Status of the Pacific Hake Resource and Recommendations for Management in 1987

by

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INTRODUCTION

In 1986, research at the Northwest and Alaska Fisheries Center (NWAFC) on offshore hake production and management has focused a re-estimation of production parameters based on new fishery (1984-85) data.

CURRENT STATUS OF THE RESOURCE

Table 1 gives recently updated estimates of hake catch since the initiation of the fishery in 1966 (Van Houten, unpublished manuscript). Figure 1 illustrates the relative age frequencies of the 1984 and 1985 catches in United States (U.S.) and Canadian waters. It is interesting to note that in both 1984 and 1985, most of the Canadian hake 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 four indices of year-class abundance. The first two (% Occurrence, Std #/tow) are two measures of relative abundance of 0-age hake from CDF&G midwater trawl surveys conducted off the California coast (south of Pt. 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 two indices of Figure 2 are Bailey's (1981) year-class index (YCI = mean percent contribution of a cohort at ages 4, 5, and 6) derived from commercial fishery catch at age data and an index of recruitment at age 3 from a cohort analysis performed on the 1973-85 catch-at-age data. There is no question but that the strong year-classes which have historically supported the fishery (1967, 70, 73, 77, 80) 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 hake may be above average. A spring 1985 Soviet survey off southern California reported catching large numbers of the 1984 year-class (Figure 3). Furthermore, the 1985 catch at age data from commercial fisheries in U. S. waters show an abundance of one year old fish which tends to corroborate that the 1984 year class may be above average strength (Figure 1). In addition to the 1984 year class, the 1986 year class may also be above average because an unusually large number of hake larvae (30-40 mm) were captured during the spring (May-June, 1986) larval rockfish survey (Tina Wyllie Echeverria personal communication).

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 hake 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 1976-80 U.S. fishery data. Of particular importance is the fact that although the effect of El Nino on hake 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 three years after the El Nino event.

New Estimates of Fishery Production

New estimates of offshore hake 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, 80, and 83 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 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 calcuated in the following manner. First an estimate of the number (N) of by fish ages 3 to 7 was calculated from the estimates of recruitment by accruing natural and fishing mortality via a Beverton and Holt type analysis i.e.,

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

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

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

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 hake recruitment to be inversely correlated to wind driven Ekman transport on the spawning ground at the time of spawning. Swartzman et al. (1983) further reasoned that offshore transport is positively correlated with the level of upwelling which, in turn, is negatively correlated with sea surface temperature. Therefore, years of "cold" water temperatures on the spawning ground are assumed to be years of high offshore transport and low larval survival, and years of "warm" water temperatures on the spawning ground are assumed to be years of low offshore transport and higher, although more variable, larval survival (Figure 5).

Although, there is no apparent relationship between the number of eggs and subsequent recruitment (Figure 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. 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
Shepherd	warm	$2.061\ 10^{-5}$	$0.568\ 10^{14}$
	cold	$0.243\ 10^{-5}$	$0.818\ 10^{14}$
Neg. Exp.	warm	$0.899\ 10^{9}$	$5.035\ 10^{-14}$
	cold	$0.140\ 10^{9}$	$5.035\ 10^{-14}$

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 R when E is equal to 50% of the minimum observed egg level.

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 (Figure 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 R 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	$0.899\ 10^{9}$	$2.518\ 10^{-14}$
	cold	$0.140\ 10^{9}$	$2.460\ 10^{-14}$

Biomass and yield estimates were calculated using historical effort levels (1966-1982) for each of the egg-recruit functions. The estimates of biomass in 1977, 1980 and 1983 were compared against the biomass observed in the 1977, 1980 and 1983 NWAFC trawl-hydroacoustic surveys. The yield estimates were compared against the observed yield (1966-82). The expected fishery yields generally agree with observed yield 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. (1985) 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,
3) The projected biomass used to initialize the fishery may have been overestimated.

Therefore, the models should be evaluated based on the 1973-82 yield estimates. Using the 1973-82 yield criteria and the mean percent error of the biomass estimates, the precision of the models was very similar (Table 3).

Figure 7 gives the 1931-82 time series of average January-March sea surface temperatures in the Los Angeles Bight. As 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, the last 40 years environmental conditions were recycled through the model (e.g. in order to make a 1000 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.

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 (unpublished manuscript) as one which greatly reduces the risk of stock collapse when compared with a constant catch or constant effort management policy.

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 1000 years each (each with a different seed) were averaged. In the deterministic cases, 1 run of 1000 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 maximum average annual surplus production of the stock ranges from 131 thousand t using the Shepherd egg-recruit function to 191 thousand t using the negative exponential function.

2) The F values range from 0.172 using the Shepherd egg-recruit function to 0.445 using the negative exponential function.

3) The average ratio of annual yield to total biomass before fishing ranged from 17.3% using the Shepherd egg-recruit function to 36.2% using the negative exponential function. Preliminary investigations of world wide hake stocks show that continuous removals of over 30% of the stock biomass usually results in a decline in stock (Bailey, 1985), whereas, continuous removal of between 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 the Shepherd.

