

## Chlorophyll and zooplankton in microbasins along the Straits of the Magellan-Beagle Channel passage\*

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**SUMMARY:** Distributions of chlorophyll and zooplankton were compared to temperature and salinity distributions along previously defined microbasins. Results were consistent for chlorophyll: 1.- Paso Ancho-Seno Magdalena showed a shallow chlorophyll maximum (ca.  $5 \text{ mg m}^{-3}$  at 0 - 20 m) in a vertically homogeneous cold and brackish water column, 2.- Canal Magdalena-Canal Cockburn-Canal Brecknock had relatively lower chlorophyll concentrations ( $2\text{-}3 \text{ mg m}^{-3}$  at 0-50 m), minor stratification of salinity and a surface lens of warmer water, 3.- Canal Ballenero-Brazo Noroeste had a subsurface layer of high chlorophyll concentration ( $>4 \text{ mg m}^{-3}$ ) in a vertically stratified water column of 2 salinity layers and 3 temperature layers, 4.- Canal Beagle presented a subsurface chlorophyll maximum ( $> 4 \text{ mg m}^{-3}$ ) extending to the bottom, and vertically homogeneous salinity and temperature distribution. *Chaetoceros* spp.-dominated phytoplankton was a common feature in the entire area. Zooplankton distributions did not match the above mentioned subdivision of microbasins despite some trends along the passage. High relative abundance of invertebrate larvae in the zooplankton was associated with a matching response to the spring bloom and implies a strong benthic-pelagic coupling.

**Keywords:** Chlorophyll, hydrography, phytoplankton, zooplankton, estuaries, microbasins, Magellan-Beagle

**RESUMEN:** CLOROFILA Y ZOOPLANCTON EN MICROCUENCAS A LO LARGO DEL PASO ENTRE EL ESTRECHO DE MAGALLANES Y EL CANAL DEL BEAGLE. – Se comparó la distribución de clorofila y zooplancton en microcuencas definidas previamente por sus características térmicas y salinas. Los resultados fueron consistentes para la clorofila: 1.- Paso Ancho-Seno Magdalena presentó un máximo somero de clorofila (ca.  $5 \text{ mg m}^{-3}$  en 0-20 m) en aguas frías y salobres homogéneamente distribuidas en la columna de agua, 2.- Canal Magdalena-Canal Cockburn-Canal Brecknock presentó concentraciones de clorofila relativamente menores ( $2\text{-}3 \text{ mg m}^{-3}$  de 0-50 m), y presentó una débil estratificación de salinidad y una lente de agua más caliente, 3.- Canal Ballenero-Brazo Noroeste presentó un estrato subsuperficial de valores altos de clorofila ( $>4 \text{ mg m}^{-3}$ ), dos estratos de salinidad y tres estratos térmicos, 4.- Canal del Beagle presentó un máximo subsuperficial de clorofila ( $>4 \text{ mg m}^{-3}$ ) que se extendió hasta el fondo y la temperatura y salinidad fueron verticalmente homogéneas. El fitoplancton dominado por *Chaetoceros* spp. fue un rasgo común de toda el área de estudio. La distribución del zooplancton no se ajustó a la subdivisión de microcuencas, a pesar de algunas tendencias a lo largo del transecto. La alta abundancia relativa de larvas de invertebrados en el zooplancton se asoció con una respuesta a la proliferación primaveral, lo cual implica un fuerte acoplamiento bento-pelágico.

