ZOOPLANKTON BIOMASS IN THE REPRODUCTIVE AREA OF THE SOUTHERN BLUE WHITING *(Micromesistius australis)*

by

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RESUMEN

Biomasa del zooplancton en el área reproductiva de la polaca (*Micromesistius australis*). Se analizó la biomasa zooplanctónica total y por fracciones (mayor y menor de 5 mm) durante dos campañas de investigación realizadas en inmediaciones de las Islas Malvinas en invierno tardío (septiembre 1994 y 1995), cuando normalmente se produce el desove masivo de polaca. La distribución de biomasa en el área fue casi uniforme y estuvo dominada por la fracción mayor de 5 mm, donde eufáusidos, y en segundo término quetognatos, predominaron tanto en peso como en número. La fracción menor estuvo mayormente constituída por copépodos. A partir de la predominancia de eufáusidos y de la abundancia estacional de varias especies de copépodos comunes en el área, se especuló que en momentos del desove invernal, los requerimientos alimenticios de todos los estadios de desarrollo de la polaca estarían satisfechos. Los datos fueron asimismo examinados en el contexto de los valores de biomasa zooplanctónica obtenidos en aguas de plataforma surpatagónica durante otoño y primavera.

SUMMARY

Total and size-fractioned zooplankton biomass (larger and smaller than 5 mm) were analysed over two cruises conducted in the late austral winter (September 1994 and 1995) in the area surrounding Malvinas Islands at the time that massive spawning of southern blue whiting was expected to take place. Biomass was rather uniformly distributed in the area and dominated by the fraction larger than 5 mm in which euphausiids and secondarily chaetognaths were dominating in terms of both weight and number. The smaller fraction was mostly made up of copepods. From the high occurrence of euphausiids and seasonal abundance of the several species of copepods normally present within the

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area it was hypothesised that the feeding requirements of juvenile and adult blue whiting as well as those of larvae and post-larvae may be met during the winter spawning season. The data were also examined in conjunction with the general pattern of zooplankton biomass occurring in autumn and spring in the Southern Patagonian shelf.

Key words: Zooplankton biomass, Malvinas Islands, Southern Patagonian shelf, southern blue whiting, *Micromesistius australis.*

Palabras claves: Biomasa zooplanctónica, Islas Malvinas, plataforma surpatagónica, polaca, *Micromesistius australis.*

INTRODUCTION

Understanding plankton-fish linkages has always been a major issue in fisheries ecology. In recent years more attention has been driven to zooplankton, along with the increasing awareness of the pivotal role that zooplankton might have -directly coupled with ocean physics- in controlling both the magnitude and fate of primary production and the inter-annual variability of important fish stock (e.g. Kiørboe, 1991; Banse, 1995). It is known that the fisheries potential of a region is ultimately determined not only by the magnitude of primary production but also by the length of the food chain, which in turn will affect the fraction of primary production that is available to zooplankton and to planktivorous fish (Cushing, 1989; Kiørboe, 1993). Therefore, long-term variations in the year class success of many fish stocks might be largely explained from the predictive knowledge of the relationships between fish and their zooplankton food, linked to the changing physics of the environment.

It was just in the late 70's that research surveys started to be carried out systematically in the Argentinian shelf and adjacent waters to the south of 45°S in coincidence with the increasing fishing levels of the southern Patagonian resources which, up to then, had been almost unexploited (Ehrlich and Sánchez, 1990 and Angelescu and Sánchez, 1995).

The most complete environmental sampling regarding the basic hydrography and plankton of the entire region was provided by the 'Walther Herwig' and 'Shinkai Maru' surveys (1978-1979). Although they were primary addressed to fisheries assessment, the resulting data set was exceptional in covering extensively all seasons and allowed to outline by the first time the seasonal pattern of zooplankton biomass related to the nutrient dynamics and phytoplankton cycle (Carreto *et al.*, 1981a, b) as well as to the abundance of fish eggs and larvae (Ciechomski and Sánchez, 1983). The distribution and abundance of the dominating copepod species were also reported in detail (Ramírez, 1981). Up to then, only occasional references to zooplankton topics were available for the Southern Patagonia (e.g. Montú, 1977; Ramírez, 1971; 1973; Ramírez and Dato,1983).

Surveys to the south of 50° S were disrupted in 1982 as a consequence of the Malvinas War. Fisheries assessment cruises, and thus plankton sampling, were restarted only in 1992. Unfortunately, this situation left behind an about ten years gap of information between the formerly gathered data series and the most recent collections.

Two joint Argentina-United Kingdom cruises were conducted in the late austral winter (September 1994 and 1995) with the overall aim of assessing the spawning stock biomass of the southern blue whiting *Micromesistius australis*. Reproduction of the species appeared to take place around the Malvinas Islands (Perrotta, 1982; Sánchez *et al.*, 1986) where besides most of the fishing stock is concentrated (Sánchez and Ciechomski, 1995). This paper focus on the pattern of zooplankton biomass occurring at that time in the Southern Patagonian shelf and adjacent waters. These data are brought into the perspective of the current background on the production cycle in the region. The ecological implications for the southern blue whiting fishery and their possible management significance are examined hereof.

