

## ON THE EXISTENCE OF PACIFIC SARDINE GROUPS OFF THE WEST COAST OF BAJA CALIFORNIA AND SOUTHERN CALIFORNIA

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### ABSTRACT

Three possible Pacific sardine groups were detected using monthly catch and sea surface temperature (SST) data from landing ports of Magdalena Bay, Cedros Island, and Ensenada in México, and San Pedro in the United States. With the use of temperature-at-catch criteria, the groups were clearly defined by monthly periods when maximum catches were observed and at specific intervals of SST: one at temperatures above 22°C, one between 17° and 22°C, and a third below 17°C. Assuming that the observed patterns are indicative of sardine stock structure, this method also serves as a practical approach to partitioning and attributing the catch data of each fishing zone to each sardine group, thus improving estimates of population abundance from stock-assessment models. A conceptual model of time-space distribution is proposed to describe the occurrence of Pacific sardine along the west coast of Baja California and southern California. This model mainly explains the seasons of higher abundance of the resource in the different fishing areas.

### INTRODUCTION

Pacific sardine (*Sardinops sagax*) is distributed in the northeastern Pacific Ocean, from southeastern Alaska to the southern tip of Baja California and into the Gulf of California (Kramer and Smith 1971; Parrish et al. 1989). Pacific sardine has a wide range of distribution, and it is important to know whether this population consists of one or several stocks and if multiple stocks do exist to define their corresponding distributions.

Some studies suggest that prior to the collapse in 1952 of the Pacific sardine fishery in California, the population consisted of several subpopulations. Radovich (1982) revised several publications (Felin 1954; Sprague and Vrooman 1962; Radovich 1962; Vrooman 1964) and identified four sardine subpopulations along Pacific sardine's distribution range as well as defined the area occupied by each one. However, Hedgecock et al. (1989) found low genetic variability among broadly distributed samples of sardine, contradicting the hypothesis of different latitudinal subpopulations of Pacific sardine. Lluch-Belda et al. (1991) proposed a hypothetical model to

explain fluctuations of abundance in the Pacific sardine population. They proposed that during cold periods the population withdraws toward the south, subsequently reducing its area for successful spawning. Conversely, during warm periods sardine expands its spawning, residence, and feeding habitats. Rodríguez-Sánchez et al. (2001) supported this hypothesis using data from the catch of juvenile sardines by tuna baitboats during 1931–1979. Félix-Uraga et al. (1996) described migratory movements of Pacific sardine along the western coast of Baja California; they proposed the existence of three stocks in this region, noting that in Magdalena Bay two sardine stocks are present, one during winter and another during summer.

Along the west coast of Baja California and southern California (fig. 1), the fishery for Pacific sardine has experienced a sustained increase in capture since 1984, when at least 3,650 t were landed; in 2002, 148,100 t

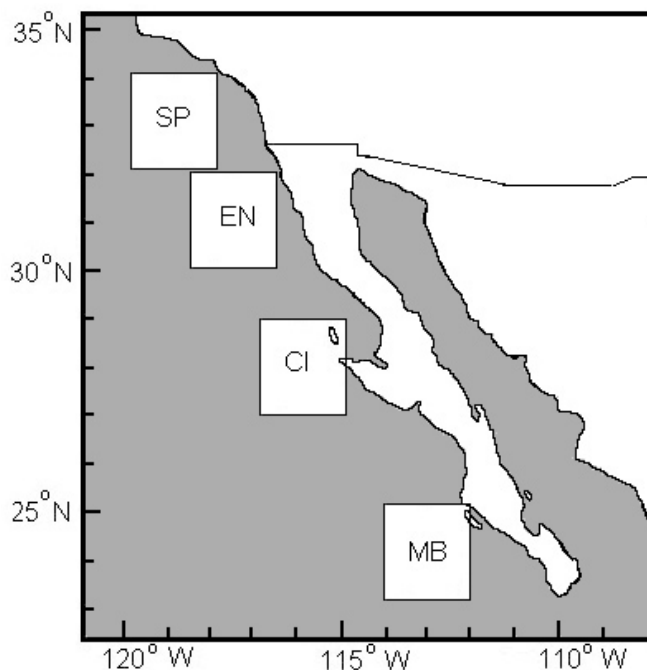


Figure 1. Landing ports of Pacific sardine on the west coast of Baja California and southern California. Magdalena Bay (MB), Cedros Island (CI), Ensenada (EN), and San Pedro (SP).

were landed. We proposed that, on the basis of catch and temperature information recorded during 1981–2002 for Magdalena Bay, Cedros Island, and Ensenada in Mexico and San Pedro in the United States, there are three possible Pacific sardine groups along the west coast of Baja California and southern California.

