Temperature conditions in the Argentine chub mackerel (*Scomber japonicus*) fishing ground: implications for fishery management

RICARDO G. PERROTTA,[1,2,*] MARÍA D. VIÑAS,[1,2,3] DANIEL R. HERNANDEZ[1] AND LEONARDO TRINGALI[1]

[1]*INIDEP, National Institute for Fisheries Research and Development, Paseo Victoria Ocampo No. l, CC. 175, 7600 Mar del Plata, Argentina*
[2]*Department of Marine Sciences, National University of Mar del Plata, Mar del Plata, Argentina*
[3]*CONICET, National Council for Scientific and Technical Research, Buenos Aires, Argentina*

ABSTRACT

We describe the seasonal migrations of Argentine chub mackerel (*Scomber japonicus*) into the fishing ground in relation to sea surface temperature conditions and analyse the temperature evolution during the fishing season on the basis of 1955–97 time-series. The upper temperature limit for the presence of schools was around 19°C. At higher values, most schools leave coastal waters (< 50 m) for the shelf. An inverse relationship was observed between catches per unit of effort (CPUE) of the inshore fishery and sea surface temperature. The highest standardized CPUE values corresponded to temperatures lower than 19°C. Above this temperature, the probability of obtaining a standardized CPUE higher than 1 was extremely low, and the standard deviations were minimal. The economic benefit from catches was also analysed through the different months of the fishing season. It was found that the mean benefit corresponding to temperatures lower than 19°C exceeded approximately 15 times that obtained at higher temperatures. A simple fishing strategy was proposed to the commercial fleet in order to improve the economic benefit of the catches. The migratory pattern followed by mackerel during the spawning period was also analysed in relationship to other environmental factors like food availability. Zooplankton composition, size structure and abundance in coastal and shelf waters are described, and their implications for feeding ecology of larvae and adults of the species are discussed.

Key words: fishery management, *Scomber japonicus*, spawning ground, temperature conditions, zooplankton

INTRODUCTION

Small pelagic fishes (sardines, anchovies, herrings, mackerels, etc.) are highly sensitive to environmental conditions and extremely variable in their abundance and distribution. They account for over a third of the global yield of marine fish (Hunter and Alheit, 1995); hence their dynamics have important economic consequences as well as ecological ones. In Scombrid species, sea surface temperature and food availability are two of the most important factors regulating the extent of their migrations (Angelescu, 1980; Collette and Nauen, 1983).

In Argentine waters, at the latitude of Mar del Plata city (37°30′–38°30′S), the *Scomber japonicus* schools migrate from the cooler, overwintering shelf waters to the warmer coastal waters in search of adequate environmental conditions to reproduce (Fig. 1). This migration begins in early October at depths of about 50 m, and continues through late January (Carreto *et al.*, 1995; Perrotta *et al.*, 1998a; Roldán *et al.*, 2000). It is only during this period that they are vulnerable to the fleet of small boats operating from the Mar del Plata harbour.

Surface temperature of coastal waters seems to play an essential role in this process, since the maximal reproductive activity taking place in late November through early December is associated with temperatures of 16–18°C (Ciechomski, 1971; Pájaro, 1993; Perrotta and Christiansen, 1993).

The *S. japonicus* fishery in Mar del Plata provides the main raw material for the canning industry of the city. The active fleet consists of 120 small purse-seining boats (Lampara net) of 13 m in mean overall length operating in the Mar del Plata inshore area, and