MATERIAL AND METHODS

Field data presented in this study were collected on cruises with the R.V. 'Capitán Oca Balda' (National Institute for Fisheries Research and Development, Argentina). Data obtained in the area around the Malvinas Islands and neighbouring waters were gathered through two acoustic surveys carried out in September 1994 (R.V. 'Cap. Oca Balda' 07/94) and 1995 (R.V. 'Cap. Oca Balda' 10/95) which were specifically aimed to asses the spawning stock of southern blue whiting in the area.

In order to better depict the overall zooplankton pattern in the region the results of the above surveys were examined in conjunction with those of two fisheries oceanographic cruises conducted in the austral autumn (April, R.V. 'Cap. Oca Balda' 04/94) and spring (November, R.V. 'Cap. Oca Balda' 09/94) 1994 on the Argentinian continental shelf between 47° and 55° S. In any case zooplankton sampling fitted the general sampling design of the cruises primary focused on stock biomass assessment. A transect sampling strategy designed for basic hydrography (CTD) and plankton was additionally carried out at 47° and 51° S on the autumn and spring cruises. The samples obtained along those transects were used to analyze the latitudinal and longitudinal variation of zooplankton biomass and composition on a temporal scale.

Zooplankton samples were collected with a Nackthai sampler (400-500 µm mesh size) towed obliquely through the water column from near the bottom to surface or from a maximum depth of 500 m at deeper stations. Depth and towing speed were monitored by means of a depth sensor outfitted to the gear. A flowmeter was used to estimate the water volumes.

Wet weights were determined either on board immediately after collection or samples were preserved in 5% buffered formalin for the subsequent analysis in the laboratory. Macrozooplankton was sorted into two size fractions (larger and smaller than 5 mm) by sorting individually the animals with tweezers. The remaining smaller fraction as well as the sorted groups (euphausiids, hyperiid amphipods and chaetognaths) were weighted separately by using a small manual scale (± 0.2 g) after removing as much water as possible. The smaller fraction was mostly made up of copepods, though occasionally ostracods, euphausiids, other crustacean larvae and fish eggs were also present. Group dominance (%) in the larger fraction was also estimated. The sum of the two fractions is referred to as 'total' zooplankton biomass herein, although it quite clearly omits the small copepods and microzooplankton. Yet, major trends in copepod abundance can be presumed from the signal provided by the larger copepod species which were effectively retained by the mesh (400 - 500 µm).

In view of the general pattern of aggregation and vertical migration of the dominant groups (e.g. Greene *et al.*, 1989) only data obtained at dusk-, dawn- or night-time were included in this study.

RESULTS

Total zooplankton biomass and size composition measured in the spawning area of *M. australis* in late winter are shown in Fig. 1. Since no significant differences were found between biomass concentrations occurring in September 1994 and 1995, all the data were pooled together. Maximum biomasses (ca. 300 - 500 mg m^{-3}) were found over the continental shelf, and at stations deeper than 200 m located to the NE and SW of the Malvinas Islands and towards the eastern part of the Burdwood Bank (ca. 200 mg m^{-3}). Minimum values (< 30 mg m^{-3})

were found to the south of Tierra del Fuego and in the vicinity of the Staten Island. Biomass was quite dominated by the fraction larger than 5 mm, the smaller one showing values lower than 10 mg m^{-3} in the 70 % of the catches. Euphausiids and secondarily chaetognaths were dominating in terms of both weight and number over the entire area (Fig. 2). While euphausiids were numerically more abundant over the continental shelf, chaetognats were located in deeper areas, mainly over the slope (Fig. 3).

The autumn data (April, Fig. 4) available for the southwestern Malvinas area indicate no changes either in the average magnitude or size composition of zooplankton biomass in comparison with the situ-

