

IFOP-IMARPE-ONUDI

PROYECTO REGIONAL
Componente: Chile

**MANEJO INTEGRADO DEL GRAN ECOSISTEMA
MARINO DE LA CORRIENTE DE HUMBOLDT**

MODULO 1

PRODUCCIÓN Y VARIABILIDAD AMBIENTAL

Síntesis de información base para el proyecto



INTEGRATED OVERVIEW OF THE OCEANOGRAPHY AND ENVIRONMENTAL VARIABILITY OF THE HUMBOLDT CURRENT SYSTEM. CHILE.

This overview is a summary of the oceanographic knowledge of the Humboldt Current Large Marine Ecosystem. It draws mainly on published scientific literature that on the last decade has shown a healthy increase due to the implementation of some key oceanographic and fisheries related research programs with the aim that together with a similar work done in Peru be the source to identify the issues, factors and threats of the Humboldt Current Large Marine Ecosystem (HCLME).

In writing this overview participated following researchers:

Jose Luis Blanco	CCPO, Old Dominion University, USA.
Giovanni Daneri	Universidad del Mar, Chile
Rubén Escribano	COPAS, Universidad de Concepción, Chile
Leonardo Guzmán	Instituto de Fomento Pesquero, Chile
Carmen Morales	COPAS, Universidad de Concepción, Chile
Jorge Osses	Instituto de Fomento Pesquero, Chile
Gemita Pizarro	Instituto de Fomento Pesquero, Chile
Renato Quiñones	Universidad de Concepción, Chile
Sergio A. Rosales	Instituto de Fomento Pesquero, Chile
Rodolfo Serra	Instituto de Fomento Pesquero, Chile

• July 2012 •



1. INTRODUCTION

The Humboldt Current Large Marine Ecosystem (HCLME) is one of the four major Eastern Boundaries of the world ocean being in many respects similar to the Benguela current running of the coast of west Africa, the California current off the west coast of USA and the Canary current off north-west Africa. The HCLME is born at the bifurcation of the West Wind Drift Current ($\sim 42^\circ$ S) which generates the Cape Horn Current to the south and Humboldt Current to the north and extends along the coast of Southwest of South America to the north of Peru ($\sim 5^\circ$ S). The bifurcation of the West Wind drift oscillates seasonally and from year to year between the Island of Chiloé (43° S) and the Gulf of Penas (47° S) (Figure 1).

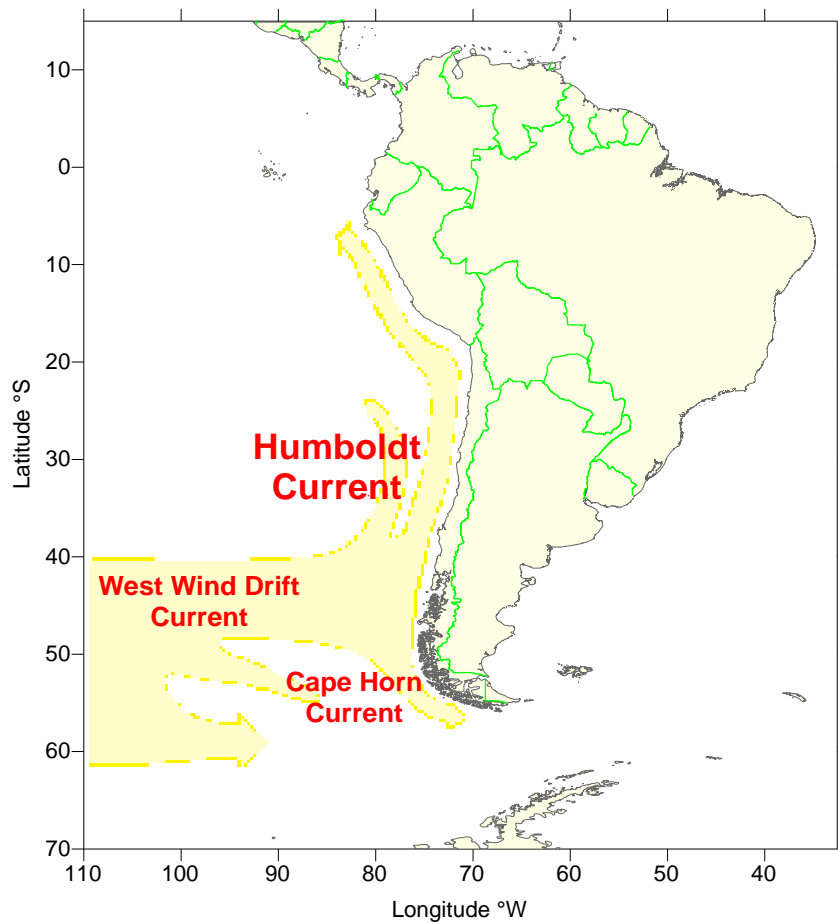


Figure 1. The Humboldt Current Large Marine Ecosystem (HCLME).



The Humboldt current system (HCS) is a highly productive large marine ecosystem supporting one of the largest fisheries of the world oceans. About 20% of the world catch is produced in this ecosystem. This high productivity is associated to the occurrence of coastal upwelling that brings nutrient rich subsurface waters to the surface. Upwelling promotes high phytoplankton and food chain associated yield (Daneri *et al.*, 2000).

The high biomass and species richness of the HCLME support important benthic, demersal and pelagic fisheries. As a result of this, a significant part of the population and economy of Chile and Peru depends directly or indirectly on the HCLME. In the last three decades however environmental changes coupled to an increase fishing pressure has resulted in dramatic fluctuations and loss of stock of marine natural resources in the HCLME.

The HCLME is not only under threat from overfishing but also from other human activity along the coastal fringe that generates pollution and habitat degradation problems. Petroleum spills, emission of organic and inorganic residuals of domestic and industrial processes, habitat degradation through aquaculture activities and the physical alteration of the coastal border by developers are increasingly threatening fragile coastal habitats that can be important nursery areas of both benthic and pelagic marine species.

Based on an ecosystemic approach, that considers different time and space scales of environmental changes this work will generate a transboundary overview and diagnosis of the main environmental and human dimension issues leading to the implementation of a Strategic Action Plan for an integrated and sustainable management of the Humboldt Current Large Marine Ecosystem (HCLME).

1.1 Objective

This overview is a summary of the oceanographic knowledge of the Humboldt Current Large Marine Ecosystem. It draws mainly on published scientific literature that on the last decade has shown a healthy increase due to the implementation of some key oceanographic and fisheries related research programs. The overview commences with a brief discussion of the main historical events and programs that has had a measurable impact on the state of art of the knowledge. Then it continues with a discussion of the main physical features and processes in the HCLME –the bathymetry, wind field, temperature, salinity, water masses, upwelling and circulation. Key aspects of the chemistry and chemical processes follow including a discussion of nutrient dynamics and the importance of dissolved oxygen. The next section deals with plankton, bacterioplankton, phytoplankton and zooplankton as well as a section on red tides and harmful algal blooms and a section on the biogeographic partitioning of the HCLME. Finally we have provided a perspective on the various issues, problems and threats facing the Humboldt and have identified the major gaps in knowledge and understanding.

1.2 A Brief history on the development of oceanographic and environmental knowledge in the HCLME.

From the perspective of oceanography, the last ten years have been the most productive in relation to knowledge development and publications. Two major events marked the beginning of a significant increment in the quality and frequency of the information acquired. One was the acquisition of the research vessels Abate Molina and Vidal Gormaz, and on the other hand, the substantial increment in the funds allocated to marine science (FONDEF, FONDAP, and FIP). Among the more important oceanographic initiatives are: JGOFS-SAREC project, the Sectorial Biomass (FONDECYT-CÓNICYT), CIMAR PROGRAM, the FONDAP-HUMBOLDT PROGRAM and the FONDAP-COPAS PROGRAM. From the standpoint of fisheries oceanography it is important to mention the grants supported by FIP (Fisheries Research Fund) in the period from 1991 to the present.



2. PHYSICAL FEATURES AND PROCESSES

2.1 Geographical Aspects

The Chilean coast extends from about 18°20'40" to 57° 30' latitude south, along the western coast of South America. This region of the Pacific is under the influence of a subantarctic system current, known as the Humboldt Current. The West Wind Drift current (WWDC), located on the subantarctic zone at 42° South, reaches the continent creating: a) an equatorward surface coastal current (the Humboldt or Peru-Chile current) and an ocean current, both flowing separated by an Equatorial Countercurrent; and b) a poleward flow known as the Cape Horn current. The WWDC carries the Subantarctic water mass (SAAW).

The southern boundary of the HCLME is set at the bifurcation of the Wind West Drift current between the Chiloé Island (42 °S) and the Gulf of Penas (46 °S). The northern limit of HCLME is set at the boundary with the Equatorial Current, while the west boundary of the HCLME extends far beyond of the 200 nautical miles Exclusive Economic Zone off Chile and Peru. In oceanographic terms, it is difficult to set the western limit of the HCLME, particularly on the extremes where the current is born and in the northern segment where it turns to the open ocean. The setting of the external limit of the HCLME, from an operational perspective, will necessarily have a certain degree of arbitrariness. Accordingly, we proposed that this limit should be set later on in the development of the proposal.

The Chilean coastline located approximately from 18°20' S to 41° 30' S, is an extended and straight, west-faced shoreline, with few embayments along the coast. The continental shelf is narrow in the northern zone and has a depth of 100 to 150 m. The shelf off Valparaiso is an exception, where a hang-shelf appears eight nautical miles wide and 800 m in depth. The widest part of the shelf in this coast is found off Talcahuano, being 25 nautical miles wide and 150 m deep, and flanked by two submarine canyons: the Itata canyon and the Bio-Bio canyon; both originated from active rivers during the Quaternary period. In the southern area as far as Puerto Montt (42° S), the continental shelf is incipient and narrower than off Talcahuano.

In regard with the bathymetry the HCLME is located in the area of subduction of the Nazca plate under the South American plate. This tectonically active and highly seismic zone boundary is associated to the presence of a deep trench and a narrow shelf, which in the case of Chile it is only wider than 10 nm off the Concepción area (Figure 2). Along the coast, the continental shelf is crossed in several places by submarine canyons such as the Loa, Aconcagua and Bio-Bio rivers. These canyons are important to the downward transfer of organic matter and for the generation of turbulence that result in upwelling of nutrients rich subsurface waters during events of strong northerly winds (Figueroa & Moffat 2000).

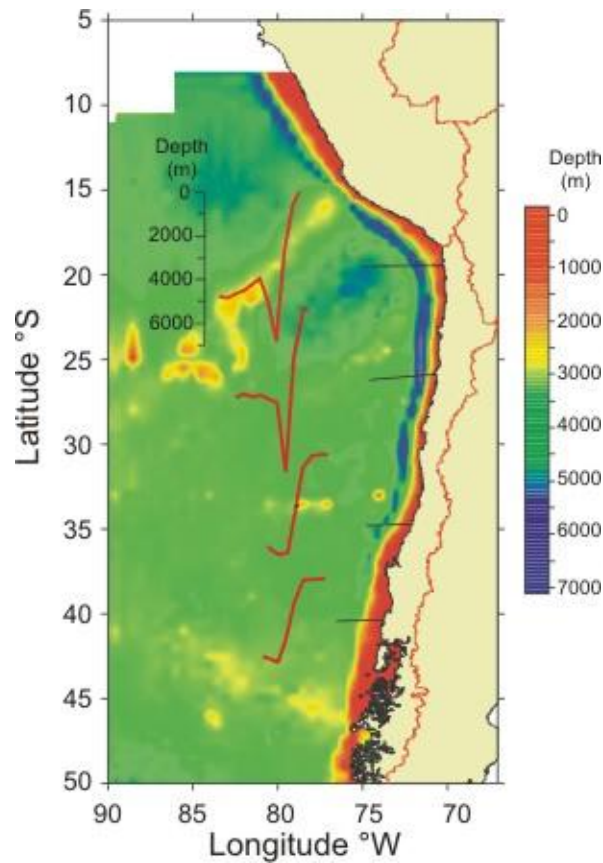


Figure 2. Bathymetry of Humboldt Current Ecosystem, show profile of depth longitudinal from north to south.

2.2 Meteorological Conditions

The marine climate off the west coast of South America arise from the interaction of basin scale atmospheric systems, combined with regional and local effects introduced by the land sea boundary and the orography (Strub *et al.*, 1996). For the HCLME area the most influential large-scale system is the southeastern Pacific subtropical anticyclone, which drives equatorward winds along the coast more or less permanently throughout the year. Associated with the anticyclone there is a subsidence inversion at the top of the marine boundary layer that comes closer to the surface near the coast, creating onshore-offshore gradients in wind stress and cloudiness. The inversion and the inland mountain ranges parallel to the coast support the poleward propagation of trapped atmospheric disturbances (e.g. coastal lows) that modulate the upwelling-favorable winds, generating variability on a scale of few days (Rutllant 1993, 1997; Lefevre *et al.* 2002). Due to the influence of regional and local wind forcing factors, maximum wind speeds along the coast are found in the austral spring-summer, while offshore winds (southeastern trades) peak during the austral winter (Strub *et al.*, 1996).



