LARGE FLUCTUATIONS IN THE SARDINE FISHERY IN THE GULF OF CALIFORNIA: POSSIBLE CAUSES

DANIEL LLUCH-BELDA, FRANCISCO J. MAGALLON
Centro de Investigaciones Biológicas de Baja California Sur
Ocampo No. 312
23000 La Paz, Baja California Sur
México

RICHARD A. SCHWARTZLOSE
Centro de Investigaciones Biológicas de Baja California Sur and
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California 92093

ABSTRACT

The sardine fishery in the Gulf of California has fluctuated widely since its beginning in the late 1960s, causing management problems. This fishery comprises the Monterrey sardine (*Sardinops caerulea*)—the same temperate species that appears on the west coast of North America—and the crinuda sardine (Mexican name for thread herring, genus *Opisthonema*)—a tropical species. The sardine fishery moves south and north as these fish populations migrate south in the winter and spring and north in the later spring and summer. Most fishing takes place along the east side of the central gulf when the Monterrey sardines are spawning. Upwelling and cold water correlate with higher catches and catch per unit of effort (CPUE) for the Monterrey sardine, whereas warmer water produces lower catch and CPUE, especially during an El Niño event. These climatic conditions produce the opposite effect on the crinuda sardine fishery. Larger, more numerous vessels have increased the catch with time, but these changes have not masked the environmental effects on the catch.

RESUMEN

La pesquería de sardina en el Golfo de California ha presentado grandes fluctaciones desde sus inicios a fines de le década de 1960, creando problemas administrativos. Esta pesquería está compuesta por dos especies: la sardina Monterrey (*Sardinops caerulea*), que es la misma especie templada presente en la costa Oeste de Norteamérica, y la sardina crinuda (género *Opisthonema*), que incluye a varias especies tropicales. La pesquería de sardina se desplaza siguiendo las migraciones de las poblaciones de sardina hacia el Sur en el invierno y primavera, y después hacia el Norte a fines de la primavera y el verano. La mayor parte de la pesca se realiza a lo largo de la costa oriental en la parte central del golfo, durante el período de desove de la sardina Monterrey. La surgencias y las aguas frías se correlacionan con las capturas y capturas por unidad de esfuerzo (CPUE) más altas para la sardina Monterrey, mientras que las aguas cálidas están relacionadas con las capturas y CPUE más bajas especialmente durante el evento "El Niño." Estas condiciones climáticas producen el efecto opuesto en la pesquería de la sardina crinuda. La incorporación de embarcaciones mayores y el aumento en el número de barcos han incrementado la captura, pero dichos cambios no han ocultado los efectos ambientales sobre la captura.

[Manuscript received February 11, 1986.]

INTRODUCTION

There is an important fishery in the Gulf of California for two species of sardines, locally known as Monterrey sardine (*Sardinops caerulea*) and crinuda sardine (genus *Opisthonema*). They are presently caught in the central gulf and, to a much smaller extent, along the west coast of southern Baja California. The Monterrey sardine is a temperate species generally considered to be isolated in the gulf from other subpopulations, which range off the west coast of North America. The crinuda sardine is a component of the tropical fauna, and ranges from the Gulf of Panama to the west coast of southern Baja California and into the Gulf of California.

Catch records are available for *S. caerulea* from British Columbia to California starting in 1916 (Radovich 1982). For the west coast of Baja California, catch data are available from 1929 (Pedrin-Osuna and Ancheita-Avalos 1976). This fishery off the west coast of North America increased to a peak catch in the 1940s, then declined rapidly; by the mid-1960s it had disappeared except off southern Baja California. Because of the small catches on Baja California's west coast, a few boats in the sardine fleet moved to the central Gulf of California, establishing a new fishery (Pedrin-Osuna and Ancheita-Avalos 1976). The catch in the 1967-68 season was estimated at 126 metric tons (MT).

Large fluctuations in annual catch have caused considerable management problems. We will discuss these fluctuations and a hypothesis concerning their causes, which appear partly to be interannual changes in the ocean climate. Our study involves only the sardine fishery for the port of Guaymas in the Gulf of California.

