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Study of the spawning area of the Northern anchovy in the Gulf of California from 1990 to 1994, using satellite images of sea surface temperatures

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Abstract. The influence of the water temperature on the distribution and abundance of eggs of the Northern anchovy in the Gulf of California was analyzed. Data on sea surface temperatures (SST) were combined with the analyses of patterns of eggs of plankton collected on the five cruises carried out from 1990 through 1994, during the spawning season of the Northern anchovy. The principal spawning area of this species is between the northern point of Angel de la Guarda Island and ~30 miles south of Tiburon Island, and the whole breadth of the Gulf of California. On the western coast of California, the Northern anchovy spawn in water temperatures between 11.5 and 17°C, while in the Gulf of California, they prefer to spawn in water temperatures between 15 and 17°C. From the satellite images, one could relate the patterns of water masses and temperature fronts to the distribution and abundance of anchovy eggs, as well as know their interannual variability.

Introduction

The influence of the environment on the distribution and abundance and on the reproductive processes of small pelagic fish has been studied. The Northern anchovy (*Engraulis mordax* GIRARD 1856) in the California current region has been thoroughly investigated for different purposes.

Some authors used remote sensing techniques to analyze and describe the spawning habitat of the anchovy, in connection with the temperature and the concentration of photosynthetic pigments in the California current (Lasker *et al.*, 1981; Fiedler, 1983, 1984).

However, in the Gulf of California, information about this species is scarce due to their recent arrival. Until 1985, the Northern anchovy was only found in the Northeastern Pacific Ocean, from Queen Charlotte Island in British Columbia, Canada, to Cape San Lucas, Baja California Sur, Mexico (Ahlstrom, 1966a; Baxter, 1966; Reid, 1966), but, starting in the 1985/6 fishing season, fishing vessels operating in the Gulf of California reported catches of 2071 metric tons of Northern anchovy, which indicated that the area of distribution had been extended (Hammann and Cisneros-Mata, 1989). Moreover, Northern anchovy eggs and larvae had increased considerably (Green-Ruiz and Aguirre-Medina, 1989, 1990; Hamman *et al.*, 1991).

Ichthyoplankton surveys were carried out by the National Institute of Fisheries of Mexico in 1985, 1987 and 1991–1994 to estimate the spawning biomass of the Monterey sardine (*Sardinops caeruleus* GIRARD 1856) and of the Northern anchovy. A cruise in 1990 of researchers from the Center of Scientific Investigation

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and of Superior Studies of Ensenada (CICESE) was initiated to study the habitat of the Monterey sardine. The results of these surveys indicated that in the Gulf of California, the proportion of eggs and larvae of these species has changed, but there is co-occurrence like in the California current (Ahlstrom, 1966b).

The Monterey sardine had diminished notably. Cisneros-Mata *et al.* (1987, 1989) reported the decrement in the catch of sardine in the Gulf, affecting the fishery of this species. At present, this fishery is recovering (Cisneros-Mata *et al.*, 1996).

The paleontological studies of Holmgren-Urba and Baumgartner (1993) in the Gulf of California, covering the last 250 years, show that during the last 100 years there were deposits of anchovy scales, and they found a cross-correlation between the time series of anchovy and sardine scale-deposition rates.

The recent reappearance of the anchovy and the reduction in the sardine catch in the Gulf of California suggested that anchovy may have been replacing sardine, but as mentioned by Cisneros-Mata *et al.* (1996), this idea can probably now be discarded because presently both sardine and anchovy seem to be increasing in abundance and co-exist.

Their abundance, importance in fisheries and ecological relationship with sardine and other small pelagic fish motivated the investigation of the principal biological and physical variables that influence the distribution and abundance of *E.mordax* in the Gulf of California.

Green-Ruiz *et al.* (1992, 1994) reported the influence of temperature on the incidence of anchovy eggs and larvae in the Gulf of California. This paper will show the relationship between the spawning area of the Northern anchovy, indicated by the geographical distribution of the eggs, and the sea surface temperature (SST) in the Gulf of California between 1990 and 1994, using satellite images of SST.

