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A Case History of an Anti-El Niño to El Niño Transition on Plankton and Nekton Distribution and Abundances

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Introduction

The management of coastal pelagic schooling fishes is complicated by vast changes in recruitment and availability. While an El Niño event can be a tragic economic event in the history of a fishery, it can also be a natural experiment for biological oceanographic monitoring to gather important dynamic information. The motivation and funding to monitor an event like "El Niño" usually arrives after the onset is well in place (McGowan, 1984). To find a time when, by chance, the onset of an El Niño was well monitored, we must return to the 1955-9 event.

While there seems little doubt of the magnitude of the 1983-84 El Niño event, the anchovy population continued to spawn eggs at the same rate in 1983-4 as in 1980-2 (Fiedler, et al., MS) (Table 1). Although the process of spawning is energy intensive (Hunter and Leong, 1981), spawning continued as the apparent production of the anchovy habitat declined (McGowan, 1984; Fiedler, 1984). Local catches were also reduced for the coastal pelagic and continental shelf fishes and increased for tropical and temperate tunas as expected for these oceanic conditions (Table 2). The comparable increase of tropical fish catch in 1957 compared to the average of the previous five years was barracuda 2.4 x, yellowtail 4.6 x, bonito 5.6 x, yellowfin tuna 18.8 x skipjack tuna 82.3 x, and dolphinfish 876.6 x, for only the first nine months of the year. Young sardine were noted in the live anchovy bait catch along the entire coast from San Diego to Monterey Bay for the first time in years. (Anon. 1958).

Reexamination of a Case History

The 1957-9 El Niño was discussed in the "Rancho Santa Fe Symposium". The report of that meeting, and particularly the personal contacts between quantitative and theoretical meteorologists and oceanographers, launched the discipline of "air-sea} interaction (Sette and Isaacs, 1960). A biological study of great magnitude (3,461 plankton observations on 20

Table 1. Northern anchovy (*Engraulis mordax*) central population reproduction parameters.

PART A Cruise	Spawning area (Sq. mi.)	Spawning biomass '000 t	Spawning biomass g/m^2	Mortality rate z	Mortality rate %/d
Mar. 1980	19000	870	13	.453	36
Feb. 1981	23000	635	8	.138	13
Apr. 1981	17000	372	6	nil	nil
Feb. 1982	24000	415	5	.158	15
Feb. 1983	28000*	652	7	.184	17
Mar. 1984	18000	309	5	.170	16

PART B Cruise	Female weight g	Specific fecundity m-eggs/d/t	Mean interval days
Mar. 1980	17	30	7
Feb. 1981	13	33	9
Apr. 1981	16	34	8
Feb. 1982	19	33	8
Feb. 1983	11	24	11
Mar. 1984	12	42	6

*About half the area of the state of Washington.

cruises quarterly for five years separated into 18 taxonomic groups) was begun as a result of that climatic change (CalCOFI atlases by Isaacs, Fleminger and Miller, 1969; Isaacs, Fleminger and Miller, 1971; and Fleminger, Isaacs and Wyllie, 1974) and a principle components analysis was reported by Colebrook (19777).

I have divided the fishes of the CalCOFI region into those which occupy an area larger than the CalCOFI survey; those which inhabit the coastal currents of the eastern boundary; and those which are mostly confined to the continental shelf. Most of the fish we have studied are planktivorous so I have included a brief section on plankton. In the "High Seas" category, I have included the tunas, the jack mackerel, the saury, and the mesopelagic fishes. In the fishes of the coastal currents, I have included anchovy, sardine, and Pacific mackerel. The flatfishes and rockfishes are considered under the heading "continental shelf" fishes. Hake are included as continental shelf fishes for the purpose of this paper because that is where most of the feeding takes place (Bailey, et al., 1982). The primary reason for dividing the fishes into these categories is to more precisely interpret the effects of El Niño.

Table 2. Commercial landings from California waters.

Species	1982 Rank	1982 Weight	1982 Value	1983 Rank	1983 Weight	1983 Value	Weight ratio
Coastal Pelagics		117.5	18.8		59.1	12.8	0.50
Mackerel	1	54.9	10.1	1	48.8	9.1	0.89
Market squid	4	16.3	3.6	14	1.4	0.6	0.09
Northern anchovy	2	42.1	1.9	10	4.1	0.4	0.10
Pacific bonito	15	2.1	1.0	12	3.2	1.3	1.52
Pacific hake	21	1.0	0.2	17	1.0	0.2	1.00
Thresher shark	20	1.1	2.0	20	0.6	1.2	0.55
Shelf & Slope		76.8	67.1		54.5	43.8	0.71
Chinook salmon	11	3.3	18.8	25	0.4	1.8	0.12
Dover sole	6	10.0	5.1	5	8.4	4.1	0.84
Dungeness crab	12	3.0	7.2	18	0.9	3.1	0.30
English sole	18	1.4	1.0	15	1.2	0.8	0.86
Lingcod	19	1.4	0.7	19	0.8	0.5	0.57
Pacific herring	5	10.3	9.7	6	8.0	12.5	0.78
Petrale sole	22	0.8	1.0	23	0.6	0.8	0.75
Rex sole	25	0.7	0.5	21	0.6	0.5	0.86
Rock crab	unrank	-	-	22	0.6	1.1	+
Rockfish	3	21.8	10.6	4	14.0	8.6	0.64
Rockfish (b-c*)	14	2.3	1.0	11	3.5	1.8	1.52
Rockfish (t*)	16	2.0	1.0	13	1.7	0.8	0.85
Sablefish	7	9.5	5.2	8	6.1	3.2	0.64
Sea urchin	8	8.3	3.1	7	7.2	3.3	0.87
Shrimp (po*)	17	2.0	2.2	24	0.5	0.9	0.25
Temperate Tuna		3.4	4.7		4.5	5.7	1.67
Albacore tuna	13	2.7	3.9	9	4.5	5.7	1.67
Bluefin tuna	24	0.7	0.8	unrank	-	-	-
Tropical tuna		9.7	14.8		37.7	39.9	3.89
Skipjack tuna	10	3.9	3.7	2	18.8	15.3	4.82
Swordfish	23	0.8	5.1	16	1.0	5.7	1.25
Yellowfin tuna	9	5.0	6.0	3	17.9	18.9	3.58

Weight is in thousands of metric tons.
Value is in millions of dollars to the fishermen.
Mackerel is Pacific mackerel and jack mackerel combined.
b-c bocaccio and chilipepper rockfish.
po Pacific Ocean shrimp.
t thornyhead rockfish.

Nekton

High seas

<u>Bluefin tuna</u>. Yamanaka (1984) noted an inverse correlation between the catch rate of young bluefin tuna (*Thunnus thynnus*) off Japan and the United States. In particular there appeared to be a

Table 3. Crude composition of zooplankton in the upper 140 m of the California Current

Functional group	1956 Rank	1956 Weight	1958 Rank	1958 Weight	Weight Ratio	Change	%
Copepoda	2	27.9	1	14.2	0.51	-13.7	12
Chaetognatha	4	6.3	2	4.4	0.70	-1.9	2
Siphonophora	5	6.1	3	3.6	0.59	-2.5	2
Thaliacea	1	91.4	4	3.3	0.04	-88.1	74
Euphausiacea	3	7.1	5	3.2	0.45	-3.9	3
Medusae	6	3.1	6	1.2	0.39	-1.9	2
Decapoda	10	1.2	7	0.6	0.50	-0.6	
Pteropoda	14	0.3	8	0.6	2.00	0.3	
Radiolaria	9	1.4	9	0.4	0.29	-1.0	
Crustacean larvae	12	0.8	10	0.3	0.38	-0.5	
Amphipoda	7	1.8	11	0.2	0.11	-1.6	1
Larvacea	11	0.9	12	0.2	0.22	-0.7	
Ostracoda	13	0.4	13	0.2	0.50	-0.2	
Ctenophora	8	1.5	14	0.2	0.13	-1.3	1
Cladocera	17	0.02	15	0.2	10.00	0.18	
Heteropoda	15	0.1	16	0.1	1.00	=	
Mysidacea	16	0.03	17	0.01	0.33	-0.02	
TOTAL		150.35		32.91	0.22	-117.44	100

Weight is in grams per 1000 cubic meters to 140 meters depth.
Change is the difference in grams between 1956 and 1958.
% is the category change as a percent of sum of categories change.

low rate of return of juveniles to Japan during the El Niño periods. He postulated that during the El Niño more juvenile bluefin migrated to the Pacific coast of America than usual and then those fish migrated to the southern hemisphere off Chile. He also pointed out that the Japanese sardine migrated out to the albacore tuna fishing grounds during the recent El Niño.

