APPENDIX 1
Pacific Hake

Introduction

1985 research at the Northwest and Alaska Fisheries Center (NWAFC) on offshore hake production and management has focused on two areas: 1) simplification of the management model of Swartzman et al (1983) and Francis et al (1984), and 2) reestimation of production parameters based on new fishery (1983,84) and NWAFC trawl/hydroacoustic survey (1983) data. The multinational management algorithm presented by Francis et al (1984) is presently being reevaluated. In its stead, current and long term fishery production is examined under simpler management policies.

Current Status of the Resource

Table 1 gives recently updated estimates of hake catch since the initiation of the fishery in 1966 (Marcelle Lynde, unpublished manuscript). Figure 1 gives the relative age frequencies of the 1983 and 1984 catches in U.S. and Canadian waters. It is interesting to note that in both 1983 and 1984, 77% of the hake catches in numbers were comprised of the strong 1977 and 1980 year-classes.

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 (% Occurence, 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 1973-84 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). Anecdotal reports from northern California and Oregon fishermen tend to corroborate that the 1984 year class may be above average strength.

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 1981-84 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 this affect of El Nino on hake weight-at-age has apparently persisted through 1984. One would expect this to be the case since growth in both length and weight appear to have been affected by the El Nino event. Accordingly, one would expect those affected year-classes to exhibit reduced lengths and weights-at-age for the rest of their lives in the fishery.

New Estimates of Fishery Production

New estimates of offshore hake fishery production were made using an age-structured simulation model along the lines of Walters (1969) and Shuter and Koonce (unpublished manuscript). 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 1983 and 1984 catch at age data, as well as the 1983 NWAFC trawl/hydroacoustic survey estimates of absolute numbers and biomass at age, new estimates of age-specific natural mortality (M) and an updated cohort analysis provide new estimates of age-specific catchability and 1983-84 stock abundance.

Estimates of age-specific natural mortality were made by estimating the decay of cohorts from the 1977, 1980, and 1983 NWAFC surveys of absolute hake abundance. Total mortality was partitioned into components of natural and fishing mortality by incorporation of catch information. For example, let

$N_i(77)$ = numbers in cohort i in the 1977 survey,

$N_i(80)$ = " " " " " " 1980 survey,

$C_i(77-80)$ = catch in cohort i between the 1977 and 1980 surveys.

Then

$Z_i(77\text{-}80)$ = total mortality on cohort i between the 1977 and 1980 surveys

$= \ln [N_i(80)/N_i(77)]$

$E_i(77\text{-}80)$ = exploitation rate between the 1977 and 1980 surveys

$= C_i(77\text{-}80)/N_i(77)$

$= F_i(77\text{-}80)\ [1-e^{-Zi(77-80)}]$

which can be solved for $F_i(77\text{-}80)$. Then

$M_i(77\text{-}80)$ = natural mortality on cohort i between the 1977 and 1980 surveys

$= Z_i(77\text{-}80) - F_i(77\text{-}80)$

Natural mortality can similarly be estimated by cohort for the time period between the 1980 and 1983 surveys. In order to try and eliminate possible errors in aging associated with the strong 1970 cohort, groups of three cohorts were tracked and their mortality parameters estimated. Table 2 gives summaries of the estimates of M, along with the corresponding values estimated by Francis (1983) and used in previous stock assessments (Swartzman et al 1983, Francis et al 1984, Francis and Hollowed 1984). As it turned out, the estimates of M between 1980 and 1983 were, on the average, 20% lower than those of Francis (1983), and the estimates of M between 1977 and 1980 were, on the average, 52% lower than those of Francis (1983). As a result, new cohort analyses were performed with 1) variable age-specific natural mortality (M) reduced an average of 36% below that of Francis (1983), and 2) a constant age-specific M = 0.23 (an estimate of the mean annual age-specific M if all cells of Table 2 were filled). It is interesting to note that this value is identical to that reported by McFarlane and Beamish (1983) for the Strait of Georgia hake stock.

The 1973-84 cohort analysis was performed in such a way to give the best (minimum sum of squares) fit between the numbers at age from the three surveys and the cohort analysis. Separate runs were made with variable and constant age-specific natural mortalities with a significantly better fit occuring with the constant M. Summaries of these results are given in Table 3. Both sets of parameters were used in subsequent model runs.

