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7.1 Zooplankton distribution and abundance in the austral Chilean channels and fjords

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Before 1995, studies on zooplankton in the austral Chilean channels and fjords were carried out by foreign researchers and based on the results of oceanographic expeditions between Golfo Corcovado and Strait of Magellan. In the early 1970s, the R/V Hero (September-October 1972) cruise provided the first results on the faunal composition of copepods (Arcos, 1974, 1976; Marín & Antezana, 1985), euphausiids (Antezana, 1976), and chaetognaths (Ahumada, 1976). Years later, between 1980 and 1983, a cooperative project was developed between the Japanese International Cooperation Agency (JICA) and the Servicio Nacional de Pesca de Chile (Chilean National Fisheries Service). This project was intended to introduce Pacific salmon into the southern Chilean channels and it included a study of the oceanographic conditions and zooplankton composition in Fiordo Aysén and adjacent waters, providing the first information on copepods in this area (Hirakawa, 1986, 1988).

Soon afterwards, between 1989 and 1999, several Italian and German oceanographic expeditions were carried out; these focused largely on the Magallanes region. The first cruise, the OGS Explora (October-November 1989), provided results on copepods and chaetognaths (Ghirardelli *et al.*, 1991; Mazzocchi & Ianora, 1991). Shortly thereafter, an expedition on board the R/V Cariboo (February-March 1991) was performed; those results allowed a careful analysis of the taxonomy and distribution of copepods, amphipods, mysids, ostracods, euphausiids, and chaetognaths collected in the Strait of Magellan (Guglielmo & Ianora, 1995, 1997). A later expedition on board the R/V Victor Hensen (October-November 1994) in the Strait of Magellan and adjacent waters provided the first results on the geographical distribution of medusae, siphonophores, and ctenophores in this area (Pagès & Orejas, 1999).

The systematic study of zooplankton in the austral zone between Puerto Montt and Cape Horn began in 1995 with the start of the CIMAR Program. This study set out to learn about the composition, distribution, abundance, and diversity of the zooplankton organisms existing in that extensive geographic area. The progress obtained in these terms is based largely on the analysis of 220 plankton samples obtained through oblique towing with Bongo nets from a maximum depth of 200 m to the surface. The quantitative and qualitative analyses of these samples increased the understanding of zooplankton biomass and faunal composition and the distribution of several zooplankton groups such as siphonophores, chaetognaths, cladocerans, copepods, and euphausiids (Palma & Rosales, 1997; Palma *et al.*, 1999; Marín & Delgado, 2001; Palma & Aravena, 2001, 2002; Rosenberg & Palma, 2003).

The zooplankton biomass, expressed as the plankton wet volume (mL·1000 m^{-3}), was basically constituted by planktonic crustaceans, especially copepods and euphausiids, followed by chaetognaths and gelatinous carnivores such as medusae and siphonophores. Between Puerto Montt and Cape Horn, a gradual north-south decrease in the biomass was determined for the three geographical zones analyzed: Puerto Montt to Estero Elefantes (northern zone); Golfo de Penas to Strait of Magellan (central zone); and Strait of Magellan to Cape Horn (southern zone) (Fig. 1).

Biomass in the northern zone averages 288.1 mL·1000 m^{-3}, with two areas having the highest values (Palma & Rosales, 1997). One of these is located between Golfo Reloncaví and Islas Desertores, where a semi-closed microbasin is formed with higher water column stability; the other extends from Canal Moraleda to Canal Darwin, where estuarine waters from the Jacaf and Puyuguapi channels in the Fiordo Aysén

