

A 250-YEAR HISTORY OF PELAGIC FISH ABUNDANCES FROM THE ANAEROBIC SEDIMENTS OF THE CENTRAL GULF OF CALIFORNIA

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ABSTRACT

The recent appearance of significant numbers of northern anchovy in the Gulf of California, along with the recent decline in sardine biomass, has prompted the fishing industry, agencies of the Mexican government, and the research community to ask whether similar events have occurred in the past. Are these events connected, and are they part of some long-term pattern? In order to answer such questions, we sampled and counted the fish scales in an 85-cm box core from the anaerobic varved sediments of the central Gulf of California. This core was collected from an area underlying one of the principal sardine spawning regions of the gulf. On the basis of these counts, we reconstructed time series of scale-deposition rates for Pacific sardine, northern anchovy, Pacific mackerel, Pacific hake (or a close variant), and an undifferentiated group of myctophids. The time series are resolved into 10-year sample blocks and extend from approximately 1730 to nearly 1980. These reconstructions show a strongly negative association between the presence of sardines and anchovies, with anchovies dominating throughout the nineteenth century, and with only two important peaks of sardine scale deposition—one in the twentieth century and one at the end of the eighteenth century. Both the mackerel and the myctophid group vary more like sardines than like anchovies (with the hake intermediate between anchovies and sardines). This suggests an overall coherent pattern in changing ecosystem structure that operates over a period of about 120 to 140 years.

By comparing the sardine and anchovy series from the Gulf of California to information from the California Current, we can examine this variability within a geographic as well as a temporal framework. Reference to the Northern Hemisphere air temperature adds another dimension to our interpretations of the inferred variability. The regional differences and relations to climate suggest that the populations (or stocks) of both species from the dif-

ferent regions do not vary independently through time. The concentrations of fish shift from one region to another over periods of several decades. The relation to climate is not yet clear, but altogether, the information here suggests that climate does mediate population sizes, but this process is still subject to strong filtering through biological interactions among species.

RESUMEN

Dos hechos recientes—la aparición de cantidades considerables de anchoveta noroesteña en el Golfo de California y la declinación de la biomasa de sardina—produjeron que tanto la industria como varias dependencias gubernamentales mexicanas y la comunidad científica se preguntaran si en el pasado ocurrieron eventos similares. ¿Cuál es la relación entre ambos sucesos? ¿Encajan en algún patrón a largo plazo? Para contestar estas preguntas, hicimos un muestreo y conteo de escamas de peces en un “núcleo-caja” de 85 cm, obtenido en sedimentos laminados anaeróbicos del Golfo de California central. El área donde se obtuvo el núcleo se encuentra en una de las principales zonas de desove de sardina en el golfo. Basándonos en estos conteos, reconstruimos series de tiempo de tasas de depositación de escamas de sardina Monterrey, anchoveta noroesteña, macarela, merluza (o una variedad afín), y un grupo de mictófidios. (Los mictófidios se analizaron en conjunto.) Las series de tiempo incluyen de 1730 hasta casi 1980, y tienen una resolución de bloques de muestro de 10 años. Las series muestran una correlación muy negativa entre la sardina y anchoveta. Las anchovetas dominan en el siglo diecinueve; en las tasas de depositación de escamas de sardina, solo hubo dos máximos, uno en el siglo veinte y otro a finales del siglo dieciocho. La variación de la macarela y los mictófidios se asemejó más a la de la sardina que a la de la anchoveta. (La variación de la merluza fué intermedia, entre la de la sardina y la de la anchoveta.) Esto sugiere que el patrón de cambio en la estructura del ecosistema es coherente (con un período de 120 a 140 años).

Las series de sardina y anchoveta del Golfo de California pueden compararse con información

de la corriente de California para examinar la variación geográfica y temporal; la temperatura del aire del Hemisferio Norte añade otra dimensión a la interpretación de la variabilidad. Las diferencias regionales y la relación con el clima sugieren que las poblaciones (o stocks) de ambas especies de las dos regiones no varían independientemente en el tiempo. Las concentraciones de peces se desplazan de una región a otra en períodos de varias décadas. El papel del clima es aún poco claro; sin embargo, en conjunto, la información que aquí se presenta sugiere que el clima interviene en los tamaños poblacionales, pero que este proceso es filtrado por interacciones inter-específicas (y quizá intra-específicas).