As was the case previously (Francis et al 1984), 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. Therefor, 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). The end results are two egg-recruit functions of the form:

$$R_3 = a\,(1-e^{-KE})$$

where

R = number of recruits at age 3

E = number of eggs produced 3 years earlier.

A separate egg-recruit curve is used for warm and cold conditions at the time of spawning. 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 are as follows:

	M	$\overline{R}$ (billions)	CV(R)
Warm	Variable	0.810	106.6%
	Constant	0.965	106.0%
Cold	Variable	0.124	68.0%
	Constant	0.158	67.7%

As was the case in Francis et al (1984), the parameter K of the egg-recruit curves were set so that recruitment equals .95 $\overline{R}$ when E is equal to 50% of the minimum observed egg level.

Figure 6 gives the 1931-82 time series of average January - March sea surface temperatures in the Los Angeles Bight. 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).

At the present time, the management policy algorithm described by Swartzman et al (1983) and Francis et al (1984) is being reevaluated and overhauled. In its stead, two management policies will be examined.

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.

Table 4 gives the results of the optimal (in terms of maximizing long term average catch) constant effort and variable effort runs of both the deterministic and stochastic versions of the model. 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. Several points stand out:

1) Under this new set of parameters, the maximum average annual surplus production of the stock is around 190 thousand t.

2) 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}) around 10% of the time as compared with around 2% of the time under the variable effort policy.

3) There is a definite difference between results produced by the deterministic and stochastic versions of the same model. Obviously, the stochastic version more accurately represents the inherent variability in the system. It also seems to produce slightly lower estimates of stock production.

4) I think that the most important thing that the stochastic model demonstrates is that there is no way that management is going to reduce the inherent variability in the system. By controling 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 accomodated and where it is least desirable.

Projections of 1986 ABC

A final set of deterministic runs of the model were made trying to incorporate the best projections of stock during the the upcoming 1986 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 and 1985 (113, 138 and 88 thousand t respectively - the 1985 estimated catch is 65 thousand t in the U.S. zone and 23 thousand t in the Canadian zone). 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). Table 5 gives the results of these four sets of runs. In the two constant effort runs, MSY effort (16.0 thousand d) was applied in 1986 with a resultant 1986 catch of over 400 thousand t. In the two variable effort runs, variable effort was applied (where B = long term average biomass under the optimal deterministic constant effort run) with a resultant 1986 catch of over 500 thousand t. The bottom line is that, due to the strengths of the 1977 and 1980 year classes and the low exploitation of the stock in recent years, the potential yield of the stock is currently very high. (In other words, there is hake up the ying yang out there.) However that potential will not be sustained over time.

The model was subsequently used to determine the amount of potential yield that might be lost in 1987 by exploiting the hake stock in 1986 at or below recent low levels (average 1983-85 catch was 113 thousand t). Indications are that a minimum of 30 to 50 thousand t potential yield in 1987 would be lost due to low exploitation in 1986 as a result of the decay of the current strong year classes in the fishery.

I therefore recommend setting the 1986 ABC for the total (U.S. and Canada) offshore Pacific hake stock at 405 thousand t, and the 1986 ABC for the U.S. portion of that stock at 300 thousand t (74% of the total which is the 1980-84 average fraction of the total hake catch made in U.S. waters).

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

	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	137.000	19.2	7.171
1967	168.699	0.000	8.959	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	145.241	0.000	0.072	145.313	15.125	0.000	0.001	15.126	160.439	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	3.453	0.000	0.000	3.453	130.955	30.9	4.244
1978	96.827	0.856	0.689	98.372	4.650	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	0.000	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	14.772	78.889	2.721	96.382	-	-	-	41.862	138.244	-	-
MEAN				125.409				30.042	155.451		

Table 2. Estimates of annual age-specific natural mortality from tracking cohorts between the 1977, 1980 and 1983 NWAFC trawl/hydroacoustic surveys.

Average Age	1977-80	1980-83	Francis(1983)
5.5	-	0.316	0.261
6.5	-	0.153	0.332
7.5	0.270	0.384	0.409
8.5	0.162	0.353	0.507

Table 3. Input data and summarized results of the Pacific hake cohort analyses.

