Bol. Soc. Biol. Concepción, Chile. Tomo 62, pp. 7-19, 1991

PHYTOPLANKTON BIOMASS DISTRIBUTION AND RELATIONSHIP TO NUTRIENT ENRICHMENT DURING AN UPWELLING EVENT OFF CONCEPCION BAY CHILE*

Distribución de la biomasa fitoplanctónica y su relación con los nutrientes durante un evento de surgencia en la Bahía de Concepción, Chile

RAMÓN AHUMADA**, PATRICIA MATRAI**+ AND NELSON SILVA***

RESUMEN

Se describe la distribución de corto período, de variables hidrográficas y pigmentos fotosintéticos, durante un evento de surgencia costera frente a la Bahía de Concepción. Los vientos locales registrados durante el período de muestreo fueron débiles y variables, pero representativos del patrón de primavera. Fue posible observar los cambios de las variables, que correspondieron a diferentes fases de un evento de surgencia: i) una fase de surgencia activa (27-29 de octubre), ii) un período de relajación (30 de octubre), y iii) una fase restitutiva del evento (31 de octubre). Además se presentan las observaciones de la intrusión de aguas subsuperficiales al interior de la Bahía de Concepción y sus efectos de fertilización de este sistema, expresado por las altas concentraciones de biomasa fitoplanctónica. El forzamiento físico que sustentó el incremento de la biomasa en la bahía tuvo una dinámica diferente de la duración de los eventos de surgencia que ocurren en la costa abierta. La interrupción de los vientos favorables a la surgencia, por más de cinco días, no produjo una respuesta de magnitud equivalente en estos sistemas.

ABSTRACT

The hydrographic variables and photosynthetic pigments distribution were followed and described over days time scale, during a single upwelling event off Concepcion Bay. During the sampling time, local winds were weak and variable although following a spring pattern. It was possible to detect three phases of an "upwelling event" during one week observation: i) an active upwelling phase (October 27th to 29th), ii) a relaxation phase (October 30th) and iii) a restitution phase (October 31st). The spreading effects of upwelled water were observed by the fertilization of the embayment and the production of a sharp subsequent increment on phytoplankton biomass. The physical support of the large biomass had a time scale dynamic diferent inside the bay, when it is compared to a coastal upwelling event off the bay. The onset of the favourable upwelling winds for a period longer than five days did not produce changes on hydrographic distribution on the observed parameters within the bay.

KEYWORDS: Coastal upwelling. Nutrients. Embayments. Chlorophyll a.

INTRODUCTION

Coastal upwelling zones have been described as areas with high biological productivity and biomass, with input of nutrient to the photic zone from subsurface waters (Boje and Tomczack, 1978; Margalef, 1978). An upwelling event can be defined as the period of time where

*This work was supported by DIUC Grant N° 17/79.
**Departamento de Oceanografía, Pontificia Universidad Católica de Chile, Sede Talcahuano, Chile.
**+Present address: Division of Marine Atmospheric Chemistry. Rosenstiel School of Marine and Atmospheric Science University of Miami, USA.
***Escuela de Ciencias del Mar, Universidad Católica de Valparaiso, Chile.

subsurface waters reach the sea surface. This process is not a continuum and it is produced under the effects of favourable winds pulses. There are two factors to initiate the upwelling event: i. The favourable wind persistency to bring up the subsurfase water to the surfase. ii. The threshold intensity to maintain the process over the time. An upwelling period can be defined as an interval where upwelling events occur more frequently under the seasonal dominance of favourable winds. Although, the upwelling events or system pulses would have a time scale of several days to a week, they are seasonal phenomena in the Southwest Pacific, where coastal upwelling events are most likely to occur during the summer, when the winds blow southward along the coastline (Smith, 1968). Different coastal areas, along the Chilean coast, have been described as potentially favourable to coastal upwelling (Fonseca & Farías, 1987). One of them is Concepción Bay and is located between 36° and 37° South Latitude.

Concepcion Bay is a restricted coastal area with two mouths (both of them oriented toward the North) and located in the central region of Chile, where the coastline has a general North-

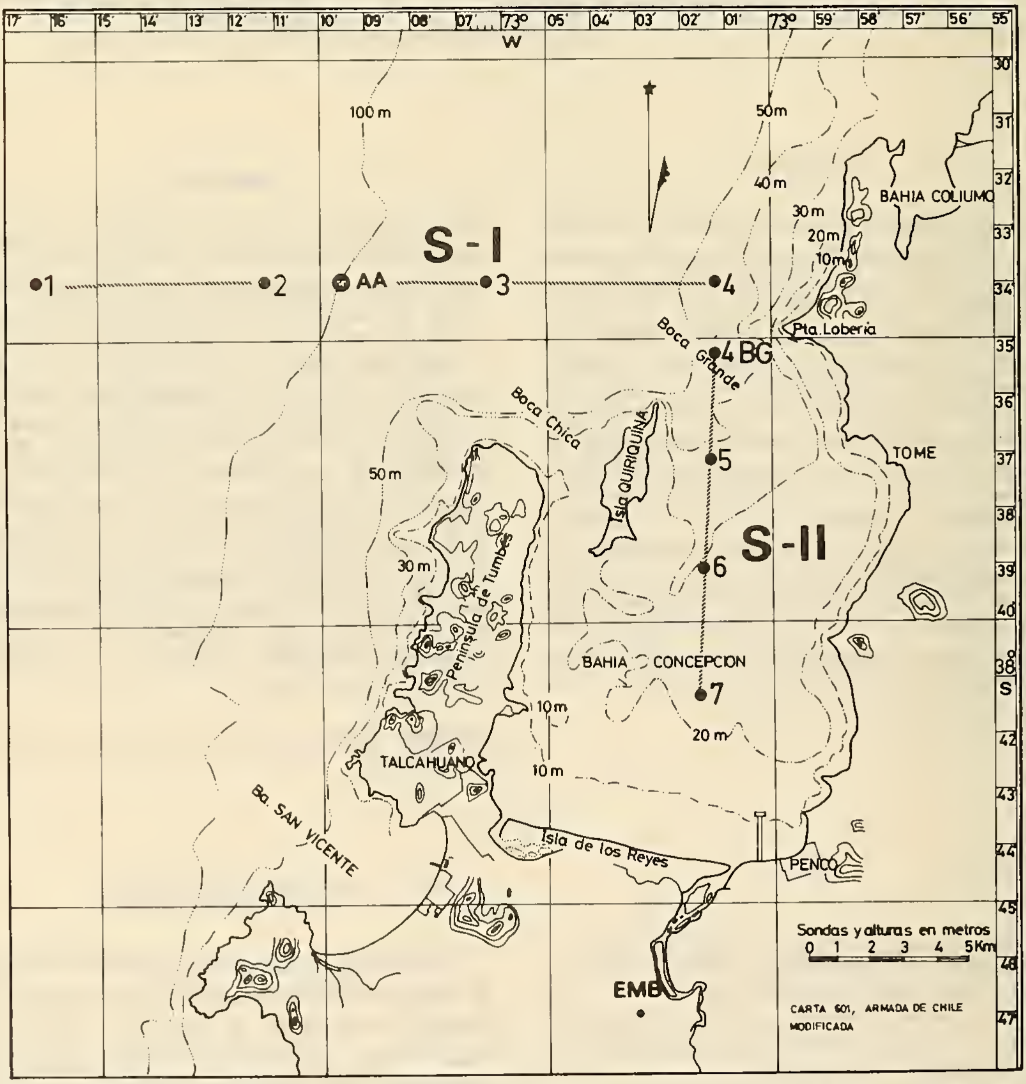

FIGURE 1.- Hydrographic stations samples in Concepcion Bay showing Section I and Section II. AA indicates location of moored Aanderaa current-meter. EMB = Bellavista Meteorological Station.