INTRODUCTION

More than 25 years ago, Ahlstrom (1967) wrote, "The northern anchovy, a somewhat more temperate species [compared to the Pacific sardine] does not occur in the Gulf [of California] . . .". With what now seems an almost offhand comment, he relegated the problem of co-occurrence and/or alternation of the Pacific sardine with the northern anchovy in the Gulf of California to a "nonquestion" of the kind described by Oliver (1991, p. 43). In 1986, however, an unexpected catch of more than 2,000 MT of northern anchovy by the gulf sardine fleet (Hammann and Cisneros 1989) quickly made this an important issue, not only because of its implications for the commercial fishery, but for our understanding of the structure and stability of the gulf's pelagic ecosystem. By the end of 1992 the catch of Pacific sardine had plummeted from a 1988–89 peak greater than 250,000 MT (Cisneros et al. 1991) to 6,400 MT¹. Accompanying this dramatic decline in sardine catch, a significant by-catch of northern anchovy has persisted. In 1991–92 this by-catch nearly equaled the sardine catch, reaching a total of approximately 5,200 MT.

Industrial-scale exploitation of the Pacific sardine in the Gulf of California began in 1969, after exploratory fishing by the Ensenada fleet first detected significant volumes in 1967–68 (Solis-Villa 1981). The history of direct observations for the sardine is thus limited mainly to a 23-year time series of catch data. Fundamental questions arising from the appearance of the northern anchovy and the current decline of the Pacific sardine in the gulf are difficult to address with this 23-year data set; the changes appear unique in this time series but may not be unusual from the

perspective of variability over decadal-to-centennial time scales. Setting aside the uncertainty of whether the immediate cause of the sardine decline was overfishing, we should first determine whether or not we should have been surprised by these developments, from the perspective of a longer history of the ecosystem.

As the initial phase in reconstructing such a history, we have inventoried scale deposition in the anaerobic sediments of the central Gulf of California since the early part of the eighteenth century. Our initial motivation for this work was the need to address two specific questions about the pelagic fish populations. First, we wanted to know whether there is evidence for any significant earlier presence of northern anchovy in the gulf. Our second question was whether the population of Pacific sardine has gone through periods of decline during the past 250 years that may have been similar to the current decline. Our work has answered these two questions and led to a broader description of the pelagic populations by revealing not only the relationships between sardine and anchovy, but also their relationships with hake, mackerel, and myctophids. In our discussion we provide a larger context for considering the results by comparing the sardine and anchovy records from the Gulf of California with observations from the California Current and with a generalized history of global climate change since the mid-nineteenth century.

Although no prior attempt has been made to use the natural record of scale deposition in the Gulf of California to detect changes in fish populations, the value of such work for documenting and understanding pelagic fish populations has been established by the studies of Soutar and Isaacs (1969, 1974) and Baumgartner et al. (1992) on the anaerobic sediments of the Santa Barbara Basin off southern California. Deposition of distinct seasonal laminae several millimeters thick in both the Santa Barbara Basin and the gulf provide the natural calendars needed for the high-resolution reconstruction of scale deposition. The annual layers (known as varves) in the Gulf of California are preserved along the continental slopes where bioturbation is inhibited within the midwater oxygen minimum (Calvert 1964).

MATERIALS AND METHODS

Material used for this study was retrieved in the summer of 1978 with an open-vented Soutar box corer measuring 30 × 30 × 100 cm; the core was frozen on board ship. The coring site (7807–1305) lies approximately 650 m deep on the continental

¹Nevárez, M. O., M. Martínez, R. Morales, and P. Santos. 1992. Analisis comparativo de la pesquería de sardina en el Golfo de California; temporadas de pesca 1990/91 y 1991/92. CalCOFI program and abstracts, Annual Conference, Asilomar, Calif.