Variable M

Year	Recruitment at age 3 (billions)	Effort (thousand d)	Age	Total q	M
1973	1.948	6.752	3	0.00276	0.18
1974	0.257	8.705	4	0.01112	0.13
1975	0.217	11.646	5	0.02157	0.12
1976	0.693	9.242	6	0.03637	0.16
1977	0.128	4.244	7	0.05737	0.23
1978	0.158	2.980	8	0.09255	0.32
1979	0.115	5.276	9	0.08586	0.32
1980	1.021	3.152	10+	0.09316	0.32
1981	0.047	4.915			
1982	0.050	3.489			
1983	2.419	-			
1984	0.054	-			

Constant M

Year	Recruitment at age 3	Effort	Age	Total q	M
1973	2.601	6.752	3	0.00228	0.23
1974	0.323	8.705	4	0.00850	0.23
1975	0.291	11.646	5	0.02094	0.23
1976	0.830	9.242	6	0.03818	0.23
1977	0.163	4.244	7	0.06531	0.23
1978	0.189	2.980	8	0.08434	0.23
1979	0.139	5.276	9	0.08073	0.23
1980	1.138	3.152	10+	0.08621	0.23
1981	0.053	4.915			
1982	0.060	3.489			
1983	2.659	-			
1984	0.056	-			

Table 4. Summary of 1000 year deterministic and stochastic model runs under constant effort and variable effort management policies.

Variable M

Management Policy		Y(CV) (thousand t)	f(CV) (thousand d)	CPUE (t/d)	B(CV) (thousand t)	% yrs below E_{75}
Constant Effort -	Det	194(38.8)	16.0(0.0)	12.1	626(40.4)	5%
	Stoch	187(67.5)	16.0(0.0)	11.7	603(71.3)	11%
Variable Effort -	Det	196(47.2)	15.8(34.9)	12.4	617(34.9)	0%
	Stoch	192(93.5)	15.4(59.4)	12.5	580(59.4)	2%

Constant M

Management Policy		Y(CV) (thousand t)	f(CV) (thousand d)	CPUE (t/d)	B(CV) (thousand t)	% yrs below E_{75}
Constant Effort -	Det	186(38.7)	16.0(0.0)	11.6	675(40.7)	5%
	Stoch	179(67.7)	16.0(0.0)	11.2	650(72.4)	10%
Variable Effort -	Det	189(47.1)	15.8(35.9)	12.0	668(35.9)	0%
	Stoch	187(95.9)	15.6(62.6)	12.0	632(62.6)	2%

E_{75}= egg production at which $R = .75\ R_{max}$

Table 5. Deterministic model runs for 1983 - 1986.

Variable M

1986 Management Policy	Year	Yield (thousand t)	Effort (thousand d)	Average Biomass (thousand t)
Constant Effort	1983	113	6.2	1,329
	1984	138	6.0	1,197
	1985	88	2.8	1,149
	1986	494	16.0	872
Variable Effort	1983	113	6.2	1,329
	1984	138	6.0	1,197
	1985	88	2.8	1,149
	1986	728	29.4	720

Constant M

1986 Management Policy	Year	Yield (thousand t)	Effort (thousand d)	Average Biomass (thousand t)
Constant Effort	1983	113	5.6	1,329
	1984	138	6.1	1,118
	1985	88	3.2	990
	1986	405	16.0	705
Variable Effort	1983	113	5.6	1,329
	1984	138	6.1	1,118
	1985	88	3.2	990
	1986	520	23.5	663

