classes which have historically supported the fishery (1967, 1970, 1973, 1977, 1980) were identifiable in the 0-age surveys. The most recent strong year class to enter the fishery is the 1980 year class. The 0-age surveys indicate that the 1981-83 year classes are complete failures and should not be expected to significantly contribute to the fishery. These surveys further indicate that the 1984 year class of whiting may be above average. A spring 1985 Soviet survey off southern California reported catching large numbers of the 1984 year class (Fig. 3). Furthermore, the 1985 catch-at-age data from commercial fisheries in U.S. waters show an abundance of 1-year-old fish which tends to corroborate that the 1984 year class may be above average strength (Fig. 1). In addition to the 1984 year class, the 1986 year class may also be above average because an unusually large number of whiting larvae (30-40 mm) were captured during the spring (May-June 1986) larval rockfish survey (Tina Wyllie Echeverria, Tiburon Laboratory, Southwest Fish. Cent., NMFS, Tiburon, CA. Pers. commun., June 1986).

As was mentioned in Francis and Hollowed (1984), commercial catch and NWAFC trawl/hydroacoustic survey age-structured data reveal a strong possibility that growth in both weight and length of Pacific whiting was severely retarded during the 1982-83 El Nino event off the west coast of North America. Figure 4 shows average weight at age from the 1981-85 U.S. fishery and compares it with the weight-age relationship derived by Francis (1983) based on the

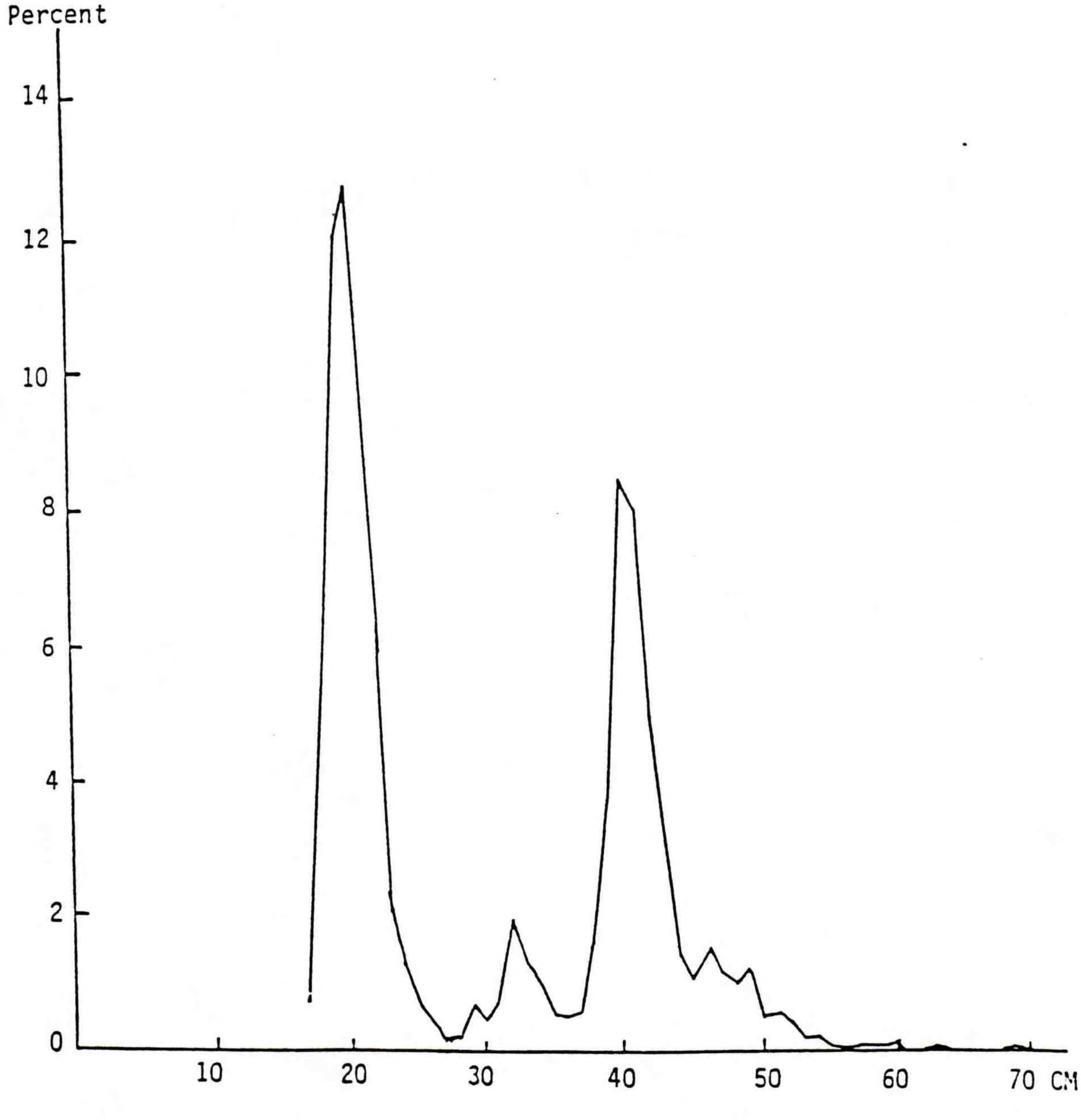


Figure 3.--Length frequency of Pacific whiting catch from spring 1985 Soviet survey (Point Conception to San Francisco).