The northern zone of Chile presents an extremely arid conditions with a predominance of South and Southwest wind throughout during the year, but peaking with more intensity during the in southern spring and summer (Thomas *et al* 1994, Pizarro *et al* 1994). The southern zone of Chile present a more pronounced seasonality, with a great quantity of precipitation during winter, and favorable upwelling winds to upwelling occurring mostly occurring during the spring and summer seasons.

The average monthly climatology in the North of Chile derived from data obtained from meteorological stations at Arica, Iquique and Antofagasta indicates that, the alongshore wind component are maximum during the spring and summer (December to march), with average magnitude between 4.2 and 6.32 m/s, and minimum in winter (June and July) and magnitude between 2.6 an 4.0 m/s (Figure 3). Offshore the wind is less intense and its seasonal variation is smaller. The coastal component is in the equatorial direction and is favorable to upwelling processes. (Blanco *et al*, 2001).

South of Valparaiso bay (33°S) the seasonality of the alongshore wind component is similar to the northern zone however the wind stress is less intense. In the case of the offshore wind component both the south and the northern areas show similar degrees of wind intensity (Figure 3).

The wind contribution to upwelling and turbulence (figure 4), is more important in the north (Arica, Iquique and Antofagasta) compared the center of Chile (Valparaiso), where the wind stress contributes more significantly to water column turbulence. The wind contribution to turbulence is more important during the winter. In the area off Talcahuano, the wind is favorable to upwelling from December to January, when the wind contribution to turbulence decreases.

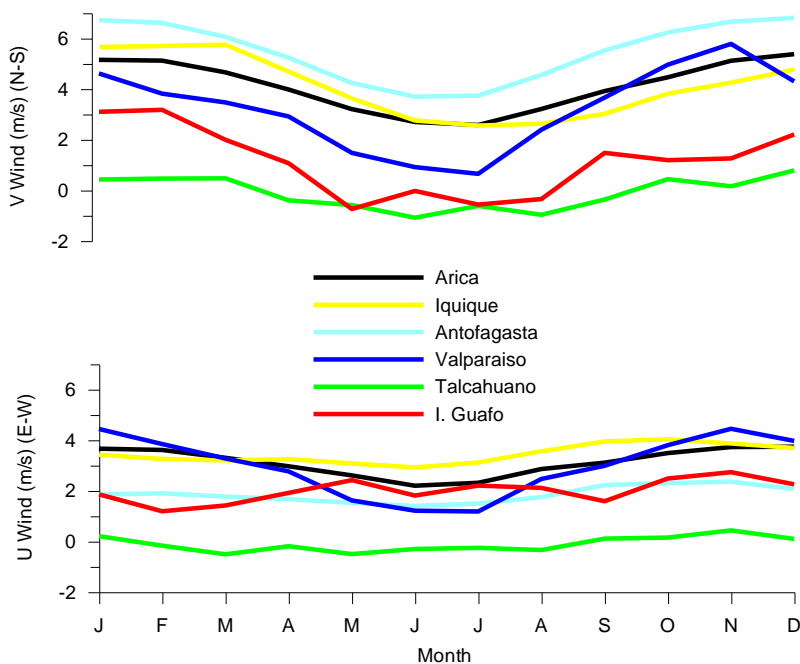


Figure 3. Average monthly of V and U wind component at the coast.

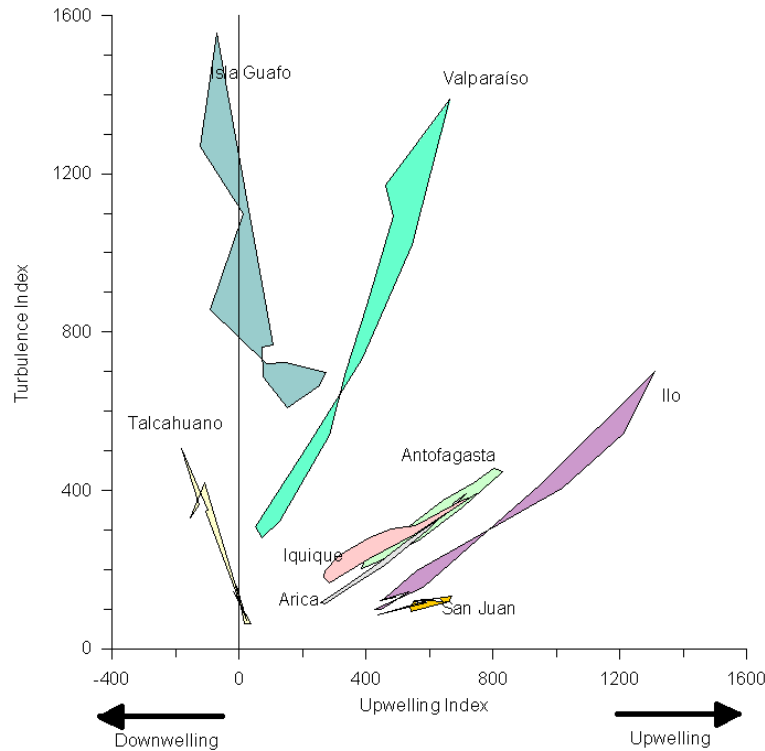


Figure 4. Wind contribution to upwelling and turbulence in different places along the coast (modified from Parrish *et al.*, 1983).

2.3 Water Masses

The oceanography of the HCS off northern Chile (18.5-30°S); between the coast and 200 nm offshore, is characterized by the presence of five water masses. Between the surface and approximately 75 m depth the Subtropical Water (STW) mass has a well-defined superficial nucleus, particularly north of 23°S. The STW is characterized by temperatures of 16-24°C and salinity of 34.9-35.3 (Silva and Konow, 1975; Robles, 1976). South of 30°S the Superficial Subantarctic Water (SSAW) is found between the surface and 120 m. The SSAW is defined by temperatures of 9-15°C and salinity of 33.0-34.3 (Silva and Konow, 1975; Robles, 1976). The area between 23°S and 30°S is a transition zone where the SSAW is located below the STW, forming an upper minimum of salinity (Gunther, 1936; Wyrki, 1963; Reid, 1965, 1973a, 1973b; Brandhorst, 1971). In the subsurface between 150 and 350 m, approximately, the Subsurface Equatorial Water (SSEW) is characterized by a salinity maximum (34.4-34.9) and a dissolved oxygen minimum (0.2 and 3 ml l⁻¹) (Reid, 1965; Silva and Konow, 1975). In the intermediate layer between, 400 and 1000 m depth the Intermediate Antarctic Water (IAW) mass is characterized by temperatures of 4-6.5°C and salinity of 34.2-34.5, (Reid, 1965; Silva and Konow 1975). The Intermediate Antarctic Water Mass (IAAW) with an equatorward flow is characterized by low temperature and low and constant salinity. This water mass appears between 500 m to 1500 m in depth and moves equatorward.



The Pacific Deep Water Mass (PDW) is characterized by low temperature and saline waters with a poleward flow. These waters have an ascending movement to the south and reach the surface at the Antarctic divergence.

Additional variability is found in the Chile Coastal Current, where fresh water ($32.7 < S < 34.2$) from fjord region around $42-45^{\circ}\text{S}$ is advected northward at the surface in summer and saltier Poleward Undercurrent Water is mixed into the surface water next to the coast during coastal upwelling. In the Table 1 are the definition of water masses from Silva y Konow (1975), Bernal *et al.* (1982) and the used in the study of Blanco *et al.* (2001).

Table 1. Definition of water mass in the Humboldt Current System. In the first line by Silva y Konow (1975), second line by Bernal *et al.* (1982), and in third line the values use by Blanco *et al.* to characterize each water mass in the northern of Chile. Modify from Blanco *et al.* (2001).

Water Mass	Depth Range (m)	Temperature ($^{\circ}\text{C}$)	Salinity psu	Oxygen (ml/l)
STW	"surface"	20.0	35.2	
	0-40	>18.5	34.9	>5
		17.0-25.0	34.9-35.7	>5
SAW	25-40	11.5	33.8	2.5-4.5
	40-80	11.5-14.5	34.1-34.8	
		11.0-14.0	34.3-34.8	3.0-6.0
ESSW	300-350	12.5	34.9	0.25-0.5
	100-300	9.5-10.5	34.6-34.8	
		11-13	34.7-34.9	0.25-1.0
AIW	>500 (710-750)	3.0	34.0	1.5-1.9
	>500 (710-750)	5.5	34.2-34.6	
	>500 (710-750)	6-8	>34.5	1.5-2.5
DPW		1.75	34.68	

The Subtropical Water Mass (STW), characterized by superficial, oceanic, warm and saline waters seasonally moves to the northern coast of Chile and southern Peru. During "El Niño" event, the STW reaches the coast as superficial water mass between 0 to 50 m deep. Changes in the physical and chemical features of the seawater induce deep changes on intertidal and subtidal coastal species. Temperature increases $+3$ or $+4^{\circ}\text{C}$ at the coast in a layer 30 to 50 m deep. The coastal upwelling process is depressed or ceases, and often exotic species are advected to or reach the coast, while nutrients are depleted and fish migrate from the coast or experience mass mortality.

The SubAntarctic Water Mass (SAAW) has a higher density than the South-tropical Water Mass (STW), and when these two water masses converge to the coast, the STW takes place on the surface. The flow of the SAAW is equatorward and has two branches: the oceanic and coastal current, jointly referred to as the Humboldt Current System. Usually, this water masses moves between 0 to 300 m deep along the coast, with some temperature and salinity changes due to the exchange of heat and water vapor with the atmosphere. The Equatorial Subsurface Water mass (ESSW) is a poleward flow characterized by low temperature and medium level salinity. The relevant feature of this water is its low content of dissolved oxygen (less than 1 ml/l). The oxygen is depleted by remineralization of organic matter produced as



detritus that "rains" from the euphotic zone. Respiration processes consume the dissolved oxygen and produce new nutrients or oxidative nutrients, distributing them along the coast during an upwelling event. This water mass is responsible for the elevated primary production on coastal waters.

On the coastal zone, the SAAW water dominates throughout the year. From 22° S and during the summer, the STW spreads causing the thinning of the SAAW as a coastal current. During "El Niño" events the STW may reach the coastline, producing several ecological changes as discussed in a next section.

2.4 Temperature and Salinity

Blanco *et al* (2001) for the northern Chile describe the seasonal patterns of surface temperature, salinity and the depth of 15°C isotherm. Their study showed that surface temperature and salinity have strong annual cycles with maximum offshore values in the summer (>24°C and 35.3 psu) and minimum values during winter (16-17°C and 34.8-35.0 psu) (Figure 5). Within 100 km of the coast, isopleths are generally parallel to the shore even during winter because of upwelling of cooler, less saline subsurface water. This upwelling moderates the annual cycle of both temperature and salinity near shore. Within 100 km of the coast, summer minimum temperatures and salinity are 19-30°C and 34.8-34.9 psu, respectively, and winter values are 16-17°C and salinity 34.8-34.9 psu. The cross-shelf gradients of both temperature and salinity are maximum during the summer and decrease from north to south. Offshore of the coastal upwelling influence area (west of ~72°W) the temperature and salinity isopleths run perpendicular to the coast as a response to the latitudinal gradients in solar heating. The 15°C isotherm get deeper offshore and slopes upward toward the coast in all seasons, reflecting the year-round upwelling.

The vertical structure of temperature (Figure 6) shows that vertical stratification is maximum in summer, and weakest in winter. Near -surface isotherms (>14°C) tilt upward towards the coast throughout the year, in response to the continuous upwelling-favorable winds. Below 150 m, isotherms deepen as they approach the coast indicating the poleward geostrophic flow associated with the undercurrent.