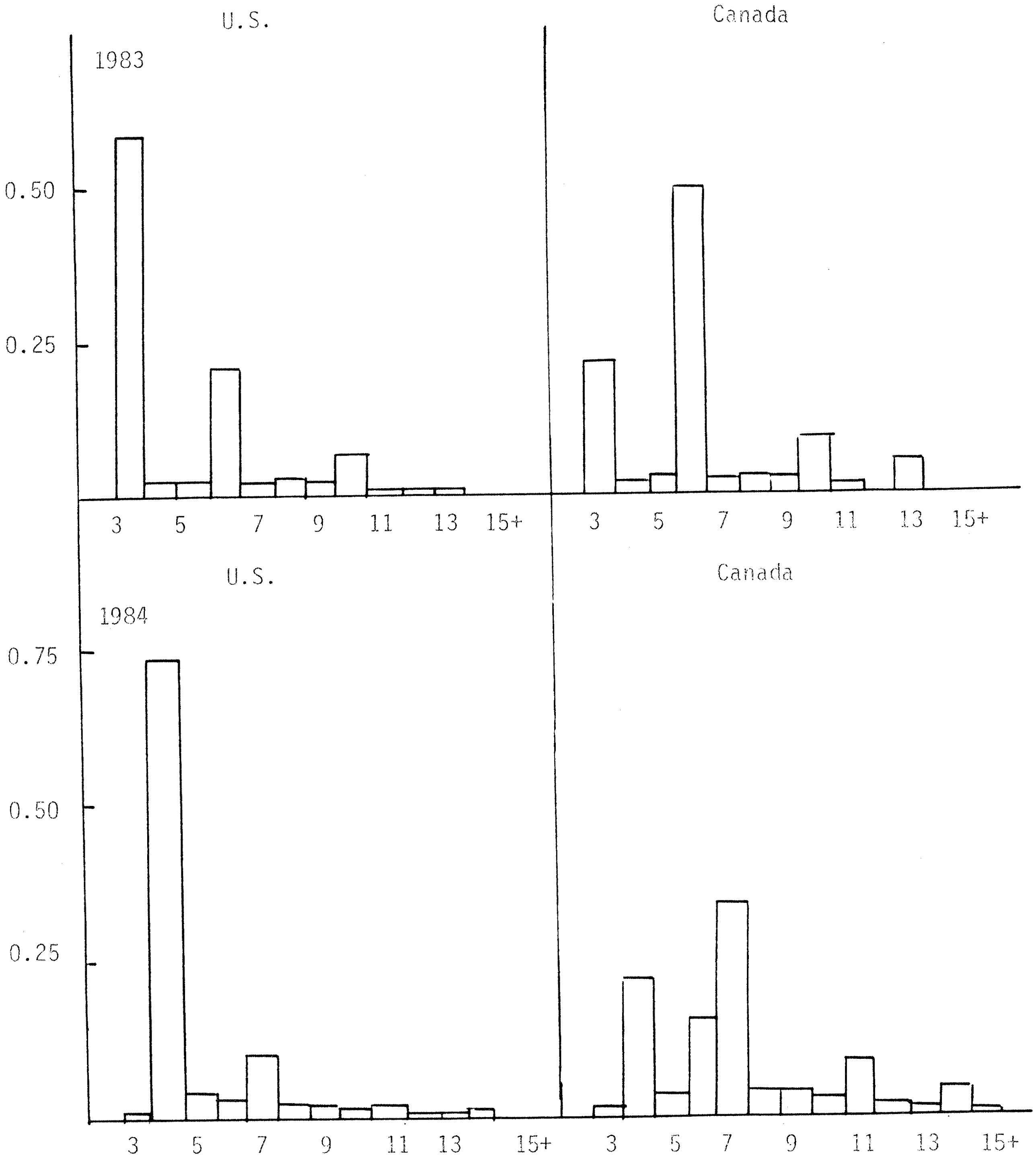


Figure 1. Relative age frequency of Pacific hake catches in U.S. and Canadian waters, 1983-1984.