MIGRATION AND SPAWNING

Sokolov (1974) hypothesized a general migratory circuit for the Monterrey sardine. He described a north-to-south migration from winter to spring along the east-

ern coast of the Gulf of California from just north of Guaymas to Topolobampo. During the 1970-71 fishing season the southward migration may have reached Mazatlan, but this is not usual. The migration begins in October-November, with the start of the northerly winds that induce upwelling along the gulf's east coast. By summer the winds shift from northerly to southerly, and the Monterrey sardines migrate back north.

January to April is the spawning period for the Monterrey sardine. Sokolov (1974) says that the eggs and larvae drift towards the gulf's western coast, where the larvae grow until they attain sexual maturity in their second year. They then move north and join the adult population around Angel de la Guarda Island.

At the same time that the Monterrey sardines are migrating south (winter to spring), crinuda sardines also move south as the water cools (as indicated by unpublished data from the Instituto Nacional de Pesca). Crinuda sardines begin returning north during late spring-early summer when the water warms, upwelling stops, and winds become southerly. Crinuda sardines spawn over much of the gulf during the summer months—the warmest period of the year (Moser et al. 1974).

There are no recent estimates of the biomass of these species in the gulf. Moser et al. (1974), using egg abundance data, calculated the spawning stock for the Monterrey sardine to be 48,000 MT in February 1956, 505,000 MT in April 1956, and 74,000 MT in February 1957. Sokolov (1974) estimated the Monterrey sardine population to be about 200,000 MT. He said that the catch should not be more than 25 percent of the resource and that 50,000 MT could be caught in 1972. There are no population estimates for the crinuda sardine.

THE FISHERY

The fishery exploits the Monterrey sardine and crinuda sardine, depending on their availability, for use as canned fish and fish meal. The fishery began in about 1967 with a very few boats. The catch data and number of boats in the fishery are not reliable until the 1969-70 fishing season. For the first 11 years the boats fished from October-November through May-June along the east coast of the gulf close to the ports of Guaymas, Sonora, and Yavaros, Sinaloa. All the boats had a small capacity and no ice for preservation. Starting in 1978 the fleet added the summer months to its fishing season and fished in the zone between the northern and central gulf, near the large islands of Tiburón and Angel de la Guarda (Figure 1).

In the second period, from 1977 to 1983, 30 boats were added to the fleet (Figure 2). This was a 75 percent increase in number, but a much greater increase in fishing capacity because the boats were larger and able to preserve the fish for a number of days before having to go to port to unload. The new boats came from the west coast of Baja California, where fishing was becoming less profitable. The additional boats enabled the fishing area to be increased and fishing activity to continue throughout the year. As a result, the 1979-80 Monterrey sardine catch increased by 169 percent from the previous year (Figure 3).

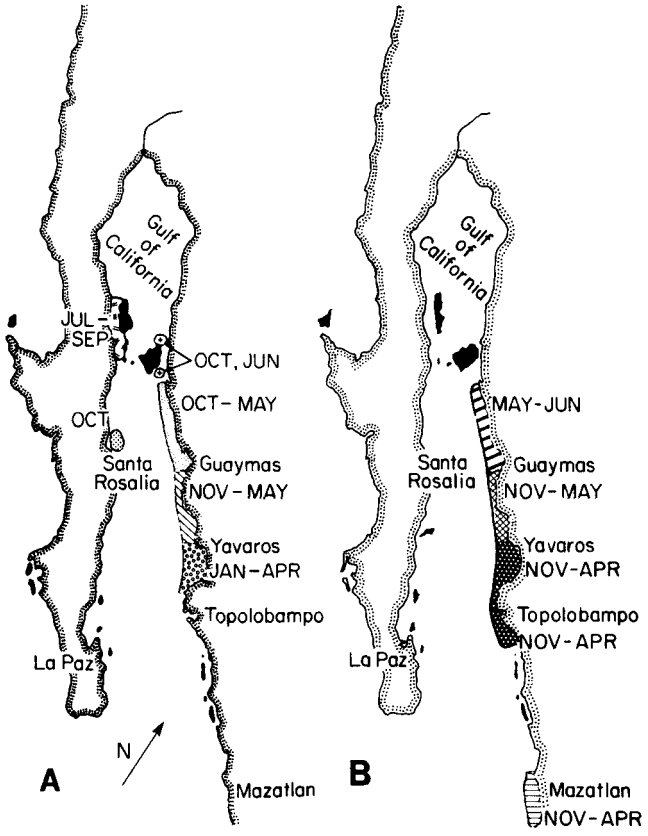

Figure 1. *A*, generalized Monterrey sardine fishery areas and months in the Gulf of California. *B*, generalized crinuda sardine fishery areas and months.