**Palabras clave:** Clorofila, hidrografía, fitoplancton, zooplancton, estuarios, microcuencas, Magallanes-Beagle.

### INTRODUCTION

The Magellan-Beagle passage stretches along some 400 km of intricate coastline and complex bathymetry, and has several connections to the open

ocean. They include the Pacific and Atlantic entrances of the Straits of Magellan, the eastern and western entrances of the Canal Beagle to the Pacific and several connections between Canal Cockburn and Brazo Noroeste. Yet, sills, shallow shelves and contractions within the passage may limit water exchange with the open ocean particularly at the

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eastern entrance of the Straits of Magellan (Artegiani and Paschini, 1991) and at the above mentioned ocean openings along the Canal Magdalena-Canal Beagle passage (Antezana, 1999). In fact, the plankton assemblage of the fjord ecosystem, although part of the Subantarctic Magellan Province (Brattström and Johansen, 1983), is characterized by distinct and less diverse biota than the open ocean (Antezana, 1976; Marin and Antezana, 1985; Mazzocchi *et al.*, 1995; Guglielmo *et al.*, 1996). Strong dispersal action by tidal and wind-induced currents within this main passage of drifting plankton may result in a randomly mixed distribution of the biota. Alternatively, the formation of microbasins with distinct biotic characteristics may occur, as was the case in the Straits of Magellan (Mazzocchi and Ianora, 1991; Cabrini and Fonda Umani, 1991; Uribe, 1991), where the combined effect of bathymetry and topography limited water circulation and fresh water inflow (Panella *et al.*, 1991; Antezana *et al.*, 1992). Our concept of microbasin is a topographically (bottom and coastline) defined enclosure with associated hydrographic characteristics. It is likely that plankton within this inland passage, instead of being randomly distributed, will be found related to physical gradients or discontinuities. The main aim of this work is to test for these two alternatives through the study of the distribution of the phytoplankton and several taxa of zooplankton along this passage.

## MATERIAL AND METHODS

This study was carried out during the austral spring cruise (2 - 6 November 1994) of R.V. "Victor Hensen" along the main passage between Punta Arenas on the Straits of Magellan and Puerto Williams on the Canal Beagle. Fourteen stations (whose names will henceforth be in Spanish) distributed every 10-30 km, with major gaps in Paso Ancho, Canal Ballenero and Brazo Noroeste, were sampled near the middle of the channel (Fig. 1).

At each station, two-liter Niskin bottles were used to sample at fixed depths of 0, 2, 5, 10, 15, 50 m and occasionally, 75 and 100 m. Water samples were drawn for determination of photosynthetic pigments (chlorophyll a and phaeopigments), nutrients and phytoplankton taxa. Photosynthetic pigments were determined on board with a Turner Design fluorometer, from GF/F filtered sea water samples (50 cc) extracted for 12-24 hr in 90% acetone. For hydrographic properties a CTD Sensor Data (SD-202) was used; casts were made at most stations to 150 m depth.

Oblique hauls of paired Bongo nets with 300  $\mu\text{m}$  mesh size and 70 cm mouth opening and equipped with a digital flowmeter were carried out between 0-50 m and at night (preferably). Taxa were identified and counted either from total samples or from replicated aliquots according to their relative abundance.