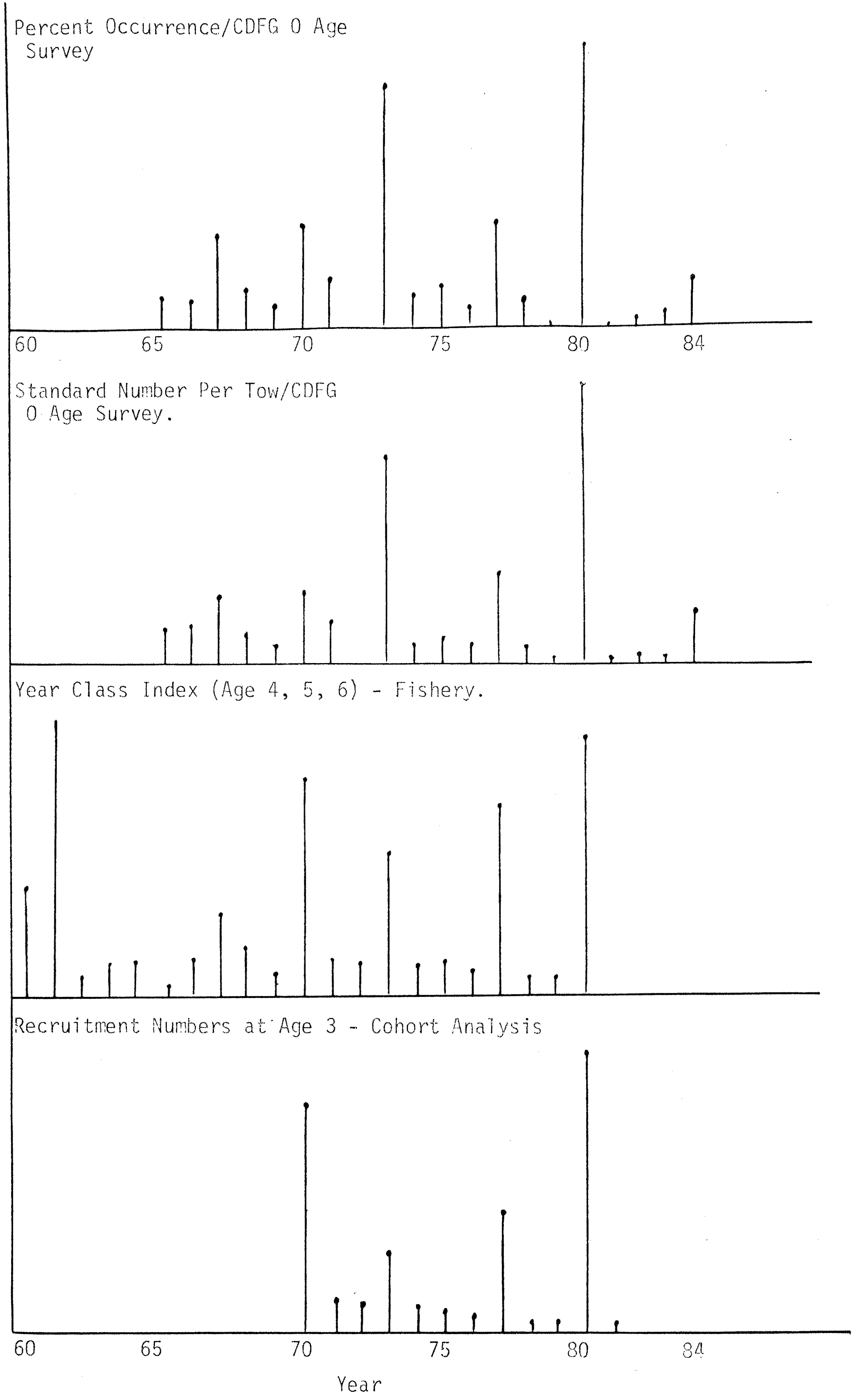


Figure 2. Indices of hake year class strength from 0 age surveys and the adult fishery.