Albacore tuna. Like the bluefin tuna, some albacore are trans-Pacific migrants in the temperate zone. The 1957-8 El Niño was associated with inverse trends in the California sport boat and Canadian jigboat catches; between 1955 and 1959 the annual catches of the sport boats was 577, 482, 304, 48, and nil tons, the Canadian jigboats nil, 17, 8, 74, and 212 tons (Laurs 1983). It is now thought that local water clarity may play a large role in determining the feeding migration patterns (Fiedler, Laurs and Montgomery, MS) of albacore and the catch by different method. Changes in prey distribution, vertical and geographic, and local temperature gradients must also have an effect on fishing success on albacore and the distribution of all the oceanic properties is altered by El Niño.

Tropical scombroids. Major predators from the tropics inhabit California Current waters warmer than 20°C. This includes skipjack, bigeye, and yellowfin tunas and the billfish (*Katsuwonus pelamis*, *Thunnus obesus*, *Thunnus albacares*, *Makaira indica*, and

Xiphias gladius). The northerly extent of these species appears to be limited by surface temperature. Blackburn (1965) found that the existence of a suitable temperature was not always accompanied by the presence of tropical predators. Schaeffer (1960) considered the chief cause of the occurrence of tropical tunas off California to be active migration during warm conditions because the warming at that time was due to heat exchange rather than advection of warm water.

Jack mackerel. The abundance of larvae of jack mackerel declined from an area averaged 2 per square meter in 1950-1957 to fewer than 0.3 per square meter between 1958 and 1960 (MacCall and Stauffer, 19883). The relative recruitment strength of the stock in 1958 was 2 times that in 1959 and 1960. It is obvious that the abundance of larvae of this species is not effective as an index of spawning biomass but is instead responsive to several environmental influences. Since the outer and northern range of spawning is not normally encompassed by the larval surveys, the variation may signal changes in the degree of overlap of the survey area and the spawning area. The change of temperature, alone, is probably incapable of exerting more than a two-fold influence on development rate, thus the 5-7 fold change is probably indicative of a change in fecundity rather than a change in spawning biomass. During the radical change between 1957 and 1958, the primary difference appeared to be the number of samples with large numbers of larvae, suggesting a change in reproductive per capita output (Ahlstrom, 1969). Cursory examination of the larval mortality rate between 3 and 11 mm does not reveal an obvious change between 1957 and 1959 but this constancy could be confounded with an abnormal growth rate.

It is not clear whether jack mackerel changes its distribution in relation to temperature directly to its temperature-related food. The food of another jack mackerel species in a similar current system off the Pacific coast of South America, (Konchina, 1983) consists of primarily Euphausiids (54%), fish (20%), decapods (12%), copepods (7%), and cephalopods (5%). Of the fish 40% were engraulids, 25% were gonostomatids, and 20% were normanichthyids. Almost all oft he euphausiid shrimps were Nyctiphanes simplex. The seasonal maximum of fish in jack mackerel was in August (Southern hemisphere winter) at 35% owing to the addition of Vinciguerria lucetia. He described the feeding interaction between hake and jack mackerel overlapping mainly in the feeding on engraulids and occasionally Vinciguerria lucetia. Thus, to understand the effect of El Niño on jack mackerel one would have to observe changes in euphausiids, and at least 3 groups of fish.

Saury. Saury spawning below 30° north latitude virtually ceased between 1957 and 1960. Either the adult fish were not there or they were unable gain sufficient surplus energy to spawn. This species exhibits a trans-Pacific distribution and is thought to be a zooplankton feeder (Smith and Ahlstrom, 1973). There was also a small decline in the abundance of eggs off southern and central California. This could be explained by more rapid hatching time in the warmer water. Another explanation would be that the zooplankton abundance was lowered which changed the per capita rate of spawning. Also, the northward migration of tropical predatory birds, fish and mammals could be a contributing cause of the decreased abundance of eggs by predation on the spawning adults or consumption of egg masses. Off Japan saury may be replaced by incursions of Scomber japonicus (Schaeffer, 1980); although this occurred in 1958 off Japan it was determined whether some oceanic boundary of the saury habitat shifted or the Pacific mackerel population expanded its range into the saury habitat.

Mesopelagic fishes. Even though the main effects of the El Niño may be above the habitat of the adult mesopelagic fishes, the larvae of some mesopelagic fishes inhabit the upper mixed layer. An examination of an atlas of the most common mesopelagic fishes (Ahlstrom, 1972) reveals several different responses to the onset of the 1957-59 El Niño.

Three of the mesopelagic species have epipelagic (100 m or less) larvae. One of the most massive distributional changes occurred with Vinciguerria lucetia. Its major concentrations were restricted to south of 30°N in the anti-Niño period 1955-56 and it spread to the oceanic areas off San Francisco to 35 north latitude by 1960. Primarily because of its increased "overlap" with the CalCOFI survey area, the abundance of V. lucetia increased an order of magnitude between 1956 and 1959. In a similar but less extensive change of geographic distribution larvae of Triphoturus mexicanus, tripled in apparent abundance through a 240 nautical mile northward shift. Larvae of a third species, Stenobrachius leucopsaurus, did not appear to respond in any way to either the anti-Niño or Niño; the southern limit of distribution remained off San Diego through the entire period.

Two of the mesopelagic species also have mesopelagic larvae. The number of larval Leuroglossus stilbius declined by 6-fold between 1957 and 1958; this appeared to be caused by the decline in spawning in a southern center off Punta Eugenia, Baja California as the northern limits did not appear to shift. Bathylagus wesethi larvae doubled in apparent abundance during the niño period, apparently by slight increases in abundance in spawning centers and by drawing closer to the coast. The larvae of Bathylagus ochotensis, a subarctic species, decreased slightly during the warming apparently due to a withdrawal from the coast and to the north. The depth distribution of this species is not well known.

Engraulis. The onset of El Niños in 1957-9 (Fig. 1) and 1982-3 (Table 1) had remarkably little effect on the apparent production of eggs and larvae. In fact the "anti-El Niño" with its colder waters and invasion of subarctic fauna appears to have a negative effect on the abundance of these planktivorous fishes. In 1957-9 increase with the onset of El Niño. There were large increases in the abundance of larvae off central California and moderate increases off the southern California coast more than 300 km. In the egg production time series from 1980 to 19884 there continued to be production rates of more than 200 eggs per square meter per day throughout the Los Angeles Bight. In addition, during El Niño in 1983, there were more than 100 eggs produced per square meter per day from 200 km to 250 km offshore. Similar rates were sustained in 1984 out to 200 km. Therefore, the prediction of diminished northern anchovy fecundity caused the apparent low zooplankton volume and chlorophyll (McGowan, 1983; 1984) has not been substantiated. Similarly, in 1957-9, the diminished primary production and zooplankton volume was met with equal or greater spawning of northern anchovy (Smith and Eppley, 1982) in the Los Angeles Bight area.

Sardinops. As with the anchovy, the sardine Sardinops caerulea, appears to be adversely affected by the cold "anti-El Niño" and favored by El Niño (Fig. 2). Murphy (1960) used temperature as a "convenient index" for other oceanic properties in his discussion of the sardine. He stated that "...cooler temperatures along the California Current are associated with accelerated southward transport, and more vigorous upwelling with its attendant offshore movement of water. Plankton densities are increased." He noted that the warm years of the late 30's and early 40's appeared to have been favorable for sardine recruitment and the cooler years 1943-1956 were accompanied by a precipitous and sustained decline in the species. The species reached a spawning biomass of 2 million tons during the El Niño of 1941. However, in the El Niño of 1982-3 off Chile, the large Sardinops population failed to recover its normal fat content in the summer and in the next spawning season the fat content of the population was again reduced by a factor of 2 (Vidal, Chile Pesquero, December 1983 p. 13).