## MATERIAL AND METHODS

Monthly catch data from Magdalena Bay, Cedros Island, and Ensenada were obtained from cannery records by Centro Interdisciplinario de Ciencias Marinas (CICIMAR) and Centro Regional de Investigaciones Pesqueras de Ensenada (CRIP) personnel from 1981 to 2002. Catch data from San Pedro were provided by Kevin Hill, Southwest Fisheries Science Center. Monthly mean of sea surface temperature (SST) data from these regions (2° latitude by 2° longitude square) were obtained from the Hadley Centre for Climate Prediction and Research (HadISST) for the same period. The selected squares were 23–25°N by 112–114°W for Magdalena Bay, 27–29°N by 115–117°W for Cedros Island, 30–32°N by 117–119°W for Ensenada, and 32–34°N by 118–120°W for San Pedro (fig. 1).

The time series of the monthly mean catch was plotted for each fishing zone for the period 1981–2002. The monthly catch information was grouped in matrixes and added by intervals of 1°C (i.e., 17°C = 16.5–17.4°C) of SST for each year and fishing zone during this period and plotted using contour graphs. Another three matrixes were made to integrate the catch for each month from 1981 to 2002, previously grouped by 1°C intervals, for Magdalena Bay, Ensenada, and San Pedro. The matrixes were plotted on a contour graph for comparative purposes for Magdalena Bay and Ensenada together, and for Magdalena Bay and San Pedro. The data from Cedros Island were scarce, so its was not included in this analysis.

The total monthly catch by degree of SST was plotted for 1981–2002 for each fishing zone and for all the zones combined. The monthly mean of SST was plotted for each fishing zone for the whole period. On this basis of this information, we propose a simple conceptual model to describe the time and space variation of several Pacific sardine groups along the west coast of Baja California and Southern California.

## RESULTS

### Landings by Area and Season

The bulk of monthly sardine landings in Magdalena Bay occur midyear, but a lower second peak occurs at the end of the year (fig. 2); in this zone, the catch increased to more than 50,000 t during 2002. The Cedros Island catch peaks during the spring and fall months. In

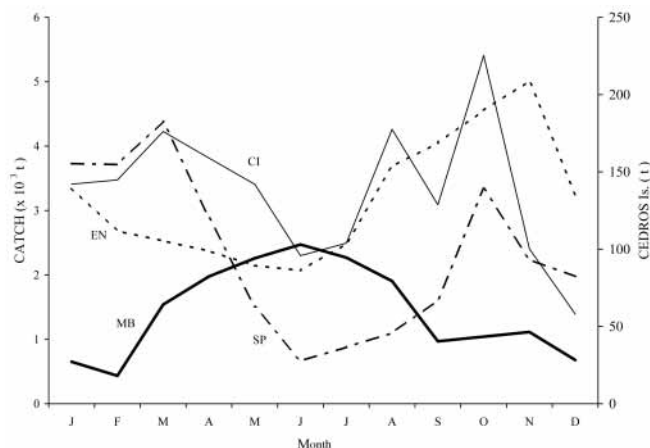


Figure 2. Monthly mean catch from Magdalena Bay (MB), Cedros Island (CI), Ensenada (EN), and San Pedro (SP).

1987 the maximum catch was 2,856 t. Fishing activities for sardine in this area were ended in 1995, when the unique cannery closed because of economic constraints. For Ensenada, the bulk of the catch occurs around the beginning and end of each year, though the catch is higher at the end of the year. At San Pedro the maximum catch occurs in March, and a lower second peak occurs in October; the minimum catch is in June. Overall, the monthly mean catch in Magdalena Bay varied inversely with that of Cedros Island, Ensenada, and San Pedro. In all the fishing zones, two catch peaks were observed in the Pacific sardine catch in different seasons of the year (fig. 2).

### Landings by Area and SST

The contour plot of catch by temperature and year for Magdalena Bay indicates (eye-balling) that two groups of sardine were present in most years: the first at SSTs of 17–22°C; the second at SSTs higher than 22°C. At Cedros Island, only one group was observed, at SSTs of 17–22°C. The data from Ensenada and San Pedro indicate two groups: the first at 17–22°C, and the second at 13–17°C (fig. 3).

