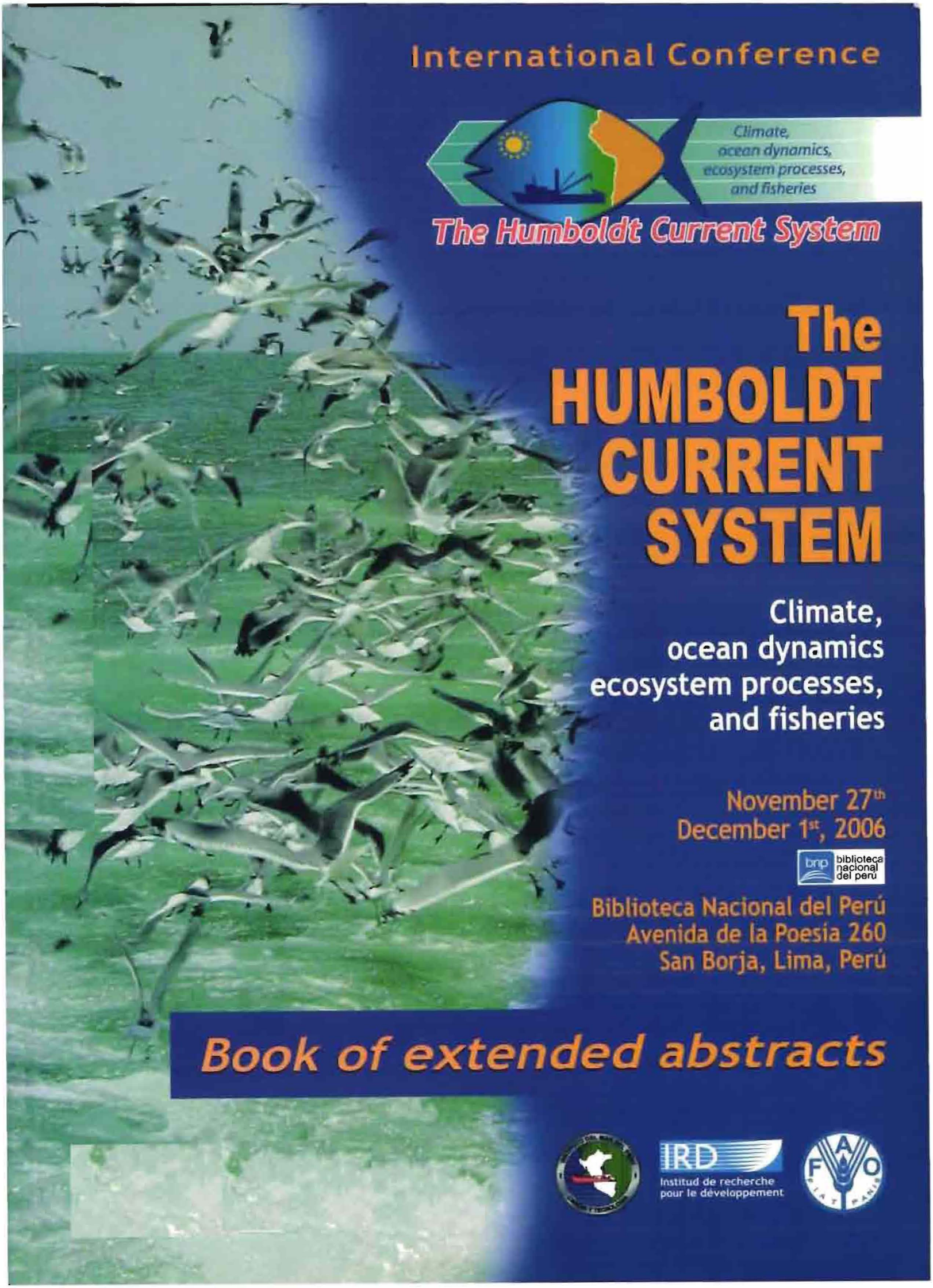

International Conference

Climate, ocean dynamics, ecosystem processes, and fisheries

The Humboldt Current System

The HUMBOLDT CURRENT SYSTEM

Climate, ocean dynamics ecosystem processes, and fisheries

November 27th
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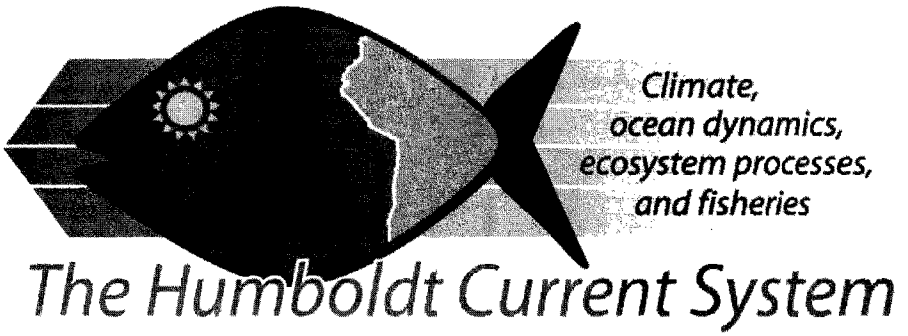

International Conference on
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Book of extended abstracts

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Foreword

The ocean off the west coast of South America is notable for several reasons. First, it produces more fish per unit area than any other region in the world oceans. It represents less than 1% of the world ocean surface, but accounts for up to 20% of the world fishing catches. Second, it is intimately linked to the ocean-atmosphere coupling over the tropical Pacific, and therefore subject to interannual, decadal and secular fluctuations in regional ocean climate. Third, it is a low oxygen and intense de-nitrification area, contributing significantly to global budgets. One of its main features is the existence of the most intense, extended and shallow Oxygen Minimum Zone (OMZ) of the open ocean. Its presence allows for the preservation of a detailed record of the climate and ecosystem history in the laminated sediments of the continental shelf over the past millennium and beyond.

An outstanding synthesis on the dynamics of the Peruvian Upwelling Ecosystem with special reference to anchovy was produced by IMARPE in conjunction with ICLARM (now World Fish Center) and the *Deutsche Gesellschaft für Technische Zusammenarbeit* (GTZ) during the mid 1980s and published as conference proceedings in 1987 and 1989. These publications continue to serve as major references for the Humboldt Current System (HCS).

Since the 1980s, important technical and conceptual advances have transformed many areas of marine sciences. These changes provide new background to re-examine the complex links and feed-backs between climate, ocean circulation, biogeochemical cycles, trophic webs and fish production. For example, are the ecological disturbances associated with large interannual to multi-decadal climate fluctuations one of the factors somehow responsible for the overall high levels of long-term fish production? New *in-situ* and satellite observing capabilities, long-term and multi-variable series of data, improved data analysis, and ocean modelling tools can now provide a view of the dynamics of the HCS within a multidisciplinary context. Operational fisheries management is also evolving from a mono-specific approach towards an "Ecosystem-Based" paradigm. This new approach, likely to be embraced in the 21st century, appears to be particularly appropriate for the HCS, in which the uncertainty associated with interannual and decadal variability and regime shifts in the context of global warming constitutes a major challenge for oceanography, ecology and fisheries research and management.

In this context, there was a clear need, which now became an opportunity, to undertake a new integration and synthesis in our understanding of the Humboldt Current System. The idea of organizing the present Conference arose in Lima in 2004 during a workshop gathering marine scientists from Chile, Peru and France within the framework of an interdisciplinary working group organised by IRD. The IMARPE, the *Institut de Recherche pour le Développement* (IRD, France), with the technical support of the Food and Agriculture Organisation of the United Nations (FAO), made a proposal which received very positive echoes from the international scientific community and was supported by international and national institutes, organisations and projects. We would like to warmly thank the International Council for the Exploration of the Sea (ICES/CIEM), the North Pacific Marine Science Organization (PICES), the "Global Ocean Ecosystem Dynamics" (GLOBEC) and "Integrated Marine Biogeochemistry and Ecosystem Research" (IMBER) IGBP–SCOR projects, the European network of excellence EUR-OCEAN, and two space agencies, the *Centre National d'Etudes Spatiales"* (CNES, France) and the National Aeronautics and Space Administration (NASA, USA) for their scientific and financial support. We also kindly acknowledge the Peruvian *Consejo Nacional de Ciencia, Tecnología e Innovación Tecnológica* (CONCYTEC), the French *Ministère des Affaires Étrangères* (MAE), the French Embassy in Peru, and the *Alliance Française* of Lima for their support. We would like to warmly thank also the private corporations which sponsored the Conference, namely ARCOPA (Peru), CLS Argos (France), CLS Peru, SIMRAD (Norway), and the *Sociedad Nacional de Pesquería* (SNP, Peru).
Special thanks go to the National Library of Peru (*Biblioteca Nacional del Perú* – BNP) which provides its new facilities for the organization of the Conference.

Thanks to all of these partners we were able to offer total and partial grants to more than 70 scientists and students from 10 countries. This was an important duty for us. We are also much

fulfilled that distinguished scientists accepted to present magisterial conferences and warmly thanks Andrew Bakun, Richard Barber, Boris Dewitte, Daniel Pauly and Elie Poulin for their kind participation.

In total, more than 210 scientific contributions will be presented during the five days of the Conference. As multidisciplinary is an important keyword for this Conference, we chose to avoid parallel verbal sessions and the 73 verbal communications will be presented in plenary assembly and all posters will have a brief verbal presentation. We hope that this choice will encourage discussions between disciplines and that physicists will actively participate to the sessions more dedicated to ecology and vice-versa. We all have to learn from each-other if we aim at resolving the challenges that face our Blue Planet. This requires complete cooperation and understanding between disciplines and nationalities.

Enjoy the Conference!

The Conveners, Arnaud Bertrand, Renato Guevara and Pierre Soler

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Keynote speakers

Daniel PAULY

Trophic Modeling of the Peruvian Upwelling Ecosystem: Towards Reconciliation of Multiple Datasets

Daniel Pauly, Sylvie Guénette and Villy Christensen

Sea Around Us Project
Fisheries Centre, University of British Columbia, Vancouver, Canada

In the 1980s a major project was conducted by IMARPE, in collaboration with many foreign experts, to study fisheries-related aspects of the Peruvian part of the Humboldt Current System and to construct long (30 + years) time series of catch, biomass and other important features of the Peruvian anchoveta, *Engraulis ringens*, along with (and partly based on) time series of abundance of anchoveta predators and competitors, as well as of abiotic parameters indicative of the dynamics of the Peruvian upwelling system.

This work, documented in two data-rich edited volumes, represented the state-of-the-art in single and multispecies fish population dynamics at the time, lead to a fair description of the Peruvian anchoveta predation, and of its responses to environmental cues, but did not allow for any measure of predictability. Simultaneous efforts at constructing an 'anchoveta-centred' model of the Peruvian ecosystem, based on coupled differential equations, failed.

This contribution documents our attempt to reinitiate modeling of the Peruvian upwelling ecosystem, based on a detailed ecosystem model constructed using the Ecopath with Ecosim (EwE) software, and fitted with the time series mentioned above. Preliminary results show that the time series of biomass, particularly of Peruvian anchoveta and its various predators (notably bonito and sea birds), can be reproduced by the EwE model only if various mechanisms are invoked which were not part of the original description of the Peruvian upwelling system. For example, a switch in dominance between large and small phytoplankton can induce abundances shifts between sardines and anchoveta. Similarly, only by assuming a 'mitigating' relationship between bonito and seabirds (wherein the once abundant bonito drove anchoveta near the surface where they became available to sea birds) could the model be made to reproduce the 1965 collapse of the seabirds.

Mechanisms of this sort, here proposed in a very tentative fashion, will have to be firmly established and quantified before a model can emerge that can harmonize the various time series available on the Peruvian upwelling system, and which can be used as part of fisheries management with an ecosystem perspective. The prospect of this happening is, however, very good, and we seek in the present contribution to give research directions for how to move toward this goal.

Boris DEWITTE

ENSO in the South Eastern Pacific ocean: the connection with Equatorial Kelvin waves

Boris Dewitte[1,2]

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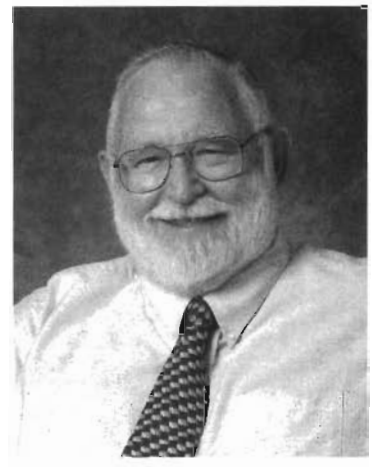
Peruvian fishers are credited with giving the name 'El Niño' to the unusual coastal warming that occurs around Christmas along the South American coast. It was further discovered that El Niño was not just a regional phenomenon but the signature of a large scale climate fluctuation that involves the whole tropical Pacific ocean-atmosphere system. Thirty years ago, very little was known about El Niño. Today, matters are very different, in part because scientists have made enormous strides in observing, explaining, simulating by means of numerical models, and predicting El Niño. In particular, the international TOGA (Tropical Ocean Global Atmosphere) program (1985-1994), an impressive array of instruments, now monitors the equatorial Pacific continuously. This observational network allows following and documenting the major changes in the circulation of the tropical Pacific Ocean that accompany the alternate warming and cooling of the surface waters of the eastern equatorial Pacific as they happen. As an extension of the equatorial wave guide, the west coast of South America experiences related significant changes in oceanic conditions that drastically affect its very productive ecosystem. How ENSO impacts the Peru/Chile coast is a major concern of the scientific community. The latter has to deal with a complex problem due to the variety of timescales and ocean dynamics involved which link the central equatorial Pacific variability to the coastal upwelling at the extra-tropical latitudes.