Method

The Gulf of California is an almost completely enclosed narrow area of ocean, the only evaporative basin on the Pacific Ocean (Bray, 1988), and is located between the Baja California peninsula and the Mexican states of Sonora and Sinaloa. A subtropical area with an arid climate, it is 1000 km long and ~150 km wide.

Hydrographically, the Gulf can be divided into two regions separated by the 'big islands': Angel de la Guarda and Tiburon. The northern region is relatively shallow (~450 m), with the exception of the El Delfin basin and the Canal de Ballenas. The southern region reaches depths of 3000 m and opens into the Pacific Ocean (Bray, 1988; Alvarez-Borrego and Lara-Lara, 1991).

From 1990 to 1994, five ichthyoplankton cruises were carried out in the Gulf of California (Table I). The technique used in the collection of ichthyoplankton samples followed that of Lasker (1985). During the season of maximum anchovy reproduction, vertical hauls of the CalVET net were carried out on lines at right angles to the coast, with 10 nautical miles (nm) between lines and 5 nm between stations (Figure 1). Because of scheduling problems, the sampling grid differed slightly in 1990 and 1993.

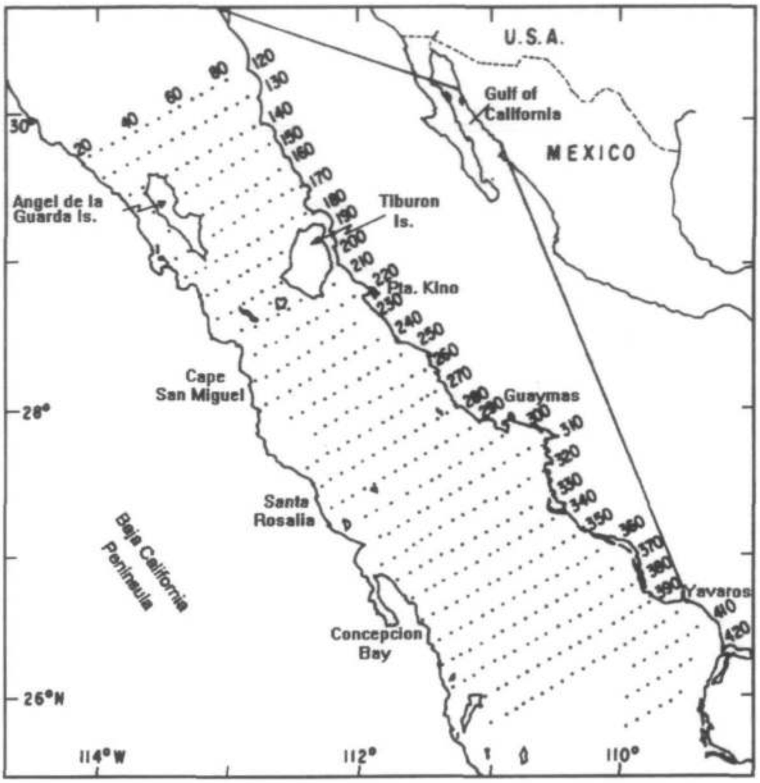

Fig. 1. Study area and station pattern for cruises into the Gulf of California for 1990–1994.

Table I. General information of ichthyoplanktonic cruises carried out in the Gulf of California for the 5 year period 1990–1994

Vessel	Date of cruise	Number of stations	Average temperature (°C)	Date (hour) of AVHRR images
ALTAIR	17/02–02/03 1990	200	16.8	23/02/90
BIP XI	21/01–14/02 1991	382	17.6	–
BIP XI	17/01–08/02 1992	320	20.0	04/02/92 (1425)
BIP XI	27/01–22/02 1993	344	18.0	04/02/93 (0400)
BIP XI	13/01–08/02 1994	382	16.9	30/01/94 (0414)

A flowmeter was installed in the mouth of the net in order to detect clogging, and the collected material was fixed with 5% formalin buffered with sodium borate. The collection of samples continued day and night, and the ocean temperature was measured at a depth of 10 m, using bottles and reversible thermometers.

