A. MARINE POLLUTION

1. INTRODUCTION

This review is a summary of present knowledge and understanding of the marine pollution aspects in the Humboldt Current. It was prepared to be integrated with a similar work done in Perú to build the foundations to identify the issues problems and gaps in knowledge in the Humboldt Current LME.

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2. THE SCENARIO

South Pacific Eastern Margin Ecosystem or Humboldt Current Large Ecosystem (HCLME), extends from latitude 18° 30' S to 45° S. This system is influenced by the Subantarctic Water (SAWW) along the coast. An important change in the conservative parameters are determined due to the extense movement and the surface condition of this water. However, in general the water temperature and salinity of the SAWW is less than that of the surrounding waters. (**i.e.,** 18 ºC and 34.8 UPS). During spring and near the city of Antofagasta, subtropical waters move to the coast causing the thinning of subantarctic waters.

2.1 Coastal Ecosystems

2.1.1 Upwelling ecosystem

Along the coast there are zones where the subsurface waters upwell seasonally. These waters provide nutrients to the surface waters. During this process, the temperature decreases and a temperature discontinuity defines the area of upwelling. Changes in physical, chemical, biological and geological variables define this particular ecosystem. South winds causing upwelling, dominate along the coast in spring and therefore upwelling events are more frequent between September to March along the northern and central coast of Chile. Typical upwelling areas along the Chilean coast have been reported by Fonseca and Farías (1987) using satellite imaging. The more conspicuous changes on the coastal zone during upwelling are the dissolved oxygen content of waters below 15 meters deep, high nutrient concentration and changes in the pH and Eh of waters and sediments. The coastal upwelled waters rich in preformed nutrients sustain annual landed fisheries of 7 million tons, approximately 20 percent of the total landed fisheries of the world.

2.1.2 Embayment ecosystem

From latitude 18°30' S to 41°50' S, there are several embayments of tectonical origin, most of them open to the North. This kind of coastal system could be defined as an ecosystem on its own with clear boundaries and characteristic dynamics (**i.e.,** as a residence time). During the upwelling season the ESSW or oxygen minimun water spreads to the embayments. This feature produces an increase of nutrients, aereation of the surface water, high primary production and high sedimentation rates (**i.e**., near 50 % of the particulated organic carbon production falls to the sediments (Ahumada, 1990) where it undergoes remineralization. In all of these embayments, the sediments are anoxic, rich in organic matter, and active sulfate reduction occurs. On the other hand, during the winter time, the water mass dominant is the SAAW, satured in oxygen, low in nutrients and salinity.

2.1.3 Estuarine ecosystem

An estuary is a semi-enclosed coastal zone where freshwater drainage produces a permanent or semi-permanent dilution of the seawater. The following type of estuaries constitute this group. I.- area adjacent to the mouth of a river (coastal plain), II.- fjord and channel system (deep basin), and III.- litoral systems such as salt marshes or coastal lagoons (bar-build estuary) (Pritchard, 1968).

Estuaries type I and III can be found north of latitude 42º S, whereas type II is located south of latitude 42º S. This region is an area of the salmon culture industry.

3. HUMAN COASTAL ACTIVITY

Chile has a population of approximately 15.401.952 inhabitants. Although nearly 22 % of the population live on coastal cities, only three of cities have more than 500.000 inhabitants, five, between 250.000 and 125.000, and the rest, less than 100.000 inhabitants (2001 Census). Chilean government divided the country into 13 administrative Regions, all of them having different natural resources and industrial activities (**Table 1**).

To understand and classify the nature of coastal pollution caused to the aquatic environment by anthropogenic activities, it is necessary to know the geography of the country. The coast is narrow and flanked by a chain of coastal mountains with an elevation of about 800 to 1200 m above sea level. Further inland a central plateau with an elevation of 700 to 900 masl appears and extends 100 to 150 kilometres before reaching the Andean range. This mountain range ascends up to 4000 to 6000 masl. The relief is the main factor controlling the water regime flowing west of the Andes. Rivers are initially turbulent, slowing their flow in the central plateau and finally modelling the coastal range as they move toward the ocean.

Rainfall is poor or absent in the north between latitude 18° S and 30° S, where the Atacama desert crosses transversal valleys formed by rivers. In the northern part of Chile, the major activity is mining. The principal cities have grown to ports by the increase of the mineral production. Some transversal valleys, where rivers flow from the Andes, are occupied mainly by natives on a subsistence agriculture. The rivers occasionally terminate on the coast and if so, they carry little water. Between latitude 30° S and 34° S, rainfall increases from 100 mm y^{-1} to 900 mm y^{-1}. Between latitude 34° S and 56° S increases to 1000 mm y^{-1} with a maximum of 3000 mm y^{-1}.

Table 1
Census of population by regions, number of inhabitants on the coastal areas and population density by Region from North to South

Region	Population	Area	Density	Rate of growth	Coastal Population	
	inhabitants	km^2	hab./km^2	10 years %	inhabitants	%
Tarapacá	341.000	56.698	5,8	2,40	321.000	94,1
Antofagasta	407.000	126.444	3,2	1,92	270.000	66,4
Atacama	231.000	75.523	3,1	2,58	33.000	14,5
Coquimbo	502.000	40.656	12,4	1,96	248.000	49,3
Valparaíso	1.374.000	16.396	83,8	1,35	719.000	52,4
Metropolitana	5.170.000	15.349	333,8	1,97	--------	-----
El Lib. Gral. B. O'Higgins	688.000	16.365	42,1	1,73	5.400	0,8
Maule	834.000	30.301	27,5	1,42	49.800	6,0
Bio Bío	1.730.000	36.929	46,8	1,39	510.000	29,5
Araucanía	775.000	31.858	24,3	1,10	14.400	1,9
Los Lagos	953.000	66.997	14,2	1,23	257.000	27,0
Aysén	82.000	109.025	0,8	2,37	10.000	12,3
Magallanes and Antarctic territory	143.000	1.382.033	0,1	0,84	138.000	96,5

In the northern part of Chile, rivers have a low flow originated on the Andean range. On the other hand, the rivers in the Central region toward the South, have a regime based on melting snow and lacustrine outflow, with an important rainwater contribution at the central plateau and superficial runoff. In this context, the human activity has been developed on different regions near the rivers and along the embayments.

In the Northern region of the country, the main economic activity is related to the mining of metal and non-metal resources. Gold, silver, zinc, lead, iron, manganese, molybdenum and copper have been the main products obtained from metallic mining at the Andes mountain range and the central plateau since the past century. Non metallic elements such as nitrate, iodate, phosphate and carbon correspond to the main non metallic mining.

The industrial activity of the coastal zone is related to: i) transport of minerals from the mining of copper, tails that reach the sea and shipment of the concentrate; ii) industrial fisheries, landing fish at the port, their industrial processes and by the activity of intensive marine aquaculture, iii) transport of petroleum, fuel terminals and oil refineries; iv) steel factories, industrial activity of metal – mechanical processes and metal smelting; v) industry of the cellulose, and vi) the discharge of urban wastewaters on the coast.