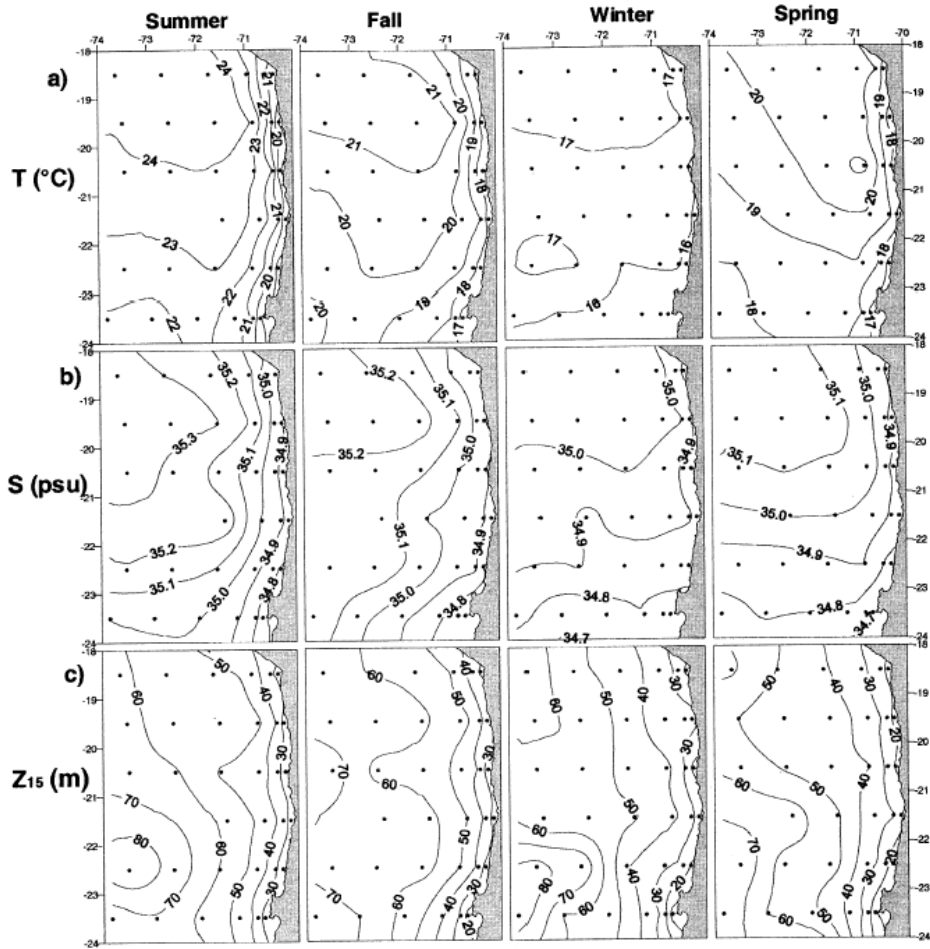


Figure 5. Seasonal climatologies of (a) sea surface temperature (SST), (b) surface salinity (S), and (c) 15°C isotherm depth (Z_{15}), from Blanco *et al* (2001).

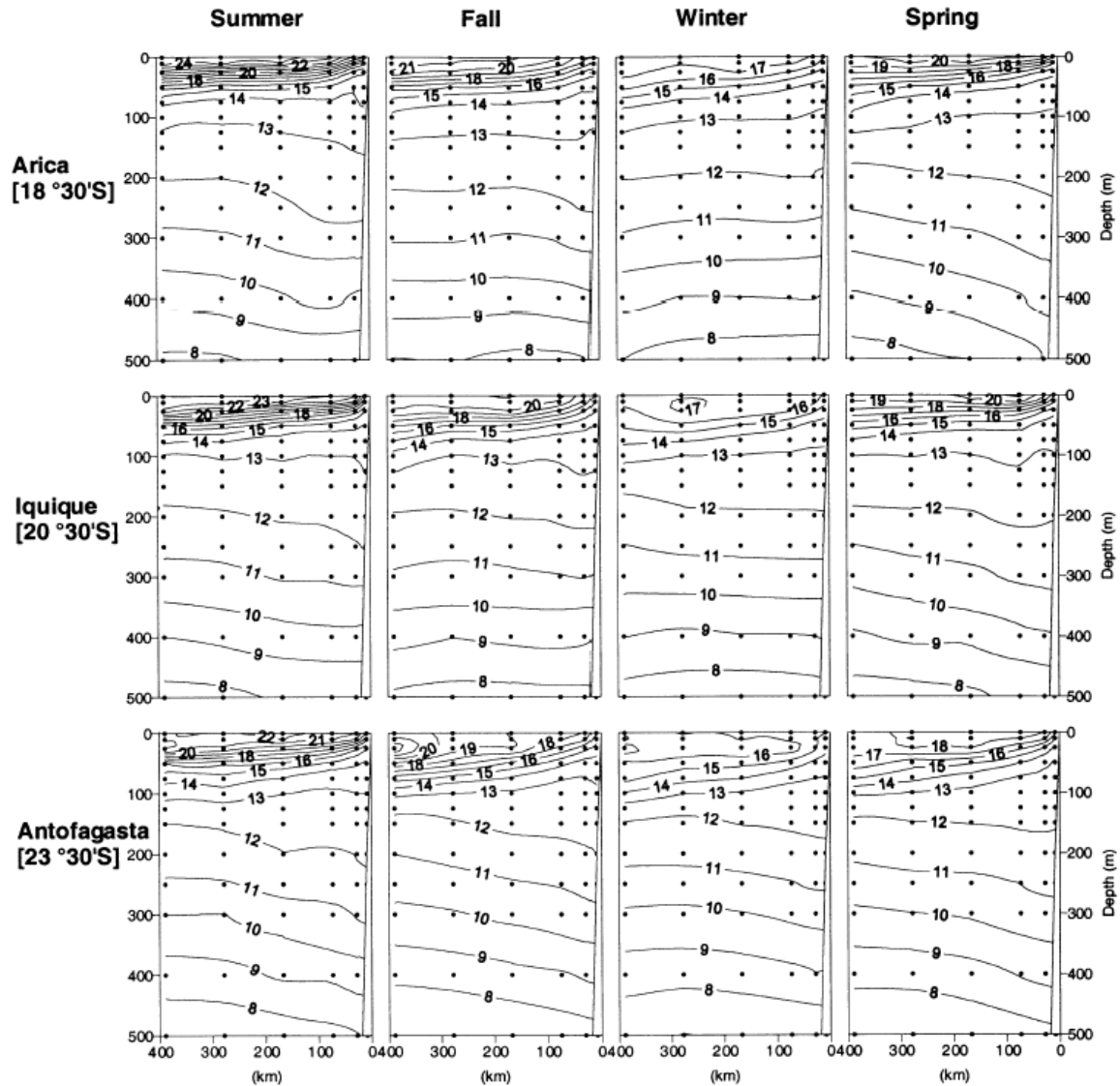


Figure 6. Seasonal climatologies of cross-shelf vertical temperature structure ($^{\circ}\text{C}$) at Arica, Iquique and Antofagasta.

The vertical salinity structure (first 800 m) is determined by the distribution of four principal water masses in northern Chile (AIW, ESSW, SAW, and STW). The freshest water mass is influenced by AIW, which is defined by a salinity minimum at a mean depth of 700 m. Between 100 and 300 m adjacent to the coast a salinity maximum is associated to the ESSW. A relative salinity minimum located above and offshore of ESSW is modified by SAW. Highest salinities are found offshore in STW. This higher salinity water (>35.1 psu), is



present in the surface water offshore in summer and fall and seen as a wedge of warm, salinity water at the surface, extending southward and toward the coast, with minimum presence in winter. Salinities in the upper 50 m indicate that upwelling brings water with lower salinity to the surface near the coast throughout the year, but is weaker in winter. Upwelled water is either ESSW or SAW or a combination of the two.

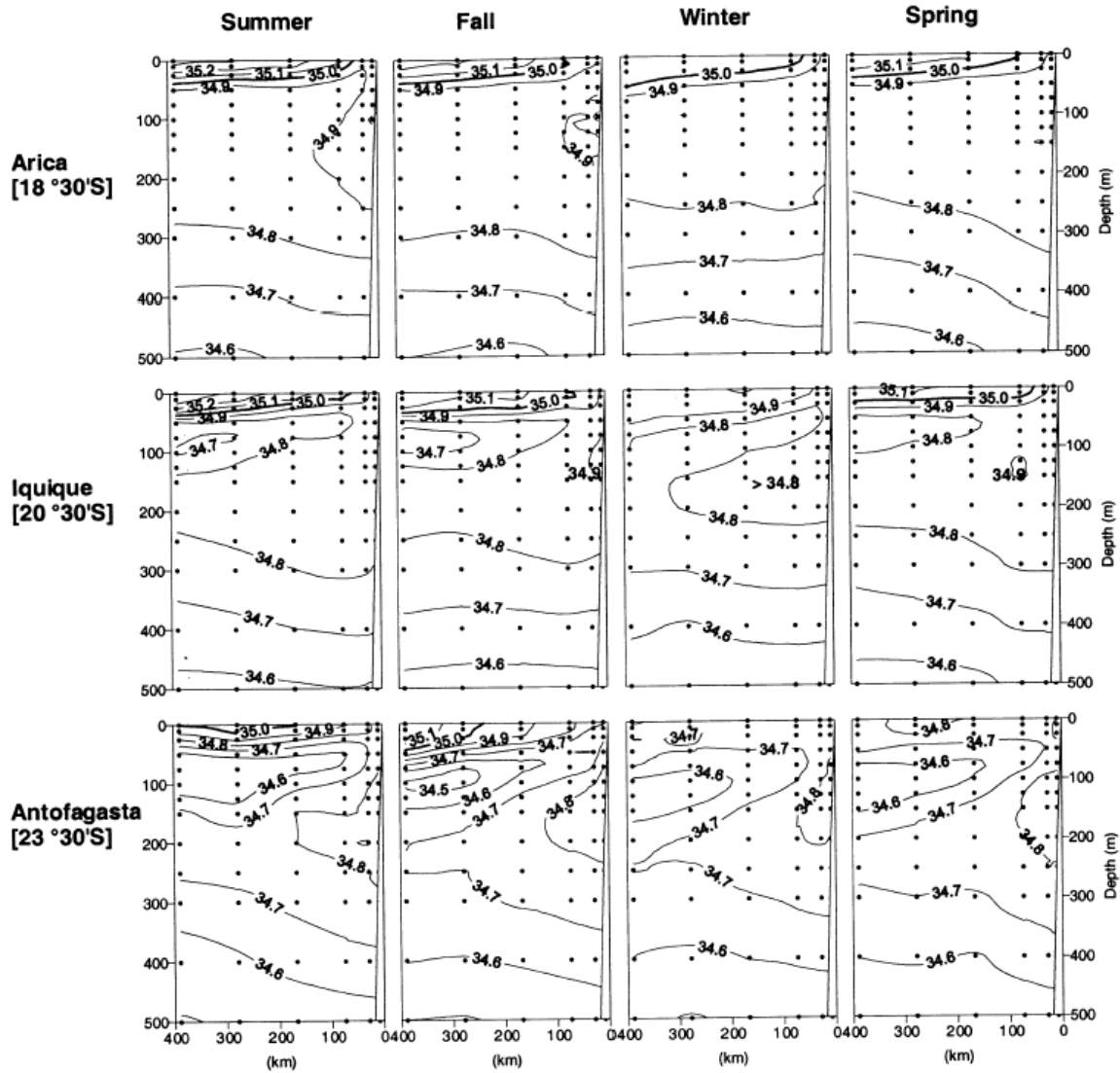


Figure 7. Seasonal climatologies of cross-shelf vertical salinity structure at Arica, Iquique and Antofagasta.



2.5 Circulation

The HCS present a net transport of 11.04 Sv to the north; calculated from the Caldera to Easter Island transect (Fuenzalida *et al* 2002). The geostrophic circulation relative to 2500 db presents the greatest velocity between surface and 1000 m, with alternated flux in north and south directions, typical of the dynamics of South Pacific Ocean. Below 1000 m the flux is slower and predominant to the pole. The general circulation pattern derived from geostrophic measurements is consistent with direct current measurements obtained by Shaffer *et al.* (1995) through the deployment of through the deployment of deep current-meters in the offshore area of Coquimbo.

The poleward flow of the Undercurrent Peru-Chile (220 m) has an average velocity of 12.8 cm/s. The Antarctic Intermediate Water (750 m) flows in direction to the equator with a velocity of 1.1 m/s. The flow directed to the Pole near the bottom is stronger in Spring and decreases and weakens in the Winter. Near the bottom (750 m), the seasonal variability is less intense. However, in the water column the interannual variability along the Chilean coast is strong (Shaffer *et al* 1999).

2.6 Upwelling

The favorable wind for upwelling causes that the Equatorial Subsurface Water (ESSW) is upwelled to the photic zone from depths even deeper than 200 m near the coast (Strub *et al* 1998, Blanco *et al* 2001). The ESSW contains large concentrations of nutrients which has the potential to promote high productivity in coastal waters (Marín *et al.*, 1993; Escribano and Hidalgo, 2000).

The intensity of the upwelling along the coast is not only because of the wind stress, but also due to topographic effects. In general the local topography and/or the geometry of the coast have an important effect over the current along the coast, which can induce or change the upwelling (Figueroa and Moffat 2000, Atkinson *et al* 2002).

In northern Chile, one of the main center of upwelling is localized offshore Antofagasta (23°S) (Blanco *et al* 2001, Escribano and Hidalgo 1998, Sobarzo and Figueroa 2001, Morales *et al.* 2001). Additionally to physical oceanographic studies in this area some studies on primary productivity (Morales *et al.* 1996, Morales *et al.* 2001, Thomas *et al.* 2000, Marín *et al.*, 1993) and secondary productivity of zooplankton are also available (Escribano and McLaren 1999, Morales *et al.* 1997); the same as studies done in anomalous periods of El Niño and La Niña (Ulloa *et al.* 2001; González *et al.* 2000; Escribano and Hidalgo, 2001, Blanco *et al.* 2002). Morales *et al.* (1997), Escribano and Hidalgo (2000) and Marín *et al.* (2001) mention a favorable area for larval retention in the circulation pattern. No studies on circulation have been done, but some based in geostrophy type of analysis were done in the passed decade (Silva and Sievers 1991, only to mention one). The dominant circulation near the coast is controlled by baroclinic and barotropic factors, whose combined effects have not been analyzed yet.