Scomber. A high rate of parent per capita recruitment occurred in the years 1958-60 (Parrish and MacCall, 1978; Schaeffer, 1980). While the catch records of Pacific and jack mackerel are frequently combined for statistical purposes, the species are radically different. The life span of the jack mackerel is several times tnat of the Pacific mackerel and the adult phase of the jack mackerel is found in transitional waters between the Central Water Mass of the North Pacific and the West Wind Drift and California Current. Juvenile jack mackerel school with Pacific mackerel in the coastal currents off California but at the age of 3 or 4 they resume the high seas distribution characteristic of their parents. There they live for about 25 years (MacCall and Stauffer, 1981). Pacific mackerel live in the coastal current region of the subtropical and temperate zone of the Gulf of California, Baja California and southern California. The maximum age of Pacific mackerel is 11 years (Schaeffer, 1980) and they probably remain in the coastal currents region.

Despite the increased recruitment of Pacific mackerel in the 1957-9 Niño the sport catch off California was 1/2 normal in this period. The Mexican catch of Pacific mackerel declined by a factor of 5 in 1957 and declined yet another factor of 5 in 1958. These conflicting facts are probably explained by a more northerly distribution of this species at this time so that they are unavailable to the fishery from the traditional ports.

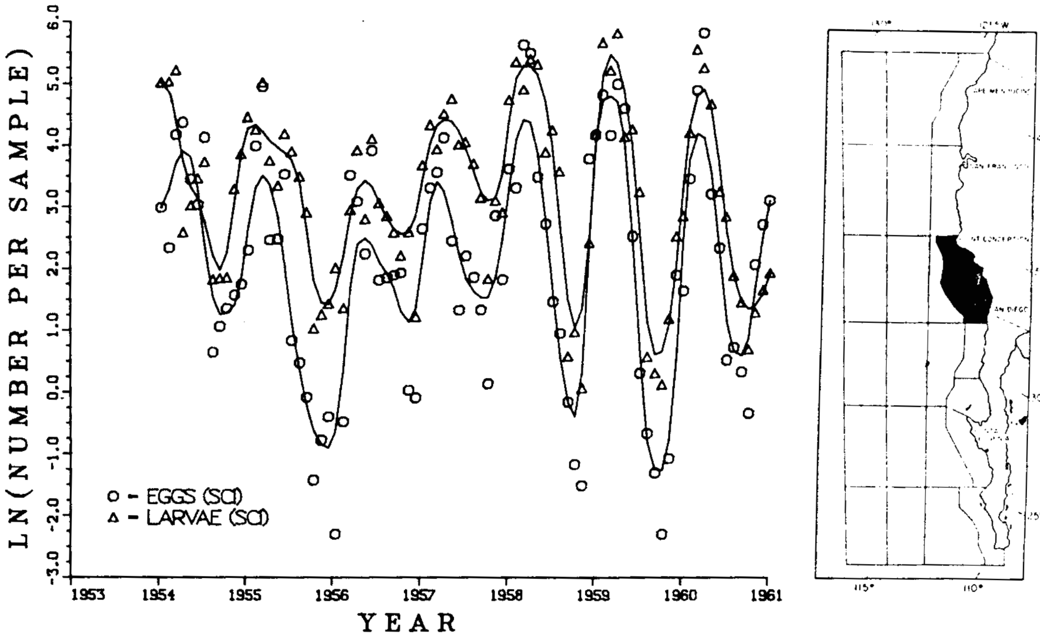

Figure 1. The increase of anchovy spawning between 1954 and 1960 in the southern California inshore region. The circles are at the natural log of the monthly average egg abundance for all stations in the region. The triangles are at the natural log of the monthly average larvae abundance for all stations in the region. The line is a resistant non-parametric smoother for these points (Velleman, 1980).

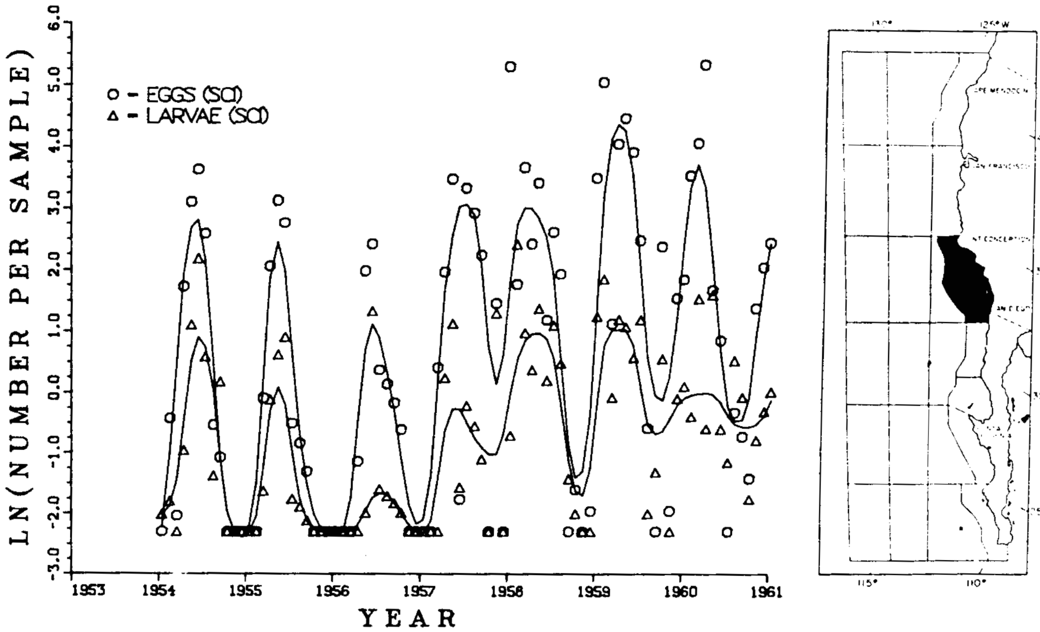

Figure 2. The increase of sardine spawning between 1954 and 1960 in the southern California inshore region. The circles are at the natural log of the monthly average egg abundance for all stations in the region. The triangles are at the natural log of monthly average larvae abundance for all stations in the region. The line is a resistant non-parametric smoother for these points.

Detailed studies of growth have not been conducted on the Pacific mackerel so changes in length at age which are observed for this species (smaller during El Niño) may be due to greater survival of the smaller members of the cohort, or smaller members of the population transported in from the southern, more subtropical sectors of the distribution (Klingbeil, pers. comm.) or larger fish migrating to the north.

Pleuroncodes. The red crab, *Pleuroncodes planipes*, is a benthic animal of the Gulf of California and the south Baja California continental shelf (Longhurst, 1966). During most years the juvenile pelagic phase drifts back and forth in the coastal currents over the adult habitat but important numbers of offspring are entrained in the California Current extension and carried into the tropics. During El Niño, similarly important numbers are carried north as far as southern California in a band 160 km wide and in a narrow coastal strip into waters off central California. New data from trawling for anchovy adults shows a similar northerly transport (Fig. 3) of red crab juveniles offshore. Although sightings of red crab are at the surface, it is not known at what depth the organisms are transported. Since the adults live in depths as great as 300 meters it is conceivable that some transport is in the California Undercurrent. The pelagic phase of red crab is about 2 years in duration but mature individuals have not been collected off Alta California thus the origin of all the young is considered to be at 25°N latitude or 1000 km south of where many young are transported (Boyd, 1967).

Shelf Fauna

The fishes and invertebrates of the continental borderland are likely to exhibit some diversity of response to El Niño. Planktivorous species or older organisms may be in part be isolated from the immediate effects of a brief El Niño. In general hake are mesopelagic spawners which feed on the continental shelf, the rockfish as a group are pelagic over canyons and around islands and the flatfish are demersal over the gentler slopes of the continental margin. The time series of larval catches of these species may permit identification of some changes associated with El Niño.