3.1 Mining

The main anthropogenic activity related to mining is located in the north region of the country. In the so called "Great Mines", mining of copper is operated by 35 companies, 28 of which are located north of 30º S. The other seven are distributed between latitude 30º S and 34º S. The mining of iron and tin is located around 30º S. The elaboration of steel is accomplished on San Vicente Bay ($\approx$ 36º S). Finally, mining of lead and zinc takes place in the south region ($\approx$46º S), in the Aysen fjord. As a rule, mining of metals is located on the Andean range and its products are transported to the coast where it is exported overseas. The risk of pollution comes from the tale liquid infiltration, transport of concentrated copper powder and during the seaport loading activities. **Table 2** shows the main metallic mining activities accomplished in Chile during the last 50 years, with the present production as a way to assess pollution risks of the coastal areas.

Most of the big mining is located in the northern part of the country. Copper is the main element extracted; however, molybdenum, gold and silver are important subproducts of copper mining. Up to 1996, 35 companies were operating in the mining of copper. Of those, 28 companies were located north of 30º Lat. S. and the other 7 were distributed north of 34º Lat. S. Iron mining represents the activity with the largest volume of minerals in exploitation and is located 30º Lat. S. Nevertheless, iron is not a toxic metal and its natural concentration in the water and sediment is higher than that of toxic metals (***i.e.***, one or two orders of magnitude). The refinement of iron to steel is accomplished within San Vicente Bay, 36º Lat. S. Finally, mining of lead and zinc is located in southern Chile (46º Lat. S.).

Mine tails obtained from copper extraction are deposited on salt mines which not permeable basins.

Table 2

Statistics of mining activities of specific metal resources in Chile.

	Number of Companies	Initial Year of exploitation**	Total Production at 1996 (TMF)
Copper	35	1929	3.141.000
Iron	2	1953	9.081.481
Gold	6	1929	51,8
Silver	3	1841	1.129,9
Molybdenum	30	1980	17.415
Lead	1	1903	1.089
Zinc	1	1924	35.625

** initiation of the activities is considered from the time an important industrial development occurs.

For the extraction of 100 ton of copper mineral, it is necessary to remove 100 ton of sterile rock materials. The rock mineral contains 1.2 % of copper, which is ground, dissolved with 300 ton of water and reacted with to 2 ton of sulphuric acid. A chemical flotation process is used to obtain copper and molybdenum and 400 ton of tails. The latter is a semi liquid residue or waste originating from the extraction process. To mitigate the impact

of harmful mine tails, the waste is deposited in basins, thus creating sedimentation lagoons. The risk of percolation and contamination of groundwater is high and driven by the pH of the tails (≈11) and the impermeability of the basin.
Export of copper mining products for 1995 were as follows: refined copper (48 %), blister copper in bars (2 %), concentrated fine copper powder (44 %), other forms of copper (5,5 %). Therefore, the pollution risk by copper is mainly associated to concentrated copper during its transportation and shipping at seaport (**Table 3**).

3.2 Fishing industry

The fishing industry is another group of activities developed on the coastal zone. The mayor product is fishmeal, which includes about 85 % of all fish captured. This activity begun in 1960 in the northern part of Chile, in Iquique, expanding later to the near localities of Arica and Pisagua. The first economical crisis borne by the fishing activity was in 1965, due to "El Niño" events of 1959 and 1964. These events affected the reproduction and recruitment of different fish species in the following years. The fish stock is increasingly facing overfishing and catastrophic events.

From 45 initial fishery industries producing fish meal and fish oil in Iquique, only 6 were operating in 1965 and 10 in the entire the northern region at the end of thise century. In 1972, the fishery industry expanded to the central part of Chile (**i.e**., San Antonio and Talcahuano) and begun a new stage of development. Actually the fisheries industries landing seven percent of the total landing of the word.

3.3 Marine Aquaculture

Marine aquaculture begun as an artisanal activity on fjords and channels on the southern part of Chile in 1970, with the farming of oysters and mussels. This artisanal activity was replaced in 1985 by the industrial salmon farming with a large development in the X and XI Regions. Intense culture brought some problems with the surplus organic matter, grease, oil, vitamins and hormones affecting in diverse ways to the aquatic environment.

Table 3

Industrial activity having an environmental impact in the coastal zone

Industrial Activity	Geographic Zone	Initial Year	Type of Industry	Locality	Current Production (ton-year in 1997)
Fishery	I Region	1960	Fishmeal	Arica	522.481
			Iquique		849.200
	II Region	1976	Fishmeal	Tocopilla	159.939
	II Region	1976	Fishmeal	Mejillones	167.708
	III Region	1980	Fishmeal	Caldera	121.632
	IV Region	1975	Fishmeal	Coquimbo	
	V Region	1970	Fishmeal	San Antonio	298.271
	VIII Region	1970	Fishmeal	Talcahuano	1.016.908
				San Vicente	741.966
				Coronel	1.114.812
Marine	III Region	1985	Algae, molluscs		
Aquaculture	IV Region	1985	Scallops culture	Guanaqueros	
	VIII Region	1975	Salmon culture	River.	951
	IX Region	1980	Salmon culture	River, Lakes	
	X Region	1980	Salmon culture	Puerto Montt 78.056	
				Chiloe	47.425
	XI Region	1980	Salmon culture	Seno Aysen	13.432
	XII Region	1990	Salmon culture	Punta Arenas 1.635	
Mining	I Region	1994	Concentrate Cu	Puerto Iquique	
	I Region	1994	Concentrate Pb	Puerto Arica*	
	II Region	1990	Concentrate Cu	Cta. Coloso, Antofagasta	
	II Region	1991	Concentrate Pb	Antofagasta*	
	III Region	1992	Concentrate Cu	Chañaral, B. Calderilla	
	III Region	1992	Pellet Fe	Chañaral	
	IV Region	1970	Pellet Fe		
	VIII Region	1949	limestone	San Vicente	
	XII Region	1949	limestone	Isla Guarello	
Mining Tails	III Region	1980	Cu	Chañaral	
	III Region	1986	Cu	Chañaral, Cta Hedionda	
	III Region		Fe	Chañaral, Huasco	
	IV Region		Fe	Coquimbo, Guayacan	
	XI Region		Zn	Seno Aysen	
Cellulose	VII Region		Cellulose	Constitución	
	VIII Region		Cellulose	Rio Bío Bío	
	VIII Region		Cellulose	Rio Bio Bio	
	VIII Region		Cellulose	Rio Bio Bio	
	VIII Region		Cellulose	Rio Bio Bio	
	VIII Region	1985	Cellulose	Golfo Arauco.	
Oil Refinery	V Region	1950	Hydrocarbons	Bahía Quintero.	
	VIII Region	1965	Hydrocarbons	Bahía San Vicente.	
Oil Terminals	All the coast		Hydrocarbons	Seaports	
Oil Platform	XII Region			Magellan Strait	
Municipal waters	in all the port		Organic matter	Coastal cities	
Municipal waters	1992 still without treatment			Arica, Iquique, La Serena,	
Submarine pipes				Viña del Mar, Bahia Concepción.	

* lead originates in Bolivia.