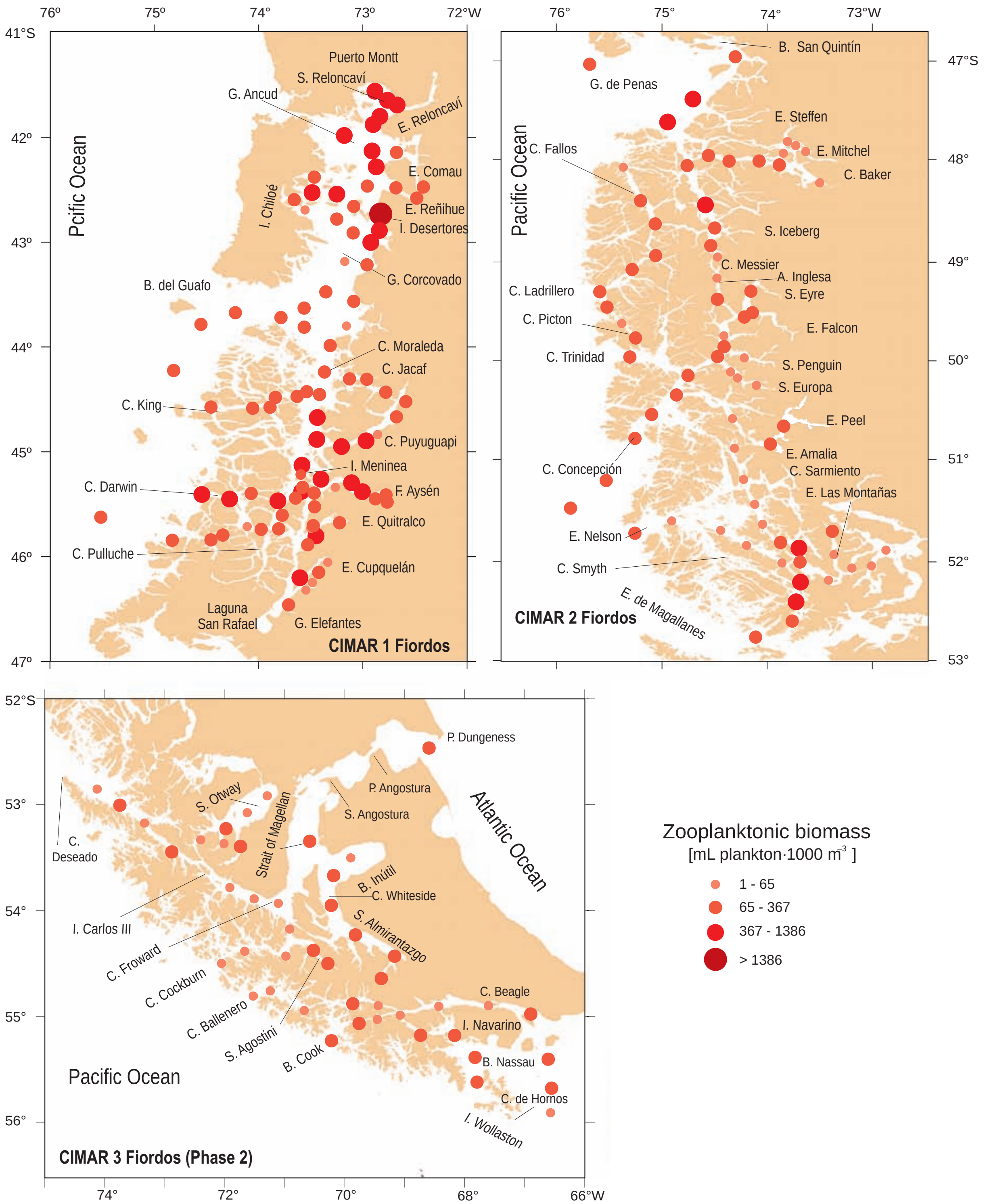

Figure 1: Zooplankton biomass distribution between Puerto Montt and Cape Horn (taken from Palma & Rosales, 1991; Palma *et al.*, 1999; Palma & Aravena, 2001).

predominate. These areas are separated by a central area (Golfo Corcovado) with low biomass values. In this area, the entrance of more saline Subantarctic oceanic waters is constant and the water column stability is low (Silva *et al.*, 1997).