In the laboratory, each sample was 100% examined, the ichthyoplankton were sorted, and the anchovy eggs were counted and identified according to the description of Moser and Ahlstrom (1985). In 1990, a net of 150 μm was used for the first 56 stations. Clogging problems necessitated changing the net to one of

333 μm. The number of eggs collected at these stations was multiplied by a correction factor of 0.91 to compensate and compare with other stations (Lo, 1983).

The satellite images of the SST were generated with a non-linear technique using bands 4 and 5 of the AVHRR/HRPT data of the satellite series of the National Oceanic and Atmospheric Administration (NOAA). The resolution of a picture element on these images is 1.1 km.

In all years of this study, except 1991, images captured for days of the cruises with minimal or zero cloud cover were selected (Table I), and were combined with data on the distribution and abundance of anchovy eggs collected in the field.

Results

According to the image of 23 February 1990 (Figure 2), the coldest waters (14–15°C) were located in the area of the big islands and coincided with abundant anchovy eggs. A gradual increase in the temperature from north to south can be seen. A lobe of warm water (19°C) at latitude 26°N, and a flux of cold water extending from north to south along the east coast of the Gulf, in front of Guaymas, coincided with the presence of eggs.

For the 1991 cruise, no satellite images of the ocean were available. The 1992 El Niño phenomenon introduced abnormally warm waters into the Gulf of California (Kousky, 1992a,b). This is clearly shown in the temperature images of 4 February 1992 (Figure 3), with temperatures ranging from 21 to 23°C along the east side of the Gulf. In this mass of warm water, the formation of an eddy at latitude 28°N can be noticed, as well as the retention of anchovy eggs in the colder waters at the north, in the area of the big islands. Some eggs seem to be in a filament of cold water that extends from north to south along the western coast of the Gulf. The highest abundance of eggs coincided with the lowest water temperatures of 1992 (17–18°C). This is 3 and 2°C higher than the lowest temperatures observed in 1990 and 1991, respectively.

During the 1993 cruise, the temperature conditions returned to normal. Only a few positive stations occurred in the colder waters (16–17°C) near the big islands. In the image of 4 February (Figure 4), a gradual decrease in the temperature is noticed from south to north without any notable features except for an eddy of cold water between latitudes 26 and 27°N. This eddy coincided with a station that registered a relative abundance of eggs. The image selected for 1994 (Figure 5) shows water slightly colder than that in 1993, with a displacement toward the south of the front which was formed by masses of cold water meeting masses of hot water. This allowed the extension of the spawning area to the south of 26°N, with the largest concentration of eggs of this year located in the central part of the Gulf, between San Miguel and Santa Rosalía along the peninsular coast.

From the histograms of Figure 6, it can be seen that in 1990 and 1993, the highest number of eggs was found at 15°C, in 1991 and 1992 at 17°C, and in 1994 at 16°C. The frequency distribution of the SST and the positive stations for each temperature interval for all the cruises (Figure 7) shows that there was little or no spawning on stations with temperatures <14.5°C (with the exclusion of 1990)