In this presentation, an overview of our current knowledge on ENSO is proposed, focusing on remaining unresolved scientific issues that are relevant to the understanding of the teleconnections between the equatorial variability and oceanic conditions of Peru and Chile. Current warm conditions in the tropical Pacific from observations and model simulations are also documented.

Richard BARBER



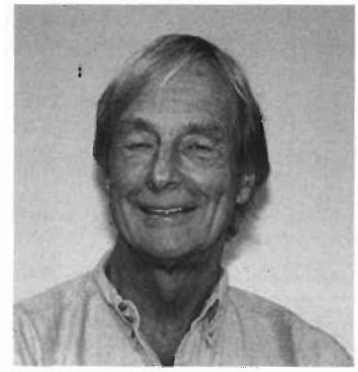
Ocean dynamics and biogeochemistry of the Humboldt Current System

Richard T. Barber

Duke University, Beaufort, NC, 28516, USA

Since the beginning of the Peruvian anchovy fishery in the late 1950's, scientists in Peru as well as many from Europe and North America, have studied the dynamics and biogeochemistry of the coastal upwelling ecosystem that is an integral part of the Humboldt Current System. Work on this system has produced many major advances such as John Ryther's classic 1969 paper entitled "Photosynthesis and fish production" or the predictive understanding of the ENSO cycle and its biological consequences in coastal ecosystems. Because of the strong physical variability in this region and strong physical-biological coupling in coastal upwelling ecosystems, it has been hypothesized that it should be possible to forecast how coastal upwelling systems and their fish resources will vary in response to natural climate variability, man-made perturbations or different fishing strategies from the knowledge of a few biological, physical and meteorological variables. Furthermore, it is also assumed that it is possible to forecast the ecosystem variability far enough in advance (6 to 9 months) to be useful to resource managers. The Humboldt region is an excellent place to test this provocative hypothesis because in addition to the world's largest single-species fishery, it is a extremely variable ocean ecosystem that is forced mainly by well understood climate variability. Because of the global importance of both ENSO variability and the anchovy fishery, this region has a good combination of environmental observations, historical fish data, comprehensive fish monitoring and climate forecast models that can be used to force high-resolution ecosystem and anchovy population models. This presentation will review the history of progress in understanding the dynamics of the Humboldt Current System and discuss a final aspect that may remain to be mastered, decadal climate forcing.

Andrew BAKUN



The Marine Ecosystem off Peru: What are the secrets of its fishery productivity and what might its future hold?

Andrew Bakun[1] and Scarla J. Weeks[2]

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[2]*PIOS Research Associate, Centre for Marine Studies, University of Queensland, Brisbane, Australia*

The marine ecosystem located off the coast of central and northern Peru has stood as the "world's champion" producer, by far, of exploitable fish biomass, generally yielding more than twenty times the tonnage of fishery landings produced by other comparable regional large marine ecosystems of the world's oceans that operate under similar dynamic contexts and are characterized by comparable, or even greater, basic primary production. Two potentially contributing aspects are discussed from a framework of interregional comparative pattern recognition: (1) the advantageous low-latitude situation that combines strong upwelling-based nutrient enrichment with low wind-induced turbulence generation and relatively extended mean "residence times" within the favorable upwelling-conditioned near-coastal habitat, and (2) the cyclic "resetting" of the system by ENSO perturbations that may tend to interrupt malignant growth of adverse self-amplifying feedback loops within the nonlinear biological dynamics of the ecosystem.

There is a developing scientific consensus that one of the more probable consequences of impending global climate changes will be a general slowing of the equatorial Pacific Walker Circulation and a consequent weakening of the Pacific trade wind system. Since the upwelling-favorable winds off Peru tend to flow directly into the Pacific southeast trade winds, a question arises as to the likely effect on the upwelling-producing winds that power the productivity of the regional coastal ecosystems of the Peru-Humboldt Current zone. It is argued that the effects will in fact be decoupled to the extent that upwelling-favorable winds will actually tend to increase off Peru. Data suggestive of this decoupling, as well as supporting dynamical arguments, are presented. Current imponderables regarding potential effects on characteristic intensity of future El Niño perturbations and on nutrient content of upwelled waters are posed.

Elie POULIN

Genetic diversity of small pelagic fish in the upwelling systems of the Eastern Pacific

Elie Poulin[1], Andrea Silva[1] and Patricio Ojeda[2]

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Species belonging to genus Engraulis, Trachurus and Sardinops correspond to small pelagic fishes especially widespread in the Humboldt and Californian Currents. These species share important life history traits such as living in large schools, having high mobility and very large population size. Moreover, they inhabit highly productive upwelling systems that undergo cyclic variation in environmental conditions. Population size variation and biological regime shift of small pelagic fish species have been well documented and are associated with different time-scale events affecting ocean productivity such as El Niño-La Niña cycles (ENSO), Pacific-Decadal Oscillation (PDO) and probably beyond at millennial scales. These changes in abundance are also associated with major shifts in the distribution ranges of the species, suggesting that favourable habitat expands and contracts over different time scales related to changes in the ocean environment. In this context, we investigated how biological and environmental factors influence the genetic diversity of small pelagic fishes in both Humboldt and Californian Currents through the analysis of mitochondrial Control Region of Engraulis, Trachurus and Sardinops species. Results indicate the absence or low level of genetic differentiation along Chilean and Peruvian coast probably as a consequence of high dispersal in pelagic fishes. However, high dissimilarity in genetic diversity has been detected among genus and may reflect differences in demographic history. Such difference is also found among jack mackerel, sardine and anchovy species in the California Current, which may illustrate the difference in which these genera respond simultaneously in both Hemispheres to global climatic and oceanographic variation at different temporal scales.

Acknowledgements: Fondecyt n°1040785, IEB P05-002, CASEB, IMARPE.

Renato GUEVARA-CARRASCO

Fisheries in the Peruvian upwelling ecosystem: more than fifty years learning how to deal with environmental uncertainty

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Fishing is the most important economic activity in the Peruvian coastal marine ecosystem. Environmental variability and particularly the high abundance of a small pelagic species, the Peruvian anchoveta (*Engraulis ringens*), have strongly influenced its development. The export value of Peruvian fishery products is around one billion dollars per year and fishing provides direct employment to around 100 thousand people (PRODUCE, 2003).

The Peruvian coastal zone is characterized by an intense upwelling which makes this area so highly productive. Although seasonal and interannual upwelling variability has always been a strong source of uncertainty affecting reproductive success and other biological processes influencing the short term productivity of the exploited species, is the longer term variability (3-12 years) produced by El Niño that has had the greatest effects on the development of fisheries in Peru, mainly due to its strong short and mid term impacts on the ecosystem and the fishery resources, lasting from one to several years This has led towards the implementation of a set of practical tools for the management of the main fisheries and fishery resources, including anchoveta, sardine (*Sardinops sagax*), jack mackerel (*Trachurus murphyi*), mackerel (*Scomber japonicus*), hake (*Merluccius gayi peruanus*) and giant squid (*Dosidicus gigas*).

Besides El Niño and the observed alternation in the periods of high abundance of anchoveta and sardine, a new source of environmental variability at a longer time scale has been recognized. The now called multi-decadal periods of El Viejo and La Vieja (Chavez et al., 2003). Evidences in support of this hypothesis has led to a rethinking of the processes involved in the observed over-exploitation and temporary depletion of some fishery resources off the Peruvian coast, the incorporation new elements in fisheries management process including the adoption of preventive measures regarding El Niño and its effects on the marine populations and related fisheries.

Remarkable observations have been made in the last 50 years regarding the natural variability of fishery resources and its effects on the fisheries sector. Active research has been made regarding the great changes in the pelagic system, including the alternation of the high abundance periods of anchoveta and sardine, the over-exploitation of anchoveta and the collapse of this fishery in 1971-72, and the over-exploitation of sardine in the 1990s (Csirke et al., 1996). Regarding the demersal system, active research work have focussed on the changes in the hake spatial distribution during the first years of the 1990s, the causes of its over-exploitation and the successive closure of this fishery by the end of 2002 (Guevara-Carrasco, 2004), as well as in the notable reduction in the diversity of its by-catch species.

Extended discussions have centered on whether the natural or the anthropogenic factors have been more important in the triggering and subsequent development of these and other events affecting the Peruvian fisheries. Preliminary findings indicate that these major crises have occurred in periods of change of phase in some environmental variables, with each phase having a mid to long term duration. The poor knowledge and lack of tools to forecast the direction of the environmental signal, added to a weak application of fisheries management measures and the non adherence to the precautionary approach criteria, all have contributed to delayed or erroneous decisions, or to simply not having these properly implement. Excess fishing capacity has also played an important role.

The full adoption of an ecosystem approach in the Peruvian fisheries will require, amongst others that a more accurate estimation of the various "equilibrium stages" of the coastal marine ecosystem be made in setting the limits for a sustainable exploitation of the abundant but highly variable Peruvian fishery resources.

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Verbal communications

HCS152 - Multiproxies of recent oceanographic and climate changes from laminated sediments of the Central Peruvian Margin

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Keywords: Humboldt system, Geochemistry, Mineralogy, Paleoproductivity; Upwelling, Peru

Introduction- The Peru–Chile margin is characterized with varying patterns of high surface-water productivity and high organic carbon fluxes (Thomas et al., 2001) as well as an intense Oxygen Minimum Zone (OMZ). The combination of high productivity and near-anoxic conditions over the bottom result in the preservation of upwelling signals in the sediments by organic and inorganic geochemical processes, especially off the central Peruvian coast. We report here the results of a systematic study using organic and mineral content markers which reveal, at different time-scales, past changes in intensity and extension of the OMZ, as well as paleoproductivity, linked to different oceanographic and climate conditions.
Methodology- Two box cores were collected in these continental margin areas: in the shelf off Callao (B0405-13, 12°00'S, 72°42'S, 184 m) and in the upper slope off Pisco (B0405-06, 14°07'S, 76°30'S, 299 m). The qualitative and quantitative mineralogical composition was obtained by X-Ray Diffraction (XRD) and by Fourier Transformed Infrared Spectrometry (FTIR) respectively. For FTIR analyses, samples were placed in a KBr disc, which ensures that Lambert-Beer's law is valid. A quantitative determination of the mineral content from various blends was performed by making a multi-component analysis of the experimental spectrum using the spectra of each component in the mixture (Bertaux et al., 1998). Organic matter characterization and quantification were done using Rock-Eval 6 programmed pyrolysis, from which the following parameters were obtained: total organic carbon (TOC), hydrogen index (HI), expressed as mg HC/g TOC, and oxygen index (OI) expressed as mg CO2/g TOC.
Results and discussion- In order to estimate the representatively of the environmental proxies and their relationships, we applied two statistical tests. A principal component analysis of the proxies shows that, in both sites, more that 74% of variance is explained by two factors. The first principal component factor indicates a negative correlation between the terrigenous fraction (quartz, feldspar and clays) on one hand and biogenic calcite and TOC on the other hand. The second factor is explained by the organic fraction, which marks a negative correlation between the quantity (TOC) and the oxic degradation (OI; Oxygen Index) of marine sedimentary organic matter. The parallel dowcore variation of the two factors in the Pisco and Callao sites indicates that the studied proxies have a regional significance and that they mark a clear shift at ~1830 AD. To confirm this interpretation we applied an ANOVA test, which shows that, before and after 1830 (AD), the mineral and geochemical proxies have significant differences. Based on these results, we interpret that before 1830 (AD), there was a higher terrestrial input related with more humid conditions in the continent and/or an intensified phase of the coastal rculation. These environmental conditions may be associated with water column characteristics responsible for the lack of calcite record due to dissolution processes. From 1830 to 1870 (AD), the increase of factor 2 values, related to higher values of OI, can correspond to an episode marked by a high oxygenation of the water column favouring the oxidation of organic matter. After that, we note a negative tendency of factor 2, dominated by the increase of TOC suggesting that productivity is the principal mechanism responsible for the enhancement of the anoxic conditions of the water column. The intensification of the negative tendency of factor 2, from 1950 to present, is explained by a TOC increase simultaneously with an abrupt IO decrease. These results indicate an enhancement of anoxic conditions generated by the intensification of productivity due to wind forcing. This interpretation is supported by the increase of factor 1, which is linked to terrigenous aeolian transport at the Pisco coastal zone. Records of instrumental data also show an enhanced intensity of alongshore winds during the same period. This change is not evidenced at Callao probably because its sedimentary record was affected by bioturbation near the core top.
Acknowledgements: This study is supported by the PALEOPECES project (IMARPE-IRD), PALEOTROPIQUE (IRD), the Humboldt Current System program (ATI-IRD) and the PCCC project (French national research agency ANR, P.I. B. Dewitte). We thank the Instituto del Mar del Peru (IMARPE) for full support of this research and acknowledge the crew of the RV José Olaya Balandra and other scientific participants in the box-coring survey.

