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SEASONAL CHANGES IN THE BATHYMETRIC DISTRIBUTION OF SIPHONOPHORES, CHAETOGNATHS AND EUPHAUSIIDS ASSOCIATED TO WATER MASSES OFF VALPARAISO, CHILE (SOUTHEAST PACIFIC)

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Abstract

The bathymetric distribution of siphonophores, chaetognaths and euphausiids were studied in an oceanic station located at 14 nautical miles off Valparaíso. During an annual cycle between July 1994 and September 1995, vertical samples of plankton were taken at six depth intervals between 0 and 900 m depth. The hydrographic parameters of temperature, salinity and dissolved oxygen showed temporal and spatial fluctuations within the surface layer (0-100 m), mainly affected by the Subantarctic Water (SAAW) mass and particularly by the SubTropical Water (STW). Between 150-400 m the presence of low dissolved oxygen content and higher salinity waters was determined, distinctive of the Equatorial Subsurface Water (ESSW), and between 400-800 m the Antarctic Intermediate Water (IAAW), characterized by its higher dissolved oxygen content, and lesser temperature and salinity.

Zooplanktonic organisms were identified and classified as 23 species of siphonophores, 15 chaetognaths and 6 euphausiids. The most abundant and frequently present species were the chaetognaths *Sagitta enflata, S. bierii* and *Eukrohnia hamata;* the siphonophores *Muggiaea atlantica*, *Agalma elegans,* and *Sphaeronectes gracilis,* and the euphausiids *Euphausia mucronata* and *Nematoscelis megalops*. With the exception of *E. mucronata*, these species were distributed mainly in epipelagic waters of 0-100 m depth. Other species were present in small quantities, particularly those of mesopelagic distribution, caught below 200 m of depth.

The vertical distribution of macroplankton showed strong associations of species with the water masses present in the zone: a) epipelagic species associated with SAAW-ESSW: *Muggiaea atlantica, Sphaeronectes gracilis, Abylopsis tetragona, Agalma elegans, Sagitta enflata, S. bierii, S. minima* and *S. pacifica*; b) mesopelagic species associated with ESSW-IAAW: *Lensia hotspur, L. multicristata, L. lelouveteau, Sagitta maxima, S. decipiens, Eukrohnia hamata, Krohnitta subtilis, Euphausia mucronata* and *Nematoscelis megalops*, and c) mesopelagic species associated with IAAW: *Sagitta marri, S. macrocephala* and *Eukrohnia fowleri.*

Introduction

Environmental parameters play an important role on the space-temporal distribution of planktonic communities, and mainly on their abundance variation

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over particular geographical areas. For this reason, some species or species assemblages have been used as hydrological indicators in areas of water masses mixing, in order to understand, explain and eventually predict oceanographic processes (Bieri, 1959; Sund, 1964; Nair, 1978; Cheney, 1985).

The siphonophores, chaetognaths and euphausiids are important components of the macroplankton, with wide areas of geographic distribution in the oceans and many of their species have well defined ecological requirements (Alvariño, 1965, 1966, 1971). This is the reason why several species have been found to be associated with specific water masses and have been proposed as potential biological indicators (Bieri, 1959; Sund, 1964; Ibanez and Dallot, 1969).

Thus, the presence or absence of certain species under specific environmental conditions, may confirm physical environmental features or the presence of other oceanographic phenomena (Schleyer, 1985). Such is the case with certain mesopelagic species that do not reach the surface layers during their dial vertical migrations, such as *Sagitta decipiens, S. maxima, S. planctonis* and *Eukrohnia hamata*, but may be found at the surface during coastal upwelling events (Bieri, 1959; Sund, 1964; Alvariño, 1965; Fagetti, 1968).

Southeast Pacific waters off the Chilean coast, are characterized by the presence of five water masses between surface and 1000 m depth (Silva and Konow, 1975). The surface layer is constituted by the Humboldt current system, where a great number of epipelagic macroplanktonic species dwell (Kramp, 1966; Fagetti, 1972, 1973; Palma, 1994). In Chilean waters there are several accounts of the composition and time-space distribution of siphonophores (Palma, 1994; Palma and Rosales, 1995), chaetognaths (Fagetti, 1968) and euphausiids (Antezana, 1981). However, with the exception of chaetognaths (Fagetti, 1972), there is a lack of knowledge about the deep bathymetric distribution of planktonic species.

Hydrographic conditions change rapidly with depth, mainly below 100 m, which implicates changes in the species composition, distribution, abundance and specific diversity. For this reason, in this study, the temporal and diurnal vertical distribution is analyzed for siphonophores, chaetognaths and euphausiids during an annual cycle between surface and 900 m depth off the coast of Valparaíso. Besides, the macroplanktonic species vertical distribution pattern is associated with the water masses present in the zone of study.

Material and Methods

Between July 4, 1994, and September 26, 1995, 14 monthly cruises were conducted and samples were taken at an oceanic oceanographic station located at 14 nautical miles off Valparaíso (32°55.1'S-71°52.4'W) (Fig. 1). Zooplankton collections were obtained during day time with WP-2 (0.25 m^2, 350 µm mesh-size) nets, provided with a closing system, flowmeter and depthmeter. At the station, casts at 50-0, 100-50, 150-100, 200-150, 400-200, 600-400 and 900-600 m depth were done. Plankton samples were fixed in 5% borax buffered formaldehyde. Sorting and species identification of siphonophores, chaetognaths and euphausiids was done using morphological descriptions contained in specialized literature. All specimens were counted (only nectophores in siphonophores) and the counts normalized to number of specimens per 1000 m^3 of water.

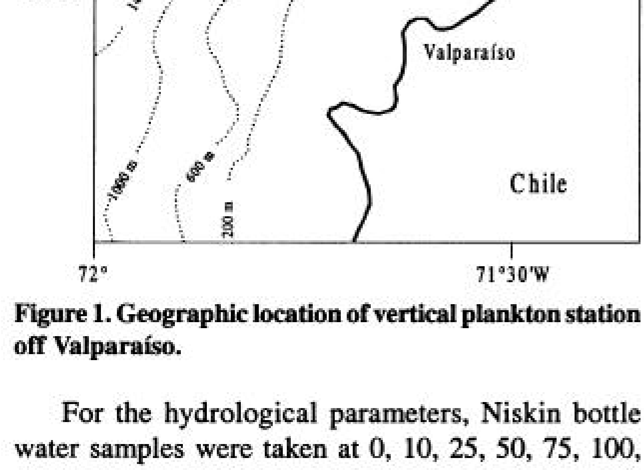


Figure 1. Geographic location of vertical plankton station off Valparaíso.

