MESOSCALE CYCLES IN THE SERIES OF ENVIRONMENTAL INDICES RELATED TO THE SARDINE FISHERY IN THE GULF OF CALIFORNIA

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ABSTRACT

Cyclical fluctuations in mean sea level and sea-surface temperature recorded at northwestern Mexican shore stations are compared to Gulf of California sardine fishery data. Sardine abundances correspond to 2-year and 5-year sea-level and sea-surface temperature cycles.

RESUMEN

Fluctuaciones cíclicas en el nivel promedio del mar y la temperatura superficial de estaciones costeras del noroeste de México son comparados con datos de pesquería de la sardina del Golfo de California. Abundancias pesqueras corresponden a ciclos de 2 y 5 años del nivel del mar y de la temperatura.

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INTRODUCTION

During recent years, there has been a renewed interest in analyzing the periodic fluctuations of certain natural phenomena, particularly those of large geographic scale. El Niño events and their seeming relation to the Southern Oscillation have been analyzed by various authors (e.g., Wooster and Fluharty 1985). The relationship between oceanographic-climatic periodic fluctuations and natural populations has also been analyzed (Mysak 1986).

Cyclic fluctuations of 5+ years have been reported on mean sea level (MSL), sea-surface temperature (SST), and salinity as related to catches of herring and salmon in the northeast Pacific Ocean by Mysak et al. (1982). Mysak (1986) also proposes a mechanism that explains the connection of such a cycle to El Niño-Southern Oscillation (ENSO) events, through the propagation of Kelvin

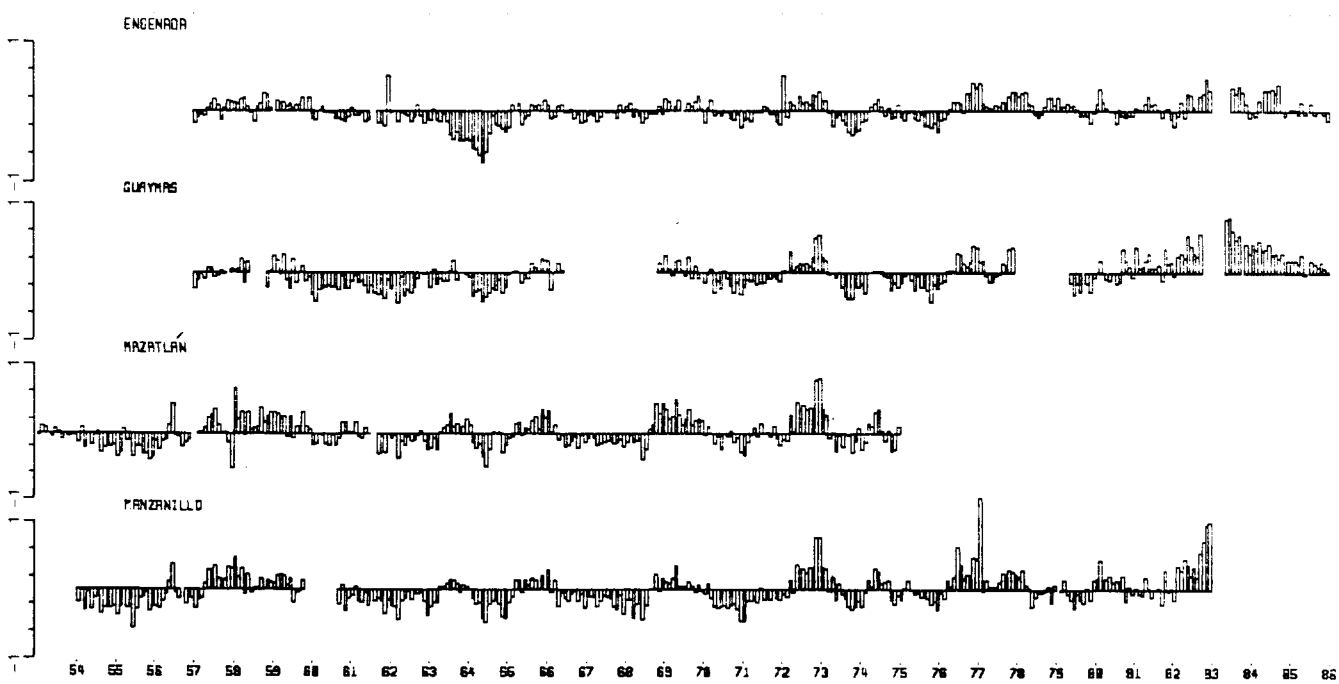

Figure 1. Monthly series of mean sea-level anomalies.