The south-center zone of Chile is dominated by coastal upwelling induced by wind and has a strong seasonal pattern. The zone also receive contribution of freshwater by rivers and onshore intrusion of eddies. The contribution of freshwater produces a strong stratification in summer. In some places the wind is not able to destroy the stratification during the upwelling process and the upwelled water do not reach the surface (Atkinson *et al.* 2002, Davila *et al.* 2002).



2.7 Coastal Trapped Waves (CTW)

The first measurement of free coastal trapped waves in the eastern limit of the HCS was made by Shaffer *et al.* (1995, 1997). During the El Niño event 1991-1992 (moderate event) free CTW with periods of ~ 50 days were recorded. Several flow inversions with Pole direction occurred above the continental shelf. This flow reached a velocity of about 12 cm/s. These waves, originated as Kelvin equatorial waves, were forced by a series of pulses of the west wind in the Equatorial Pacific, and are apparently an expression of the Madden-Julian oscillation in the atmosphere during the beginning of El Niño (Shaffer *et al.* 1999, Pizarro *et al.* 2001). Similar changes in the flow direction are reported by Blanco *et al.* (2002) for El Niño 1997-1998, observe through geostrophy. The presence of CWT are too observed by Hormazabal *et al.* (2001) offshore of Valparaiso (33°S), who find which the sea superficial temperature are significantly relation with adjusted sea level, consequently, with the CWT.

In general the intra-seasonal variability associated with the CWT is weaker during the winter but stronger during El Niño and weaker during La Niña event (Shaffer *et al.* 1999). To south of 20°S a portion of intra-seasonally variation is forced by local wind associated with atmospheric teleconnection (Hormazabal *et al.* 2002).

This oscillation of low frequency have the capacity of change the mean deep of the coastal thermocline/nutricline, and modulate the effectiveness of nutrients pumping in the euphotic zone during the local upwelling events, whit the consequent change in productivity in the coastal zone (Morales *et al.* 2001, Rutllant and Montecino 2002).

2.8 Eddies de mesoscale

The mesoscale eddies are responsible of energy transport from and to the coast, and the larval retentions or dispersion. Offshore the coastal of Chile this eddies have been mentioned by various authors (Silva and Sievers 1981, Barbiery *et al.* 1987, Fonseca and Farias, 1987 between others), who observed eddies using data from oceanographic cruise or data of sea surface temperature from satellite, for example, in Talcahuano zone the work of Caceres (1992) and in Antofagasta zone the work of Sobarzo and Figueroa (2001). Using altimetry data Blanco *et al.* (1998) and Pizarro *et al.* (2000) observed and described some mesoscale eddies in the zone between Peru and north of Chile. Continue this idea, Narváez (2000) analyze to the northern off Chile the information of lot oceanographic cruise and images of the sea level from satellite, in this work he describe the principal characteristic and recurrence. The horizontal scale of this eddies is approximated of 150 Km, and in the vertical over 600 m of depth. The displacements of them is in direction south or west depend of period of year, reach velocity of the order of 3 and Km by day as maximum in the period of winter.



3. CHEMISTRY AND RELATED PROCESSES

3.1 Dissolved Oxygen

As shows in the Figure 8, the vertical structure oxygen concentration in the zone north of Chile are characterize by strong gradient in the first 100 m of deep during the year, from concentration >5 ml/l to 1 ml/l. Below the depth of 1ml/l the concentration decrease to valor <0.25 ml/l. The oxygenated thickness layer in surface is more deep offshore and decreases the think to coast, by the action of continuous upwelling in the zone. The layer with concentration minor of 0.5 ml/l are know as oxygen minimum layer, and dominate the water column from 100 to 450 m, and is associated with ESSW.

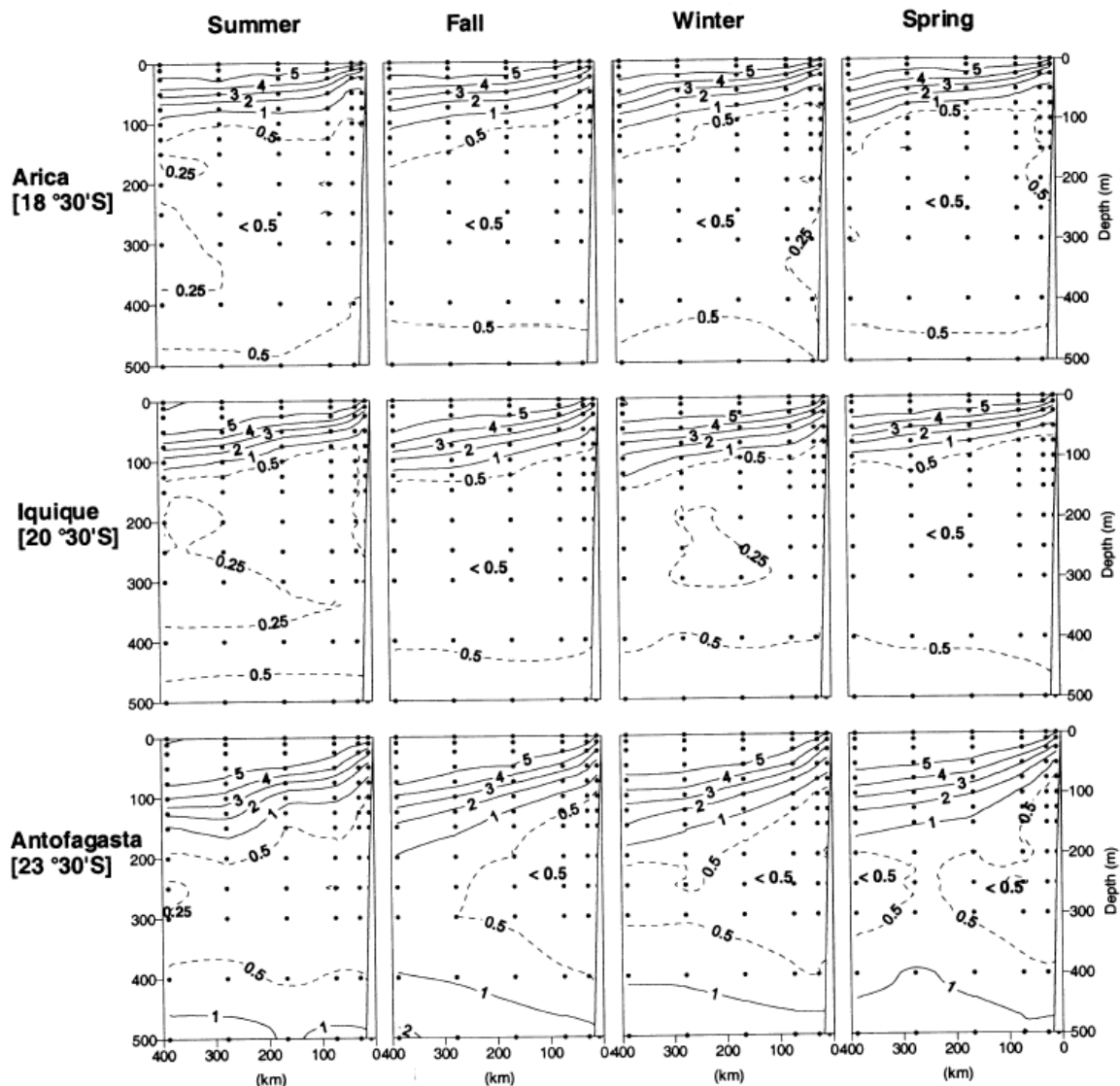


Figure 8. Seasonal climatologies of cross-shelf vertical oxygen structure (ml/l) at Arica, Iquique and Antofagasta.



The upper limit of oxygen minimum layer coincide with the oxycline, this present a great vertical variability intra and interannual associated with dynamic process in the system. According to time serial data obtain in the northern of Chile (1980-1997; JGOFS and FONDAP-Humboldt projects), the oxycline is located in 50 m of depth in the coast, and at oceanic waters in 100 m. However, this limit has been detected in shallower waters at 10 m during strong ENSO, as the event 1997-1998.

The upper limit of oxygen minimum layer coincide with the oxycline, this present a great vertical variability intra and inter-annual associated with dynamic process in the system. According to time serial data obtain in the northern of Chile (1980-1997; JGOFS and FONDAP-Humboldt projects), the oxycline is located in 50 m of depth in the coast, and at oceanic waters in 100 m. However, this limit has been detected in shallower waters at 10 m during strong ENSO, as the event 1997-1998. This characteristic impact over the structure and dynamics of the pelagic and benthonic communities, as well in the biogeochemistry cycles a regional level. The Figure 9 is the presentation of the effect of El Niño over oxygen minimum layer and their influence in the system, in normal conditions the water mass ESSW upward to surface in the coast transport to surface layer nutrients and favored of gases interchange between atmosphere and ocean.

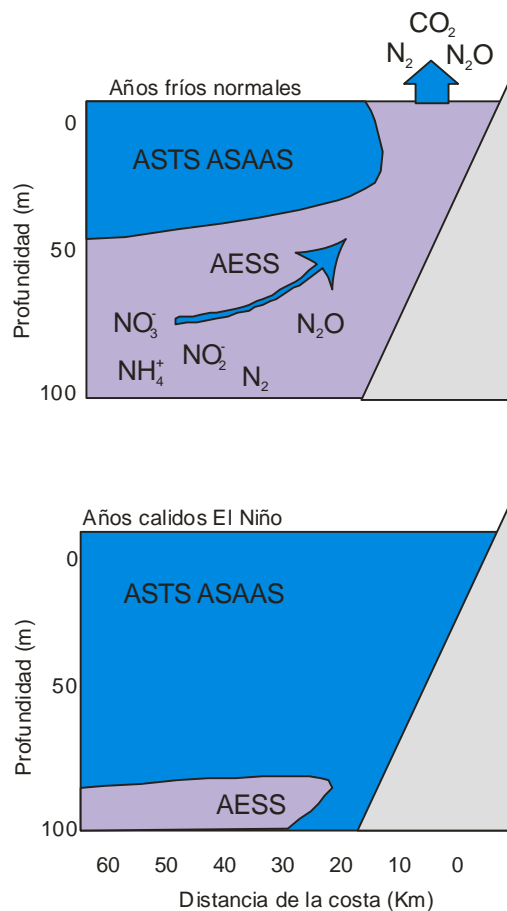


Figure 9. Transversal representation of the vertical displacement of oxygen minimum layer in northern zone of Chile, as consequence of El Niño and their influence in the nutrient contribution to surface layers and gaseous interchange ocean-atmosphere ASAAS: Subantarctic Superficial Water; ASTS: Subtropical Superficial Water; AESS: Equatorial Subsuperficial Water. (Modify from Gallardo *et al.* 2001).



4. PLANKTON

4.1 Bacterioplankton

The high fish production in upwelling systems has been primarily associated with recurrent upwelling pulses and to the predominance of short, thermodynamically efficient food chains (Ryther 1969, Ryther *et al.*, 1971). This early view, based on a simplified structure and functioning of food chain in upwelling systems, is now under revision. Central to this has been a re-evaluation of the importance of bacteria in a variety of marine environments (McManus & Peterson 1988). Bacterioplankton constitutes an important fraction of the total carbon biomass in pelagic ecosystems. In oligotrophic waters bacterial biomass can be 2-3 times more abundant than phytoplankton (Cho & Azam, 1990) and in meso and eutrophic environments 0.5 to 2 times greater (Azam *et al.*, 1983). Bacteria are an important pelagic mineralizer of organic matter. It has been reported that depending on environmental conditions, bacterial secondary production (BSP), as a percentage of primary production (PP), can fluctuate between 2 to 1101% (Andrews & Williams 1971, Sieburth *et al.* 1977, Hagstrom *et al.* 1979, Fuhrman & Azam 1982, and see references in Table 1). This may represent an underestimation as most of the estimates of BSP/PP % do not take into consideration that bacterial activity continues at night (Mc Manus & Peterson 1988).

Watson (1978) estimated ocean global production to be 25-75 gC m⁻² y⁻¹ for open ocean areas, 100 gC m⁻² y⁻¹ for coastal areas and up to 300 gC m⁻² y⁻¹ for upwelling ecosystems. Higher values of 1 kg C m⁻² yr⁻¹ and 0.93 kg C m⁻² yr⁻¹ have been estimated for the Peruvian upwelling (Walsh 1981) and for the southern Chilean upwelling (Daneri *et al.*, 2000), respectively. While the PP in oligotrophic areas depends mostly on regenerated (NH₃-based) nitrogen in upwelling, or highly productive coastal areas, PP is mainly supported by the injection of NO₃ into the photic layer. New production in highly productive ecosystems is typically of the order of 50-70% of the total production, indicating the dependence of primary production on nutrients advected from subsurface waters. Although in these productive areas dependence of PP on epipelagically produced nutrients is not as critical as in oligotrophic areas, absolute rates of nutrient regeneration by the heterotrophic community are not insignificant (Carmen Morales pers. comm.). It is now accepted that a high proportion of the organic carbon produced by the phytoplankton may flow through the bacteria in a variety of marine environments including upwelling areas. A significant amount of carbon flowing through the bacterioplankton may imply that the carrying capacity for fish in upwelling ecosystems is considerably less than that which may be anticipated for a simple herbivore-dominated food chain (Newell & Turley, 1987).