On the basis of SST range, we identified (by eye-balling) three Pacific sardine groups in the combined contour plots of catch by temperature and month for Magdalena Bay versus Ensenada and Magdalena Bay versus San Pedro (fig. 4). The group present in Magdalena Bay at SSTs above 22°C was captured mainly from July to December. The second group, present in Magdalena Bay at SSTs of 17–22°C, was captured primarily from February to June. This 17–22°C group is probably the same as that observed from July to November off Ensenada and San Pedro. A third group was present in Ensenada and San Pedro at SSTs of 13–17°C and was caught mainly from December to May (fig. 4).

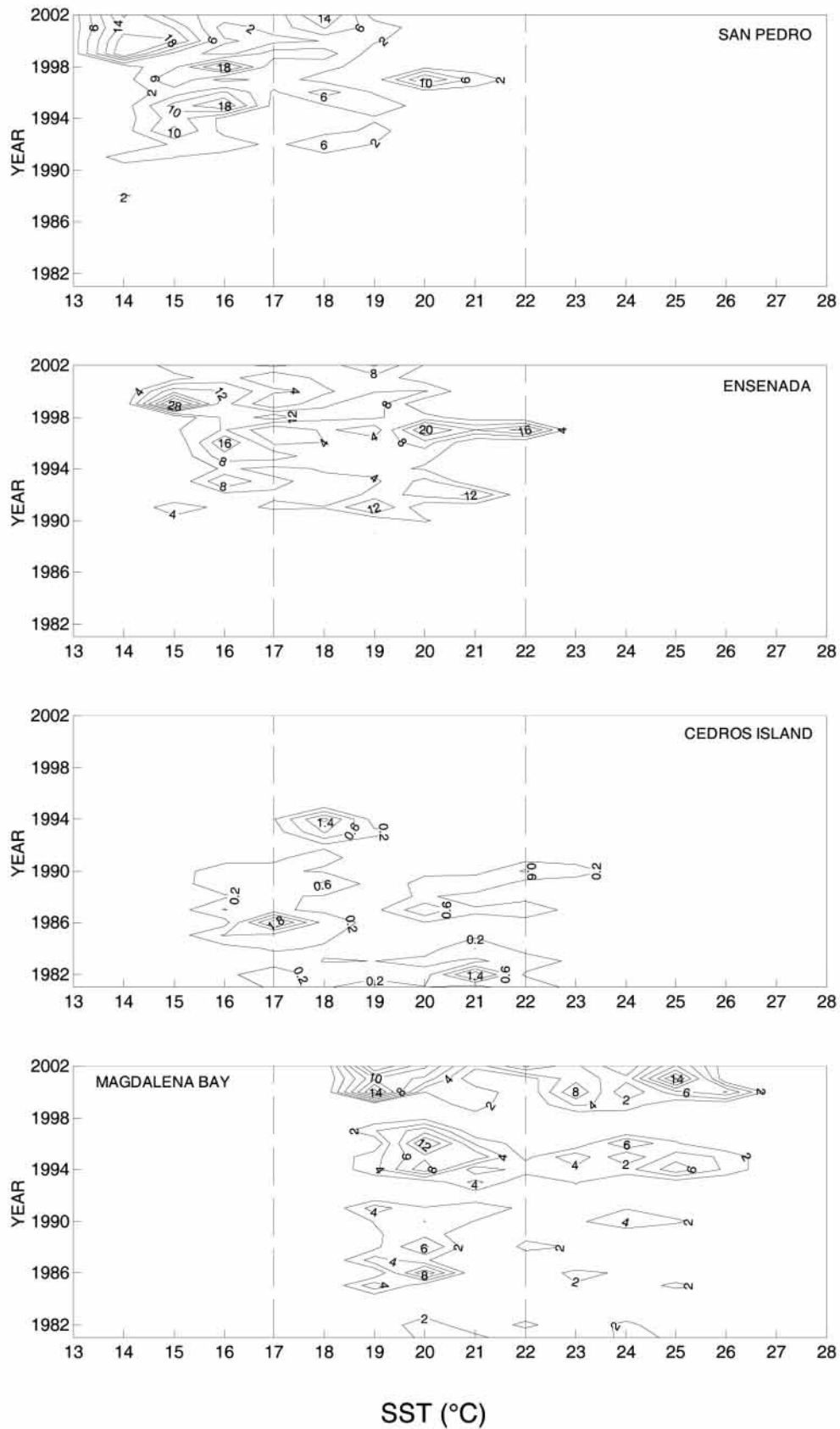


Figure 3. Catch isolines (thousands of tons), added by 1°C intervals of SST at San Pedro, Ensenada, Cedros Island, and Magdalena Bay.