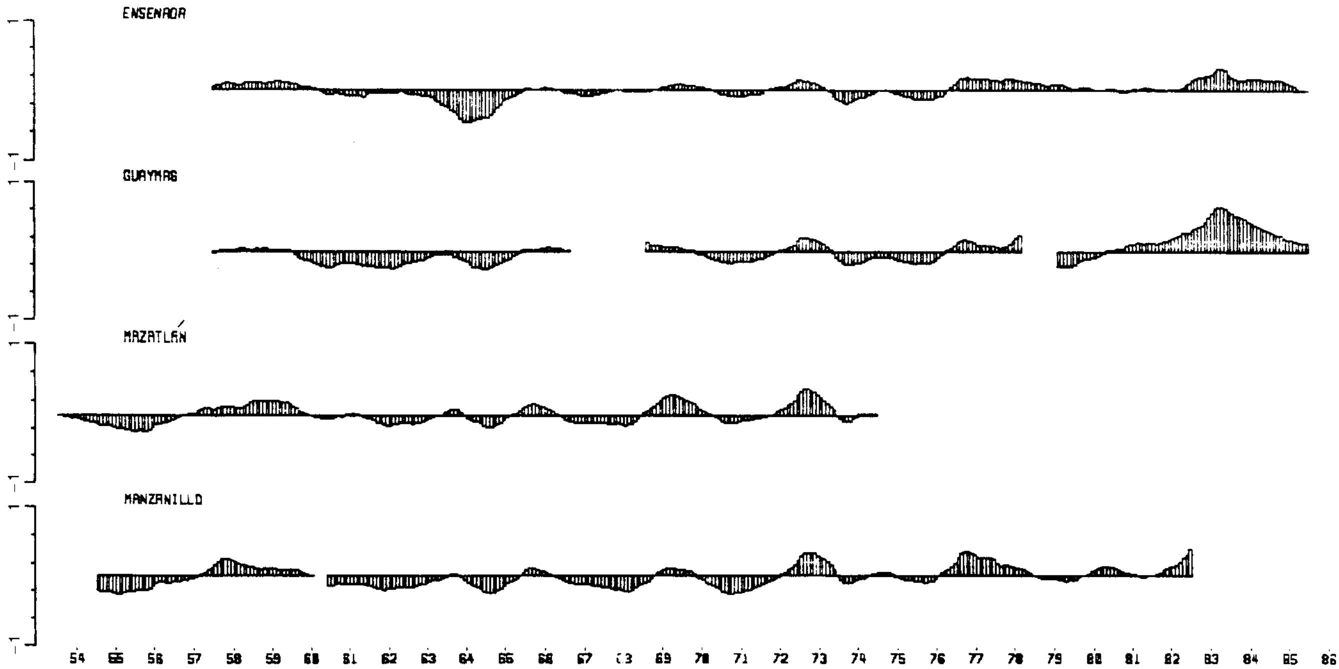

Figure 2. Smoothed monthly series of mean sea-level anomalies.

and Rossby waves along the west coast of North America.

Cyclic fluctuations have also been observed in the sardine fishery of Baja California's west coast (Casas-Valdez 1983), as well as in Baja California's rainfall series, which is used as a climatic indicator (Rueda-Fernández 1983).