4) As was pointed out by Shuter and Koonce (unpublished manuscript), 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) 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 ABC/OY

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 from the 1983 NWAFC trawl/hydroacoustic survey. Effort was then set to remove the observed catches for 1983, 1984, 1985, and 1986 (113, 138, 111, and 178) thousand t, respectively.

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 three years and summed to produce an overall average cumulative proportion. The observed U. S. catch as of September 6, 1986 was 121.5 thousand t. The average proportion of the catch for the week of September was 0.875. Therefore, the estimate for the U. S. catch in 1987 was 139 thousand 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 thousand t making a total U.S. and Canadian combined catch of 178 thousand t.

In order to account for the apparent effects of the recent El Nino on hake growth, average weights at age were reduced according to patterns observed in the 1983 and 1984 fisheries (Figure 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) (Figure 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 1987 optimum yield projections range from 175 to 485 thousand tons depending on the egg-recruit function used Table 6. Under the variable effort policy, the negative exponential allows for removal of 70% of the 1986 stock. Whereas, the Shepherd and modified versions allow for removal of only 25.0% or 38.0% of the 1986 stock, respectively. As mentioned earlier, the modified egg-recruit function is preferred over the Shepherd and the negative exponential because the long term average yield as a percentage of the stock biomass falls between 20-25%. Furthermore, the Peruvian hake stock collapsed after the removal of approximately 50% of the stock and has still not recovered (Bailey, 1985). These two factors suggest that the acceptable biological catch (ABC) projected by the negative exponential is too high. Therefore, we consider the yield of 250 thousand tons projected using the modified egg-recruit curve to be reasonable. This estimate reflects a substantial reduction from last year's ABC (405 thousand t). This reduction is attributed to two factors. First, the MSY effort level projected using the modified egg-recruitment relationship (9.3 thousand d.) was lower than that projected by the negative exponential last year (16.0 thousand d.). Second, the stock biomass available to the fishery in 1987 is smaller than in 1986 resulting from fishing and natural mortality of the 1977 and 1980 year classes, and the virtual failures of the 1981-83 year classes. However, the projections remain above MSY (approximately 152 thousand t) because of the projection of a strong incoming 1984 year class.

We, therefore, recommend setting the 1987 ABC for the total (U.S. and Canada) offshore Pacific hake stock at 250 thousand t, and the 1987 ABC for the U.S. portion of that stock at 195 thousand t (78% of the total which is the 1980-85 average fraction of the total hake catch made in U.S. waters).

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Table 1. Annual catches of Pacific hake (1000 mt) in U.S. and Canadian waters by foreign, joint venture (JV), and domestic fleets.

	U. S.				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	7.381
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		

Table 2. Input data and summarized results of the Pacific hake cohort analyses.

Constant M

Year Class	YCI Billions	Recruitment at age 3 Billions	Eggs Trillions	Temp. Index	Age	Total 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)	(254.1)	W	10+	0.11080
1968	0.282	(0.297)	(203.5)	W		
1969	0.254	(0.257)	(119.0)	W		
1970	1.650	2.601	(125.5)	W		
1971	0.247	0.314	(132.2)	C		
1972	0.197	0.238	138.7	C		
1973	0.776	0.742	240.4	W		
1974	0.194	0.164	264.4	C		
1975	0.310	0.262	276.6	C		
1976	0.141	0.137	258.8	C		
1977	1.408	1.234	219.2	W		
1978	0.072	0.067	196.0	W		
1979	0.039	0.055	164.8	C		
1980	1.830	2.734	170.4	W		
1981	0.243	0.263	162.2	W		
1982	-	0.012	121.9	C		
1983	-	-	192.7	W		
1984	-	-	221.4	W		
1985	-	-	236.1	W		

1. YCI = Year Class Index

2. Recruitment estimated from YCI as:

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

3. Eggs estimated as:

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

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

4. Mean warm year recruitment = 0.899, CV = 109.1%
Mean cold year recruitment = 0.140, CV = 80.6%

Table 3. Summary of historical runs.

		Neg.Exp.	Shepherd	Modified
Biomass				
77-80-83	MPE	43.7%	46.7%	45.6%
Yield	MPE	26.2%	26.7%	26.7%
1973-82	r	.865	.863	.863
Yield	MPE	68.6%	79.0%	68.8%
1966-82	r	.173	.182	.170

r = correlation coefficient
MPE = mean percent error

Table 4.--Average recruitment and coefficients of variation from 1000 yr runs of the stochastic model under constant effort and variable effort management policies.

		Effort	R (billions)	CV(R)
Shepherd				
	Warm	Variable	0.768	104.4%
		Constant	0.738	105.9%
	Cold	Variable	0.114	82.9%
		Constant	0.113	85.6%
Negative Exponential				
	Warm	Variable	0.866	103.2%
		Constant	0.836	104.2%
	Cold	Variable	0.131	78.8%
		Constant	0.127	80.2%
Modified Negative Exponential				
	Warm	Variable	0.804	103.9%
		Constant	0.768	105.3%
	Cold	Variable	0.122	80.1%
		Constant	0.119	82.1%

Table 5. Summary of 1000 year deterministic and stochastic model runs under constant effort and variable effort management policies.