*Correspondence. e-mail: perrotta@inidep.edu.ar
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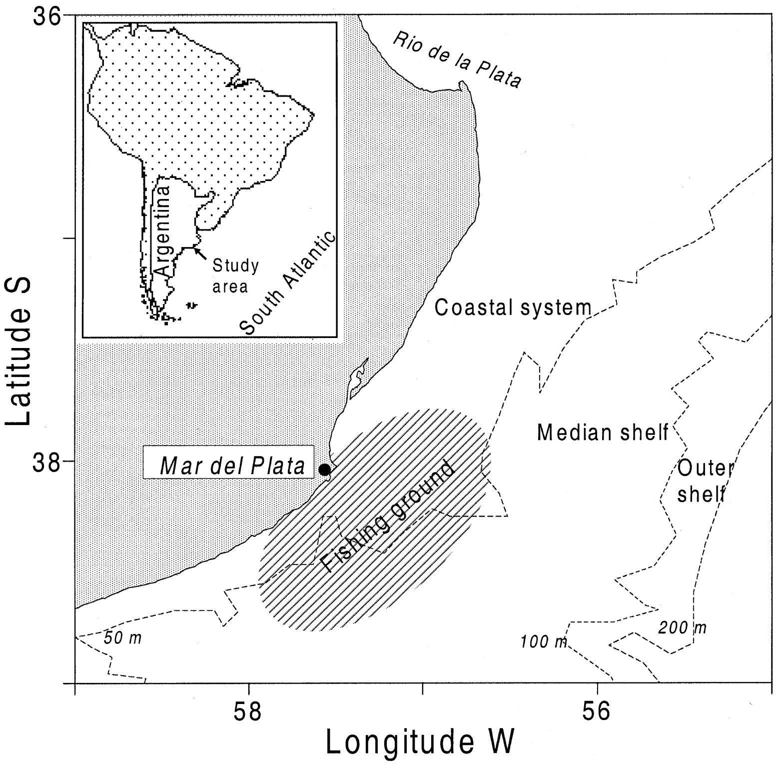


Figure 1. Location of the study area.

the number of boats remains approximately the same throughout the season. Chub mackerel landings averaged 2200 tons during the last five fishing seasons. This catch level is absolutely sustainable, since the resource is currently in an underexploited state (Perrotta and Pertierra, 1993; Perrotta *et al.*, 1998b; Perrotta *et al.*, 2000). During September and early October the inshore fleet, operating in the same area with the same gear, targets *Engraulis anchoita*.

Based on widespread time-series data, we analysed in this work the relationship between CPUE and sea surface temperature on the fishing grounds in order to determine the temperature range for the occurrence of schools. The knowledge of this relationship may permit prediction of the migratory behaviour of the species, with important implications for fishery exploitation (Bez *et al.*, 1995).

The inshore zooplankton community includes a limited number of key species showing strong links with larval fish growth and survival and adult fecundity, and an accessory group of species that show only weak links with fish populations (*sensu* Runge, 1988). Argentine chub mackerel feeds on different zooplankton species during its life span, but the incidence of zooplankton in its diet is most important in larval and juvenile stages (Angelescu, 1980; Pájaro, 1993). In order to understand zooplankton–chub mackerel linkages, it is necessary to know which zooplankton species show strong rather than weak links with fish population dynamics. In a first approach, we describe in this paper the biomass, size structure and composition of zooplankton in coastal and shelf ecosystems included in the migratory route of chub mackerel, and evaluate its adequacy as a food source for the larval and adult stages of the species.

Knowledge of ideal conditions for the occurrence of chub mackerel on the fishing grounds will make it possible to optimize the departures of the boats, minimizing unnecessary fishing effort.

MATERIALS AND METHODS

Data sources

The information used in this work corresponds to the chub mackerel fishery area off Mar del Plata (Fig. 1) and was obtained from October to January. It includes:

Fishery data

Catches in kilograms and fishing effort in the fishing ground were obtained during the 1983–97 period. The fishing effort was measured as the time consumed both searching for schools and fishing operations. The craft from which this information was obtained, from now on referred to as 'pilot boat', belongs to the commercial inshore fleet from Mar del Plata harbour, and its structural and functional characteristics correspond to the average type of boat (Perrotta *et al.*, 1998b and references therein). The position of the pilot boat during the different months is shown in Fig. 2. Economic data for the fishery during the period 1987–97 were provided by the COOMARPES (Fishery and Manufacturing Cooperative of Mar del Plata).

Sea surface temperature in °C

In the fishing area, this parameter (FASST) was recorded from 1983 to 1997 by the pilot boat by means of a mercury thermometer (precision 0.1°C) immersed in a water bucket, between 7 am and 10 am.

At the Mar del Plata's Tide-Indicator (Naval Hydrography Service) the sea surface temperature (MSST) was obtained during the period 1955–97. In all the cases, the method and instrument adopted were those previously mentioned.