The catch of Monterrey and crinuda sardines for the November-May period of each fishing season has fluctuated widely (Figure 3). The 1975-76 season showed a Monterrey sardine catch of 51,000 MT, whereas the next season it was about 8,000 MT. By 1978-79 the catch was about 23,000 MT; the next season it increased to 62,000 MT. The crinuda sardine catch has also fluctuated, but not nearly as dramatically as the Monterrey sardine catch until the 1982-83 season, when the crinuda catch increased from the previous year by 42,000 MT. The largest catch for Monterrey sardine was in the 1980-81 season, when approximately 88,000 MT were caught. The largest crinuda sardine catch was in 1982-83, when approximately 68,000 MT were caught.

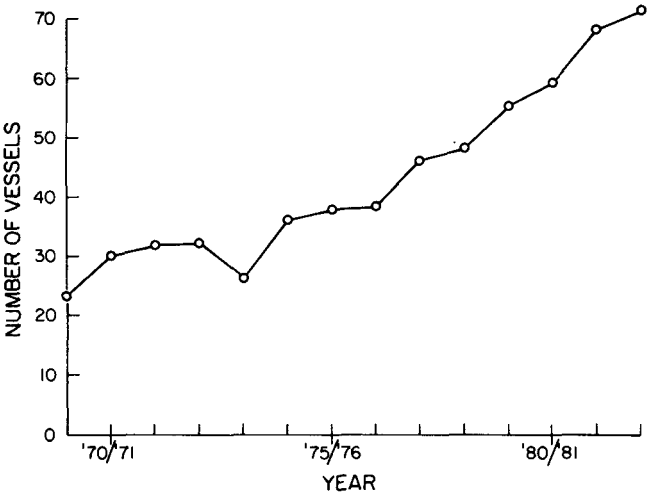

Figure 2. Number of sardine fishing vessels, Guaymas, Sonora.

THE DATA

Catch and effort data for the sardine fishery have been obtained from published reports (Pedrin-Osuna and Ancheita-Avalos 1976) as well as unpublished internal reports from government fisheries offices (Molina et al. 1984). For comparison purposes, we have used data from all catches registered in the Gulf of California wherever available, but our analysis is mostly based on port of Guaymas data for the November-May season. This port accounted for 81 percent of the total registered catch in the gulf in 1980 and a higher percentage in earlier years.

Catch per unit of effort (CPUE) has been used as an index of availability (either abundance, accessibility, or both combined). It is obtained by simply dividing the total catch per species for the fishing season by the corresponding total number of registered trips. The use of CPUE as an index of abundance of small pelagic species has been severely questioned by various authors, for example, Radovich (1982). Two considerations are in order in this respect: first, CPUE is the best possible index available at the present time; second, we are not attempting to estimate the parameters of the sardine's population dynamics, but only to obtain a gross relative estimate of the availability of either species on the fishing grounds accessible to the Guaymas-based fleet.

Yearly mean sea-level and sea-surface temperature data for Guaymas and Manzanillo from October through September were compared with the seasonality of CPUE for each fishery (Figure 4). Because of missing data for each station, we constructed composite series of yearly mean sea level and yearly mean sea-surface temperature data by averaging the two