In the central zone, biomass values are lower, averaging 149.7 mL·1000 m^{-3}. The highest biomass values were found in Golfo de Penas, at some stations of the Messier and Baker channels, and along Canal Smyth, where subantarctic waters with higher temperature and salinity predominate. The lowest values were recorded in all the fjords adjacent to the Campos de Hielo Sur (Baker, Penguin, Europa, Peel, and Las Montañas channels) (Palma *et al.*, 1999), where estuarine waters with higher temperature and salinity predominate (Sievers *et al.*, 2002).

The southern zone is characterized by low biomass values, averaging 84.4 mL·1000 m^{-3}. In the Strait of Magellan, the biomass values are higher in the occidental sector. This is due to its greater depth, which favors the presence of mesopelagic organisms. The biomass values decrease in the oriental sector due to its depth. The maxima recorded in the Otway, Almirantazgo, and Agostini sounds are maintained shallower by the high phytoplankton concentrations found therein (Pizarro *et al.*, 2000). In Seno Almirantazgo, high concentrations of phytoplankton were recorded, favoring increased demographic rates of copepods, gelatinous carnivores, and planktonic larvae. In the case of siphonophores, there were numerous eudoxids (reproductive stage) aggregates; this stage was six times more abundant than the polygastric stage (Palma & Aravena, 2001).

In the austral Chilean channel and fjord region from Puerto Montt to Cape Horn, 143 zooplankton species were recorded: 29 hydromedusae species, 2 scyphomedusae, 14 siphonophores, 2 ctenophores, 8 chaetognaths, 3 cladocerans, 55 copepods, 7 amphipods, 4 mysids, 13 ostracods, and 6 euphausiids (Table I). Since these species have not been caught throughout the entire austral zone and many of them were recorded in specific geographic sectors, the faunal records obtained in each considered zone are as follows.

In the northern zone, 11 siphonophore species were recorded between Puerto Montt and Laguna San Rafael (Palma & Rosales, 1997), 3 chaetognaths between Boca del Guafo and Estero Elefantes (Palma & Aravena, 2002), and 3 copepods in Fiordo Aysén and its adjacent waters (Hirakawa, 1986, 1988).

In the central zone, 9 siphonophores species, 6 chaetognaths, 3 cladocerans, and 5 euphasiids were recorded between Golfo de Penas and Strait of Magellan (Palma *et al.*, 1999; Rosenberg & Palma, 2003); 25 copepod species were collected exclusively from Isla Madre de Dios (Marín & Antezana, 1985).

In the southern zone, 29 hydromedusae species, 2 scyphomedusae, 8 siphonophores, 2 ctenophores, 5 chaetognaths, 48 copepods, 7 amphipods, 4 mysids, 13 ostracods, and 6 euphasiids were recorded between Strait of Magellan and Cape Horn (Arcos, 1974, 1976; Ghirardelli *et al.*, 1991; Mazzocchi & Ianora, 1991; Guglielmo & Ianora, 1995, 1997; Pagès & Orejas, 1999; Marín & Delgado, 2001; Palma & Aravena, 2001). Information about amphipods, mysids, and ostracods is only available from the Strait of Magellan (Guglielmo & Ianora, 1997).

The species richness in this vast estuarine area is very low, equivalent to only 8-10 % of the total species known for each of these zooplanktonic groups in the different oceans. This percentage is similar to that recorded for Northern Hemisphere fjords such as those in Scandinavia (Sands, 1980; Bamstedt, 1988) and Canada (Richard & Haedrich, 1991). Moreover, these results show that most foreign expeditions focused on the Magallanes region. Therefore, most of the species identified between Puerto Montt and Strait of Magellan (CIMAR 1 to 4 cruises) constitute first records for this channel and fjord area, increasing the corresponding geographical distributions in the eastern South Pacific waters. Furthermore, the presence of some species such as the siphonophores *Physophora hydrostatica*, *Vogtia pentacantha*, and *Vogtia serrata* and the cladoceran *Podon leuckarti* constitute new records for Chilean waters (Palma & Rosales, 1997; Rosenberg & Palma, 2003).

