

RECENT CHANGES IN THE DISTRIBUTION OF HAKE LARVAE: CAUSES AND CONSEQUENCES

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ABSTRACT

In the mid-1960's hake larvae decreased in abundance off the coast of Baja California and increased off central California. The hypothesis that this shift resulted from intensive fishing pressure is difficult to test with the available data. A simulation model indicates that fishing is a likely explanation. Hake larvae in central California are distributed farther offshore compared to Baja California. The offshore distribution of larvae is correlated to indices of Ekman transport.

RESUMEN

A mediados de 1960 la abundancia de larvas de merluza disminuyó fuera de las costas de Baja California y aumentó frente a la zona central de California. La hipótesis de que este cambio se debía a la acción de una pesquería intensiva es difícil de probar con los datos disponibles. Un modelo simulado indica que la acción de la pesquería pudiera resultar una explicación probable. Las larvas de la merluza de California central están distribuidas más lejos de la costa que las de Baja California. Existe una correlación entre la distribución de larvas fuera de la costa y los índices de transporte Ekman.

INTRODUCTION

Starting in the mid-1960's and persisting through 1979, hake larvae became much less abundant off Baja California and more abundant off central California (Figure 1). An intensive hake fishery beginning in 1966 coincides with the redistribution of the larvae; an explanation related to environmental conditions seems unlikely since there is no evidence for a persistent change of temperature in the spawning region (Johnson et al. 1978). Environmental conditions differ between Baja and central California, and the shift in larval distribution could affect their survival and thus influence the pattern of recruitment.

Where and when hake spawn has been examined from the distribution of the smallest size class of larvae (2-3 mm) from the CalCOFI surveys. Spawning occurs primarily from January to March throughout the Los Angeles Bight and over the continental slope outside of the Bight region (Table 1). Prior to the mid-1960's the distribution of larvae was closely related to temperature (Figure 2). In cold years most larvae were spawned off Baja

California; however, larvae have been sparse in that area during recent cold years, including 1968, 1972, and 1975.

HYPOTHETICAL EFFECTS OF A FISHERY ON THE DISTRIBUTION OF LARVAE

Smith (1975) first related the change in larval hake distribution to the beginning of an intensive fishery in the Pacific Northwest. He hypothesized that the increasing cline in length of adult hake which is observed northward in summer (Alverson and Larkins 1969) reverses itself southward in winter and that large fish, now depleted by the fishery, once spawned farther south. Spawning in the northern end of the spawning range could be intensified due to advanced maturity of young fish after exploitation, as has been observed for other stocks. Spawning hake have been difficult to locate to test this hypothesis; however, a limited amount of support comes from three winter trawl surveys. Of four areas examined, the greatest proportion of large fish (greater than 55 cm) occurred in 1976 at 28-29°N. In the same year at 30-32°N, a smaller proportion of the large fish occurred. An alternative to the length cline explanation is that hake are multiple spawners (they have more than one mode of eggs in the ovaries; MacGregor 1966), and large fish are more likely to develop multiple broods. Thus, as spawning schools progress south, the percentage of eggs contributed by large fish increases because smaller adults are not developing further broods. A test of these two hypotheses may come in the next 1-3 years as the abundant 1973 year class becomes older; we may expect more spawning off Baja California in cold years than has recently been observed.

Assuming that large females are responsible for larvae located off Baja California, I have used a modified yield per recruit model (Gunderson 1977) to analyze the effect of a fishery on the age structure and theoretical distribution of eggs in a population. The variables are fishing mortality (F) and age of recruitment, varied by changing the vulnerability coefficient (V_i). The model calculates age-group fecundity,

$$E_i = N_i m_i, \text{ where } N_{i-1} \exp(-(V_{i-1}F + M)); \text{ mean biomass,}$$