3.4 Petroleum

Along the coast there are ***ca.*** 40 oil terminals, 2 petroleum refineries and 2 oil platforms. Crude oil, fuel oil, diesel oil, and several refined products are the main petroleum products transported along coastal waters. Oil spills greater than 10 m^3 are shown on **Table 4**. Accidental spills smaller than 5 m^3 are frequent on oil terminals and seaports. This low but continuous input of oil causes a major impact on these ports. High-risk or “critical” areas as defined by CPPS-PNUMA (1985) are Antofagasta, Valparaiso, Talcahuano and Punta Arenas. A recent study of different sedimentary hydrocarbons and organic matter done at San Vicente bay identifies a coke gas plant, discharges of fish industries and petroleum maritime terminals as the source for hydrocarbon contaminants (Mudge & Seguel, 1998).

These results are consistent with the general hydrographic dynamic of San Vicente bay (Ahumada, 1992, 1995 and Arcos et al., 1993).

Studies of hydrocarbon and organosulphur contaminants in sediments of coastal zones are relevant to evaluate changes in the ecosystem caused by anthropogenic activity. Similar studies to those carried out along the North-east Pacific (Pinto & Leif, 1991; Prahl et al., 1996) are starting to be carried out locally (Mudge & Seguel, 1997, Pinto, 1998).

3.5 Industrial wastewater

The best protected embayments have been used as seaport, and around them a series of industrials activities have developed. There are several examples along the coast: Mejillones, Calderilla, La Herradura, Concepcion, etc. There is only one iron and steel factory in Chile, located in San Vicente Bay, on the VIII Region. Around this factory several related industries exist, producing different types of wire, steel balls for mills, cement, dockyards.

Table 4

Major oil spills (**i.e**., more than 10 ton) produced during the last 20 years along the coast of Chile

Ship name	Year	Site of accident	Type of hydrocarbons	Impact and mitigation.
B/T Napier	1973	Chiloé, Guamblin	30.000 ton crude oil	Without report of impact.
B/T Metula	1974	Magellan Strait.	52.000 ton crude oil	40 kms of coast exposed to the asphaltic fraction. Beach cleaning.
B/M Astrapatagonia	1975	Southern Channels	1.000 ton fuel oil	Without report of impact.
B/M Northern Breeze	1975	Quintero Bay.	440 ton diesel/fuel oil	Beach cleaning.
B/T Cabo Tamar	1978	San Vicente Bay	17.000 ton crude oil	4 km. of coast with Asphal-tic fraction. Beach and salt marsh cleaning.
OBO Valparaiso	1987	Concepción Bay	Not evaluated	Light and polar fractions of crude oil, was partitioned into seawater*
Breakage of pipeline	1993	San Vicente Bay	Diesel fuel general damage	Lost of small ships and and fire.

3.6 Cellulose industry

The processing of cellulose uses two different systems: the Kraft chemical process using a sulphur solution and the physical process. Major industries use the Kraft system requiring large amount of water. Two especies of tree are utilized: pine and eucalyptus, both species have been introduced to Chile and require a rain mean greater than 700 mm $y^{-}y^{-1}$. This type of industry is located on the south part of Chile, next to big rivers and where large areas of pine and eucalyptus trees are planted. There are nine cellulose industries among them, four Kraft processing plants located along the Bio Bio river, one in Constitucion and another in Arauco along the coast disposing their liquid waste on the river and the coastal zone, respectively. Among the major pollutants of this activity are organic mater (***i.e.,*** BOD5), resin acids, totals solids, dioxins, sulphides, merchaptans, chloride, phenols, etc.

3.7 Municipal wastewaters

Municipal waste is normally discharged on rivers and lakes when the cities are located in the interior of the country, or waste is evacuated to the sea in coastal cities. There are 113 major cities that discharge their wastewaters on rivers and about 41 mayor cities that introduce them into the sea. In any of these coastal cities more than 10 discharge points can exist, usually involving no treatment. In recent years, the wastewater discharge to the sea is changing from a superficial dumping of wastewater on the intertidal zone to a submarine pipe. The volume of domestic wastewater discharged in Chile in 1992 was estimated in 1,8 x 10^6 m^3 per day. Half of this volume is discharged in Santiago to the Mapocho river, and transported to the coast by the Maipo river. Two indexes are used to evaluate the possible impact of the effluent rich in organic waste to the reception water body: the Biochemical Oxygen Demand (BOD_5) and the Chemical Oxygen Demand (COD). Both of them are based on the oxidation of organic matter content per unit of volume of waste and offer a projection of the impact on the oxygen comsuption by the discharged waters. BOD_5 refers to a bacterial oxidation of organic matter on a time of five days. The COD index represents oxidation of organic matter caused by a strong chemical oxidant. In both cases, the result is the oxygen consumed by the oxidation of organic matter content on the liquid waste. For different effluents there are typical values such as: BOD_5 for municipal waste is 300 to 800 ml l^{-1}; for fishmeal waste product is between 3000 to 5000 ml l^{-1}; for a cellulose plant is 1500 ml l^{-1}; and 4000 ml l^{-1} for a dairy product plant (Rudolph, Pers. Com.).

3.8 Cases of study

Four study cases are analysed to assess environmental problems on the coastal zone. Each one corresponding to the worst case scenario in relation to a specific type of contamination.

3.8.1 Mining impact: lessons to the future

Copper mining is the main mining activity in Chile. Molybdenum, gold, silver and renium are other metals obtained from copper mines. An annual extraction of 1.250.000 tons of copper, produces 15.000 tons of molybdenum and significant quantities of gold, silver and rhenium. For this purpose about 100.000.000 tons of minerals must be removed and an equal tonage of sterile materials. The process requires 300.000.000 tons of water, 2.000.000 tons of sulphuric acid, and chemical additives for flotation producing 100.000.000 tons of tails (Corvalán, 1985).

Two copper mines located on the Andes mountains in the III Region, discharge theirs liquids tails on the Rio Salado basin: one of them begun its production on 1929 and the other begun on 1959. The sediments are transported 150 km reaching the coast in Chañaral, a small city of 41,450 inhabitants (census of 1992). During forty six years, the tails reached the coast accumulating in the sediments of Chañaral Bay changing the depth of the bay. Between 1962 and 1969 the coastal line moved down 130 m on the north and 100 m on the southern area of the bay. About 250 million tons of tails were deposited as sediment on the bay affecting the subtidal region of the bay. Fine dry sediment, also carried by the wind and became a nuisance over the city. During 1975, the tail waste was discharged on Caleta Palitos, a fishing village about 10 kilometres north of Chañaral Bay. During 12 years another 100 million tons of tail waste built the new deposits of tail sediments on Caleta Palitos.

Castilla (1983) assessed the tail waste impact over the biological communities on the beaches around Chañaral. He reported only two species on the contaminated area: *Bateus truncatus* (green shrimp) in tidepools and *Enteromorpha compressa* an algae, both very abundant. *E. compressa* exposed to high levels of copper is studied by Correa ***et al.*** (1996) to define whether the mechanism of resistance for this algae has an adaptative nature or is controlled by heredity. According to García (1985) the impact of tail sediments reached 50 kilometres along the coast of Chañaral. Several beaches were silt up and the people of Chañaral in 1987 complained to the mining company for the pollution of about 100 kilometres of coast by tail sediments. The civil suit was accepted by the Supreme Court, constituting the first legal settlement of the citizens for an environmental case in Chile.