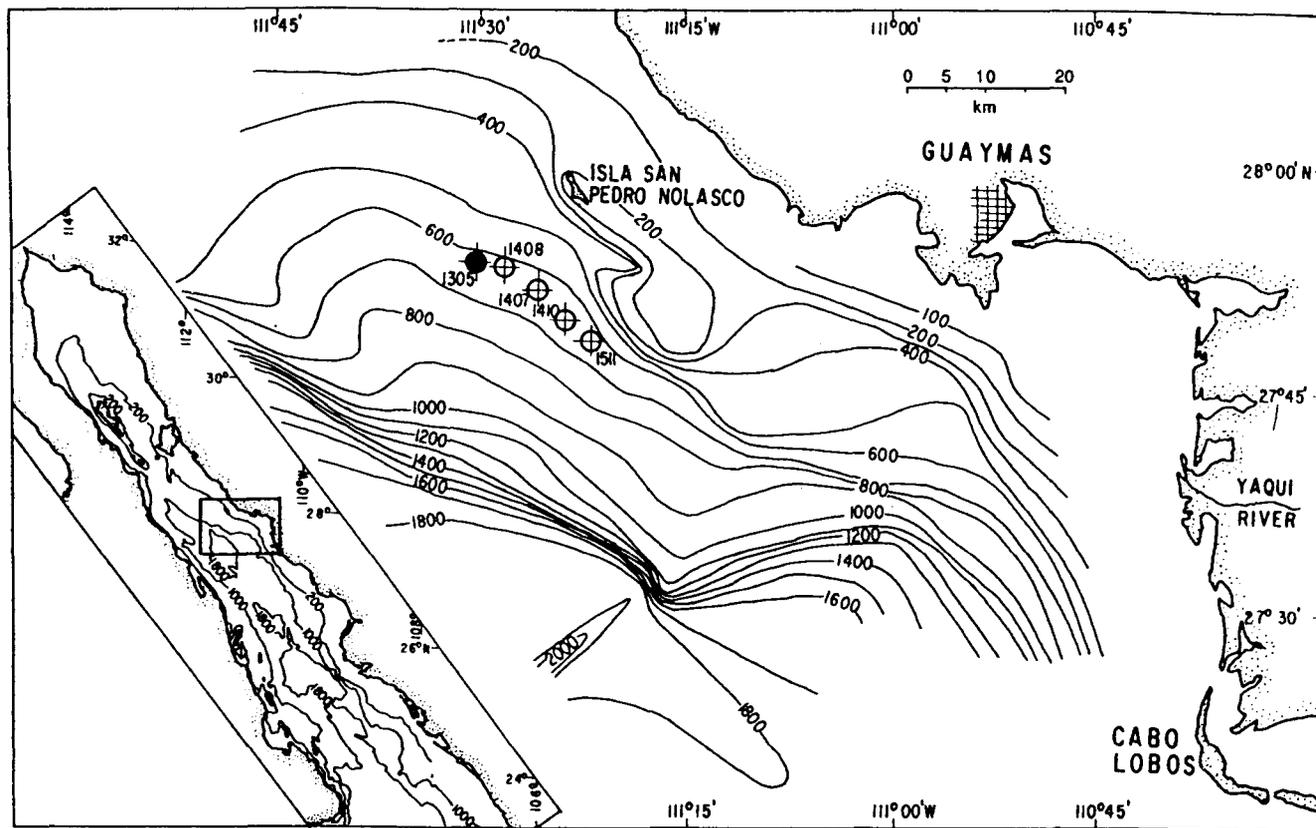


Figure 1. Solid circle, location of box core 7807-1305 on continental slope of the central Gulf of California. Open circles are locations of box cores used for reconstructing the twentieth-century varve chronology (Baumgartner et al. 1991).

slope off Guaymas, Sonora (figure 1), and is located within the Pacific sardine's principal spawning grounds in the gulf (Hammann et al. 1988). The core is approximately 85 cm long and represents sedimentation since the beginning of the eighteenth century. Coring and handling procedures are described in Baumgartner et al. 1991.

A sediment column equivalent to one-quarter of the core was dedicated to the analysis of fish scales; this represents an area of deposition of approximately 200 cm². The abrupt decrease in depositional area for the upper two samples (table 1) is due to deformation and loss of material associated with freezing of the core, which caused vertical doming in the laminae in the center of the core (more pronounced near the top of the core). Individual samples for scale counts constitute a continuous series of 10-year intervals cut from the sediment column; varve boundaries were identified visually from photographs of the exposed faces of the sediment column.

A detailed master chronology for the Guaymas Slope was developed for the twentieth century by Baumgartner et al. (1991) from cross-correlation and independent radiometric dating of the five (in-

cluding core 1305 used in this study) taken from the sites shown in figure 1. Although varve preservation is excellent over the past 250 years, the lateral continuity of the varves along the slope is occasionally disrupted by small-scale, secondary mass movement (described in Baumgartner et al. 1991). This has delayed development of a well-constrained, year-by-year chronology like that attained for the period after A.D. 1910. For the period before 1910 our chronology is based only on varve counts from core 1305 (as opposed to cross-dating among the five available box cores). We estimate the resulting chronological uncertainty to be approximately 10 years at the bottom of the core, which is dated to the nearest 5 years as A.D. 1735.

Each of the 25 samples was thawed and washed through 500- and 250- μ m sieves with the aid of a dispersant (Kodak Photo-Flo) in order to separate the fish scales and other remains from the sediment. The sieved residue was preserved in a solution of 60% ethanol. We used a Wild stereo microscope to identify the fish scales, and counted them from both size fractions of the wet subsamples. Identifications were made with the aid of the reference collection

TABLE 1
 Fish-Scale Data by Sampling Interval Based on Preliminary Varve Chronology of Box Core 7807-1305,
 Central Gulf of California

