SOME EFFECTS OF EL NIÑO 1983 ON THE NORTHERN ANCHOVY

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ABSTRACT

A major California El Niño began in late 1982, bringing unusually large positive anomalies in sea-surface temperature and sea-level height. Analysis of historical records reveals a weak positive relationship between northern anchovy population growth and interannual variations in these parameters, except in the second year of major El Niño events. 1983 spawning activity was marked by an extended spawning range, dominance of small, year-old females, and faster egg maturation caused by warm water. El Niño 1983 appears to have been unfavorable for the growth of larvae, juveniles, and adults, possibly because of reduced food availability.

RESUMEN

A finales de 1982 se inició en California un fenómeno similar a El Niño, el cual originó altas anomalías positivas en las temperaturas superficiales y en el nivel del mar. El análisis de los datos históricos señala una débil relación positiva entre el incremento de la población de la anchoveta del norte, *Engraulis mordax*, y las variaciones interanuales en esos parámetros, excepto durante el segundo año de aquellos El Niño de mayor intensidad. La actividad de puesta de la anchoveta durante 1983 se caracterizó por cubrir un área más extensa, la dominancia de hembras pequeñas, de un año, y la rápida madurez de los óvulos ocasionada por la influencia de las aquas cálidas. El Niño de 1983 resultó al paracer desfavorable para el crecimiento de larvas, juveniles y adultos, debido posiblemente a una escasez de alimento.

INTRODUCTION

El Niño events have contributed to catastrophic declines in populations of seabirds and pelagic fish in the normally highly productive coastal upwelling system off Peru (Idyll 1973). An unusually strong El Niño began to affect the eastern tropical Pacific in mid-1982 (Cane 1983). Sea-surface temperature anomalies greater than +2°C were observed off California beginning in November (Auer 1982). During peak northern anchovy spawning in January-April 1983, very unusual oceanographic conditions prevailed off southern California: sea-surface temperatures were up to 3°C warmer than normal; the mixed-layer depth increased by 50 m; and unprecedented sea-level heights were recorded (Simpson 1983, Lynn 1983). This paper is a brief discussion of some consequences of El Niño for the anchovy central subpopulation between Point Conception, California, and Punta Baja, Baja California.

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HISTORICAL RELATIONSHIP BETWEEN ANCHOVY AND EL NIÑO

One of the best biological time series available to relate to interannual oceanographic variability off California was recently developed by MacCall and Methot (1983, Table 3-1 therein). This 1951-82 series of annual estimates of anchovy central subpopulation spawning biomass was constructed from four separate data sets: (1) CalCOFI ichthyoplankton surveys, (2) California Department of Fish and Game acoustic surveys, (3) commercial aerial spotter logbooks, and (4) CalCOFI egg production method surveys. MacCall (MacCall and Methot 1983) fit the following population growth model to this time series:

$$B_{t+1} = aB_t^b - \delta C_t + r_t$$

where B_t is spawning biomass in year t,
C_t is total catch discounted by a factor δ,
r_t is a random error term including both measurement error and the effects of environmental anomalies,
a and b are constants.

The term δC_t represents spawners that would have survived natural mortality had they not been caught by the fishery. Parameters a and b can be related to more meaningful parameters—maximum net productivity (MNP) and the spawning biomass at which MNP occurs (BMNP)—as follows:

$$\text{MNP} = \max(aB^b - B)$$

$$\text{BMNP} = (ab)^{1/(1-b)}$$

If the model describes the *true* influence of the population on itself, then r_t would be the added effect of the environment. I solved the above equation for $ln(r_t)$, t = 1954 to 1982, using the log-transformed