In 1992 the Division El Salvador (CODELCO) constructed a big lagoon of tail. A long channel of 70 kilometres connects the extraction processing site to the lagoon. The residual liquid is adjusted to flow at a pH $\approx$ 11, to maintain the metal elements as complexes in the tail. The accumulations lagoon of tails has 130 Has of area and 10 m of depth **(Figura 6)**. In this lagoon, the sediments settle and the supernatant water (clear water) is pumped back to Rio Salado. Some of this water is used to irrigate experimental cultures of native plants of the area. The content of metal in the clear water is low and the flora and fauna that use the water is monitored for metals according to environmental laws.

3.8.2. Fishmeal industry: effect on the coastal zone

There are two important environmental impacts caused by the fishmeal industry, the first is related to the resource. The total capture of fish in Chile during 1996 was 6.725.734 tons. The percentage use is as follows: 85.6 % to the industrialised fishmeal and oil; 4.3 % frozen; 4.2 canned, 4.1 dry/smoked fish and 1.6 % of cold/fresh fish. Producing a residual liquid with a high oxygen requirement.

The fishmeal production in 1997 was 1,227,561 tons/annual, ca., 12.4 % lower than 1996 and the production of oil in 1997 was 291,981 tons/annual, ca., 29.5 % lower than 1996. The pelagic fish capture affects species such as: anchovies (*Engraulis ringens*) with 1,757,499 tons/annual and Jack mackarel (*Trachurus murphii*) with 2917.064 ton/annual. Other species used for fishmeal are: common sardine (*Clupea bentinki*) and Merluza de cola (*Macroronus magellanicus*).

The second environmental impact is related to the industrial-liquid waste: a) liquid discharge with a high content of organic matter which includes digested liquids, blood and ground fish are dumped to the water during the transport of fish from the area of fishing to the seaport. The main content of the organic waste depends on the time of transport, temperature, size of the ship hold and size of fish. b) the residual liquid from the industrial processes contains solids, ammonia, organic matter and grease material (**Table 4**). For years the fishmeal industry dumped their residual waste directly in coastal waters producing a local hypertrophic area near the fishing port. Under these circumstances, dissolved oxygen is consumed during degradation of organic matter creating an anoxic environment.

In all sites where fishmeal residue is discharged, an oxygen-depleted black sediment appears. The actual organic discharge for the fishing industry, as a mean is shown on **Table 4**, corresponding to the sum of discharged fish waters plus the residual process waters.

The residual waters of effluents dumped to the bay require the total amount oxygen contained in ≈2315 m^3 of seawater. In each embayment there are about eleven fish industries. Recently the fishing discharge has been done with recirculating water coming from the industrial process.

Environmental impact of the fishmeal production has been localised on beaches near harbors and industrial areas. Among the major sites environmentally impacted we find the coastal zones of Arica, Iquique, Mejillones, Taltal, Calderilla, San Antonio, Talcahuano, San Vicente, Coronel y Lota.

Table 5
Characteristic parameters of a fish industry effluent

Type of Industry	Parameter	Concentration	Unit	Flow ($l\ sec^{-1}$)	Charge (kg in 8hs)	Seawater affected* (m^3).
Fishmeal						
Discharged water	$BOD_{(5)}$	2000	$ml\ O_2\ l^{-1}$	66	5431	749
	COD	4000	$mlO_2\ l^{-1}$		10861	1498
	Ammonia	5.0	µM		0.13	
	Grease & oil	0,5	$g\ l^{-1}$		950	
Processing residual waters	$BOD_{(5)}$	2600	$mlO_2\ l^{-1}$	150	16046	2315
	COD	3600	$mlO_2\ l^{-1}$		22217	3206
	Ammonia	20	µM		1.21	
	Grease & oil	0.2	$g\ l^{-1}$		864	
Canning						
	$BOD_{(5)}$	3500	$mlO_2\ l^{-1}$	10	1.440	199
	COD	6000	$mlO_2\ l^{-1}$		2468	340
	Ammonia	20	µM		0,81	
	Grease & oil	2,0	$g\ l^{-1}$		57,6	

* Normal oxygen saturation content of sea water necessary to oxidated the organic matterof emisary charge of 8 hours (calculated).

The major chronic contaminated area has occurred in the Rocuant saltmarsh of Talcahuano (Rudolph y Ahumada, 1987; Ahumada et al., 1989). Around this saltmarsh nine fishing industries are located spilling their wastewater on this water body. All of the aquatic fauna was replaced by bacteria and microciliates, the water became suboxic with anoxic sulphide producing sediments.

3.8.3 Municipal wastewaters: the submarine disposal solution

Municipal wastewaters are an important contaminant along the whole country. Until 1985, most wastewater was dumped directly to rivers, lakes and along the seashore on the intertidal or near the infralitoral zone in all of the coastal cities. Starting in 1990, environmental laws restrained disposal of wastewaters. Major pipelines are being constructed to carry wastewaters to the coast and dumped through submarine conduits offshore. Design for these pipelines is based on the LT-90 index, corresponding to the time when 90% of bacteria have been destroyed. Apparently, the country has favored the construction of submarine disposal pipelines to wastewater treatment. But data is still lacking to demonstrate the best option or the best investment on this type of infraestructure. Potential damage to the benthic fauna due to the toxicity of residues in the area has not been fully addressed. Recent studies indicate that flat fish present in Concepcion Bay show lesions on the skin attributed to contaminants (Leonardi & Tarifeño, 1996, 1997).

3.8.4 Marine aquaculture: potential euthrofication problems on semi enclosed systems.

The salmon farming is one of the main commercial activity in southern Chile on the HCLME boundaries mainly in the Chiloe Islan inner sea. This activity need well protected areas wich at the same time are important areas for nursery and recruitment of native marine especies.

Environemental impact of samon farming are related with organic matter surplus on sediments and the water column. The oxidation of OM increases nutrient levels in the water column and and suboxic zones on sediments. As an example Ackefors & Enell (1994) reporst that one ton of salmon produce 2,5 ton of organic matter/year (wet weight), and in a global scale the total activity generate 750.000 ton of wastes per year.., From the environmental point of view this excess of organic matter impact on the chemical, physical and biological features on the embayments where the activity is located.

4. STRENGTH, PROBLEMS, THREATS AND GAPS IN KNOWLEDGE

Advances on the control and pollution abatement.

Two periods are distinguished in relation to environmental coastal protection in Chile. Initially, some legal ordinance existed dispersed throughout the legislation. Responsibility to sanction environmental problems was difficult to achieve since many different organisms had a degree of interest in the matter but they had no technical expertise and funding to carry out their mission. This is a permissive period due to the lack of enforcing regulations.

In 1987, based on Navigation laws, Regulation 12600-550 was established to oblige all industries emptying liquid effuents into the sea to make a statement and a study of impact assessment. Some of these studies have been partially published (**i.e**., Arcos et al. 1993, Ahumada, 1995a,b). This Regulation provided a grace period of five years to finish the study and present a proposal to mitigate the impacts and to generate a monitoring program for three consecutive years with seasonal sampling on the receptor water body. During this period a lot of experience was gained and after five years, in 1992, more than the 90 % of the industries were observing this rule.