In the austral region, the zooplankton populations are subject to great spatial heterogeneity due to latitudinal, seasonal, and vertical gradients in the oceanographic parameters. This variability is caused by the permanent entrance of more temperate and saline

Table I: Presence (+) or absence (-) of the zooplankton species recorded in the different geographic zones between Puerto Montt and Cape Horn. Two crosses (++) indicate the most abundant species in each zone; and an asterisk (*) indicates the lack of information in a particular zone. In the northern zone, copepods were only recorded in Fiordo Aysén (Hirakawa, 1986, 1988) and, in the central zone, around Isla Madre de Dios (Marín & Antezana 1985). In the southern zone, amphipods, mysids, and ostracods were recorded exclusively in the Strait of Magellan (Guglielmo & Ianora, 1997).

Species	North. Zone	Central Zone	South. Zone
Hydromedusae			
Aequorea macrodactyla	*	*	+
Amphogona plicata	*	*	+
Amphinema rugosum	*	*	+
Bougainvillia macloviana	*	*	++
Bougainvillia sp.	*	*	+
Calycopsis sp.	*	*	+
Clytia simplex	*	*	++
Colobonema sericeum	*	*	+
Cosmetirella davisi	*	*	+
Cunina sp.	*	*	+
Euphysa aurata	*	*	+
Halopsis ocellata	*	*	+
Heterotiara anonima	*	*	+
Hybocodon sp.	*	*	+
Laodicea pulcra	*	*	+
Linvillea sp.	*	*	+
Leuckartiara octona	*	*	+
Margelopsis australis	*	*	+
Mitrocomella frigida	*	*	+
Mitrocomella polydiademata	*	*	+
Modeeria rotunda	*	*	+
Obelia spp.	*	*	++
Podocoryne minuta	*	*	+
Podocoryne borealis	*	*	+
Proboscidactyla mutabilis	*	*	+
Rathkea formossisima	*	*	+
Rhabdoon singulare	*	*	+
Rhopalonema velatum	*	*	+
Solmundella bitentaculata	*	*	+
Scyphomedusae			
Aurelia aurita	*	*	+
Desmonema gaudichaudi	*	*	+
Siphonophores			
Abylopsis tetragona	+	+	–
Chelophyes appendiculata	–	+	–
Dimophyes arctica	+	+	+
Eudoxoides spiralis	+	+	+
Lensia conoidea	++	++	++
Lensia meteori	–	+	–
Muggiaea atlantica	++	++	++
Physophora hydrostatica	+	–	–
Pyrostephos vanhoeffeni	++	+	++
Sphaeronectes fragilis	+	–	+
Sphaeronectes gracilis	+	+	+
Sphaeronectes irregularis	–	–	+
Vogtia pentacantha	+	–	–
Vogtia serrata	+	–	–
Ctenophores			
Beroe cucumis	*	*	+
Callianira antarctica	*	*	+
Chaetognaths			
Eukrohnia bathyantarctica	*	+	–
Eukrohnia hamata	+	+	+
Sagitta decipiens	+	–	+
Sagitta enflata	*	+	–
Sagitta gazellae	*	+	+
Sagitta marri	*	++	–
Sagitta maxima	*	–	+
Sagitta tasmanica	++	++	++
Cladocerans			
Evadne nordmanni	*	++	*