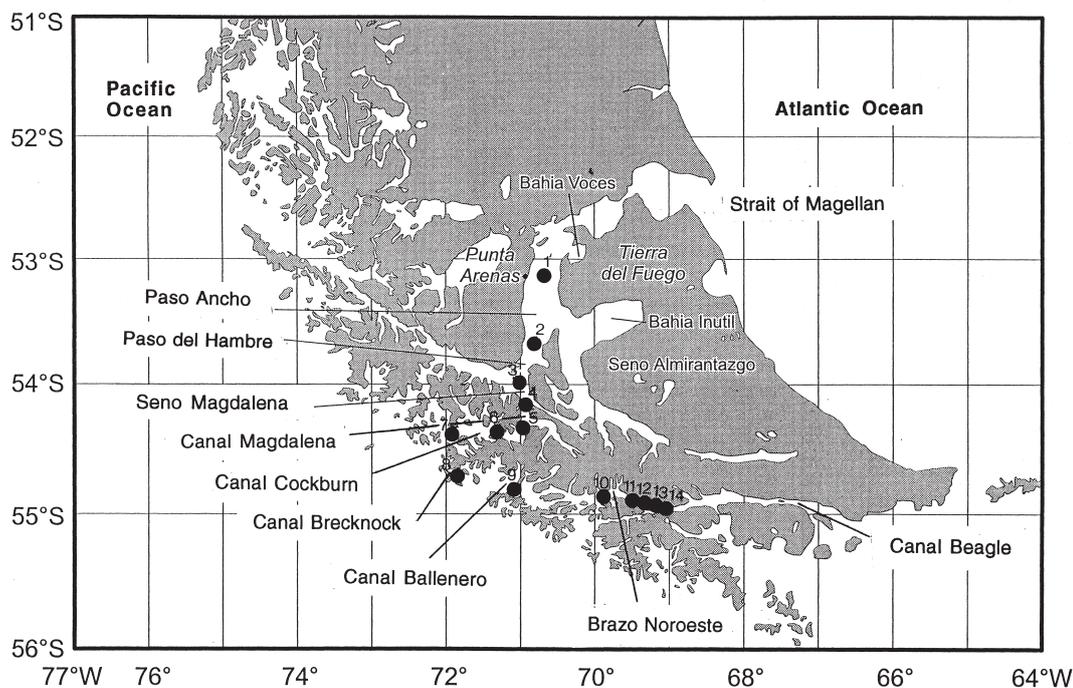


FIG. 1. - Distribution of study sites along the Magellan-Beagle passage during 2-6 November 1994 on R. V. "Victor Hensen".

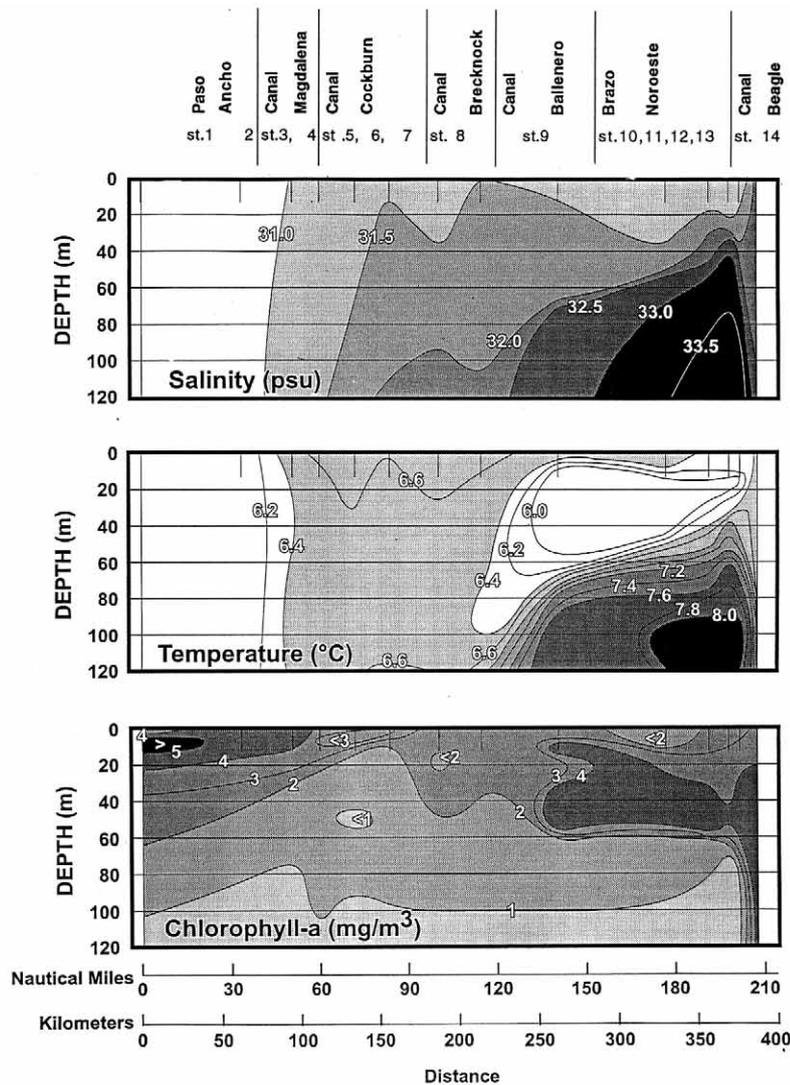


FIG. 2. – Vertical distribution of salinity, temperature and chlorophyll along the Magellan-Beagle passage.