Sample interval	Area cm ²	Anchovy		Sardine		Hake		Mackerel		Myctophids	
		N	SDR	N	SDR	N	SDR	N	SDR	N	SDR
1970-80	61.3	0	0.0	0	0.0	0	0.0	0	0.0	4	8.7
1960-69	61.3	0	0.0	2	3.3	1	1.6	3	4.9	25	40.8
1950-59	186.3	0	0.0	3	1.6	1	0.5	2	1.1	95	51.0
1940-49	186.3	0	0.0	13	12.1	3	1.9	1	1.0	58	56.5
1930-39	177.1	0	0.0	4	1.7	0	0.1	2	1.9	119	108.3
1920-29	222.2	0	0.4	1	0.3	1	0.9	8	3.6	454	165.9
1910-19	168.4	3	1.8	0	0.0	4	2.4	6	3.6	64	38.0
1900-09	175.9	7	4.0	0	0.0	1	0.6	0	0.0	94	53.4
1890-99	192.5	10	5.2	0	0.0	2	1.0	0	0.0	44	22.9
1880-89	202.7	7	3.5	0	0.0	1	0.5	0	0.0	67	33.1
1870-79	194.7	114	58.5	0	0.0	3	1.5	4	2.1	69	35.4
1860-69	206.9	21	10.1	0	0.0	1	0.5	1	0.5	54	26.1
1850-59	224.9	20	8.9	0	0.0	3	1.3	0	0.0	30	13.3
1840-49	192.2	0	0.0	0	0.0	0	0.0	0	0.0	15	7.8
1830-39	216.2	5	2.1	0	0.0	0	0.0	0	0.0	17	7.1
1820-29	203.6	2	2.5	0	0.0	0	0.0	0	0.0	55	67.5
1810-19	197.5	1	0.5	0	0.0	0	0.0	0	0.0	99	50.1
1800-09	205.6	0	0.0	0	0.0	0	0.0	0	0.0	8	3.9
1790-99	184.0	1	0.9	4	5.0	0	0.0	10	9.1	262	237.3
1780-89	197.5	4	2.0	1	0.5	0	0.0	13	6.6	118	59.7
1770-79	204.2	5	2.4	2	1.0	0	0.0	0	0.0	69	33.8
1760-69	214.0	5	2.3	0	0.0	0	0.0	0	0.0	3	1.4
1750-59	197.8	2	1.0	0	0.0	1	0.5	0	0.0	14	7.1
1740-49	197.8	7	3.5	0	0.0	1	0.0	1	0.5	100	50.5
1730-39	197.8	4	3.4	0	0.0	1	0.8	2	1.7	40	33.7

Area = measured depositional surface of each sample. N = number of scales in 10-year interval. SDR = scale-deposition rate per year normalized to depositional area of 1000 cm². Note that where sample intervals do not encompass a full 10 years of deposition (i.e., first and last intervals, 1734-39, 1970-78; and intervals interrupted by hiatuses: 1820-29, 1940-49), the SDR values are still normalized to represent a 10-year interval.

assembled by A. Soutar at the Scripps Institution of Oceanography complemented by a collection assembled at CICESE.

It is important to note that these data were obtained from a single box core and, for now, must be considered without recourse to replicates from the same core or from other cores within the study area. However, the 200-cm² sample of depositional area provides a considerably higher margin of reliability for the scale counts than for any single sample in previously published work (cf. Soutar and Isaacs 1974). Careful analysis by Baumgartner et al. (1992) has shown that counts made for sampled areas as small as 30 cm² yield between-core results that are reproducible over distances of approximately 7 kilometers in the Santa Barbara Basin.

RESULTS

In addition to scales of *Sardinops sagax*, significant numbers of scales of Pacific mackerel (*Scomber japonicus*) and a large number from *Engraulis mordax* were found. There also is a significant presence of hake (*Merluccius angustimanus*?) with scales indistinguishable from Pacific hake, *M. productus*. Difficulty in distinguishing among scales of the various myctophids led us to lump all mesopelagic species of this

group into a single category of "undifferentiated myctophids." Holmgren-Urba (1993), however, shows that most of the variation in the myctophid group can be explained by *Benthosema panamense* and *Diogenichthys laternatus*.

The data needed to reconstruct scale-deposition rates are given in table 1. These include the measured area of depositional surface for each sample and the number of scales found in each 10-year sample block. Scale-deposition rates (SDR's) are reported as number of scales per 1,000 cm² per year to allow direct comparison with plots in Soutar and Isaacs 1974 and Baumgartner et al. 1992. We emphasize here that the dates of the sample intervals are based upon a preliminary chronology that we expect to refine in the future. However, we do not expect accumulative changes downcore to be greater than about 10 years.