Shepherd

Management Policy		Y(CV) thousand t	f(CV) thousand d	CPUE	B(CV) thousand t	% yrs below E_{75}	F	AVG % Y/B
Constant Effort -	Det	139(37.0)	6.0(0.0)	23.2	763(38.5)	20%	0.172	18.6
	Stoch	131(64.4)	6.0(0.0)	21.9	719(68.2)	32%	0.172	19.0
Variable Effort -	Det	144(47.4)	6.2(30.4)	23.1	744(34.0)	18%	0.185	18.2
	Stoch	140(90.1)	5.8(57.3)	23.9	708(57.4)	26%	0.195	17.3

Negative Exponential

Management Policy		Y(CV)	f(CV)	CPUE	B(CV)	% yrs below E_{75}	F	AVG % Y/B
Constant Effort -	Det	187(42.8)	22.0(0.0)	8.5	538(45.0)	8%	0.381	35.5
	Stoch	182(74.4)	22.0(0.0)	8.2	522(80.2)	12%	0.382	36.3
Variable Effort -	Det	191(51.9)	22.1(39.1)	8.7	524(39.1)	0%	0.412	34.1
	Stoch	190(116.8)	21.0(69.5)	9.1	499(69.5)	3%	0.445	32.4

Modified Negative Exponential

Management Policy		Y(CV)	f(CV)	CPUE	B(CV)	% yrs below E_{75}	F	AVG % Y/B
Constant Effort -	Det	158(39.0)	9.3(0.0)	17.0	686(40.7)	13%	0.226	23.5
	Stoch	149(67.0)	9.3(0.0)	16.1	649(71.4)	24%	0.226	23.9
Variable Effort -	Det	163(48.2)	9.6(35.5)	17.0	671(35.5)	8%	0.245	23.0
	Stoch	160(95.6)	9.1(60.4)	17.5	636(60.4)	15%	0.258	21.9

E_{75} = egg production at which R = .75 R

Where:

E_{75} = 0.771 for Shepherd
E_{75} = 0.275 for Negative Exponential
E_{75} = 0.522 for Modified Negative Exponential

Table 6--Deterministic model runs for 1983-87.

Constant M

Egg - Recruit Function	Policy	Year	Yield (thousand t)	Effort (thousand d)	Estimated Biomass (thousand t)	Y(87) as % of B(86)
Observed		1983	113	6.20	1,171	
		1984	138	6.05	1,045	
		1985	111	4.38	856	
		1986	178	6.15	694	
Shepherd	CE	1987	178	6.00	811	26%
	VE	1987	175	5.88	813	25%
Neg.Exp.	CE	1987	423	22.00	655	61%
	VE	1987	485	30.50	604	70%
Modified	CE	1987	250	9.30	770	36%
	VE	1987	266	10.13	761	38%