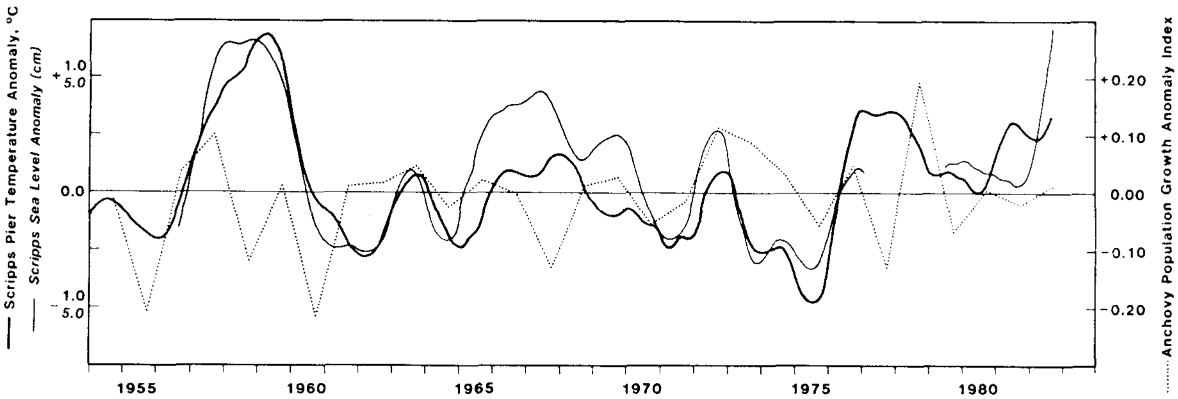

Figure 1. Time series of yearly anchovy population growth anomaly index and monthly anomalies of surface temperature and sea level at Scripps Pier.

biomass time series and MacCall's parameter values ($a = 7.164$, $b = 0.742$, $\delta = 0.82$). The anchovy population growth anomaly index, $ln(r_t)/ln(aB_t^b)$, represents the relative deviation of annual recruitment and adult survival from what would be expected for a stock of a given size. I assume it reflects influences of interannual environmental changes, compounded by errors in the biomass estimates.

Interannual variability in the California Current is closely associated with El Niño (Chelton et al. 1982). Time series of anomalies of monthly mean surface temperature[1] and sea level[2] at Scripps Pier in La Jolla were used as indicators of environmental variability off southern California. Both series were smoothed twice by a 13-month running mean, which serves as a low-pass filter to isolate interannual variability. Coastal sea level is strongly related to seasonal and interannual variations in geostrophic flow of the California Current, with high sea levels corresponding to anomalous northward flow (Chelton et al. 1982). A linear trend of $+0.21$ cm yr^{-1} was removed from the sea-level data.

The monthly records of surface temperature and sea level are strongly correlated, although there was a notable exception to this relationship in 1981 (Figure 1). The maximum correlation ($r = +0.85$, $P << .001$) occurs when the sea-level record is lagged by one month. In comparison, Enfield and Allen (1980) found that temperature lagged sea level by 2-6 months, at interannual frequencies, in an analysis of 1950-74 records from four California shore stations. I used the smoothed Scripps Pier temperature record as an index of environmental variability associated with El Niño. Changes at La Jolla, however, may not always represent changes over the entire range of the central subpopulation.

There is no significant correlation between anomalies in anchovy population growth and surface temperature ($r = +0.04$ using December surface temperature values). However, there are large negative population growth anomalies associated with the 1957-59, 1966-68, and 1976-78 California El Niño events. The two largest anomalies, in 1955 and 1960, occur during cold or cooling years before and after the 1957-59 event. A more interesting pattern emerges when the large anomalies in 1958, 1967, and 1977 are considered: the anchovy population growth anomaly index drops well below zero in the second year of each of the three multiyear warm events observed prior to 1980.

If 1958, 1967, and 1977 are excluded from the time series, a weak positive correlation between anomalies in anchovy population growth and temperature is observed ($r = +0.32$, $0.10 > p > 0.05$). This implies that the relationship is nonlinear: i.e., relatively warm or warming years tend to be favorable for population growth, but prolonged warming is unfavorable.

SPAWNING ANOMALIES IN 1983

Spawning activity has been monitored once or twice yearly since 1980 by month-long CalCOFI egg and trawl surveys during the height of the spawning season (February-April). The 1983 spawning range, indicated by the distribution of first-day eggs, extended beyond Point Conception at the northwest edge of the Southern California Bight (Figure 2). In contrast, spawning during 1980-82 was apparently excluded from this region by a plume of cold California Current water to the south of Point Conception (Lasker et al. 1981; Fiedler 1983). The February 21, 1981, satellite image

[1]E. Stewart, Scripps Institution of Oceanography.
[2]D. Brown, Scripps Institution of Oceanography.