Merluccius. The Pacific hake does not continuously occupy the zone of coastal currents (Bailey et al., 1982). During the spring and summer, the adult population migrates 1000 km northward to feed on the continental shelf of the north temperate eastern north Pacific. Depending on the age structure and the temperature at depth (Smith, 1975), the hake migrate to various distances to the south in the fall and spawning is conducted in winter. Since the onset of the El Niño was in April 1957, the first year of effect on hake larvae was in 1958. An index of larvae from winter abundance in 1954-1960 was 5, 8, 14, 21, 8, 2, 3. That portion of the larval index in the region seaward of about 300 km for the same years is 2, 4, 11, 15, 3, .1, and .9. The survival of the 1957-9 spawn to fishable age was low relative to 1960 and 1961.

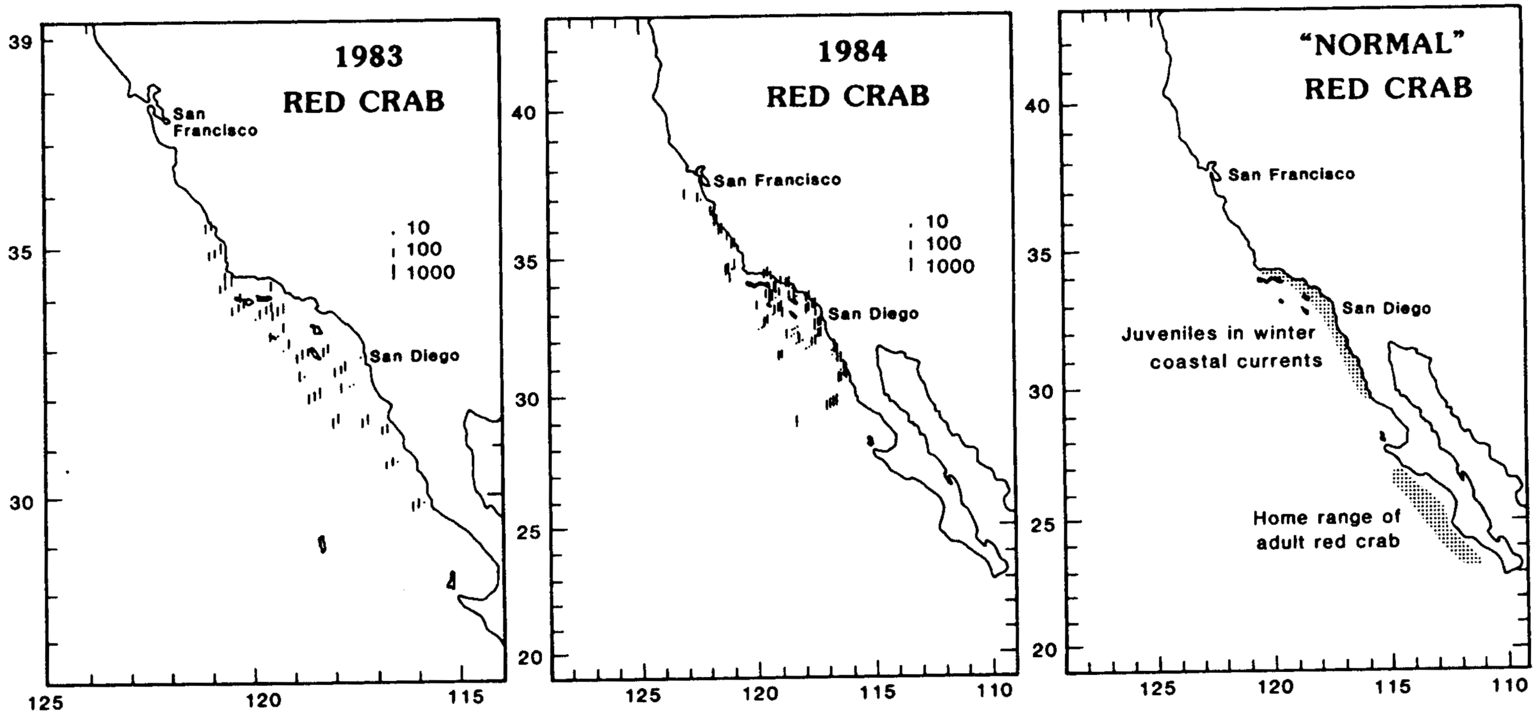

Figure 3. Temperate distribution of red crab. a) juveniles caught in near surface trawls in 1983; b) juveniles caught in near surface trawls in 1984; c) normal range and adult habitat. For maps of trawling effort see Picquelle and Hewitt, 1984 and Hewitt, 1984.

Since the larval index was high in 1957, the per capita survival of spawn must have been extremely low for that year.

Rockfish. The first effects of the 1957-9 El Niño on the production of rockfish larvae were noted in 1958. Since the onset of El Niño condition was in April of 1957 after the most rockfish births (rockfish bear live young) had occurred for the year. At 42°N there was an apparent increase in the number of rockfish larvae in 1958. At 37°N there were moderate decreases in 1958 and 1959. At 32°N the number of rockfish larvae per stations decreased by more than half in 1958 and again by a factor of three in 1959. The decline of larvae was similar at 27°N. There were no obvious effects of El Niño on the commercial fishery. The decline in larval abundance may have been caused by the decline of the productivity of the waters adjacent to the continental shelf. The El Niño may have had a profound effect on the reproductive rate of this group of species. A description of these time series is found in Ahlstrom, Moser and Sandknop (1978). This arctic to temperate genus has 69 species in the eastern North Pacific and about 40 species are taken in commercial and sports fisheries in California.

Flatfishes. Of eight kinds of flatfishes that Ahlstrom and Moser (1975) analyzed only four showed major declines in abundance during El Niño of 1957-9. The species which declined less than 2-fold (possible temperature/development rate effect) were the California halibut, Paralichthys californicus, English sole, Parophrys vetulus, Rex sole, Glyptocephalus zachirus, and the Dover sole, Microstomus pacificus. The species which appeared to change more drastically were the speckled sanddab, Citharichthys stigmaeus, other sanddabs, Citharichthys spp., slender sole, Lyopsetta exilis and the turbots, Pleuronichthys spp. It would be interesting to know the feeding habits of these two groups and what mechanism differentiates their response to El Niño.

Plankton

The plankton sampling program of CalCOFI was designed to quantitatively capture the eggs and early larval stages of fishes which occupy the euphotic zone. Thus, observations of organisms which occur in and deeper than the 140-m depth of the CalCOFI oblique tows must be interpreted cautiously. For example, the adults of many euphausiids substantially evaded the bridled ring-net, even at night, and most euphausiids range throughout the upper 600 meters (Brinton and Townsend, 1981). Important amounts of copepod biomass were not retained by the .505 mm mesh apertures of the CalCOFI standard net. Important fractions of the zooplankton are totally destroyed by contact with the filtering surface under tow and others are extruded from the mesh during vigorous washing. Thaliaceans shrink greatly before the displacement volume is taken in many samples the large thaliaceans were discarded before fixation owing to the lack of adequate containers and fixative (Thrailkill, pers. comm.). Planning and sample design, like that conducted for the eggs and larvae of sardine, would be a prerequisite for a quantitative analysis of any of the 500 or so populations now captured in the fish egg and larva surveys. Still the regularity of the sample techniques has permitted advanced analysis and important conclusions about widespread biological oceanographic phenomena and much of the interpretation is based on the strength of the non-seasonal changes during the 1957-9 Niño and the cooler period which preceded it (Bernal, 1981).

As pointed out by Smith (1971) most of the change in zooplankton volume during the El Niño of 1957-59 was caused by a radical diminution in the volume of thaliaceans (salps, pyrosomes and doliolids) and larvaceans. This category comprised 75% of the zooplankton in October of 1956 and by April of 1958 this category was only 7%. The crustaceans had during the same period risen from 17% to 60%. These relative changes in plankton group composition cannot be interpreted in terms of productivity since changes in standing crop merely represent changes in the relative rates of natality, growth and mortality. One would need to know much more about the demographics of the planktonic populations and the vulnerability of the life stages to sampling to make useful inferences about zooplankton production.