Podon leuckarti	*	++	*
Pseudoevadne tergestina	*	+	*
Copepods			
Acartia omorii	+	–	–
Acartia tonsa	–	+	+
Aetideus arcuatus	–	–	+
Aetideus australis	*	*	+
Augaptilus glacialis	*	*	+
Bachycalanus atlanticus	*	*	+
Calanoides patagoniensis	*	+	+
Calanus chilensis	*	+	+
Calanus simillimus	*	+	++
Calocalanus pavoninus	*	*	+
Candacia cheirura	*	+	+
Candacia norvegica	*	*	+
Centropages abdominalis	+	*	–
Centropages brachiatus	*	+	+
Centropages bradyi	*	+	+
Chiridius gracilis	*	+	+
Chiridius subgracilis	*	*	+
Clausocalanus brevipes	*	+	++
Clausocalanus ingens	*	+	+
Clausocalanus laticeps	*	+	+
Ctenocalanus citer	*	*	++
Ctenocalanus vanus	*	+	+
Drepanopus forcipatus	*	+	++
Eucalanus elongatus	*	*	+
Eucalanus longiceps	*	+	+
Eucalanus subtenuis	*	+	-
Euchirella rostrata	*	+	–
Gaetanus antarcticus	*	*	+
Heterorhabdus spinifrons	*	*	+
Lubbockia aculeata	*	*	+
Lubbockia minuta	*	*	+
Lucicutia clausi	*	*	+
Metridia brevicauda	*	*	+
Metridia lucens	*	+	++
Monstrilla grandis	*	+	–
Microcalanus pygmaeus	*	*	+
Nanocalanus minor	*	+	–
Neocalanus tonsus	*	+	+
Oithona atlantica	*	+	+
Oithona davisae	+	*	–
Oithona similis	*	*	++
Oncaea confiera	*	+	+
Oncaea curvata	*	*	+
Oncaea englishi	*	*	+
Paracalanus parvus	*	+	+
Pareuchaeta antarctica	*	+	+
Paraeuchaeta biloba	*	*	+
Phaenna spinifera	*	*	+
Pleuromamma robusta	*	*	+
Rhincalanus nasutus	*	+	+
Scaphocalanus curtus	*	*	+
Scaphocalanus farrani	*	*	+
Scolecithricella dentata	*	*	+
Scolecithricella minor	*	*	+
Spinocalanus brevicaudatus	*	*	+
Amphipods			
Cyllopus magellanicus	*	*	+
Hyperiella dilatata	*	*	+
Hyperoche mediterranea	*	*	+
Hyperoche medusarum	*	*	+
Primno macropa	*	*	+
Scina borealis	*	*	+
Themisto gaudichaudii	*	*	++
Mysids			
Arthromysis magellanica	*	*	+
Boreomysis rostrata	*	*	++
Neomysis monticellii	*	*	+
Pseudomma magellanensis	*	*	+
Ostracods			
Conchoecilla cd. chuni	*	*	+
Discoconchoecia aff. elegans	*	*	++
Loricoecia loricata	*	*	+
Macrocypridina poulseni	*	*	+
Metaconchoecia australis	*	*	+
Mikroconchoecia cf. acuticosta	*	*	+
Obtusoecia antarctica	*	*	+
Paradoxostoma sp. aff. hypselum	*	*	+
Paradoxostoma magellanicum	*	*	+
Paramollicia rhynchena	*	*	+
Philomedes cubitum	*	*	+
Philomedes eugeniae	*	*	+
Pseudoconchoecia serrulata	*	*	+
Euphausiids			
Euphausia lucens	*	+	+
Euphausia vallentini	*	++	++
Nematoscelis megalops	*	++	+
Stylocheiron longicorne	*	–	+
Stylocheiron maximum	*	+	+
Thysanoessa gregaria	*	+	+