In 1990, the National Environmental Commission was created as a legal support department to the government on environmental issues. In 1993, the Basis for the Environmental Law was written and several regulations approved thereafter. Finally, the Environmental Impact Assessment document was incorporated to all industrial or environmental projects to be carried out in Chile. One of the important aspects of these documents recommend that an environmental monitoring program ought to be carried out seasonally by the industry to detect any environmental change caused by their activity. When undesired changes occur, the company is obliged by law to present an abatement program to minimise those changes.

Environmental protection in Chile have strengths and weaknesses. The main strength is the existence of a public establishment responsible for the sustainable use of the marine ecosystem and the surveillance and prevention of the effects of human activities on the ecosystem. The main weakness are associated with the lack of basic environmental information in order to know the variables and parameters relevant for the formulations of environmental laws and the strategic control of the different problems generated by man. In this scenario can be identified at least seven different polluted areas in Chile with scarcity of information:

4.1 Mining

There are at least 6 new large mines beginning to exploit minerals deposits on the north region of Chile. The mining activities required new facilities to transport and new dock to export the minerals. Impacts were increased on the urban and coastal zone, in this sense it is crucial to know the baseline in sediments, water and organisms, the ecotoxicology and the geochemical pathways of trace metals.

The dumping and disposal of mining tails on the coast is considered one of the major environmental impacts of mining activities in the country.

4.2 Fishing industry

Problems exits with the general management of wastes such as greases, oils and oxygenation and disposal or organic residues to the coastal water bodies in agreement with the assimilative patterns of those ecosystems, such as open embayments and high residence times.
The main impact of this activity is the oxygen depletion on the water column, and the increase of organic mater in the sediment, triggering the hypereutrophication of the embayments.

4.3 Marine Aquaculture

In Chile the environmental impact of salmon farming has not been evaluated in a systematic way however this problem is a big deal for this activity. The scarcity of the relevant information is crucial, and as an example the only measured sinking rates of particulate organic matter to the sediments was done by González *et al*. (1997), and they reports that in average this rate is 26.89 g/m^2/day in a control station located 3.000 meters from salmon cages, close to the cages the rate increases to 210 g/m^2/day. At the same time the results indicated the enviromental impacts of organic matter from salmon is restricted to the cages; In this scenario a prioritary activity is to measure the sedimentation rates of organic matter an the spatial and temporal impact on the ecosystem.

4.4 Hidrocarbons or petroleum pollution

The fishing industry, an others industrial activities and mining development in the north part of Chile favouring the installation of fuel terminals at the coast. The impact of the terminals were local, but intense, produced defauned areas at the embayments.

4.5 Industrial wastewater

Chemical and metal mechanics industries deposed different types of pollutants such as: lubricant, grease, heavy metals, lights hydrocarbons and others.

4.6 Cellulose industry

Pulp, cellulose and paper manufacturing industries appears in the central part of Chile, between 34º and 42º S. The main residues of these activities are damping on the rivers or at the coastal zone. Pollutants as polychlorinated phenols and high chemical demands were relevant impact of these industries.

4.7 Municipal wastewaters

Introduction of high-nutrient, low-oxygen waters to shallow embayments causes high primary production to increase, high sedimentation rates generating suboxic bottom waters. These ecosystems are highly susceptible to contamination by high loads of organic matter creating eutrophic or even hypertrophic conditions. Saltmarshes are an example of subsystems where hypertrophication has occur (Rudolph and Ahumada, 1987; Ahumada et al., 1988).
Recent development on coastal areas has expanded the oil and fishmeal industries, chemical industry, oil refineries, the loading of mineral ores, and general loading of goods excerting pressure on semi-enclosed embayments.

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B. ECOSYSTEM STRUCTURE, FUNCTIONING AND HEALTH STATE OF THE PELAGIC REALM IN THE CHILEAN HUMBOLDT CURRENT

1. INTRODUCTION

This overview is a summary of present understanding of the health aspects of the Humboldt Current Large Marine Ecosystem.

The overview starts with a discussion of the general aspects of the ecosystem health and the general characteristics of the Humboldt Current. The next section deals with patterns of biodiversity and the description of three biogeographic provinces. Finally some relevant issues and gaps in knowledge are discussed. This overview together with a similar document from Peru should be the foundation to identify the issues, problems, threats and gaps in knowledge in the Humboldt Current LME.

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2. ECOSYSTEM HEALTH OF THE HUMBOLDT CURRENT SYSTEM

There is a worldwide concern about health of coastal ecosystems subjected to strong exploitation of marine resources and pollution. For instance, a general view indicates that pollution is a major cause for changes of biomass yields in various coastal systems of World Ocean (Sherman and Duda 1999). The Humboldt Current System (HCS) is one of those Large Marine Ecosystem (census Sherman 1995) that may deserve special attention in terms of ecosystem health. Unfortunately the lack of long-term monitoring and ecosystem integrated studies may strongly limit our understanding to evaluate present state of this ecosystem. Pollution in this region seems a critical issue along the nearshore zone, mostly derived from domestic and industrial activities. Strong artisanal fishery may also add a negative impact in coastal waters. The nearshore zone however plays a major role as spawning and nursery area for small pelagics, also concentrating phytoplankton and zooplankton productivity associated with coastal upwelling sites. So far, there have not been attempts to evaluate the impact of these perturbances on biological diversity and productivity on the pelagic assemblages, nor even on fishery production. Certainly, there is much basic knowledge to be gained before attempting an ecosystemic approach to assess ecosystem health of the HCS. This brief review describes the main physical, chemical and biological features of the HCS. The main objective is to identify the key processes that help maintain biological diversity and productivity of the pelagic realm and which could be considered as baseline processes for ecosystem integrated studies and management.

3. GENERAL CHARACTERISTICS OF THE HUMBOLDT CURRENT SYSTEM

In the eastern South Pacific, the Humboldt Current System (HCS) is well-known for by its rich biological productivity, reflected in the strong fishery of Chile, mostly based on the small pelagics anchovies and sardines (Cushing 1982) and on jack mackerel. The HCS sustains its high production upon the fertilizing effect of wind-driven upwelling, which promotes new production by pumping nutrients into the euphotic zone over the continental shelf off Chile (Barber and Smith, 1981). This system however is subjected to strong interannual variability caused by the El Niño-Southern Oscillation (ENSO) cycle. Evidence indicates that during the warm phases of ENSO, i.e. El Niño, the upwelling process becomes greatly depleted and this causes a major reduction in primary production (Barber and Chavez 1983), and then the whole marine ecosystem becomes dramatically impoverished (Artnz & Farhbach, 1996 for review).