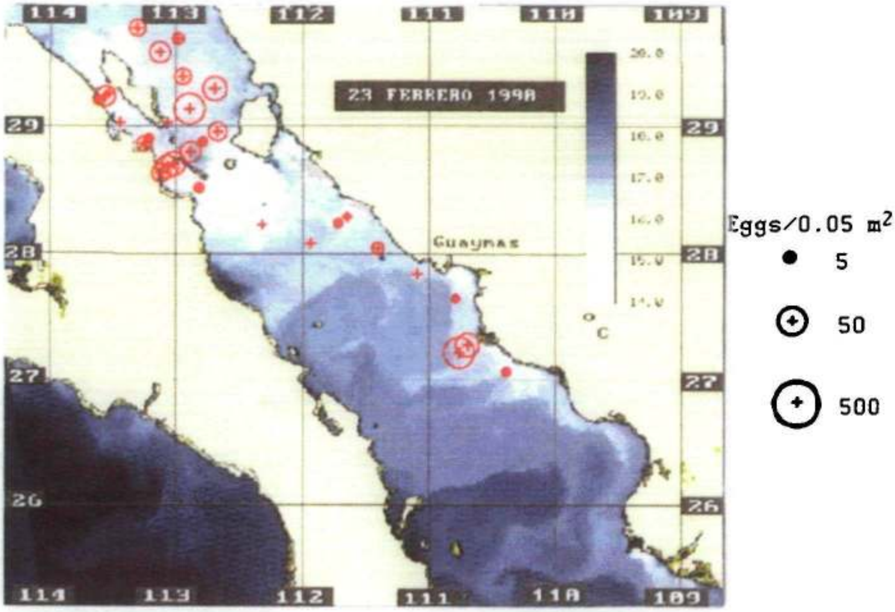

Fig. 2. Distribution of anchovy eggs, overlaid on the SST image (AVHRR/HRPT) captured on 23 February 1990.

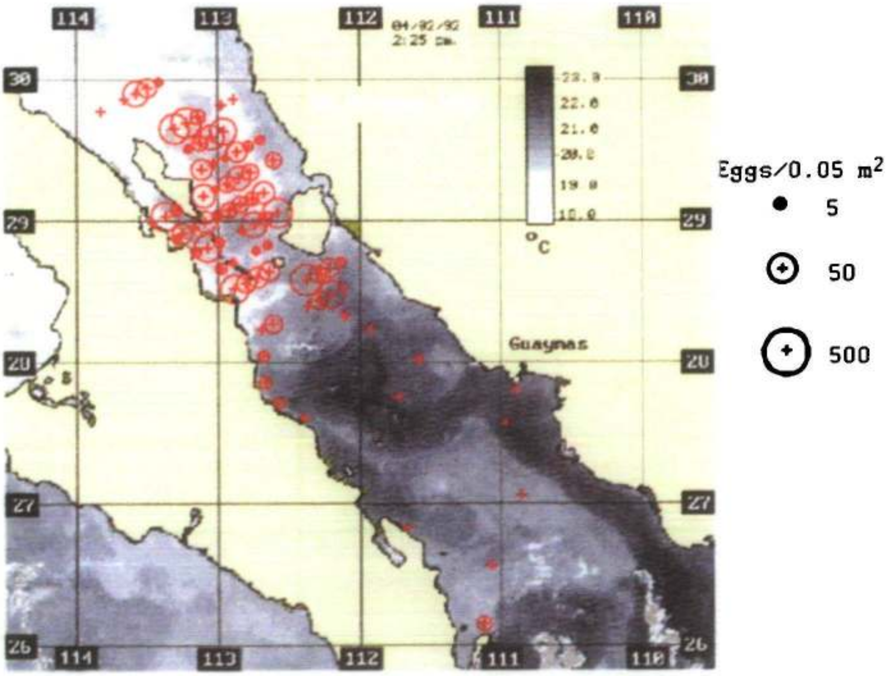

Fig. 3. Distribution of anchovy eggs, overlaid on the SST image (AVHRR/HRPT) captured on 4 February 1992.