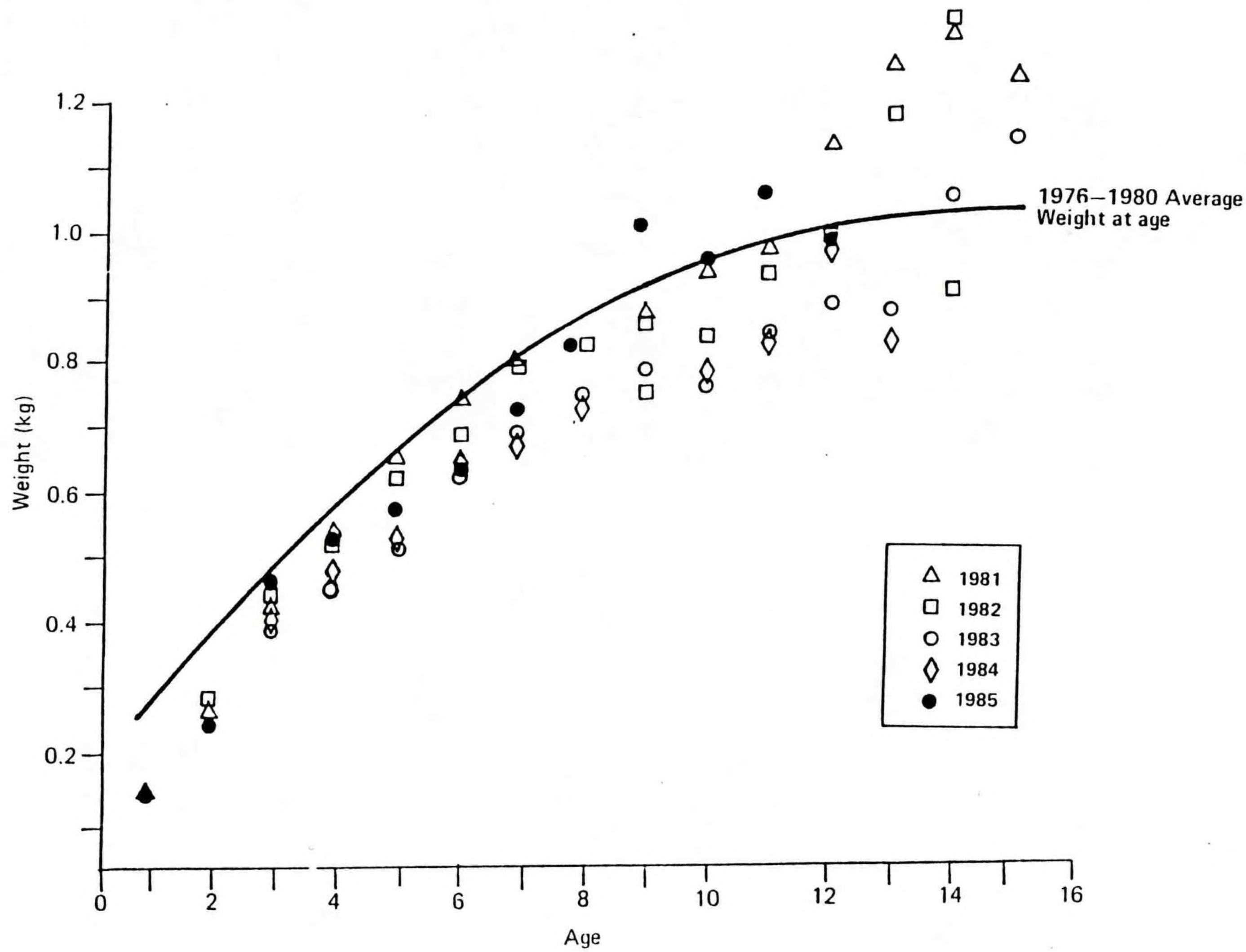


Figure 4.--Pacific whiting average weight (kg) at age from 1981-85 U.S. Fisheries.

1976-80 U.S. fishery data. Of particular importance is the fact that although the effect of El Nino on whiting weight at age persisted through 1984, it apparently did not continue in 1985. One would expect growth in both length and weight to have been affected by the El Nino event. However, it appears that those affected year classes regained their normal weight at age 3 years after the El Nino event.

NEW ESTIMATES OF FISHERY PRODUCTION

Estimation of Parameters

New estimates of offshore whiting fishery production were made using the age-structured simulation model described in Francis (1985). The model has both a deterministic and a stochastic form. Stochastic variability is associated with variations in the relative abundance of individual cohorts when they recruit to the fishery at age 3.

With inclusion of the 1984 and 1985 catch-at-age data, an updated cohort analysis was performed using the estimate of constant natural mortality (0.23) derived by Francis (1985). This analysis provided new estimates of age-specific catchability and 1984-85 stock abundance. The 1973-85 cohort analysis was performed in such a way to give the best (minimum sum of squares) fit between the estimated numbers at age from the 1977, 1980, and 1983 NWAFC trawl/hydroacoustic surveys and the cohort analysis. Summaries of these results are given in Table 2.

As in Swartzman et al. (1983), relative measures of both recruitment at age 3 and egg numbers were used to obtain as many egg-recruitment points as possible. The relative estimate of recruitment for the years 1963-72 was calculated from an index of year-class strength. The year-class index represented the percent contribution of the number of 4-, 5-, and 6-year-olds

Table 2.--Input data and summarized results of the Pacific whiting cohort analyses under constant natural mortality (M).