Scale-deposition rates for each of the five species or groups are plotted in figure 2. This figure provides a clear and resounding answer to the question of whether the northern anchovy has been present prior to its appearance in the late 1980s. The data plotted in figure 2 demonstrate that *Engraulis mordax* was sufficiently abundant to leave a record of its scales from the early part of the eighteenth century

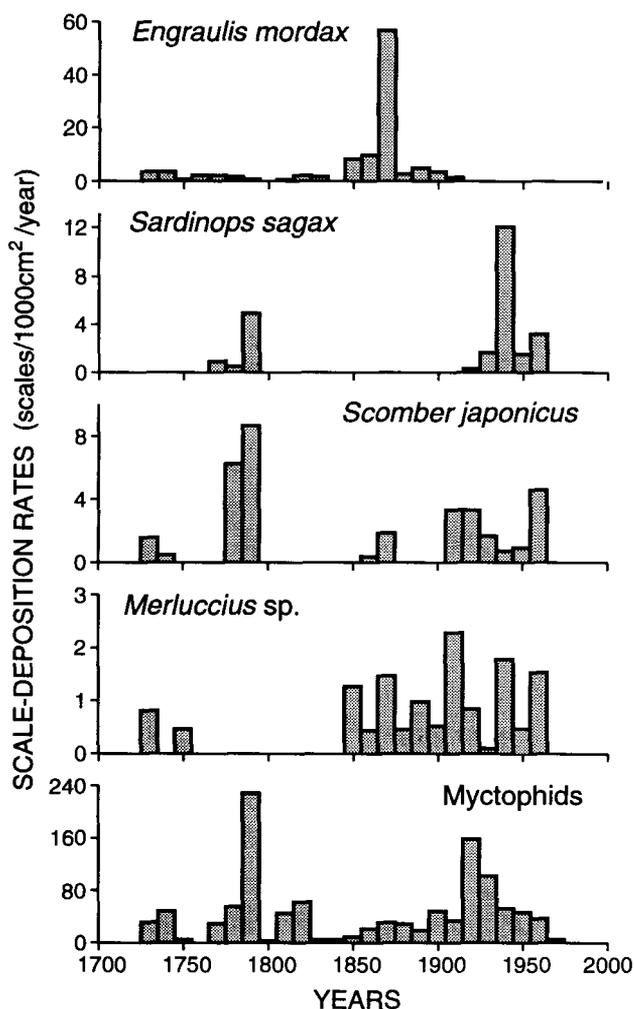


Figure 2. Time series of scale-deposition rates of *Engraulis mordax*, *Sardinops sagax*, *Scomber japonicus*, *Merluccius* sp., and the myctophid group reconstructed from box core 7807-1305 collected from the Guaymas Slope in the central Gulf of California. The time series covers the period from 1730 through 1980 and is resolved into 10-year intervals. Note that the chronology below 1910 is preliminary and has an associated uncertainty of approximately ± 10 years.

and persisted through the decade of the 1920s. The large peak in the anchovy SDR's suggests an abrupt expansion followed by an equally abrupt decline of the anchovy biomass in the gulf around the decade of the 1870s.

Looking beyond the presence of the anchovy, we find the pattern of sardine presence/absence adds another very important aspect to this history by its striking relationship to the anchovy record. The two episodes of sardine scale deposition occur virtually 180° out of phase with anchovy scale deposition. Table 1 and figure 2 show that the major transition between anchovy and sardine scale deposition in the early twentieth century occurred with only one decade of overlap (the 1920s). The peak of sardine scale deposition at the end of the eighteenth century was

accompanied by a measurable decrease in the anchovy SDR followed by a decade of no anchovy scales (1800–1809; see table 1).

The record of mackerel scale deposition is much more similar to the sardine pattern than to the anchovy pattern. This is seen in the strong peak of mackerel SDR in the late eighteenth century, its poor representation during the nineteenth century, and its return in the twentieth century (displaying, however, a locally inverse relationship with the sardines between 1910 and 1970).

The pattern of the myctophid record also resembles the sardine series. In particular, the two very large peaks in myctophid scale deposition occur in almost perfect synchronicity with the increase in sardine scale deposition of the late eighteenth and early twentieth centuries. Like the sardines, the myctophid group also appears to vary roughly 180° out of phase with the anchovies.

The hake record in figure 2 is the most different from all other records of scale deposition and thus adds another dimension to the information from the scales. We can characterize the hake from another approach by noting the presence of hake scales during the anchovy peak of the 1870s, during the sardine-anchovy transition (reaching a maximum value during the decade of crossover between the anchovies and sardines), and continuing into the twentieth century with the sardines.

The relations among the five time series are summarized more succinctly in figures 3 and 4. These figures show the plots of the cross-correlation functions for each pair of the species in figure 2. The correlations have been calculated with the log-transformed data (natural logarithm) of the original series. This provides smoother curves of the lagged correlations and more emphasis on the negative correlations without altering the overall pattern (see Holmgren-Urba 1993). Because the effects of autocorrelation (relative to the length of the series) severely reduce the effective degrees of freedom, these figures should be used more to describe and compare the associations among the species than to determine absolute measures of significance. Of course, the degrees of freedom are also decreased with the increasing lags. Correlation values of approximately 0.5, in the neighborhood of 0-lag are, however, significant at a level of 95% confidence.