CE = Constant effort
VE = Variable effort

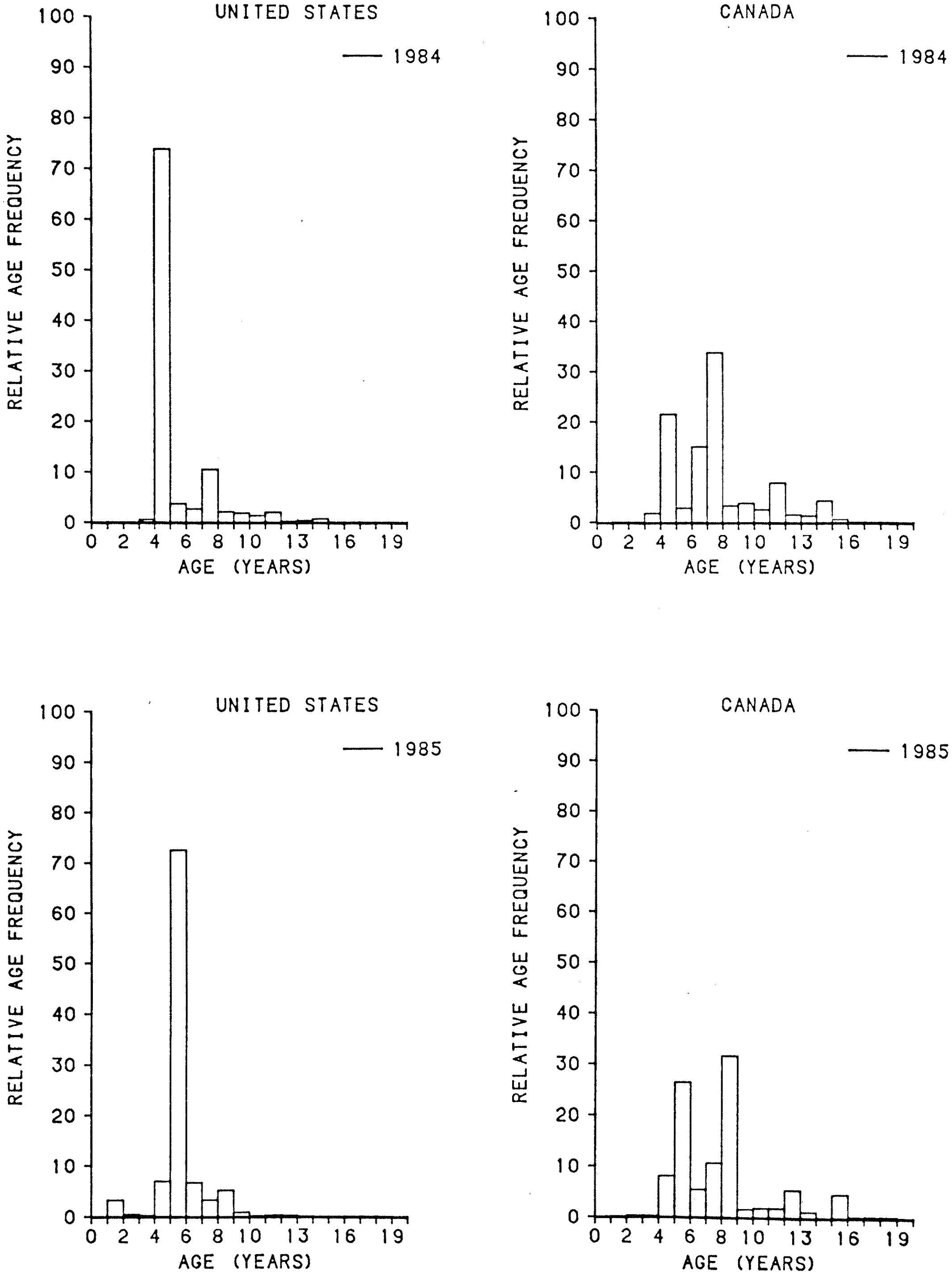


Figure 1. Relative age frequency of Pacific hake catches in U.S. and Canadian waters, 1984-85.

Appendix 1
Pacific Hake

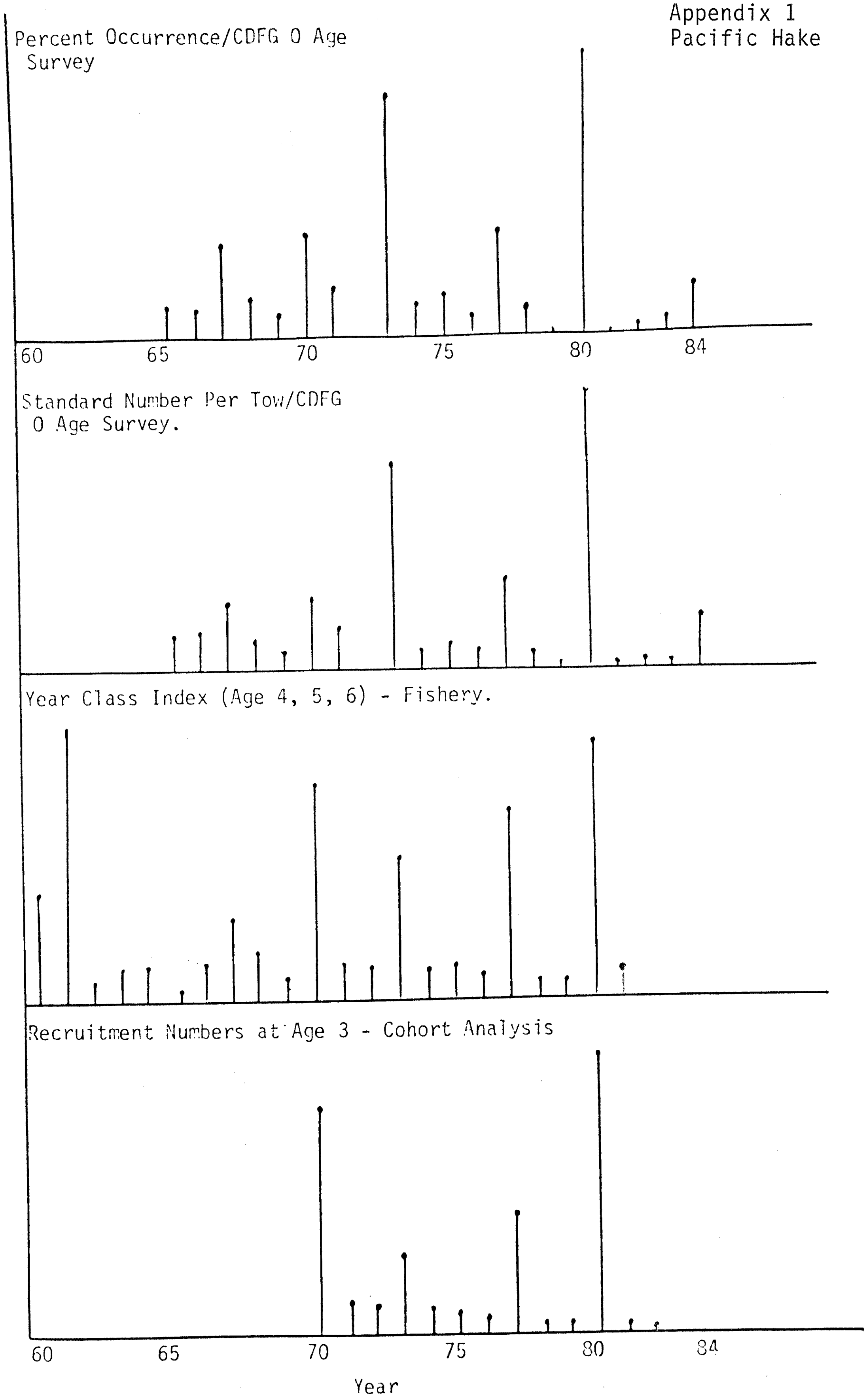


Figure 2. Indices of hake year-class strength from age 0 surveys and the adult fishery.