$$B_i = ((N_i W_i)/(V_i F + M) (1 - \exp(-(V_i F + M))); \text{ and yield,}$$

$$Y_i = F V_i B_i$$

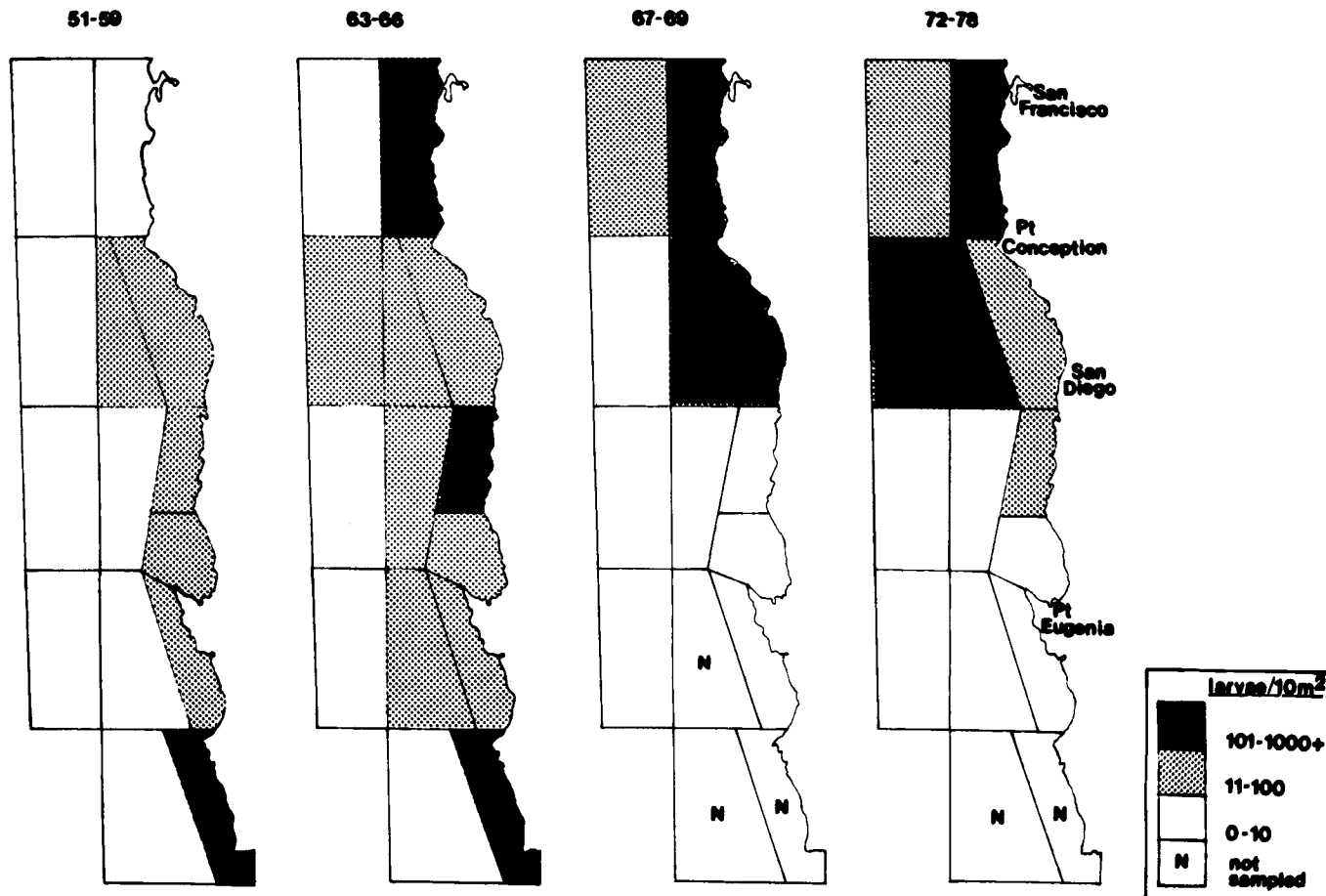


Figure 1. Historical changes in the distribution of Pacific hake larvae in January surveys.

TABLE 1
 The Distribution of Eggs and Larvae in Relation to the Continental Slope.¹

	Over slope		Not over slope (inshore or offshore)	
Larvae	37937	90.6	3922	9.4
Eggs	34639	92.7	2717	7.3

¹Analysis of eggs is from the January 1955 survey; analysis of larvae, 2.0-2.7 mm length, is from the 1963-69 surveys.