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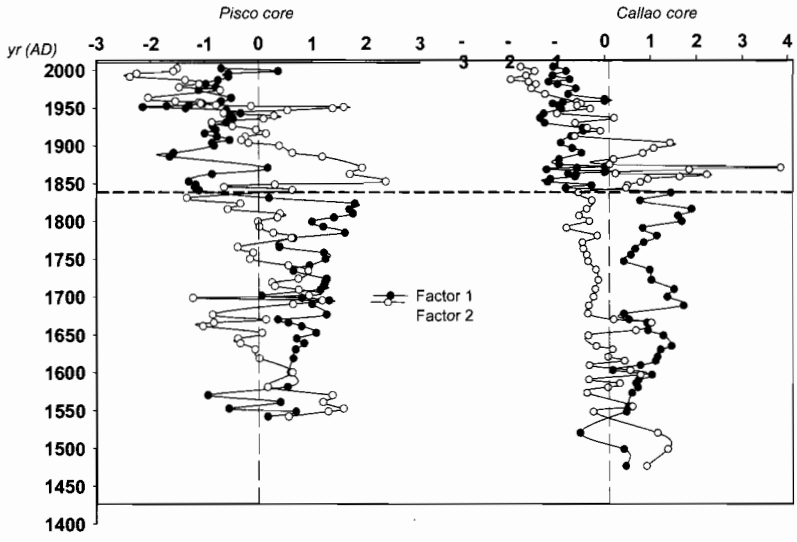

*Figure 1. Downcore variations of PC1 and PC2 Factors (*principal component analysis) *from Pisco and Callao zones.*

HCS030 - Climate control of Peru Margin Productivity and Denitrification over the last 20 kyr; Local vs Remote Forcing

M. A. Altabet, R. Agnihotri, T. D. Herbert, S. Higgins, and M. J. Higginson

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Keywords: Peru Margin, climate change, denitrification, productivity, sediment record

The Peru Margin sustains high biological productivity and important fisheries due to perennial coastal upwelling of nutrient-rich waters. The source of upwelled waters is the sub-surface, poleward flowing Peru Undercurrent which via the Equatorial underwater is sourced primarily in the Subantarctic Pacific. The combination of poor ventilation of this water mass and the high flux of organic matter from above creates suboxic conditions that extend far out into oceanic waters. Suboxia sustains water column denitrification which removes combined nitrogen from the ocean. The Peru Margin, thus also plays an important role in the global oceanic nitrogen budget. Peru Margin productivity and denitrification are likely sensitive to climate change on a variety of temporal/spatial scales through local wind forcing and/or remote ventilation of subsurface waters.

We have examined a series of high resolution cores from the upper Peru Margin using a multi-proxy approach using N isotopic composition to record denitrification intensity; major and minor elemental composition for sediment provenance, water column redox state, and productivity; alkenone UK37 for SST. Scanning XRF determination of major elemental composition has also been employed to achieve sub-decadal resolution. Similarly, digitized x-radiographs show sediment density to be a high-resolution record of the relative biogenic/lithogenic composition of the sediment.

Denitrification intensity is observed to vary sharply at a variety time scales. The last deglaciation experienced a sharp and early rise in Peru denitrification that preceded by 2 kyr any major changes in local productivity (Fig. 1). Forcing appears to be remote from the Peru upwelling zone, likely due to changes in either the ventilation of source intermediate waters in the Subantarctic and/or changes in the relative isolation of the 'shadow zone' from the subtropical gyre circulation. By contrast, the late Holocene is marked by large excursions in denitrification that are only centennial scale in duration and are unique to this region (Figs.1 and 2). These excursions are also marked by maxima in upwelling-driven productivity. A regime shift appears to have occurred in which local, productivity-driven forcing appears to dominate. Spectral analysis suggests that the late Holocene variations are linked to solar variability perhaps mediated by shifts in the latitudinal position of the ITCZ that would also influence ENSO sensitivity.

Both the remote and local modes of forcing inferred from the sediment record imply routes by which future climate change will impact the Peru Margin. If future warming causes the ITCZ to shift northward, increased productivity and denitrification may result. Similarly, southward shifts in the subantarctic westerlies, would further decrease ventilation of source waters and also increase suboxia and denitrification.

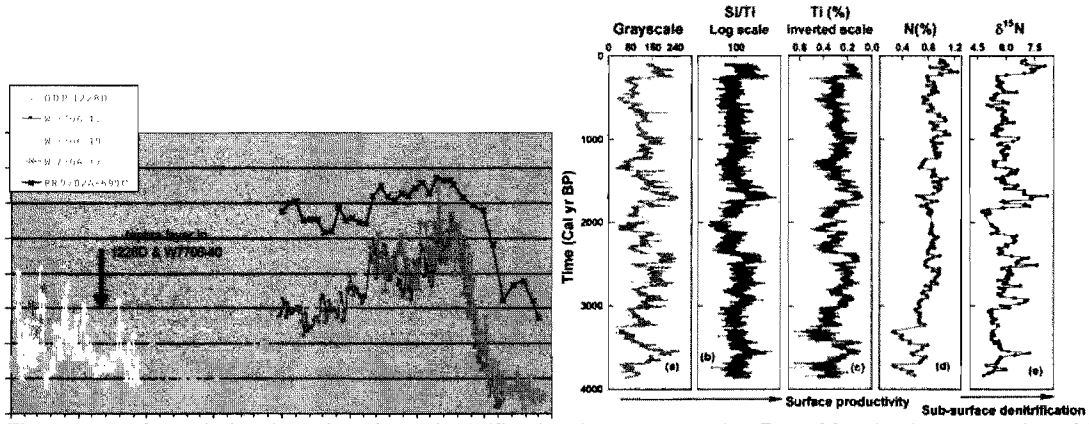

Figure 1. Left, variation in subsurface denitrification intensity on the Peru Margin during the last 20,000 years monitored by sediment N isotope ratio. Notable are the very rapid early deglacial rise, the mid-Holocene and LGM minima, as well as the centennial scale variability in the late Holocene. Right, Surface productivity variations on the mid-Peru margin during the last ~4000 years monitored by sediment density (x-radiograph grayscale, XRF Si/Ti, XRF %Ti, and % N (a-d). Panel 'e' shows sediment N isotopic ratio, a poxy for sub-surface denitrification, showing it to be controlled by surface productivity during this time interval.

HCS185 - High resolution diatom biostratigraphy and paleoproductivity for the past 300 years from the Lima and West Pisco basins, Peru

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Keywords: core sediments, diatoms, high resolution biostratigraphy, paleoproductivity, Peruvian upwelling, phytoplankton

Introduction- High Primary Productivity, distributed in discrete cells, is one of the most notable features of the Humboldt Current System along the Peruvian margin. Diatoms compose the dominant algal group in the modern phytoplankton followed by dinoflagellates, silicoflagellates, coccolithophorids and phytoflagellates. Continuous flux of dead organic matter to the seafloor in this nutrient-rich environment helps maintain anoxic conditions and results in the preservation of relatively undisturbed sedimentary sequences. The biogenic remains in these sediments, therefore, may reflect past fluctuations in productivity and elucidate the main species composition of primary productivity over the past few centuries. Thus, we investigate the paleoproductivity and variability in diatom species in 2 cores from Pisco and Callao, off central Peru that are taken in dysoxic sediments underlying upwelling regions of the coastline.

Methods- Two box cores were retrieved from the shelf off Pisco (14°07.9'S, 76°30.1'W, 73 cm length) and Callao (12°00.8'S, 77°42.64'W, 78 cm) at 299 m and 185 m of water depth respectively. They contain good sedimentary records with mm to cm-scale sedimentary laminations. An age model of core B0405-6 based on excess ^{210}Pb activities, bomb-derived ^{241}Am signals, and sediment structures derived from historically well-known seismic events, suggests a sedimentary record of approximately 300-yrs. The Age model from core B0406-13 is still in progress although we don't expect major deviations from that of the Pisco core. Samples for siliceous microfossils analysis were taken continuously every 3 to 8 mm following the main sedimentary structure. Mean sedimentation rate is 2.2 mm x yr^{-1} in the upper section of the Pisco core, which indicates that each of our sampled intervals may represent from 1.3 to 3.6 yr. Phytoplankton samples taken across the annual cycle from 2000-2005 at two different locations served as modern observations to interpret the diatom distribution and dominance. These phytoplankton samples were taken around the area of core retrievals at 20 n.m. from the coast and 10 m of water depth.

Results and conclusions- High-resolution records from box-cores B0405-6-IV (off Pisco,) and B0405-13-IV (off Callao) show important diatom species changes during the periods of deposition. Four diatom species dominated the relative abundance throughout the cores (Fig. 1). Following the Pisco core age model, we were able to discern 4 different sequences of diatom assemblages, which are present in both cores. The *Chaetoceros* resting spore group dominates the lower half of the core sediments and defines the first

diatom assemblage. This assemblage is present in the bottom half of the core from about 73 cm (around 1750 AD) to 33 cm and contains *Actinopthychus senarius, Cocconeis* sp., *Fragilariopsis doliolus* and *Thalassiosira eccentrica* as subordinated species. A second assemblage is found from about 33 cm (1850 AD) to 26 cm, and is dominated by the centric diatom *Skeletonema costatum,* with *Pseudo-nitzschia pungens*, *Pseudo-nitzschia australis* and *Prosbocia alata* as subdominant species. The third assemblage extends from about 26 cm (1880 AD) to 10 cm and contains abundant *Thalassionema frauenfeldii* and *T. bacillare* and a presence of *Coscinodiscus argus*. Finally, the fourth diatom assemblage represents the past 50 years with an important increase in *Thalassionema nitzschiodes,* coupled with the presence of *Actinocyclus octonarius* as a less dominant species.

Chaetoceros resting spores dominate the whole sequence, reflecting the active coastal upwelling system that overlies the sites. This group contains several morphotypes, all of which are present in the modern day upwelling coastal waters of Peru. Modern water column samples indicate high abundances of *Chaetoceros* spp. throughout the year with maxima during the summer. *Skeletonema costatum* follows a seasonal pattern with higher abundances in summer and fall. This species dominates the assemblage in eutrophic waters. Occurence of *Thalassionema frauenfeldii* generally peaks during winter. *Thalassionema nitzschiodes* is present throughout the year although with lower abundances than the aforementioned species. Although these 4 diatom assemblages characterize the Pisco and Callao cores, water column samples show a different characterization of the dominant diatom species. Species such as *Guinardia delicatula, G. striata, Leptocylindrus danicus* and *L. mediterraneus* were abundant in the water column but were not observed in the sediment cores. We hypothesize that the diatom assemblage suffers an active dissolution in the water column and on the seafloor before sedimentary burial. On the other hand, rare occurrences of freshwater diatoms were found downcore from the 25 cm level to the bottom of the Pisco core, which suggests that some valves reach the sedimentary site via pulses of riverine discharge originated in the Andes. Only a few freshwater diatom individuals were encountered in the Callao core. Total diatom concentrations are diminished in the lower half of the core (around 33 cm or 1850 AD) relative to the upper part and then decrease towards the top one. However, this decrease on diatom concentration near the core top is accompanied by a significant increase of the abundance of silicoflagellates, which may account for an important part of the paleoproductivity. The cause of the inferred increase in ocean productivity and shift in species composition in the middle of the XIX century is still unknown although it might be influenced by higher nutrient levels due to greater upwelling. Moreover, the increase of primary productivity is also supported by sustained increases in Total Organic Carbon, and preservation of calcite and benthic foraminifera by diminished oxygen levels. These combined evidences suggest a centennial-scale regime shift in the upwelling environment of the Humboldt Current off Peru

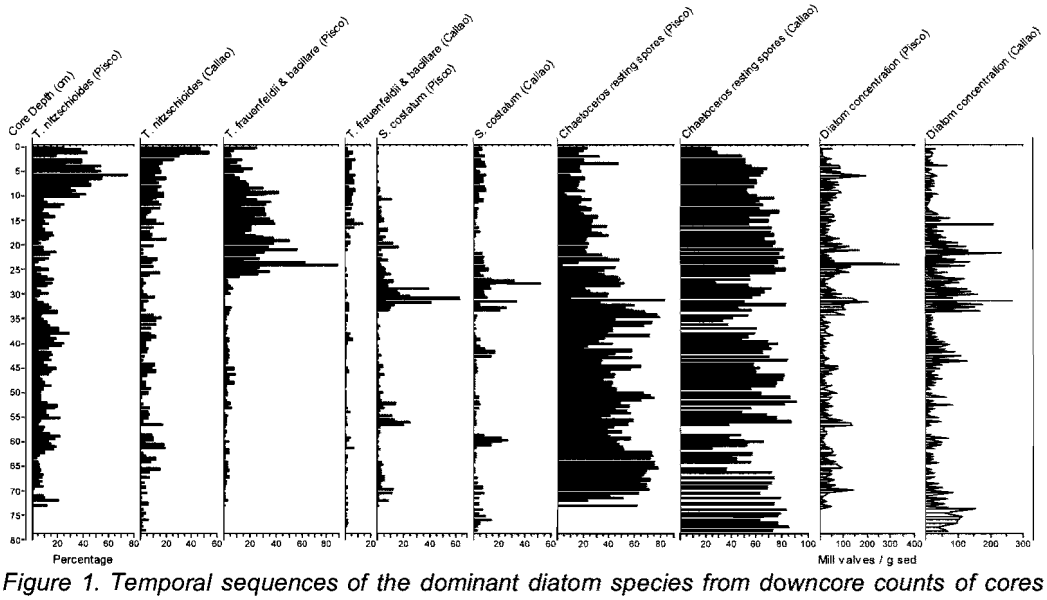

Figure 1. Temporal sequences of the dominant diatom species from downcore counts of cores B0405-6 (Pisco) and B0405-13 (Callao). Note that there are no data after the 73 cm level in the Pisco core.