We report on cyclic fluctuations of mean sea level and sea-surface temperature from Ensenada, Guaymas, Mazatlán, and Manzanillo, on the west

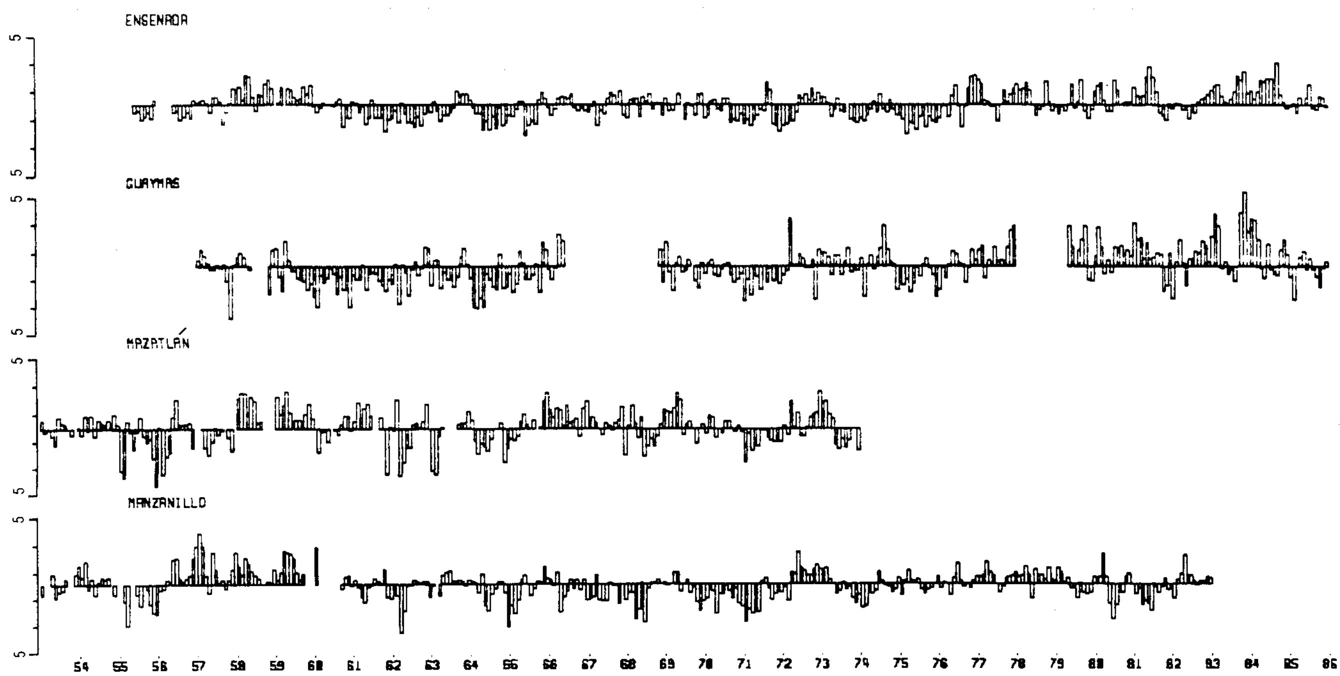

Figure 3. Monthly series of sea-surface temperature anomalies.

TABLE 1
Common Harmonic Parameters and Maxima for Mean Sea Level Series

Period in years	Amplitude	Phase	Peaks (year-month)					
Ensenada								
3.593	0.0721	−2.8336	5808	6203	6510	6905	7212	7607
			8003	8310	8705			
5.278	0.064	0.58722	6110	6701	7205	7708	8211	8803
2.422	0.048	−2.25853	5711	6004	6209	6502	6707	6912
			7205	7410	7703	7908	8202	8407
			8612	8905				
20.996	0.0335	−0.09193	5704	7804	9904			
Guaymas								
5.052	0.0954	−0.98318	5710	6211	6711	7212	7712	8301
			8802					
25.703	0.075	−0.5462	5903	8412				
2.962	0.0676	−0.77293	5705	6004	6304	6604	6903	7202
			7502	7802	8101	8401	8612	8912
3.499	0.0556	3.04577	5810	6204	6510	6904	7210	7604
			7910	8304	8609	9004		
Mazatlán								
3.177	0.095	−0.86458	5306	5608	5910	6212	6602	6904
			7207	7509	7811	8201	8503	8805
5.221	0.0545	−0.39012	5304	5807	6310	6812	7403	7906
			8408	8911				
2.223	0.0546	1.93914	5407	5610	5812	6103	6306	6508
			6711	7002	7204	7407	7610	7812
			8103	8306	8508	8711		
Manzanillo								
3.341	0.0796	2.12008	5603	5907	6211	6603	6907	7212
			7604	7908	8212	8604	8908	
4.817	0.0966	0.54975	5805	6303	6801	7211	7708	8206
			8704					
22.471	0.0632	−0.82863	5612	7906				
2.751	0.0885	3.07264	5505	5802	6011	6308	6605	6902
			7111	7409	7706	8003	8212	8509
			8806					