South direction. Concepcion Bay acts as a natural extension of the coastline for the alongshore dominant flows of the coastal current system (Fig. 1). This location plays an important role on the intrusion of subsurface waters into the bay during upwelling periods. An extensive lens of cold nutrient-rich-upwelled water has been observed off-bay (Brandhorst, 1963 and 1971; Neshyba & Mendez, 1976; Espinoza, Neshyba & Maoxiang, 1973). Studies on Concepcion Bay have confirmed the presence of offshore subsurface waters inside the bay with seasonal appearance and the late upwelling of these subsurface waters (Ahumada & Chuecas, 1979; Ahumada *et al.*, 1983). However, the sampling frequency (*i.e.*, monthly) of these studies provides a limited view of the upwelling effects at the bay, related to the fertilization by advective nutrients and the plant biomass present in the coastal waters. The extent of an upwelling event may occur in few days (*i.e.*, two or three) whereas the development of the whole process can take place in a week (Arcos *et al.*, 1987). From this point of view, the time scale (frequency) of experiments must be taken into account.

Concepcion Bay sustains high concentrations of zooplankton (Bernal, pers. com.) and it is the second most important spawning ground in the southern central part of Chile, in which is possible to find a great abundance of larvae of important commercial fisheries, such as sardine [*Clupea (Strangomera) bentincki*], anchovy [*Engraulis ringens*] and herring [*Ethmidium maculatum*] (Mujica & Rojas, 1980).

The present study has been motivated by the necessity of a better understanding of the effects of an upwelling event on the biomass production. This paper analyzes: wind velocities, current distribution over the continental shelf, physical and chemical characteristics of the upwelling and discuss photosynthetic pigment distribution inside and outside Concepcion Bay.

METHODS

Samples were collected at eight stations: four of them arranged perpendicularly to the coastline (Section I: toward West) and four located along the longitudinal axis of the bay (Section II: facing north, see Fig. 1). In the first part of Section I, along the 100 m isobath, an Aandera RCM4 current meter was moored at 50 m below the surface measuring current velocity every 15 minutes. The current meter recorded 1097 hours (October 21st to December 7th, 1979) (The analysis of the current meter data has been reported by Blanco, 1984). Wind velocities were measured at Bellavista Meteorological Station (4.5 Km. South of the head of the bay), University of Concepcion.

Water samples for temperature, salinity, oxygen, nutrients and phytoplankton pigments were collected from pre-fixed depths, over the range 0-100 m, using Nansen (1.21) and Van Dorn (3.51) bottles at all stations. Temperature was measured with reversing thermometers. Salinity was determined with an induction salinometer AUTOLAB 601 MK III. Disolved oxygen content was measured using the modified Winkler method (Carpenter, 1965). Nutrient analysis were done after sample filtration, according to Strickland & Parsons (1968). For phosphates analysis a secondary obsorvance pick, at 710 nm wavelength, was used instead of primary peak at 885 nm, as suggested by Strickland & Parson (*op. cit.*), due to the limited wavelength range of the available spectrophotometer (Perkin Elmer 124). For the pigments analysis (chlorophyls, carotenes and phaeopigments) a volume of one liter was filtered through a 0.35 u cellulose acetate filter. Pigment extraction and spectrophotometric analysis were conducted according to SCOR-UNESCO (1966) and Lorenzen (1967). Statistical calculations were achieved following Sockal and Rolf (1981) techniques. Pigment average over the water column was calculated and normalized by dividing the amount of pigment by the maximal depht sampled at each station.

RESULTS

Annual winds scale of Concepcion area usually shows a clear seasonal pattern being south and southwest winds dominant during spring and summer (September to April) and north during autumn and winter (May to August) (U.

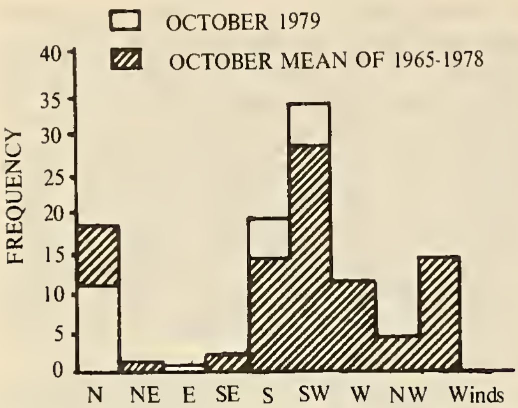

FIGURE 2.- October frequencies of wind directions, in the diagram: dark, bars show thirteen year average and light bar show October of 1979.

Concepcion, 1979). Early spring months show a high variability on the winds dominance pattern, but a behavioural tendency is consolidated on the late month of the same season. October 1979, when this research took place, was not an exception to this general pattern (Fig. 2). Nevertheless a short period of observations was necessary in orden to stablish the relationship between the local wind forcing the surface water and advection process. A record of winds and currents registered for the mooring period (October 24 to December 28), showed a wind average speed of 4.63 m s^{-1} to south. Shelf currents measured at 50 m depth had a speed average of 9.3 cm s^{-1} to west (Blanco, 1984). The analysis of these series revealed on one hand a timelag of 18 hours approximately between the wind changes and current responses at 50 m depth (Fig. 3). On the other hand, current intensity response seemed to be independent from wind intensity.

The north-south components of wind stress (Fig. 4), averaged on 6 h running mean, for the period of hidrographic field sampling. On a day basis scale, strong favourable upwelling winds occurred one day before sampling (negative values of tau) and variables winds for the period were also found. Weak northward winds were observed before the onset of the event (28 October), followed by increasing northward winds (29 October). After a calm period in the morning of October the 30th, the still dominant alongshore northward component of the stress shifted towards south later in the day.