Thaliaceans dominated plankton collections in the California Current region in 1956 being more than triple the quantity of copepods and 13 times the volume of euphausiids. The rank order was thaliaceans, copepods, and euphausiids. By 1958 the copepods had decreased to 50%, the euphausiids had decreased to 45%, and the Thaliaceans had decreased to 4% of their volumes. Table 3 lists these functional groups with the other 14 for comparison. Following the climatic shift, copepods became the most abundant group in the biomass and the thaliaceans and euphausiids were nearly equal at fourth and fifth rank abundance. The chaetognaths had risen from fourth to second rank and the siphonophores had risen from fifth to third rank.

Thaliaceans. Thaliaceans were most abundant seaward of 150 km in the main branch of the California Current (Figure 4). The annual average reached a maximum of 200 grams per 1000 m^3 in 1956 and decreased to less than 10 grams per 1000 m^3 by 1958 and in 1959. The annual average temperature shifted from 14 to 16.5° degrees in this outer region over the same period (Fig. 5). Alongshore thaliaceans changed from 140 cc per 1000 m^3 in 1956 to nil in 1958 and remained there in 1959 in the Vizcaino Bay region (Fig. 6). There were parallel temperature rises along the entire coast (Fig. 7).

During the actual onset of El Niño in April of 1957, the thaliacean displacement volume declined 20-fold between April and July. In a similar period in 1956 the thaliaceans increased 5-fold in the southern California section.

Copepods and Euphausiids. Across the coastal currents and main branch of the California Current the annual average abundance of copepods decreased from about 50 and 10 grams per 1000 m^3 in 1955-57 to about 20 and 6 grams per 1000 m^3 in 1958-9 (Fig. 8).

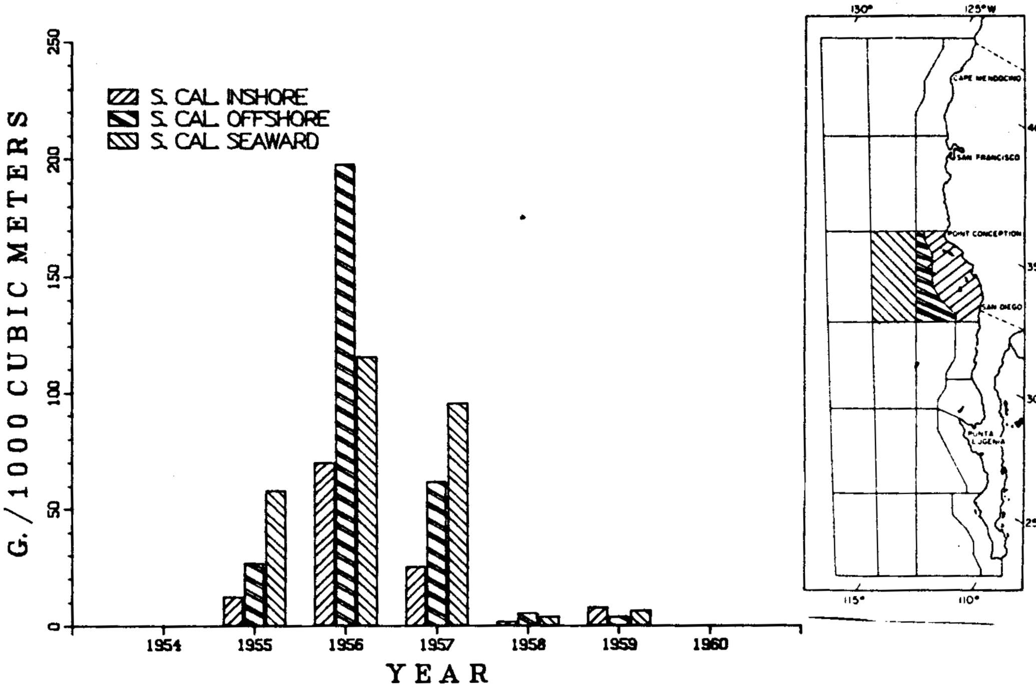

Figure 4. The decrease of thaliacean displacement volume between 1955 and 1959. The first bar is the volume calculated from the average of all stations in the southern California inshore region for the entire year. The second bar is the same value for the southern California offshore region. The third bar is the same value for the southern California seaward region.

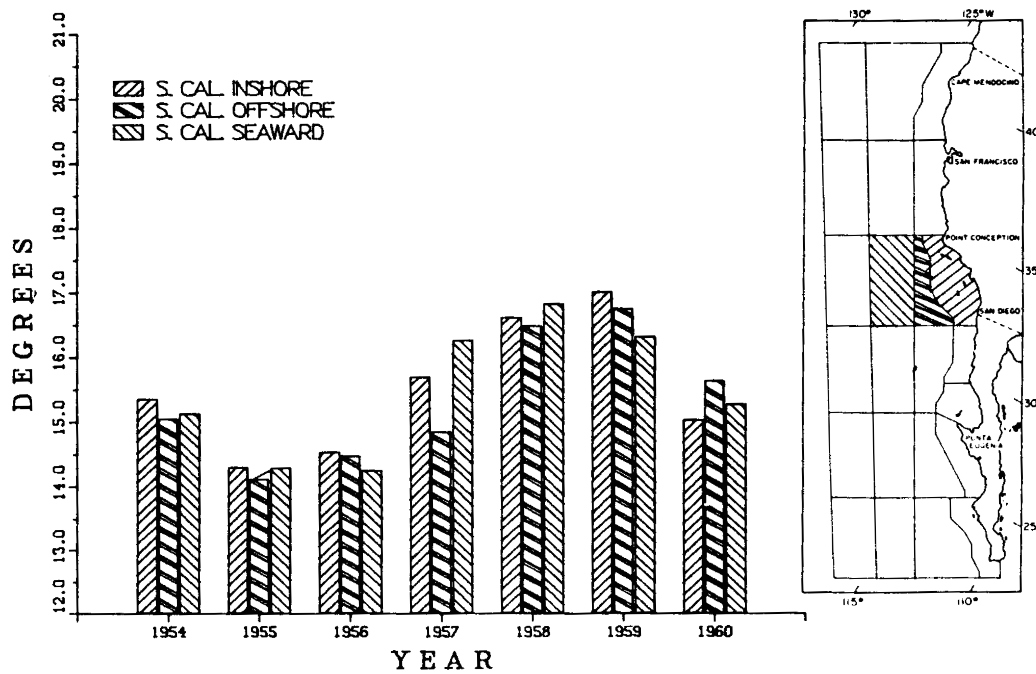

Figure 5. The increase of 10 meter temperatures between 1954 and 1960. The first bar is the 10 m temperature calculated from the average of all stations in the southern California inshore region for the entire year. The second bar is the same value for the southern California offshore region. The third bar is the same value for the southern California seaward region.