For the hydrological parameters, Niskin bottle water samples were taken at 0, 10, 25, 50, 75, 100, 150, 200, 250, 300, 400, 500, 600, 700 and 800 m depth. Temperature was registered with reversing thermometers. The salinity was determined with an

Autolab inductive salinometer and dissolved oxygen with the a modified Winkler method (Carpenter, 1965). Vertical time series sections were prepared for temperature, salinity and dissolved oxygen. Using T-S diagrams and the Mamayev's mixing triangle method (Mamayev, 1973), different water masses were identified and quantified at the study area. A water mass is considered predominant in the diagram when its percentage of participation is over 50%. In order to analyze the relationship between the presence of the different species and the thermal and salinity structure of the sea, Temperature-Salinity-Species Diagrams (TSSD) were constructed taking into account only the most frequent species during the annual cycle.

The mean density in each depth layer was expressed as a percentage of the total population abundance in the water colum. To further relate the macroplankton collections with the hydrographic parameters a Principal Components Analysis (PCA) was performed on the numerical abundance data for the most common species. Abundance was expressed as log transformed (log (x+1)) number of individuals per 1000 m^3 (Ludwig and Reynolds, 1988).

Results

Oceanographic features

The surface layer showed an annual temperature cycle, with the lowest temperatures during both winters of 1994 and 1995, and highest in the summer of 1995 (Fig. 2). The temperature increase in the upper 50 m from October to May develops a seasonal thermocline which in February 1995 reached a maximum gradient of 1.3°C/10 m; the lower limit of the thermocline was associated with isotherms of 12 and 13°C.

Surface temperature was lowest in August (11.9°C) and showed a maximum during February 1995 (19.3°C). The water column had its greatest thermal stability in the 50-200 m layer of depth where temperatures between 11 to 12°C were predominant. A gradual decrease of temperature from 10 to 5°C was observed between 200 to 800 m depth (Fig. 2).

The salinity vertical distribution indicated that major vertical fluctuations occurred in the surface

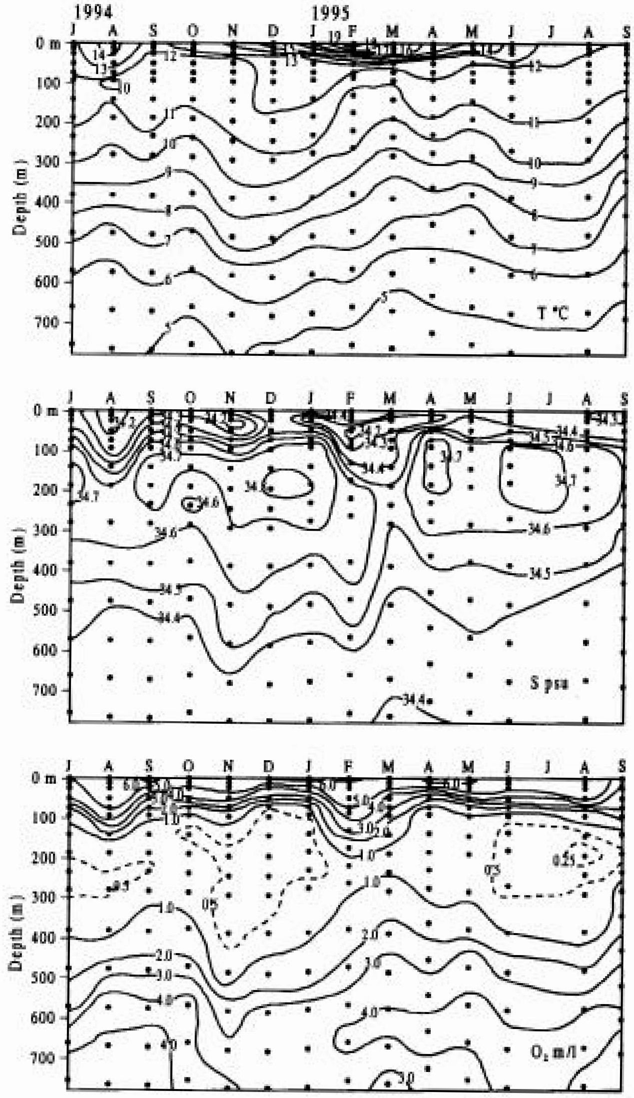


Figure 2. Vertical distribution of temperature, salinity and dissolved oxygen at the oceanographic station off Valparaíso (June 1994 – September 1995).

layer, with comparatively low salinity values (34.2-34.4) in the upper 75 m. Between 100 to 300 m depth, higher salinities (34.5-34.8) were observed. From 300 to 800 m depth, salinities again showed low values, with a minimum centered at 650 m (< 34.4). Nevertheless, at these depths salinity vertical gradients were smoother relative to those in the surface layers (Fig. 2).

A thin well oxygenated layer, with nearly 100% saturation (5-6 ml/l), was observed in the surface (0 to 10 m) during all the sampling period. Below this surface layer, the dissolved oxygen decreased rapidly with a strong vertical gradient (oxycline) between 10 and 100 m depth. The oxycline was present in this layer during all the year, with a maximum gradient of 0.6 ml/l/10 m in January of 1995. A dissolved oxygen minimum layer was present between 100 and 400 m depth, with minimum concentrations ranging from 0.24 to 3 ml/l. Below this layer oxygen increased generating a maximum of 3-4 ml/l, centered at 650 m (Fig. 2).

Water masses

According to the T-S diagram, in the upper 800 m water column, the presence of four water masses was detected (Fig. 3). In the surface layer, the Subantarctic Water (SAAW), was characterized by its low salinity (<34.4). Nevertheless, during several periods of the year, remnants of the SubTropical Water (STW), were also identified in the surface layer by the relatively high values of surface salinity (>34.4). Below the surface layer and between 100-400 m, the Equatorial Subsurface Water (ESSW), characterized by a subsurface salinity maximum (>34.6) and minimum dissolved oxygen (< 1 ml/l), was present. The Intermediate Antarctic Water (IAAW), characterized by a relative salinity minimum (<34.4) and a maximum of dissolved oxygen (>3 ml/l), was observed in the layer of 400-800 m.

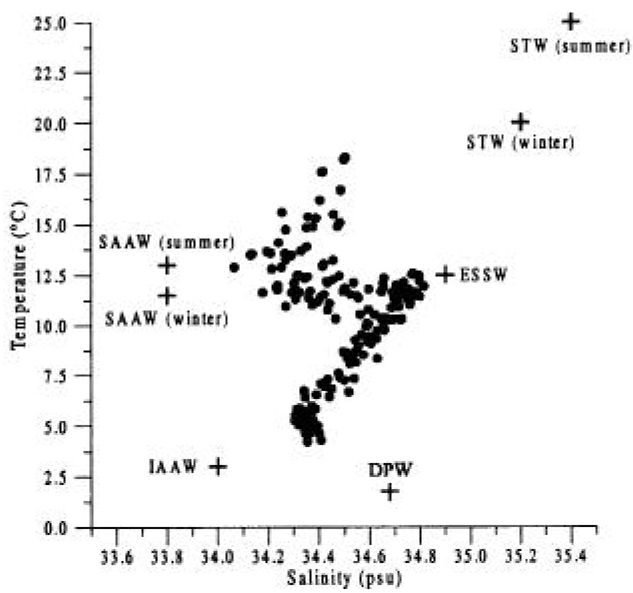


Figure 3. T-S diagrams for the oceanographic station off Valparaíso (June 1994 – September 1995). STW: Subtropical Water, SAAW: Subantarctic Water, ESSW: Equatorial Subsurface Water, IAAW: Antarctic Intermediate Water, and DPW: Deep Pacific Water.