These behaviours were also reflected in the general hydrography of the bay: the cold subsurface waters, with a temperature near to 10

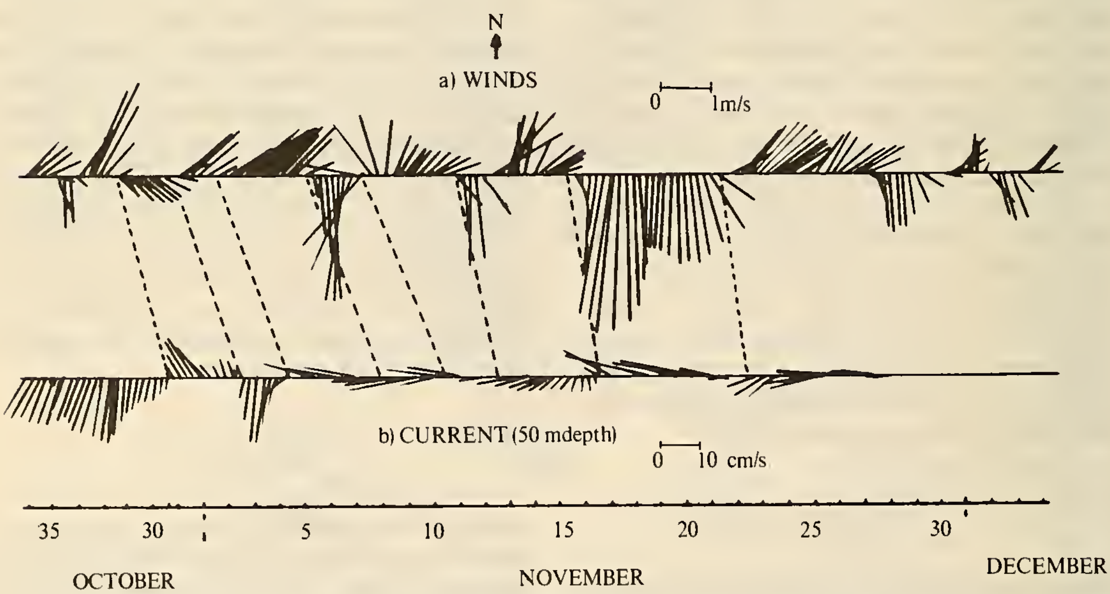

FIGURE 3.- Stick diagram showing: a) Winds and b) Current at 50 m depth off Concepcion Bay, from October 23th to December 30th, 1979. (After Blanco, 1984).

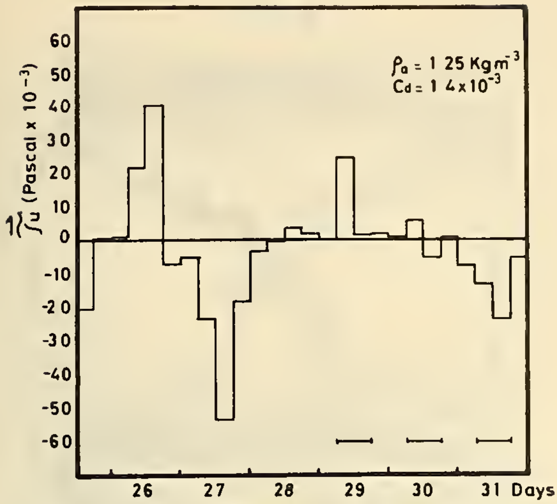

FIGURE 4.- Alongshore wind stress (component U, -- 360°) on Concepcion Bay.

degrees, were represented by coastalward ascending isoterm from 75 m on the shelf to 25 m inside the bay with a cooling effect or surface temperature (Fig. 5a). The surface temperature inside the bay was higher than for the outside waters. Cold surface water was present at the onset of the event, followed by a progressive heating up in 2°C at all stations over the time length of the event. On the second day a 10 degrees isoterm was interrupted: a core was retained on the bay bottom and the shelf isoterm was sinking down to a depth of 65 m. On the third day a tendency to the re-establishment of the characteristics observed on the first day, was detected.

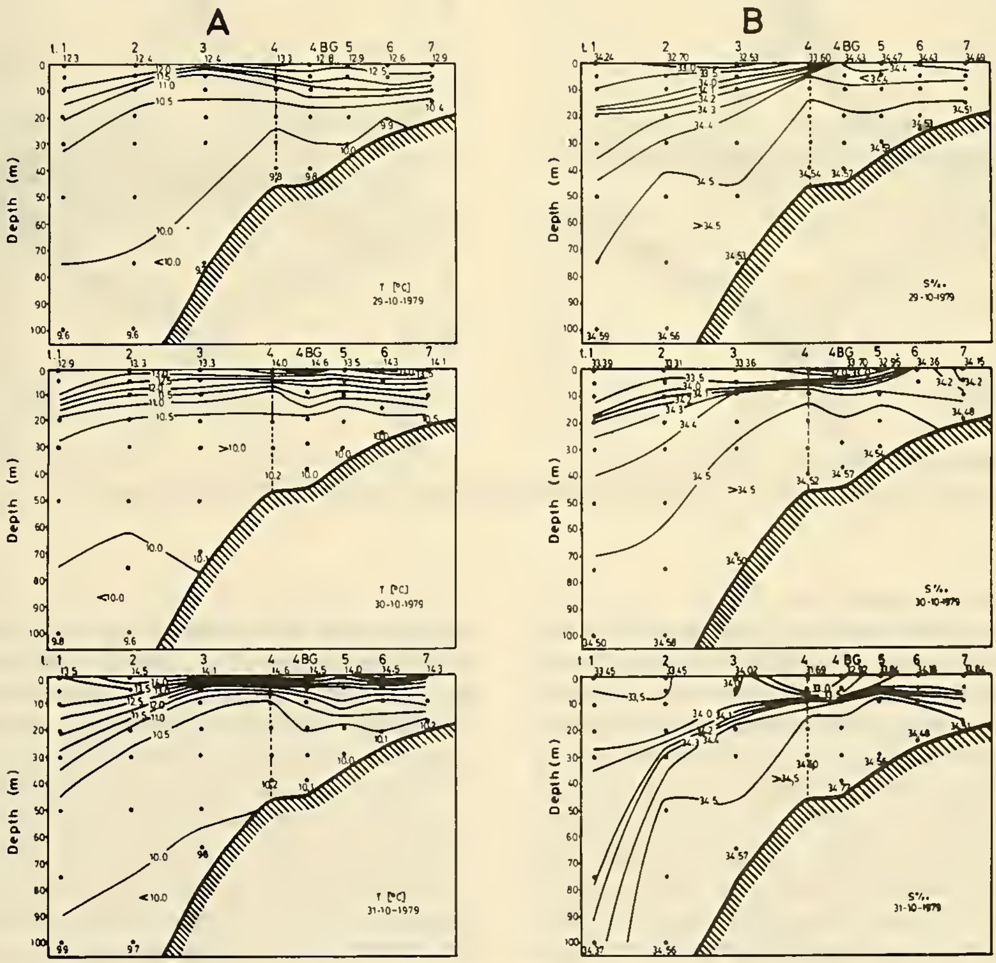

FIGURE 5.- Vertical section for temperature (°C) and salinity (S x 10^{-3}) during field sampling.