Zooplankton biomass

Bongo net samples (220 μm mesh size) were obtained in cruises carried out by INIDEP's vessels in the study area, by oblique trawls from the bottom to surface. The filtered volume was estimated by a mechanical flowmeter. At each station, one of the two paired samples was preserved in 4% formaldehyde for subsequent analysis in the laboratory and the other was used to estimate the wet biomass. For the latter, the zooplankton was filtered on board, through a 220-μm mesh, after removing the large gelatinous zooplankton (medusae, ctenophores, etc.). The interstitial water was eliminated by placing the filter containing the sample upon a sheet of absorbent paper for a few minutes. The wet biomass was measured by a small manual scale (precision 0.5 g).

Information about size structure, composition and distribution of the zooplankton was obtained from previous regional works. A complete list of data sources is included in Table 1.

Standardization of the CPUE index

In order to make the CPUE values independent from annual fluctuations in abundance, a standardization method was applied, considering the fishing season of 1983 as the reference. The equations adopted were:

$$\mathrm{CPUEs} = \mathrm{CPUE_t}\frac{\overline{\mathrm{CPUE}}_{1983}}{\mathrm{CPUE_t}}$$

where CPUEs, standardized CPUE corresponding to year t; $\mathrm{CPUE_t}$, CPUE corresponding to an individual

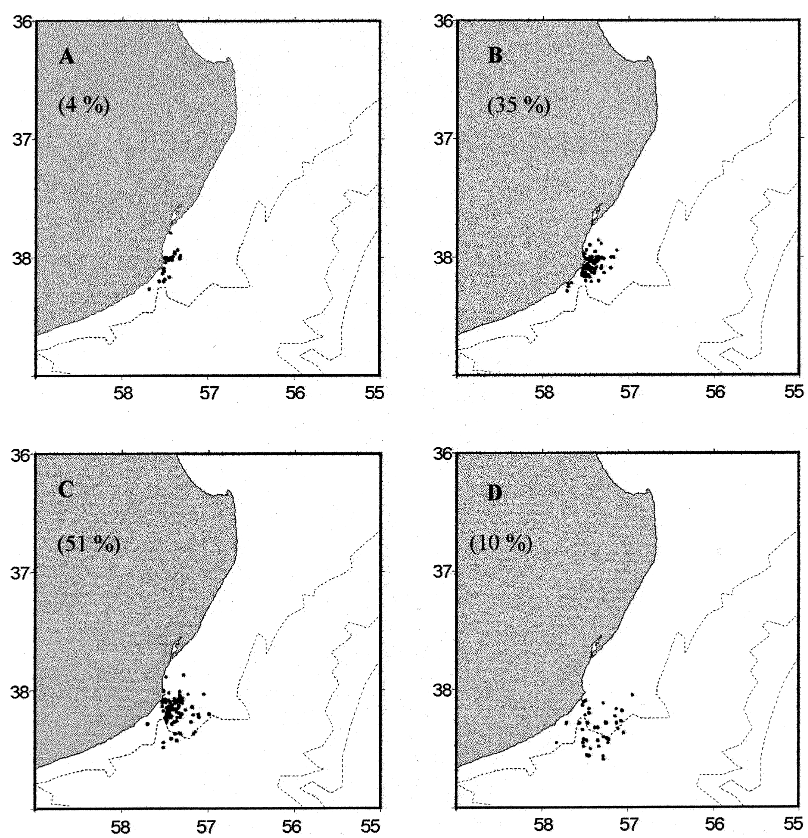


Figure 2. Position of the pilot boat during each month of the fishing season (1983–97 period). October (A), November (B), December (C) and January (D). Mean percentage of the total fishing effort corresponding to each month is indicated between brackets.

Table 1. Sources of zooplankton data.

Date of the cruises	Information	Source
April–October 1978	B	Carreto *et al.*, 1981
April–October 1978	C,D	Ramírez, 1981
April 1978–April 1979	B	Ciechomski and Sánchez, 1986
November 1986	C,D	Fernández Aráoz *et al.*, 1991
October 1982	C,D	Fernández Aráoz *et al.*, 1994
November–December 1995	B, C and D	Perrotta *et al.*, 1998b
October 1995	B	Original
October 1996	B	Original
December 1998	B	Original

B, biomass; C, composition and D, distribution.

fishing trip occurring in year t; $\overline{CPUE}_{1983}$, mean CPUE of 1983; $\overline{CPUE}_t$, mean CPUE corresponding to year t.