The mixing composition of water masses in the surface layer was characterized by the dominance of the SAAW, which was present throughout the year with percentages over 50%. This water mass was present as a surface layer, varying between 5 and 110 m in thickness (Fig. 4). In August and November 1994, and February 1995 this water mass showed its greatest presence, with 65 to 75% of SAAW in its core, with low salinities between 34.0 a 34.2 and temperatures lower than 14°C.

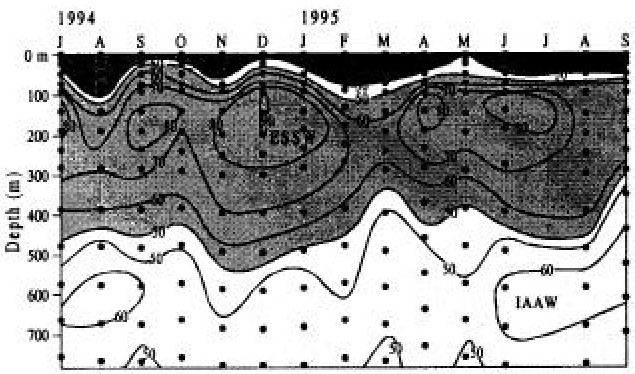


Figure 4. Vertical distribution in terms of percentage of water masses (higher than 50%), identified off Valparaiso (June 1994 – September 1995). SAAW: Subantarctic Water, ESSW: Equatorial Subsurface Water, IAAW: Antarctic Intermediate Water.

During the whole period of study, excepting September 1995, remnants of STW were also detected in the surface layer, characterized mainly by comparatively high values of salinity (>34.4). However, this water mass was never dominant in the area, since its participation in the water mass mixture fluctuated from 0 to 47%, during the year. Highest percentages of STW (*i.e.* >30%), were found in the upper 25 m of the cruises of December 1994 through May 1995, associated with temperatures >15°C and salinities >34.4. Elsewhere the STW had lower percentages, the surface layer may then be considered having subantarctic features

In the subsurface layer the ESSW was centered around 150 m depth, with a thickness in the order of 300 m, with presence in the water columns over 50% all year round. This waters were associated with temperatures between 8 and 13°C, salinities between 34.4 and 34.8, and dissolved oxygen between 0.25 and 3 ml/l. The upper limit of the 50% of ESSW fluctuated from 20 to 130 m, while its lower limit was between

320 and 530 m. With the exception of August 1994, February, March, May and September of 1995, this water mass reached percentages higher than 80% in its core, associated with high salinities (>34.7), temperatures between 10 and 12°C and low dissolved oxygen (<0.5 ml/l) (Fig. 4).

In the intermediate layer, centered around 650 m of depth and with a thickness of 300 m, the IAAW was detected. Values higher than 50% in the diagram were detected during all year associated with temperatures of 4-8°C, salinities of 34.3-34.5, and dissolved oxygen of 3-4 ml/l. The upper limit of the IAAW fluctuated between 425 and 550 m depth, with the exception of March and September of 1995, when the 50% was present near 320 m. This shallower presence of values over 50% may be attributed to the weakening of the core of ESSW, which only reached 67% due to the absence of salinities over 34.5 (Fig. 4). The lower limit of percentages greater than 50% was located below the maximum sampling depth (<800 m), with the exception of the January, March and May cruises of 1995, when it occurred at 750 m depth.

Specific composition

Identified zooplanktonic organisms were classified as 23 species of siphonophores, 15 chaetognaths and 7 euphausiids (Table 1). Among the siphonophores, 18 species belong to the suborder Calycophorae and 5 to the suborder Physonectae. The most abundant species of siphonophores were *Muggiaea atlantica* (36.0%), *Agalma elegans* (22.1%), *Sphaeronectes gracilis* (20.7%), of chaetognaths *Sagitta enflata* (80.7%), *S. bierii* (10.1%), *Eukrohnia hamata* (3.0%) and of euphausiids *Euphausia mucronata* (20.7%) and *Nematoscelis megalops* (20.7%). Other species were rare, mainly those caught in mesopelagic waters below 200 m depth; some of which were collected only once (Table 2).

Sseasonal and vertical distribution

The vertical distribution of the siphonophores (Fig. 5) showed that the higher densities were in the surface layer from 0-50 m; only in November was a large number of specimens recorded down to 200 m. In late winter and early spring the presence of a significant number of organisms in deeper waters was observed down to nearly below 600 m. The dominant species *Muggiaea atlantica, Agalma elegans* and *Sphaeronectes gracilis* were found mainly in epipelagic waters. *M atlantica* and *S. gracilis* were mainly between 0-50 m, while *A. elegans* showed a larger range of vertical distribution, and in several occasions at 100-200 m depth, reaching below 200 m in August 1995.

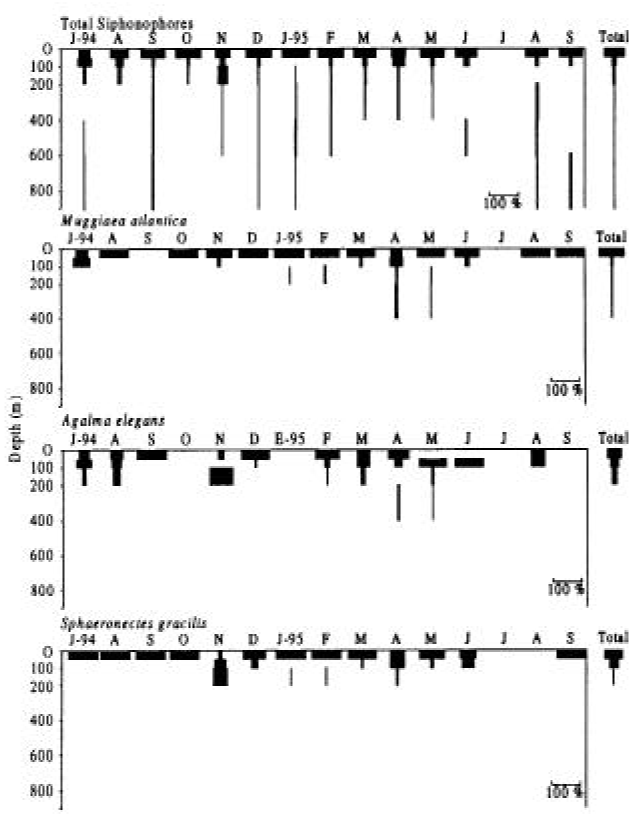


Figure 5. Monthly vertical distribution of siphonophores for the annual cycle (ind./1000 m³).