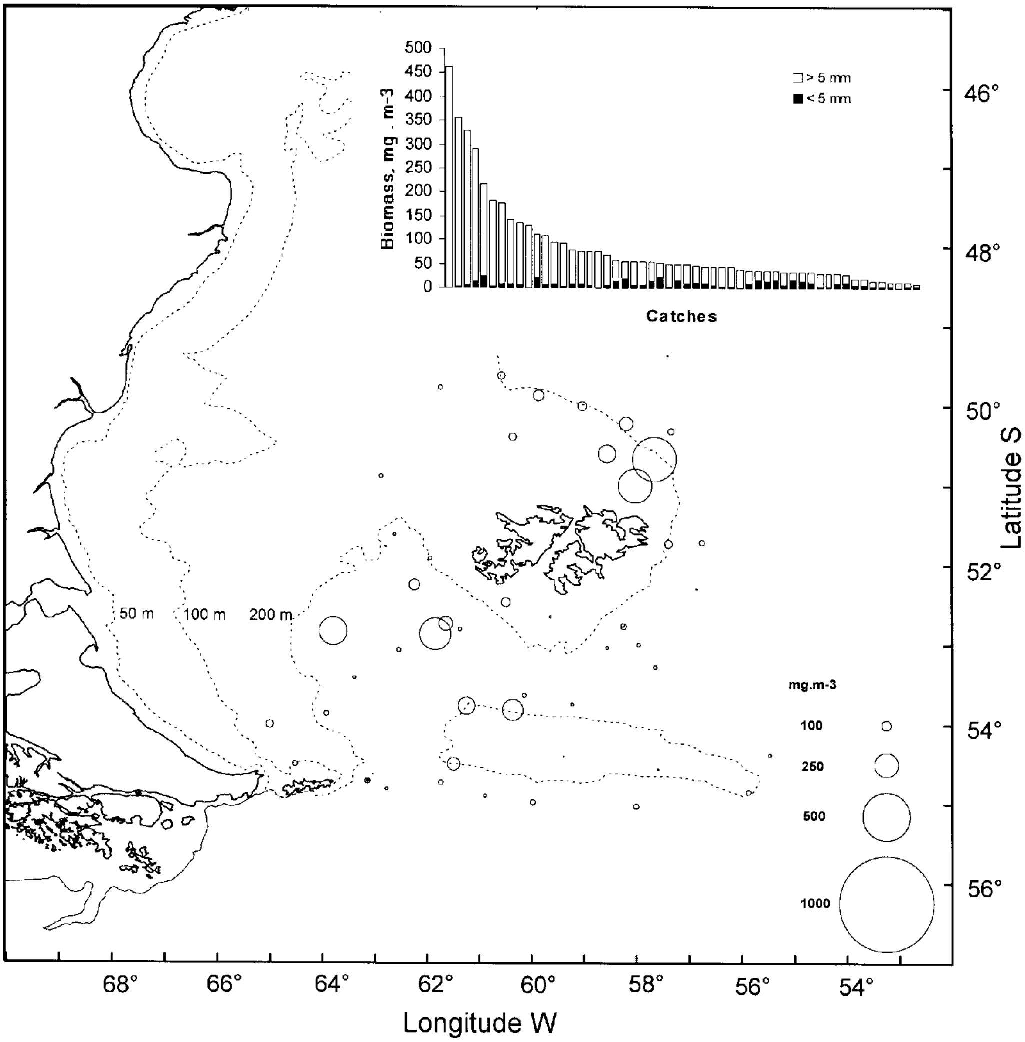

Figure 1. Total and size-fractioned zooplankton biomass (wet weight) occurring on the Argentinian continental shelf around the Malvinas Islands and adjacent waters in the late austral winter. Data collected during September 1994 and 1995 were pooled together.

Figura 1. Biomasa zooplanctónica total y por fracciones (en peso húmedo) registradas en la plataforma continental argentina alrededor de las Islas Malvinas y aguas adyacentes en invierno tardío. Los datos colectados en septiembre 1994 y 1995 fueron graficados juntos.

ation found in late winter (September). Instead, the bulk of biomass in neritic and mid-shelf waters was quite different between ca. 50° and 52° S where concentrations ranging ~500 - 1500 mg m^{-3} were found in contrast with the low values occurring in >200 m depth waters.

Later in spring (November, Fig. 5), the total biomass occurring on the remainder adjacent shelf between 47° and 55°S was overall the same as that found around the Malvinas Islands, except for the maximum values (>1000 mg m^{-3}) measured in neritic waters and to the northeast, approaching the shelf-break. Contrastingly, the fraction smaller than 5 mm dominated over the continental shelf while within the area surrounding the Malvinas Islands the larger one did.

Some broad spatial and seasonal trends in zooplankton biomass were drawn by examining the patterns found along the transects performed at 47° and 51° S. The most complete series of data to analyze the latitudinal and longitudinal distribution of biomass was gathered in spring (November, Fig. 5). At this time the highest concentrations (~1300 mg m^{-3}) were measured in the mid continental shelf at 47°S