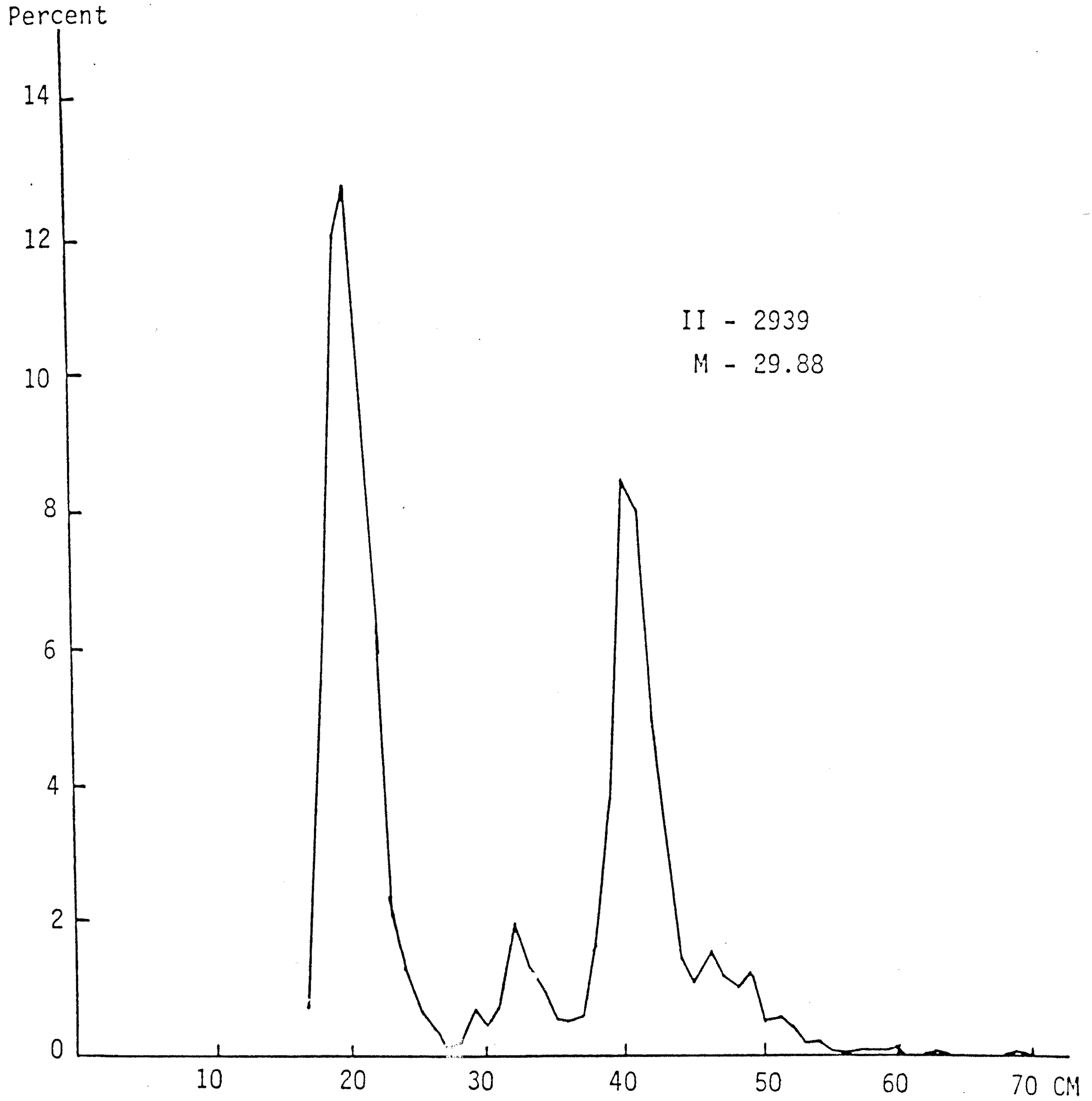


Figure 3. Length frequency of Pacific hake catch from Spring 1985 Soviet survey (pt. Conception--San Francisco).