The Chilean continental shelf is very narrow, almost inexistent at northern Chile, and high levels of productivity appears well restricted to the coastal band. This region may also significantly contribute to regulate the climate system in the southern hemisphere, because substantial exchange of heat and CO_2 can occurr between the ocean and the atmosphere due to upwelling of sub-surface, cold, nutrient-rich and CO_2 saturated waters. Upwelling promotes heat transport to the ocean and out-gassing of CO_2 to the atmosphere, then fertilization of the photic zone increases primary production and uptake of CO_2 from the atmosphere, promoting carbon export to deeper waters. The HCS also holds an intense and shallow (<100 m) oxygen minimum zone (OMZ) near the coast (Morales *et al.*, 1996a). In the OMZ the biologically-mediated process of denitrification contributes to the global sink of nitrogen in the ocean, and considerable amounts of the greenhouse gas N_2O can be released to the atmosphere. Although general physical characteristics of the HCS have been well described (Strub et al. 1998), biodiversity, trophic and physical biological interactions have received much less attention. Daneri et al. (2000) have summarized measurements of primary production rates at different locations from the north to the south region and concluded that estimated rates are comparable to those found in Peruvian waters. However the processes and pathways that allow phytoplankton carbon to be tranfered to highest trophic levels are hardly known. There is also an urgent need to identify the key species and their trophic interactions to evaluate changes in the structure and functioning of the pelagic ecosystem upon large scale phenomena, such as the ENSO cycle, or ongoing climate change. Particulary due to flu leign impacts of these events on economic activity

4. PATTERNS OF BIODIVERSITY

Much of the theory and practice regarding biological diversity and biogeographic partitioning of ecosystems comes from terrestrial communities, which can easily be allocated to geographic discontinuities. The dynamical and three dimensional character of the ocean make this task much more complex for oceanographers. Therefore, any physical boundary that may be used to allocate biomes and provinces, for most cases, should be considered as transient, and changing seasonally or between years. According to Longhurst (1998), at a large scale the HCS may be part of the Pacific coastal biome, which may contain characteristics from two types of larger scale biomes, the Trade Wind Biome, and the Westerlies Biome. The Pacific Trade Wind can be divided into the Peruvian and Chilean zones by the bent of the coast at about 18º S. This biome is better known as the tropical ocean and defined by the trade wind. The annual balance of radiation allows a net positive downward flux of heat across the sea surface and the surface mixed layer is maintained throughout the year, such that there exist a permanent tropical thermocline. Its limits vary somewhat between 5º and around the tropical convergence (30º S). The westerlies biome is characterized by a strongly seasonal mixed layer, which deepens in winter upon increased wind stress. This biome can be considered as a transition zone between the trade wind and the polar biome and its southest limits may be considered to be around 55º, at the area in which subduction of Antartic Intermediate waters (AAIW) takes place. The eastern south Pacific may contain several biogeographic provinces from 18º to 55º S. Having in mind the variable nature of oceanographic boundaries in the ocean, three biogeographic provinces are suggested for the HCS (**Figura 1**): 1) The northern upwelling province, 2) the central/south upwelling province, and 3) the austral fjords upwelling provinces.

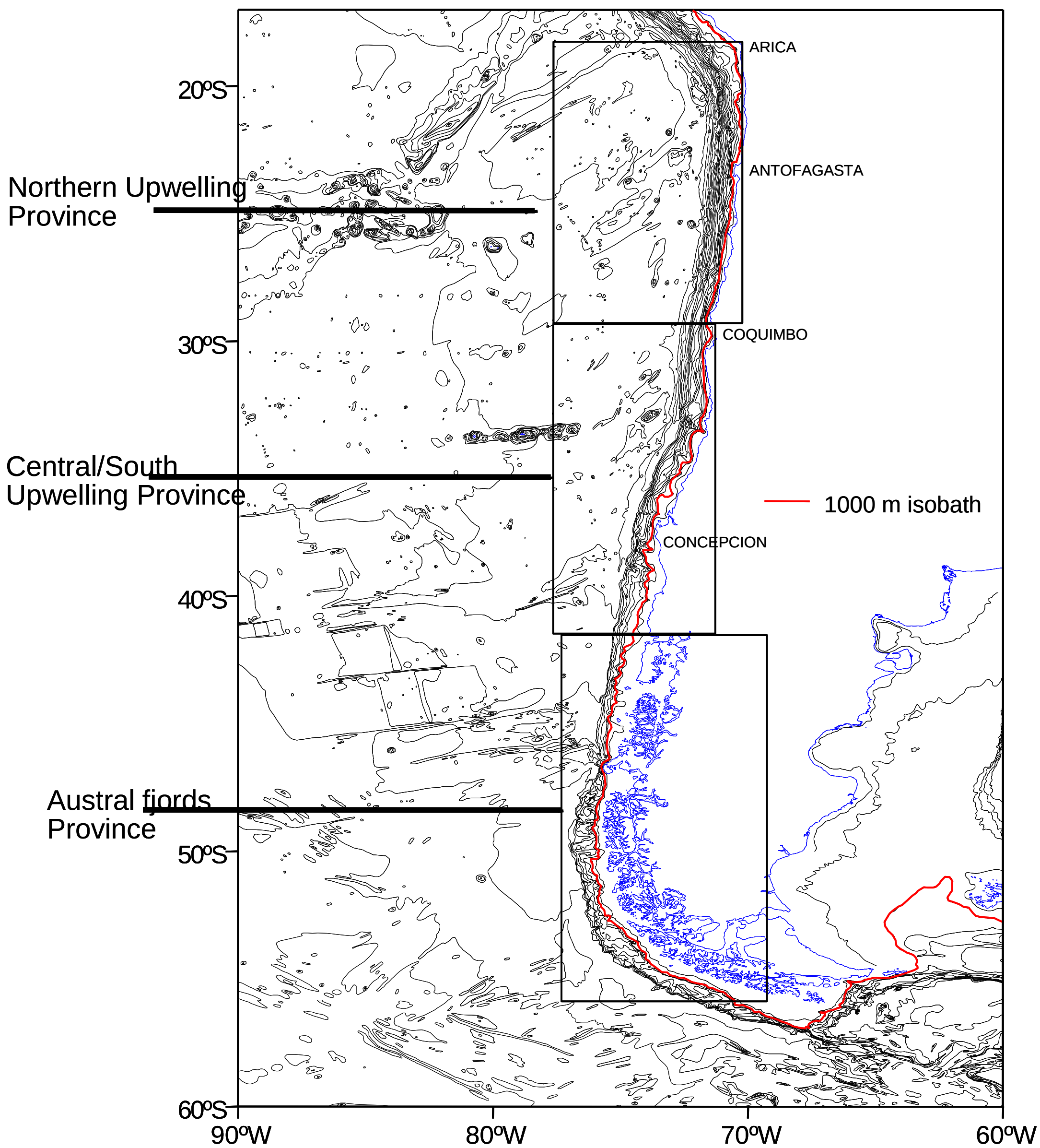
ARICA
ANTOFAGASTA
COQUIMBO
CONCEPCION
Northern Upwelling Province
Central/South Upwelling Province
Austral fjords Province
1000 m isobath
20ºS
30ºS
40ºS
50ºS
60ºS
90ºW
80ºW
70ºW
60ºW

Figure 1. The Humboldt Current Coastal System divided into biogeographic provinces for the pelagic ecosystem.