HCS169 - Decadal to centennial variability of the Peruvian upwelling ecosystem during the last centuries as inferred from fish scale deposition rates of anchovy and other marine sediment records

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Keywords: anchovy, fish scale fluxes, Peru upwelling, marine sediment records

Introduction- The Humboldt Current System (HCS) undergoes large temporal variability at multiple time scales, which is mostly originated by climate and/or global changes. The ENSO cycle and other manifestations of climate and oceanographic interactions play a major role in both biogeochemical and ecological changes in the HCS. The length of instrumental records limits our current knowledge of the HCS variability to recent decades. Furthermore, multidecadal-to- centennial changes that have been detected in other marine systems are still largely unknown in the HCS. Fortunately, laminated sediments accumulating on the Peruvian continental margin provide paleo-archives of sufficiently high temporal resolution to resolve different modes of past climate and ecosystem changes in the HCS. In turn, revealing and understanding ecosystem changes of the system under different modes of variability can help develop scenarios of the HCS evolution for future decades, including the effects of the global change.
Because primary production and fish production can reach very high levels in the HCS, we focus our study on records of fish scale deposition from recent centuries, as a proxy of local fish biomass. In addition, we use records of total organic carbon to infer changes in primary productivity, which may be associated with fish biomass.

Methods- Four sediment cores spanning at least the past two centuries were collected at different dates from 1974 to 2004 in the upper continental margin off Callao, Peru (12°S), from water depths ranging between 179 and 305 m. Three of these cores were retrieved close to the shelf break (<190 m) within a distance of less than 3 miles (Figure 1). The cores were dated using sedimentation models derived from excess ^{210}Pb activity profiles and, in some cases, from radiocarbon analyses of organic matter. High resolution estimates of downcore fluxes of fish scales and other fish remains were calculated and compared between cores. Likewise records of total organic carbon and other sedimentological properties were also developed in some cores.

Results and Discussion- Within the twentieth century, fish scale fluxes from the different sediment cores exhibit similar patterns of variability on decadal time-scales. Anchovy and sardine scale fluxes near the core tops reflect the decline of anchovy biomass and the increase of sardine populations during the seventies and eighties, respectively. A boxcore (B0413) collected in 2004 also reflects the increase of anchovy biomass following the mid-nineties. These patterns support the use of fish scale flux as a proxy for biomass. Prior to the development of the industrial fishing activities, the highest anchovy scale fluxes are observed around the mid- twentieth century while an increase in sardine scale deposition was observed for the earlier decades of the twentieth century.
Looking backwards, the cores suggest the same multidecadal period of low fish scale deposition from the early twentieth century well into the nineteenth century, given the uncertainties associated with dating and redeposition of sediments within any given core. Observations of fissures in scales and downcore variations in the ratio of fish scales with respect to other fish remains in core B0413 suggest that dissolution of fish scales may have occurred with varying intensity through time. Nonetheless a reduction in associated fish remains that are less susceptible to dissolution (e.g. vertebrae and bones) is interpreted as reflecting an actual reduction of the flux of fish remains during much of the nineteenth century relative to other periods.
The reduction of fish scale fluxes can be attributed to lower fish biomass and/or a shift in the distribution of the population. However, total organic carbon contents in some of the cores indicate that productivity was reduced in parallel with the multidecadal period of low fish scale fluxes in most of the nineteenth century. This suggests that the ecosystem was characterized by lower primary productivity and reduced pelagic fish production, followed by a shift towards greater productivity during the twentieth century.
In conclusion, this study on past conditions of the HCS documents that, on decadal-to-centennial timescales, the Peruvian upwelling ecosystem can experience the same range in the sizes of anchovy and sardine populations as what was observed since the development of modern fisheries in the second half of the twentieth century.

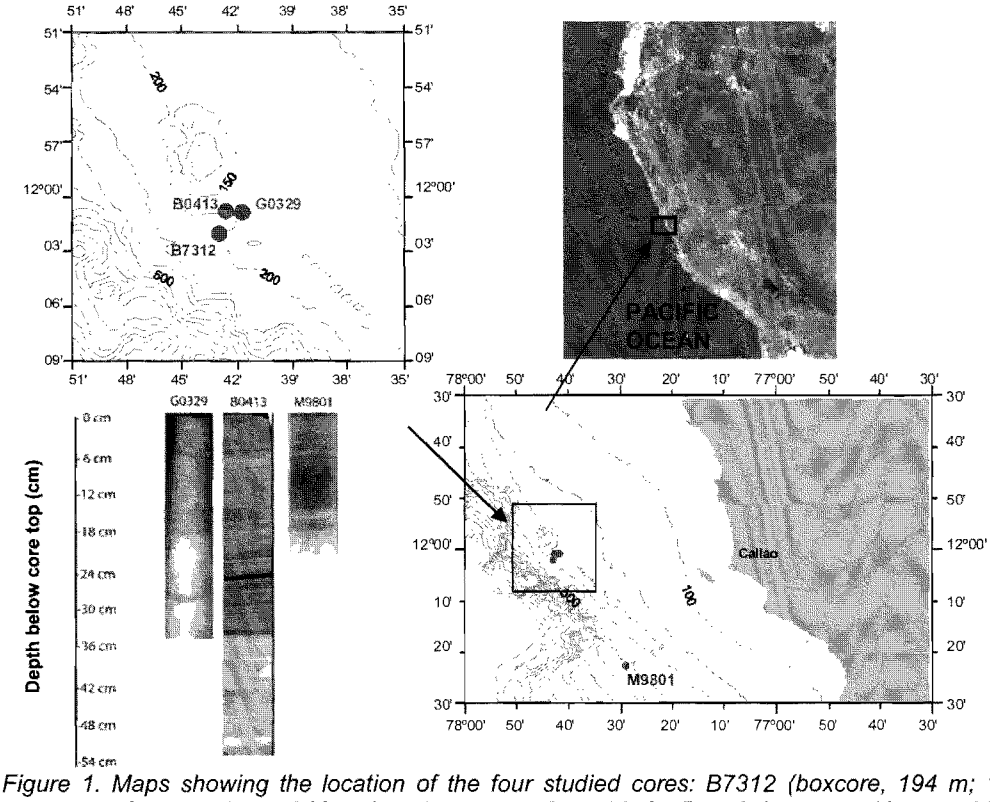

Figure 1. Maps showing the location of the four studied cores: B7312 (boxcore, 194 m; 1973), M9801 (multicore, 305 m; 1998), G0329 (gravity core, 179 m; 2003), B0413 (boxcore, 184 m; 2004), and X-ray radiographies of three of them.

HCS195 - Is long-term warming off the coast of Peru similar to that of the North Pacific?

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Keywords: Sea Surface Temperature, winds, warming, trend, Puerto Chicama

The Humboldt Current Ecosystem (HCE) is affected by large-scale climate forcing on multiple timescales. Although large decadal changes in the HCE have been observed in instrumental records, the nature of decadal-scale variability and the relative influence of the warming trend are unclear.
We examine the relative roles of decadal variability and the secular trend in Sea Surface Temperature (SST) and wind stress records from both coastal shore stations and oceanic data from International Comprehensive Oceanic and Atmospheric Database (ICOADS) off the coast of Peru. The longest coastal SST series comes from Puerto Chicama, Peru (8°S), spanning 1925- 2005, while other coastal monthly time series are from 1950-2005. Both interpolated ICOADS data products and the non-interpolated historical observations are examined from 1900-2005. These series are then compared with other SST series from the central and North Pacific. Measured SST variability is also placed in perspective of longer term variability with historical records from corals and marine sediments.
Decadal-scale variability in SST off Peru shows a similar correlation with the Pacific Decadal Oscillation (PDO) as other regions of the North Pacific. However, ICOADS SST data off Peru show a more clear secular warming trend and correlation with the PDO than coastal SST stations. We discuss the possibility that the lack of a trend in coastal SST stations may result from a concurrent increase in alongshore winds as well as the possibility that changes in data observation quality and interpolations have biased the trends in SST and alongshore winds. In contrast to the dominant interannual variability off the coast of Peru, SST records in the California Current have both a relatively greater proportion of variability associated with the PDO and a more coherent secular warming trend between coastal SST stations and COADS based data.
Paleoceanographic records from the California Current and tropical Pacific indicate that the warming since the mid-1970s is unlike prior decadal and centennial-scale variations and is best explained by the accumulation of greenhouse gasses in the atmosphere. This warming in the California Current occurs

despite an apparent increase in alongshore wind stress. A trend towards increasing wind stress and upwelling off California and Peru may be related to the increased atmospheric pressure gradients associated with 20th century warming. However, the relative influences of wind-induced upwelling and ocean-atmosphere heat exchange differ between the regions.

HCS053 - Interannual Variability of the Humboldt Peru/Chile Current System in 1997-98: a Modeling Study Using ROMS.

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Keywords: ENSO, Humboldt, Interannual Variability, Lagrangian Diagnostics, Mesoscale Processes, Numerical Modeling.

The Humboldt Peru/Chile Current System, flowing along the South American West Coast (SAWC) is the most productive eastern boundary current system. It is also the only upwelling region in direct connection with the equatorial ocean. A high resolution regional model (ROMS, 7km) encompassing the whole SAWC and its equatorial surroundings is used to investigate the mean circulation and mesoscale activity with a special focus on near-shore dynamics (i.e., within 300km from the shore). We assess the interannual variability by carrying out a downscaling experiment where boundary conditions are provided by a lower resolution basin-scale model of the Pacific. This framework allows us to investigate how low-frequency equatorial signal affect the SACW through poleward propagation of Kelvin-wave like anomalies. We focus on the 1997/98 El Niño event because it had an unambiguous signature and was well sampled both with in-situ and satellite measurements. The model captures well the strong double-peak signal of this ENSO event and reveals significant changes in the ocean state and dynamics.
We discuss the implication of this Niño event with a focus on near-shore mesoscale activity. In particular, the changes in dispersion, retention and advection are determined with the help of LaGrange diagnostics.

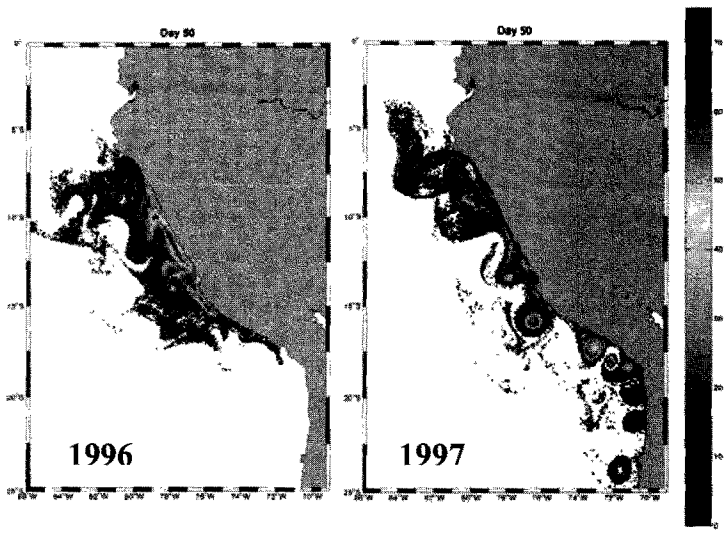

Figure1: 100000 LaGrange particles initially released over the Peruvian shelf and advected by the numerical model during 50 days. Release in May 1996 (left panel) and May 1997 (right panel). Colorscale is for particles concentration (per model grid cell).

HCS092 - Understanding the coupled dynamical/biogeochemical processes at seasonal time scale in the Humboldt Current System: comparison of model results to recent IMARPE data.

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The Humboldt Current System thrives one of the richest ecosystems in the world. Located in an upwelling region where vertical velocity brings nutrient rich waters to the enlighted surface layers, primary productivity is very high and a large amount of organic matter is generated and exported to the deep ocean. In subsurface layers, a zone of suboxic to anoxic waters appears in part due to the local intense remineralisation of organic matter and to the low rate of ventilation. However, the processes that control the spatial and temporal variations of this high productivity are not well known.