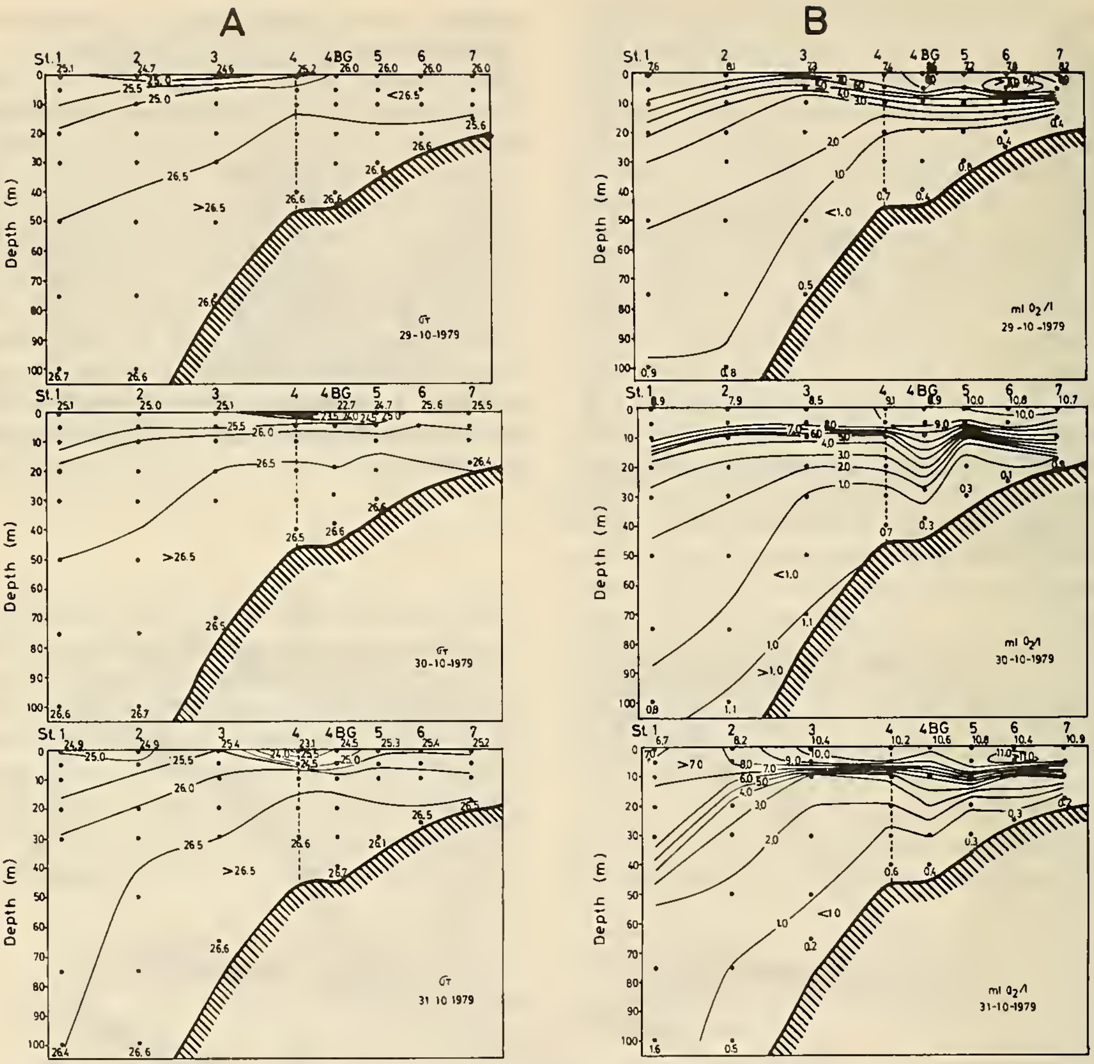

FIGURE 6.- Vertical section for density (Sigma-t) and dissolved oxygen ($mlO_2 l^{-1}$) during field sampling.

The spatial salinity distribution on the sections is showed in *Figure 5b*. Salinity was homogeneous and the values were close to 34.4 x 10^{-3} at all of the water column. A surface lens of less saline waters was located on the shelf waters, near the mouth of the bay.

Figure 6a shows the vertical distribution of density in the water column. Density was expressed as sigma-t units, showing a maximal range of 4.0 units. On the figure it is possible to observe that a surface light density core over the shelf waters increased the stratification. Homogeneous high density water was observed in the whole bay. On the second day the core was reduced and transported to the bay mouth. Turbulence and mixing induced a decreased density on the superficial water inside the bay.

Oxygen vertical distribution shows strong gradient from surface to near bottom waters (*Fig 6b*). Surface values were over the saturation point and only at 40 m depth inside the bay were detected values near anoxia. Oxygen content of the water column indicated three layers: a bottom layer with low oxygen content (<1 ml