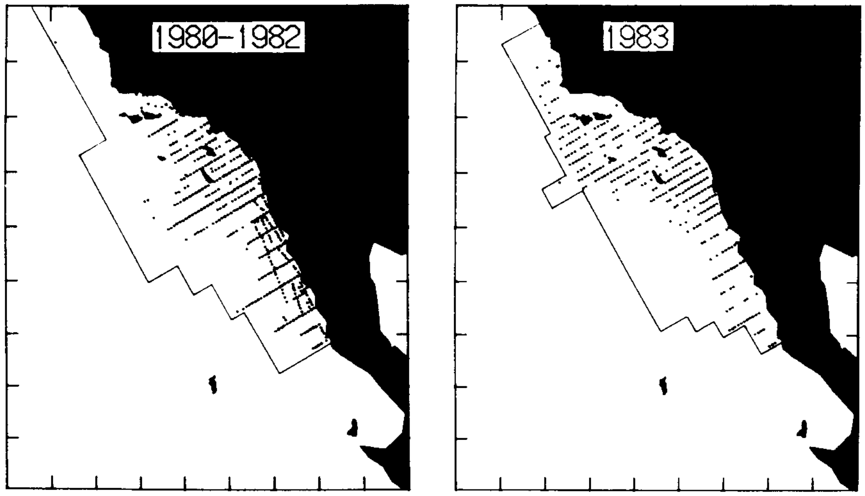

Figure 2. Distribution of CalVET tows with first-day eggs on CalCOFI cruises: *left*, 8003, 8102, and 8202; *right*, 8302. Boundaries mark limit of sampling effort.

in Figure 3a shows the influence of this cold-water boundary (the six lines of stations south of Point Conception were occupied on February 15-20). The boundary corresponded approximately to the 14°C isotherm.

Sea-surface temperatures (SSTs) off southern California were 1°-3°C warmer than the 1942-69 means during the first few months of 1983 (Auer 1983). Figure 3b illustrates the unusual SST pattern present in the Southern California Bight during CalCOFI cruise 8302: there was no cold-water plume south of Point Conception. In fact, the 14°C isotherm remained north of Morro Bay at lat. 35°20′N from February until the middle of March, when it moved south to Point Conception[3]. No SSTs colder than 14°C were measured on this cruise, although the warmest temperatures did not exceed the extreme of 17.7°C recorded on cruise 8003

[3]Weekly GOSSTCOMP sea-surface temperature maps distributed by NOAA, National Environmental Satellite Data and Information Service, Washington, D.C.

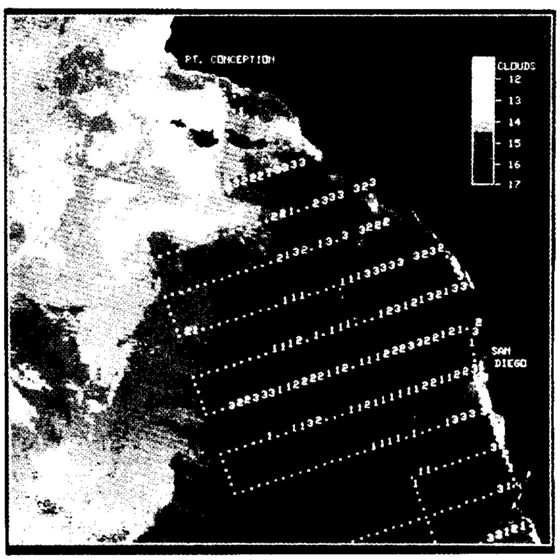

Figure 3a. CalCOFI 8102 A-day anchovy egg distribution, February 12-March 10, 1981. · = 0, 1 = 1 – 4, 2 = 5 – 15, 3 = 16 – 157 eggs/0.05 m². Sea-surface temperature from NOAA-6 AVHRR, channel 4, February 21, 1981.