In an effort to better understand the biogeochemical cycles and their relation to the Oxygen Minimum Zone in the Humboldt Current System, a biogeochemical data base of recent years (92-2004) from IMARPE, SeaWifs satellite data (Figure 1a) and a coupled physical/biogeochemical model composed of an ocean model ROMS (Penven et al., 05) and a biogeochemical component (PISCES, Aumont et al., 03, Figure 1b) were used.

The database was used to construct a seasonal climatology of surface biogeochemical fields, as well as some specific crosshore sections repeated over the years by IMARPE scientists. The coupled model was run at 1/6° resolution which enables to represent a large part of the eddy activity. The dynamical model is forced by monthly mean climatological surface forcing from quikscat and COADS, and by climatological outputs of the ORCA ½° global model over the period 1992-2000. For the biogeochemical model, WOA conditions for nutrients (Nitrates, Phosphates, Silicates) are imposed at inflow and at initial time.

The following questions were addressed: what are the physical and bio processes controlling the seasonal cycle of surface chlorophyll? What limits phytoplankton growth near shore and offshore in the HCS? What drives the seasonal variations of Oxygen concentration in the OMZ?

In an attempt to answer these questions, available observations and model results are compared in order to identify the model biases and to document the coupled physical/biogeochemical processes at seasonal time scale that are well represented by the model.

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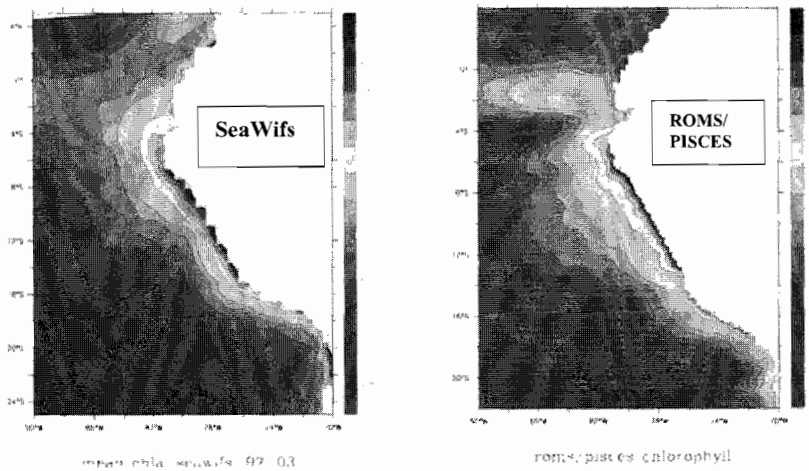

Figure 1. Mean surface chlorophyll (mgC/m3) observed by (a) SeaWifs in 97-03 and produced by (b) the coupled ROMS/PISCES model at 1/6°.

HCS220 - Coupled mechanisms involved in the unusual termination of extreme El Niño events

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Keywords: El Niño, ocean-atmosphere interactions, convection, coupled general circulation models

The extreme 1982-83 and 1997-98 El Niño events both terminated unusually in the eastern Pacific in contrast to other moderate events (e.g. 2002-2003). During these extreme events, sea surface temperature anomalies along the South American coast exceeded 4°C at the winter event peak and lasted well into the following spring. This unusual persistent warming could have important consequences in terms of fisheries but also in terms of climatic impacts on the South American continent. A coupled general circulation model (CGCM; HadOPA) has been shown to reproduce this persistent costal warming during the termination of extreme El Niño events. The coupled processes that control this unusual termination have been explored with this model. In this model, this persistent warming in winter and spring occurs despite a strong eastern Pacific thermocline shallowing and subsurface cooling and is maintained by the disappearance of trade winds from the eastern Pacific in the winter and spring due to the development of an equatorial intertropical convergence zone (ITCZ). This warming only decays when the seasonal march of solar insolation brings back the ITCZ north of the equator in summer. These CGCM results are in agreement with the studies of Vecchi and Harrison (2006) and Vecchi (2006) obtained with forced oceanic and atmospheric models. This persistent warming is also shown to be associated with very strong and

unusual precipitations along the South American coast in spring. A careful analysis of the IPCC-AR4 database highlights that some other coupled models exhibit the same kind of behaviour during extreme El Niño events, hence showing the robustness of the results. The distinctive termination of the 1982-83 and 1997-98 El Niño events is therefore that to be expected from most of extreme El Niño events.

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HCS137 - Response of the North American West Coast to the 97-98 El Niño event in ROMS: modulation of mesoscale and submesoscale activity by a basin-scale signal.

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Keywords: ENSO, Mesoscale Processes, Numerical Modeling.

A numerical investigation of scale interactions along the North American West Coast (NAWC) is proposed with the thought that it is of strong relevance for the study of the Humboldt system and that the differences/similarities between the two systems will lead to a deeper understanding of their respective functioning. Specifically, we focus on the period 1992-1999 that encompasses the 97-98 El Niño event. The model reproduces the propagation of Kelvin-wave type signals along the NAWC with temperatures and sea level anomalies consistent with the existing observations. Its eddy resolving horizontal resolution (7km) allows us to study how the nearshore mesoscale activity is altered in response to the basin-scale signal. In particular, we show that El Niño events trigger the formation of cyclones about every major headlands and capes, which in turns hampers the northward propagation of the signal. Downscaling experiments at even finer resolution focusing on subregions of the system reveal how the submesoscale activity is itself indirectly impacted by ENSO. Elements of comparisons between the NAWC and the Peru Chile system are discussed.

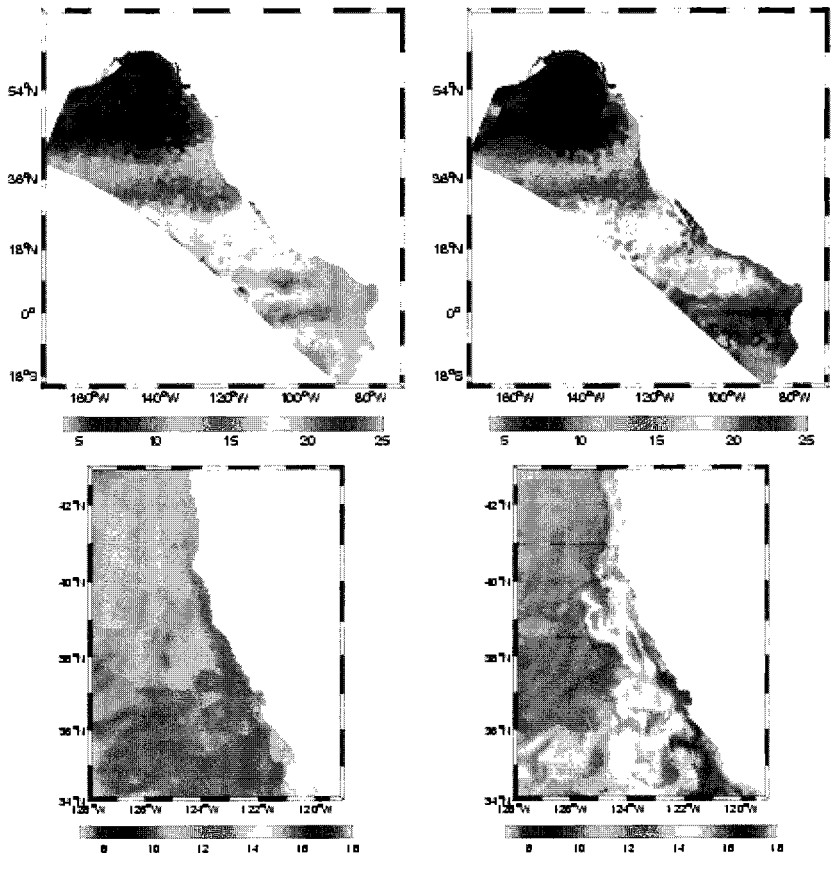

Figure 1. Dec, 15 1996 (left) and 1997 (right) temperature at 100m depth. The whole 7km resolution configuration is plotted (top) along with a blow-up on the California Coast region (bottom). Enhanced nearshore poleward advection of warm water is noticeable in 1997.

HCS115 - Enhancement of ENSO-like coastal upwelling variability in the Peru-Chile eastern boundary Current during the twentieth century warming

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Coastal upwelling along the arid margin of western South America, in the Peru-Chile Current, supports one of the most productive areas of the global ocean. Upwelling-favourable winds with different seasonality along this coast, pump nutrient-rich waters into the euphotic zone, enhancing primary production. The dynamics of the whole system is itself under the influence of south eastern Pacific subtropical anticyclone and associated intraseasonal to interdecadal variability that modulates the depth of the nutri/thermocline in the coastal ocean. In spite of the importance of these phenomena, relationships between interdecadal ENSO-like variability and global warming have not been thoroughly elucidated.
Here we take advantage of a marine laminated sediment record from northern Chile (23°S) covering the last 250 years to show an increase in the amplitude of ENSO-like interdecadal variability since the large 1878-79 El Niño event, along with a mean 2°C decrease in upwelling-induced sea surface temperature. Consistent trends in the sedimentary proxies and late twentieth century instrumental observations, point towards an intensification and amplified variability of the upwelling-favourable winds. We propose here that intensified wind stress due to increased land-sea thermal contrast derived from a reduction in the mean low-cloud cover along northern Chile and southern Peru overcompensates a slight deepening of the thermocline documented during warm interdecadal El Niño-like conditions, resulting in enhanced primary and export production. This makes for an unexpected physical feedback and biogeochemical response to the Bakun's global warming-related increase in upwelling-favourable winds.

HCS087 - Air-Sea Carbon Dioxide Fluxes in the Peruvian Coastal Upwelling System

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Keywords: Air-Sea Transfer, Carbon Dioxide, Nutrients, Primary Productivity

Comprehensive sea surface surveys of the partial pressure of carbon dioxide (pCO2) have been made in the upwelling system along the Peruvian coast since 2004. The shipboard data have been supplemented by a few mooring and drifter based observations. Air-sea flux estimates were made by combining satellite derived wind fields with the direct sea surface pCO2 measurements. While there was considerable spatial heterogeneity, there was a significant flux of CO2 from the ocean to the atmosphere during all survey periods in the region between 5 and 16 degrees south latitude. During periods of strong upwelling the average flux out of the ocean exceeded 10 moles of CO2 per square meter per year. During periods of weaker upwelling and high productivity the CO2 evasion rate was near 2.5 moles per square meter per year. These findings are in contrast to results obtained in mid-latitude upwelling systems along the west coast of North America were the average air-sea CO2 flux is low and can often be from the atmosphere into the ocean. In the Peruvian upwelling system there are several likely factors that contribute to the high levels of sea surface pCO2 that persist in spite of elevated primary productivity. The upwelling source waters contain little pre-formed nitrate and may at times be affected by denitrification. Under these conditions the complete consumption of available nitrate may not reduce sea surface pCO2 to atmospheric levels. In addition the relatively rapid sea surface warming that can occur at these latitudes may lead to further pCO2 increases.

HCS079 - Modeling Study of the Oxygen Minimum Zone in the Eastern Tropical South Pacific at Basin and Regional Scales

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Keywords: Numerical Study, Oxygen Minimum Zone, South Pacific Ocean General Circulation, Subsurface Cyclonic Gyre

Decadal numerical simulations of the basin-scale circulation in the Southern Pacific Ocean were conducted to explore the remote and regional oceanic processes responsible for the development of the extreme oxygen minimum zone (OMZ) off Peru and northern Chile. Regional Ocean Model System (ROMS) was employed as an investigative tool, using a 98×176 element mesh in the horizontal at 1° resolution. The domain was the south Pacific basin, closed at the Antarctic Circumpolar Current to the south (60°S), the Equatorial Current system to the north (21°N), the Drake Passage to the east (–65°W) and the 120°E meridional line passing Mary Ann Haven, Australia, to the west. A total of 20 vertical layers were chosen, with finer resolution in the upper ocean. An initial six-year of model integration was performed by systematically ramping the smoothed Southampton Oceanographic Center (SOC) monthly climatological forcing (Josey et al., 2005).

Realization of the regional general circulation was as complex as in the real ocean. Simulations three decades after statistical equilibrium showed realistic basin-scale and sub-basin scale phenomena, including recurring Tropical Instability Waves at wavelengths of *O*(1000 km) and a number of seasonally varying features such as the Equatorial Undercurrents (EUC), the westward Equatorial Intermediate Currents (EIC), the equatorial Tsuchiya Jet (TJ), eastern boundary currents, the eastward mid-latitude Subtropical frontal currents (STFC), the westward mid-latitude Subtropical gyre currents (STGC), and upwelling along the Peruvian/Chilean coast. The simulated coastal upwelling layer was 400-m deep at 15°S, progressively shoaling toward the equator. In the surface layer, eastern equatorial currents of *O*(1 m/s), Ekman drift along the Peruvian coast of *O*(0.4 m/s) and STFC were all relatively strong from December to March. For all seasons except austral summer, the STGC, the TJ, and the poleward Peruvian coastal undercurrents (PUC) formed a cyclonic recirculation at 200m within the OMZ, which likely serves as a poorly ventilated 'nutrient trap' that helps maintain suboxic conditions (Figure (a)). This cyclonic gyre produced dome-shaped isopycnals with interior water properties of ~13°C temperature and ~34.5 salinity, similar to either the 13° Water property by Tsuchiya (1981) or the SPESTMW (South Pacific Equatorial Subtropical Mode Water) property by Wong and Johnson (2003). In austral summer, however, reversal of the northern PUC broke down this closed cyclonic loop (Figure (b)).