5. THE NORTHERN UPWELLING PROVINCE (NUP)

At this region the continental shelf is very narrow and coastal upwelling occurs year round (Blanco *et al.* 2001). The seasonal climatology of oceanographic conditions of this region has been summarized by Blanco et al. (2001), whereas the large scale circulation patterns are described by Strub *et al.* (1998). Coastal upwelling drives the ascent of equatorial subsurface waters in the coastal zone, causing a persistent shallow oxygen minimum zone (OMZ), which can even penetrate the euphotic layer (< 50 m) in the nearshore (Morales et al. 1996a). Presence of a shallow OMZ is a particular feature of the northern upwelling region that rise interesting questions about the biogeochemical processes taken place within this suboxyc environment and the role that may play in governing vertical distribution and adaptations of planktonic assemblages. Upwelling may also cause abrupt changes in circulation patterns as well as in oceanographic conditions in both space and time (Marín et al. 2001). The ascent of cold waters brings low oxygen and cools down surface waters altering the stratification of the water column and giving rise to a highly heterogeneous environment. Pelagic organisms may take advantage of high productivity of upwelling sites, but they also have to cope with those changing conditions. The understanding of these physical- biological interactions in the water column of upwelling systems may give much insight on the key processes that control production and population dynamics of pelagic species. Although much information on some of those interactions has been gathered (Mann and Hilborn 1992, Summerhayes *et al.* 1995), most of it comes from other upwelling systems, such as the Benguela system (Verheye *et al.* 1992, Roy 1998), the California Current (Wing *et al.* 1998), Oregon system (Peterson *et al.* 1979, Wroblewski 1982). In the NUP, examples on physical-biological interactions that take place in the water column upon coastal upwelling, are much more limited and restricted to some particular conditions and sites (e.g. Escribano & Hidalgo 2000, Escribano *et al.* 2001, Giraldo *et al.* 2002). Recent studies (Marín *et al.* 2001), have allowed gathering of some relevant findings that may help understanding mechanisms through which pelagic populations have succeed in the coastal zone of the NUP. Off Mejillones Peninsula (23º S) the interaction between a poleward flow and cold upwelling plumes may give rise to a number of large eddies by which non-migrant plankton can be maintained nearshore. This complex circulation may act as an efficient retention mechanisms to avoid offshore advection of zooplankton (Giraldo *et al.* 2002) and fish larvae (Rojas *et al.* 2002). A major finding is that for most species there is no need to perform diel vertical migration to maintain their population in the food-rich upwelling centers. Indeed many species appear well restricted to the upper layer (< 100 m), possibly constrained by the shallow OMZ (Escribano and Hidalgo 2000, Morales *et al.* 1996b).

The NUP is subjected to weak seasonaliy, but strong interannual variation due to the ENSO cycle. Phytoplankton in the coastal zone is dominated by large diatoms and dinoflagellates, composed by typical upwelling species. About 200 species among five taxonomic groups have been identified. In the nearshore zone (< 10 nm) diatoms dominate the phytoplankton, whereas offshore dinoflagellates account for more than 80% of total numerical abundance (Avaria and Muñoz 1983). Dominant genera of diatoms are *Leptocylindrus, Rhizosolenia, Detonula, Nitzschia, Chaetoceros* and *Skeletonema* and dominant genera for dinoflagellates are *Ceratium, Prorocentrum* and *Gymnodinium*. The nannoplankton (< 20 μm) composed by small diatoms, naked dinoflagellates and autotrophic protozoa have not received attention. Small phytoplankton, including nanno and picoplankton, may account for a large proportion (> 60%) of primary production and chlorophyll-a concentration in coastal waters of the NUP (Gonzalez *et al.* 1998, Iriarte *et al.* 2000). Also within the OMZ large amount of small *Prochlorococcus* and *Synnecococcus* have been recorded, utilizing light under low oxygen conditions. Adaptations under these particular conditions may give rise to a large amount of genetic variability, which deserves some molecular approaches to elucidate species and tackle biological diversity. This remarkable lack of knowledge can also be extrapolated to the microbial compartment in the NUP. Large amounts of bacterioplankton and protozoa are expected associated with phytoplankton blooms upon upwelling, but the study of biodiversity of these components may expect a long wait, before being carried out.

Zooplankton in the NUP has received some more attention. Although dominant species can be considered as part of the subantarctic fauna, they mix with some species of tropical and equatorial origin. The most studied groups are copepods (Heinrich 1973, Vidal 1975, Hidalgo and Escribano 2001) and euphausiids (Antezana 1978, Fernandez *et al.* 2002). Among copepods about 50 species have been recognized, of which the dominant one are the herbivores *Calanus chilensis*, *Centropages brachiatus*, *Paracalanus parvus*, *Eucalanus inermis*. *C. chilensis* is an endemic species of the HCS (Marín *et al.* 1994), whereas *C. brachiatus* and *P. parvus* are cosmopolites and widely distributed along the Chilean coast. *E. inermis* is a typical tropical species. In the NUP however the genus *Eucalanus* may contain about 6 species which have not being clearly defined (unpublished data). Small copepods are also abundant components of the epipelagic zooplankton among which the dominant genera are *Oithona* and *Oncaea*. Among euphausiids the endemic species of the HCS *Euphausia mucronata* should be mentioned because of its high abundance, wide distribution and its close association with the OMZ (Antezana, 1978). This species forms large aggregations in upwelling centers off northern Chile, possibly interacting with early stages of anchovy during the winter spawning season (Escribano *et al.* 2000). *Euphausia eximia* is another abundant species, which increases in number during the El Niño (Antezana 1978, Gonzalez *et al.* 2000). Gelatinous zooplankton may exhibit large seasonal variation in abundance (Gonzalez *et al.* 2000), but taxonomic studies on this group have not yet developed. Other important components in the pelagic ecosystem of the NUP are mesopelagic fishes. There are few studies dealing with this group, mostly represented by myctophidae (Sielfeld *et al.* 1995), but their early life stages are abundant components in the upwelling center off Mejillones Peninsula (Loeb and Rojas 1988, Rojas *et al.* 2002), suggesting that myctophid fishes may subtantially contribute to total biomass of the pelagic system in this province.

Studies on trophic interactions in the pelagic ecosystem of the NUP have not been carried out. The strong fishery of northern Chile is mostly sustained by the anchoveta *Engraulis ringens* and sardine *Sardinops sagax*. Early stages of these small pelagic fishes are known to feed on microplankton, composed by a mixture of diatoms, flagellates, copepod eggs and nauplii, whereas late stages might well prey upon abundant copepods aggregated in the coastal upwelling zone. Euphausiids however might exert a strong predation on anchovy eggs, which may also be exposed to a strong predation pressure by abundant gelatinous zooplankton. Therefore, early mortality of small pelagics may strongly depend on size-dependent, or top-down processes. These potential interactions require urgent studies to evaluate their roles in regulating population dynamics of small pelagics in the NUP.