Chaetognaths (Fig 6), showed highest densities between 0 and 100 m depth, but the largest percentage of individuals in October was between 100-200 m; below 200 m the density of organisms greatly decreased even though the number of species increased (Table 2). Large aggregations of *Sagitta enflata* and *S. bierii* were recorded in July. Greatest densities of *S. enflata* were between 0-50 m of depth, but some specimens were below 100 m and only in october, summer and autumn it was distributed down to 400 m. *S. bierii* was also at 0-100 m, whereas *S. enflata* was found below 200 m in late summer and autumn. *Eukrohnia hamata* had a preferred distribution in mesopelagic waters (200-900 m), but it was rarely present in the surface layer of 0-50 m.

Table 1. Monthly distribution of macroplankton collected during annual cycle (ind/1000 m^3).

	Months														
Species	**J-1994**	**A**	**S**	**O**	**N**	**D**	**J-1995**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**
Siphonophores															
Halistemma sp.	-	-	-	34	4	-	-	-	-	-	-	2	-	-	-
Agalma elegans	90	16	20	-	35	45	-	32	27	21	10	2	-	1	-
Rosacea plicata	-	3	3	2	-	1	-	1	1	-	-	-	-	-	2
Rosacea cymbiformis	-	-	-	-	-	8	-	-	-	-	-	1	-	-	-
Vogtia kuruae	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Sulculeolaria chuni	-	-	-	-	-	15	-	-	-	-	-	-	-	-	-
Lensia hostile	1	-	-	-	-	4	1	-	-	-	-	-	-	-	1
Lensia conoidea	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-
Lensia multicristata	-	-	1	-	1	1	-	1	-	-	-	-	-	-	-
Lensia hotspur	-	-	-	-	-	12	-	1	1	-	-	-	-	-	-
Lensia meteori	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Lensia lelouveteau	1	-	1	-	-	-	-	1	1	-	-	2	-	1	-
Gilia reticulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Muggiaea atlantica	4	2	-	40	38	119	9	113	33	31	46	92	-	-	6
Eudoxoides spiralis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crystallophyes amygdalina	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Heteropyramis maculata	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Sphaeronectes gracilis	2	9	4	24	15	54	16	16	38	32	30	9	-	-	3
Sphaeronectes fragilis	-	-	-	-	3	6	-	3	-	1	-	1	-	-	3
Sphaeronectes gamulini	-	-	1	-	-	-	-	-	2	-	-	-	-	-	-
Sphaeronectes irregularis	-	-	-	-	-	-	-	66	-	-	-	-	-	-	-
Abylopsis tetragona	3	3	2	4	41	22	10	15	4	18	3	2	-	-	-
Bassia bassensis	-	-	-	-	-	-	-	3	-	-	-	1	-	-	-
Chaetognaths															
Sagitta enflata	49882	2797	988	1300	14221	12310	7401	17950	9419	21260	8803	5879	-	7396	11485
Sagitta bierii	4442	415	445	286	287	5912	1333	1874	529	4207	263	393	-	678	317
Sagitta minima	806	289	103	-	132	556	235	848	210	199	59	191	-	443	-
Sagitta pacifica	1822	208	51	-	-	185	-	528	-	79	-	-	-	471	-
Sagitta tasmanica	-	-	12	-	-	-	22	-	86	20	-	-	-	-	-
Sagitta decipiens	90	169	60	914	74	114	120	346	68	-	-	116	-	138	14
Sagitta maxima	17	-	-	57	15	222	59	159	69	40	69	28	-	75	361
Sagitta lyra	-	-	30	-	-	-	-	150	35	-	9	28	-	-	-
Sagitta macrocephala	-	-	12	-	31	23	7	31	-	-	-	-	-	34	-
Sagitta marri	-	16	-	-	-	-	4	-	-	68	-	-	-	-	29
Sagitta planctonis	8	-	30	-	-	-	-	12	-	-	-	-	-	-	-
Sagitta gazellae	-	-	-	-	-	-	-	-	-	-	-	-	-	11	-
Eukrohnia hamata	2388	169	811	1193	236	218	67	549	153	21	42	-	-	476	59
Eukrohnia fowleri	-	-	-	-	-	10	38	43	-	-	-	-	-	-	-
Krohnitta subtilis	45	78	104	223	25	100	78	-	124	-	-	187	-	443	125
Euphausiids															
Euphausia mucronata	331	-	274	1511	617	108	3318	87	138	398	368	47	-	101	1507
Euphausia eximia	-	-	-	-	-	-	-	-	-	-	-	14	-	-	-
Nematoscelis megalops	-	-	214	-	870	-	13	15	-	38	-	14	-	-	-
Stylocheiron affine	161	-	30	-	-	-	78	-	52	-	-	185	-	-	-
Thyssanoesa gregaria	-	-	-	-	53	-	-	-	-	17	-	30	-	-	45
Nematobrachion flexipes	-	-	-	190	16	62	-	-	35	17	-	-	-	-	-
Larvae	5548	809	10388	3582	5255	11470	5020	9464	19427	1457	840	2255	-	392	1098

Both Euphausiids species (Fig. 7) showed greater variations in vertical distribution, during spring and summer their population distribution deepened. In summer they had a greater vertical distribution, with maximum abundance between 200 and 600 m. The most abundant species, *Euphausia mucronata*, had a wide vertical distribution, mainly 100-400 m; in summer important concentrations were observed below 400 m. *N. megalops* was less frequent with highest densities in summer at deeper strata (200-600 m). Euphausiid larvae were abundant above 50 m during the whole annual cycle, except in June 1995 when a high percentage of organisms were observed below 200 m; occasionally the larvae were captured below 600 m.

Vertical distribution and water masses

The vertical distribution of the various species referred to the different water masses, showed a group formed by chaetognaths *S. enflata*, *S. bierii*, *S. minima*, *S. pacifica* and *Krohnitta subtilis* and siphonophores

Table 2. Vertical distribution of macroplankton collected to differents interval of depth during annual cycle (ind. /1000 m³).