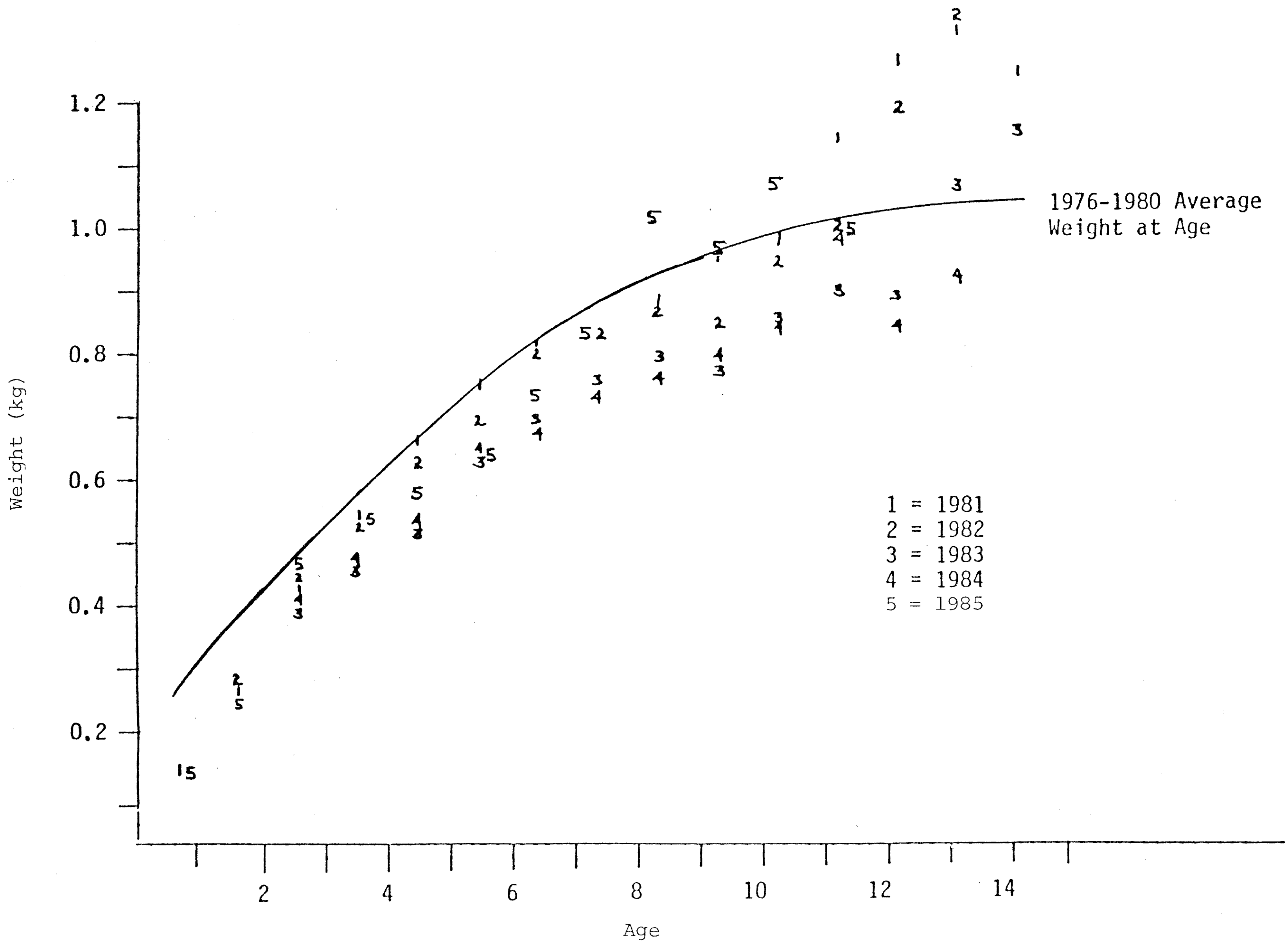
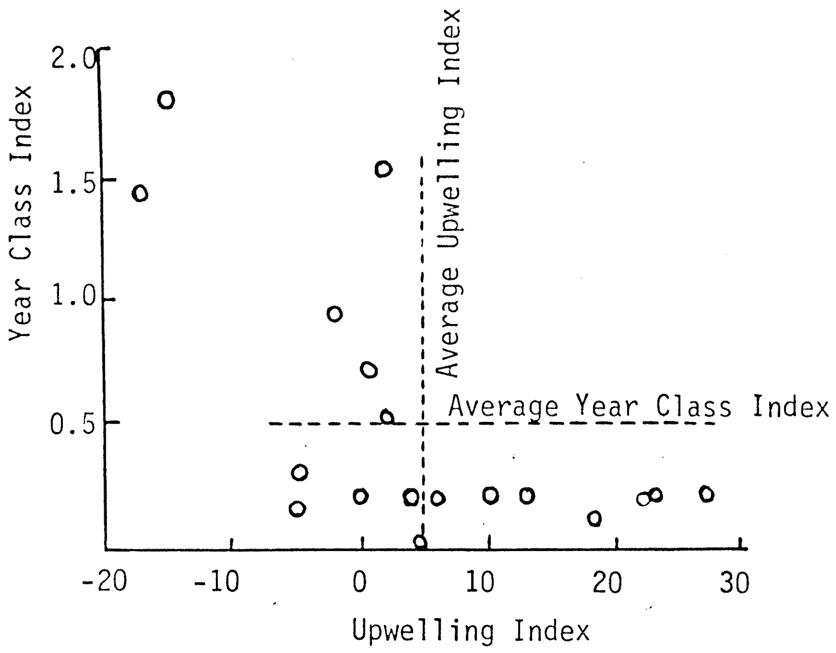


Figure 4. Pacific hake average weight (kg) at age from 1981-85 U.S. Fisheries.