TABLE 2
 Catches of Large Mature Hake During the Spawning Season.

Survey	Latitudes °N	% Larger than 55 cm
Poseidon 1976	28-29	33
Cobb 1964	29-30	14
Poseidon 1976	30-32	12
Cobb 1965	32-33	12

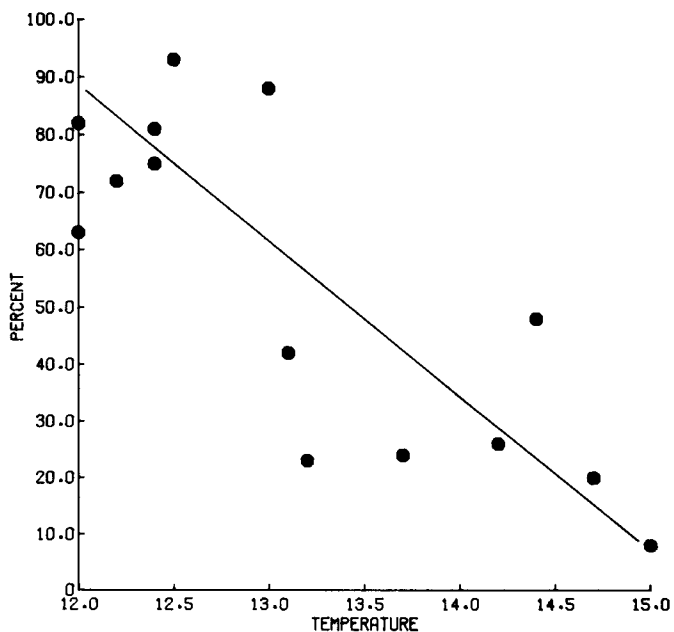


Figure 2. Percent of larvae south of CalCOFI line 100, as an index of the north-south distribution, versus the January temperature at 50 m in the Los Angeles Bight.

Average weight (W_i) and fecundity (m_i) for each age class (i) are estimated from Dark (1975) and MacGregor (1966). The natural mortality coefficient $M = 0.35$ was estimated as a middle value from a range of published values (Pacific Fishery Management Council 1979).

In the simulated virgin population ($F = 0.0$), 34% of eggs are spawned by fish greater than 55 cm. Making a simplifying assumption that large fish, 55 cm and greater, are spawning off Baja California, this number compares to the pre-fishery distribution of larvae, when 45% of hake larvae occurred off Baja California. After fishing pressure is applied, the proportion of eggs contributed by large adults declines (Figure 3). With $F = 0.40$, only 7% of all eggs are contributed by fish greater than 55 cm. At this moderate fishing intensity, which probably approximates the actual fishery (calculated from the catch equation with $M = 0.35$, average exploited biomass = 7×10^5 metric tons and the average yield = 2×10^5 metric tons), the abundance of eggs produced by large females greater than 55 cm decreases 87% from the virgin population. Assuming that these large fish were spawning off Baja California, this decrease in eggs compares closely to the actual observed 93% decrease in abundance of larvae off the coast of northern and central Baja California since 1967.

CONSEQUENCES

What effect might the redistribution of larvae have on recruitment? Transport of larvae from favorable juvenile nursery grounds could be one of the important factors establishing recruitment strength. Bakun's (1973) upwelling indices have been used here as an indirect measure of offshore advection. The three strongest year classes of hake in recent history, 1961, 1970, and 1973, were spawned in three Januaries of the strongest onshore transport in central California since 1950 (Bailey in preparation), suggesting that larvae transported far seaward of the continental shelf and slope may not find conditions suitable for survival as juveniles.