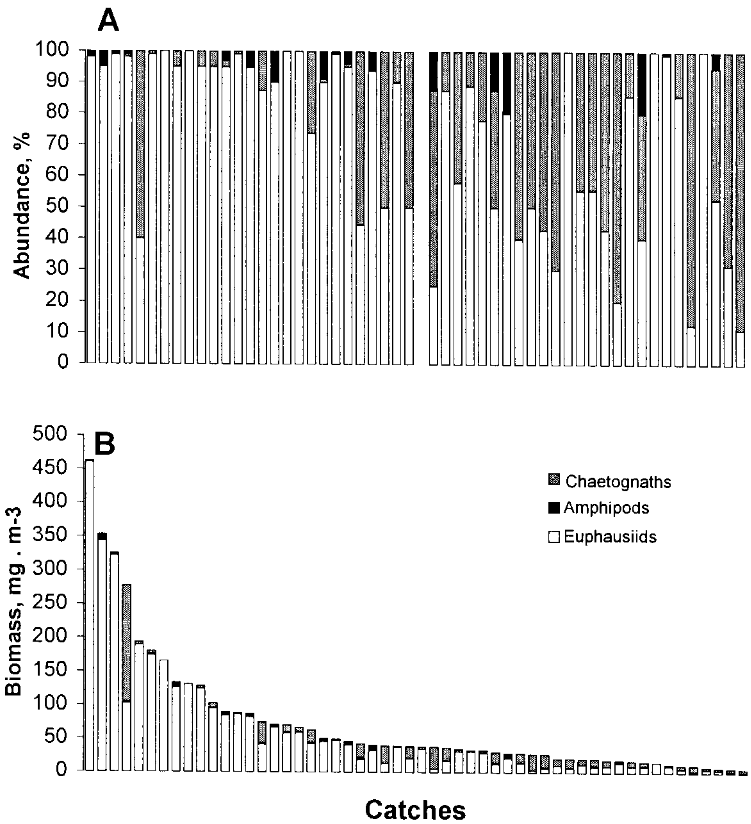

Figure 2. Contribution of major taxonomic groups to the larger fraction (> 5 mm) of zooplankton abundance (A) and biomass (B) in the Nackthai catches obtained in the area surrounding the Malvinas Islands and adjacent waters. Data collected during September 1994 and 1995 were pooled together.

Figura 2. Composición por grandes grupos taxonómicos de la fracción > 5 mm del zooplancton colectado en el área de Islas Malvinas y aguas adyacentes; A, Abundancia . B, Biomasa. Los datos colectados en septiembre 1994 y 1995 fueron graficados juntos.

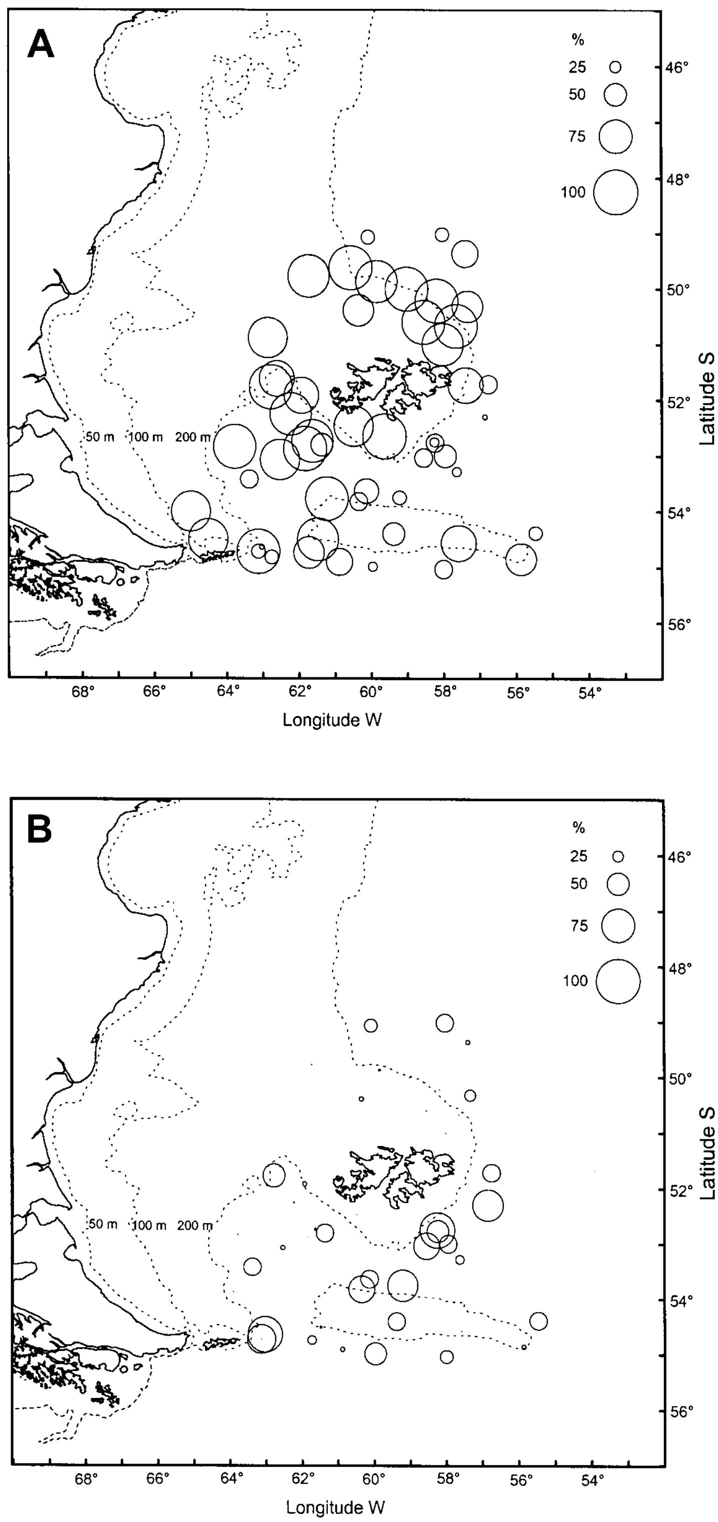

Figure 3. Abundance distribution (as percentage) of euphausiids (A) and chaetognaths (B) in the study area.
Figura 3. Distribución porcentual de la abundancia de eufáusidos (A) y quetognatos (B) en el área de estudio.