Total temperature range was divided in 2°C classes. For each interval, mean values and CPUE standard deviations were estimated. These values were related to mean temperature values from each interval. In this way, the mass centres of the temperature–CPUE relationship were defined and plotted. To measure the correlation between the CPUE and the FASST, the Spearman rank coefficient (Steel and Torrie, 1985) was calculated. The comparison of the CPUEs between months was made by means of the nonparametric Kruskal–Wallis test (Steel and Torrie, 1985). Furthermore, the nonparametric Dumm test (Zar, 1996) was applied to determine the pairwise differences.

The profit corresponding to a single trip was obtained as:

$$B = \frac{f_1 \times CPUE \times p - (f_1 + f_2)C_v - C_f}{f_1}$$

where B, Economic benefit, in US$ min^{-1} trip^{-1}; f_1, time of searching and fishing in min; CPUE, catch per unit of effort in kg min^{-1}; p, price in US$ kg^{-1}; f_2, time of travelling to the fishing ground in min; C_v, variable cost (fuel and oil cost) in US$ min^{-1}; C_f, daily fixed cost (COOMARPES's societary quota, maintenance and taxes) in US$.

The benefits estimated at different temperature ranges were compared by means of the Kruskal–Wallis test. This analysis was also carried out by grouping the benefits respective to November, December and January. For the pairwise comparison, Dumm's test (Zar, 1996) was used.

RESULTS

Sea surface temperature in the fishing area

For the period 1983–97, the sea surface temperature data obtained in the fishing area (FASST) by the commercial craft were compared with those from the Mar del Plata's Tide-Indicator (MSST), at the same hour. The records were significantly correlated in a linear predictive regression: MSST (°C) = 1.3457 + 0.9732 FASST (°C) ($r = 0.90$; $n = 92$). This result allowed us to utilize a larger data series of MSST (1955–97) to analyse the possible occurrence of important changes in thermal conditions and to extrapolate the results to the whole fishing area.

In the 1955–97 period, MSST gradually increased in the area as the fishing season progressed (October to January), with values ranging between 13°C and 20°C (Table 2). The low standard deviations observed within months indicates a thermal stability in the fishing area.

Relationship between CPUEs and FASST

The scatterplot of the CPUEs vs. FASST showed that the highest CPUEs values corresponded to temperatures lower than 19°C. Beyond this value, the likeli-

Table 2. Statistics corresponding to monthly variation of the MSST (°C) recorded in the Mar del Plata's Tide-Indicator (1955–97 period).

Statistic	October	November	December	January
Number of records	1213	1190	1208	1231
Average	13.13	15.68	18.22	19.92
Maximum	17.50	20.20	23.40	24.20
Minimum	9.90	12.10	14.00	15.90
Standard deviation	1.26	1.41	1.50	1.31