Mean size of dominant adult and larvae were obtained in order to appreciate escape through plankton mesh and resulting underestimation of densities. A 5-minute surface haul of a phytoplankton net with 30  $\mu\text{m}$  mesh and a vertical cast with a LiCor submersible spherical quantum meter were additionally carried out whenever possible.

## RESULTS

### Salinity, Temperature and Chlorophyll Distributions

Data were plotted and depicted as a continuum along the passage to investigate similarities, gradients and discontinuities (Fig. 2). Salinity was lowest throughout the water column in the Paso

Ancho-Seno Magdalena sector and highest in the deep layer of Brazo Noroeste. A sharp break was noticed eastward (Canal Beagle) where salinity was homogeneously low through the water column. In between, a gradient of increasing salinity from Paso Ancho to Brazo Noroeste and from shallow to deeper water was observed. This pattern may be associated with increased fresh water inflow in the Paso Ancho-Seno Magdalena sector and subsequent mixing and increased advection of oceanic water in the eastern sector of Brazo Noroeste. Here a strong halocline was related to fresh glacier water in the upper 40 m.

Temperature measurements showed two layers of warm water: a deep core of oceanic water in Brazo Noroeste where the high salinity core occurred, and a surface layer of warm water in the intermediate Canal Cockburn-Canal Brecknock

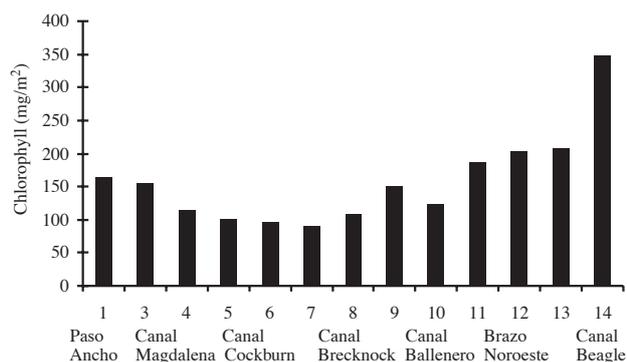


FIG. 3. – Chlorophyll content of the water column (0-50 m) along the Magellan-Beagle passage. Photic layer : average 22 m, range 19-25 m.

passage. They also revealed two temperature minima: a surface layer in the glacier sector sliding downward and westward through Canal Ballenero right over the warm deep layer, and a homogeneously cold water mass in Paso Ancho. A sharp break in the temperature (and salinity) distribution was noticed in the Canal Magdalena which seems a transition between the Paso Ancho sector and the Canal Cockburn sector.

Chlorophyll data showed three maxima: a shallow layer extending from Paso Ancho through Canal Magdalena, a subsurface intermediate layer along Brazo Noroeste and a subsurface layer extending toward the bottom on Canal Beagle. In between, from Canal Cockburn to Canal Brecknock, chlorophyll values were moderately high with a decreasing gradient downward. Integrated chlorophyll in the upper 50 m (Fig. 3) showed maximal values on the Canal Beagle, intermediate values in the glaciers sector and in Paso Ancho, Canal Magdalena, and lowest values in-between (Canal Cockburn to Canal Ballenero).

## Distribution of Zooplankters

Copepods and invertebrate larvae dominated the zooplankton throughout the region both day and night (Table 1). Copepods and crustacean larvae (nauplii, zoeae and calyptopis) were among the most numerous taxa in Paso Ancho, whereas echinoid larvae (plutei) were most important in Canal Brecknock and Brazo Noroeste. Cladocerans were poorly represented all along the transect. Adult euphausiids showed higher relative abundance in both Paso Ancho and in the glacier sector of Brazo Noroeste. Nauplius larvae (likely of copepods, decapods and barnacles) were present in most sectors reaching maximal abundance in Paso Ancho. A trend of increasing densities for benthic invertebrate larvae (particularly plutei) and furcilia larvae was identified between Paso Ancho and Brazo Noroeste. An opposite trend appeared in the distribution of nauplii, with minimal values in Brazo Noroeste-Canal Beagle and maximal values in Paso Ancho.