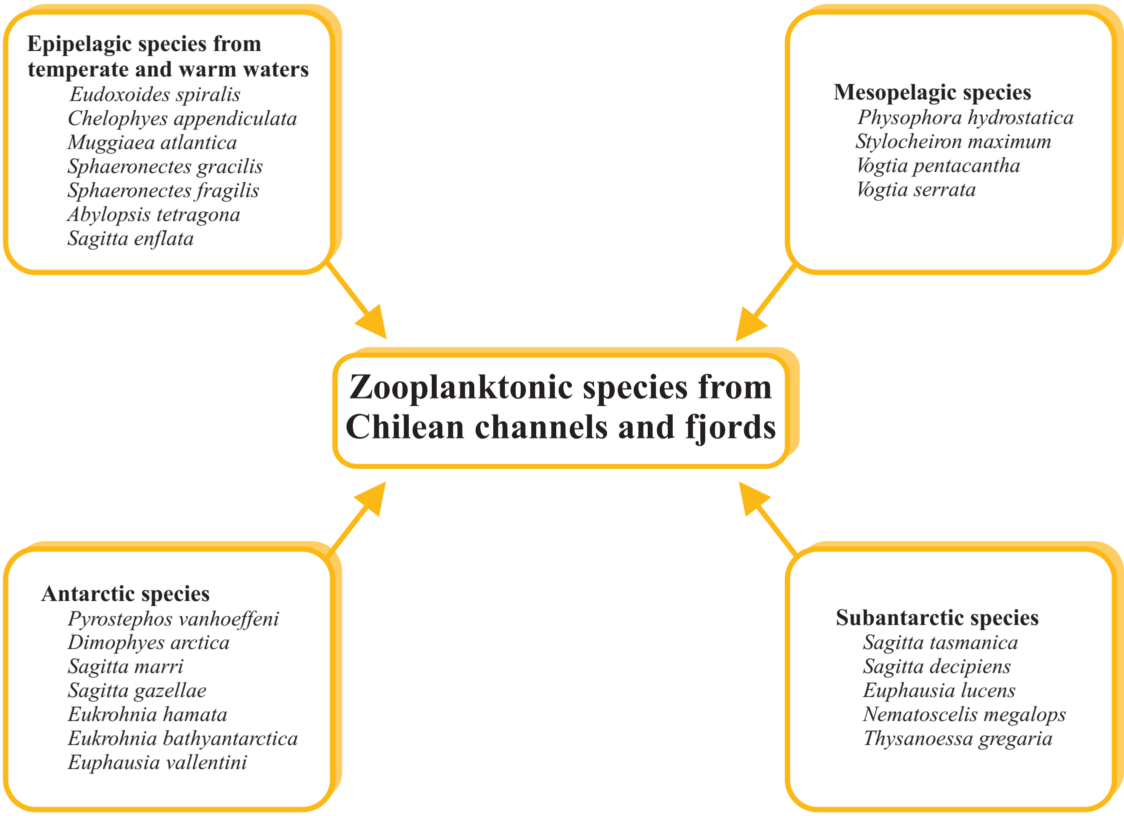

Figure 2: Biogeographical origins of the zooplankton species collected in the austral Chilean channels and fjords (adapted from Palma & Silva, 2004).

oceanic subantarctic waters through Boca del Guafo, Golfo de Penas, Strait of Magellan, and several oceanic channels. These waters mix in the interior zone with low temperate fresh waters coming from precipitation, river discharge, and melting glaciers and mountain snows. This mixture generates a positive, general two-layer estuarine circulation in which the lower temperature and salinity surface layer (0-50 m) exhibits net movement to the adjacent ocean and the higher temperature and salinity deep layer (> 50 m) shows net movement to the interior region (Silva *et al.*, 1997; Sievers *et al.*, 2002; Valdenegro & Silva, 2003). This high environmental heterogeneity is a disadvantage for successful colonization in interior waters; in fact, the different taxa are dominated by only one or two species such as *Muggiaea atlantica*, *Lensia conoidea*, *Sagitta tasmanica*, *Evadne nordmanni*, *Ctenocalanus citer*, and *Euphausia vallentini*.