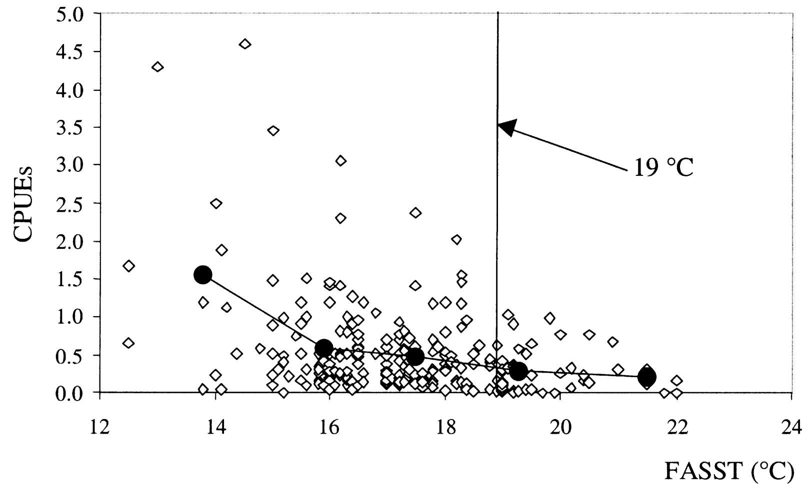
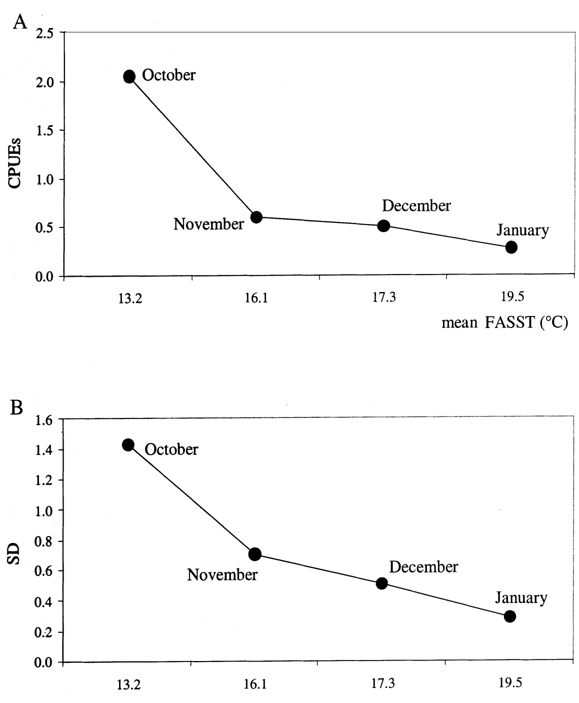


Figure 3. Relationship between CPUEs and FASST. The trend line corresponding to the mass centres is shown.

hood of obtaining a CPUEs higher than 1.0 was nearly null (Fig. 3).

The Spearman coefficient (−0.26) was highly significant ($P < 0.0001$, $n = 237$) indicating a weakly negative correlation between the CPUEs and the FASST. The centre of mass of the CPUEs distribution, calculated for two-degree ranges of temperature, confirmed this trend (Fig. 3).

Figure 4. Relationship between the mean monthly CPUEs (A) and standard deviations (B) and the mean temperature.



The differences between the monthly CPUEs were highly significant, with $H = 25.79$ for $P < 0.00001$. As the temperature increased towards the end of the fishing season (January), the mean CPUEs and standard deviations (Fig. 4A,B) became minimal.

The comparison between monthly CPUEs showed highly significant differences between all the months and January, October/November, and October/December. Differences between November/December were not significant. Furthermore, in October the interquartile interval of the CPUEs distribution was greater than those of the following months (Fig. 5), indicating that in this month there is a high possibility of obtaining the highest CPUEs values for the fishing season. In November and December, the probability of obtaining a lower CPUEs value (less than 0.5) surpasses 50%. In January, the possibility of obtaining a CPUEs similar to those recorded on October is quite low. As the stock is underexploited, this is unlikely to be due simply to accumulated fishing mortality.

Comparison of the economic benefits obtained under different temperature conditions

As previously mentioned, beyond 19°C the likelihood of obtaining a CPUEs higher than 1.0 was nearly null. On the basis of this result, the economic benefits obtained from catches from sea surface temperatures < and ≥ 19°C were compared. Highly significant differences were obtained ($P < 0.0001$). The mean benefit corresponding to temperatures lower than 19°C exceeded approximately 15 times that obtained at higher temperatures (Table 3). Otherwise, at higher temperatures, the median values indicated that 50% of the benefits were less than US$ 0.6, while in the lower temperature range, the same percentage corresponded to a benefit approximately 10 times higher. Moreover,