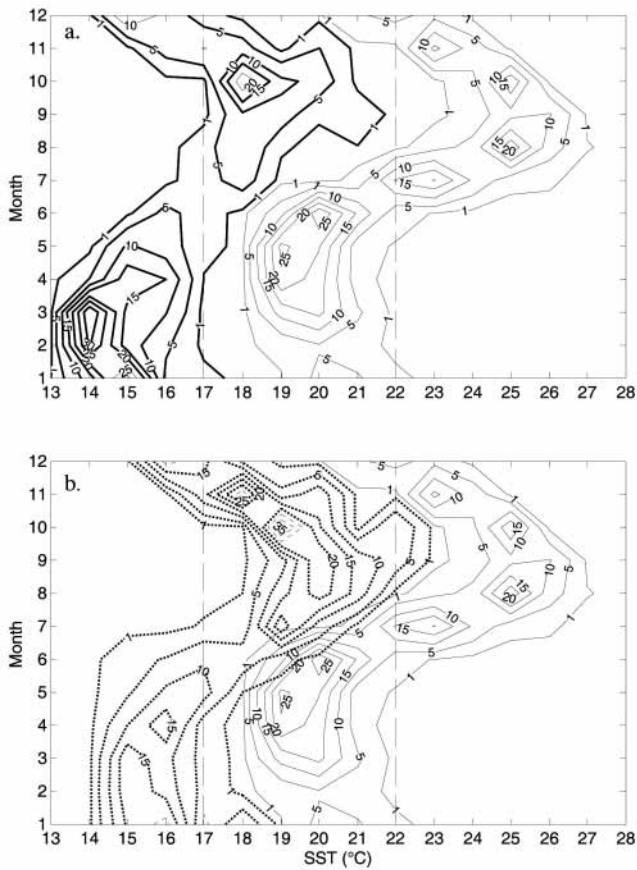


Figure 4. Catch isolines (thousands of tons) by SST and month during 1981–2002 for (a) San Pedro (thick line) and Magdalena Bay (thin line) and (b) Ensenada (dotted line) and Magdalena Bay (thin line).

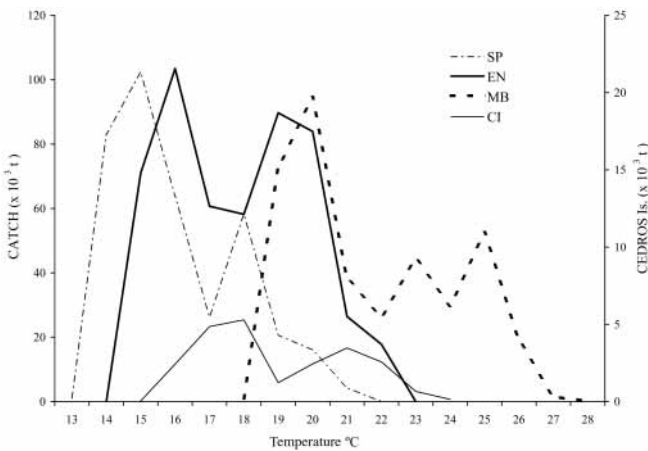


Figure 5. Pacific sardine catches added by 1°C intervals of SST at landing ports: San Pedro (SP), Ensenada (EN), Cedros Island (CI), and Magdalena Bay (MB).

In summary, the total catch integrated by SST, landed in Magdalena Bay, Ensenada, and San Pedro, showed two peaks in each fishing zone at different temperature ranges. The two peaks at Cedros Island correspond to

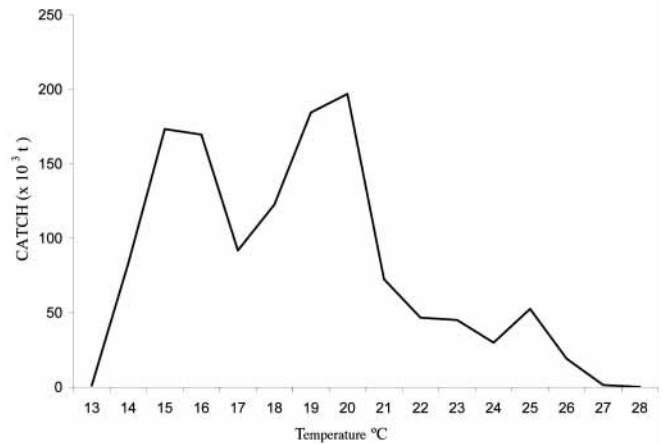


Figure 6. Pacific sardine total catches added by 1°C intervals for the four landing ports during 1981–2002.