The relative abundance of taxa was examined to search for consistencies with the above mentioned subdivision of microbasins (Fig. 4). A distinguishing feature of the Paso Ancho-Seno Magdalena sector was the low proportion of meroplankton. Zoeae and nauplii dominated over the pluteus stage, which was the dominant larval stage in the other basins. A distinguishing feature of Canal Magdalena-Canal Brecknock was an even partition of density among plutei and nauplii, which together amounted to 50% of the zooplankton density. Further into the Canal Ballenero-Brazo Noroeste, the proportion of meroplankton increased to 42% which was close to that of adult plankters (52%). In Canal Beagle the relative proportion of meroplankton decreased to 18%. Plutei

TABLE 1. – Day-night abundances (ind/100 m<sup>3</sup>) and sizes of dominant groups of zooplankton along the Magellan-Beagle passage. (\*) Day samples.

Station	ADULTS		Pluteus	Nauplius	LARVAE		
	Copepoda	Cladocera			Zoea	Calyptopis	Furcilia
1	25500	7	0	9962	272	136	14
3*	252	0	943	377	38	1	0
4*	6574	0	481	564	56	19	16
5*	1032	0	819	1801	56	0	0
6*	3440	2	1195	1050	4	190	9
7	1535	0	768	2763	28	10	10
8	1760	0	3916	4099	0	12	14
9	1872	4	374	842	105	32	17
10	6970	10	6463	0	29	38	41
13*	636	0	1513	153	58	1	3
14	365	3	123	60	12	9	0
Mean size (µm)	1500	770	640	400	2000	1000	2000