Year class	YCI[a] billions	Recruitment[b] at age 3 billions	Eggs[c] trillions	Temp.[d] index	Age	Total[e] q
1960	0.716	(0.909)	-	W	3	0.00203
1961	1.833	(2.483)	-	W	4	0.01330
1962	0.128	(0.080)	-	C	5	0.02408
1963	0.201	(0.183)	-	W	6	0.04388
1964	0.216	(0.204)	-	W	7	0.07161
1965	0.040	(0.000)	-	C	8	0.08862
1966	0.216	(0.204)	-	W	9	0.08984
1967	0.357	(0.403)	(130.1)	W	10+	0.11080
1968	0.282	(0.297)	(99.4)	W		
1969	0.254	(0.257)	(62.2)	W		
1970	1.650	2.601	(65.4)	W		
1971	0.247	0.314	(69.4)	C		
1972	0.197	0.238	(73.1)	C		
1973	0.776	0.742	120.2	W		
1974	0.194	0.164	132.2	C		
1975	0.310	0.262	138.5	C		
1976	0.141	0.137	129.4	C		
1977	1.408	1.234	109.6	W		
1978	0.072	0.067	98.0	W		
1979	0.039	0.055	82.4	C		
1980	1.830	2.734	85.2	W		
1981	0.243	0.263	81.1	W		
1982	-	0.012	60.9	C		
1983	-	-	96.4	W		
1984	-	-	110.7	W		
1985	-	-	118.1	W		

[a] YCI = Year Class Index.

[b] Recruitment estimated from YCI as:

$$R = -0.1005 + 1.4094 \text{ YCI} \quad (r^2 = 0.922)$$

[c] Eggs estimated as:

$$E_{3-7} = \sum_{i=3}^{7} N_i \, A_i \, 1.8934 \, \overline{W}_i^{\,1.25}$$

$$E_{3-11} = 0.9452 + 0.6949 \, E_{3-7} \quad (r^2 = 0.625)$$

[d] W = warm year; mean recruitment = 0.899; coefficient of variation (CV) = 109.
C = cold year; mean recruitment = 0.140; CV = 81.

[e] Catchability coefficient.

to the total population (Bailey et al. 1982). Recruitment was estimated according to regressions obtained from years when both the year-class index and a recruitment estimate from the cohort analysis were available.

The relative estimates of egg numbers were calculated in the following manner. First an estimate of the number (N) of fish ages 3-7 was calculated from the estimates of recruitment by accruing natural and fishing mortality via a Beverton and Holt (1957) type analysis i.e.,

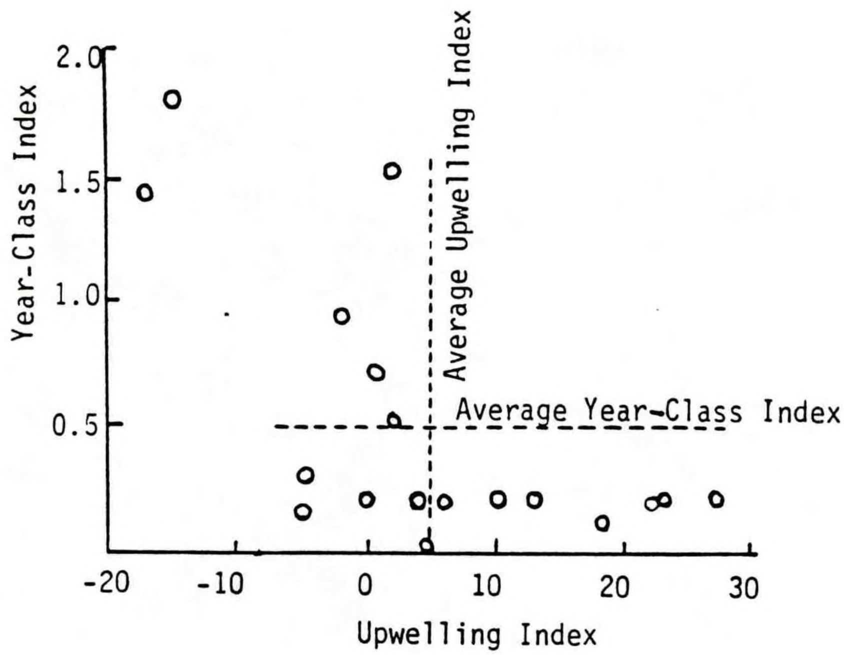
$$N_{i+1}(t+1) = N_i(t) * e^{(M_i + f(t) * q_i(t))},$$

where M, q, and f are, respectively, the natural mortality rate, the annual catchability coefficient, and annual fishing effort. Subsequently, an estimate of the total number of eggs spawned by fish age 3-7 was estimated as follows:

$$E_{3-7} = \sum_{i=3}^{7} 0.5\ N_i\ A_i\ 1.8934 * 10^5\ \overline{W}_i^{1.25},$$

where A is the fraction mature and $\overline{W}$ is the average weight at age estimated in Francis (1983). The number of eggs spawned by fish age 3-7 was then regressed against the number of fish spawned by fish age 3-11 estimated by the cohort analysis for years when both values were available. Based on this regression, the total number of eggs spawned by fish age 3-11 was estimated for the years 1967-72.