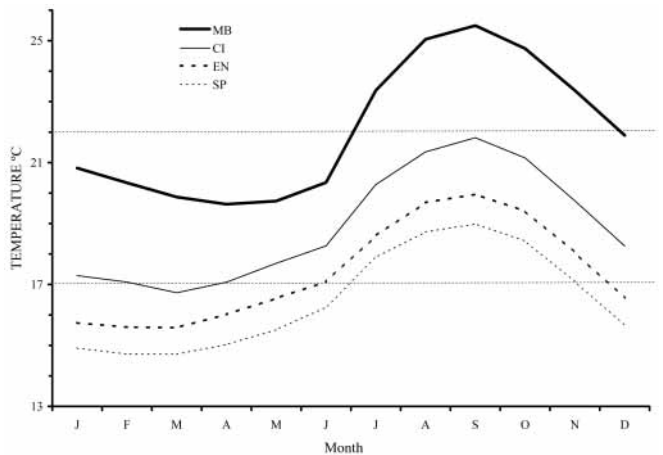


Figure 7. Monthly mean of SST at landing ports: San Pedro (SP), Ensenada (EN), Cedros Island (CI), and Magdalena Bay (MB).

the same temperature range (fig. 5). Plots of total landings for all fishing zones, from Magdalena Bay to San Pedro, at 1°C intervals of SST, clearly showed three peaks of catch (fig. 6). We assume that each peak corresponds to a different group of Pacific sardine.

The monthly mean SST showed that in Magdalena Bay SSTs were higher than 22°C from July to December and were 17–22°C from January to June. Off Cedros Island, SSTs were 17–22°C for nearly the entire year. At Ensenada, SSTs were 17–22°C from June to December and were below 17°C from January to May. At San Pedro, SSTs below 17°C occur from December to June, and those above 17°C from July to November (fig. 7).

## DISCUSSION

As is well known, catch data is a crude measure of abundance (Lluch-Belda et al. 1989). However, we considered catch data to be a good index of the availability of Pacific sardine at Magdalena Bay, Cedros Island,

Ensenada, and San Pedro. The pronounced seasonality of the catch among the four zones (fig. 2) indicates changes in availability and probably means latitudinal movements among these locations. The ability of the Pacific sardine to realize rapid, large-scale migrations was demonstrated by Clark and Janssen (1945).

Changes in sardine availability are quite evident in Figure 2; the catch in Magdalena Bay was inversely related to the catch in Cedros Island, Ensenada, and San Pedro. In Magdalena Bay, higher catches occurred from March to August, and lower catches from September to February; at Cedros Island, Ensenada, and San Pedro, higher catches occurred from September to March. This observed seasonality in the catch from Ensenada and San Pedro is similar to that reported for southern California (Clark and Janssen 1945; Clark 1952).

Several researchers have been indicated that oceanic environmental conditions affect the distribution of Pacific sardine (Radovich 1982; Lluch-Belda et al. 1989; Lluch-Belda et al. 1991; McFarlane 1999). In the contour plots of catch by temperature and year, it is clear that there are two catch groups in each fishing zone (fig. 3); these could represent two groups of Pacific sardine adapted to different temperature intervals.

Despite a low level of genetic variation, Hedgecock et al. (1989) found that the current Pacific sardine population shows a north-south cline in size-at-age that is as large as that observed in the historical, precollapse population. Felin (1954) noted that a significant difference in sardine growth rates may represent a phenotypic response of a plastic genotype to varying hydrographic conditions and that it could be useful as an indicator to separate homogeneous populations of certain fishing areas without implying significant genetic differences. Similarly, we propose that it is possible to separate Pacific sardine groups according to the temperature-at-catch criteria, because Pacific sardine seems to be adapted to different temperature ranges.