Bacterial production and abundance in coastal upwelling ecosystems is similar to that reported for other coastal environments and seems to be closely coupled to upwelling cycles (Field *et al.* 1980, Zimmermann *et al.* 1980, Gocke *et al.* 1983, Rheinheimer & Schmaljohann 1983, Hanson *et al.* 1986, McManus & Peterson 1988). In the Humboldt Current System BSP has been shown to increase a few days after the peak of PP (McManus & Peterson 1988). McManus & Peterson (1988) showed that PP was lowest during periods of active upwelling and highest during subsequent periods of calm or light northerly winds with BSP showing the greatest increase one or two days after the peak in phytoplankton production. A similar decoupling between PP and BSP has been reported by Painting *et al.* (1993) for the Benguela upwelling.



A more comprehensive understanding on the role that bacteria play in the HCLME can be found in Troncoso *et al.* in press. Troncoso *et al.* studied the relationship between bacterial production and abundance and phytoplankton biomass and production in three upwelling ecosystems in the Humboldt Currents System (HCS) off Chile (Antofagasta, 23°S, Coquimbo 30°S and Concepción 36°S). Based on estimated bacterial growth yields, the total carbon flux through the bacteria was assessed under a range of environmental conditions. Troncoso *et al.* data show that bacteria constitute one of the most fundamental component of the pelagic planktonic community in upwelling ecosystems in the Humboldt currents system (HCS) off Chile. With the exception of Bacterial Secondary Production (BSP) values measured in the Coquimbo upwelling system, the upper values of BSP reported for the HCS are greater than any reported in the literature for a variety of marine environments (Brown *et al.* 1991, Kirchman *et al.* 1995, Weibing *et al.* 1997, Lochte *et al.* 1997, Pomroy & Joint, 1999, Shiah *et al.* 2000). A value of ca 5 g C m⁻² d⁻¹ measured in Antofagasta is possibly the highest value of BSP ever reported in the literature. These findings are not unexpected as the Humboldt Currents System (HCS) constitutes one of the most productive large marine ecosystems and is consistent with the fact that the highest values of primary production (PP) have been reported in the area (Daneri *et al.* 2000).

Troncoso *et al.* in press also reported significant latitudinal, seasonal and coast to offshore differences in the levels of bacterial activity. Highest BSP values have been measured in the Antofagasta upwelling area while the lowest BSP values have been recorded in the Coquimbo upwelling area. The levels of BSP are higher during the spring and summer as a consequence of increased upwelling during this period which is associated to the seasonal strengthening of the Pacific Anticyclone. During the winter a weakening of the Pacific anticyclone coupled with a reduced light field results in a decrease in the productivity of the system which has been reflected in overall two to five fold drops in primary production and four to six fold drops in BSP (Troncoso *et al.* in press). In general BSP is two to five fold higher inshore than offshore in the HCLME (Troncoso *et al.* in press) although under more oligotrophic conditions, such as those encountered during the winter or in less productive areas such as the Coquimbo upwelling area, the coast to offshore gradient in BSP become less pronounced.

Interannual variations in bacterial productivity were also reported by Troncoso *et al.* During January 1997 the Antofagasta upwelling area suffered an anomalous decrease in winds favoring upwelling. These more quiescent upwelling conditions have been characterized as pre-El Niño conditions that resulted in an overall drop in both PP (Daneri *et al.* 2000) and bacterial secondary production (Troncoso *et al.* in press).

The fundamental role played by bacteria in the HCLME can be assessed from the very significant fraction of the organic matter produced by phytoplankton activity that is being channeled through the bacteria in the HCS off Chile. The proportion of carbon utilized by bacteria, taken as a percentage of PP, range from 16% to 96% (ca. 63%-96% in Antofagasta, 16%-34% in Coquimbo and 10%-24% in Concepción). Assuming a conservative bacterial growth yield of 0.25 (Daneri *et al.* 1994), the overall carbon utilization by bacteria often seems to be in or excess of the *in situ* PP. These results are in agreement with reported data for other upwelling systems (Brown *et al.* 1991, Ducklow 1993, Weibing *et al.* 1997) and for the Concepción shelf upwelling area (McManus & Peterson 1988) and confirm the view that bacteria are an important component of upwelling ecosystems capable of processing an important fraction of the organic carbon fixed by algal activity.



4.2 Phytoplankton

Rivera (1995) indicated in Chile are known 84 genera and 563 species of diatoms of marine phytoplankton, but only 14% of genera have a taxonomic review update. Of dinoflagellate are 42 genera and 295 species, with 26% of the genera with a taxonomic review update. In referent to the silicoflagellates indicate is known 2 genera with 5 species. In this value are included the phytoplankton from the Humboldt Current, Oceanic Islands, Horn Cape Current and fjords of Chile.

The phytoplankton in the coast in the northern of Chile are species typical from upwelling systems, diatoms bigger and dinoflagellate, find around of 200 species from 5 taxonomic groups. The diatoms are dominant in coast zone (< 10 nm) and in the oceanic zone the dinoflagellate (Avaria & Muñoz 1983). The diatoms more numerical dominant are: *Leptocylindrus*, *Rhizosolenia*, *Detonula*, *Nitzschia*, *Chaetoceros* and *Skeletonema*, while of dinoflagellate dominant are: *Ceratium*, *Prorocentrum* and *Gymnodinium*. In the Center of Chile the bigger diatoms are more abundant during the year.

4.3 Red tides and harmful algal blooms

In a global scale during the last three decades a notorious increase of Red Tides or Harmful Algal Blooms (HAB) has been reported in frequency, intensity and geographical wide spread. A HAB phenomenon is an increase of harmful algae, toxic for to human beings and marine biota. Direct effects of HAB at the human scale are intoxications, allergic reactions by inhalation of toxic compounds and at the ecosystem level an increase in massive mortalities of marine organisms in the natural environment, and alterations of the structure of marine habitat has been reported.

In the Chilean marine ecosystem during the 2000 and 2001 a sudden increase in HAB phenomena has been observed, but only in the inner sea of Chiloé Island. The increase was associated to *Alexandrium catenella* a dinoflagellate responsible for the production of a paralytic toxin and the other organisms is the diatom *Pseudonitzschia spp* producer of an amnesic toxin (Guzman *et al.* 2002, Suarez-Isla *et al.*, 2002). In the rest of the Chilean coast, HABs has been detected scarcely in northern Chile, between regions I and IV associated to the diatom *Pseudonitzschia spp* without impact on human beings or the regional economy (Córdova *et al.*, 2001). A different scenario was described by Guzman *et al.* (2002) for southern Chile between latitude 43° and 55° where the toxic dinoflagellate *A. catenella* had a huge impact on the health and economic system.

Although those toxic species has been observed in inner seas, channels and fjords, does not exist enough information to discriminate the origin of this blooms. A single reference had the hypothesis about the oceanic origin of HAB but for the hemolytic dinoflagellate *Gymnodinium sp* (Clement *et al.*, 2001) a phytoplanktonic specie with different ecophysiological fitness, so the question is still open and must be taken in account by any ecological research program.

The diatoms, such as *Pseudonitzschia spp*, are organisms with a size higher than 20 µm, this size require a specific environment in order to achieve an adequate ecophysiological fitness and factors like a continuous supply of nutrients and light, specially in upwelling areas are critical (Montecino & Quiroz, 2000), at the same time and due to the physical characteristics of upwelling ecosystems, diatoms presents high abundance levels in a wide geographical scale from the coast to 200 km (Pizarro *et al.*, 2000). This diatoms have not been involved causing a severe impact on public health and economic activities, however it is not clear their toxicity potential and the environmental factors that trigger and regulate the ecological dynamic of this blooms.



Several ecophysiological studies on diatoms indicate that they are cosmopolitan organisms, with a high tolerance for different temperature and salinity regimes. Increase his toxin production associated to several factors like nutrient limitation, mainly phosphate and silicate, high nitrate concentrations and an adequate supply of iron. Some physical constrains has been cited in order to turn a harmless diatom in a toxic phytoplankter, been one of the main factors its cellular size. In this sense a diatom will be toxic only if it has a minimum size threshold which can be happen in several years. In this scenario the diatom *P. delicatissima* was toxic only in Canada, but now is harmful in New Zealand and Denmark too.

From an ecophysiological point of view for the diatom *P. delicatissima* severas questions remain open like the life cycle, the places where the diatoms rest as cysts; the resilience time for those cysts in winter time are big goals. From this information it is clear that the HAB problem must be focused through studies of events that occur in the mesospacial scale and in the short time scale that affect the species's ecophysiology and trigger the toxin production.

The presence of toxic phytoplankter in the inner sea of Chiloé Island only between 2000 and 2001 and the relative scarcity of HABs in the rest of the Chilean coast, is an enigma if we compare with other large ecosystems like the Benguela Current in South Africa and the California Current in USA, where HAB are ubiquitous processes. The possibility to understand this enigma is to establish a comparative research program in order to connect the ecophysiology of the diatoms and other toxic phytoplankters. This is the main scope of the Science Plan GEOHAB (2001) where the comparison between ecosystems is a master piece of research.

In this scenario the presence of toxic phytoplankton in the HCLME suggest that the ecological factors that trigger and regulate these processes are related with physical processes like turbulence and the response of phytoplankton to nutrient and trace metals supply. By the other side the low impact and comparative distribution of HAB in the HCLME on respect other upwelling ecosystems, is indicative that the evolutive convergence of ecophysiological (i.e. life strategies, trophic characteristics) and morphological (i.e. allometrics) features of phytoplanktonic species had been functioning in different ways in order to achieve an adaptative fitness to the ecosystem, driving to life styles or functional groups with a virtual absence of toxic species.

4.4 Zooplankton

Palma and Kaiser (1993) made a review of marine zooplankton in Chilean waters and include a list of papers of zooplankton in the Chilean coastal before 1993. This papers are write mainly about distribution and systematic of zooplankton, this paper are concentrate in state larval and larval development of crustacean, mollusk and fish (64 papers) (Table 2).

After 1993 the productivity in zooplankton increase by the return to Chile of investigators that made graduate study (masters and doctoral), and the increase of national and international funds to made research in biological oceanography, in dynamic and biological process. The main contributions are made by the projects as JGOFS, FONDAP-Humboldt, and FONDECY projects, which study the ecosystem an integrated vision, including physical and chemical parameters.



Table 2. Numbers of papers made in zooplankton before 1993 (from Palma & Kaiser, 1993).

Group	N° Papers
Larvae	43
Ichtioplankton	24
Poliquetos	23
Copepods	16
Quetognatos	6
Medusas	5
Euphausids	4
Foraminifers	4
Siphonophors	4
Anfipods	2
Ctenophoros	2
Salpas	1

The groups more study are the copepods (Heinrich 1973, Vidal, 1975, Hidalgo and Escribano, 2001, Rosales and Sepúlveda 1992), and the euphausids (Antezana, 1978, Fernandez et al 2002). Near of 50 copepod species are know in HCLME, and the more dominant in number are: *Calanus chilensis*, *Centropages brachiatus*, *Paracalanus parvus* and *Eucalanus inermis*, from these species *C. chilensis* is endemic and *C. brachiatus* and *P. parvus* are cosmopolites species, with a long distribution in all coast of Chile. In the central zone of Chile Rosales and Sepulva (1992) determinate as coastal species (inside of 10 nm from de coast) to *Ctenocalanus vanus*, *Pleuromamma xiphias*, *Centropages brachiatus*, *Lucicutia flavicornis*, *Haloptilus longicornis* y *Acartia tonsa*, while *Candacia curta*, *Gaetanus minor*, *Phyllopus helgae*, *Scolecithricella marginata*, *Clausocalanus furcatus* and *Calanus tenuicornis* are oceanic species with abundance high in distance great that 10 nm from the coast.

Euphausia mucronata is an endemic species of euphausids highly abundant with a extend distribution associated to minimum oxygen layer (Antezana 1978). In the northern zone of Chile in the upwelling center this species have bigger abundance and increase during the El Niño events (Escribano et al 2000). Another abundance species with increases during El Niño events is *E. eximia* (Antezana 1978, Gonzalez et al. 2000).