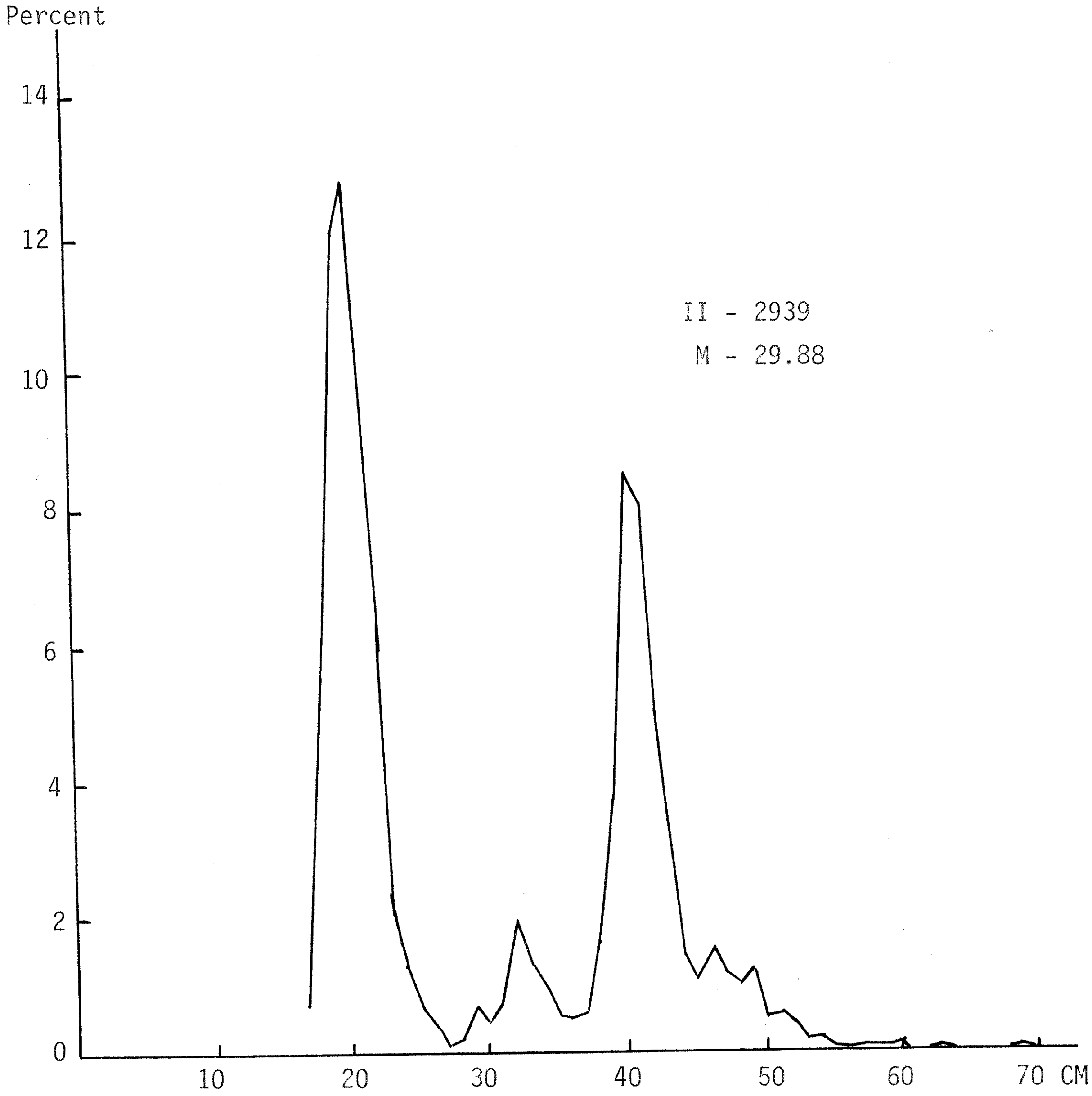


Figure 3. Length frequency of Pacific hake catch from Spring 1985 Soviet survey (Pt. Conception-San Francisco).