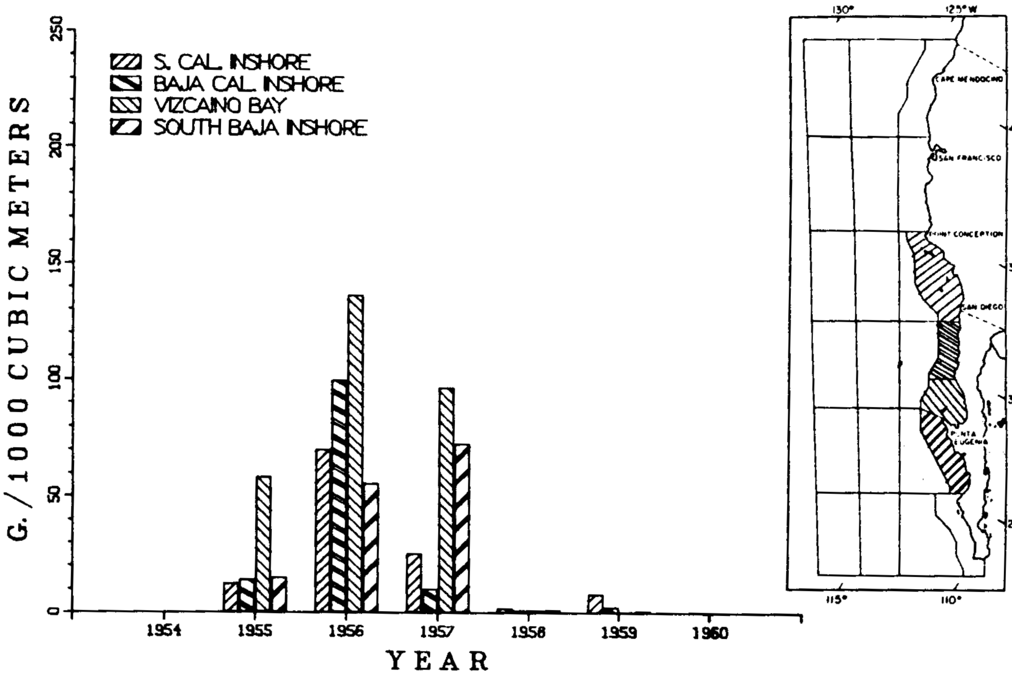

Figure 6. The decrease of thaliacean displacement volume between 1955 and 1959. The first bar is the volume calculated from the average of all stations in the Southern California inshore region for the entire year. The second bar is the same value for the Baja California inshore region. The third bar is the same value for the Sebastian Vizcaino Bay region. The fourth bar is the same value for the south Baja inshore region.

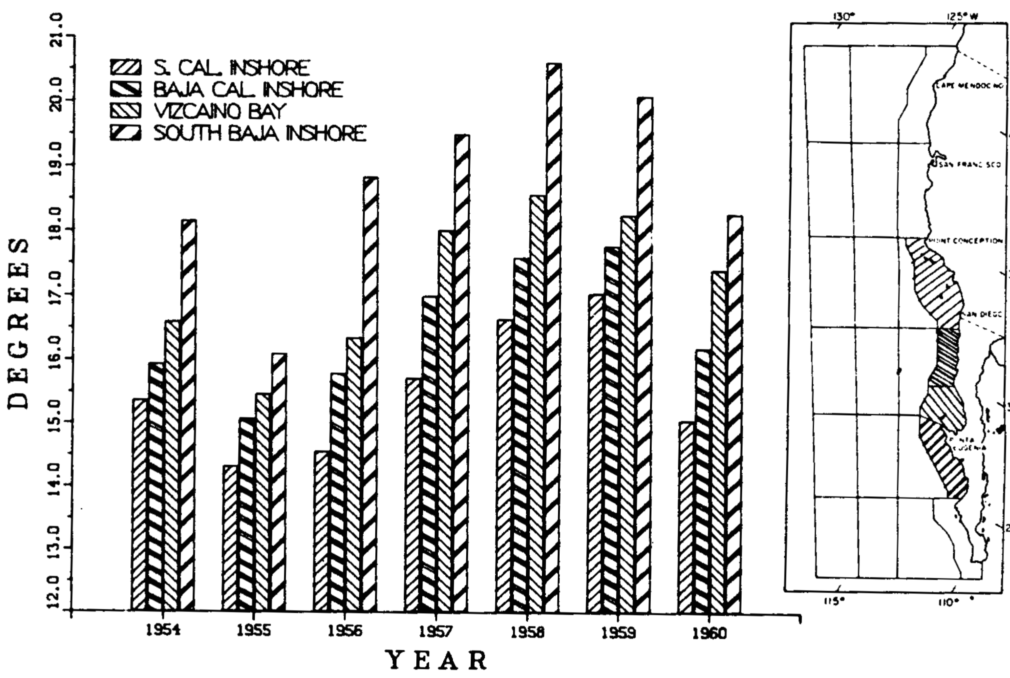

Figure 7. The increase of 10 m temperatures between 1954 and 1960. The first bar is the average 10 m temperature calculated from all stations in the southern California inshore region for the entire year. The second bar is the same value for the Baja California inshore region. The third bar is the same value for the Sebastian Vizcaino Bay region. The fourth bar is the same value for the south Baja inshore region.

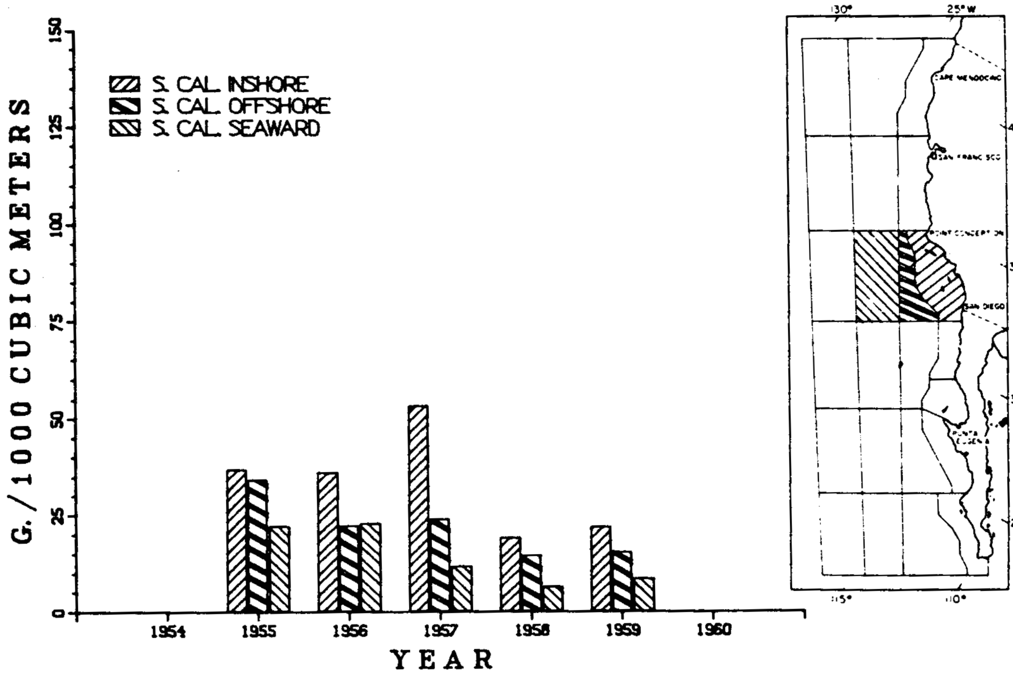

Figure 8. The decrease of copepod displacement volume between 1955 and 1959. The first bar is the volume calculated from the average of all stations in the southern California inshore region for the entire year. The second bar is the same value for the southern California offshore region. The third bar is the same value for the southern California seaward region.

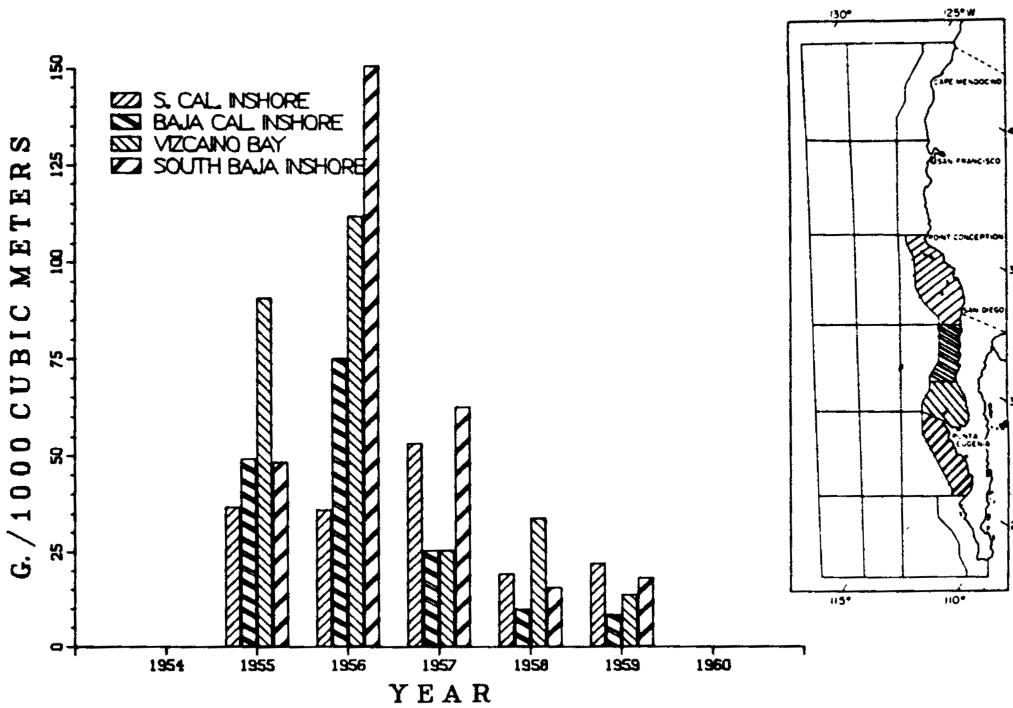

Figure 9. The decrease of copepod displacement volume between 1955 and 1959. The first bar is the volume calculated from the average of all stations in the southern California inshore region for the entire year. The second bar is the same value for the Baja California inshore region. The third bar is the same value for the Sebastian Vizcaino bay region. The fourth bar is the same value for the southa Baja inshore region.