The plots in figures 3 and 4 are grouped according to distinct patterns of the cross-correlation functions. The plots in the left-hand column of figure 3 exhibit a pattern similar to that of a sine wave. This pattern is best developed for the comparison between the anchovy and sardine, with the best fit

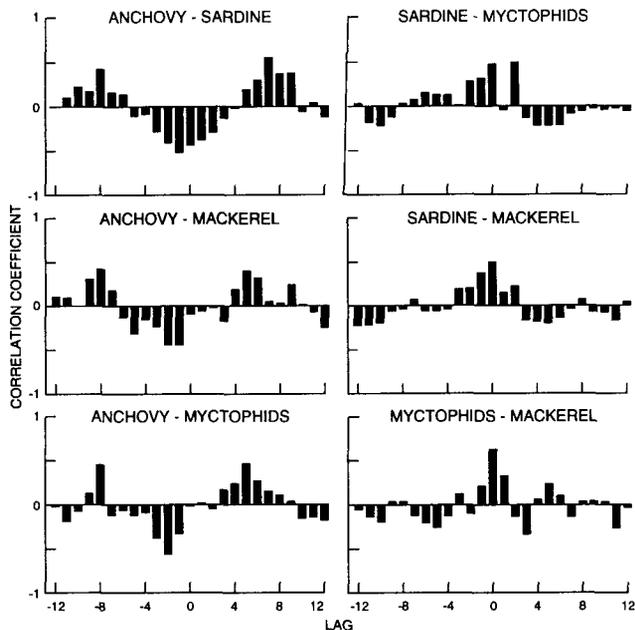


Figure 3. Cross-correlation functions of the time series of pairs of taxa formed from the combinations of the anchovy, sardine, mackerel, and myctophids in figure 2. Correlations have been calculated for the log transformations of the data in the figure 2 series. Plots are arranged in two columns according to the characteristics of the cross-correlation functions.

occurring when the anchovy series lags the sardine series by one decade. The cross-correlation also measures the period between the two peaks of the sardine series and that of the anchovy as 80 years (anchovy lags) and 70 years (sardine lagging the anchovy series).

The cross-correlation functions for comparisons between anchovy and mackerel and between anchovy and myctophids (lower two plots in left-hand column of figure 3) are very similar to that of the anchovy-sardine pair. These patterns highlight the basic similarity of the sardine, mackerel, and myctophid series and their common inverse relation to the anchovy. The three plots in the right-hand column of figure 3 directly illustrate the correlation structure among the sardine, mackerel, and myctophid series. The plots in figure 4 constitute a separate group composed of the correlations between hake time series and the other four time series.

DISCUSSION

For a broader context, we can compare the scale-deposition data from the Gulf of California with data from two nearshore sites in the California Current. The northern site is the Santa Barbara Basin just south of Point Conception. The southern site is the Soledad Basin off southern Baja California, just north of Magdalena Bay. For a reference to global climate, we have also included in this comparison

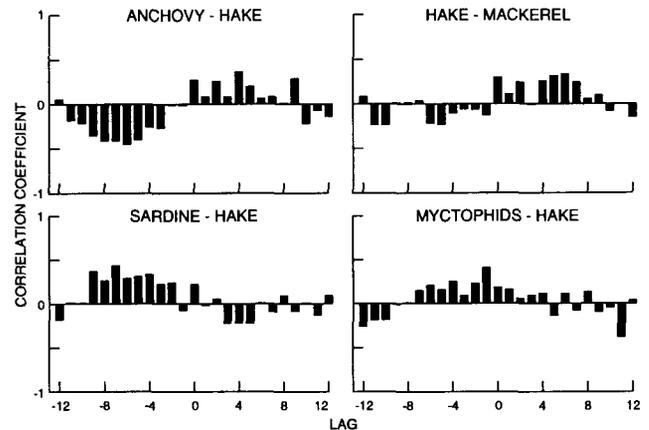


Figure 4. Cross-correlation functions calculated from the combinations of hake with the four taxa of anchovy, sardine, mackerel, and myctophids.