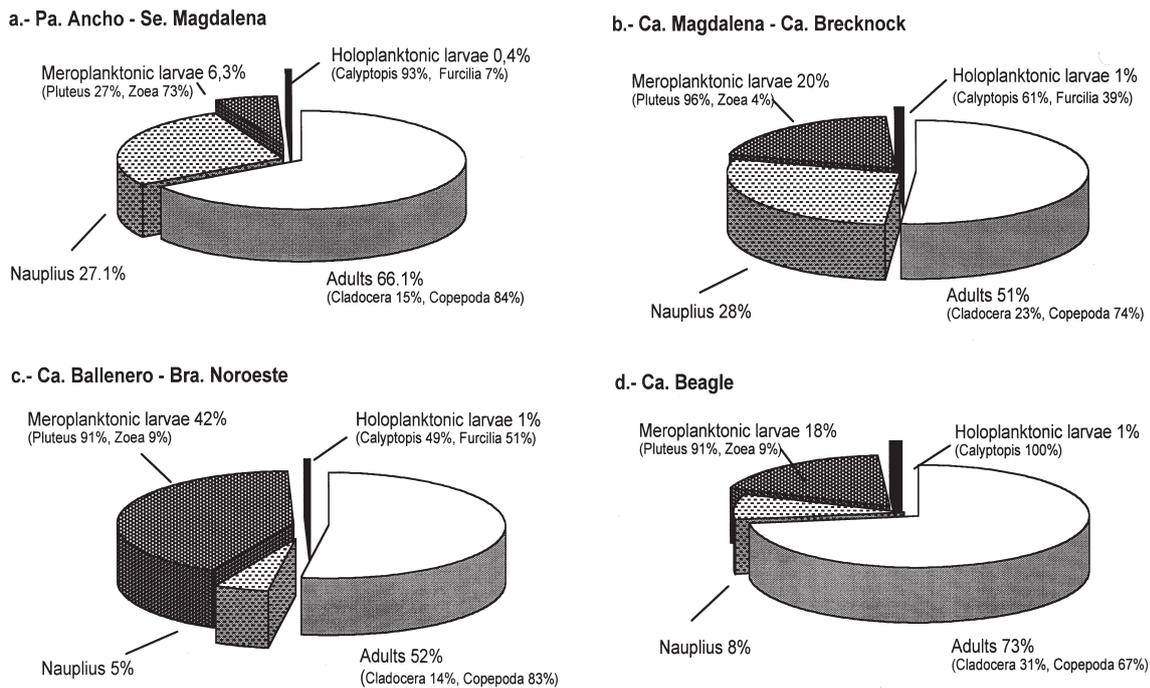


FIG. 4. – Zooplankton assemblages in microbasins of the Magellan-Beagle passage.

dominated the zooplankton as in other sectors while the proportion of adults increased compared to the other intermediate sectors.

## DISCUSSION

Patterns in chlorophyll distribution along the passage were found to be consistent with previously defined microbasins: 1.- Paso Ancho-Seno Magdalena, 2.- Canal Magdalena-Canal Cockburn-Canal Brecknock, 3.- Canal Ballenero-Brazo Noroeste and 4.- Canal Beagle (Celio, 1991; Antezana, 1999). Temperature and salinity (density followed salinity closely) were plotted along the passage disregarding open-ocean connections, since this inland passage is assumed to be a rather semiclosed environment. Exchange with the open ocean is likely constrained by the presence of sills, and distribution of water masses within the passage is apparently affected by minor topographic (bottom and coastline) features (Antezana, 1999).

Despite the fact that patterns of chlorophyll distribution coincided with temperature or salinity discontinuities along the passage, they could not be associated with stratified or homogeneous conditions. For instance, while an extended maximum throughout the water column occurred in homogeneous waters of the Canal Beagle microbasin, dis-

tinct chlorophyll maxima were found in vertically homogeneous waters of the Paso Ancho-Seno Magdalena microbasin, but also in stratified waters of the Brazo Noroeste-Canal Ballenero microbasin. Lower chlorophyll concentrations were found in intermediately stratified waters of the Canal Magdalena-Canal Brecknock microbasin. Therefore temperature, salinity and density distributions by themselves do not explain changes in chlorophyll concentration.

Most striking was the presence of a subsurface chlorophyll maximum or a maximum extending to the bottom in homogeneous waters, since phytoplankton growth is usually associated with vertical stratification preceded by vertical mixing; this is one of the most important sequences in marine ecosystems (Mann and Lazier, 1991). Conditions of vertical homogeneity found in these waters could have been the result of recent vertical mixing in the process of switching to vertical stratification. Vertically homogeneous water may not necessarily indicate real time mixing. In fact, development of phytoplankton blooms in the absence of vertical stratification has been observed in other fjords and semiclosed embayments (Eilertsen, 1993; Townsend *et al.*, 1992). This subject, however, is beyond the scope of the sampling, since the time at which active mixing ceases and is followed by vertical stratification could not be determined.

One may attempt to mechanistically explain variations in chlorophyll in such a complex and unknown system as a function of physical or biological forcing (resuspension, lateral advection, turbulence, grazing, specific growth rates, etc.). However, sampling limitations of this synoptic survey (not oriented to a process study) imposed obvious constraints. Therefore, differences in chlorophyll distribution should be considered a circumstantial evidence of microbasin delimitation within this passage, rather than a characteristic feature of each microbasin. In fact, chlorophyll concentration may vary abruptly in the same basin (e.g. Paso Ancho) on the scales of months (Mazzocchi *et al.*, 1995) and days (Antezana and Hamamé, 1999). However, chlorophyll discontinuities between microbasins may also suggest that differences exist in the structure and functioning of these microbasins.