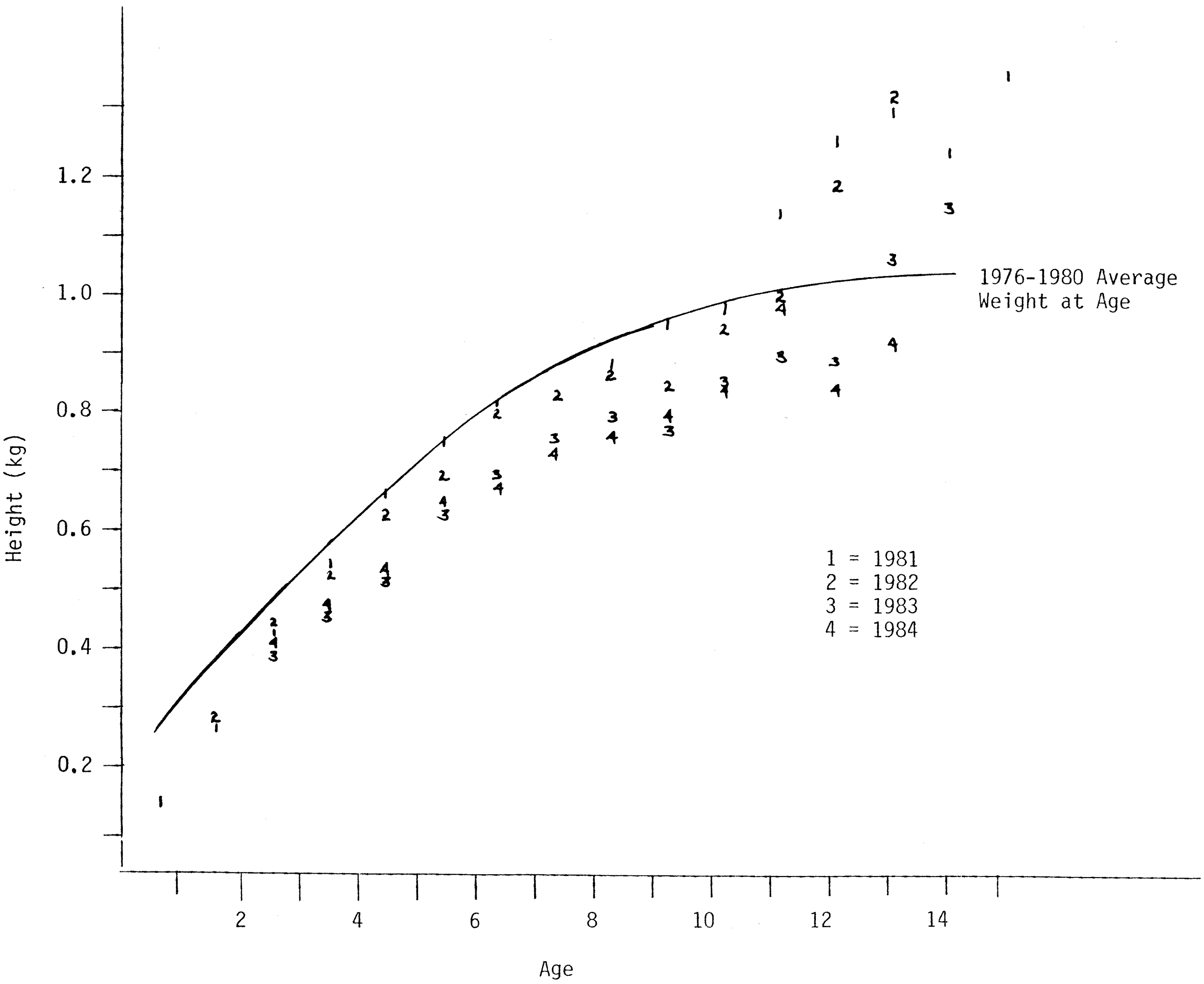
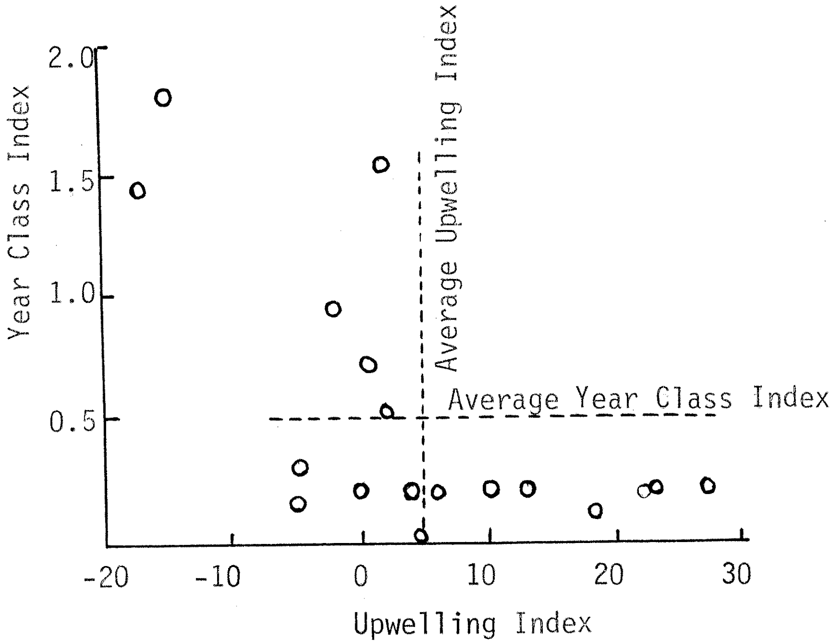


Figure 4. Pacific hake average weight (kg) at age from 1981-1984 U.S. fisheries.