Species	Depth interval (m) 0-50	50-100	100-200	200-400	400-600	600-900
Siphonophores						
Halistemma sp.	26	12	-	-	3	-
Agalma elegans	162	88	49	1	-	-
Rosacea plicata	2	6	3	1	1	-
Rosacea cymbiformis	8	1	-	-	-	-
Vogtia kuruae	-	-	-	-	1	-
Sulculeolaria chuni	15	-	-	-	-	-
Lensia hostile	-	-	2	-	3	2
Lensia conoidea	-	-	-	1	1	-
Lensia multicristata	-	-	1	1	1	-
Lensia hotspur	-	10	2	2	-	-
Lensia meteori	-	-	1	-	-	-
Lensia lelouveteau	-	-	-	1	3	1
Gilia reticulata	-	-	-	-	-	-
Muggiaea atlantica	499	36	4	3	-	-
Eudoxoides spiralis	-	-	-	-	-	-
Crystallophyes amygdalina	-	-	-	-	1	-
Heteropyramis maculata	-	-	-	-	1	-
Sphaeronectes gracilis	200	43	9	-	-	-
Sphaeronectes fragilis	10	1	5	-	-	-
Sphaeronectes gamulini	2	1	-	-	-	-
Sphaeronectes irregularis	66	-	-	-	-	-
Abylopsis tetragona	88	28	10	3	1	-
Bassia bassensis	4	-	-	-	-	-
Chaetognaths						
Sagitta enflata	134,414	30,704	3,649	2,324	-	-
Sagitta bierii	10,296	9,093	1,659	334	-	-
Sagitta minima	2,839	979	241	12	-	-
Sagitta pacifica	2,267	870	208	-	-	-
Sagitta tasmanica	-	52	35	-	55	-
Sagitta decipiens	163	726	726	310	262	35
Sagitta maxima	-	171	203	354	329	115
Sagitta lyra	-	124	52	51	24	-
Sagitta macrocephala	-	-	-	-	64	75
Sagitta marri	-	-	-	-	20	98
Sagitta planctonis	-	30	-	12	8	-
Sagitta gazellae	-	-	-	-	-	11
Eukrohnia hamata	114	3,676	1,344	478	518	253
Eukrohnia fowleri	-	-	-	-	30	61
Krohnitta subtilis	525	603	390	14	-	-
Euphausiids						
Euphausia mucronata	845	2486	1833	3446	168	27
Euphausia eximia	-	-	-	14	-	-
Nematoscelis megalops	279	633	188	34	31	-
Stylocheiron affine	256	250	-	-	-	-
Thyssanoessa gregaria	17	98	17	14	-	-
Nematobrachion flexipes	-	62	242	-	16	-
Larvae	65647	8057	1294	695	235	1078

Muggiaea atlantica, Sphaeronectes gracilis, Abylopsis tetragona and *Agalma elegans*, the latter with its highest abundance associated with SAAW, but also with participation of ESSW water masses. However, these epipelagic species can meander into deeper waters down to 400 m (Table 2). The second group, formed by chaetognaths *Eukhronia hamata*, *S. decipiens* and *S. maxima*; siphonophores *Lensia hotspur*, *L. multicristata* and *L. lelouveteau*, and euphausiids *Euphausia mucronata* and *Nematoscelis megalops*, had greater densities associated with ESSW, which was influenced by IAAW. A third group formed of chaetognaths *S. macrocephala*, *S. marri* and *E. fowleri*, were collected rarely and was strongly associated with the IAAW (Fig. 8).

Analysis of principal components

The PCA indicated that the first axis explained 32.28% of the variance, while the first two components explained 53.43% of the accumulated variance.

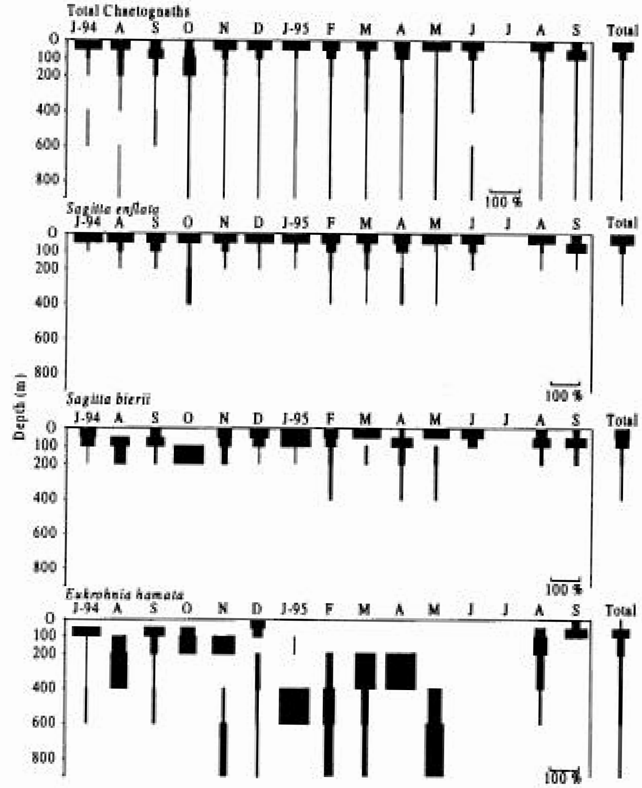


Figure 6. Monthly vertical distribution of chaetognaths for the annual cycle (ind./1000 m³).

Results defined by the planes of components I and II segregated three groupings (Fig. 9). The first group was formed by the most abundant species in epipelagic waters (*Agalma elegans, Muggiaea atlantica, Sphaeronectes gracilis, Abylopsis tetragona, Sagitta enflata, S. bierii, S. minima* and *S. pacifica*), which were strongly associated with fluctuations of temperature and explained the higher percentage of the variance. The second group was constituted by mesopelagic species associated with the ESSW (*Lensia hotspur, L. multicristata, L. lelouveteau, Sagitta maxima, S. decipiens, Eukrohnia hamata, Krohnitta subtilis, Euphausia mucronata* and *Nematoscelis megalops*) and finally, a third group, composed of mesopelagic species associated with the IAAW (*Sagitta macrocephala, S. marri* and *Eukrohnia fowleri*). The corresponding salinity and dissolved oxygen variables were not associated with any of the identified species.

Discussion

Most of the identified species have been previously registered in waters of the Chilean coast