After copepods and euphausids, the gelatinous have received the attention in the research, principally the ctenophorous and siphonophorous, with emphasis in studies over taxonomy, distribution, and abundance (Palma, 1973, 1977, 1984, 1986, 1994). Gonzalez et al (2000) find a big variation in abundance between seasons in northern of Chile. In the central region of Chile Palma and Rosales (1995) identify 45 species while hydrozoa (17), siphonophorous (12), ctenophorous (4), chaetognaths (10) and salps (2), the dominant are *Muggiaea atlantica*, *Obelia* spp., *Phialidium* spp., *Sagitta bierii*, *S. enflata* and *Thalia democratica*. These species present a seasonal distribution with more abundance en summer (December to January, *T. democratica* only are present from November to March.

More recently Aravena and Palma (2002) publish a taxonomic identification of 15 species of appendicularians off northern Chile, the dominants species are: *Oikopleura longicauda*, *O. gracilis*, *O. albicans*, *O. cophocerca* *Fritillaria pellucida* typical, *F. pellucida omani* and *F. venusta*. Vargas (in review) review the importance in the biogeochemistry cycles of this group in the HCMLE, determinate the relevance and the necessity of made more study to understand the role in the energetic transfers from the surface layer to the deep layers.



5. ENVIRONMENTAL VARIABILITY AND FISHERIES

5.1 El Niño and La Niña

Climate changes in physical oceanographic variables have been clearly linked with oceanic ecosystem changes on many temporal and spatial scales. This physical forcing is especially obvious on seasonal (and shorter) timescales where variations in sea-surface temperature (SST) and upwelling, for example, strongly influence productivity, growth and migration patterns. This forcing is also evident on interannual timescales associated with ENSO events (El Niño and La Niña episodes), when the Southeastern Pacific is remotely forced by the concomitant oceanic and atmospheric teleconnections.

The mechanisms by which physical forcing affects oceanic ecosystems range from those associated with the smallest scales of dissipation, turbulent mixing and diffusion, to those acting on the mesoscale associated with fronts, eddies, and upwelling, to those operating on the basin scale associated with gyres, El Niño, and the thermohaline convective circulation (Denman *et al.* 1996). The regional and local manifestations of this physical forcing on the biology can occur instantaneously or with a time delay.

Among the most important physical oceanographic variables that can influence marine populations are sea surface temperature (SST), mixed-layer depth (MLD), thermocline depth, upwelling strength, and upper-ocean current fields. These physical environmental changes occurring in the ocean affect viruses, bacterioplankton, phytoplankton and so on up to whales. Correlations between these physical variables and long-term changes in ecosystems have routinely been identified, but the specific mechanisms involved are usually difficult to elucidate. The challenge is to understand the mechanisms of the responses to these instantaneous and delayed physical environmental changes and the various modes of significant feedback through the trophic web. The basin-scale nature of climate change appears to organize patterns of response in fishery resource populations. In fact, it is known that sardine populations at basin scale seem to be teleconnected in terms of cycles of high and low abundance as well as inversely correlated to other fish species such as anchovy and herring (Schwartzlose *et al.* 1999).

Over the past decade and a half, earlier beliefs in an essential stability of marine ecosystems have been largely displaced by a growing appreciation of the importance of large-amplitude low frequency variability occurring in many regions of the world's oceans. For example, Roemmich and McGowan (1995) reported a 70% decrease in zooplankton biomass in the California Current since the 1950s, along with corresponding drastic declines in certain seabird species. A very sharp 60%-70% decline in zooplankton biomass off Peru in the mid-1970s, following the collapse of the anchoveta, was also reported (Carrasco and Lozano, 1989; Loeb and Rojas, 1988; Alheit and Bernal, 1993). Remarkably, a significant component of this mode of variability appears, at least in the period of the 1970s and 1980s, to have been synchronized over very large spatial scales (Kawasaki 1983; Lluch-Belda *et al.* 1989, 1992). Accordingly, some manner of linkage via large-scale climatic (atmospheric) teleconnections would appear to be a logical necessity.

This mode of low frequency variability seems often to take on the appearance of periods of relative stability over time scales of one to several decades which are interspersed by comparatively sudden "regime shifts". These *regime shifts* tend to be characterized by radical expansions or contractions of occupied habitat of important populations and/or by replacement of one dominant species of fish by another. The question of how



to properly account for regime shifts in fisheries management and endangered species protection has become a major issue. In relation to the Humboldt Current System, regime shifts have been detected to take place in the late 1960s and mid 1980s (R. Serra pers. Comm).

Like in other upwelling systems which are pulsed, the biota in the Humboldt ecosystem are generally well adapted to the inherent variability in physical forcing on seasonal and shorter time scales. The biota are, however, less well adapted to sustained major events or changes which occur less frequently i.e. every several years or even over decades. Accordingly, we provide only abridged comments on aspects of small-scale and seasonal variability, and focus most of the discussion on the "catastrophic" occurrences which have system-wide impacts. We also highlight some long-term and decadal changes which have been observed in the system.

A major issue is how to link this climatic variability to the biological populations involved. It has been suggested three classes of processes that tend to determine favorable reproductive habitats for fish stocks, which are:

- a) Enrichment processes: upwelling, mixing, Ekman divergence and cyclonic eddy formation.
- b) Concentration processes: convergent frontal formation, Ekman convergence, lack of dispersion by turbulent mixing processes (Lasker's stability hypothesis).
- c) Retention processes: lack of offshore transport in Ekman field, availability of enclosed gyral circulations, and stability of current patterns to which life cycles are adapted.

Beside this processes food and temperature has been thought to be also key factors (Schwartzlose *et al*, 1999).



6. ISSUES AND GAPS IN KNOWLEDGE

There are many issues considered to be relevant for management purposes in the context of a Large Marine Ecosystem approach and that reflect our major gaps in knowledge. The following processes are suggested to be key study targets, and they are not presented in an order of priority:

- Regimen shifts and interdecadal changes in the HCLME.
- Interannual variability up the ENSO cycle. Much work on El Niño phenomenon has been carried out, mostly in the Peruvian system (Arntz and Fahrback 1996). However how the resources and relevant community and ecosystem parameters respond to year-to-year variability associated with the cold and warm regimes of the ENSO cycle is an open question.
- The effect of seasonal changes on life cycles and distribution of marine resources, key species and trophic structure.
- To improve the knowledge on the main environmental forcing factors affecting population and ecosystem dynamics.
- The effect of variability of the OMZ for the functioning of the trophic web and distribution and abundance of resources.
- To improve knowledge on mesoscale circulation and other oceanographic features (e.g. eddies, filaments, jets) relevant to the survival or early life history stages and migration patterns of adults stocks
- Coastal upwelling. This is certainly a key process to understand why the HCS, subjected to a high fishing pressure, still has the capacity to maintain large biomasses of clupeids, jack mackerel and other biological resources. Changes in the rate of nutrient pumping by upwelling into the euphotic zone needs to be understood. Variability of upwelling intensity in both space and time is also relevant for ecosystem production studies and management
- Developing a monitoring program to make reliable estimates of primary production rates and their variability along the HCS is a quite important task. The monitoring of oceanographic variables although important is clearly not sufficient to understand ecosystems responses to climate and ENSO variability and process studies and estimates of rates are key issues.
- Biological diversity and trophic interactions are certainly relevant aspects of ecosystem studies. It is necessary to clearly define biological components and how they connect to each other.
- The need to develop integrated models of the HCLME to improve our understanding on the ecosystem and as a tool to better manage the system.



7. REFERENCES

- Alheit, J. and P. Bernal. 1993. Effects of physical and biological changes on the biomass yield of the Humboldt Current Ecosystem, In: Large Marine ecosystems. V.: Stress, mitigation and sustainability.
- Atkinson, L.P. , A. Valle-Levinson, D. Figueroa, R. De Pol-Holz, V. Gallardo, W. Schneider, J. L. Blanco and M. Schmidt. (2002). Oceanographic observations in Chilean coastal waters between Valdivia and Concepción. *Journal of Geophysical Research*, 107(C7), 10.1029/2001JC000991.
- Anónimo, 1996. Design and implementation of some harmful algal monitoring system. IOC Technical Series N° 44, IOC of UNESCO, 102 pp.
- Antezana, T. 1970. Eufáusidos de la costa de Chile. Su rol en la economía del mar. *Rvta Biol. Mar. Valparaíso* 14: 19-27.
- Antezana, T., 1978. Distribution of euphausiids in the Chile-Peru Current with particular reference to the endemic *Euphausia mucronata* and the oxygen minima layer. Ph.D. thesis, University of California, USA, unpublished.
- Arancibia, H. 1989. Distribution patterns, trophic relationships and stock interactions in the demersal fish assemblage off central Chile. Dr. rer. Nat. Thesis. University of Bremen, German, 221 pp.
- Arcos, D. F. 1975. Copépodos calanoideos de la Bahía de Concepción, Chile. *Conocimiento sistemático y variación estacional. Gayana (Zoología)* 32: 43 pp.
- Arntz, W.E. & E. Fahrbach, 1996. El Niño Experimento Climático de la Naturaleza. Fondo de Cultura Económica, Mexico, DF, 312 pp.
- Ashford, J.R. 1993. An exploratory fishing expedition for *Dissostichus eleginoides* to the South Sandwich Islands – Feb/Mar 1993. Scientific Observers Report, CCAMLR.
- Avaria, S. & P. Muñoz. 1982. Producción actual, biomasa y composición específica del fitoplancton de la bahía de Valparaíso en 1979. *Rvta Biol. Mar. Valparaíso* 18: 129-157.
- Avaria, S. & P. Muñoz. 1983. Composición y biomasa del fitoplancton marino del norte de Chile en mayo de 1981 (operación oceanográfica MarChile XII-ERFEN III). *Cien. y Tec. del Mar, CONA* 7: 109-140.
- Barber, R.T. & E.P. Chavez, 1983. Biological consequences of El Niño. *Science* 22: 1203-1210.
- Barber, R.T. & R.L. Smith. 1981 Coastal upwelling ecosystems. In Longhurst, A.R. (ed). *Analysis of Marine Ecosystem*. Academic Press, pp. 31-68.
- Barbieri, M.A., F. Naranjo, E. Yanez, M. Farias, G. Daneri y P. Rojas. 1987. La pesquería artesanal de atun aleta larga (*Thunnus allunga*) en la zona de Valparaíso (33 S-72 W) y el satélite NOAA. *Invest. Mar., Valparaíso*, 15:41-61.



- Barría, P., G. Bohm, A. Aranis, R. Gili, M. Donoso & S. Rosales. 1999. Evaluación indirecta y análisis de la variabilidad del crecimiento de la sardina común y anchoveta en la zona centro-sur. Informe Final Proyecto FIP 97-10. SubSecretaría de Pesca, Valparaíso, Chile.
- Bates S. 1998. Ecophysiology and Metabolism of ASP Toxin Production. In: Anderson, DM, AD Cembella and GM Hallegraeff [eds.]. Physiological ecology of harmful algal blooms, p. 405-426. Springer-Verlag, Heidelberg.
- Bates S, D.L. Garrison & R.A. Horner. 1998. Bloom Dynamics and Physiology of Domoic-Acid-Producing *Pseudo-nitzschia* Species. In: Anderson, DM, AD Cembella and GM Hallegraeff [eds.]. Physiological ecology of harmful algal blooms, p. 267-292. Springer-Verlag, Heidelberg.
- Bilbao, P., Características físicas del fenómeno de El Niño 1982- 1983 en la costa de Chile, Oceanography thesis, Univ. Católica de Valparaíso, Valparaíso, Chile, 1992.
- Blanco, J. L.; A. Thomas; M. E. Carr and P. T. Strub. 2001a. Seasonal Climatology of Hydrographic Conditions in the Upwelling Region off Northern Chile. Journal of Geophysical Research vol 106 No. C6, 11,451-11,467.
- Blanco, J. L.; M. E. Carr; A. Thomas and P. T. Strub. 2002. Oceanographic conditions off northern Chile during the 1996 La Niña and 1997-1998 El Niño: Part 1: Hydrographic conditions. Journal of Geophysical Research, Vol. 107 No. C3, 10.1029/2001JC001002.
- Blanco, J. L., P. Barría, J. Castillo and L.P. Atkinson. 2001b. Response of Anchovy (*Engraulis ringens*) off Northern Chile to the 1997-1999 El Niño - La Niña Sequence. Trabajo presentado en AGU Ocean Science Meeting en Hawaii.
- Blanco, J. L., Pizarro, L., de la Cuadra, T., Camacho, G.A., Martínez, R., Quintana, J., 1998. Oceanographic and meteorological characteristics of the Southeast Pacific during the decline of El Niño 1997-98. Jointed regional cruise of May 1998. Contribution of the South Pacific Permanent Commission (CPPS) for the International year of the Oceans. Special Publication, 1998.
- Braun, M.; J. L. Blanco y J. Castillo. 1997. Monitoreo de las condiciones Bioceanográficas en la I y II Región. Informe final Proyecto FIP 95-05.
- Braun, M.; J. L. Blanco; J. Osses y J. Castillo. 1998. Monitoreo de las condiciones Bioceanográficas en la I y II Región. Informe final Proyecto FIP 96-07.
- Cáceres, M. and D. F. Arcos, Variabilidad en la estructura espacio-temporal de un área de surgencia frente a la costa de Concepción, Chile. Invest. Pesq. (Chile) 36, 27-38. 1991.
- Cáceres, M. 1992. Vórtices y filamentos observados en imágenes de satélite frente al área de surgencia de Talcahuano, Chile central. Invest. Pesq. (Chile), 37, 55-66. 1992.