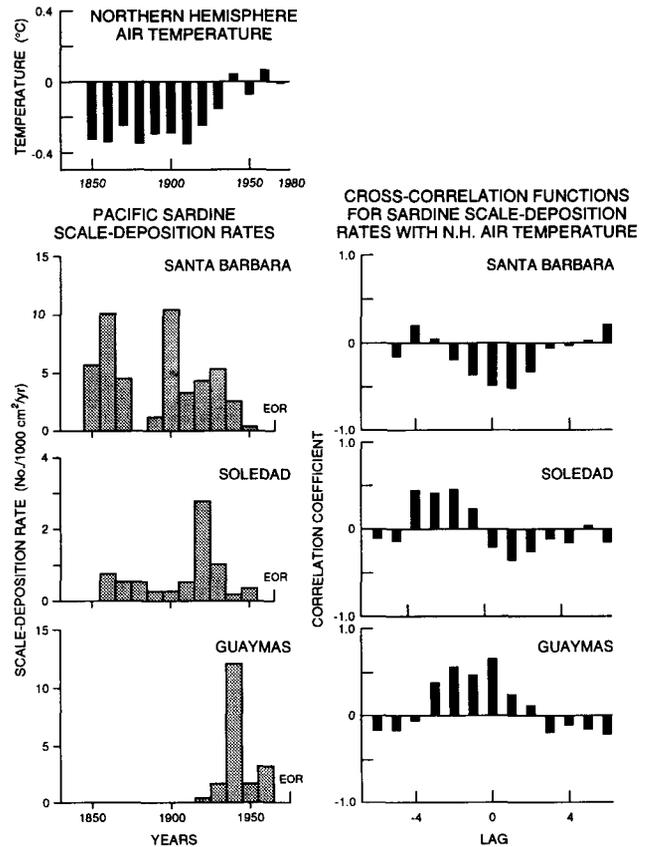


Figure 5. Plots of the time series of scale-deposition rates from A.D. 1850 for Pacific sardine from Santa Barbara Basin, Soledad Basin, and Guaymas Slope (lightly shaded bars in column at left of figure) compared with the Northern Hemisphere record of air temperature from Jones and Kelly (1988). The three plots to the right of the SDR series are the cross-correlation functions calculated from comparison of each series with the Northern Hemisphere air-temperature record.

Jones and Kelly's (1988) now familiar record of air temperature over the Northern Hemisphere.

Figure 5 contains the plots of the Pacific sardine records from the Santa Barbara Basin, the Soledad

Basin, and the Guaymas Slope. Figure 6 shows the plots of the northern anchovy from these three areas. The two California Current sites have been used to compare the histories of the northern and southern stocks of the sardine and anchovies (Soutar and Isaacs 1974), which are centered around the Southern California Bight and the area around Punta Eugenia in central Baja California. In figures 5 and 6 the Northern Hemisphere air-temperature record is aligned with the three scale-deposition plots. The beginning of the records has been set at 1850 to coincide with the start of the temperature record. The SDR records from the Santa Barbara and Soledad basins are reported as 5-year averages by Soutar and Isaacs (1974). We have modified both the SDR records of Soutar and Isaacs (1974) and the air temperature record to yield 10-year averages for this comparison. The right-hand columns in figures 5 and 6 show the cross-correlations between the Northern Hemisphere air-temperature curve and each of the sardine and anchovy series.

Intercomparison of the sardine series shows an intriguing pattern of successive 20-year displacements of the recent major peaks in these three regional "populations." We refer to the peak centered at 1900–10 in Santa Barbara, at 1920–30 in the Soledad Basin, and at 1940–50 in the Guaymas records. It is also worth noting that the earlier high sardine abundance in the Santa Barbara record (1850–80) is not obvious in the Soledad record, although scale deposition did occur in the Soledad Basin in a pattern that might be consistent with a 10–20-year lag of lowered deposition in Santa Barbara. From the Guaymas record we learn that the earlier peak in Santa Barbara, which is markedly lower in Soledad Basin, is completely absent in the central Gulf of California.

Intercomparison of the three regional northern anchovy populations (figure 6) indicates a decidedly different pattern than for the sardine. The anchovy series show that the major peak of abundance in the Gulf of California (1870–80) co-occurs with the major peak in the sediments of the Soledad Basin. These two coinciding peaks show a moderately inverse relationship to the pattern in Santa Barbara with its major peak in 1870–80.

The relations between the Northern Hemisphere air temperature and both sets of scale-deposition series are equally intriguing. The more readily interpretable relation is that of the Santa Barbara anchovy record and the air temperature (figure 6). This shows a well-knit pattern of cross-correlation, indicating a strong negative association between anchovy and temperature, with strong correlation at 0-lag. Thus