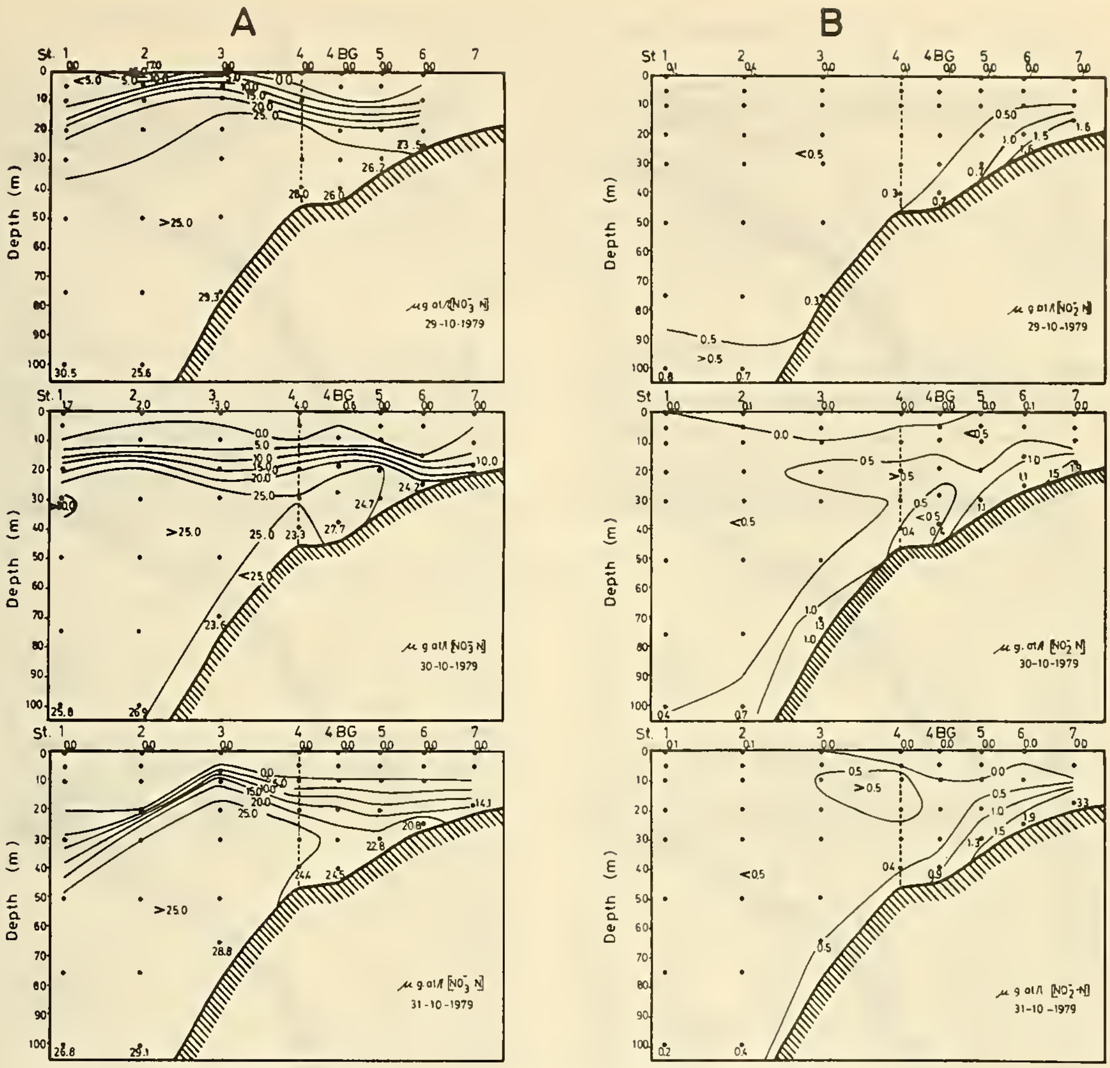

FIGURE 7.- Vertical section for Nitrate (μM N-NO_3^-) and Nitrite (μM N-NO_3^-) during field sampling.

l^{-1}), an intermediate layer with an oxygen content over 1 ml l^{-1} but less than 2 ml l^{-1} but less than 3 ml l^{-1} and a surface layer with values higher than 3 ml l^{-1}. The presence of these three layers was well defined in the waters outside the bay. In the waters inside the bay, the intermediate layer was diminished in thickness up to the point of disappearance.

In general, nutrients content in surface waters was low or near zero, contrasting to their high concentration at only a few meters down. Nitrate and phosphate maximum concentrations were coincident with the oxygen minimum waters (*Figs. 7a* and *8a*). Nitrates presented a fairly constant distribution in the subsurface waters outside the bay. The nitrate bottom concentrations decreased as these waters penetrated into the bay, while an increasement of nitrite concentration occurred with a symmetrical spatial pattern as the product of the denitrification process (*Fig. 7b*). Apparently, these changes may be related to local redox reaction in the water-sediment interphase, due to the low oxygen concentration and high organic content (Seitzinger, 1988). As a consequence, the nitrite concentration was higher inside the bay

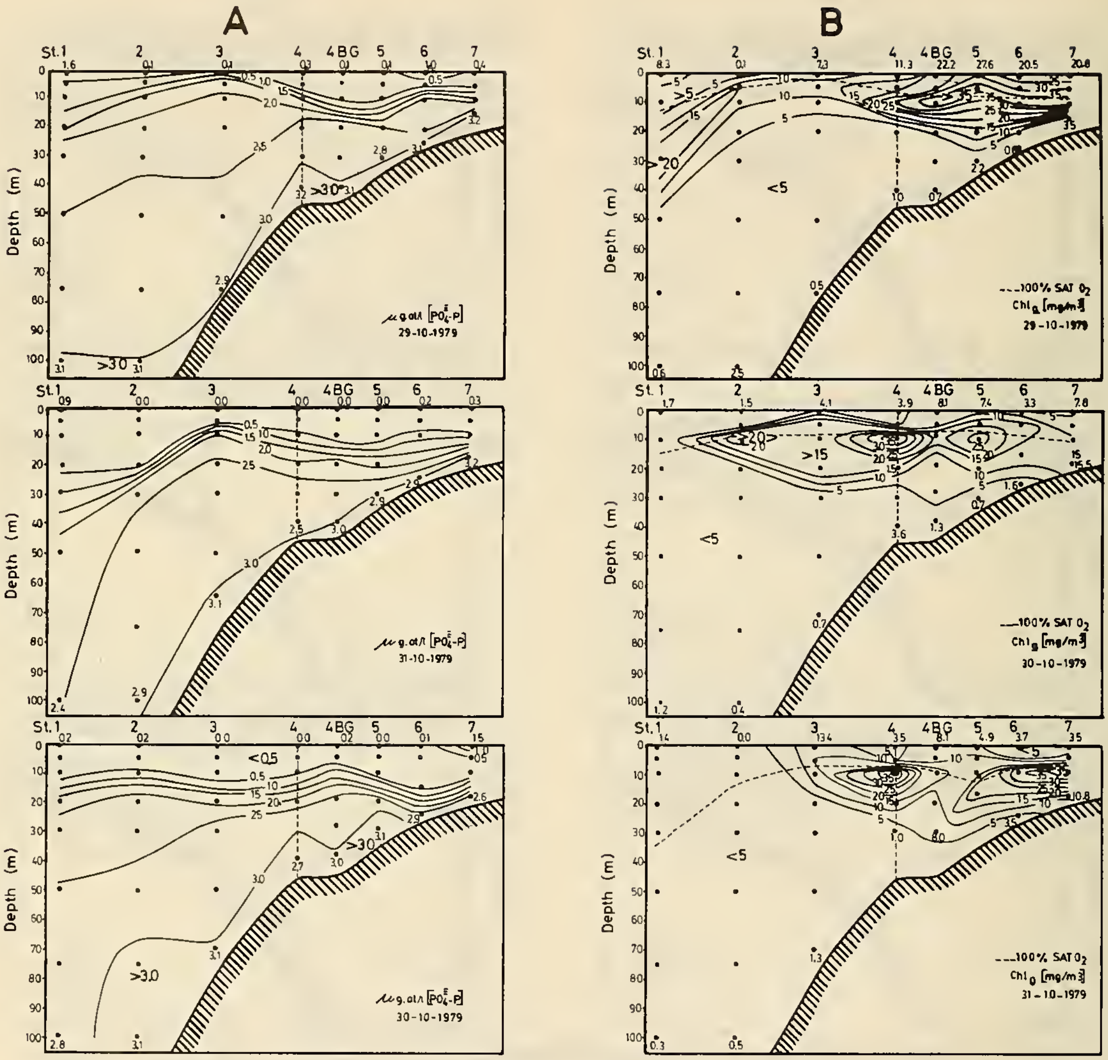

FIGURE 8.- Vertical section for temperature (M P-PO_4^{3-}) and Chlorophyll *a* (mg Chl a m^{-3}) during field sampling.

than in the shelf waterbody. This fact constitutes a cualitative evidence that the denitrification occurs as permanent process on Concepcion Bay during the upwelling event (Ahumada *et al.*, 1984a).