coast of Mexico, as well as on the average size of sardines caught in the Gulf of California fishery.

METHODOLOGY

Mean sea level (MSL) and sea-surface temperature (SST) data series for Ensenada, B.C.; Guaymas, Son.; Mazatlán, Sin.; and Manzanillo, Col. were published by Grivel-Piña (1975, 1977, 1978) for the years 1950 through 1974. Later data were furnished by the Centro Regional de Investigaciones Pesqueras (CRIP) at Guaymas, as were monthly size averages of Monterrey sardine (*Sardinops sagax*) landed at Guaymas from November 1971 through December 1984.

Time series analysis techniques were used to determine the internal structure of the data series. Because these methods decompose the series into elements that are caused by different phenomena (not necessarily independent), hypotheses on causal effects may be established (Chatfield 1980), as well as statistical criteria for forecasting relevant variables.

Preliminary analysis was conducted by means of anomalies; noise was filtered by using a 12-order running means. After trend filtering, the program SPECTRA, supplied by the Centro de Investigación Científica y Enseñanza Superior de Ensenada (CICESE) was used to estimate the frequency spectra of the series and to determine the main harmonics. Once the frequencies were determined, a cosine model of harmonic components was used to determine both amplitude and phase by least squares, using Bloomfield's (1976) program modified to operate with incomplete data vectors.

RESULTS

The positive anomalies in the MSL series (Figure 1) occur during the years 1957–59, 1965–66, 1972–73 and 1982–83, all of which correspond to moderate-to-strong ENSO events (Mysak 1986). Thus we may estimate an average period of 5.5 years for a moderate-to-strong ENSO event to occur.