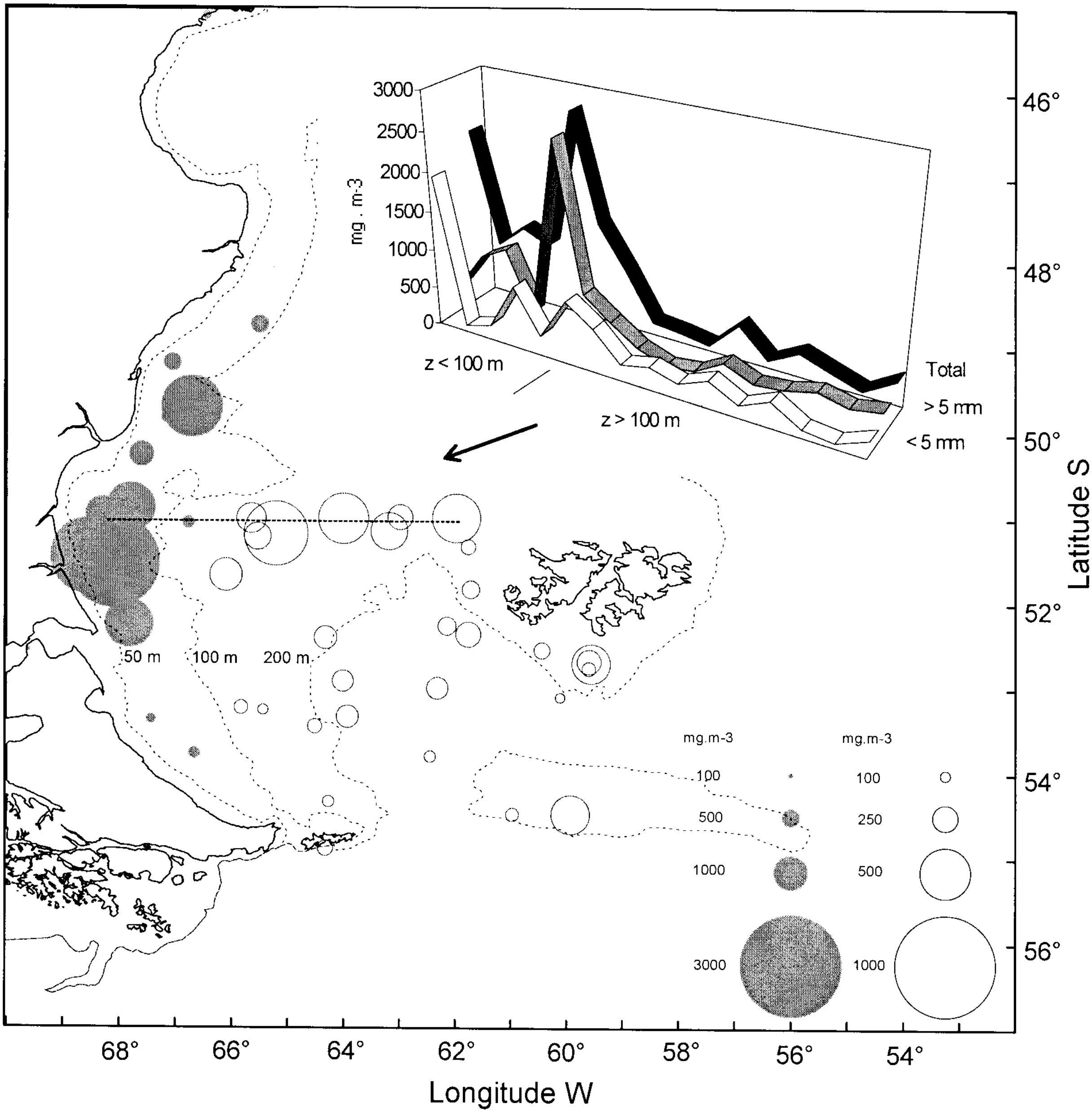

Figure 4. Total zooplankton biomass (wet weight) occurring on the shelf off Argentina and adjacents waters to the south of 45° S in the austral autumn (April 1994). Size-fractioned zooplankton biomass through the water column in shallower and deeper than 100 m depth along a transect at 51° S is shown in the upper pannel.

Figura 4. Distribución de biomasas zooplanctónicas (peso húmedo) en la plataforma continental argentina y aguas adyacentes al sur de los 45° S en abril 1994. En el panel superior se muestra la variación de la concentración de las dos fracciones de tamaño desde profundidades menores de 100 m a mayores a lo largo de una sección ubicada a 51° S.