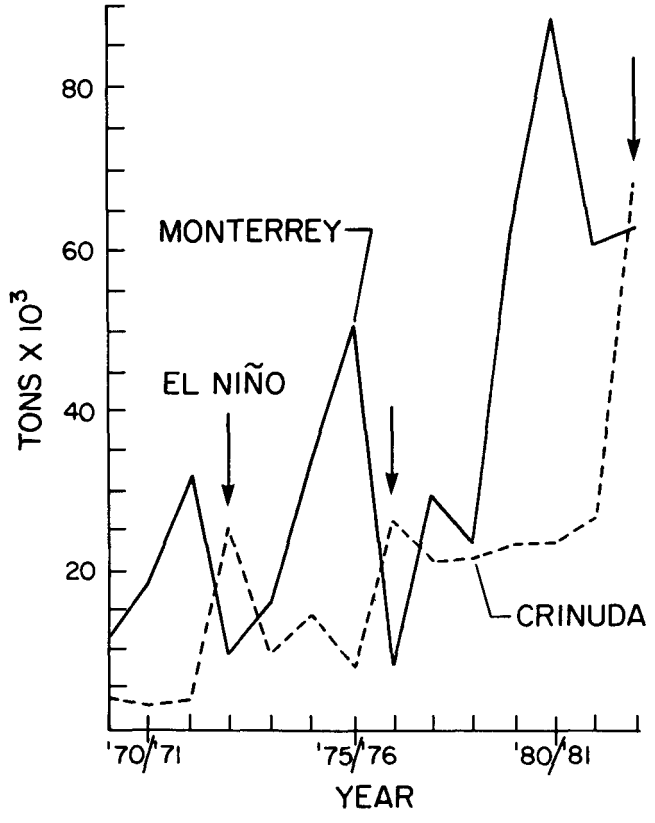

Figure 3. Guaymas, Sonora, sardine catch for the months from November through May. Arrows indicate El Niño events.

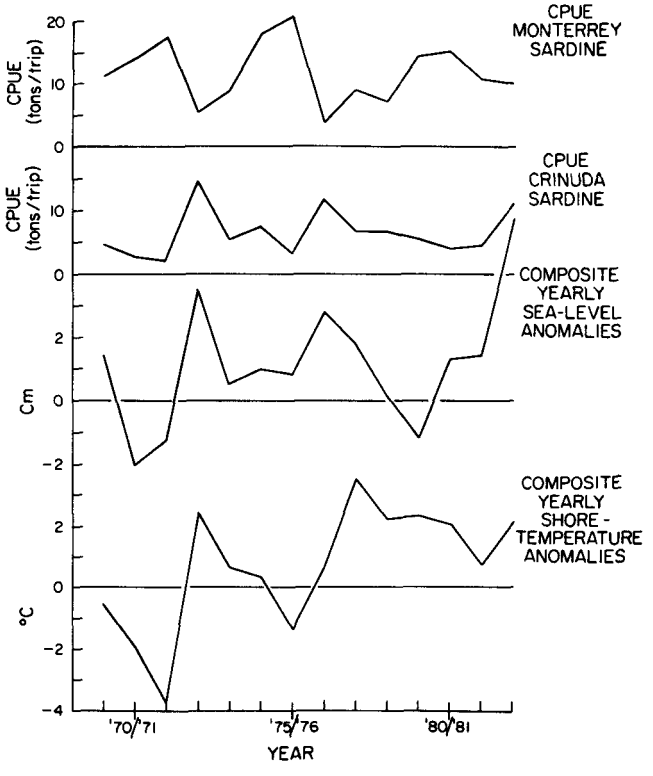

Figure 4. Anomalies of catch per unit of effort for Monterrey and crinuda sardines, and a composite of Guaymas and Manzanillo sea level and sea-surface temperature.

stations' data. Whenever gaps were present for one of the series, we used the value for the other station. Our aim was to construct a series that could be used to indicate extensive geographical conditions.

DISCUSSION

The causes for the large fluctuations in catch, particularly for the Monterrey sardine, have been discussed by several authors. Holtschmit (1977) analyzed the catches and CPUE of Monterrey and Crinuda sardines unloaded at Guaymas as related to environmental parameters such as atmospheric and water temperatures, rainfall, and prevailing winds. He found that the most significant correlations were an inverse relationship between Monterrey sardine catch and water temperature for December of the same season, whereas crinuda sardine catches were inversely related to the average atmospheric temperature of the preceding year.

Molina et al. (1984) assumed that sardine catches were strongly influenced by their availability to the fleet, particularly during 1969-77, when the boats operated almost exclusively on a one-night-per-trip basis, mostly because of their restricted carrying capacity and lack of refrigeration. When more, larger boats began to enter the fleet in 1978, the fishing area and season were increased. Molina et al. further concluded that the intensity of the north-south migration was the main factor affecting the size of catches, as well as the composition of species during 1969-77. Since that time, Molina et al. believe, this factor has mainly affected the smaller boats; the larger boats have moved wherever sardines are available.