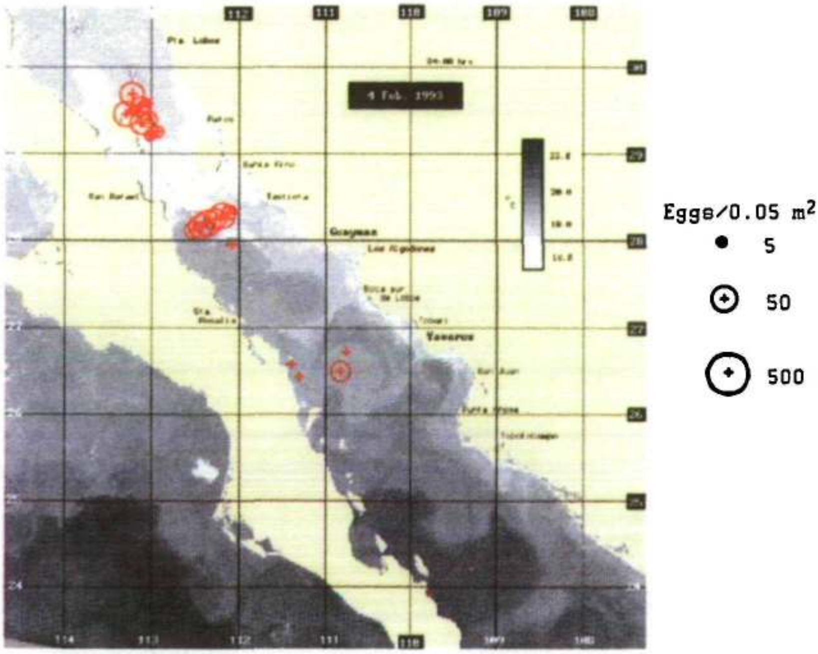

Fig. 4. Distribution of anchovy eggs, overlaid on the SST image (AVHRR/HRPT) captured on 4 February 1993.

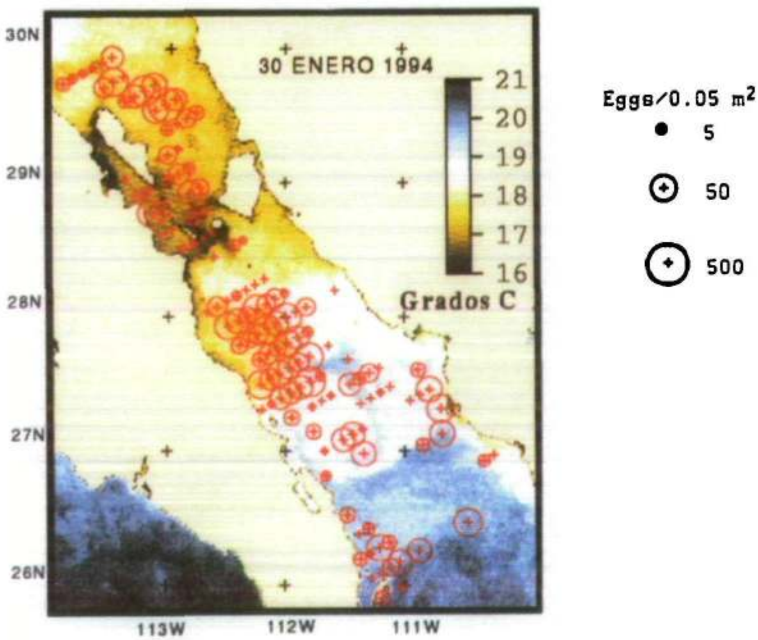

Fig. 5. Distribution of anchovy eggs, overlaid on the SST image (AVHRR/HRPT) captured on 30 January 1994.