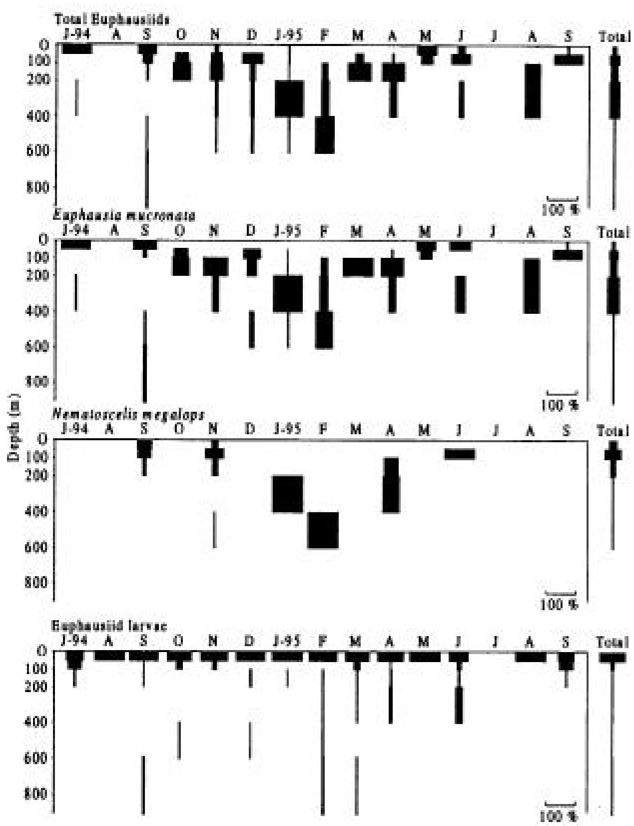
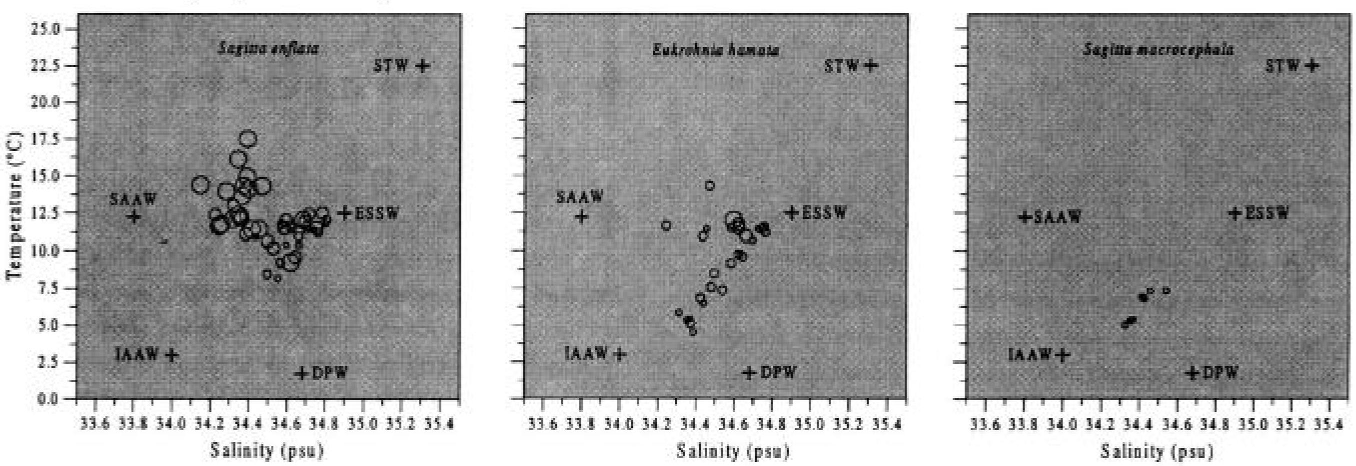


Figure 7. Monthly vertical distribution of euphausiids for the annual cycle (ind./1000 m³).

(Fagetti, 1958, 1972; Palma, 1994; Antezana, 1981). However, a number of species, both epi- and mesopelagic, are recorded here for the first time in waters of the Southeast Pacific. These include *Vogtia kuruae, Lensia hostile, L. lelouveteau, L. multicristata, Gilia reticulata, Crystallophyes amygdalina, Heteropyramis maculata* and *Sphareronectes irregularis. Sagitta marri* is also a first record, off Valparaíso.

The seasonal abundance fluctuations of the main siphonophore and chaetognath species are in concordance with previous results obtained off the coast of Valparaíso (Palma and Rosales, 1995). These variations are related to the annual thermal fluctuations in the surface layer described for the Valparaíso zone, which may be altered in coastal zones by upwelling events (Avaria *et al.*, 1989).

The greater number of epi- and mesopelagic species is found between 50 and 400 m, which is the layer where mixing of the SAAW and ESSW masses occurs. The bathymetric distributions indicate that several species may be found at greater depths, since specimens were caught between 600 and 900 m depth.



SAAW	ESSW	IAAW
Sagitta enflata	*Sagitta maxima*	*Sagitta marri*
Sagitta bierii	*Sagitta decipiens*	*Sagitta macrocephala*
Sagitta minima	*Eukrohnia hamata*	*Eukrohnia fowleri*
Sagitta pacifica	*Lensia hotspur*	
Krohnitta subtilis	*Lensia multicristata*	
Muggiaea atlantica	*Lensia lelouveteau*	
Sphaeronectes gracilis	*Euphausia mucronata*	
Abylopsis tetragona	*Nematoscelis megalops*	
Agalma elegans		

Figure 8. Species assemblages associated with the water masses present off Valparaíso. The graph represents an example of a typical TSSD association for each group.

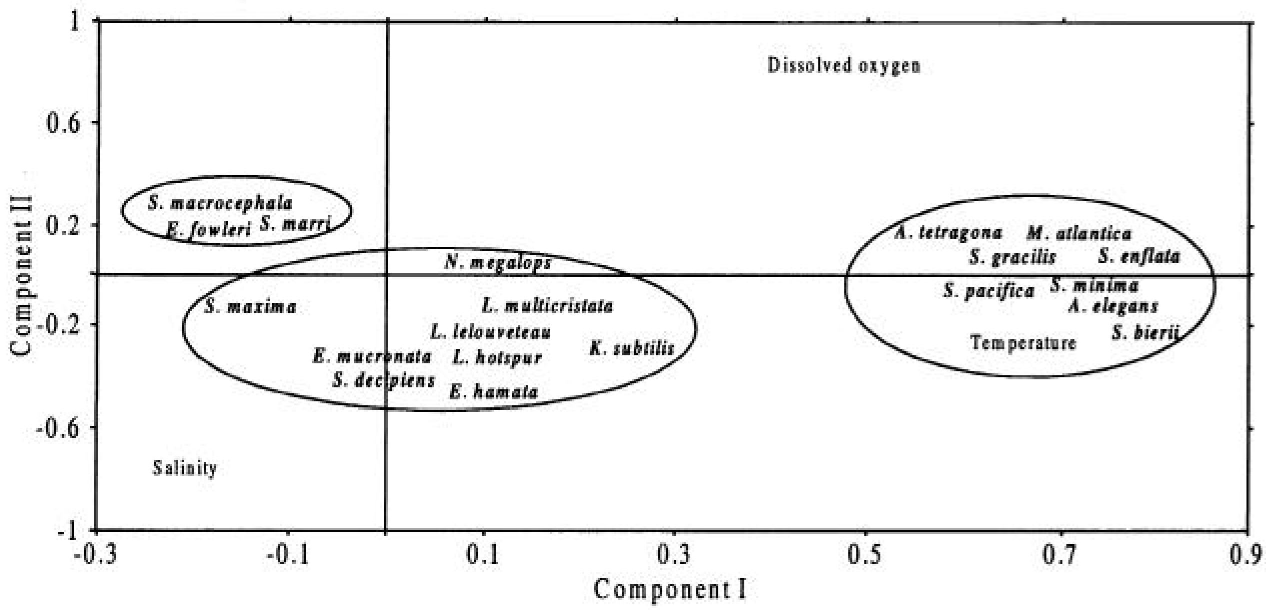


Figure 9. Plot of macroplankton dominant species collected during the annual cycle, the first two principle components, I and II.