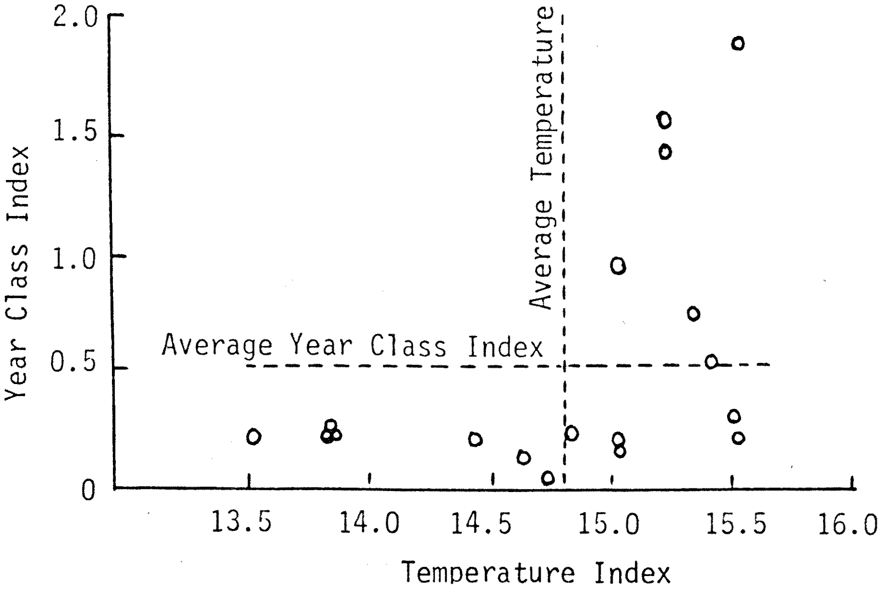


Figure 5. Pacific hake year-class index (1960-77) as related to upwelling and temperature indices at the time of spawning (36° N. latitude, January).