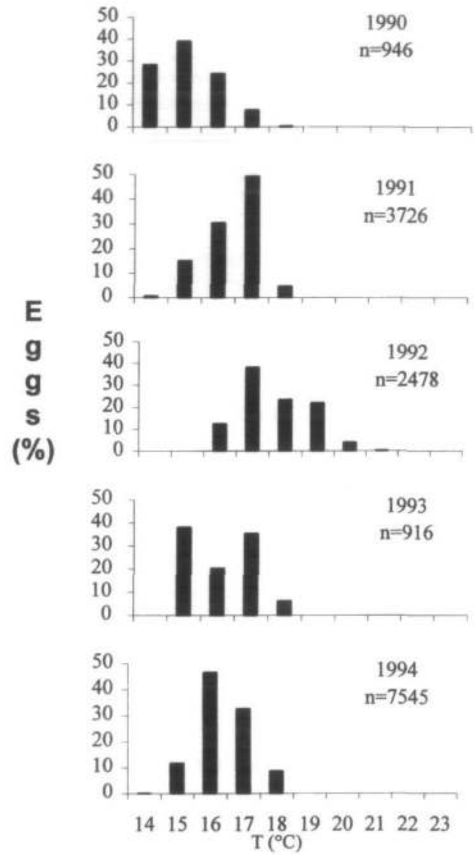

Fig. 6. Distribution of the relative abundance of anchovy eggs as a percentage with respect to temperature from 1990 to 1994.

and >18°C (with the exception of the El Niño year, 1992, when anchovy eggs were found in waters with temperatures of 21°C).

Discussion

The satellite images of the SST, combined with the information on the distribution and abundance of anchovy eggs, clearly show the existing relationships between the anchovy spawning habitat and the SST, as well as the retention and transport of eggs due to fine structures in the water circulation patterns in the Gulf of California, such as fronts, eddies and plumes, which vary in intensity, shape and location each year.

In 1968, Cushing proposed that a fish stock uses tides or currents in different ways at different seasons in such a way that it is retained within a region (Cushing, 1995).

The physical processes of retention and transport affect the population growth of small pelagic fish like anchovy, and the study of processes like El Niño events

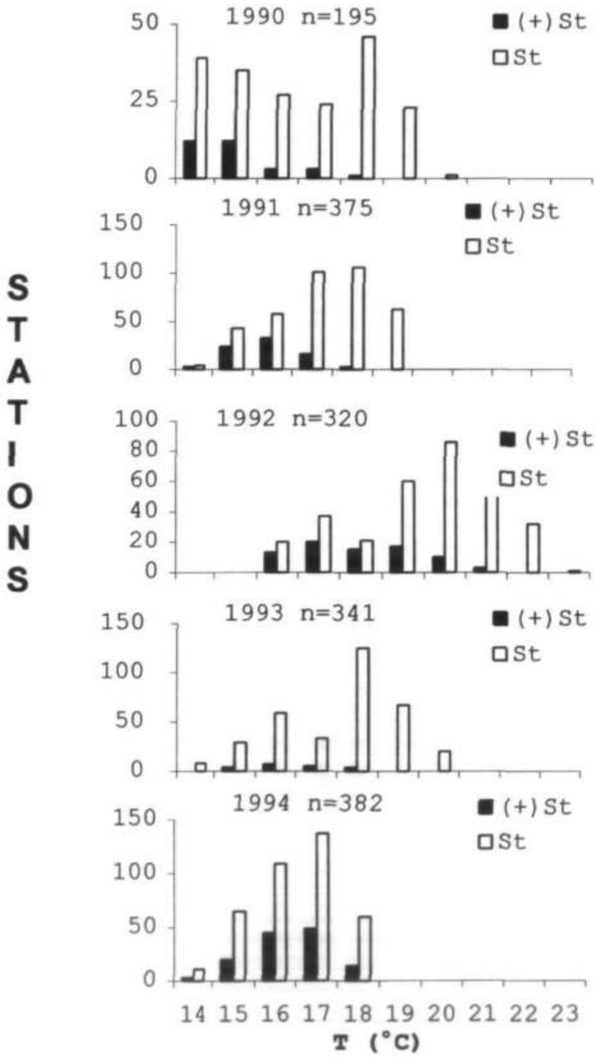

Fig. 7. Frequency of stations and positive (+) stations as a function of SST from 1990 to 1994.

or the interannual variability in the transport and retention system were emergent topics at the International GLOBEC Small Pelagic Fishes and Climate Change Program (Hunter and Alheit, 1995).