Figure 3b. CalCOFI 8302 A-day anchovy egg distribution, February 9-March 29, 1983. · = 0, 1 = 1 – 3, 2 = 4 – 12, 3 = 13 – 229 eggs/0.05 m². Sea-surface temperature from NOAA-7 AVHRR, channels 4 and 5, March 15, 1983.

TABLE 1
Egg Production Estimates of Anchovy Spawning Parameters

	1980[a]	1981[a]	1982[a]	1983[b]
Spawning biomass ($x10^3$ metric tons)	870	635	415	625
Average female weight (g)	17.4	13.4	18.8	11.2
Sex ratio by weight (females/total)	0.48	0.50	0.47	0.55
Spawning frequency of mature females (1/day)	0.14	0.11	0.12	0.09
Batch fecundity (eggs/batch)	7750	8330	10840	5300
Population production of spawned eggs ($x10^{12}$ eggs/day)	26.3	21.0	13.5	17.2
Incubation period (days)	2.71	2.75	2.91	2.56
Egg mortality rate (1/day)	0.45	0.14	0.16	0.18
Population production of hatching eggs ($x10^{12}$ eggs/day)	7.7	14.3	8.5	10.8

[a]Picquelle and Hewitt (1983). Original estimates of egg production and spawning biomass were elevated by a factor of 1/0.91 to correct for 91% retention of eggs by nets on 1980-82 surveys (R. Hewitt, NMFS/Southwest Fisheries Center, pers. comm.).
[b]Picquelle and Hewitt (1984).

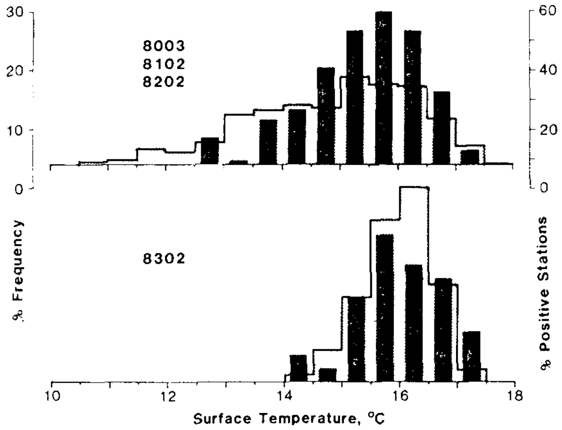

Figure 4. Frequency distributions of CalCOFI stations by surface temperature (stippled), with frequency of positive A-day anchovy egg catches within each temperature interval (solid bars), for 1980-82 (3 cruises, 2036 stations) and 1983 (850 stations).

(Figure 4). Spawning success, measured by frequency of positive egg stations in a temperature interval, was shifted slightly to warmer temperatures in 1983. Several factors associated with El Niño contributed to changes in the SST field off southern California at this time: diminished wind-driven flow of the California Current (Simpson 1983), an anomalously strong poleward countercurrent (Lynn 1983), and weakened coastal upwelling. Monthly upwelling indices between lat. 30° and 36°N averaged 70% (range 8%-309%) below the 1948-69 means during January-April 1983.[4]

Several 1983 spawning parameters appear to have been anomalous (Table 1), although the limited history of egg production surveys, beginning in 1980, precludes statistical evaluation of departures from "normal." Estimated spawning biomass increased for the first time since 1979. However, females were young and of low body weight, resulting in subnormal spawning frequency and fecundity. A slightly increased egg maturation rate, probably related to warmer water temperatures, was not sufficient to reduce egg mortality to less than normal. El Niño seems to have had no net effect on the total production of hatching eggs in 1983.