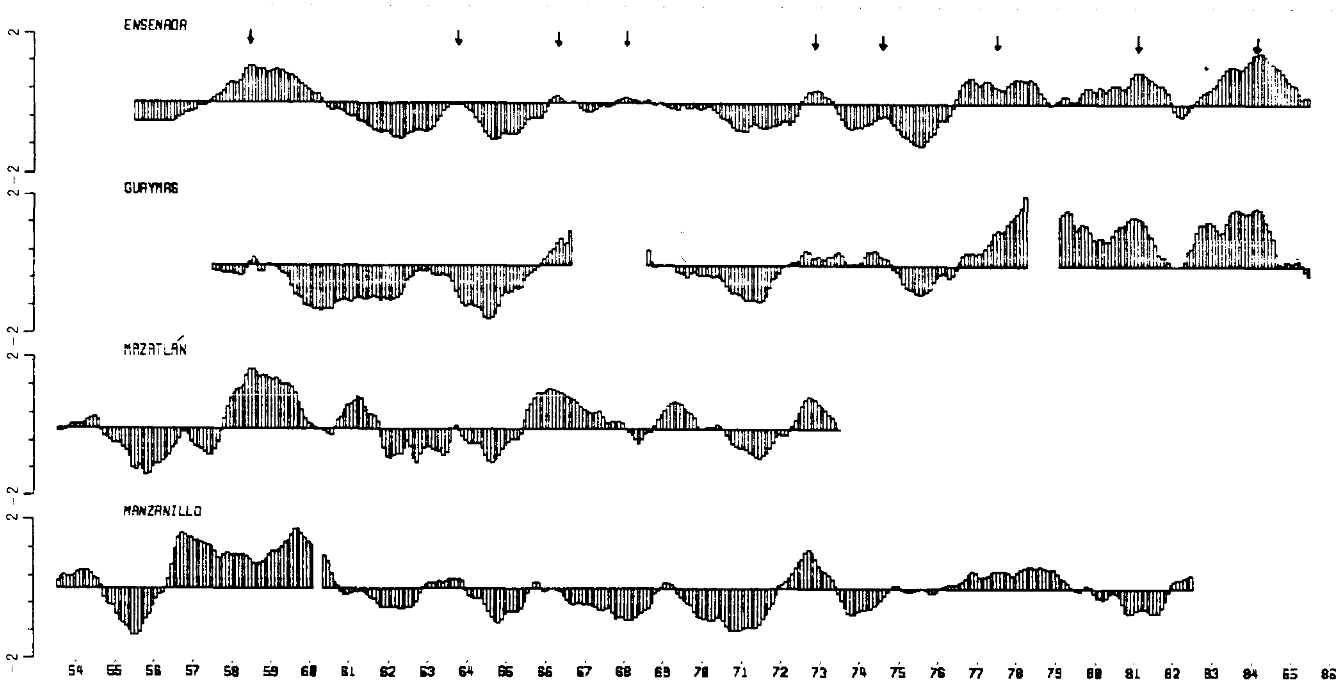

Figure 4. Smoothed monthly series of sea-surface temperature anomalies.

Anomalies at Mazatlán and Manzanillo show other maxima during 1963, 1974, and 1980 (the last one showing only in the Manzanillo series), of which only the first has been reported as a low-intensity ENSO event (Mysak 1986). If we consider all of these, a periodicity of 3.66 years may be estimated for an ENSO event of any intensity. Mysak does not report on the 1974 and 1980 anomalies.

When the series is smoothed by means of moving averages (Figure 2), dominance of sign on longer periods becomes evident. Negative anomalies thus

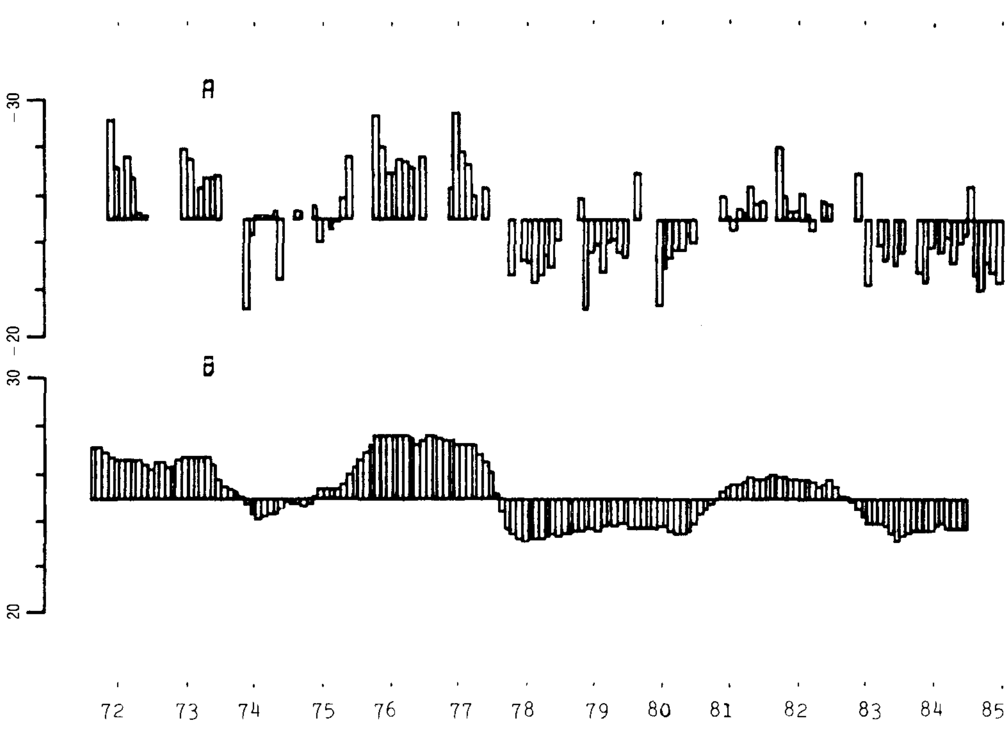

Figure 5. *A*, Monthly mean series of length anomalies for Pacific sardine in the Gulf of California. *B*, Smoothed monthly mean series of length anomalies.

predominate between 1960 and 1971, following a period of normal years through 1981; from 1982 there are only positive anomalies, with a maximum during 1982–83. A component of longer than 25 years is suggested.