- Castro, L.R. & E.H. Hernandez. 2000. Early life survival of the Anchoveta *Engraulis ringens* off central Chile during the 1995 and 1996 Winter spawning seasons. *Trans. Amer. Fish. Soc.* 129: 1107-1117.
- Castro, L.R., G.R. Salinas & E.H. Hernandez. 2000. Environmental influences on winter spawning of the anchoveta *Engraulis ringens* off Central Chile. *Mar. Ecol. Progr. Ser.* 197: 247-258.
- Castro, L. R., P.A. Bernal & H.E. Gonzalez. 1991. Vertical distribution of Copepods and the utilization of the chlorophyll-a rich layer within Concepción Bay, Chile. *Estuarine Coastal and Shelf Sciences* 32: 243-256.
- Castro, L.R., P.A. Bernal & V.A. Troncoso. 1993. Coastal intrusion of copepods: mechanisms and consequences on the population biology of *Rhincalanus nasutus*. *Journal of Plankton Research* 15: 501-515.
- Castro, L., A. Llanos, J.L. Blanco, E. Tarifeño, R. Escribano and M. Landaeta. 2001 Influence of latitude variations in spawning habitat characteristics on the early life history traits of the anchoveta, *Engraulis ringens*, off northern and central Chile. Report of a GLOBEC-SPACC/ IDYLE/ ENVIFISH Workshop on Spatial Approaches to the Dynamics of Coastal Pelagic Resources and their Environment in Upwelling Areas (6 - 8 September 2001, Cape Town, South Africa). GLOBEC Report No.16.
- Castro, L.R., J.L. Blanco, M. Landaeta, R. Escribano, E. Tarifeño & A. Llanos. 2002. Latitudinal variations in spawning habitat characteristics of the anchoveta *Engraulis ringens* along Chile. Manuscript in preparation for *Journal Fisheries Oceanography*.
- Castro, L.R., R. Quiñones, H. Arancibia, D. Figueroa, R. Roa, M. Sobarzo & M. Retamal. 1997. Areas de desove de la anchoveta y sardina común en Chile Central. Informe Final Proyecto FIP 96-02. SubSecretaría de Pesca. Valparaíso, Chile.
- Clément A., M. Seguel, G. Arzul, L. Guzmán & C. Alarcon, 2001. Widespread outbreak of a haemolytic, ichthyotoxic *Gymnodinium* sp. in Chile. In: Harmful Algal Bloom 2000, G. Hallegraeff *et al.* (eds.). Intergovernmental Oceanographic Commission of UNESCO. p. 66-69.
- Córdova J.L., A. Jamet, J. Aguayo, M.T. Fauré, O. Villarroel & L. Cárdenas. 2001. An *in vitro* Assay to detect Paralytic Shellfish Poison. *Journal of Shellfish Research* 20(1): 55-61.
- Cushing, D.H. 1982. "Climate and fisheries", pp. 1-372. Academic Press, San Diego, USA.
- Daneri, G., V. Dellarossa, R. Quiñonez, B. Jacob, P. Montero & O. Ulloa. 2000. Primary production and community respiration in the Humboldt Current System off Chile and associated oceanic areas. *Mar. Ecol. Progr. Ser.* 197: 41-49.
- Djurfeldt, L. 1989. Circulation and mixing in a coastal upwelling embayment; Gulf of Arauco, Chile. *Continental Shelf Research*, Vol. 9, No 11, pp 1003-1016, 1989.
- Escribano, R. & P. Hidalgo, 2000. Spatial distribution of copepods in the north of the Humboldt Current region off Chile during coastal upwelling. *J. Mar. Biol. Ass. U.K.* 80: 283-290.



- Esc ribano, R. and P. Hidalgo. 2001. Circulación inducida por el viento en Bahía de Antofagasta, norte de Chile. *Revista de Biología Marina y Oceanografía*, 36:43-60.
- Esc ribano, R., V. Marín, & P. Hidalgo. 2001. The influence of coastal upwelling on the distribution of *Calanus chilensis* in the Mejillones Peninsula (northern Chile): implications for its population dynamics. *Hydrobiologia* 453: 143-151.
- Esc ribano, R., V. Marín & C. Iribarren. 2000. Distribution of *Euphausia mucronata* at the upwelling area of Peninsula Mejillones: the influence of the oxygen minimum layer. *Scientia Marina*. 64: 69-77.
- Esc ribano, R., Marín, V., Hidalgo, P. & G. Olivares. 2002a. Physical-biological interactions in the nearshore zone of the northern Humboldt Current ecosystem. In: *Nearshore Processes in the Ocean*. Largier, J. & J.C. Castilla (Eds).
- Esc ribano, R. and I.A. McLaren, 1999. Production of *Calanus chilensis* in the upwelling area of Antofagasta, northern Chile. *Mar. Ecol. Progr. Ser.* 177: 147-156.
- Esc ribano, R., S. Rosales and J.L. Blanco. 2002b. Understanding upwelling circulation off Antofagasta (northern Chile): A three-dimensional numerical-modeling approach. Manuscript submitted to *Continental Shelf Research*.
- Fernandez, D., R. Esc ribano & P. Hidalgo. 2002. Euphausiids ecology in the Mejillones Peninsula upwelling system (23° S): spatial and temporal distribution as related to conditions prior and during the 1997/98 El Niño. *Investigaciones Marinas* 31: 56-68.
- Figueroa, D. and C. Moffat. 2000. On the influence of topography in the induction of coastal upwelling along the Chilean coast. *Geophy. Res. Lett.*, vol. 27, 23, 3905-3908. 2000.
- Fonseca, T.R. & M. Farías. 1987. Estudio del proceso de surgencia en la costa chilena utilizando percepción remota. *Investigaciones Pesqueras* 34:33-46.
- Fuenzalida, R, J. L. Blanco and W. Schneider. 2002. Humboldt current system and water masses between Caldera and Eastern Island. (In Spanish) Manuscript submitted to *Ciencia y Tecnología del mar (CONA)*, Chile.
- Fuenzalida, R, J. L. Blanco; R. Núñez; S. Hormazabal. 1999. Efectos oceanográficos y meteorológicos durante el evento El Niño 1997-98, en la zona de Iquique (20° S). *Rev. Invest. Cient. Tecnol.*, 5: 56-59., Antofagasta, Chile.
- GEOHAB, 2001. Global ecology and oceanography of harmful algal blooms, Science plan. P. Glibert and G. Pitcher (eds.). SCOR and IOC, Baltimore and Paris. 86 pp.
- Giraldo, A., Esc ribano, R & V. Marín 2002. Spatial distribution of *Calanus chilensis* off Mejillones Peninsula (northern Chile): ecological consequences upon coastal upwelling. *Marine Ecology Progress Series* 230: 225-234.



- Gonzalez, H.E., V.C. Ortiz & M. Sobarzo. 2000. The role of faecal material in the particulate organic carbon flux in the northern Humboldt Current, Chile (23°S), before and during the 1997-1998 El Niño. *Journal of Plankton Research* 22: 499-529.
- Gonzalez, H.E., G. Daneri, D. Figueroa, J. L. Iriarte, N. Lefèvre, G. Pizarro, R. Quiñonez, M. Sobarzo & A. Troncoso. 1998. Producción primaria y su destino en la trama trófica pelágica y océano profundo e intercambio océano-atmósfera de CO₂ en la zona norte de la Corriente de Humboldt (23° S): Posibles efectos del evento El Niño, 1997-98 en Chile. *Revista Chilena de Historia Natural*, 71: 429-458.
- Gonzalez, H.E., Pagés, F., Sobarzo, M. And R. Escribano. 2002. Effects of the 1997/98 El Niño on the oceanographic conditions and zooplankton community structure in the coastal upwelling system off northern Chile. *Investigaciones Marinas Valparaíso (extended abstract)* 30: 112-114.
- Guzmán L, Pacheco H, Pizarro G & Alarcón C. 2002. *Alexandrium catenella* y veneno paralizante de los mariscos en Chile. In: Sar, Ferrario y Reguera (eds.) *Floraciones algales nocivas en el cono Sur Americano*, Cap. 11.
- Heinrich, A.K., 1973. Horizontal distribution of copepods in the Peru Current region. *Oceanology* 13: 97-103.
- Hidalgo, P. & R. Escribano. 2001. Succession of pelagic-copepod species during the period 1996/1998 in northern Chile: the influence of the 1997-98 El Niño. *Hydrobiologia* 453: 153-160.
- Hormazabal, S., G. Shaffer and O. Pizarro. 2002. Tropical Pacific control of intraseasonal oscillations off Chile by way of oceanic and atmospheric pathways. *Geophysical Research Letters*, Vol. 29, No. 6, 10.1029/2001GL013481, 2002
- Hormazabal, S., G. Shaffer, J. Letelier, and O. Ulloa. 2001. Local and remote forcing of sea surface temperature in the coastal upwelling system off Chile, *J. Geophys. Res.*, 106, 16,657 –16,671, 2001.
- Intergovernmental Panel on climate Change. 1996. *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific – Technical Analyses. Contribution of Working Group II to the Second Assessment report of the Intergovernmental Panel on Climate Change* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge and New York, 880pp.
- Iriarte, J.L. A. Kusch, J. Osses and M. Ruiz. 2001. Phytoplankton biomass in the sub-Antarctic area of the Straits of Magellan (53°S), Chile during spring-summer 1997/1998. *Polar Biology* (2001) 24: 154 - 162.
- Iriarte JL, Pizarro G, Troncoso VA, Sobarzo M 2000. Primary production and biomass size-fractioned phytoplankton off Antofagasta, Chile (23-24°S) during pre-El Niño and El Niño 1997. *J. Mar. Syst.* 26:37-51.
- Leth, O. and G. Shaffer. 2001. A numerical study of the seasonal variability in the circulation off central Chile. *Journal of geophysical Research*, Vol. 106, No C10, 22,229-22,248, 2001.



- Loeb, V. and Rojas, O. (1988) Interannual variation of ichthyoplankton composition and abundance relations off northern Chile, 1964-83. Fish. Bull. 86:1-24.
- Longhurst, A. 1998. Ecological Geography of the Sea. Academic Press, London, 398 pp.
- Mann, K.H., Lazier, J.R.N., 1991. Dynamics of marine ecosystems. Oxford: Blackwell Scientific Publications, Inc. pp. 563.
- Mann, K.H. and R. Hilborn. 1992. Benguela Trophic Functioning. South Afr. J. Mar. Sci. 12: 561-585
- Marín, V.H., Espinoza S. & A. Fleminger. 1994. Morphometric study of *Calanus chilensis* males along the Chilean coast. Hydrobiologia 292/293: 75-80.
- Marín, V.H., Escribano, R., Delgado, L.E., Olivares, G. & P. Hidalgo. (2001). Nearshore circulation in a coastal upwelling site off the northern Humboldt Current System. Continental Shelf Research, 21: 1317-1329
- Marín, V., L. Rodríguez, L. Vallejo, J. Fuenteseca and E. Oyarce. 1993. Efectos de la surgencia costera sobre la productividad primaria primaveral de Bahía Mejillones del Sur (Antofagasta, Chile). Revista Chilena de Historia Natural 66: 479-491.
- Martínez, R., E. Zambrano, L. Pizarro, M. Braun, L. Otero. 2000. Comportamiento meteorológico y Oceanográfico en el Pacífico Sudeste durante mayo de 2000. Tercer Crucero Regional Conjunto de investigación Oceanográfica en el pacífico sudeste, Mayo 2000. Comisión Permanente del Pacífico sur (CPPS). Publicación especial. 2000.
- Mesias, J., M.; R. Matano and P.T. Strub. 2001. A numerical study of the upwelling circulation off central Chile. J. Geophys. Res. Volume:106 Number: C9, 19,611-19,624
- Medina, M. And H. Arancibia. 2002. Dinámica trófica del jurel (*Trachurus symmetricus murphyi*) en el norte de Chile. Investigaciones Marina 30: 45-56.
- Melendez, R. 1983/84. Alimentación de *Merluccius gayi* (Guichenot) frente a Chile Central (36°05-36°50). Bol. Mus. Nac.Hist.Nat. Chile. 40: 145-152.
- Montecino V & D Quiroz, 2000. Specific primary production and phytoplankton size structure in an upwelling area off Chile (30° S). Aquatic Sciences 62: 364-380
- Morales, C., J.L. Blanco, M. Braun and N. Silva. 2001. Chlorophyll-a distribution and associated oceanographic condition off northern Chile during the summer and autumn 1994 and seasonal comparison for period 1993-1994. J. Mar. Biol. Ass. UK 81: 193-206 (2001).
- Morales, C.E., J.S. Blanco, M. Braun, H. Reyes & N. Silva, 1996a. Chlorophyll-a distribution and associated oceanographic conditions in the upwelling region off northern Chile during the winter and spring 1993. Deep-Sea Res. 43: 267-289.