As was the case previously (Francis et al. 1984; Francis 1985), recruitment in the simulation model is assumed to be a function of: 1) environmental conditions at the time of spawning, and 2) an index of egg production. Bailey (1981) showed whiting recruitment to be inversely correlated to wind driven Ekman transport and positively correlated with temperature on the spawning ground at the time of spawning. Therefore, years of "cold" water temperatures on the spawning ground are assumed to be years of low larval survival, and years of "warm" water temperatures on the spawning ground are assumed to be years of higher, although more variable, larval survival (Fig. 5).



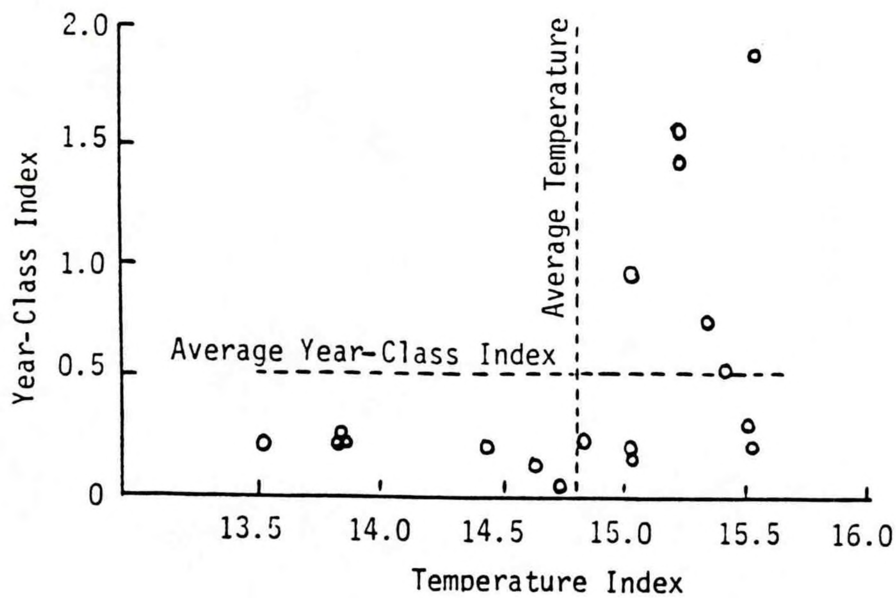


Figure 5.--Pacific whiting year-class index (1960-77) as related to upwelling and temperature indices at the time of spawning (36° N latitude, January).

Egg-Recruitment Relationship

Although there is no apparent relationship between the number of eggs and subsequent recruitment (Fig. 6), an egg-recruit function was estimated to account for the possibility of density dependent effects at low levels of egg production. An egg index was used instead of stock since egg production regressed on fish weight gave a significant nonlinear relationship and eggs are considered a more reliable index of spawning potential than numbers or biomass of mature fish. The estimates of egg production are calculated as a function of the female spawning stock. The function is based on the weight-fecundity relationship for the Strait of Georgia whiting stock (McFarlane and Beamish 1983) which is considered more realistic than those of McGregor (1966) for the offshore stock. As in Francis et al. (1985), the egg-recruit functions were estimated assuming either a negative exponential or using the method suggested by Shepherd (1982). The form of these two egg-recruit functions appears below:

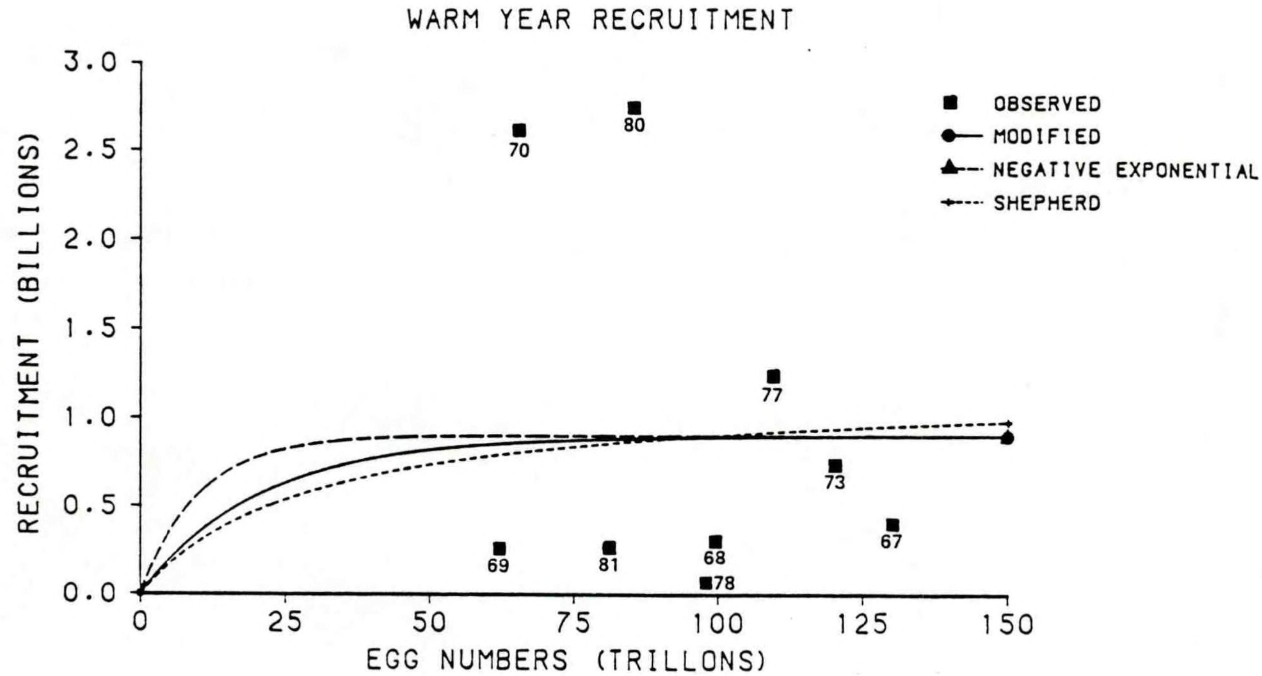
Negative Exponential $R = a\,(1-e^{(-kE)})$