When we filtered the linear trend, the spectral analysis showed 14 harmonic components in the Ensenada series, accounting for 80.71% of the total variation; 13 components in the Guaymas series, accounting for 93.75% of the total variation; 10 in the Mazatlán series, accounting for 83.14%; and 11 in the Manzanillo series, accounting for 77.37%. This analysis validated the preliminary findings.

Three of these components are shared by all the series; another is common to only three of them. These components are possibly generated by macroscale phenomena, since they show up in spite of the distance between points, and in spite of the different local current systems. Parameters and maxima estimated for these harmonics are shown in Table 1.

SST anomalies (Figure 3) fluctuate much more randomly. When 12-month running averages are used (Figure 4), two cycles are suggested. The first is shown by the trends toward positive anomalies (shown by arrows in the figure), with an approximate period of 3.6 years, coincident with ENSO events. The second cycle, deduced through sign dominance, has an approximate period of 26 years.

Of the harmonic components detected by spectral analysis—10 for Ensenada (91.81% of the variation), 9 for Guaymas (96%), 8 for Mazatlán (90.53%), and 11 for Manzanillo (84.53%)—there is coincidence in one component for all the series with a period of 3+ years (also found in the MSL

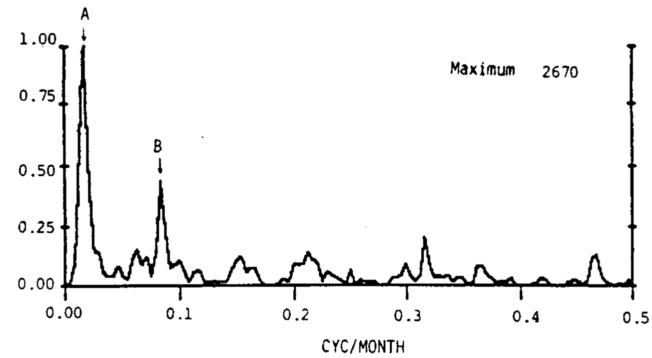

Figure 6. Mean length frequency normalized spectrum of Pacific sardine: *A*, frequency 0.0153 cycles/month (5.4383 years/cycle); *B*, frequency 0.0831 cycles/month (12.03 months/cycle). Maximum is for the main harmonic variance.

series). A second component, of longer period, is not totally consistent, since it does not appear in the Mazatlán series. Furthermore, although in Manzanillo there is a 19.5-year period, Guaymas shows a 26.4-year period, and Ensenada a 25.7-year period (Table 2).

Size anomalies (Figure 5A) show an evident cycle, with maxima during 1971–72, 1975–76, and 1981–82—all of them one year ahead of moderate or strong ENSO events. Frequency is estimated at 4.66 years. The anomalies, smoothed by running averages (Figure 5B) show another smaller amplitude cycle that shows up twice for every time the former one appears. This smaller cycle has a period of 2.3 years.