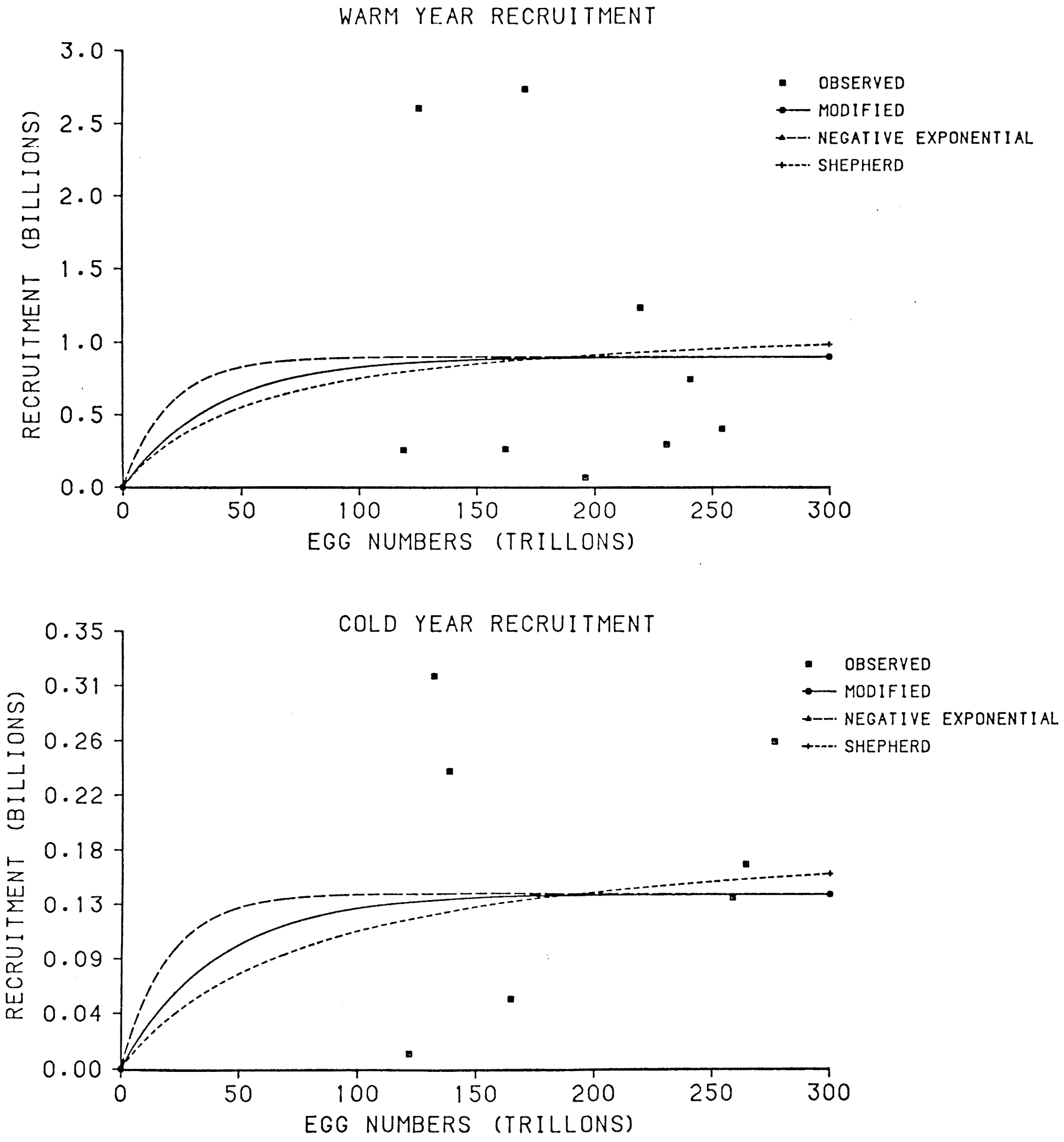


Figure 6. Observed and predicted egg-recruit relationships under warm and cold environmental conditions at the time of spawning.

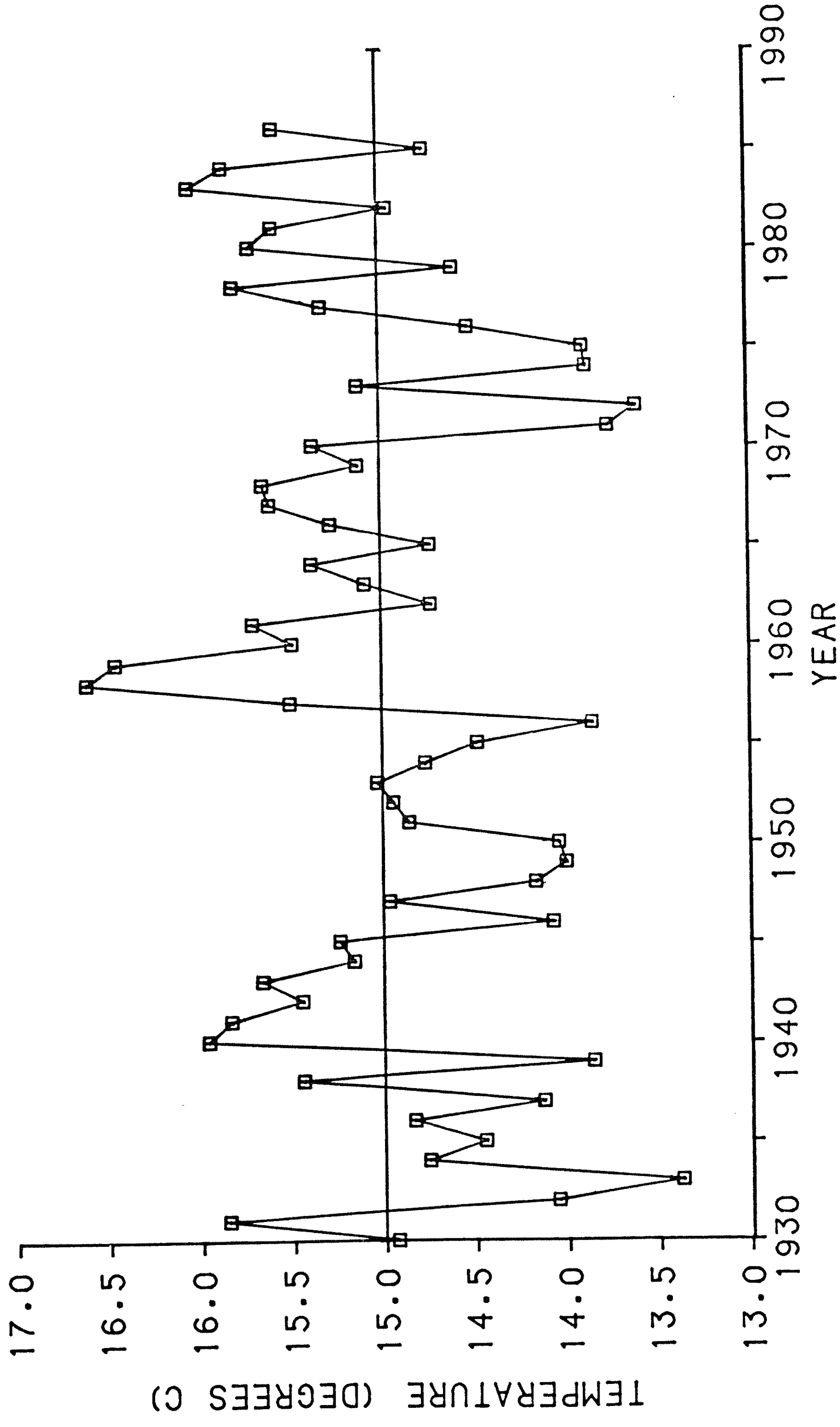


Figure 7. The 1931 to 1982 mean January through March sea surface temperature (°C) in Los Angeles Bight.