Despite the described differences between microbasins, there were some features in common. Depth of the photic zone varied little between sectors (median 22 m; range 19-25 m) and blooming conditions prevailed. The same bloom indicator species, such as the chain forming diatoms *Chaetoceros* spp. and *Thalassiosira* spp. (Uribe, 1988; Iriarte *et al.*, 1993), or other large diatoms (*Pseudonitzschia* spp.) and dinoflagellates (*Prorocentrum* spp.), dominated the net phytoplankton. Integrated values in the upper 50 m were over 100 mg m<sup>-2</sup>, which are similar to the highest registered spring value in the Straits of Magellan but much higher than late summer values there (Magazzù *et al.*, 1996).

Unfortunately, little information on the plankton of this passage is available since local or major expeditions either focused on hydrography (Pickard, 1971; 1973) or the benthic environment (Brattström and Dahl, 1951; Brattström and Johanssen, 1983) or overlooked the area (e.g. RV "Challenger", "W. Scoresby", "Eltanin", "Hero").

The zooplankton did not conform to the above mentioned subdivision of microbasins. This disparity may be explained by species specific or size specific behavioural responses. Although plankton by definition is drifting, some plankters, notably the larger species, are able to control their horizontal transport in spite of net water movement (Kaarvedt, 1993) and particularly in association with the bottom topography in fjords and other shallow habitats (Kaarvedt, *op. cit.*; Wooldridge and Erasmus, 1980). On the other hand, differences in species composition and relative abundance of zooplankters

in nearby fjords could be attributed to differing water properties, and also to bottom depth and substrate type (Richard and Haedrich, 1991). Topographic and hydrographic complexities of this fjord region (Pickard, 1971) support such possibilities, although detailed information on the fjords adjacent to the main passage studied is unavailable.

Populations may be continuously exposed to dispersive physical forces, so some components become "vagrant" *sensu* Sinclair while others remain the "members" of a geographically distinct unit (Sinclair, 1988). The observed complex zooplankton distribution may also be the result of a given population living in various habitats, with local demographic advantages from "good quality" habitats (sources), and demographic disadvantages from sink habitats, as recently proposed for a number of species (Días, 1996).

Nevertheless, several features of zooplankton composition and abundance associated with microbasins may be pointed out. Some are unique and associated with a given microbasin, as is the dominance of copepods and zoeae and nauplii in Paso Ancho. Other features encompassed several microbasins, such as the increasing abundance of plutei between Paso Ancho and Brazo Noroeste. These gradients suggest species adaptation and organization of the plankton assemblage. Other trends in zooplankton distribution, such as the increasing gradients of abundance of furciliae between Paso Ancho and Brazo Noroeste and their exclusion from the Canal Beagle sector, may indicate a poor adaptation to fully mixed shallow and turbulent environments, despite the high chlorophyll concentrations.

Besides peculiarities in hydrography, chlorophyll and zooplankton among microbasins, a common feature of the Magellan and Beagle passage was the low diversity of plankton and the high proportion of invertebrate larvae during this spring cruise. Dominance of a few and highly aggregated species is considered typical of the plankton of the Chilean fjords (Antezana, 1976) and particularly of the Straits of Magellan (Mazzocchi and Ianora, 1991; Guglielmo *et al.*, 1996).

High probability of encounter of larvae in the plankton may be associated with intensive spawning of both planktonic (euphausiids) and benthic (echinoids) invertebrates in a matching response to blooming conditions, particularly in Brazo Noroeste. These results seem consistent with the match-mismatch hypothesis, which proposes that

spawning should be timed so that the appearance of larvae overlaps with seasonal plankton blooms (Cushing, 1990). In fact, coupling between phytoplankton blooms and the production of larvae occurs for many invertebrates living in and below the euphotic zone (Thorson, 1946) and has recently been shown in a benthic crab as the direct effect of a sedimentation peak of phytoplankton in a subarctic fjord (Starr *et al.*, 1994). On the other hand, a mismatch of *ca.* 3 months between the increments of fish larvae and their prey showed the occurrence of pelagic coupling in a temperate north Pacific fjord (Bollens *et al.*, 1992). Our results in the semiclosed environment of the Magellan and Beagle passage emphasized benthic-planktonic coupling rather than nekto-planktonic coupling.

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