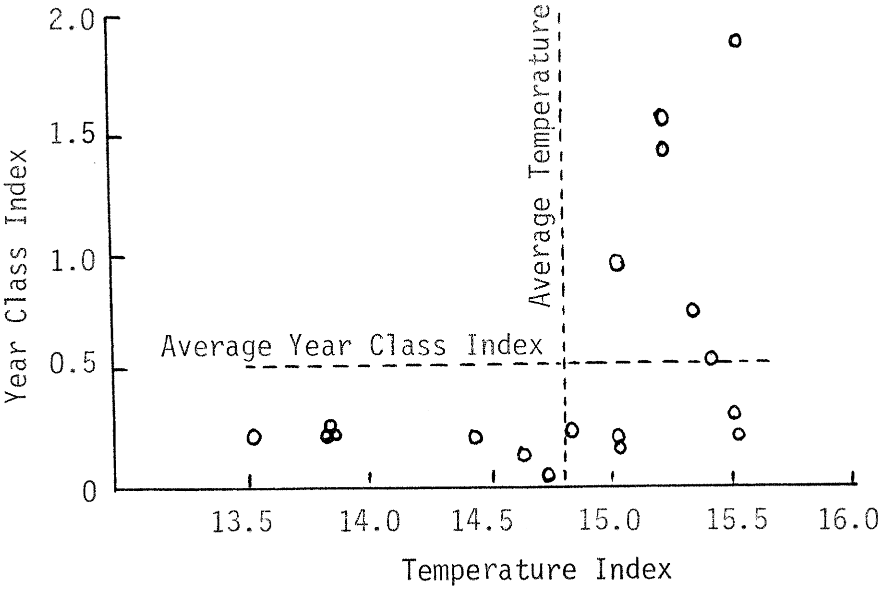


Figure 5. Pacific hake year class index (1970-1977) as related to upwelling and temperature indices at the time of spawning (36° N. latitude, January).

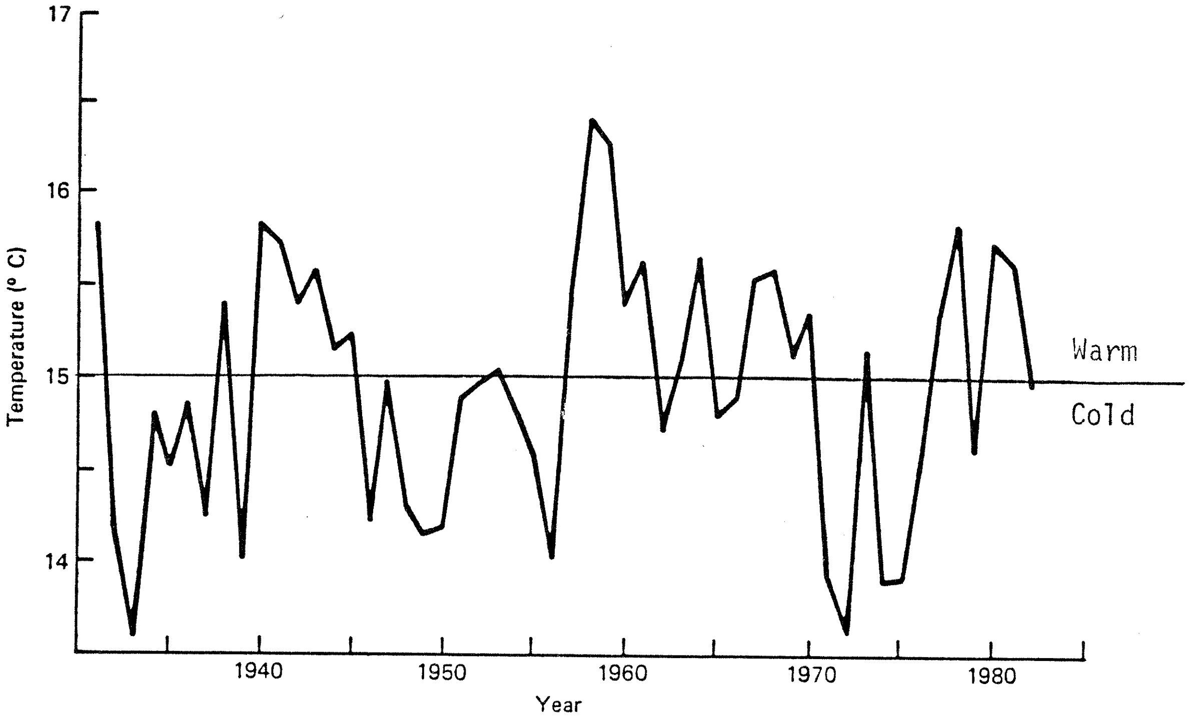


Figure 6. 1931-1982 mean January through March sea surface temperature (^{o}C) in Los Angeles Bight.

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