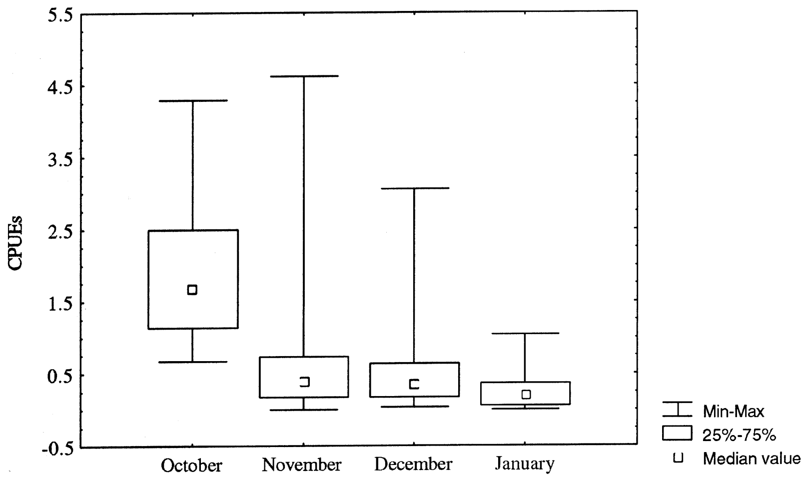


Figure 5. Box and whisker plot corresponding to the CPUEs of each month.

it is important to point out that, according to the lower quartile value, 25% of the boat departures carried out when the sea temperature exceed 19°C, would produce economic loss.

In Table 4 basic statistics of economic profits made by the pilot boat, available for months of November to January in the period 1987–97, are shown. From this table the decrease in the economic profits occurring late in the season may be deduced.

Zooplankton biomass

Highest zooplankton biomasses were found in the median shelf (50–100 m depth) averaging 577 mg m^{-3} in October ($n = 13$) and 318 mg m^{-3} in November–December ($n = 6$). In coastal waters, biomasses were approximately three times lower than in the shelf, with mean values of 170 mg m^{-3} in October and 104 mg m^{-3} in November–December (Fig. 6). At the outer shelf (100–200 m), the biomass values were intermediate between both, coastal and median shelf ones.

Table 3. Basic statistics of economic benefits per minute and trip corresponding to temperatures < 19°C and ≥ 19°C.

	Temperature < 19°C	Temperature ≥ 19°C
Mean (US$)	14.93	1.00
Standard deviation (US$)	38.16	1.50
Median (US$)	5.97	0.60
Lower quartile (US$)	2.85	−0.09
Upper quartile (US$)	10.97	2.06

Table 4. Basic statistics of the economic benefit per minute and trip corresponding to each month of the fishing season.

	November	December	January
Mean (US$)	29.21	6.73	2.26
Standard deviation (US$)	60.30	4.43	3.17
Median (US$)	7.32	5.87	0.99
Lower quartile (US$)	2.70	2.98	0.11
Upper quartile (US$)	14.37	9.58	4.40

DISCUSSION

Reproductive activity of Argentine chub mackerel takes place in warm coastal waters during spring and early summer months, with a maximum recorded between 16 and 18°C (Ciechomski, 1971; Perrotta and Christiansen, 1993; Perrotta *et al.*, 1998a). Temperature conditions in this system would be more suitable for embryonic and larval development (Fig. 7), as deduced from the observations of Hunter and Kimbrell (1980) for the Pacific mackerel. Vertically homogeneous waters characterize the coastal sector during the whole year. They are separated from stratified subantarctic shelf waters by a seasonal front approximately coincident with the 50-m isobath (Carreto *et al.*, 1995). Zooplankton biomass was considerably lower in this system than in shelf waters, and that seems to be the regular pattern all over the year (Carreto *et al.*, 1981; Ciechomski and Sánchez, 1986). In this sector, small sized (< 1 mm total length, TL) copepods are dominant components of the mesozooplankton fraction (Ramírez, 1981; Fernández Aráoz *et al.*, 1994; Perrotta *et al.*, 1998b). Dense populations of their immature stages, in spring have been reported by Ramírez (1981), in coincidence with the main peak of chlorophyll *a* (Carreto *et al.*, 1995). Only small copepod species produce eggs and nauplii in the appropriate size range (70-μm wide on average) to be ingested by the