Phosphates were found to have a vertical distribution similar to nitrates but in this case the concentration values are maintain as long as the waters reached the bay. The highest values of concentrations were 2.5 uM, being the maximum values 3.2 uM (*Fig. 8a*).

Finally, data obtained in this high frecuency sampling were used to characterized the waters mass involved in the upwelling process. The mean values of the different parameters of the upwelled water were presented in **Table I.** The variances and variation coefficient show a stable water body. Salinity value of 34.5 x 10^{-3} defined a lower limit of Equatorial Sub-Surface Waters (ESSW) for this latitude (Silva & Konow, 1975).

TABLE I.- Ranges and Mean values of ESSW off Concepcion Bay. Variation coefficient is expressed as percentage (N = 45 values).

Salinity gr/Kg	Temperature °C	Oxygen ml O_2/l	Density Sigma-t	Nitrate µM	Nitrite µM	Phosphate µM
34.50-34.60	9.61-10.26	0.27-1.17	26.56-26.72	23.3-31.3	0.10-1.34	2.55-3.21
$\bar{S}$ = 34.55	$\bar{T}$ = 9.96	$\bar{O}_2$ = 0.91	$\bar{\sigma}_t$ = 26.63	$\overline{NO_3}$ = 27.8	$\overline{NO_2}$ = 0.40	$\overline{PO_4^{3-}}$ = 2.90
SD = 0.03	SD = 0.21	SD = 0.37	SD = 0.05	SD = 2.10	SD = 0.29	SD = 0.21
CV = 0.08	CV = 2.08	CV = 40.6	CV = 0.18	CV = 7.56	CV = 72.0	CV = 7.24

To analize the spacial distribution of phytoplakton biomass three types of pigments were measured: Chlorophyll *a.*, Carotenes and Phaeopigments. The results of integrated values for the hydrographic stations can be seen in **Table II.**

TABLA II. Integrated values (mg m^{-2}) and means values (mg m^{-3}) of pigments over the sections during the different stages of an Upwelling event, at Concepcion Bay.

Date	Pigments	Hydrographic Stations 1	2	3	4	4BG	5	6	7
29th Oct.	Chl *a*	494.4	318.1	186.3	382.5	533.9	641.8	501.8	361.4
	$\bar{X}$	4.9	3.2	2.5	9.6	13.3	21.4	20.1	24.1
	Car.	59.2	1.9	0.4	6.0	6.8	6.9	4.5	7.0
	$\bar{X}$	0.6	0.0	0.0	0.1	0.2	0.2	0.2	0.4
	Phaeo.	174.8	256.0	18.7	18.6	219.0	144.2	127.3	104.1
	$\bar{X}$	1.7	2.6	0.2	0.5	5.5	4.8	5.1	6.9
30th Oct.	Cl *a*	24.9	300.8	489.3	571.8	569.8	446.8	378.4	183.5
	$\bar{X}$	0.3	3.0	7.0	14.3	14.2	14.9	15.1	10.2
	Car.	0.8	13.5	6.7	7.6	8.4	7.2	4.2	3.0
	$\bar{X}$	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.3
	Phaeo.	147.7	54.3	76.7	96.2	134.8	46.0	111.4	47.2
	$\bar{X}$	1.5	0.6	1.1	2.4	3.4	1.5	4.5	2.6
31st Oct.	Chl *a*	188.5	100.6	299.0	504.2	399.0	413.8	378.4	347.7
	$\bar{X}$	1.9	1.0	4.6	12.6	8.5	13.8	15.1	19.3
	Car.	68.3	0.5	3.1	7.7	6.4	5.7	5.8	6.2
	$\bar{X}$	0.9	0.0	0.0	0.2	0.2	0.2	0.2	0.3
	Phaeo.	150.9	26.0	97.5	105.5	109.0	73.0	94.0	75.6
	$\bar{X}$	2.0	0.3	1.5	2.6	2.7	2.4	3.8	4.2

Chlorophyll *a*, was the most abundant pigment. Phaeopigments were present in relatively lower concentrations as compared to the former and carotenes were the least abundant among, all of them. Phytoplankton biomass, expressed as chlorophyll *a*, showed important and persistent patches, with maximum values as high as 35 mg m^{-3} inside the bay (**Fig. 8b**). The highest concentrations were found inside the bay and towards its head.

The integrated pigment as an expression of the total biomass, masking the concentration of pigment on deeper zone, nevertheless giving and idea of the potential biomass production of this area.

In order to aid the interpretation of the original patch of pigments and their further transport and dispersion **Table III** shows the averages of pigments over all the data from the hydrographic stations. Highest values of pigments concentration were located inside the bay, and a decreased gradient was observed on the stations toward off shore. This tendency was as valid for chlorophyll *a* as for phaeopigments.

TABLA III.- Average concentration of major photosynthetic pigment, over time on the field sampling for each station.

HYDROGRAPHIC STATIONS

	off shore			mouth of the bay			head of the bay	
Pigments	1	2	3	4	4BG	5	6	7
Chl *a*	2.37	2.39	4.69	12.15	12.02	16.69	16.78	17.86
Phaeo.	1.74	1.13	0.95	1.85	3.86	2.91	4.44	4.58

DISCUSSION

In the present study, it has been tried to describe the effect of a single upwelling event on the coastal zone. The main interest was focused on nutrient and photosynthetic pigment distribution over the shelf and inside the Concepcion Bay. As it was said earlier of this paper the aim was to understand the effect on upwelling and different scale of time responses of this restricted area.

Three important physical aspect should be taken into account on the analysis of the biomass production in the Concepcion Bay: i) Coastal topography and orientation of the bay, ii) Favourable coastal upwelling seasonal pattern (Arcos & Navarro, 1986), and iii) distribution of nutrient offshore and those which spread into the bay. During the upwelling period (Ahumada & Chuecas, 1979; Ahumada et al., 1983), several upwelling event take place over shelf as pulses of short time scale (week).