The major part of the species in the set of epipelagic organisms, *Agalma elegans, Muggiaea atlantica, Sphaeronectes gracilis, Abylopsis tetragona, Sagitta enflata, S. bierii, S. minima* and *S. pacifica*, are common in the waters of the Humboldt current (Fagetti, 1972; Palma, 1994). With the exception of *S. bierii* which is restricted to the California and Humboldt currents (Alvariño, 1964; Fagetti, 1968), all are worldwide in warm-temperate regions (Alvariño, 1971, 1992; Nair, 1978; Cheney, 1985; Pagès and Gili, 1992; Terazaki, 1996). In some periods of the year, mainly during spring and summer, several of these epipelagic species form dense aggregations in neritic waters of the Chilean coast, as *Muggiaea atlantica, Sphaeronectes gracilis, Sagitta enflata* and *S. bierii* (Palma and Rosales, 1995).

The large densities of the epipelagic organisms were associated with surface waters of subantarctic origin, mixing with waters of subtropical and equatorial subsurface origin, and characterized by temperatures of 9-18°C and salinities of 34.2-34.8 (Fig. 8). This relationship with high temperatures, was clearly observed in summer, when the largest densities were associated to maximums of 19°C. This behavior confirms the epipelagic character of these species in the Southeast Pacific (Fagetti, 1958, 1968; Palma and Rosales, 1995).

The species in the upper part of the mesopelagic layer (200-400 m), and associated with ESSW water, were scarce in terms of abundance and occasionally meander into epipelagic waters. These include *Lensia hotspur, L. multicristata, L. lelouveteau, Sagitta maxima, S. decipiens, Eukrohnia hamata, Krohnitta subtilis, Euphausia mucronata* and *Nematoscelis megalops* (Fig. 8). The three siphonophores of the genus *Lensia* are common in waters of the California current system (Alvariño, 1985) and have a similar bathymetric distribution pattern to that determined off the coast of Valparaíso. *S. decipiens* is a dominant species in mesopelagic waters of the Indian Ocean, but can occur in bathypelagic waters, accompanied between 200-1000 m by of *S. maxima* (Nair, 1978). *E. hamata* is cosmopolitan and it is distributed in meso and bathypelagic layers of equatorial and subtropical regions, but at high latitudes is found to be epipelagic and even be surface waters (Alvariño, 1964; Fagetti, 1958, 1968; Bieri, 1959). The euphausiids *E. mucronata and N. megalops*, in spite of being classified as epipelagic in the Chile-Perú current system, are recorded as well at 200-300 m within the oxygen minimum layer in the Southeast Pacific between 30-38°S (Antezana, 1981). *N. megalops* has also been registered in waters of the patagonian shelve of the southwest Atlantic (Ramírez, 1971).

In occasions, some of these mesopelagic species may show a wide vertical distribution, such as *Eukrohnia hamata* and *Euphausia mucronata* (Figs. 6 and 7), but during events of coastal upwelling they can reach the surface layers (Sund, 1964; Fagetti, 1968, 1972; Antezana, 1978; Terazaki, 1996). Cheney (1985) suggests that the bathymetric distribution of *Eukrohnia hamata* could be related to its ontogenetic migration rather than to oceanographic fluctuations. Antezana (1978) finds that the diurnal vertical extension of *E. mucronata*, is related to the width and depth of the oxygen minimun layer that presents latitudinal variation.

The ESSW fluctuations have been previously described for this zone where the higher salinities (>34.8) and lower dissolved oxygen (<0.25 ml/l) have been detected occasionally (Avaria *et al.*, 1989). It is possible that the observed fluctuations in thickness and intensity of the ESSW, as well as its proximity to the surface, might be caused by fluctuations in the intensity of poleward currents and the presence of coastal trapped waves (Strub *et al.*, 1998). In association with these fluctuations of the ESSW there is a vertical variation in the distribution of *E. mucronata* during the year. This species is endemic to the Chile-Perú current system and is particularly adapted to an oxygen minimum layer (Antezana, 1978). In the same way, high densities of *Eukrohnia hamata* have been associated with a subsurface layer of low temperature and minimum dissolved oxygen (Sullivan, 1980).

The group of mesopelagic species formed by *S. marri, S. macrocephala* and *E. fowleri,* inhabiting the lower layer (400-900 m), were localized in low temperature (4.5-8°C) and low salinity (34.3-34.5) IAAW waters. Given that a significant number of individuals were found between 600-900 m, it is likely that these species are also distributed at greater depths. In fact, *S. macrocephala* and *E. fowleri* have been collected in meso and bathypelagic waters off Canada (Terazaki and Miller, 1986), Southeastern Pacific (Fagetti, 1972) and the Indian Ocean, where they are also associated with the IAAW (Nair, 1978). *S. marri* is abundant in Antarctic and SAAW (Alvariño, 1965), and its presence in deep waters off the central Chilean coast might be explained by its transport towards lower latitudes by the IAAW.

It is important to note the fact that the recorded association between the diurnal vertical distribution of the organisms and the water masses, is mainly valid during the day since it is know that some of the species found in the area, such as *E. mucronata*, show diel vertical migrations and are located mainly, to the evasion at the visual predators and also to the fact that it represents a metabolic advantage in the more efficient use of energy or as an adaptive response for avoidance of damage by solar radiation (Angel, 1985; Hayney, 1988).

These evidences indicate that the vertical distribution of the diverse macroplanktonic species is strongly related to specific hydrological characteristics, reflected in a strong association in depth with the water masses, as supported by the principal components results analysis.

Conclusions

1. The water column between 0-100 m showed existence of an annual cycle. Below this layer, temperature variations were smaller.

2. Between the surface and 800 m depth, the presence of three water masses was determined: Subantarctic Water (SAAW) and Subtropical Water (STW) between 0-100 m, Equatorial Subsurface Water (ESSW) between 100-400 m and Intermediate Antarctic Water (IAAW) between 400-800 m.

3. The siphonophores *Vogtia kuruae, Lensia hostile, L. lelouveteau, L. multicristata, Gilia reticulata, Crystallophyes amygdalina, Heteropyramis maculata* and *Sphaeronectes irregularis* are first records for the southeast Pacific Ocean.

4. The vertical distribution of some macroplanktonic species was well associated with water masses present in the zone SAAW-ESSW: *Muggiaea atlantica, Sphaeronectes gracilis, Abylopsis tetragona, Agalma elegans, Sagitta enflata, S. bierii, S. minima, S. pacifica, Krohnitta subtilis,* ESSW-IAAW: *Lensia hotspur, L. multicristata, L. lelouveteau, Sagitta maxima, S. decipiens, Eukrohnia hamata, Euphausia mucronata, Nematoscelis megalops* and IAAW: *Sagitta marri, S. macrocephala, Eukrohnia fowleri.*

REFERENCES

Alvariño, A., 1964, Bathymetric distribution of Chaetognaths. *Pacific Science,* 18 (1), 64-82.