The data are sparse concerning these species' movements and location at different times of the year. It is apparent, however, that Monterrey sardine can be found in most regions of the gulf during some years. (Sokolov 1974; Moser et al. 1974; de la Campa de Guzman and Gutierrez 1974; de la Campa de Guzman and Ortiz 1975). This appears to be true also for the crinuda sardine, but each species is restricted by the environment during different seasons of the year. The spawning Monterrey sardine is concentrated in the east side of the central gulf, with outlying patches to the north and south during the winter and spring. The spawning crinuda sardine dominates the gulf in the summer, particularly concentrating in the coastal zones of the central and northern regions.

We incorporate some of the observations of Sokolov (1974), Molina et al. (1984), and Holtschmit (1977), but we believe our hypothesis is more complete concerning the large fluctuations of the sardine fishery in the gulf.

In October-November, northerly winds begin to sweep the gulf because of the changing atmospheric pattern toward a winter circulation (Granados and Schwartzlose 1977; Hubbs and Roden 1964). These winds, plus the normal seasonal cooling of the gulf waters, cause a more temperate ocean climate. There is upwelling along the east coast of the gulf. These conditions along the eastern shore coincide with the Monterrey sardine's annual southward spawning migration and the beginning of the fishing season. The crinuda sardine is also migrating southward because of the cooling water. The fish, especially the preferred Monterrey sardine, thus become available to fishermen from the port of Guaymas.

The southernmost movement of the fish depends on the intensity of the upwelling, the seasonal cooling of the surface water, and southern flow of the surface waters. Thus in cool years fish should be available to the fishermen over a longer period and over a greater geographic region along the east coast of the central gulf. Conversely, the warmer the season the less available are Monterrey sardines, because of a shorter migratory season and a smaller geographic region. From Figures 2, 3, and 4 we see that 1971-72 and 1975-76 were clearly colder years; they were also years of much higher catch, and the CPUE was up, even with only a small change in the number of fishing vessels. The cold year of 1971-72 was one of the few seasons when Monterrey sardines were caught as far south as Mazatlan. From these same figures, we see that the catch and CPUE is down for Monterrey sardines and up for crinuda sardines in the warm years while the water temperature is increased from the previous year. The El Niño events, as shown by Baumgartner et al. (1985), Wooster (1983), and Baumgartner and Christensen (1985), among others, are marked by arrows on Figure 3 and coincide with dramatically lower Monterrey sardine catches and higher crinuda sardine catches. Thus the availability of the species is clearly shown in Figure 4 in the relationships for each species with sea level and water temperature. The cross-correlation coefficients of these parameters are all significant at either the 95 or 99 percent level (Table 1).

Cold years may also result in successful spawning for the Monterrey sardine, since there is a larger area for spawning and the growth of recruits. This might be reflected by the relative dominance of year classes. Although we do not present evidence of this, unpublished material by Leonardo Huato Soberanes of CICIMAR seems to confirm the assumption.

Seasonal warming of the water and reduced upwelling cause adult Monterrey sardines to end their spawning and return north to the vicinity of the large islands of Angel de la Guarda and Tiburón. This region has strong tidal mixing and upwelling most of the year, and surface temperatures are lower than in the remainder

TABLE 1
Coefficients of Cross-Correlation

	Manzanillo		Composite		Monterrey sardine	Crinuda sardine
	MSL	MST	MSL	MST	CPUE	CPUE
Guaymas						
MSL	.89**	—	—	—	−.62*	.69**
MST	—	.55*	—	—	—	—
Composite						
MSL	—	—	—	.56*	−.57*	.79**
MST	—	—	—	—	−.53*	.57*

MSL = yearly mean sea level
MST = yearly mean sea-surface temperature
Composite = Guaymas and Manzanillo
* Significance at the 95% level
**Significance at the 99% level

of the gulf even during summer (Hubbs and Roden 1964; Badan-Dangon et al. 1985, among others). It is quite possible that there is a resident population in this region year-round. Summer catches of Monterrey sardine are made in this region, particularly in the southern portions of the upwelling area of the Ballenas Channel. This additional fishing area and season added about 22 percent to the total annual catch of Monterrey sardine. In 1985 the area around the islands of Tiburón and Angel de la Guarda was closed to Monterrey sardine fishing in July, August, and September because juveniles constituted the largest part of the catch in the near-surface layer.