The local winds observed on a preview (three days) to sampling period were weak but favourable to upwelling, with a change to northward winds that developed values near to 14 Pascal, on the fore day of the hydrographic sampling (October 28th). After that date a decreased north component was observed, following a calm period (October 29^{th}) and a new change to south wind re-established the favourable conditions for upwelling. Offshore response to this short-time changes, could be observed on the variables distribution by an increased warming of the surface and the sinking of the isoterm of 10.5 °C for October 30^{th} (see **Fig. 5**). The presence of advective processes may account for the increment of surface temperature by 2 °C in two days. This assertion is supported by the fact that the energy necessary to produce this change does not correspond to a local change of temperature. The air temperature during these days showed an increment of 3.5 °C, reaching a maximum of 16.5 °C. Other fact that may support this idea is the presence of a low salinity nuclei, that increased the stratification, was observed near the mouth of the bay. Its origin is attributed to a dilution effect by the Bio-Bio river plume, as it can be found in Díaz (1980).

The distribution of the variables suggests the onset of an upwelling event by the 29th of October with the presence of cold upwelled water with high salinity inside the bay. A relaxation period would have followed on the 30^{th}: the river water formed a lens over previously upwelled water at the mouth of the bay, and the intrusion of the ESSW into the bay was less obvious. The possibility of a relaxation is enhanced by the decreased northward winds and the later inversion of wind direction. The evolution in time of these variables is an indicator of existing short-scale changing systems. The nutrients concentration of the bottom waters inside the bay was highly contrasting with a paucity in surface waters. This fact was probably due to high biological requirements on the euphothic zone (*i.e.*, 2.5 to 4.0 m. secchi disk depth). The upwelling pattern distribution observed outside the bay, on the 29^{th} was re-established on the 31^{st} of October, as evidenced by a decrement in the temperatures of the bottom waters.

One of the major effects detected was the decrement of the [$N\text{-}NO_3^-$] concentration and the increase of newly formed [$N\text{-}NO_2^-$] concentration, during the water spreading towards the bay. The spatial overlap of this isolines suggests the occurrence of a reduction process, derived from an oxygen minima and the organic demand from recently formed sediments. An increase of reactive phosphate concentrations in the bay in relationship to the concentration of ESSW, helps to confirm the idea of an oxidative origin of phosphates. The major nutrients supply was found on the advection of ESSW at the bay. Oxidative nutrients were not important, because the low oxygen concentration produced an impoverishment of nitrate content to turn it as a limited nitrogen system (Ahumada *et al.*, 1984b).

The chlorophyll *a* distribution found and its evolution in time also supports the existence of different stages in the upwelling event previously described. Thus, on the 29th of October, the highest concentrations were located at the back of the bay (**Table II** and **Fig. 11**) with average values up to 24 mg Chl *a* m^{-3}.

The vertical section of chlorophyll *a* showed two clearly defined systems: the first one corresponding to the bay and second one to the adjacent shelf. **Table IV** shows the changes in pigment concentration inside the bay (*i.e.*, Sts. 4BG to 7), the adjacent shelf areas and the entire transect. The highest chlorophyll *a* concentration, can be mainly related to a minimum stability inside the bay. The daily variations could be explained by the relaxation of upwelling and a decrement in the biomass on the 30th and by a biomass increasement on the 31st when reactivation by southward winds was observed.

TABLE IV. Daily weighted* average of photosynthetic pigments of coastal zone of Concepción.

Date	Pigments	Concepción Bay		Shelf Zone		Total Section
		mg m^{-3}	C.V.(%)	mg m^{-3}	C.V.(%)	mg m^{-3}
Oct. 29	Chl. *a*	19.72	23.18	5.04	63.22	12.37
	Car.	0.26	52.27	0.06	106.28	0.16
	Phaeo.	5.58	17.05	1.39	86.52	3.48
Oct. 30	Chl.*a*	13.61	18.63	6.15	99.06	9.36
	Car.	0.20	17.23	0.08	73.93	0.14
	Phaeo.	3.00	41.23	1.40	56.85	2.19
Oct. 31	Chl. *a*	14.18	31.51	6.08	79.70	10.13
	Car.	0.23	34.23	0.21	128.58	0.22
	Phaeo.	3.28	25.61	1.54	63.74	2.40

*Average considering the integrate values for the water column.

Inside the bay and particularly at its head, the greatest concentrations for all the photosynthetic pigments were located. The concentration was twice as higher than the shelf value and the variability outside the bay was smaller than inside A similar phenomenon has been reported by González *et al.*, (1987) for studies achieved later on. A negative gradient is generated towards the mouth in Section II and outwards the seashore in Section I afterwards. Both, Chl *a* distribution profiles (see **Fig. 8b**) and integrated values (see **Tabla III**) can ilustrate this situation. This p Both, Chl *a* distribution profiles (see **Fig. 8b**) and integrated values (see **Tabla III**) can illustrate this situation. This pigment distribution is an indirect evidence of the high level of productivity at the bay and of the pigments transportation by advection toward the adjacent coastal zone.

An important reason urged in support of this process is the existence of two layers and the direction followed by the upper layer on its way out, which originates the photosynthetic pigment gradient towards the external zone of the day. Detected changes in the pigments distribution, at different stages of the upwelling event were not noticeable and they do not show a clear answer to the problem. This situation is probably due to the fact that the phytoplankton turn over rate is longer than 24 hours. Hence, it could be inferred that the required time for registering any detectable change in pigments production should be longer than 48 hours. This fact would reinforce the concept of an advective change related to pigments concentration. Phaeopigments were accounted for a significant fraction of the Chl *a* - derived produced by the hydrolysis when it passed through the guts of zooplankton (Shuman & Lorenzen, 1975). Instead the phaeopigments average were 24.5% of the Chl *a* at the bay, percentage which is slightly lesser than the average of shelf water. Although the proportional concentration is maintained in-and-outside the bay (24.5%). The bay bulk content of phaeopigments was higther as twice the external value.

The most relevant oceanographic features observed in this area were: i) Low surface salinity, ii) high stability of the water column in the adjacent shelf area, with strong stratification "enhancing phytoplankton patchiness", iii) high phytoplankton biomass sustained by the Concepcion Bay, iv) high zooplankton biomass with volumes larger than 25 ml 100 m^{-3} (Mujica and Rojas, 1980) and v) a dynamic system providing a long residence time (*i.e.*, 4-20 days) for fish eggs and larvae in shallow waters (Arcos and Wilson, 1984).

In conclusion an upwelling event was detected in the shelf waters off Bahia de Concepción in October 1979. The Equatorial Subsurface Water mass was identified as being involved in the process. The upwelled water mass spreading over the bottom into the bay, showed a surprising continuity in stratification for such shallow waters. Inside the bay the preformed nutrient concentrations, as inorganic nitrogen compound, were modified before reaching the euphotic zone, most probably by redox processes due to low oxygen concentration. Upwelling nutrient load was the most important input of nutrient during the spring-summer seasons. Internal processes as advection, wind turbulent mix, tides, chemical redox processes and biological uptake modified the nutrient distribution and produced the typical gradient of specific pattern of the bay. Observing the vertical parameters distributions and the pattern of fluxes inside the bay (Ahumada & Chuecas, 1979) it can be suggested the existence of two vertical layers: one subsuperficial and that moves towards the head of the bay and a flushing superficial layer. In this squematic representation an important biomass content was transported by the advection away from the bay. As the relaxation time during the upwelling period was short, weak and developed between two upwelling events, the advected production plume from the bay was not completely destroyed. Therefore an important biomass content produced on the bay (phytoplankton biomass up to 35 mg Chl *a* m^{-3}) was used to sustain high concentrations of zooplankton. Furthermore an important fraction of it was transported and dispersed outside the bay.