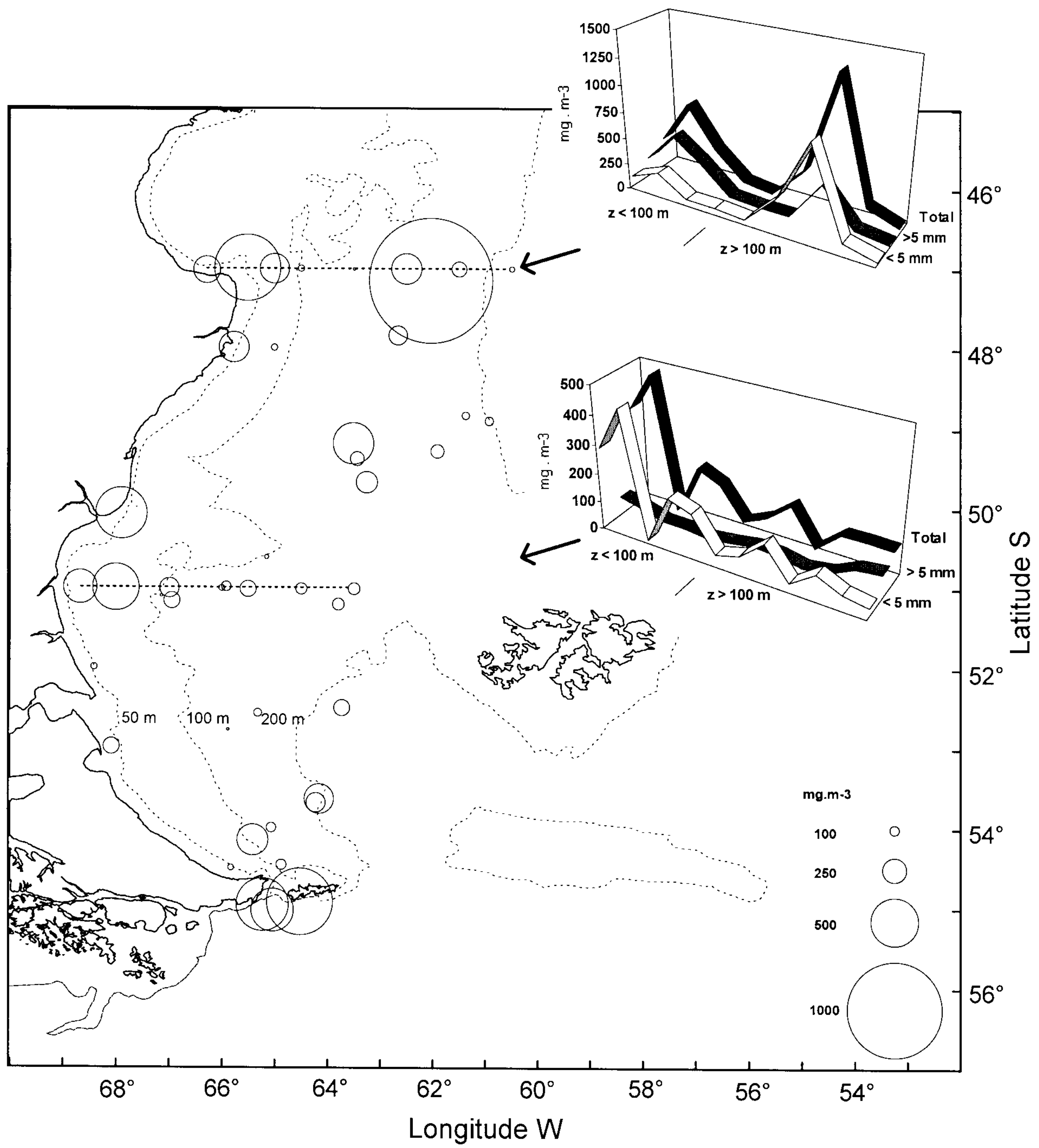

Figure 5. Total zooplankton biomass (wet weight) occurring on the shelf off Argentina and adjacents waters to the south of 45° S in the austral spring (November 1994). Size-fractioned zooplankton biomass through the water column in shallower and deeper than 100 m depth along two transects at 47° and 51° S is shown in the upper pannels.

Figura 5. Distribución de biomasas zooplanctónicas (peso húmedo) en la plataforma continental argentina y aguas adyacentes al sur de los 45° S en noviembre 1994. En los paneles superiores se muestra la variación de la concentración de las dos fracciones de tamaño desde profundidades menores de 100 m a mayores a lo largo de las secciones ubicadas a 47° y 51° S.