Southward along the coast in the coastal currents zone the decrease in the southerly regions was more dramatic for the copepods, from 140 grams per 1000 m^3 to 20 (Fig. 9). Euphausiids decreased by a factor of three (Fig. 10 and 11).

During the onset of El Niño in April 1957, the inshore copepods decreased by a factor of 4 and the euphausiids decreased by a factor of 3 by July. In the same period in 1956 the volumes were equal over the 3 month span in the southern California inshore area.

Presumed Secondary Production

While secondary production is difficult to infer from zooplankton displacement volume, it may be interesting to note that the slope of the seasonal increase of zooplankton is similar in the southern California inshore area in the years 1955 through 1959 (Fig. 12 and 13). One can infer from this that the reproductive capacity less the predation rate favored increases in zooplankton volume both when the system was dominated by thaliaceans and when dominated by copepods. The second figure is a display of the adjacent month differences displayed as ratios. In this area one can expect sustained increases from 10 to 60% per month in the winter and spring months whether the system is dominated by thaliaceans or copepods and at either the 14° temperature of the 1955-56 period or the 16.5° temperature of the Niño period. Since the currents are sluggish in this area one would expect local growth to dominate over transport as a factor in this rate of increase, transport in the gyre is largely from the south and west with only minor entrainment of the California Current as indicated from the offshore position (270 km at line 90) of salinity less than 33.4% (Bernal, 1981).

Primary Production

Unfortunately, there were no primary production estimates at the time of the 1957-9 El Niño. There are no spatially and temporally coherent time series of an area the size of the California Current region. A coastal time series reported by Smith and Eppley (1982) did capture one extremely high phytoplankton production rate of 1.41 g C per m^2 per day in June of 1975 and a relatively low value of 0.1 g C per m^2 per day in October of 1976 and February 1977. Assuming the Scripps Pier Temperature Anomaly was related to primary production in the same way in the years 1955-59, the annual average production declined from 0.4 to 0.2 g C per m^2 per day and December minima of 0.1 were obtained in 1957 and 1958. There appeared to be moderate agreement in the change in values of zooplankton volume over the same period Table 4.

Summary and Recommendation for Future Study

Re-examination of the more thoroughly sampled transition from anti- to El Niño conditions in 1955-9 suggests answers to the question "Why was the effect on anchovy spawning so moderate in

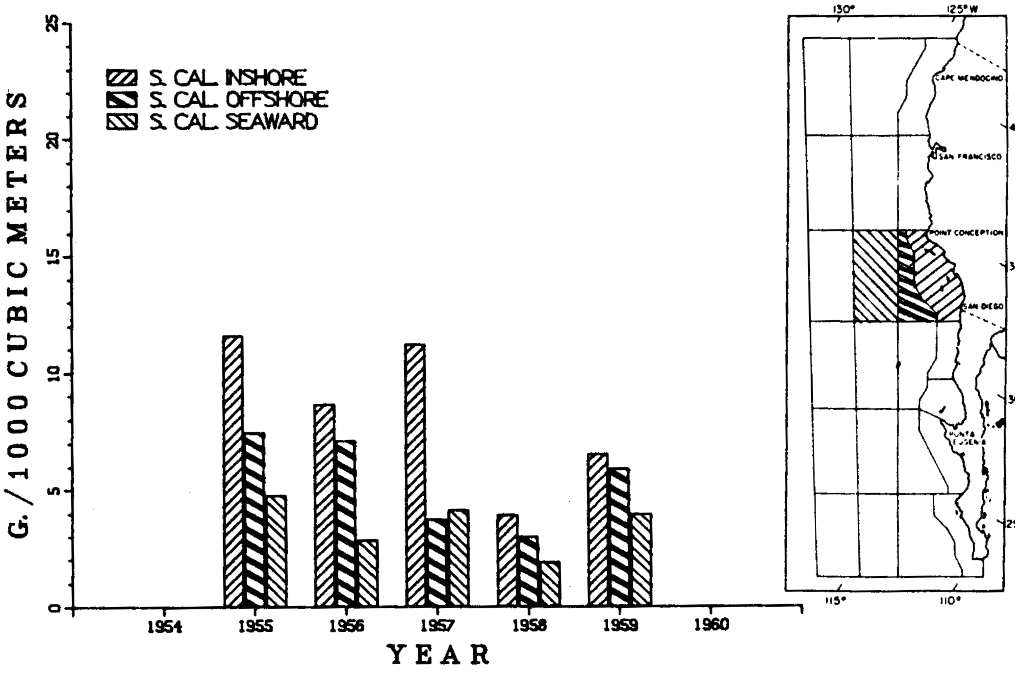

Figure 10. The decrease of euphausiid displacement volume between 1955 and 1959. The first bar is the volume calculated from the average of all stations in the southern California inshore region for the entire year. The second bar is the same value for the southern California offshore region. The third bar is the same value for the southern California seaward region.

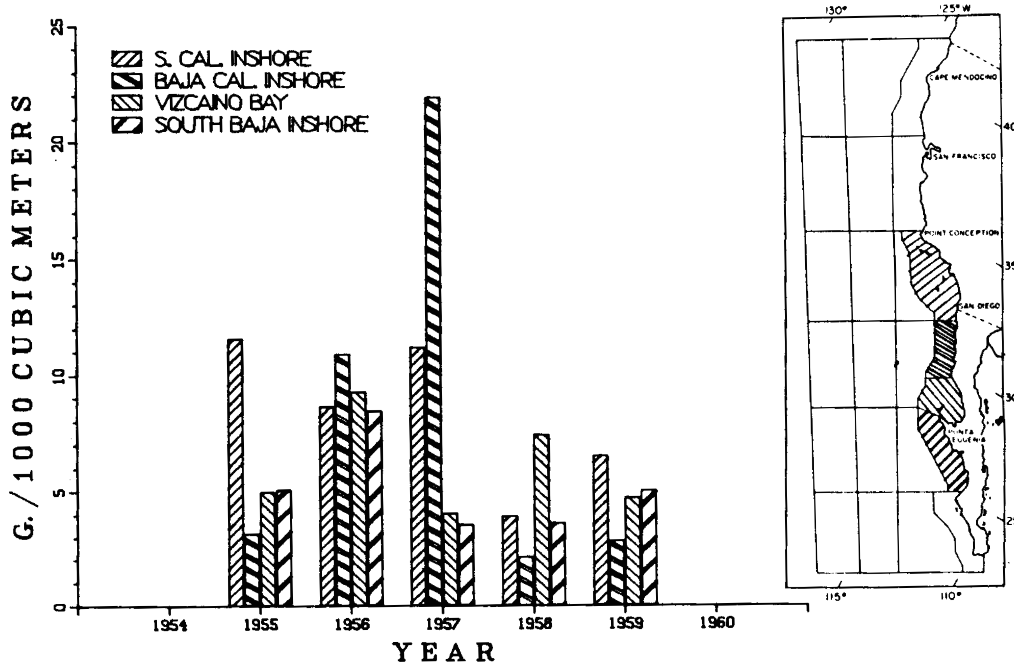

Figure 11. The decrease of euphausiid displacement volume between 1955 and 1959. The first bar is the volume calculated from the average of all stations in the southern California inshore region for the entire year. The second bar is the same value for the Baja California inshore region. The third bar is the same value for the Sebastian Vizcaino Bay region. The fourth bar is the same value for the south Baja inshore region.