Figures 4, 5, and 6 identify three different groups of sardine along the west coast of Baja California and southern California, each one adapted to a different temperature interval. The warmer group, adapted to temperatures ranging from 22° to 27°C, was present in Magdalena Bay from July to December, when higher SSTs are recorded at this latitude. This group may be coming from the Gulf of California, as suggested by Ahlstrom (1954, 1957; cited by Hedgecock et al. 1989), particularly during cold years.

The temperate group, adapted to temperatures ranging from 17° to 22°C, was present at all four fishing zones but at different seasons of the year. This group was captured in Magdalena Bay mainly from March to June, in the lower SST recorded in the area. At Cedros Island it was the only group observed during two sea-

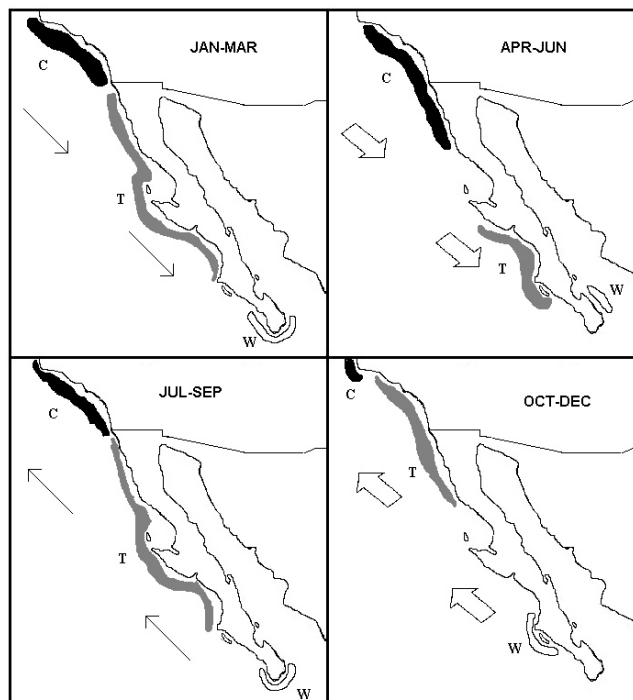


Figure 8. Time-space model of Pacific sardine displacements to explain the presence of three possible stocks on the basis of monthly periods of maximum landings and observed SST. C = cold group, T = temperate group, and W = warm group.

sons of the year. Off Ensenada and San Pedro it was caught mainly from August to December, when higher SSTs are present.

The colder group, adapted to SSTs ranging from 13° to 17°C, was caught off Ensenada and San Pedro mainly from January to April, when lower SSTs were present. Using data from IMECOCAL (Investigaciones Mexicanas de la Corriente de California) surveys, two groups of sardine eggs were identified (van der Lingen and Castro 2004; fig. 2), the first in temperatures above 17.5°C, which could have been spawned by the temperate sardine group (17–22°C), and the other below 17.5°C, which would have come from the colder group (13–17°C).

The intermediate group (17–22°C) seems to be the most important for its contribution to the catch along the west coast of Baja California, and perhaps has an important impact on southern California catches. We believe that the colder group (13–17°C) contributes more to the San Pedro catch than to the Ensenada catch (figs. 2, 4, and 5).

The thermal subdivision of the sardine population was used to build a conceptual distribution model in space-time for the three sardine groups (fig. 8). The model shows that the southward movement of the three groups begins in winter with the strengthening of flow of the California Current. In spring, with the full influence of the California Current, all the groups reach their southernmost distri-

bution. In summer, the northward movement of the three groups begins with the onset of the equatorial counter-current flow. In fall, all groups reach their northernmost latitudinal distribution. A tagging study for Pacific sardine is strongly recommended to probe this model.

Our proposed model is similar to that reported by Radovich (1982). Our model also agrees with the perspective presented by Sprague and Vrooman (1962), Vrooman (1964), and Mais (1972): that the different sardine groups do not generally distribute in the same space and at the same time, even though the distribution areas are shown as overlapping, since all stocks move toward the north or the south simultaneously, with little exchange among the three groups.

Finally, if our proposal is true, that each sardine temperature group is adapted to a specific temperature interval, it represents a practical approach to separating and attributing the monthly catch data (catch-at-age) from each fishing zone by sardine group. Thus, it is possible to better evaluate the stock-specific population abundance using virtual population analysis and compare this with previous estimates of sardine abundance (Barnes et al. 1992; Barnes et al. 1996; Deriso 1993; Deriso et al. 1996) using information from fishing zones rather than just stock assessments.

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