CalCOFI larval survey data from 1950-72 in the region between CalCOFI lines 70-80 were analyzed to see whether transport of larvae is also correlated to the upwelling indices. The mean distance of hake larvae offshore was calculated as $\Sigma(\text{Number} \times \text{Distance})/\Sigma \text{Number}$. Two very large catches (greater than 10,000 larva/10 m²) of the smallest size class of larvae were excluded from the calculations. The mean distance of larvae offshore in January and February surveys is positively correlated to the January upwelling index ($r = 0.70$, significant at the 99% confidence level, $n = 17$; Table 3, Figure 4). Furthermore, larvae in January 1961 and March 1970, which grew into strong year classes, were located relatively inshore compared to other years.

Does the change in the distribution of larvae affect

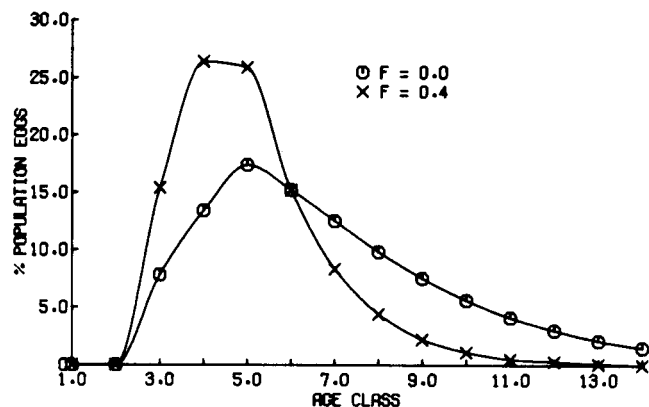


Figure 3. The theoretical percentage of eggs contributed by each age class in simulated populations for the current fishery and the virgin population.

TABLE 3
January-February and March Mean Distances of Larvae Offshore.¹

Year	Distance Jan.-Feb. lines 70-80	Distance Jan.-Feb. lines 107-17	March Distance lines 70-80	Jan. Upwell Index 36°N	Jan. Upwell Index 30°N
1950	124	33	118	35	60
1951	120	25	115	41	112
1952	nl	40	82	5	24
1953	81	53	96	11	56
1954	40	102	nl	14	77
1955	112	10	88	15	81
1956	40	64	100	3	72
1957	nl	8	95	4	20
1958	69	40	87	-4	105
1959	12	29	ns	12	99
1960	10	20	ns	1	45
1961	1	5	ns	-15	33
1963	39	38	ns	6	9
1964	34	38	ns	23	69
1965	3	24	ns	7	44
1966	53	19	ns	4	44
1968	22	ns	ns	-3	32
1969	33	37	ns	-3	8
1970	ns	ns	50	-17	33
1972	53	39	78	15	69
mean	50	35			
variance	1554	514			

ns = not sampled
nl = no larvae

¹Calculations used a 40 nautical-mile grid.

their transport offshore? Larvae averaged 15 miles farther offshore in the above northern region (CalCOFI lines 70-80, approximate Latitudes 35-36°N) than in a southern region (lines 107-117, approximately Latitudes 29-30°N) in years when both areas were surveyed (Table 3). Furthermore, the average width of the continental shelf is 20 miles in the northern region and 29 miles in the southern region; relatively, larvae are even farther from suitable nursery area in the north than in the south. Perhaps even more important, the variability in mean distance offshore between years is much greater in the northern region than in the southern region.

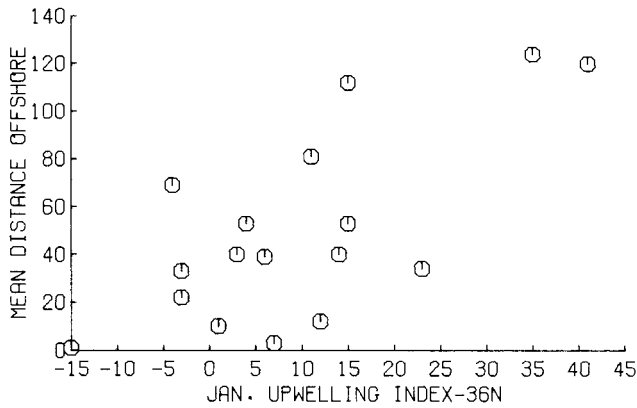


Figure 4. January upwelling index at 36°N versus the mean distance of larvae offshore in January-February surveys between CalCOFI lines 70-80.