with the smaller fraction -mainly copepods- accounting for up to 80% of total biomass. Lower values (~700 mg. m^{-3}), dominated by the larger fraction (mostly euphausiids and mysids), were found in <100 m depth waters. Total biomasses of about the same magnitude were also measured in neritic waters of the southern area (51° and 55° S) but the smaller fraction dominated (most of it made again of copepods representing ~80% of total biomass). At 51°S the larger one prevailed in the deeper area with dominance gradually changing from amphipods to euphausiids as distance offshore increased (no data available for the most southern area). It appears thus that in spring zooplankton biomass -consisting mainly of copepods- peaked offshore nearby the shelf-break in the northern area (47°S) while to the south (51° S) highest values occurred in neritic waters. In autumn (April, Fig. 4) highest biomass were located in neritic waters (50 m > z <100 m) with values ranging ~200 - 1500, but up to 2500 mg. m^{-3}. In this area the larger fraction -mainly made up of hyperiid amphipods- was dominating. In deeper waters (>100 m) both fractions contributed almost equally to total biomass (maximum values ~700 mg. m^{-3}) but in the larger one the dominance gradually changed again from amphipods to euphausiids with increasing distance from the coast as it was observed in spring. Unfortunately there are no data available in this season for the further northern area.

On the account above, some main features -though based on quite limited data- may be outlined:

i) The outer continental shelf off Argentina surrounding the Malvinas Islands and the deeper adjacent waters located to the SW emerge as a distinct area where zooplankton biomass, primarily dominated by the fraction larger than 5 mm, is rather uniformly distributed (range ~50 - 500 mg. m^{-3}) and likely shows a low seasonal variation, as suggested by the comparison of Fig. 1 and Fig. 4.

ii) Despite spatial fluctuations in abundance, euphausiids are most frequently present in large biomass concentrations within the area around Malvinas and neighbouring waters.

iii) It appears that zooplankton biomass does not peak synchronously on the whole southern Patagonian shelf but the magnitude and size-composition shift temporally from the coast to the shelf-break and from north to south.

iv) The largest bulk of biomass, mostly made up of hyperiid amphipods, occurs in autumn in neritic waters between 51° and 52° S.

DISCUSSION

The reproductive strategy of the southern blue whiting *M. australis* is expected to be synchronized with the plankton production cycle of the area where it occurs, which in turn will be linked to the bottom topography and physical processes affecting water column stability. Spawning areas are normally fixed in time and space in order to meet the conditions leading to the occurrence of an abundant food supply for larvae and juveniles (e.g. Cushing, 1975; 1984; Bakun and Parrish, 1991). Recruitment of the northern blue whiting *Micromesistius poutaussou* in particular has been shown to be directly affected by even short changes in phyto - and/or zooplankton production cycles in waters off the west coast of Scotland (Bainbridge and Cooper, 1973) and in the Catalonian Sea (Bas and Calderón-Aguilera, 1989).

The plankton production cycle in waters off Argentina was first decribed by Carreto *et al.* (1981a, 1981b) from the seasonal sampling provided by the 'Walther Herwig' and 'Shinkai Maru' surveys (1978-1979), mainly for the northern region down to 46° S. The cycle follows the typical development and breakdown of the seasonal thermocline characteristic of cold-temperate seas, the main phytoplankton peak occurring in spring and the secondary one in autumn. The algal bloom starts in October-November in the inshore shallow waters of the northern shelf and gradually develops southwards and offshore later in the season (November-December). Zooplankton biomass peaks following the spring bloom, its magnitude also shifting temporally from the coast to the shelfbreak and from north to south. Though based on too fragmentary information since nutrient and phytoplankton data are lacking, the main trends found in zooplankton biomass from the data collected through the more recent surveys support their view of a similar pattern for southern Patagonian shelf. As suggested earlier, at higher austral latitudes the secondary phytoplankton pulse, normally of lower magnitude, might not occur (likely due to light limitation) but a single longer phytoplankton maxima during late spring and summer would develop. Some differences in the production cycle depending on the latitude should be however expected, regarding mainly the delay period (the time it takes for effective grazing to develop from the start of algal production) which in turn will be related to temperature, bathymetric features and to the population dynamics of the species involved (Cushing, 1975; Kiørboe, 1993).