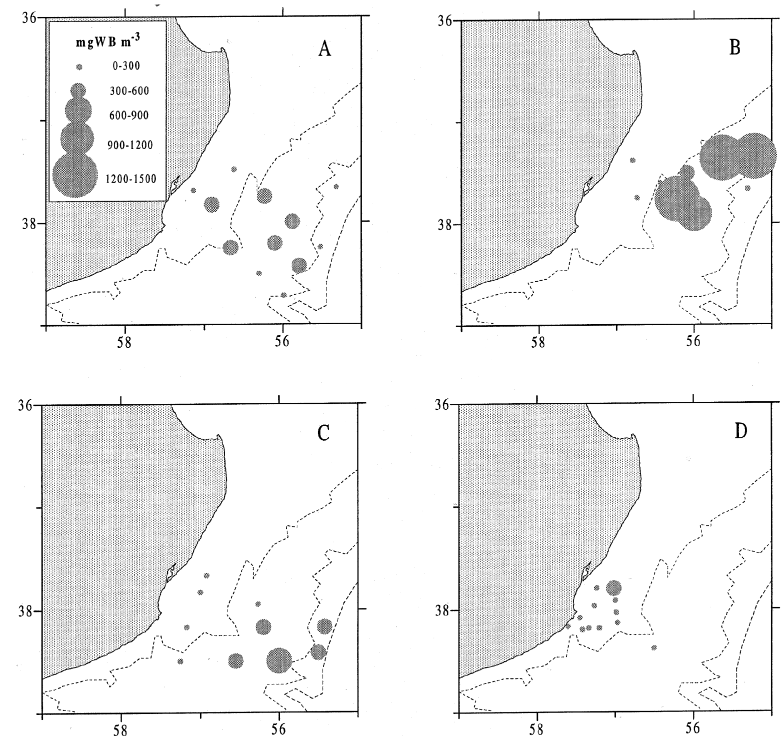


Figure 6. Distribution of wet biomass of zooplankton (mg WB m^{-3}) in the study area. Each circle represent a single Bongo sample. October 1995 (A), October 1996 (B), November 1995 (C) and December 1998 (D).

first-feeding larvae of most fishes (Arthur, 1976; Houde and Alpern Lovdal, 1984; Viñas and Ramírez, 1996; Viñas and Santos 2000) including *Scomber scombrus* (Conway *et al.*, 1996) and *S. japonicus* (Hunter and Kimbrell, 1980). Thus, during the spawning period of mackerel, the coastal system might provide not only adequate temperatures ranges but also availability of nutritious prey for first-feeding larvae (Fig. 7).

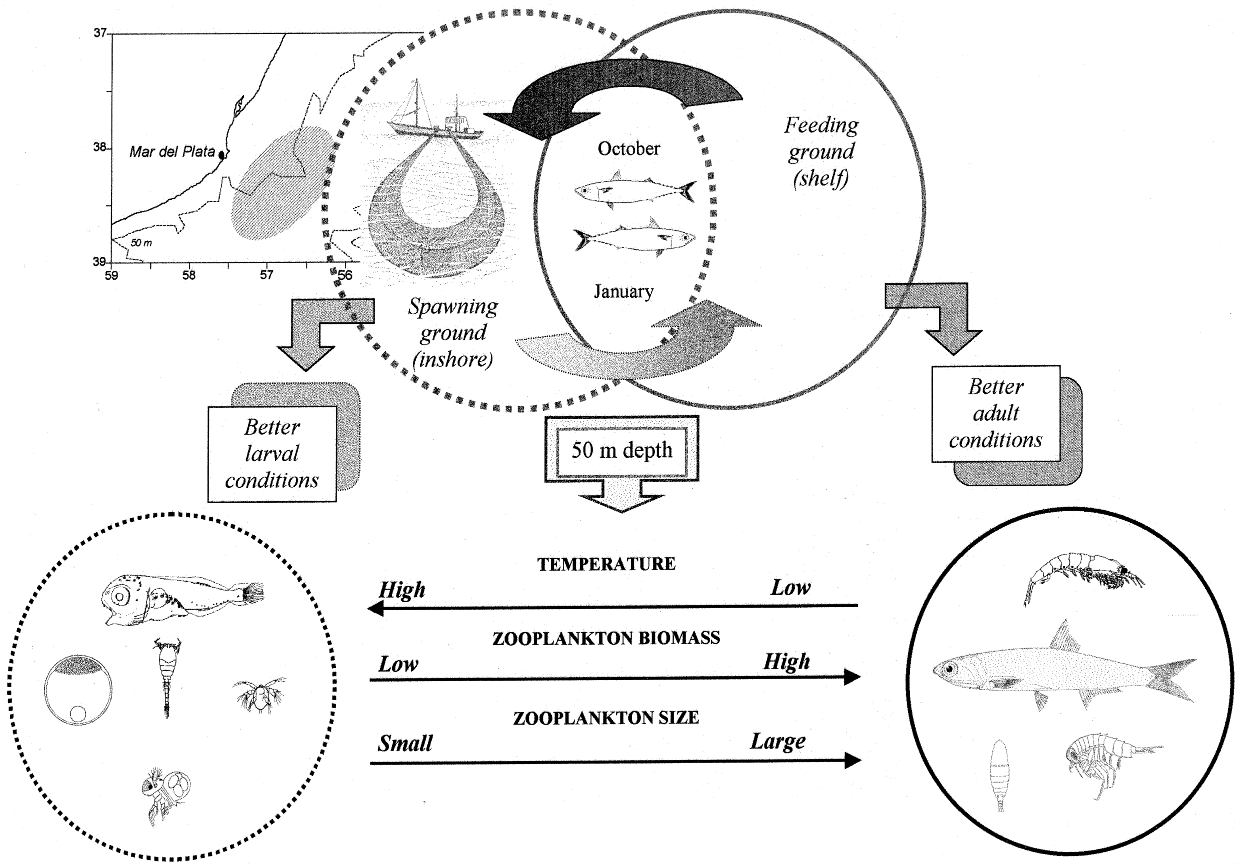
The warming of the sea waters in the coastal fishing ground beyond the upper thermal limit adequate for reproduction determines, late in the fishery season (January), the migration of mackerel schools towards to the shelf. The changes in the location of the pilot boat (representative of the whole fleet), as the fishing season develops, indicate this offshore movement (Fig. 2).