Shepherd $R = a\,E/(1+(E/k)^{1})$.

R is the number of recruits at age 3, and E is the number of eggs produced 3 years earlier. Separate egg-recruit curves were used for warm and cold spawning conditions. The parameters of both equations are given below:

		a	k
Neg. Exp.	warm	$0.899\ 10^{9}$	$9.832\ 10^{-14}$
	cold	$0.140\ 10^{9}$	$9.832\ 10^{-14}$
Shepherd	warm	$3.966\ 10^{-5}$	$0.295\ 10^{14}$
	cold	$0.448\ 10^{-5}$	$0.459\ 10^{14}$.

As was the case in Francis (1985), the parameter K of the negative exponential egg-recruit curve was set so that recruitment equals 95% of the mean warm year recruitment when E is equal to 50% of the minimum observed egg level.



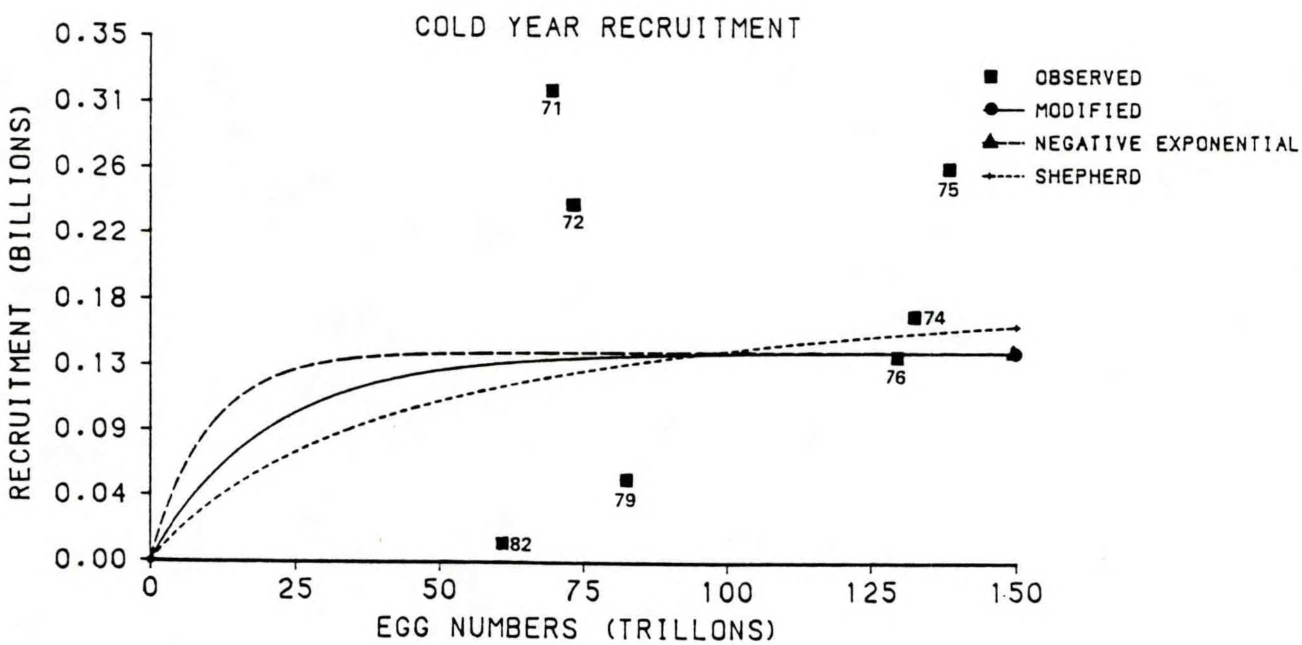


Figure 6.--Observed and predicted egg-recruit relationships under warm and cold environmental conditions at the time of spawning.

The Shepherd and the negative exponential egg-recruit relationships represent two very different scenarios. The negative exponential function projects the observed mean cold or warm year recruitment until the stock reaches extremely low levels. In contrast, the Shepherd egg-recruit relationship is sensitive to reductions in egg numbers at observed egg levels (Fig. 6). Therefore, an intermediate curve was tested by modifying k in the negative exponential. The parameter k was set so that recruitment equals 95% of the mean warm year recruitment when E was equal to the minimum cold or warm year egg level. The parameters for this egg-recruit relationship appear below:

		a	k
Modified	warm	$0.899\ 10^{9}$	$4.820\ 10^{-14}$
	cold	$0.140\ 10^{9}$	$4.917\ 10^{-14}$.