Simulation analysis of the subsurface cyclonic gyre implied that seasonal variability of the EUC modulated the TJ over the course of a year. When the EUC extended eastward in March, the simulated TJ stretched far east to the Peruvian coast, achieved maximum speed, and eventually merged with the poleward coastal undercurrent. However, as the EUC weakened and retreated westward to 110°W in November, the TJ gradually migrated to the southwest due to intensification of the westward EIC ultimately disappearing by January. Meanwhile, the reversal of the PUC supplanted the eastward TJ in the region (Figure (a)). The break-down of the cyclonic circulation appeared to be related to the southerly excursion of the ITCZ in austral summer and the strong convergence associated with it. A more northerly position for the ITCZ and relatively weak trade winds predominated during the period of persistent subsurface cyclonic gyre circulation.

The large-scale general circulation of the S. Pacific, which was modeled in various previous studies by Penven et al. (2005) using ROMS, by Toggweiler et al. (1991; 1989) using the GFDL MOM, by Aumont et al., (1999) using the OGCM (Ocean General Circulation Model)–OPA (Océan Parallélisé), was equally well simulated with our configuration. Uniquely, our work also successfully simulated the highly dynamic regional circulation as well as sub-basin-scale features on- and off-shore of Peru that are likely essential in maintaining suboxic conditions at intermediate depths.

In conclusion, unprecedented success in simulating most components of the highly variable and dynamically complex subtropical and tropical circulation system in the S. Pacific basin provides a valuable tool to study both remote as well as regional forcing of OMZ development and persistence.

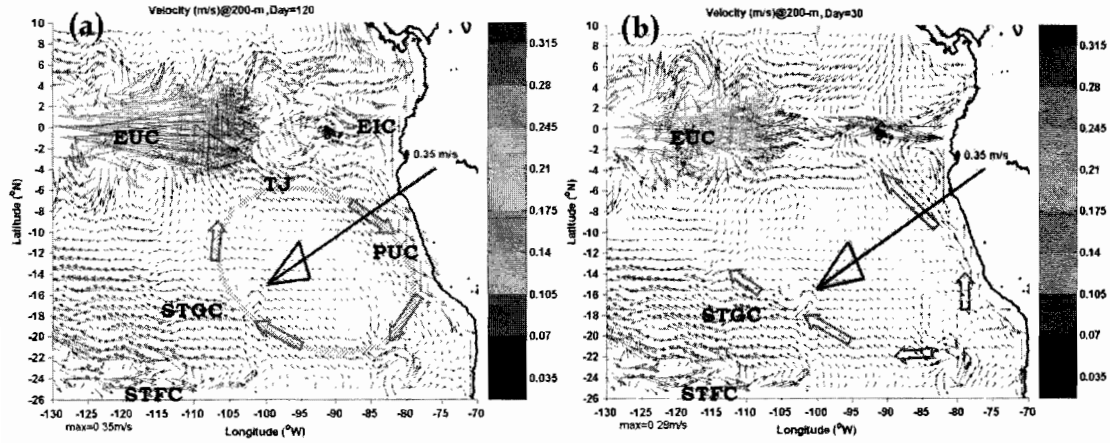

Figure 1. Simulated velocity field at 200-m depth for (a) April (austral fall), and (b) January (austral summer). Color and size of arrows represent the magnitude. A large arrow is a reference vector of 0.35 m/s speed. See text for acronyms.

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HCS164 - Biogeochemical variability in the oxygen minimum zone of the upwelling humboldt system off central peru

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Keywords: Nutrients, oxygen minimum zone, upwelling, El Niño, Callao, Perú

Oxygen minimum zones (OMZs) have important influences on biogeochemical cycling and the geographic and vertical distributions of marine species in the ocean. Fluctuations in the extent of the OMZ can have significant environmental, ecological and economical impacts. OMZs are found in large areas of the Eastern Pacific Ocean, and intercept the continental margin at the shelf and continental slope creating extensive habitats subject to hypoxic conditions and potential large nitrogen sink at global scale, such as those of the Peruvian coastal upwelling system.

This work focuses on the distribution, variability and biogeochemical impacts of oxygen deficient conditions (< 1 mL/L) in the coastal margin off central Perú (Callao, 12°02'S). A 1996-2004 time series including the large 1997-98 El Niño event was examined from one station in the continental shelf (St 4, 145 m depth, 20 nm from the coast). Dissolved oxygen, nitrite, N deficit, 15° C isotherm and density values were used to describe the OMZ in the coastal margin (Fig. 1). In order to explore the seasonal and interannual variability, time series analysis of dissolved oxygen and nutrients data were performed and related to physical parameters (temperature, salinity and density) by EOF analysis. During the study period, temperature and dissolved oxygen in the water column exhibit a significant positive correlation (R^2= 0.65, p< 0.05). Oxygen deficient waters (< 1 mL/L) were characterized by > 25 densities values and low temperatures, suggesting the presence of cold coastal waters (CCW) except during 1997-98 and 2002. The results show that the upper boundary of the oxygen deficient waters, defined as an oxygen concentration of 1 mL/L, often occurs at 20-40 m depth and match up with the 15° C isotherm distribution. The core of OMZ had oxygen concentrations less than 0.5 mL/L and anoxic (< 0.1 mL/L) bottom waters. However, towards the end of 1997 and the start of 1998 years there was a deepening of the 15°C isotherm and the upper boundary of the OMZ changes significantly, oxygen deficient waters are found below 100 m depth. During 2002, both the 15° C isotherm and oxygen values lowers than 0.5 mL/L were deeper in the water column.

Nitrate and nitrite concentrations within the OMZ waters ranged from ca. 0 to 27 µmol L^{-1} and ca. 0.2 to 9.0 µmol L^{-1} values respectively. Maximum nitrite was just below the oxycline, and over the sediments. Nitrogen deficits (N*) ranged from negative values-0 up to 35 µmol N L^{-1}. High values indicate the largest N lost in shelf bottom waters. N* versus nutrients, temperature and oxygen reveals maximum N* (35 µmol Kg) associated with low N/P ratio (~6), low temperatures (< 15° C) and low oxygen values (≤ 0.5 mL/L) and were dominant during non El Niño periods (e.g., 1999). A strong significantly negative correlation between N* and N/P ratio (R^2 0.84, p< 0.05) was observed. During the end of 1997 and the start of 1998 nitrate concentrations occur in a similar range (0 to 22 µmol L^{-1}) but higher values are only distributed below 75 m depth. Moreover, nitrite concentrations were lower than 1.5 µmol L^{-1} over the entire water column and zero-negative N* deficit values and higher N/P (≥10) were observed.

The results suggest important interannual changes in the distribution of oxygen deficient waters and biogeochemical cycling off central Perú during El Niño conditions of 1997-1998, and also 2002. One of the strong changes is associated with processes related with productivity and a potential loss of nitrogen from the system that leaves an imprint on waters chemical properties. In fact, during EN period, phosphate and silicate concentrations decrease significantly in the surface and the bottom suggesting low productivity and/or low organic matter transport to the sediments. Moreover, high nitrite concentrations and high N* disappear and N/P ratio increases (≥ 10), which suggest low denitrification rates.

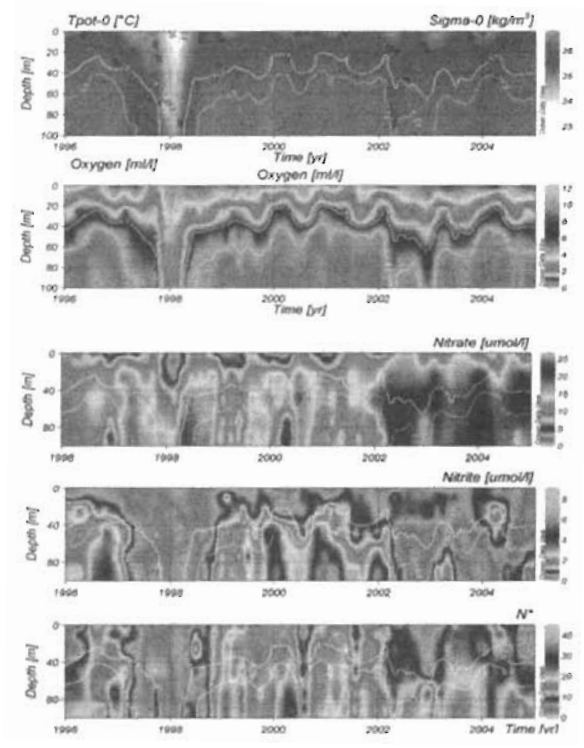

Figure 1. Characterization of the water column in terms of density values, potential temperature and 1 mL/L and 0.5 mL/L oxygen distribution (upper panel), dissolved oxygen, nitrate and nitrite distribution (middle panels) and N deficit (N) concentrations (lower panel). Lines indicate the oxygen deficient waters with values lower than 1 mL/L, and 0.5 mL/L.*

Invited paper: HCS154 - Nonlinear state-space modeling reveals differences between the Humboldt and California Current Systems.

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Variability in physical and biological oceanographic time series collected over the last century represents a combination of secular trends, dynamic behavior, stochastic events and observational uncertainty. The extent to which each one of these sources dominates the variability in a particular time series controls our ability to forecast the behavior of that times series into the future. Recently we demonstrated that key biological and physical times series from the North Pacific may be empirically categorized as having variability that is dynamically nonlinear (biological series) or that is indistinguishable from stochastic fluctuations (physical indices; Hsieh et al. 2005, *Nature* 435: 336-338). This result implies that biological variability will be difficult to forecast effectively far into the future, and that erratic and catastrophic shifts might be expected to arise naturally from the internal dynamics of such systems. We have recently extended this analysis to physical and biological data from the Humboldt Current region, including analysis of secular trends over the past century.

Our analyses of the Humboldt Current System (HCS), composed of several coastal SST time series (e.g. Puerto Chicama, Peru), coastal COADS data off of Peru, and Peruvian sardine and anchoveta data, reveal several important differences in comparison with the California Current System (CCS). While the COADS SST data appeared to be dominated by linear-stochastic variability, the P. Chicama SST revealed a low-dimensional signature and an improvement of forecastability with nonlinear models. This result is inconsistent with all of the physical time series from the CCS and the N. Pacific, and we hypothesize that this result arises from a strong ENSO imprint. Normalized sardine and anchoveta landings (mean, variance = 1) from the past 52 years were analyzed in composite. For the normalized case, these data show strong cross-predictability in that low dimensional, nonlinear models fitted to one species provide significant out of sample forecast skill for the other (ρ = 0.86). However, for the more conservative case of temporally first-differenced data, sardine and anchovy variability does not appear to reside on a well-defined low dimensional attractor, and cross-predictive skill is low (ρ=0.23). P. Chicama SST, in a lagged embedding of 4 dimensions, shows significant predictive skill for composite sardine and anchoveta data. Although our results are not unanimous, we hypothesize that (at least in the landings data from the 20th century), sardine and anchoveta form a coupled system that may be characterized by a weak non-linear attractor interacting with non-linear physical forcing.

HCS074 - Decadal variability off the South American coast: the connection with the modulation of the intraseasonal equatorial Kelvin wave

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Keywords: Interdecadal modulation, intraseasonal Kelvin wave, SST.

Climate trends modify the nature of Tropical Pacific Ocean and atmosphere interactions and consequently have an impact on the El Niño Southern Oscillation (ENSO) characteristics. For instance the abrupt climate shift in the Pacific circulation centred in the Tropics that occurred in the 70s has increased both the average amplitude and frequency of the El Niño events. Associated to the ENSO modulation, the sub-seasonal variability of the equatorial Pacific also experiences change in characteristics. Of particular interest are the intraseasonal and semi-annual equatorial Kelvin waves that transmit energy along the Peru/Chile coast as coastal-trapped Kelvin waves. Due to the nonlinearities of the coastal ecosystem, this high-frequency variability although with a weaker amplitude than the ENSO event itself can have a large impact on the coastal marine resources over long period of time.
In this study we investigate the relationship between the changes in characteristics of the intraseasonal variability along the equator with the one along the coast. In situ data for the equator band (FSU, CAC) and Reanalysis (SODA) are first used to document the low frequency modulation of the intraseasonal variability along the equator, focusing on the (~70) days-1, (~120) days-1, semi-annual and near-annual frequencies. It is shown first that these signals experiences change in vertical structure variability, which consists mostly in a swinging of energy between the first and second baroclinic modes at decadal timescales. Second the near-annual equatorial mode exhibits a change in its dominant period depending on the decade.
In the light of the linear theory for coastal-trapped wave, in situ data for the period 1950-2005 and altimetric data for the period 1992-2005 along the coast (5°S-38°S) are interpreted focusing on particular frequency bands. It is shown that the changes in the dominant period and baroclinic mode energy distribution of the intraseasonal equatorial variability, associated to change in vertical stratification, relates to the changes in coastal variability: In particular, the change in dominant period and vertical structure of the equatorial forcing modifies the critical latitude at which the coastal variability is trapped. It is suggested that such process could explain some observed decadal patterns of the fish abundance off the coast of South-America and Humboldt Current Ecosystem.