We conclude that the large fluctuations of the November-May catch of both the Monterey and crinuda sardines are due to their availability to the fishing fleet, and that availability is largely influenced by the ocean climate in the Gulf of California—for example, a cool year of upwelling and northerly winds, or a warm year that might result from an El Niño event. A cold year increases the area of availability for the Monterrey sardine; there is an opposite effect on the crinuda sardine. A warm year supports the crinuda sardine's availability and depresses the Monterrey sardine. The large, sustained increases in the catch from 1979 through 1983 were due to the growing number of larger-capacity vessels and their ability to preserve the catch for several days.

ACKNOWLEDGMENTS

We wish to thank Guillermo Portillo Clark for data processing, and the illustrators under the direction of Fred Crowe at SIO's Marine Life Research Group.

LITERATURE CITED

Badan-Dangon, A., C.J. Koblinsky, and T. Baumgartner, 1985. Spring and summer in the Gulf of California: observations of surface thermal patterns. Oceanol. Acta 8(1):13-22.

Baumgartner, T.R., and N. Christensen, Jr. 1985. Coupling of the Gulf of California to large-scale interannual climatic variability. J. Mar. Res. 43(4):825-848.

Baumgartner, T., V. Ferreira-Bartrina, H. Schrader, and A. Soutar. 1985. A 20-year varve record of siliceous phytoplankton variability in the central Gulf of California. Mar. Geol. 64:113-129.

de la Campa de Guzman, S., and C.H. Gutierrez. 1974. Distribución horizontal de huevos y larvas de sardina monterrey y larvas de sardina crinuda y bocona en el Golfo de California en april de 1972. Inst. Nac. Pesca, INP-SC:2, 17 p.

de la Campa de Guzman, S., and J.M. Ortiz-J. 1975. Distribución y abundancia de larvas de peces en el Golfo de California durante abril-mayo 1973, con especial referencia a sardina monterrey y japonesa. Inst. Nac, Pesca, INP-SC:11, 25 p.

Granados-G., J.L., and R.A. Schwartzlose. 1977. Corrientes superficiales en el Golfo de California *In* F.A. Manrique (ed.), Memorias, V. Congreso Nacional de Oceanografía, Guaymas, Sonora, México, 22-25 de octubre 1974, p. 271-285.

Holtschmit-M., K.H. 1977. Pesca de la sardina (*Sardinops sagax caerulea* y *Opistonema ibertate*) en Guaymas, Son. (México) y su relación con factores ambientales. Tesis, Instituto Tecnológico de Estudios Superiores de Monterrey, Guaymas, Son.

Hubbs, C.L., and G.I. Roden. 1964. Oceanography and marine life along the Pacific coast of Middle America. *In* Natural environments and early cultures. Vol. 1 of Handbook of Middle American Indians. Univ. Texas Press, p. 143-186.

Molina, D.H., F. Paez, F.J. Magallón, F.A. Castro, and A.C. Castro, 1984. Análisis biológicos pesqueros de la pesquería de Sardina en el Puerto de Guaymas, Son. Inst. Nac. Pesca Informal Rpt.

Moser, H.G., E.H. Ahlstrom, D. Kramer, and E.G. Stevens. 1974. Distribution and abundance of fish eggs and larvae in the Gulf of California. Calif. Coop. Oceanic Fish. Invest. Rep. 17:112-130.

Pedrin-Osuna, O.A., and A. Ancheita-Avalos. 1976. Estadísticas básicas de la explotación de sardina en el noroeste de México. Inst. Nac. de Pesca, INP-SI:i 79, 12 p.

Radovich, J. 1982. The collapse of the California sardine fishery: what have we learned? Calif. Coop. Oceanic Fish. Invest. Rep. 23:56-78.

Sokolov, V.A. 1974. Investigaciones biológico pesqueras de los peces pelágicos del Golfo de California. Calif. Coop. Oceanic Fish. Invest. Rep. 17:92-96.

Wooster, W.S. 1983. An index of anomalous SST in the Eastern Equatorial Pacific, 1970-1982. Trop. Ocean. Atm. Newsletter 16:6-7.