Spectral analysis of this series yielded a model with 11 harmonic components, explaining 82.96% of the total variation. Of all the components, three are major contributors to variance, with periods of 5.44, 1, and 2.8 years. The first and last com-

TABLE 2
Common Harmonic Parameters and Maxima for Sea-Surface Temperature Series

Period in years	Amplitude	Phase	Peaks (year-month)					
Ensenada								
25.762	0.3286	−0.92495	5810	8407				
3.575	0.3181	−1.0592	5508	5903	6210	6604	6911	7306
			7701	8008	8403	8709		
Guaymas								
3.564	0.4599	2.83911	5812	6207	6601	6908	7303	7610
			8005	8311	8706			
26.465	0.3318	0.28934	8203					
Mazatlán								
3.658	0.3798	−2.96814	5409	5805	6201	6509	6905	7301
			7609	8005	8312	8708		
Manzanillo								
19.567	0.5283	−1.71554	5805	7711	9706			
3.139	0.5104	−1.61298	5310	5612	6001	6303	6605	6906
			7208	7510	7811	8201	8503	8804

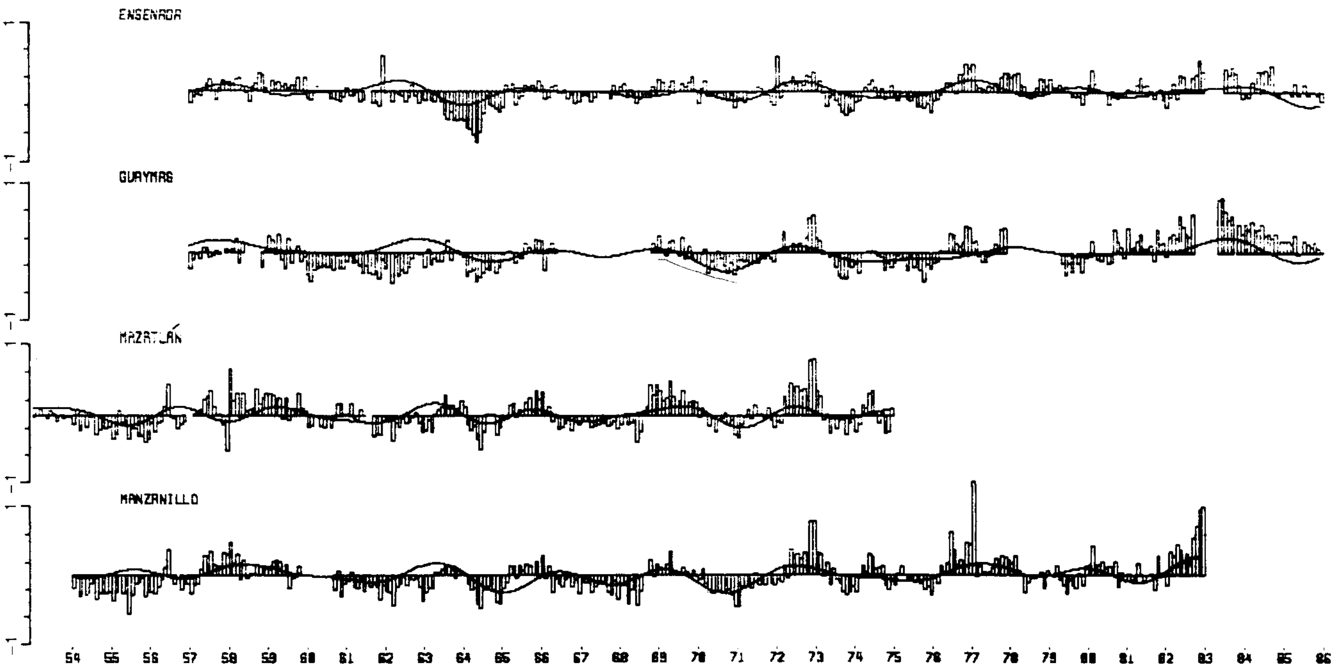

Figure 7. Observed anomalies (bars) and common harmonics in the mean sea-level series (continuous line).

ponents coincide with components on the MSL series.

DISCUSSION

The analysis showed, besides the obvious annual component, four more components that are coherent (in the sense that they appear in most of the series) with 2+ years, 3+ years, 5+ years, and 20+ years. Not all of the components appeared in every series. SST series are less clear, particularly inside the Gulf of California, possibly because of the particular dynamics of the area.