There is in contrast very little information about the outer Argentinian shelf off Malvinas and the adjacent southern deeper area. It appears to be a highly dynamic region showing a complex circulation pattern with the predominant influence of the Malvinas Current (Sánchez and Ciechomski, 1995 and references therein). High chlorophyll 'a' concentrations and phytoplankton growth have been reported throughout summer and autumn in the shelf-break (Carreto *et al.*, 1995) while maximum zooplankton biomasses have been found in winter and summer to the NE of the Malvinas Islands near the slope (Ciechomski and Sánchez, 1983). Values of Bongo net settled zooplankton volumes measured in spring (Rodhouse *et al*., 1992) were roughly within the same range as we found in late winter. A distinctive zooplankton assemblage, mainly based on variations in abundance of predominantly neritic species typical of the southern zones was related to the water masses occurring over the same area at that time (Tarling *et al*., 1995). The dominating occurrence of euphausiids we found within the area may be related to the fact that they appear to be more buffered than copepods in responding to environmental fluctuations. Because of their relatively longer lifespan (~1 year versus ~1 month for copepods), they may be more capable of smoothing out some of the effects of seasonal variability (Pillar *et al.*, 1992). Besides, euphausiids are typically omnivorous, with a tendency towards either herbivorous or carnivorous behaviour, depending on the trophic conditions of their environment. Their occurrence is clearly reflected in the food of zooplanktivorous fish such as southern blue whiting, for which euphausiids prevail in the diet of juveniles and adults all year long while copepods and hyperiids amphipods appear to have rather a more seasonal importance (Otero, 1976,1977; Perrotta, 1982). Two very abundant euphausiid species occur around Malvinas: *Thysanoessa gregaria* and *Euphausia vallentini* (Ramírez, 1973). These species reach ovarian maturity by the end of the winter (Ramírez and Dato, 1983) and in spring larvae and adults peak noticeably within the southwestern area of the Malvinas Islands (Montú, 1977). A second fast-growing population of *T. gregaria* would develop in the same area during the summer (Ramírez and Dato, 1983). Hence, the feeding requirements of juvenile and adult blue whiting may be fully met in the area. On the other hand, the occurrence of large species of copepods such as *Calanus australis* and *C. propinquus* that apparently peak in September - December in the area along, with the small ones *Drepanopus forcipatus* and *Oithona helgolandica* occurring in high densities all year long (Ramírez, 1981), may provide good food conditions for the larvae and postlarvae. Eggs, nauplii and early copepodite stages of copepods are the most frequent organisms found in the guts of larvae of the northern blue whiting (Bainbridge and Cooper, 1973; Conway, 1980). At present we could not but speculate about the resulting production cycle in this area.

The recently gathered data of zooplankton biomass are within the range of former findings as it is shown in Table 1. Differences in magnitude should be rather attributed to the different sampling methodologies applied throughout time, since major spatial and seasonal trends seem to keep the same. There is no evidence to suspect any dramatic change in either group composition or abundance of zooplankton from the late 70's to nowadays.

Up to here we have reported on the synoptic distribution of zooplankton biomass at the time that massive spawning of southern blue whiting was

Table 1. Zooplankton biomass measured on the outer and mid continental shelf off Argentina to the south of 45° S. For comparison all the records were converted to wet weight by asuming DW=0.17 WW (Båmstedt, 1986) and WW(mg)= 0.711 V (m^{-3}) (Santos, 1994) where DW is dry weight, WW is wet weight and V is volume.

Tabla 1. Biomasas de zooplancton medidas en aguas de plataforma intermedia y externa al sur de los 45° S. A los efectos de la comparación todos los registros se expresaron en mg peso húmedo por metro cúbico. Cuando necesario se usaron las siguientes conversiones: PS= 0.17 PH (Båmstedt, 1986) and PH (mg)= 0.711 V (m^{-3}) (Santos, 1994) donde PS es peso seco, PH es peso húmedo y V es volumen.

Season	Biomass mg WW m^{-3}	Sampler (mesh size, µm)	Original data measured as	Reference
		Outer Shelf		
Winter	2 -70	Conical net (300)	dry weight	Carreto *et al*., 1981
	7 - >700	Bongo net (505)	displacement volume	Ciechomski & Sánchez, 1983
	10 - 450	Nackthai (400)	wet weight	This study
Spring	10 -80	Conical net (300)	dry weight	Carreto *et al*., 1981
	7 -700	Bongo net (505)	displacement volume	Ciechomski & Sánchez, 1983
	No data	Nackthai (400)	wet weight	This study
Summer	70 - 700	Bongo net (505)	displacement volume	Ciechomski & Sánchez, 1983
Autumn	2 -70	Conical net (300)	dry weight	Carreto *et al*., 1981
	7 -70	Bongo net (505)	displacement volume	Ciechomski & Sánchez, 1983
	80 - 400	Nackthai (400)	wet weight	This study
		Mid Shelf		
Winter	6 - 100	Conical net (300)	dry weight	Carreto *et al*., 1981
	7 -70	Bongo net (505)	displacement volumen	Ciechomski & Sánchez, 1983
Spring	13 - 300	Conical net (300)	dry weight	Carreto *et al*., 1981
	7 -700	Bongo net (505)	displacement volume	Ciechomski & Sánchez, 1983
	20 - 1500	Nackthai (400)	wet weight	This study
Summer	6 - 260	Conical net (300)	dry weight	Carreto *et al*., 1981
	70 -700	Bongo net (505)	displacement volume	Ciechomshi & sánchez, 1983
Autumn	6 - 100	Conical net (300)	dry weight	Carreto *et al*., 1981
	7 - 700	Bongo net (505)	displacement volumen	Ciechomski & Sánchez, 1983
	80 - 600	Nackthai (400)	wet weight	This study

expected to take place, along with the overall pattern occurring throughout the previous and following season in the Patagonian region. It quite clearly emerges that despite its economical importance, waters off Southern Patagonia as a whole, but primarily the area surrounding the Malvinas Islands, are still poorly known. Further exhaustive plankton research related to the physical environment needs to be carried out in order to characterize the production cycle and thus clearly establish the links between hydrography, plankton and the fish resources occurring in the region.

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