Historical Runs

Biomass and yield estimates were calculated using historical effort levels (1966-82) for each of the egg-recruit functions. The estimates of biomass at the beginning of the year between 1973 and 1982 were compared against estimates of biomass at the beginning of the year derived from the corhort analysis. The yield estimates were compared against the observed yield (1966-82). The expected fishery yields generally agree with observed yields for 1973-85, whereas for 1966-69 the yields calculated by the model are consistently higher than those reported by the fishery (Table 3). As discussed in Francis et al. (1984) three factors could be responsible for the early discrepancy between the observed and predicted yields from the model: 1) incorrect standardization of effort in early years, 2) under-reporting of early catches, or 3) overestimated projected biomass used to initialize the fishery. Therefore, the models should be evaluated based on the 1973-82 yield estimates. Based on the mean percent error of the yield

Table 3.--Summary of historical runs using three egg recruitment function methods

		Negative Exponential	Shepherd	Modified
Biomass 1973-82	MPE	28.7%	24.6%	27.9%
	r^2	.470	.643	.532
Yield 1973-82	MPE	28.7%	31.4%	29.2%
	r^2	.776	.759	.774
Yield 1966-82	MPE	67.7%	77.3%	67.9%
	r^2	.094	.092	.093
Yield & Biomass combined 1973-82	MPE	28.7%	28.0%	28.6%

r = correlation coefficient

MPE = mean percent error

and biomass estimates combined (1973-82), the precision of all three models was very similar (Table 3).

Equilibrium Yield Analysis

Figure 7 gives the 1931-82 time series of average January-March sea surface temperatures in the Los Angeles Bight. Following the technique described in Francis (1985) the data were divided (Francis et al. 1984) into warm (>15°C) and cold (<15°C) based on examination of the temperature frequency histogram. The environmental time series was used as a driving variable for subsequent runs of the age-structured model. In cases where runs of longer than 40 years were needed, data of the environmental conditions of the last 40 years were recycled through the model (e.g., in order to make a 1,000-year run, the 1943-82 environmental conditions were cycled through the model 25 times).

Two management policies were examined in this report:

1) constant effort, and

2) variable effort where

f_i = effort in year i

$= f_{op} \, (B_i/B_{op})$

f_{op} = constant effort which produces maximum average yield

B_{op} = average stock biomass during constant effort run which produces maximum average yield,

B_i = biomass in year i.

This second management policy is identical to that described by Shuter and Koonce (1985) as one which greatly reduces the risk of stock collapse when compared with a constant catch or constant effort management policy.

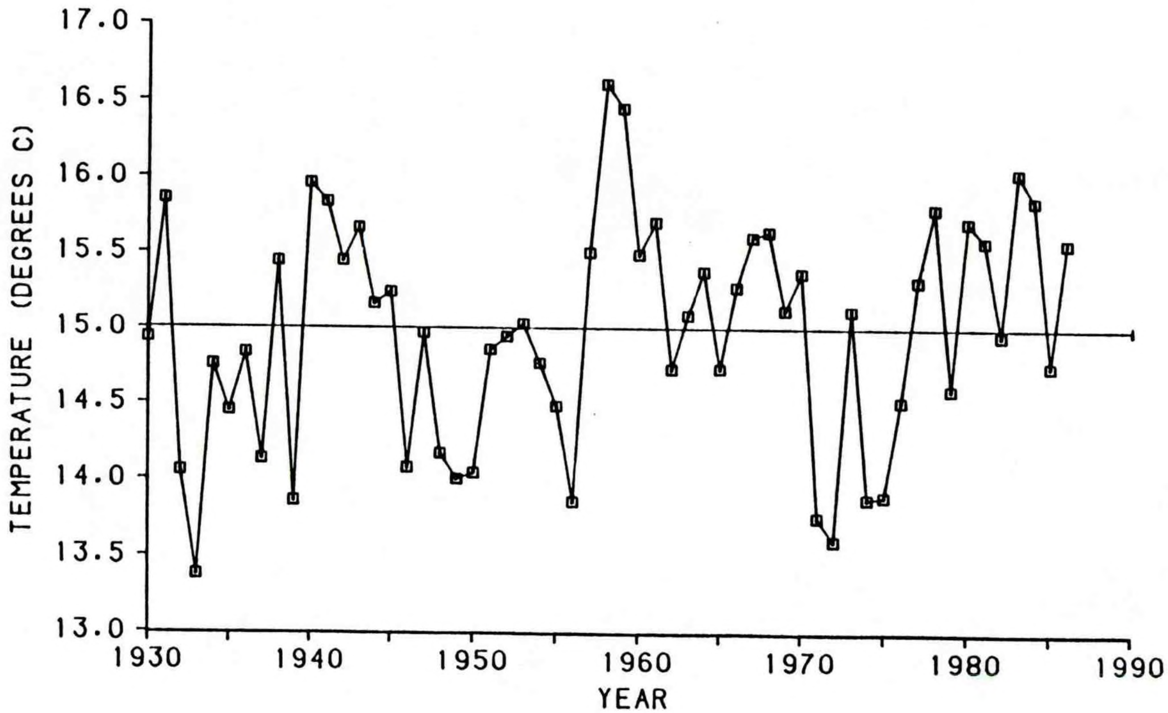


Figure 7.--The 1931 to 1982 mean January through March sea surface temperature (°C) in Los Angeles Bight.