The decrease of mackerel availability inshore, coincident with temperatures ≥ 19°C, is clearly reflected also by the low CPUE records and standard deviations which in turn diminish the possibilities of obtaining high CPUE values. As was demonstrated under such temperature conditions, 25% of the catches generate economic losses. In the subantarctic shelf waters, cooler and richer in nitrates than those of the coastal system (Carreto *et al.*, 1995), high zooplankton biomass were recorded, as expected (Carreto *et al.*, 1981; Ciechomski and Sánchez, 1986). This may be attributed to the increasingly abundance of medium and large sized copepods (1–2, > 2 mm TL) as well as of euphausiids and hyperiids (Ramírez, 1981; Fernández Aráoz *et al.*, 1991) towards the shelf. *Engraulis anchoita* and macrozooplankton (> 1.7 mm length) are, in order of importance, the main component of the diet of adults of *Scomber japonicus* in Argentine waters (Angelescu, 1980; Cousseau *et al.*, 1987; Perrotta *et al.*, 1999). Thus, the migration of anchovy into shelf waters after spring spawning (Angelescu, 1982), as well as the high densities of macrozooplankton occurring in this sector, determine the potentiality of this area as a feeding ground for the adults of mackerel.

The conceptual scheme in Fig. 7 summarizes our hypothesis concerning the main factors affecting the migratory behaviour of chub mackerel in the Mar del Plata region during the fishing season. A similar model of distribution in space and time was reported for *S. japonicus* in the Canary Islands (Lorenzo-Nespereira and González Pajuelo, 1993, 1996; Castro and Hernández-García, 1995).

Present knowledge about the seasonal movements of mackerel schools have important implications for the inshore fishery. According to the above considerations, when temperature reaches 19°C in coastal waters, the schools migration to the shelf determines a change in their spatial distribution that becomes more dispersed, resulting in an increase of the searching cost

Figure 7. Conceptual scheme of the main factors determining the migration pattern of chub mackerel in the Mar del Plata region.



for the fleet. In such circumstances, the economic return from catches is minimal and sometimes negative, as demonstrated from the analysis of benefit evolution during the fishing season. Therefore, we suggest avoiding sailing under such temperature regimes. Since some fishermen are beginning to check daily sea surface temperature (FASST or MSS) in order to reduce non-productive trips, we infer that some kind of fleet feedback does exist.

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