Interannual variability upon the ENSO cycle may impose abrupt changes in the structure of the pelagic ecosystem of the NUP. During the warm phase, i.e. El Niño small diatoms and flagellates dominate coastal waters, accounting for most of the primary production (Iriarte *et al.* 2000), replacing the large diatoms and dinoflagellates that dominate during cold upwelling conditions. Species replacements also occur in the zooplankton associated with El Niño/ vs non-El Niño regimes (Hidalgo and Escribano 2001). Large copepods and euphausiids, mainly *Calanus* and *Eucalanus* genera, dominate during upwelling, whereas during El Niño cyclopoid copepods, *Paracalanus* and *Acartia* take over the zooplankton compartment (Gonzalez et al. 2002). Warm conditions during El Niño may also cause a reduced size of copepods at maturity (Ulloa *et al.* 2001). All these changes in structure of the pelagic system may have profound implications for functioning and productivity of the NUP and should also be considered in ecosystem studies.

6. THE CENTRAL/SOUTH UPWELLING PROVINCE (CSUP)

The CSUP presents several coastal upwelling centers (Fonseca and Farías 1987), although with strong seasonal variation. Upwelling intensifies during the spring-summer period (Bernal et al. 1989, Shaffer *et al.* 1999), and downwelling may occurr during the winter due to prevalence of strong north wind. The continental shelf is wider (ca. 40 km from the coast), and sometimes interrupted by submarine canyons (Sobarzo *et al.* 2001). River runoff, and rainfall is important in this area and low salinity waters can extend way offshore during the winter-early spring period, in association with waters flowing northward from the fjord area (Strub *et al.* 1998). Some of the highest primary production values have been obtained here, which sustain one of the largest fisheries in the world ocean (Daneri *et al.* 2000). The OMZ in this area is deeper (> 100 m) and less intense (> 0.5 ml/L) than in the NUP. Studies on physical-biological interactions in the CSUP are scarce. Peterson and Bellantoni (1987) examined the influence of water column stratification, phytoplankton size and copepod fecundiy off Concepcion (36º S) while Peterson *et al.* (1988) studied the coupling between primary and secondary production in this productive upwelling center. Additional studies have dealt with vertical distribution and spatial variation of dominant copepods (Castro *et al.* 1991, 1993). More recent studies have been focused on physical-biological interactions of early life stages of clupeids in the upwelling zone off Concepcion (Castro and Hernandez 2000, Castro *et al.* 2000). A major conclusion from all these studies suggests that mixing and advection can have a strong influence on population dynamics of dominant zooplankton and small pelagics. Thus, there seems to be that bottom-up pressure may be more important in regulating pelagic populations in the CSUP, as compared to the NUP where biological interactions might have a greater influence.

Biological diversity of the pelagic system of the CSUP differs somehow from the NUP. Phytoplankton is dominated by large diatoms for most of the year (Avaria and Muñoz 1982). Zooplankton share species between the CSUP and NUP. Among dominant herbivores, the endemic species *C. chilensis* and *E. mucronata* distribute to mid latitudes (45º S). The CSUP however exhibits a fauna mostly originated in the subantarctic zone. Large copepods are represented by the abundant *Rhyncalanus nasutus* and *Calanoides patagoniensis* (Arcos 1975, Castro *et al.* 1991), whereas euphasiids are well represented by the the abundant *Thysanoessa gregaria* and *Euphausia lucens*, which become more abunant farther south at the fjiords region. Macroplankton, including gelatinous species, have been identified off Valparaíso (Palma 1973, 1994, Palma and Rosales 1995). About 45 species among hydrozoa, siphonophore, ctenophore, chaetognath and appendicularia have been identified (Palma and Rosales 1995).

Small Pelagics are also important fishery resources in the CSUP. The anchovy *E. ringens* maintains a population distributed between 32º and 40º S. This population appears as distinct and geographically separated from the population in the NUP. Interbreeding is uncertain and how much these populations differ to each other may require some molecular tools to elucidate. The jack mackerel, *Trachurus murphyi*, is a major fishery resource in the upwelling zone between Valparaíso (33º S) and Arauco Gulf (38º S). This species however exhibits large-scale migrations and is widely distributed in the Pacific ocean, so that it has been difficult to identify and allocate populations to specific geographic locations. The identification of target populations to tackle problems about population dynamics of this species is an important issue for managing this resource, but also to answers questions regarding its ecology, and this may need some molecular work. Crustacean Galatheidae are also important components of the CSUP fishery economy. From about 16 species identified in Chilean waters (Retamal 1981), only two of them *Pleuroncodes monodon* and *Cervimunida johni* have been subjected to exploitation. Although these species are distributed from Peruvian to southern Chile waters the fishing area has been restricted between 30º and 37º S (Palma 1994). The Chilean hake *Merluccius gayi* should also be mentioned as an important biological resource in the CSUP. This species inhabitat mid-depths at about 200-400 m mostly feeding on euphausiids (Melendez 1983/84, Arancibia 1989).

Studies on trophic interactions in the CSUP have been mostly focused on prey items used by commercial fishes after stomach analyses. Much work has been done on feeding behaviour of jack mackerel. This species may exhibit a wide food spectrum, but euphaudiids are a major component ot its diet. Other preys are mycthopids, anchovies, copepods and chaetognath (Medina and Arancibia, 2002). From these studies it appears that euphausiids, which may form dense aggregations in coastal waters of the CSUP (Antezana 1970), are a key trophic link between phytoplankton and fish production, sustaining large biomasses of jack mackerel and Chilean hake. It is unfortunate however that ecological studies of euphausiids in the CSUP do no exist and this is an issue also needing urgent attention.

7. RELEVANT TASKS AND PENDING STUDIES FOR ECOSYSTEM MANAGEMENT OF THE HCS

There are many issues considered to be relevant for management purposes, which may need attention. However each system has unique features that ought to be taken into account when dealing with biological productivity and sustainable development. A major point to be considered regarding the pelagic system of the HCS has to do with particular processes, which help maintain and enhance biological diversity, productivity and sustainability. Understanding these processes and their mechanism by which they regulate biodiversity and production is a key issue. From this rather brief description of the HCS, the following processes are suggested to be key study targets:

1. Interannual variability upon the ENSO cycle. Much work on El Niño phenomenom has been carried out, mostly in the Peruvian system (Arntz and Fahrbach 1996). However how the whole Chilean HCS responds to year-to-year variability associated with the cold and warm regimes of the ENSO cycle is an open question.

2. The biogeochemical role of the OMZ. This particular feature of the HCS may have a key role in the cycling of bioelements in the HCS ecosystem. Low oxygen may favour high rates of denitrification influencing new production in coastal upwelling systems. The distribution and intensity of the OMZ, as well as its variability need to be known and understood.
3. 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.

4. 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.

5. Biological diversity and trophic interactions are certainly relevant aspects of ecosystem studies. It is necessary to clearly define biological components and how they connecto to each other. This would give us much insight on the pathways of carbon and nitrogen through the food web. A conceptual scheme of the pelagic food web is a basic task to develop ecosystem modelling of the HCS.

6. I have not distinguished ecosystems of the HCS in the vertical plane. The permanent pycnocline in the NUP and seasonally in CSUP may be considered a physical boundary that allow vertical comparatments of species assemblages. The presence of an almost permanent OMZ, separating the upper euphotic zone and the IAAW may also act as a barrier for many zooplanktonic species, such that distinct ecosystems with their own energy flows and biological communities might develop in the vertical axis. These ecosystems need to be defined and their major components identified, as well as their trophic interactions.

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