Alvariño, A., 1965, Chaetognaths. *Oceanography and Marine Biology: Annual Review,* 3, 115-194.

Alvariño, A., 1966, Zoogeografía de California: Quetognatos. *Revista de la Sociedad Mexicana de Historia Natural,* 27, 199-243.

Alvariño, A., 1971, Siphonophores of the Pacific with a review of the world distribution. *Bulletin of the Scripps Institution of Oceanography,* University of California, 6, 1-432.

Alvariño, A., 1985, Distribución batimétrica de especies del género *Lensia* en aguas de California y Baja California (Diphyidae, Siphonophorae, Coelenterata). *Investigaciones Marinas, CICIMAR,* 2 (1), 59-80.

Alvariño, A., 1992, Distribución batimétrica, diurna y nocturna, de diez y siete especies de quetognatos, durante las cuatro estaciones del año 1969, en aguas de California y Baja California. *Investigaciones Marinas, CICIMAR,* 7 (1), 1-169.

Angel, M., 1985, Vertical migrations in the oceanic realm: possible causes and probable effects. *In:* M.A. Ranken (ed.) Migration: Mechanisms and adaptative significance. Marine Science Institute. *Contribution Marine Science,* Supl., 27:45-70.

Antezana, T., 1978, Distribution of euphausiids in the Chile-Perú current with particular reference to the endemic *Euphausia mucronata* and the oxygen minimum layer. *Ph. D. dissertation,* University of California, San Diego, 465 pp.

Antezana, T., 1981, Zoogeography of euphausiids of the South Eastern Pacific Ocean. *Memorias del Seminario sobre Indicadores Biológicos del Plancton,* UNESCO, Montevideo, pp. 5-23.

Avaria, S., Palma, S., Sievers, H. and Silva, N., 1989, Revisión sobre aspectos oceanográficos físicos, químicos y planctológicos de la bahía de Valparaíso y áreas adyacentes. *Biología Pesquera,* 18, 67-96.

Bieri, R., 1959, The distribution of the planktonic Chaetognatha in the Pacific and their relationship to water masses. *Limnology and Oceanography,* 4, 1-28.

Brinton, E., 1962, The distribution of Pacific euphausiids. *Bulletin of the Scripps Institution of Oceanography,* University of California, 8, 51-270.

Carpenter, J., 1965, The Cheapeake Bay Institute Technique for the Winkler dissolved oxygen method. *Limnology and Oceanography,* 10, 141-143.

Cheney, J., 1985, Spatial and temporal abundance patterns of oceanic chaetognaths in the western North Atlantic. I. Hydrographic and seasonal abundance patterns. *Deep-Sea Research,* 32 (9), 1041-1059.

Fagetti, E., 1958, Investigación sobre quetognatos colectados especialmente frente a la costa central y norte de Chile. *Revista de Biología Marina,* Valparaíso, 8(1-3), 25-82.

Fagetti, E., 1968, Quetognatos de la expedición "Mar Chile I" con observaciones acerca del posible valor de algunas especies como indicadoras de masas de agua frente a Chile. *Revista de Biología Marina,* Valparaíso, 13(2), 85-153.

Fagetti, E., 1972, Bathymetric distribution of chaetognaths in the south eastern Pacific Ocean. *Marine Biology,* 17, 7-29.

Fagetti, E., 1973, Medusas de aguas chilenas. *Revista de Biología Marina,* Valparaíso, 15(1), 31-75.

Haney, J., 1988, Diel patterns of zooplankton behavior. *Bulletin of Marine Science,* 43(3): 583-603.

Ibanez, F. and Dallot, S., 1969, Etude du cycle annuel des Chaetognathes planctoniques de la rade de Villefranche par la méthode d'analyse des composantes principales. *Marine Biology,* 3(1), 11-17.

Kramp, P., 1966, A collection of medusae from the coast of Chile. *Vidensk. Meddr. dansk naturhist. Foren,* 129, 1-23.

Ludwig, J. and Reynolds, J., 1988, Statistical ecology. A primer on methods and computing. *John Wiley & Sons Inc.,* New York.

Mamayev, O., 1973, Water masses of the South East Pacific Ocean. *In:* R. Fraser (comp). *Oceanography of the South Pacific 1972.* New Zealand National Comission for UNESCO, Wellington, pp. 71-79.

Pagès, F. and Gili, J.M., 1992, Siphonophores (Cnidaria, Hydrozoa) of the Benguela Current (southeastern Atlantic). *Scientia Marina,* 56, (Supl. 1), 65-112.

Nair, V., 1978, Bathymetric distribution of chaetognaths in the Indian Ocean. *Indian Journal Marine Science,* 7, 276-282.

Palma, S., 1994, Distribución del macroplancton gelatinoso en un área de desove de peces frente a la costa central de Chile (32°-33°S). *Revista de Biología Marina,* Valparaíso, 29(1), 23-45.

Palma, S. and Rosales, S., 1995, Composición, distribución y abundancia estacional del macroplancton de la bahía de Valparaíso. *Investigaciones Marinas,* Valparaíso, 23, 49-66.

Ramírez, F., 1971, Eufáusidos de algunos sectores del Atlántico Sudoccidental. *Physics,* 30(81), 385-405.

Schleyer, M.H., 1985, Chaetognaths as indicators of waters masses in the Agulhas current system. Oceanographic Research Institute, South Africa. *Investigational Report,* 61: 1-20.

Silva, N. and Konow, D., 1975, Contribución al conocimiento de las masas de agua en el Pacífico Sudoriental. Expedición Krill. Crucero 3-4 julio-agosto 1974. *Revista de la Comisión Permanente del Pacífico Sur,* 3, 63-75.

Strub, T., Mesías, J., Montecino, V., Rutllant, J. and Salinas, S., 1998, Coastal ocean circulation off western south America. Coastal segment (6,E). *In:* A. Robinson and K. Brink (Eds.). *The Global Coastal Ocean. Regional Studies and Syntheses.* John Wiley & Sons, Inc. New York. *The Sea,* 11, 273-313.

Sullivan, B., 1980, *In situ* feeding behavior of *Sagitta elegans* and *Eukrohnia hamata* (Chaetognatha) in relation to the vertical distribution and abundance of prey at ocean station "P". *Limnology and Oceanography,* 25(2), 317-326.

Sund, P., 1964, The chaetognaths of the waters of the Peru Region. *Inter-American Tropical Tuna Commission Bulletin,* 9 (3), 115-162.

Terazaki, M., 1996, Vertical distribution of chaetognaths and feeding of *Sagitta enflata* in the Central Equatorial Pacific. *Journal of Plankton Research,* 18, 673-682.

Terazaki, M., and Miller, C.B., 1986, Life history and vertical distribution of pelagic chaetognaths at ocean station P in the Subarctic Pacific. *Deep-Sea Research,* 33, 323-337.