The results obtained by the CIMAR Fiordos cruises reveal that, as with zooplanktonic biomass, the abundance of the predominant species in the north-south gradient decreases progressively (Palma & Silva, 2004). Moreover, the analysis of the faunal composition indicates that the zooplankton community in the austral channels and fjords is made up of species with different biogeographical origins, mixing species from Temperate, Subantarctic, and Antarctic waters, as proposed in the adjunct scheme (Fig. 2). Thus, many epipelagic (*Abylopsis tetragona*, *Chelophyes appendiculata*, *Dimophyes arctica*, *Eudoxoides spiralis*, *Muggiaea atlantica*, *Sphaeronectes gracilis*, *Sphaeronectes fragilis*, *Physophora hydrostatica*, *Sagitta enflata*, *Sagitta gazellae*, *Pseudoevadne tergestina*, *Euphausia lucens*, *Thysanoessa gregaria*) and mesopelagic species (*Vogtia pentacantha*, *Vogtia serrata*, *Eukrohnia bathyantarctica*, *Eukrohnia hamata*) that are occasionally found in interior waters were collected at the entrance point of the oceanic subantarctic waters, e.g., Boca del Guafo; Golfo de Penas; the Fallos, Ladrillero, and Concepción channels; and Strait of Magellan. Most of these species are frequent in the temperate and warm waters of all the oceans and their presence at these latitudes indicates their southern geographical distribution limit in the Southern Hemisphere (Palma & Silva, 2004). However, in exceptional situations, some species can successfully colonize the interior region. One such example is *Muggiaea atlantica*, which is widely distributed and even forms dense aggregates in some areas, and is the predominant siphonophore between Puerto Montt and Cape Horn.

The presence of a variety of species from Subantarctic and Antarctic waters (*Pyrostephos vanhoeffeni*, *Dimophyes arctica*, *Sagitta gazellae*, *S. decipiens*, *S. tasmanica*, *Eukrohnia hamata*, *E. bathyantarctica*, *Euphausia vallentini*, *E. lucens*, *Nematoscelis megalops*, and *Thysanoessa gregaria*) was also determined. Many of these species, such as *Sagitta tasmanica* and *Euphausia vallentini*, were very abundant in interior waters. In addition, the frequent but scarce presence of *Lensia conoidea*, *Lensia meteori*, *Sagitta marri*, and *Stylocheiron maximun* was recorded in the fjord sectors, including those adjacent to the Campos de Hielo Sur where temperature and salinity are extremely low and turbidity is high.

Although the zooplankton fauna in the channels and fjords consist of a mixture of species from different biogeographic regions (Fig. 2), none of the species collected in interior waters are endemic. This could be due to the constant interchange between oceanic and estuarine waters caused by the typical surface and subsurface currents of the general circulation between the interior zone and the adjacent ocean. There are just a few species that have successfully colonized the interior waters, probably due to the high oceanographic variability. Some of these species, particularly *Muggiaea atlantica*, *Sagitta tasmanica* and *Euphausia vallentini*, are currently forming dense aggregates in some sectors.

References

Ahumada, R. 1976. Nota sobre los quetognatos captura dos en la Expedición "Hero" 72-4 segunda etapa. Bol. Soc. Biol. Concepción, 50: 27-34.

Antezana, T. 1976. Diversidad y equilibrio ecológico en comunidades pelágicas. In: F. Orrego (ed.). Preservación del medio ambiente marino. Instituto de Estudios Internacionales, Universidad de Chile, Santiago, pp. 40-54.

Arcos, D. 1974. Los copépodos calanoídeos colectados en la región Magallánica por la Expedición "Hero" 72-4b. Bol. Soc. Biol. Concepción, 47: 215-225.

Arcos, D. 1976. Los copépodos calanoídeos de la región Magallánica. Expedición "Hero" 72-4. Rev. Com. Perm. Pacífico Sur, 5: 85-100.

Bamstedt, U. 1988. The macrozooplankton community of Kosterfjorden, Western Sweden. Abundance, biomass, and preliminary data on the life cycles of dominant species. Sarsia, 73: 107-124.

Ghirardelli, E., L. Guglielmo & G. Zagami. 1991. Chaetognaths in the Strait of Magellan (a preliminary note). Mem. Biol. Mar. Oceanogr., 19: 167-171.

Guglielmo, L. & A. Ianora. (eds.). 1995. Atlas of marine zooplankton. Straits of Magellan. Copepods. Springer-Verlag, Berlin, 279 pp.

Guglielmo, L. & A. Ianora. (eds.). 1997. Atlas of marine zooplankton. Straits of Magellan. Amphipods, Euphausiids, Mysids, Ostracods, and Chaetognaths. Springer-Verlag, Berlin, 275 pp.