ACKNOWLEDGEMENTS

We would like to express our gratitude to Uwe Ohme, Anny Rudolph, Victorino Martínez, José Luis Blanco and Tomás Fonseca who assisted us in the cruisse and analytical work. To Dr. Jorge Muñoz for his patience on english version corrections and Mrs. Carlota Briceño by the final english version. Financial support was provided by Dirección de Investigación Pontificia Universidad Católica de Chile, through Research Project DIUC 17/79, granted to Ramón Ahumada.

REFERENCES

Ahumada, R. & L. Chuecas. 1979. Algunas características hidrográficas de la Bahía de Concepción (36° 40'S; 73° 02'W) y áreas adyacentes, Chile. Gayana, Misc., *8*:1-56.

Ahumada, R., A. Rudolph & V. Martínez. 1983. Circulation and fertility of Concepcion Bay. Est. Coast. and Shelf Sci. *16*:95-105.

Ahumada, R., Rudolph & P. Matrai. 1984a. Oxígeno disuelto y su relación con los nutrientes de la Bahía de Concepción, durante el período de surgencia. Invest. Mar., Valparaiso, *12*:15-26.

Ahumada R., R. Morales, A. Rudolph & P. Matrai. 1984b. Efectos del afloramiento costero en la diagénesis temprana de los sedimentos de la Bahía de Concepción, Chile. Bol. Soc. Biol. Concepción, Chile. *55*-135-146.

Arcos D. & N. Navarro. 1986. Análisis de un índice de surgencia para la zona de Talcahuano, Chile (Lat. 37°S). Invest. Pesq. (Chile), *33*:91-98.

Arcos D., S.P. Núñez, L. Castro, & N. Navarro. 1987. Variabilidad vertical de clorofila a en un área de surgencia frente a Chile Central. Invest. Pesq. (Chile), *34*:47-55.

Arcos, D.F. & R.E. Wilson. 1984. Upwelling and the distribution of chlorophyll a within the Bay of Concepcion Chile. Est. Coast. and shelf Sci. *18*:25-35.

Blanco, J.L., 1984. Características de la circulación sobre la plataforma continental de Talcahuano. Tesis para optar al título de Oceanógrafo. Universidad Católica de Valparaíso. 42 p.

Boje, R. & M. Tomczak. 1978. Ecosystem analysis and the definition of boundaries in upwelling regions. In: Upwelling ecosystems, Boje, R. & M. Tomczak, eds., Springer Verlag, pp. 1-9.

Brandhorst, W. 1971. Condiciones estivales frente a la costa de Chile. Rev. Biol. Mar., 14(3):45-84.

Brandhorst, W. 1963. Descripción de las condiciones de las aguas costeras entre Valparaiso y el Golfo de Arauco con especial referencia al contenido de oxígeno y su relación con la pesca. Dirección de Agricultura y Pesca. Santiago, Chile. 55 pp.

Carpenter, J.H., 1965. The Chesapeake Bay Institute technique for the Winkler dissolved oxygen method. Limnol and Oceanography. *10*:141-144.

Díaz, M. 1980. Descripción del régimen Oceanográfico entre Punta Nugurue y Punta Lavapié (julio-diciembre, 1979). Corporación de Fomento de la Producción. Gerencia de desarrollo. Inst. Fom. Pesq. AP 80-3. Santiago-Chile. 68 pp.

Espinoza, F., S. Neshyba & Z. Maoxiang. 1983. Surface Water Motion off Chile Revealed in Satellite Images of surface Chlorpyll and temperature. En: P. Arana (Ed.) Recursos Marinos del Pacifico, pp. 42-57. Univesidad Católica de Valparaíso (Chile).

Fonseca T. & M. Farías. 1987. Estudio del proceso de surgencia en la costa chilena utilizando percepción remota. Invest. Pesq. (Chile), *34*:33-46.

González H., P. Bernal y R. Ahumada. 1987. Desarrollo de la dominancia local en la taxocenosis de fitoplancton de Bahia de Concepción, Chile, durante un evento de surgencia. Revista Chilena de Historia Natural, 60(1): 19-35.

Lorenzen, C. 1967. Determination of chlorophyll and phaeopigments spectrophotometric equations. Limnol. and Oceangr. *12*(2):343-346.

Margalef, R. 1978. What is an Upwelling ecosystem. In: Upwelling ecosystem, Boje, R. & M. Tomczack, Eds., Springer-Verlag, pp. 10-15.

Mujica, A. & O. Rojas. 1980. Estudio de reproducción, fecundidad y desove de la sardina común (Clupea (Strangomera) bentincki) y de la anchoveta (*Engraulis ringes*) de la zona de Talcahuano. Corporación de Fomento de la Producción. Gerencia de Desarrollo. Inst. Fom. Pesq. AP 80-3. Santiago Chile. 30 pp.

Neshyba, S. & R. Méndez. 1976. Análisis de las temperaturas superficiales del mar como indicadores de movimiento de aguas superficiales del Pacífico Sur-Este. Rev. Com. Perm. Pacífico Sur, *5*:129-137.

SCOR UNESCO. 1966. Determination of photosynthetic pigments in sea water. Monographs on oceanic methodology, UNESCO Working Group N°s 17, 25 pp.

Seitzinger S.P. 1988. Denitrification in freshwater and coastal marine ecosystems: ecological and geochemical significance. Limnol. Oceanogr., *33*(4) Part. 2:702-724.

Shuman F.R. & C.J. Lorenzen 1975. Quantitative degradation of chlorophyll by marine herbivores. Limnol. Oceanogr., *20*:580-586.

Silva N. & D. Konow. 1975. Contribución al conocimiento de las masas de aguas en el Pacífico Sudoriental. Expedición Krill. Crucero 3-4. julio-agosto 1974. Rev. Com. Perm. Pacífico Sur, *3*:63-75.

Smith R.L. 1968. Upwelling. In: H. Barnes (Ed.). Oceanogr. Mar. Biol. Ann. Rev., 6:11-47.

Sokal R.R. & F.J. Rolf 1981. Biometry. 2nd. Ed., W.H. Freeman and Company. San Francisco. 859 pp.

Strickland J. & T. Parsons. 1968. A practical handbook of sea-water analysis. Bull. Fish. Res. Bd. of Canada, *167*:1-311.

Universidad de Concepción. 1979. Anuario Meteorológico. Depto. de Física, Sección Meteorológica, 53 pp.