Runs of both the deterministic and stochastic versions of the model were made under the constant effort and variable effort management policies. In the stochastic cases, 10 runs of 1,000 years each (each with a different seed) were averaged. In the deterministic cases, 1 run of 1,000 years was made with coefficients of variation of recruitment set equal to zero. In the stochastic form of the model, the coefficients of variation of recruitment are assumed to be constant about each of the egg-recruit curves. Average recruitments and their coefficients of variation for each of the three recruitment scenarios appear in Table 4.

Table 5 gives the results of the optimal (in terms of maximizing long-term average catch) runs of the model. Using the estimates of average catch (C) and stock size (N in numbers of fish), the average fishing mortality (F) was calculated from the following relationship:

$$\overline{C}/\overline{N} = \frac{F\,[1-e^{-(F + M)}]}{(F + M)}.$$

Several points stand out:

1) The long-range projections of maximum average annual production are very sensitive to the form of the stock recruit curve used in the model. The maximum average annual surplus production of the stock ranges from 127,000 t using the Shepherd egg-recruit function to 193,000 t using the negative exponential function.

2) The F values range from 0.184 using the Shepherd egg-recruit function to 0.534 using the negative exponential function.

3) The average ratio of annual yield to the biomass at the beginning of the year ranged from 15.7% using the Shepherd egg-recruit function to 31.6% using the negative exponential function. Preliminary investigations of world-wide whiting stocks show that continuous removals of over 30% of the exploitable stock biomass usually results in a decline in stock (Kevin Bailey, Northwest

Table 4.--Average recruitment (R) and coefficients of variation (CV) from 1,000 year runs of the stochastic model under constant effort and variable effort management policies.

	Effort	R (billions)	CV(R)
Shepherd			
Warm	Variable	0.699	106.6%
	Constant	0.731	104.8%
Cold	Variable	0.107	87.5%
	Constant	0.108	84.1%
Negative Exponential			
Warm	Variable	0.806	105.1%
	Constant	0.842	103.6%
Cold	Variable	0.123	81.6%
	Constant	0.126	79.3%
Modified Negative Exponential			
Warm	Variable	0.715	106.0%
	Constant	0.771	104.4%
Cold	Variable	0.111	83.0%
	Constant	0.111	80.7%

Table 5.--Summary of 1,000 year deterministic (Det) and stochastic (Stoch) model runs under constant and variable effort management policies.

Management Policy	Y(CV)[a] (1000 t)	f(CV)[b] (1000 d)	CPUE[c]	B(CV)[d] (1000 t)	% years[e] below E_{75}	F[f]	AVG[g] % Y/B
Shepherd							
Constant effort							
Det	137(38.0)	6.7(0.0)	20.4	705(39.5)	23	0.185	16.3
Stoch	127(66.3)	6.7(0.0)	19.0	657(70.2)	40	0.184	16.9
Variable effort							
Det	141(48.2)	7.0(30.4)	20.2	684(34.8)	23	0.201	16.1
Stoch	136(92.3)	6.6(58.8)	20.7	645(58.6)	35	0.210	15.7
Negative Exponential							
Constant Effort							
Det	187(44.9)	29.0(0.0)	6.5	474(46.9)	13	0.455	30.3
Stoch	179(78.6)	29.0(0.0)	6.2	454(84.7)	19	0.454	31.6
Variable Effort							
Det	193(54.6)	29.5(41.0)	6.5	461(41.1)	0	0.497	29.6
Stoch	189(126.2)	27.7(74.2)	6.8	433(74.2)	8	0.534	28.9
Modified Negative Exponential							
Constant Effort							
Det	157(40.4)	11.0(0.0)	14.3	627(42.1)	20	0.251	20.5
Stoch	146(69.4)	11.0(0.0)	13.3	584(74.0)	32	0.250	21.3
Variable Effort							
Det	163(49.2)	11.5(36.5)	14.2	611(36.5)	15	0.274	20.3
Stoch	157(99.8)	10.8(66.0)	14.6	574(62.3)	24	0.289	19.9

[a] Y(CV) Average yield and the coefficient of variation in yield.

[b] f(CV) Average effort and the coefficient of variation in effort.

[c] CPUE Catch per unit of effort.

[d] B(CV) Average biomass and the coefficient of variation in biomass.

[e] E_{75} = egg production at which $R = .75\ \overline{R}_w$

Where: $E_{75} = 0.402$ for Shepherd
$E_{75} = 0.141$ for Negative Exponential
$E_{75} = 0.288$ for Modified Negative Exponential

[f] F Fishing mortality coefficient.

[g] Y/B Yield as a percentage of the exploitable biomass at the beginning of the year.

and Alaska Fish. Cent., NMFS, Seattle, WA. Pers. commun., 1986), whereas continuous removal of 20-25% of the stock biomass does not have a noticeable effect on the stock. From that point of view, the modified egg-recruit function is perhaps more realistic than the negative exponential and Shepherd methods.

4) As was pointed out by Shuter and Koonce (1985), the constant effort scenario has a higher risk of driving the stock to low levels than the variable effort scenario. Under constant effort, the fecund stock is below that level on the stock-recruit curves at which recruitment is 75% of its maximum value (E_{75}) more often than under the variable effort policy.