HCS175 - Climate, fish and bird abundance correlates at multiple temporal scales

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Keywords: El Niño Southern Oscillation, Guano-producing seabirds, Pacific Decadal Oscillation, Peruvian anchovy, Sardine.

We explore relationships between climate, fish biomass and seabird numbers off the coast of Peru. We examine the hypothesis that changes in fish biomass and seabird numbers in the Peruvian Upwelling System are indirectly driven by climate variability at multiple time scales. We test this hypothesis by analyzing time series on fish biomass (anchovy *Engraulis ringens*; sardine, *Sardinops sagax*) and guano-producing seabird numbers (cormorant, *Phalacrocorax bougainvillii*; booby, *Sula variegata*; pelican, *Pelecanus thagus*) off the coast of Peru from 6° S to 14° S, in relation to oceanographic variables (sea surface temperature, thermocline depth) and atmospheric indices (El Niño/La Niña Southern Oscillation, ENSO; El Viejo/La Vieja – Pacific Decadal Oscillation; PDO) from 1950 to 2005. This hypothesis is important because much of the primary literature attributes changes in fish biomass and seabird numbers to climate variability at interannual (ENSO) and interdecadal scales (PDO), yet no analysis has shown how much variability can be truly explained by these indices. We also test for co-variation in climate, fish and seabird time series, and examine lags or leads that could be used to predict one from the other.

HCS048 - Natural variability of fisheries: Is climate the only key factor?

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Keywords: Fish larvae, fisheries, lunar cycle, zooplankton, upwelling areas

Long-term trends in the fisheries catch around the world shows synchronies which suggest that fish populations are governed by the same global climate events. However, the development of fish populations is heavily stressed by biological controls such as mortality. Recent findings in the development of zooplankton with the lunar cycle in subtropical waters may help to explain a common observation in the literature related to the influence of the moon cycle on fish maturation, spawning and biomass. It is hypothesized that the observed changes in zooplankton promote periods of enhanced feeding of adult fish and lower mortality in the early planktonic stages of fish. The consequence of coupling between the moon illumination, zooplankton and fish larvae is suggested to decrease their mortality and increase growth. A striking pattern of ~9-year periodicity in mortality in sardine and anchovy fish was observed in the four major upwelling areas, coinciding with the long-term variability in moon illumination. Long-term changes in moon illumination are also suggested to influence mortality and this should be taken into account in order to model the effect of climate on the natural variability of fisheries.

HCS118 - Synchrony in decadal-scale dynamics of small pelagic fish in Humboldt and Kuroshio Current Ecosystems

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Keywords: Anchovies, Humboldt Current, Kuroshio Current, Regime Shifts, Sardines

Several large marine ecosystems with huge populations of small pelagic fish such as the Humboldt Current (HCE), the California Current, the Kuroshio Current (KCE) and the Northern Benguela Current are characterized by alternating regimes of anchovies and sardines. In the 1980s, it was suggested by Kawasaki and others that the large Pacific sardine populations swing in synchrony alternating with anchovy populations and that Benguela sardines and anchovies exhibit antagonistic dynamics. This was disproved to a large extent in the 1990s with new additional data, with the exception of the HCE and the KCE. There is now compelling evidence of synchronous dynamics of anchovy and sardine populations in these two systems.

In the HCE, long-term dynamics are controlled by shifts between alternating anchovy and sardine regimes which restructure the entire ecosystem from phytoplankton to the top predators. The end of the anchovy and the beginning of the sardine regime from 1969-1971 were marked by (i) drastic reductions of zooplankton biomass off Peru and Northern Chile in 1969 as demonstrated by two independent time series, (ii) conspicuous shifts in relative abundance of the mesopelagic larval fish community off Northern Chile in 1969, (iii) the increase of sardine spawning in 1969, (iv) the anchovy recruitment collapse in 1971 and (v) the dramatic decrease of biomass and catches of anchovy populations in 1970 and 1971 (Alheit and Niquen 2004). Similarly, the transition from an anchovy- to a sardine-dominated regime in the KCE in 1969-1971 was indicated by (i) the decrease of the economically important larval anchovy (shirazu) fishery in 1969, (ii) the sardine mass spawning in Toga Bay in 1970, (iii) the first appearance of sardine eggs in the Enshu-nada Sea in 1971 and (iv) the increase of sardine catches in 1971. Also, new results on fish scale accumulation rates in anaerobic sediments demonstrate that the Japanese anchovy population decreased around 1970 (M. Kuwae, ASLO Summer Meeting 2006, Victoria). The reversal back to an anchovy-dominated system in the HCE between 1984-1986 was initiated by (i) the dramatically improved anchovy recruitment in 1984, (ii) the beginning decline in sardine catches in 1986, (iii) the beginning increase in offshore phyto- and microzooplankton in 1986 and (iv) the beginning increase in coastal phytoplankton in 1987 (Alheit and Niquen 2004). The return to an anchovy regime in the KCE happened from 1986-1988, documented by (i) the dramatic decrease of sardine recruitment and of juvenile sardines in 1986, (ii) the increase of the anchovy shirazu fishery in 1987 and (iii) the beginning decrease of sardine catches and the sardine shirazu fishery in 1988.

The causes for these dramatic, abrupt changes of major biological components in both ecosystems are a puzzle. However, the synchrony of events in both systems might be the key to solving the regime shift problem as it points to an external forcing mechanism which drives both systems. Recent work in both systems has drawn attention to subsurface processes which might be involved in the regime shift mechanisms. Changes in mixed layer depth in the Kuroshio Extension region and associated changes in biological production (e.g. Yasuda et al. 2000) coincide with the population changes observed in the KCE. The change from a shallow to a deeper mixed layer around 1970 coincided with decreasing SSTs and the beginning of the sardine regime. The return to a shallower mixed layer and warmer temperatures in the KCE occurred when the sardine stock began to decrease again in the mid-1980s. Similarly, interdecadal

changes of thermocline depth off the coast of Peru and Chile which are well correlated with interdecadal SST anomalies (Pizarro and Montecinos 2004) occurred at the time when the HCE changed from anchovy to sardine and back to anchovy dominance. Around 1970, when the HCE began to turn from an anchovy to a sardine regime, the thermocline started to deepen. This was reversed around the mid-1980s, when the HCE started to return to an anchovy system. *Inter alia*, this might have modulated the nutrient supply to the surface layer impacting biological productivity (Pizarro and Montecinos 2004). The coincidence of the timing of physical processes and ecosystem regime shifts in both ecosystems which are thousands of miles apart from each other raises the question whether both systems are governed by basin-wide climatic teleconnection patterns.

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HCS039 - Inter-Annual to Inter-Decadal Variability of Upwelling off Northern Chile. Regime Changes and a New Index Definition.

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Keywords: decadal variability; ENSO; regime change; time series; upwelling.

The coastal ocean of northern Chile has persistent wind-driven upwelling that produces high nutrient and chlorophyll concentrations in a narrow band along the coast. The objective of this work is to study the low frequency temporal variability of this upwelling system and this effect over the pelagic fisheries.. Data used includes time series of wind, sea level, sea surface temperature, and atmospheric pressure at coastal stations of Arica, Iquique, Antofagasta and Easter Island from 1960 to 2003 and global indexes (Southern Oscillation Index (SOI), Outgoing Longwave Radiation (OLR), Sea Surface Temperature at Niño 1, 2, 3, Quasi-Biennial Oscillation (QBO) and Pacific Decadal Oscillation (PDO)). The time series are analyzed using the STL method (Seasonal Trend Decomposition procedures based on locally weighted regression and smoothed scatter plots (LOESS)), maxima entropy spectral analysis, wavelets, cross spectra, and EOFs (Empirical Orthogonal functions). The spectral analysis show that the principal variability occurred at four frequency bands: quasi-biennial (2-3 years), ENSO (3-8 years), decadal (9-12 years), and interdecadal (13-25 years). The origin of quasi-biennial variability could be explained by means of the Delayed Oscillator Model (White et al. 2003).

The ENSO effects in the region are forced remotely by planetary waves, and advection. The OLR that represents the activity of the Madden and Julian Oscillation (MJO) showed a high coherence with the SST and the wind at the coastal stations in the bands of biennial, and ENSO with a lag between 3 to 4 months, a similar pattern was found for the SOI. A measurement of the meso scale activity along the coast was estimated by the atmospheric pressure differential between Easter Island and Antofagasta. This standardized difference was defined here as Humboldt Current Index (HCI). This index emphasizes variations in the decadal scale, showing a high coherence, in phase with the SST along the coast. The EOF analysis shows that the first mode corresponds to the inter-decadal and quasi-biennial changes explaining 64% of variance showing a similar pattern than the HCI and the second mode correspond to ENSO explaining 34% of the variance.

The STL trend shows three regime changes: before 1976 (cold), between 1976 and 1998 (warm), and after 1998 (cold). These regime changes correspond with the changes in anchovy and sardine populations in the Chile-Peru system (Schwartzlose et al., 1999).

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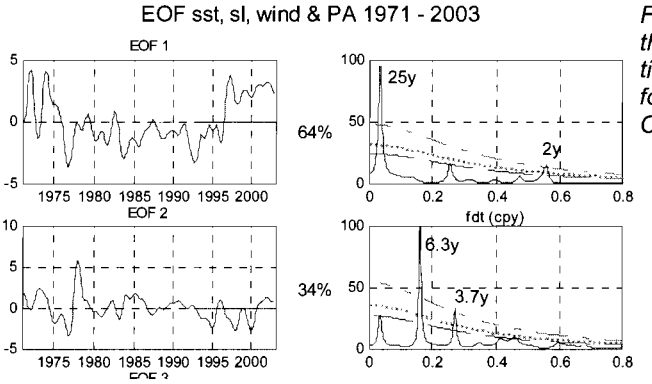

Figure 1. First three EOF modes and their MEM spectrum for the monthly time series of SST, SL, winds and SLP for the period 1971 to 2003 in northern Chile.

HCS066 - Application of a spatial Eulerian ecosystem and population dynamic model (SEAPODYM) to small pelagic fish: Modelling approach and preliminary tests

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A spatial Eulerian ecosystem and population dynamic model (SEAPODYM) has been developed for investigating the population dynamics of large pelagic fish (tuna) in relation with their bio-physical environment. The spatial dynamic of fish is based on an advection-diffusion equation simulating random and oriented movements. Surface currents passively transport larvae, then, young and adult fish movements are driven using habitat indices. Advection and diffusion are proportional to the size of the fish and the advection term is proportional to the gradient of habitat *(taxis)*, while the diffusion decreases when the habitat index increases. For mature fish, the habitat index switches seasonally from the feeding to the spawning habitat definition to reproduce change in migration patterns of mature fish during the spawning season. The principles on which SEAPODYM is based are quite general and can be adapted to small pelagic species like sardine and anchovies. Results from a preliminary simulation test for sardine in the Pacific Ocean and Humboldt system are presented and future potential applications discussed with a special interest on the analysis of multi-scale climate variability.

HCS029 - Modeling Peru Upwelling Ecosystem Dynamics: from Physics to Anchovy

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Keywords: Physical-biological modeling, ENSO and PDO, biogeochemistry and anchovy

The coastal waters of Peru are among the richest and most productive of ocean ecosystems with the world's largest single-species fishery, the Peruvian anchovy. Coastal upwelling brings cool, nutrient-rich deep water into the euphotic zone and thus enhances biological production at all levels of the food web. The Peru coastal upwelling ecosystem varies dramatically in responding to El Niño and Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). In order to link natural climate variability (ENSO and PDO) with nutrients and plankton dynamics to Peruvian anchovy growth, distribution, and abundance, a Peru upwelling ecosystem model has been developed, which consists three components. First, a Pacific basin-wide circulation model based on the Regional Ocean Model Systems (ROMS), with 12.5-km resolution, is forced with daily air-sea fluxes derived from the NCEP reanalysis between 1990 and 2005. A basin-wide physical model is necessary for simulating effects of ENSO and PDO on the Peru coastal upwelling system. Second, biogeochemical processes are simulated with Carbon, $Si(OH)_4$, Nitrogen Ecosystem (CoSINE) model containing multiple nutrients and plankton groups. The CoSINE model is embedded into the Regional Ocean Model System (ROMS) for the Pacific Ocean. The Pacific ROMS- CoSINE model is integrated synchronously, and produces monthly outputs of three-dimensional temperature, current, nutrient and plankton distributions from January 1990 to December 2005. The basin-wide ROMS-CoSINE model reproduces many features similar to the observations, Figure 1. The third component of this upwelling ecosystem model is an anchovy dynamical model using an individual based model (IBM) approach. The IBM anchovy model takes the coupled physical-biological model outputs for the Peruvian coast, and links each life-stage of the anchovy growth and reproduction with environmental

conditions, such as temperature and food availability. The IBM anchovy model also tracks location and moving trajectory of each individual, ranging from larvae stage to adult life-stage. Our analyses will focus on each sub-model system performance, their connections, and how these processes along the coast of Peru respond to ENSO and PDO natural climatic variability.