In the SST images generated from AVHRR/HRPT data for this study, we observed as a common pattern in every year, during the spawning season of the Northern anchovy, the presence of colder waters in the north part and warm waters in the south.

This characteristic from winter, in the Gulf of California, has been mentioned by authors like Badán-Dangón *et al.* (1985) when they analyzed satellite images of the Gulf of California; Alvarez-Borrego and Lara-Lara (1991), who described the physical environment and the primary productivity in the Gulf of California; Paden *et al.* (1991) when they examined the temporal and spatial patterns of the SST variability in the Gulf of California; Simpson *et al.* (1994) when they investigated the impact of strong tidal flows in the stratification of the water column in the region of the big island; and Gaxiola-Castro *et al.* (1985) who studied the distribution of chlorophyll *a* and the primary productivity in connection with the physical structure of the Gulf of California in winter. It is necessary to point out that during summer in the Gulf, when winds are weak and the water column is stratified, the surface layer becomes uniformly warm throughout the Gulf (Paden *et al.*, 1991).

In relation to the range of temperature at which the most anchovy eggs were found in this study (15–17°C), Ahlstrom (1966a) noticed a temperature range for anchovy eggs of 9.9–23.3°C in the California current, with the most eggs collected between 12 and 18.9°C. Lasker *et al.* (1981) found that in March and April of 1980, the anchovy did not congregate in waters colder than 12.5°C, nor warmer than 17°C, with the greatest abundance at 14°C. Fiedler (1983) mentions that between 1980 and 1982, the interval of temperatures with positive stations for anchovy eggs was between 11 and 17°C, and that spawning was most frequent between 14.5 and 17°C. Recently, Lluch-Belda *et al.* (1991), through analyzing the proportion of positive stations against the total number of stations, found that the preferred spawning temperature for this species was between 11.5 and 16.5°C. In that same study, Lluch-Belda *et al.* (1991) noticed that there was an absence of information concerning the spawning temperatures of the anchovy in the Gulf of California.

Many small pelagic fish spawn in locations where there is a boundary between warm and cool water; these boundaries may stabilize the water column, enrich nutrients or concentrate food particles at the interface (Botsford *et al.*, 1995). Smith (1978) mentioned that there are four scales related to the species: the behavioral (aggregation induced by the individual behavior of the organism, like a fish school in clupeids); the hydrographic (which attracts and holds fish in a small geographical area like an upwelled water mass, or a rich zooplankton bloom area); the physiological (the distribution of a species constrained by physiological limits such as temperature tolerance); and external (events by which food or predators enter the environment of a species from outside its area of distribution). Later, Sinclair (1988, p. 30) stated that 'the number of herring stocks and the geographic location of their respective spawning sites are determined by the number, location and extent of geographically stable larval retention areas'.

In this study, we combined two scales, the hydrographic and the physiological, and show how these characteristics determined that the big island region is a geographical retention area.

Conclusions

The spawning temperature range of Northern anchovy, observed in the Gulf of California from 1990 through 1994, was between 14.5 and 21°C, with the most eggs being observed in water temperatures between 15 and 17°C.

In this study, we show how the region of the big islands is an area of high concentration of anchovy eggs. The physical and biological processes that take place there create favorable conditions for the spawning and retention of *E.mordax* eggs.

We would like to make special note of the abnormal physical characteristic that occurred during 1992 when the normally cold water in the region of the big islands met the warm waters of El Niño in the Gulf of California.

The measured temperature changes during the 5 year study coincide with those calculated from the satellite images. With the resolution of the satellite images taken from the AVHRR/HRPT system, it was possible to detect fine oceanographic structures which are difficult to detect with information collected in the field.

Thus, this combination of SST images with the plankton information collected during the cruises was useful in the study of the Northern anchovy spawning habitat in the Gulf of California.

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