In the southern region the mean distance of hake offshore is not correlated to a southern upwelling index (at 30°N, $r = 0.12$) or to the distance of larvae offshore in the north ($r = 0.08$). The region off Baja California, at least from Punta Baja to Punta Eugenia, is one where negative wind stress curl, associated with downwelling, extends from seaward to the coast (Bakun and Nelson 1977). As a result of downwelling, the thermocline is deepened in this region. The depth of hake eggs and larvae appears to be closely associated with the depth of the thermocline zone (Figure 5), thus when the thermocline is deep, as off Baja California, eggs and larvae are below the Ekman layer and are protected from transport offshore.

Larvae in central California appear to be more affected by wind stress transport than are larvae off Baja California. Because relatively more larvae are now spawned in the north than previously, recruitment of hake may be more variable due to an increased dependence of year-class strength on an environmental variable, i.e. wind stress. However, the change in the distribution of larvae has not affected the ability of the hake population to spawn strong year classes, as evidenced in 1970 and 1973. Intensive fishing pressure increases a stock's sensitivity to environmental conditions. Low-fecundity species may respond eventually to this increased sensitivity by stock collapse (Smith 1978). How an increase in sensitivity to environmental conditions, i.e. recruitment variability, may affect the production of high-fecundity stocks, such as hake, is at present unknown and is probably best approached as a question by simulation studies.

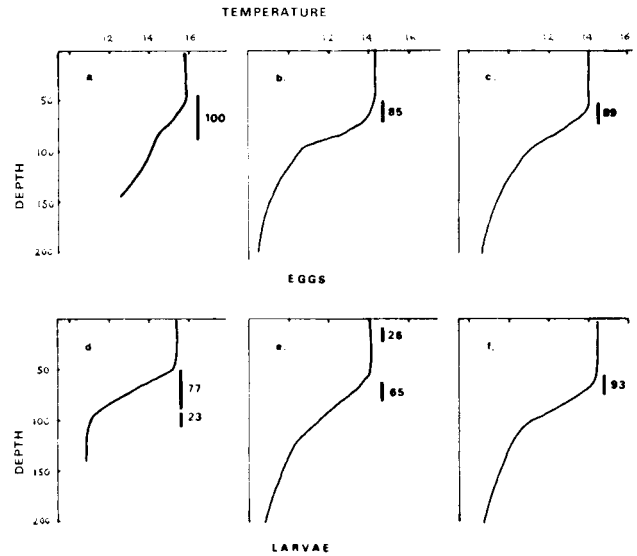


Figure 5. The vertical distribution of hake eggs and larvae less than 5-mm length compared to the temperature profile. Numbers beside bars are the percent found within that depth interval: a) Cruise 5504, Station 107.80, $n = 15$; b) 5403, 94.80N, $n = 102$; c) 5403, 94.80D, $n = 99$; d) 5504, 120.50, $n = 35$; e) 5403, 94.80D, $n = 687$; f) 5403, 94.80N, $n = 1656$.

CONCLUSIONS

A shift in the distribution of hake larvae coincides with the beginning of an intensive fishery for large adults off the Oregon-Washington coast. No evidence currently exists to indicate that changes in the ocean environment are connected to the redistribution. A simple model of the hake fishery suggests that fishing pressure can explain the redistribution of larvae if large adults are mostly responsible for spawning in the southern end of the range. More information on spawning adults is necessary to critically examine this hypothesis. This data has been unavailable in the past due to difficulty in locating schools of spawning hake; however, with recent findings on where and when hake spawn, future surveys may be more successful.

Correlations between indices of Ekman transport, larval distribution, and adult year-class strength suggest that advection of larvae offshore may be an important influence on recruitment. Larvae in the northern end of the hake spawning range appear to be more vulnerable to transport offshore than in the southern end of the range. Consequently, a shift in the distribution of larvae towards the north, under the influence of the fishery, could increase the dependence of year-class strength on favorable advection.

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