Hirakawa, K. 1986. A new record of the planktonic copepod *Centropages abdominalis* (Copepoda, Calanoida) from patagonian waters, southern Chile. Crustaceana, 51(3): 296-299.

Hirakawa, K. 1988. New records of the North Pacific coastal planktonics copepods, *Acartia omorii* (Acartiidae) and *Oithona davisae* (Oithonidae) from southern Chile. Bull. Mar. Sci., 42(2): 337-339.

Marín, V. & T. Antezana. 1985. Species composition and relative abundance of copepods in Chilean fjords. J. Plankton Res., 7(6): 961- 966.

Marín, V. & L. Delgado. 2001. La taxocenosis de copépodos calanoídeos en los canales magallánicos: un patrón anidado. Cienc. Tecnol. Mar, 24: 81-89.

Mazzocchi, M. G. & A. Ianora. 1991. A faunistic study of the copepod assemblages in the Strait of Magellan. Boll. Oceanol. Teor. Appl., 9(2-3): 163-177.

Pagès, F. & C. Orejas. 1999. Medusae, siphonophores and ctenophores of the Magellan Region. Sci. Mar., 65(Supl. 1): 51-57.

Palma, S. & G. Aravena. 2001. Distribución de sifonóforos, quetognatos y eufáusidos en la región magallánica. Cienc. Tecnol. Mar, 24: 47-59.

Palma, S. & G. Aravena. 2002. Distribución estacional y vertical de los quetognatos colectados entre el golfo Corcovado y el estero Elefantes. Cienc. Tecnol. Mar, 25(2): 87-104.

Palma, S. & S. Rosales. 1997. Sifonóforos epipelágicos de los canales australes chilenos (41° 30'-46° 40' S). Cienc. Tecnol. Mar, 20: 125-146.

Palma, S. & N. Silva. 2004. Distribution of siphonophores, chaetognaths and euphausiids and oceanographic conditions in the fjords and channels of southern Chile. Deep-Sea Res. II, 51: 513-535.

Palma, S., R. Ulloa & L. Linacre. 1999. Sifonóforos, quetognatos y eufáusidos de los canales australes entre el golfo de Penas y Estrecho de Magallanes. Cienc. Tecnol. Mar, 22: 111-142.

Pizarro, G., J. L. Iriarte, V. Montecino, J. L. Blanco & L. Guzmán. 2000. Distribución de la biomasa fitoplanctónica y productividad primaria máxima de fiordos y canales australes (47°-50° S) en octubre 1996. Cienc. Tecnol. Mar, 23: 25-48.

Richard, J. & R. Haedrich. 1991. A comparison of the macrozooplankton faunas in two Newfoundland fjords differing in physical oceanography. Sarsia, 76: 41-52.

Rosenberg, P. & S. Palma. 2003. Cladóceros de los fiordos y canales patagónicos localizados entre el golfo de Penas y el Estrecho de Magallanes. Invest. Mar., Valparaíso, 30(1): 15-24.

Sands, N. J. 1980. Ecological studies of the deep-water community of Korsfjorden, western Norway. Population dynamics of the chaetognaths from 1971-1974. Sarsia, 65: 1-12.

Sievers, H. A., C. Calvete & N. Silva. 2002. Distribución de características físicas, masas de agua y circulación general para algunos canales australes entre el golfo de Penas y el Estrecho de Magallanes (Crucero CIMAR Fiordo 2), Chile. Cienc. Tecnol. Mar, 25(2): 13-39.

Silva, N., C. Calvete & H. A. Sievers. 1997. Características oceanográficas físicas, químicas y circulación general para algunos canales entre Puerto Montt y laguna San Rafael, Chile (Crucero CIMAR-Fiordo 1). Cienc. Tecnol. Mar, 20: 23-106.

Valdenegro, A. & N. Silva. 2003. Caracterización física y química de la zona de canales y fiordos australes de Chile entre el Estrecho de Magallanes y Cabo de Hornos (CIMAR 3 Fiordos). Cienc. Tecnol. Mar, 26(2): 19-60.