- Morales, C.E., Braun, M., Reyes, H., Blanco, J.L. & A. Davies. 1996b. Anchovy larval distribution in the coastal zone off northern Chile: the effect of low dissolved oxygen concentration and of a cold-warm sequence 1990-95. *Invest. Mar. Valparaiso*. 24: 77-96.
- Morales, C., M. Braun, H. Reyes, J.L. Blanco and A.G. Davies. 1997. Anchovy larval distribution in the coastal zone off northern Chile: the effect of low dissolved oxygen concentration and of a cold-warm sequence (1990-1995). *Investigaciones Marinas*. Valparaiso, Chile, 24: 77-96.
- Morales, C., S. Hormazabal and J.L. Blanco. 1999. Inter-annual variability in the meso-scale distribution of the upper boundary of the oxygen minimum layer off northern Chile (18-24S): Implications for the pelagic system and biogeochemical cycling. *Journal of Marine Research* 57, 909-932.
- Narvaez, D.A. 2000. Observaciones de vortices de mesoescala frente a la costa norte de Chile utilizando altimetría satelital y datos hidrográficos. Tesis para el título de Oceanógrafo, Universidad Católica de Valparaiso. Chile. 2000. 47pp.
- Nixon S. and A. Thomas (2001) On the size of the Peru upwelling ecosystem. *Deep-Sea Research I* 48 (2001) 2521-2528.
- Palma, S. 1973. Contribución al estudio de los sifonóforos encontrados frente a la costa de Valparaíso. I. Taxonomía. *Investigaciones Marinas Valparaíso* 4: 17-88.
- Palma, S. 1994. Distribución del macroplankton gelatinoso en un área de desove de peces frente a la costa central de Chile (32°-33°). *Rvta Biol. Mar.* 29: 23-45.
- Palma, S. and S. Rosales. 1995. Composición, distribución y abundancia estacional del macroplankton de la bahía de Valparaíso. *Investigaciones Marinas* 23: 49-66.
- Pages, F., H.E. González, M. Ramón, M. Sobarzo & J-M Gil. 2001. Gelatinous zooplankton assemblages associated with water masses in the Humboldt Current System, and predatory impact of *Bassia bassensis* (Siphonophora: Calycophorae). *Mar. Ecol. Prog. Ser.* 210: 13-24.
- Parrish, R.H., A. Bakun, D.M. Husby and C.S. Nelson. 1983. Comparative climatology of selected environmental processes in relation to eastern boundary current pelagic fish reproduction. *FAO Fish. Report* N° 291: 731-777.
- Peterson, W.T., C.B. Miller & A. Hutchinson, 1979. Zonation and maintenance of copepod populations in the Oregon upwelling zone. *Deep-Sea Res.* 26: 467-494.
- Peterson, W.T., and D.C. Bellantoni. 1987. Relationships between water column stratification, phytoplankton cell size and copepod fecundity in Long Island Sound and off central Chile. *S. Afr. J. mar. Sci.* 5: 411-421.
- Peterson, W., D. Arcos, G. McManus, H. Dam, D. Bellantoni, T. Johnson, and P. Tiselius. 1988. The nearshore zone during coastal upwelling; Daily variability and coupling between primary and secondary production off Central Chile. *Progress in Oceanography* 20: 1-40.



- Pizarro, G., Alarcón, G., Retamal, L., Ruiz, M., Yuras, G., Montecino, V. & Guzmán, L. 2000. Variabilidad espacial de las características biológicas y ópticas de la columna de agua entre Caldera-Isla de Pascua-Isla Salas y Gómez y áreas adyacentes a las islas. Taller de Presentación de Resultados Crucero CIMAR-ISLAS OCEÁNICAS V. 9-10 de septiembre. Valparaíso. Libro de resúmenes.
- Pizarro, G., J.L. Iriarte, V. Montecino. 2002. Meso-scale primary production and bio-optical variability off Antofagasta (23-24°S) during the transition to El Niño 1997-1998. *Revista Chilena de Historia Natural* 75:201-215, 2002.
- Pizarro, G., J. L. Iriarte, V. Montecino, J. L. Blanco y 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.
- Pizarro, L., J.L. Blanco, R. Martínez, A.R. Pineda. 2000. Meteorological and oceanographic adjustment in the Southeast Pacific during the La Niña 1999. Second jointed regional cruise, May 1999. South Pacific Permanent Commission (CPPS). Special Publication, 2000.
- Pizarro, O. 1999. Low frequency fluctuations in the eastern boundary current off South America: Remote and local forcing. Doctoral thesis, Göteborg University, 36 pp.
- Pizarro, O., A. Clarke and S. Van Gorder. 2001. El Niño Sea Level and Currents along the South American Coast: Comparison of observations with theory. *Journal of Physical Oceanography*, Vol.31:1891-1903, 2001.
- Pizarro, O., S. Hormazabal, A. Gonzalez and E. Yañez. 1994. Variabilidad del viento, nivel del mar y temperatura en la costa norte de Chile. *Invest. Mar.*, Valparaíso 22: 85-101.
- Plan Nacional sobre Floraciones de Algas Nocivas en Chile. 1999. S. Avaria, M. Cáceres, P. Muñoz, S. Palma y P. Vera T. (Eds.). Grupo de Trabajo sobre Floraciones de Algas Nocivas del Comité Oceanográfico Nacional (CONA)
- Retamal, M. 1981. Catálogo ilustrado de los crustáceos decápodos de Chile. *Gayana, Zool.* 44: 1-110.
- Rojas, P., Escribano, R. and V. Marin. 2002. The influence of coastal upwelling on fish larvae distribution off Mejillones Peninsula, northern Chile. *Fisheries Oceanography*. 11: 233-244.
- Rojas, R., y N. Silva. 1996. Atlas Oceanográfico, Vol. 1 [18°21'S a 50°00'S], Serv. Hidro. y Oceanogr. de la Armada de Chile, Valparaíso, Chile.
- Rojas, R., y N. Silva. 1996. Atlas Oceanográfico, Vol. 1 [18°21'S a 50°00'S], Serv. Hidro. y Oceanogr. de la Armada de Chile, Valparaíso, Chile.
- Roy, C. 1998. An upwelling-induced retention area off Senegal: A mechanism to link upwelling and retention processes. In: Benguela Dynamics: Impacts of Variability on Shelf Sea Environments and their Living Resources. Pillar, S., C. Moloney, A. Payne & F. Shillington (Eds.) *S. Afr. J. Mar. Sci.* 19: 89-98.



- Rodríguez, LM & LR Castro. 2002. Ichthyoplankton distribution off the Península de Mejillones under variable hydrographic conditions in two seasons of El Niño 1997. *Hidrobiología* (in review).
- Rutllant, J. and H. Fuenzalida. 1991. Synoptic aspects of the Central Chile rainfall variability associated with the southern oscillation. *International Journal of Climatology*, 11: 63-76.
- Rutllant, J. and V. Montecino. 2002. Multiscale upwelling forcing cycles and biological response off north-central Chile. *Rev. chil. hist. nat.*, Mar 2002, vol.75, no.1, p.217-231.
- Schwartzlose, R. A. *et al.* 1999. Worldwide large-scale fluctuations of sardine and anchovy populations. *S. Afr. J. mar. Sci.* 21: 289-347.
- Shaffer, G., S. Hormazabal, O. Pizarro, and S. Salinas. 1999. Seasonal and inter-annual variability of currents and temperature over the slope off central Chile, *J. Geophys. Res.*, 104, 29,951 – 29,961, 1999.
- Shaffer, G., O. Pizarro, L. Djurfeldt, S. Salinas, and J. Rutllant. 1997. Circulation and low-frequency variability near the Chilean coast. Remotely forced fluctuations during the 1991-1992 El Niño, *J. Phys. Oceanogr.*, 27, 217-235.
- Shaffer, G., S. Salinas, O. Pizarro, A. Vega y S. Hormazabal. 1995. Currents in the deep ocean off Chile. *Deep-Sea research I*. Vol.42.No.4.pp 425-436.
- Sielfeld, W., Vargas, M. and R. Fuenzalida. 1995. Peces mesopelágicos frente a la costa norte de Chile (18°25' – 21° 47' S). *Investigaciones Marinas Valparaíso* 23: 83-98.
- Silva, S. N. And H.A. Sievers. 1981. Masas de agua y circulación en la región de la rama costera de la Corriente de Humboldt: latitudes 18° S - 33° S (operación oceanográfica MARCHILE X - ERFEN I). *Ciencia y Tecnología del Mar*. CONA 5: 5-50.
- Sobarzo, M. and D. Figueroa. 2001. The physical structure of a cold filament in a Chilean upwelling zone (Península de Mejillones, Chile, 23° S). *Deep-Sea Res.* 48: 2699-2726.
- Sobarzo, M., D. Figueroa and D. Arcos. 1997. The influence of wind and tides in the formation of circulation layers in a bay, a case Study: Concepcion Bay, Chile. *Estuarine, Coastal and Shelf Science* (1997) 45, 729-736.
- Strub, P., J. Mesias, V. Montecino, J. Rutland, & S. Salinas. 1998. Coastal ocean circulation off western South America. In: Robinson, A., Brink, K. (eds.), *The Sea*, Vol.11. The Global coastal ocean. First Workshop on Coastal Ocean Advanced Science and Technology Studies (COASTS) IOC, Liege. John Wiley & Sons, Inc.
- Suárez-Isla B, A. López, C. Hernández, A. Clément y L. Guzmán. 2002. Impacto económico de las floraciones de microalgas nocivas en Chile y datos recientes sobre la ocurrencia de veneno amnésico de los mariscos. In: Sar, Ferrario y Reguera (eds.) *Floraciones algales nocivas en el cono Sur Americano*, Cap. 12.



- Summerhayes, C. P.; K. -C. Emeis, M. V. Angel, R. L. Smith and B. Zeitzchel (1995) Upwelling in the ocean: modern processes and ancient records. In: Upwelling in the ocean: modern processes and ancient records. Summerhayes, C. P.; K. -C. Emeis, M. V. Angel, R. L. Smith and B. Zeitzchel (editors). Pp. 1-38. John Wiley & Sons.
- Thomas, A., J. L. Blanco, M.E. Carr, P.T. Strub and J. Osses. 2001. Oceanographic conditions off Northern Chile during the 1996 La Nina and 1997-1998 El Nino. Part 2: Satellite-measured chlorophyll and temperature patterns. *Journal of Geophysical Research*, Vol. 106, NO.C1, 899-915.
- Thomas, A.C., Strub, T., Huang, F. and C. James. 1994. A comparison of the seasonal and interannual variability of phytoplankton pigment concentrations in the Peru and California Current System. *J. Geophys. Res.* 99: 7355-7370.
- Ulloa, O., R. Escribano, S. Hormazabal, R. Quinonez, M. Ramos & R. Gonzalez. 2001. Evolution and biological effects of the 1997-98 El Niño in northern Chile. *Geophys. Res. Lett.* 28: 1591-1594
- Uribe, E., y J.L. Blanco. 2001. Capacidad de los sistemas acuáticos para el sostenimiento de cultivo de pectinidos: El caso de *Argopecten purpuratus* en la bahía Tongoy, Chile. En: *Los Moluscos Pectinidos de Iberoamerica: Ciencia y Acuicultura*. A. N. Maeda-Martinez (ed.) 2001, Cap. 12. 16 p.
- Valle-Levinson, A., J. Moraga, J. Olivares, J.L. Blanco. 2000. Tidal and residual circulation in a semiarid bay: Coquimbo bay, Chile. *Continental Shelf Research* 20 (2000) 2009-2028.
- Vergara, J. 1991. La surgencia costera a la latitud de 30° S: Un estudio numérico. *Rev. Biol. Mar. Valparaíso* 26: 375-401.
- Verheye, H.M., Hutchings, L., Huggett, J.A. & Painting, S.J., 1992- Mesozooplankton dynamics in the Benguela ecosystem, with emphasis on the herbivorous copepods. In: Payne, A.I.L., Brink, K.H., Mann, K.H., Hilborn, R. (eds.), *Benguela Trophic Functioning*. *South African Journal of Marine Sciences* 12: 561-585
- Vidal, J. 1976. Copépodos calanoideos epipelágicos de la expedición Marchile II. *Gayana (Zoología)* 15: 1-98.
- Wing, S, L. Botsford, S. Ralston and J. Largier. 1998. Meroplanktonic distribution and circulation in a coastal retention zone of the northern California upwelling system. *Limnol. Oceanogr.* 43: 1710-1721.
- Wroblewski, J.S., 1982. Interaction of currents and vertical migration in maintaining *Calanus marshallae* in the Oregon upwelling zone – a simulation. *Deep-Sea Research*, 29, 665-686.