GROWTH AND SURVIVAL DURING EL NIÑO

Three environmental processes have received much attention as potential regulators of recruitment of pelagic fish and, in particular, northern anchovy. Fluctuations in primary productivity associated with upwelling are important in the California Current as in other major upwelling regions (Bakun and Parrish 1980). Availability of appropriate food organisms in dense, subsurface layers is critical for survival of first-feeding anchovy larvae (Lasker 1978). Finally, offshore transport of larvae by wind-induced Ekman flow may be especially important where seasonally strong flow occurs over a narrow continental shelf, as in central and northern California (Parrish et al. 1981). We know less about factors affecting the survival of juvenile anchovy, after metamorphosis at the age of ~50 days, but it is likely that food availability continues to be important. Unusual conditions off southern California during the first few months of 1983 may have affected food availability:

1. Coastal upwelling was weak from January through April.
2. The thermocline was up to 50 m deeper than the long-term mean (Simpson 1983). The chlorophyll maximum layer, which often indicates a subsurface accumulation of phytoplankton, was also 10 to 50 m deeper than normal (McGowan 1983).
3. Phytoplankton pigment levels estimated from satellite data were relatively low in March (Fiedler,

[4]Monthly analyses of North Pacific wind-driven surface transport, from surface marine weather observations, distributed by NMFS/Pacific Environmental Group, Monterey, California 93942. See also Bakun (1973).

1984). Vertically integrated chlorophyll concentrations along CalCOFI line 90 steadily declined from March to August, when they were about one-quarter the normal value. (J. A. McGowan, Scripps Institution of Oceanography, pers. comm.).
4. The coast was hit by violent storms in late January and in late February and early March because of an equatorward shift of the normal storm track.

This evidence, although indirect, indicates reduced phytoplankton productivity in the spawning habitat of the northern anchovy. Turbulent mixing by the winter storms could have dispersed any near-surface layers of phytoplankton that would normally support first-feeding larvae.

The California Department of Fish and Game has conducted trawl surveys of pelagic fish off California and Baja California since 1966. Preliminary data are available from two surveys in late 1983: September 23-October 12 from Blanca Bay (lat. 28°50′N) to Point Conception; and November 2-21 in the Southern California Bight[5]. The catch rate for 1983 year-class anchovy was not unusual: among eight annual surveys since 1976, the 1983 rate ranked fourth by weight and third by number of fish. However, these fish were remarkably small, with a mode of 65-75 mm, compared to 85-95 mm for young-of-the-year in 1976-82.

Adult fish were also abnormally small, with a mode of 100-105 mm, compared to an expected 115-120 mm. Yet these fish were still much larger than southern subpopulation fish (south of lat. 29°N), which averaged 87 mm in 1966-73, with only 10% exceeding 106 mm (Mais 1974). The small size of central subpopulation anchovy in 1983 cannot be explained simply by transport or migration of smaller southern subpopulation fish: very few or no anchovies were caught south of Punta Baja (lat. 30°N) on the trawl surveys. The anomaly more likely reflects reduced growth during El Niño 1983. The 1982 year-class fish appeared to have grown by only 10 mm since a survey in February 1983, compared to a normal growth increment of 15 mm for year-old fish from February to November (Mallicoate and Parrish 1981).

CONCLUSIONS

Anchovy population growth since 1954 has shown a weak positive correlation with interannual sea-surface temperature variations. This relationship has broken down, however, in the second year of major California El Niño events in 1957-59, 1966-68, and 1976-78. The 1983 California El Niño brought large and, in some cases, unprecedented oceanographic anomalies beginning just before the peak northern anchovy spawning season. Several aspects of 1983 spawning were unusual: an extended spawning range, relatively young and small-sized spawners, and rapid egg maturation. The resultant production of hatching eggs was not unusually large or small, and no marked effect on the size of the 1983 year class could be detected by the end of the year. However, both juveniles and adults appeared to be abnormally small, possibly because of reduced food availability throughout the year.

As 1983 ended, the consensus of meteorologists and oceanographers was that El Niño was well into its final, decay phase at the equator (Rasmusson and Wallace 1983; Cane 1983). However, the California El Niño lingered: sea-surface temperature anomalies > 1°C and subsurface anomalies > 2°C were observed up to 400 km offshore between Point Reyes and Santa Monica on CalCOFI cruise 8401 (R. Lynn, NMFS/Southwest Fisheries Center, pers. comm.; see also Auer 1984). The ultimate effect of the 1983 California El Niño may yet be manifested in the size of the 1984 year class of northern anchovy.

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