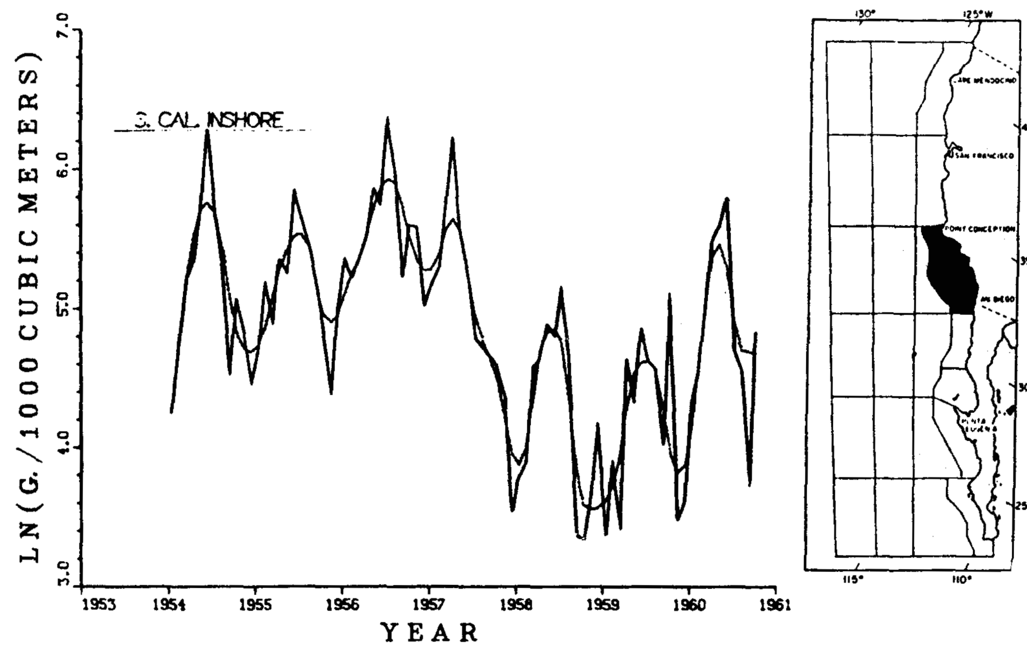

Figure 12. The time series of small zooplankton volume between 1954 and 1960 in the southern California inshore region. The jagged line is the natural log of the average of all stations on a monthly interval with missing values (about 10% mostly August or September) interpolated linearly. The smooth line is a resistant non-parametric smoother for these points. The similarity of seasonal slopes in anti-Niño (1954-60) and Niño (1958-59) years is an indication that the growth rate per unit initial zooplankton volume is similar for both conditions.

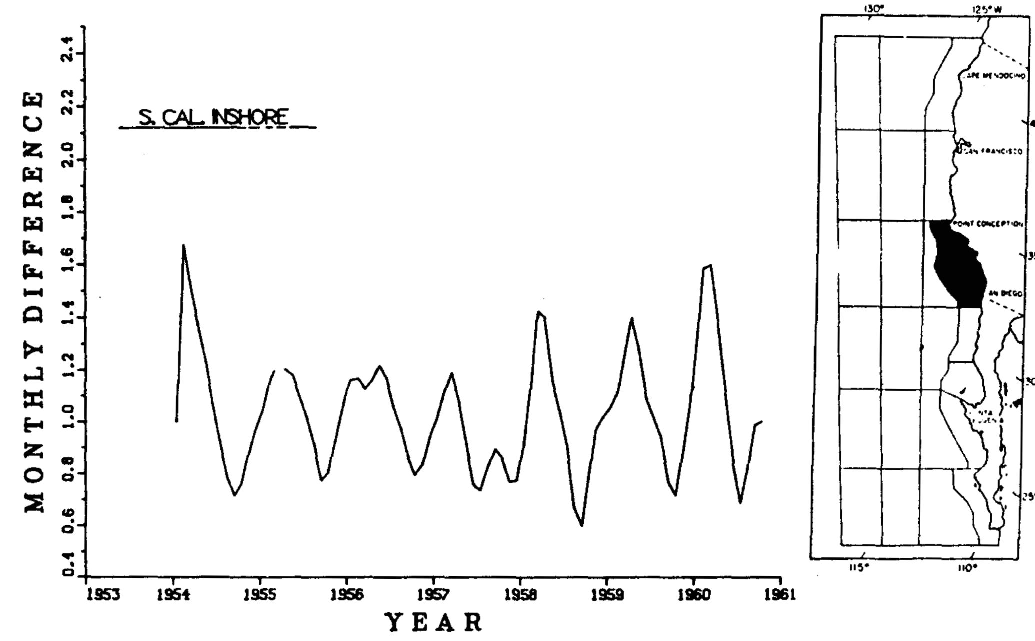

Figure 13. The time series of monthly differences of small zooplankton volume expressed as a ratio between the displacement volume of a given month and that of the previous month in the southern California inshore region from 1954 to 1960. Raw, interpolated and smoothed data in Figure 12.

Table 4. Comparison of estimated primary production and zooplankton standing stock during the 1955-9 transition from anti-Niño tc• Niño.

		Primary production g C/m^2/day	Zooplankton standing stock g/m^2	Change g/m^2/qtr
1955	March	0.5	11	-
	June	0.7	25	14
	September	0.3	13	-12
	December	0.3	13	0
1956	March	0.5	17	4
	June	0.7	42	25
	September	0.4	23	-19
	December	0.2	23	
1957	March	0.3	17	-6
	June	0.5		
	September	0.3	6	-8
	December	0.1	5	-1
1958	March	0.2	7	2
	June	0.6	11	4
	September	0.3	2	-9
	December	0.1	2	0
1959	March	0.2	5	3
	June	0.3	9	4
	September	0.2	7	-2

1983-4?" The energy required for anchovy spawning could have been "gleaned" from local island and coastal enriched areas which would be inadequately represented in wide-scale oceanic surveys. Anchovy, Pacific mackerel, and sardines may draw substantially on stored reserve energy from preceding seasons (Smith and Eppley, 1982) and may delay growth (Table 1b.) Another possibility is that diminished populations of salps, dalialids and pyrosomes (thaliaceans) allowed greater production of other herbivores, like crustaceans which are in the anchovy food chain.

Given these elements of resilience in the anchovy, Pacific mackerel, and sardine populations, one can speculate on why the spawn production of jack mackerel and saury was so low following the 1957 onset of El Niño. The jack mackerel spawning adults occupy the same habitat as the thaliaceans. This area is so broad and homogeneous that the twenty-fold decline in thaliaceans signaled a similar seven-fold decline in larval production by jack mackerel. This could have been mediated by the production of crustacea on which jack mackerel depend in part, or by the withdrawal of key mesopelagic fishes toward the north without equivalent replacement from the south. I would favor the mesopelagic fish explanation because the zooplankton predator, saury, did not change its spawn production rate markedly. Thus the mobility of the jack mackerel was not adequate to compensate for the scale of El Niño event in the main and outer branches of the California Current.

The responses of the hake, rockfish and flatfish to the onset of the El Niño appear similar. The hake feeds along the continental shelf of the British Columbia, Washington, Oregon and northern California coastlines. In the 1955-59 anti-and El Niño transition the main branch of the California Current impinged on these continental borderlands and the rockfish and flatfish are permanent members of that continental border. Thus the similarity of response was probably mediated by the interruption of the usual high rate of primary and secondary productivity usually ascribed to these coastal areas. Since these fishes and the jack mackerel all prey on the sardines and anchovies, one must assume that the predation withdrawn to the north roughly counterbalanced the added predation from the tropical and temperate tunas during the Niño.

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