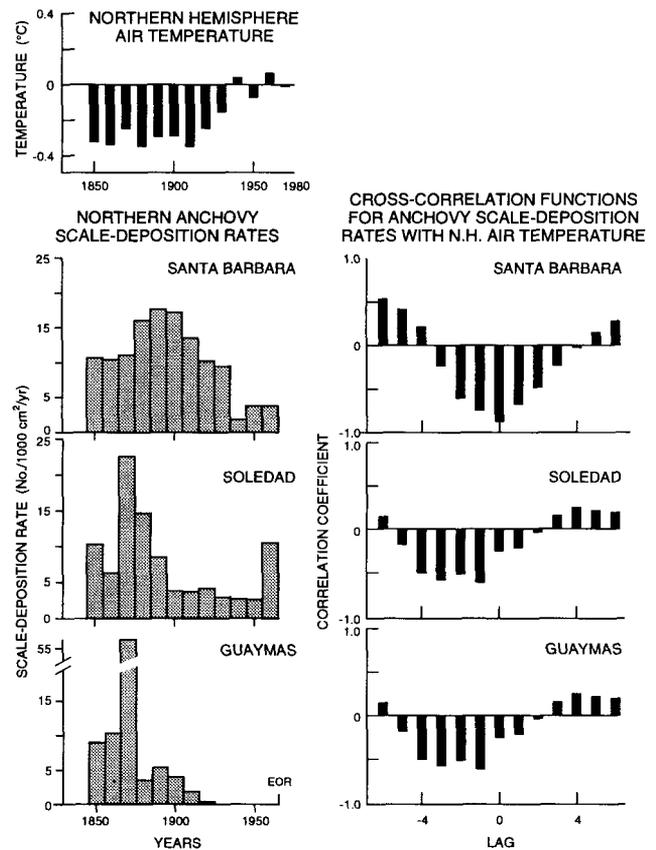


Figure 6. Plots of the time series of scale-deposition rates from A.D. 1850 for northern anchovy from Santa Barbara Basin, Soledad Basin, and Guaymas Slope (lightly shaded bars in column at left of figure) compared with the Northern Hemisphere record of air temperature from Jones and Kelly (1988). The three plots to the right of the SDR series are the cross-correlation functions calculated from comparison of each series with the Northern Hemisphere air-temperature record.

the anchovy maximum coincides with the cool period of the nineteenth century, whereas the decline and minimum abundance coincide with the period of global warming into the twentieth century. The Soledad Basin and Guaymas records are also negatively correlated with the temperature record (figure 6), but the decline in both areas began before the global warming began.

The relation between hemispheric air temperature and the regional sardine records is more difficult to interpret. The successive displacement of the population maxima between Santa Barbara and Guaymas results in a reversal in the correlation structure plotted in figure 6. Guaymas shows a well-defined positive relationship compared to hemispheric temperature; the Santa Barbara record is negatively correlated to the temperature, although not in the degree shown by the anchovy. Interestingly enough, the Soledad Basin, which is geographically intermediate, is also a transition between the Santa Bar-

bara and the Guaymas relations to hemispheric air temperature.

CONCLUSIONS

The scale-deposition data (table 1, figure 2) indicate that northern anchovy played a significant role in the pelagic ecosystem of the Gulf of California. The importance of the anchovy in the gulf seems to have been unsuspected until only a few years ago (cf. Ahlstrom 1967; Hammann and Cisneros 1989). The record also demonstrates a clear tendency for the anchovy to fluctuate out-of-phase with the sardine over a long cycle of roughly 150 years (figure 3). Moreover, there appears to be a broader pattern of coherence among the sardine, mackerel, and the myctophids (figure 3), resulting in a generally negative or inverse relation with the abundance of anchovies. The interrelations among the sardine, anchovy, mackerel, and myctophids (figure 3) are not shared with the hake (figure 4).

It is difficult to ignore the parallels between the recent collapse of the sardine population in the Gulf of California and the collapse in the California Current during the late 1940s and 1950s. Both populations declined under heavy fishing pressure (Barnes et al. 1992) superimposed on broad, natural, decadal-to-centennial-scale biomass fluctuations (Soutar and Isaacs 1974). Both declines appear to be accompanied by an increasing population of northern anchovy (cf. MacCall and Praeger 1988).

From figure 2, however, we see that the alternation or replacement of populations may occur in the gulf without fishing pressure. This has apparently happened repeatedly in the California Current through the past 1700 years over time scales of 50 to 100 years (Baumgartner et al. 1992). The time scale for a full cycle of alternation between the populations in the gulf is of the order of 120 to 140 years (i.e., 1790 to 1940). However, the much shorter record from the gulf (compared to that from Santa Barbara) allows us to sample at best only two major events. Thus we have few degrees of freedom with which to judge the confidence of a typical time scale of the changing ecosystem structure inferred from the scale-deposition series in figure 2.

Comparison of the sardine and anchovy series in the Gulf of California to those in the California Current provides a wider geographic context for interpreting and understanding data not only for the Gulf of California, but also for the entire region of the California Current-Gulf of California. Making these comparisons with reference to Northern Hemisphere air temperature (figures 5 and 6) allows us to consider the geographic differences in the in-

ferred population variability in the light of global climate change. The regional differences and relationships to climate suggest that regional populations (or stocks) of both species probably do not vary independently through time. There are indications of migrational shifts from one region to another over periods of several decades. The relation to climate is not yet clear, but altogether, the information here suggests that climate does mediate population sizes, but this process is still subject to strong filtering through biological interactions among species.

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