5) We believe the stochastic version more accurately represents the inherent variability in the system. It also seems to produce slightly lower estimates of stock production.

6) As pointed out by Francis (1985), when controlling the variability in one part of the system (e.g., by stabilizing the effort in the fishery) one simply transfers that variability into another part of the system (e.g., into the biomass levels of the stock itself). Thus in a highly variable system such as this, managers must make the decision as to where variability can be accommodated and where it is least desirable.

Projections of 1987 Acceptable Biological Catch

A final set of deterministic runs of the model were made trying to incorporate the best projections of stock during the the upcoming 1987 fishing season. The model was initiated in 1983 with the estimates of absolute stock abundance at the beginning of the year. These biomass estimates were calculated by correcting the 1983 NWAFC trawl/hydroacoustic survey estimates of biomass at age for natural and fishing mortality that occurred during the eight months prior to the survey. Effort was then set to remove the observed catches for 1983 (113,000 t), 1984 (138,000 t), 1985 (111,000 t), and 1986 (178,000 t).

The catch for 1986 was estimated using the time density technique described by Mundy and Mathisen (1981). The proportion of the catch was estimated on a weekly time step from radio messages sent by foreign observers in 1983, 1984, and 1985. The weekly proportion of catch was averaged over the 3 years and summed to produce an overall average cumulative proportion. The observed U.S. catch as of 6 September 1986 was 121,500 t. The average proportion of the catch for the first week of September was 0.875. Therefore, the estimate for the U.S. catch in 1987 was 139,000 t (121.5/0.875). Assuming the U.S. portion of the catch is 78% of the total, the Canadian catch was estimated to be 39,000 t, making a total U.S. and Canadian combined catch of 178,000 t.

In order to account for the apparent effects of the recent El Nino on whiting growth, average weights at age were reduced according to patterns observed in the 1983 and 1984 fisheries (Fig. 4). Age classes recruited after 1984 were assumed to have weights at age equal to the long term averages (1976-80) estimated in Francis (1983) (Fig. 4). In the constant effort run, maximum sustainable yield (MSY) effort was applied in 1987. In the variable effort run, variable effort was applied (where B_{op} = long term average biomass under the optimal stochastic variable effort run).

The yield projections for 1987 range widely depending on the level of effort used. The 1987 optimum yield projections range from 264,000 to 756,000 t depending on the egg-recruit function used in Table 6. Under the constant effort policy, the negative exponential allows for removal of 59% of the 1986 stock, whereas the Shepherd and modified versions allow for removal of only 24 or 35% of the 1986 stock, respectively. As mentioned earlier, Kevin Bailey

Table 6.--Deterministic model runs for 1983-87 under constant natural mortality (M).

Egg Recruit Function	Policy	Year	Yield (thousand t)	Effort (thousand d)	Average Biomass (thousand t)	Y(1987) as % of B(1987)
Observed		1983	113	4.35	1,437	
		1984	138	4.30	1,285	
		1985	111	3.15	1,074	
		1986	178	4.48	888	
Shepherd	CE	1987	264	6.70	936	24
	VE	1987	332	9.06	897	30
Neg. Exp.	CE	1987	633	29.00	683	58
	VE	1987	756	56.72	550	69
Modified	CE	1987	380	11.00	868	35
	VE	1987	473	15.58	808	43

CE = Constant effort

VE = Variable effort

d = Days

Y = Yield

B = Total exploitable biomass at the beginning of the year

(Northwest and Alaska Fish. Cent., NMFS, Seattle, WA. Pers. commun., 1986) found continuous removal of 20 to 25% of the exploitable stock biomass did not have a noticeable effect on various whiting stocks. Furthermore, the Peruvian whiting stock collapsed after the removal of approximately 50% of the stock and has still not recovered. These two factors suggest that the acceptable biological catch (ABC) projected by the negative and modified exponential models are too high. Therefore, we consider the yield of 267,000 t projected using the modified egg-recruit curve to be reasonable. This estimate reflects a substantial reduction from last year's ABC (405,000 t). This reduction is attributed to the fact that the maximum sustainable yield (MSY) effort level projected using the modified egg-recruitment relationship (6,700 days) was lower than that projected by the negative exponential last year (16,000 days). However, the projections remain above MSY (127,000 to 193,000 t) because of the large number of 7-year-old fish (i.e., the 1980 year class) that are available in the stock. The catch at age projected from the model reveals that 78% of the catch in 1987 would be 7-year-old fish.

RECOMMENDATIONS

We recommend setting the 1987 ABC for the total (United States and Canada) offshore Pacific whiting stock at 267,000 t, and the 1987 ABC for the U.S. portion of that stock at 208,000 t (78% of the total which is the 1980-85 average fraction of the total whiting catch made in U.S. waters).

We recognize that our estimates of yield for 1987 are very sensitive to the stock recruit curve used in the model. Therefore our estimates of yield for 1987 are conservative. With the addition of biological information from the 1986 triannual hydroacoustic survey we hope to improve our estimates of age-specific natural mortality. In addition, we are conducting an investigation of factors influencing recruitment of Pacific whiting in an attempt to improve our understanding of processes underlying the production of this important resource. This research will involve a re-examination of physical processes underlying recruitment using response and surface analysis (Schunte and McKinnel 1984). In addition, the distribution and abundance of eggs, larvae, and juveniles will be examined to test the validity of the relationships between recruitment and the environment.

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