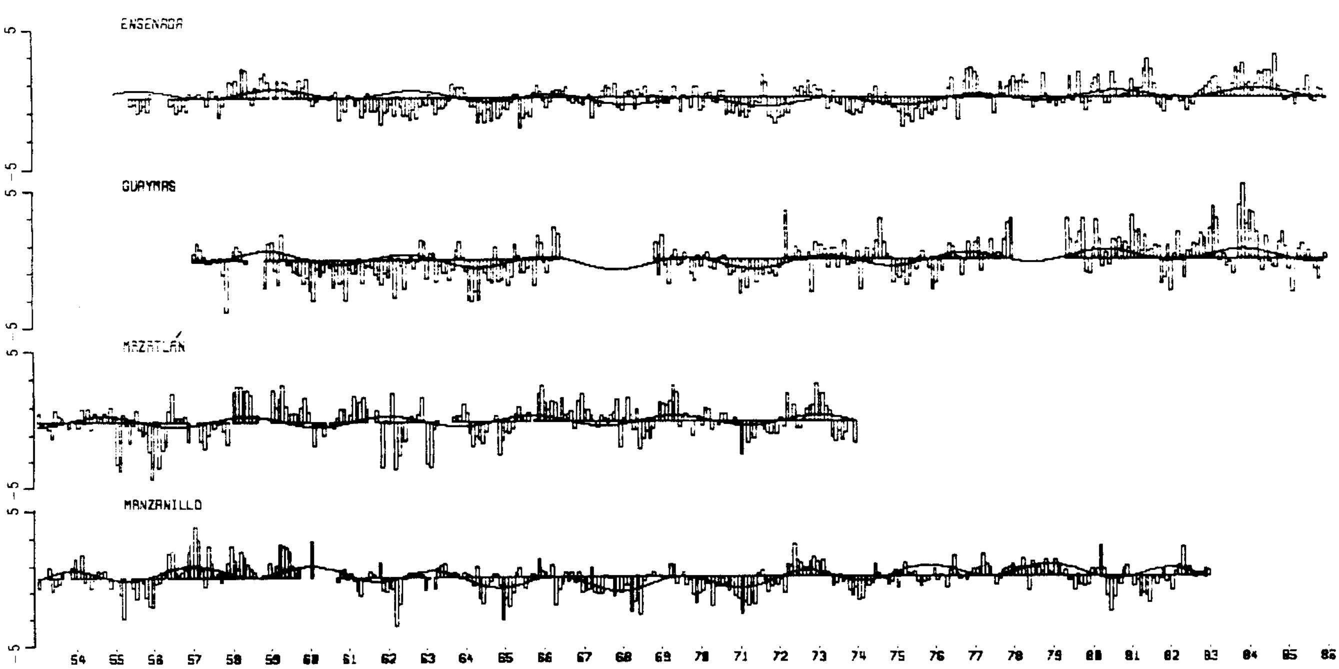

Figure 8. Observed anomalies (bars) and common harmonics in the sea-surface temperature series (continuous line).

The cycle of 5+ years is the one most clearly reflected in the series of sardine average size (Figure 5A). The signal of this cycle is so strong in the sardine size series that it overrides the annual component (Figure 6). We suggest that this is due to abnormally strong recruitment. Similar length-frequency distributions have been reported for Pacific sardines off California (Clark 1936). This cycle also coincides with the cycle of 5+ years reported by Mysak (1986). Besides the cycle of 5+ years, the sardine series also shows the cycle of 2+ years that has been related to El Niño (Monin et al. 1977).

The cycles of 3+ years and 20+ years are not previously reported, possibly because distance attenuation precludes their being detected as far north as British Columbia. They show up in our series because they have been recorded in areas that are considerably closer to the equatorial belt, where the phenomenon seems to originate.

We show the interaction of the anomalies of the four MSL and SST series to simulate their general behavior (Figures 7 and 8). In particular, the strong ENSO events are coincident with years in which the three cycles are in phase (such as 1958–60 and 1982–83). Weak events are associated with years during which cycles are out of phase. Events of intermediate strength are, as expected, associated with partially out-of-phase years at varying degrees.

Thus we suggest that the four cycles detected originate independently from each other and that they determine the ENSO events, with a strength proportional to their degree of coincidence.

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