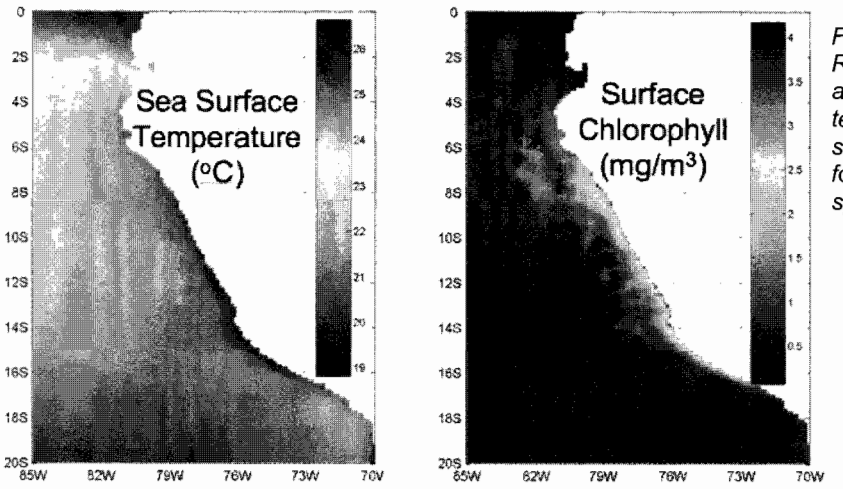

Figure 1: The Pacific basin ROMS-CoSINE simulated annual mean sea surface temperature (left) and surface chlorophyll (right) for the Peru upwelling system.

HCS004 - The Annual Cycle of Heat Content in the Peru Current Region

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The relative importance of the processes responsible for the annual cycle in the upper ocean heat content in the Peru Current, in the southeastern tropical Pacific, was diagnosed from an oceanic analysis dataset. It was found that the annual cycle of heat content is forced mainly by insolation. However, the ocean dynamical processes play an important role in producing different regional budget characteristics.
In a band 500 km from the coast of Peru the annual heat content changes in this region are relatively large and can be approximated as sea surface temperature (SST) changes in a fixed depth mixed layer. The annual cycle of the albedo associated with low-level clouds enhances the annual cycle in insolation, which explains the relatively strong annual cycle of heat content. These clouds, to a large extent, act as a feedback to SST but a small additional forcing, which is proposed to be cold air advection in this paper, is needed to explain the fact that the maximum cloudiness leads the lowest SST by around a month. Ocean dynamics is important closer to the coast, where upwelling acts partly as damping of the heat content changes and forces it to peak earlier than farther offshore.
In a band farther to the southwest, locally wind-forced thermocline motions, which becomes shallower (deeper) in the warm (cool) season, cancel partially the effect of net surface heat fluxes, whose annual cycle is comparable to that in the region previously mentioned, producing a relatively small annual cycle of heat content. The local forcing appears to be associated with the annual meridional displacements of the South Pacific anticyclone. The annual cycle in SST is also relatively small, which is probably due to the changes in the temperature of the water entrained into the mixed layer associated with the thermocline motions, but also to a mixed layer deeper than that closer to the coast.

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HCS089 - Interdecadal variability of the upwelling season off southern-central Chile (37°S): impact on common sardine (*Strangomera bentincki*).

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We present observational evidence for low frequency modulation of the onset of the upwelling season off southern-central Chile (at about 37°S), in terms of an index computed through the integration of daily wind-based zonal Kerman transport. According to our analysis during the period 1976-88, which is characterized by low common sardine (*Stringier bethink*) landing, the onset of the upwelling season starts delayed by several weeks relative to the upwelling onset observed during years characterized by high landing. We hypothesis that continuous years with delayed (early-to-normal) upwelling onset during spring

can force a negative (positive) feedback of the spawning and recruitment, which results in a depressed (enhanced) abundance of this endemic specie, lasting for several years.
An earlier-to-normal (delayed) upwelling onset can produce higher (lower) amount of available feed for pre-recruit of common sardine during the spring season, in association with enhanced (decreased) primary production. The juvenile surviving until the adult stage would be influenced by the coupling (uncoupling) between the local productivity peak and the larval abundance, as pointed out by Hot-Cushing hypothesis. Therefore, the mechanism of early-to-normal (delay) onset of the upwelling season could explain, in part, interdecadal fluctuations of common sardine landing off southern-central Chile.

HCS209 - Intra-annual and inter-annual variability in the Equatorial Undercurrent regime in the Ecuadorian sea during a determined period

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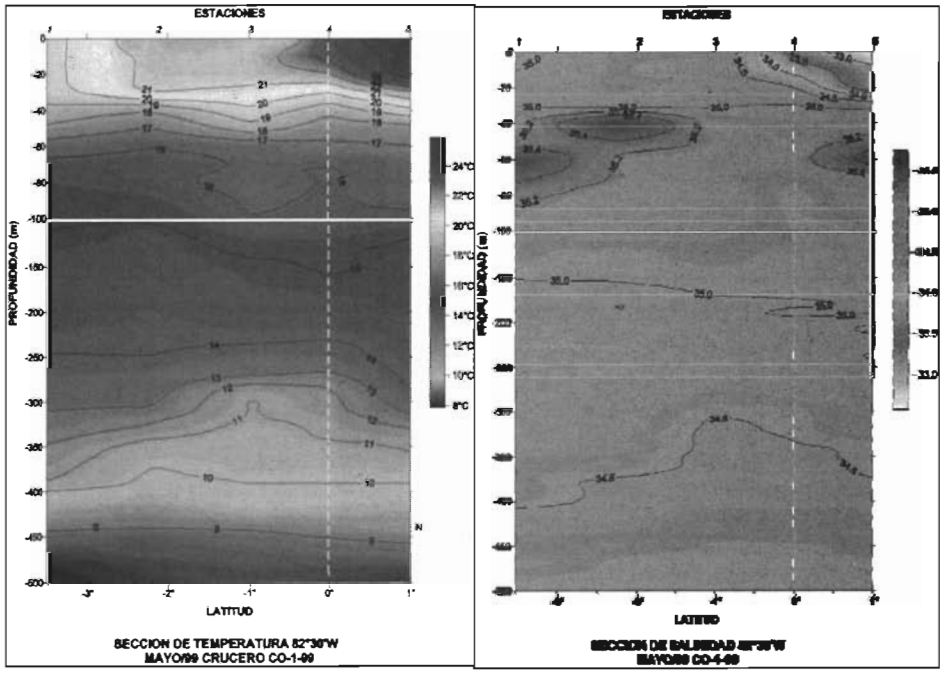
Key words: Ecuador, ENSO, EUC, Galapagos, Gunther, Upwelling.

Based on vertical oceanographic sampling of temperature, salinity and currents, along 92°W, 87°30´W and 82°30´W sections between 1°N to 3°S (Figs. 1 and 2) made during more than 20 research cruises since 1990 to 2004, the interannual and interannual variability of Equatorial Undercurrent (EUC) was analyzed. The results suggest the continuity of the EUC, Eastward from Galapagos Islands, and then a southward displacement. Salinity cross sections show significant differences of the subsurface flux, between humid season (December-May) and dry season (June-November) (Lucero et al, 2004). The comparison indicates more strength in the EUC during last half of the year in normal conditions, which implies the extension of EUC to Peruvian waters, and a possible connection with Gunther undercurrent (Garcés et al, 1998). Interannual variability is also evidenced between warm and cold ENSO phases. The comparison between sections during El Niño 1997-1998 and La Niña 1999-2001, suggests that EUC is weakened during warm events and probably do not reach Peruvian waters. However during cold ENSO episodes, EUC is strengthened and extends southward (Zambrano,et al, 2000). The correlation between the EUC regime and the strength of Equatorial Upwelling in Western Galapagos is significant high.



Figures (INOCAR, 1999)

HCS088 - Spin-up of South Pacific subtropical gyre freshens and cools the upper layer of the eastern South Pacific Ocean

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Keywords: Climate Change, South Pacific

The general circulation in the South Pacific Ocean is dominated by the subtropical gyre, which manifests itself through elevated mean dynamic topography at its center (Figure 1). Gyre circulation consists of the westward South Equatorial Current, a narrow poleward western boundary current, the East Australian current, the eastward South Pacific Current streaming along the South Tropical Front (centered at around 40°S in the western ocean basin and at 30-35°S in the eastern basin), and the Humboldt Current System, a broad equatorward eastern boundary current, (in the literature, also referred to as the Peru/Chile Current) (Tomczak and Godfrey 1994; Levitus 1982; Reid 1986). The volume transport of upper water (700 m) between the Pacific coast of South America and the East Pacific Rise amounted to 18 Sv across 32.5°S (WOCE section P06) and 14 Sv across 17°S (WOCE section P21) (Tsimplis et al. 1998), emphasizing the importance of equatorward transport by this eastern boundary current system. This boundary current also plays a vital role in the fresh water budget by advecting fresher Subantarctic Surface Water northward thus forming Eastern South Pacific Transition Water (Emery and Meincke 1986) (Figure 1).
Here, temperature and salinity from the upper 200 m of the water column in the South Pacific Ocean were compared basin wide along 32°30'S between 2003 and 1992, based on two vertically and horizontally high resolution hydrographic repeat-sections involving 227 station pairs (WOCE, BEAGLE, figure 1). Additionally, the seasonal cycles of the upper water column temperature and salinity between 90-140°W and 30-35°S were established utilizing 1508 ARGO profiles from 2003 to 2006. The surface waters (0-200 m) of the eastern South Pacific Ocean, on average and seasonally adjusted, were clearly fresher in 2003 by 0.14 PSU. The seasonally adjusted, depth integrated temperature was 0.65°C colder in the same region. We further concluded a spin-up of the South Pacific subtropical gyre circulation since the fading of the 1997/98 El Niño, as referred from observations of satellite-born mean sea level anomalies, caused by intensified wind stress over the South Pacific. We relate the observed temperature and salinity changes in the eastern South Pacific to a spin-up of the subtropical gyre circulation caused by intensified winds.

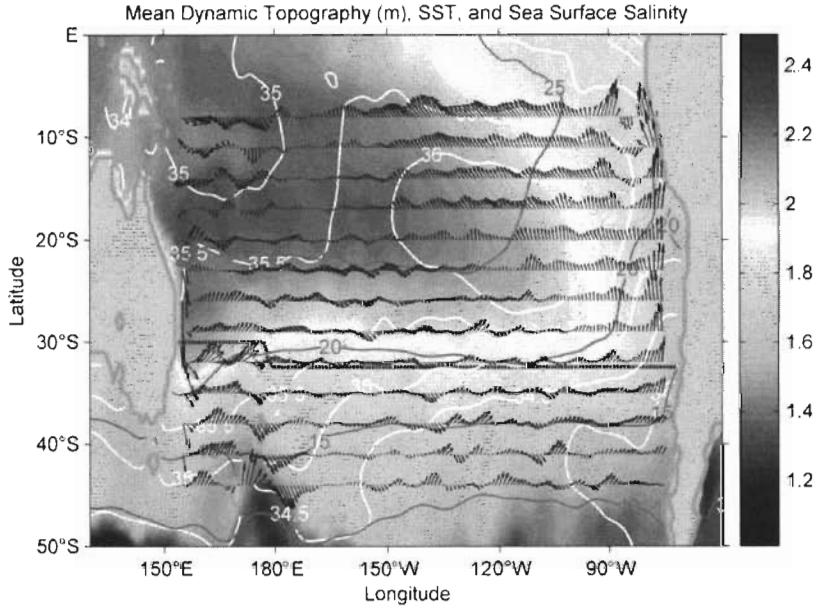

Figure 1. Mean dynamic topography, sea surface temperature and salinity, and cruise track. The CLS Combined Mean Dynamic Topography (CMDT) named RIO-03 was computed over the 1993-1999 period with a multivariate analysis using hydrographic data, surface drifter velocities, and altimetry. The estimate used was based on both the CLS01 MSS - EIGEN2 (CHAMP) geoid and the Levitus '98 climatology (referenced to 1500 dbar) (Río and Hernandez, 2004). CMDT is color contoured, units are in meter. Surface geostrophic velocity derived from the CMDT is shown by black errors, in relative units. Sea surface temperature and salinity stem from World Ocean Database 2001 (Conkright et al. 2002) and are line contoured in pink (°C) and in white (PSU), respectively. The dotted blue line corresponds to the cruise track, for both the WOCE P06 line and the BEAGLE repeat P06 section. Continents and islands are depicted in green bordered by a solid dark green line.

HCS072 - A Lagrangian study of the PCUC source waters

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Key words: Lagrangian, undercurrent, upwelling, model, source water

The ROMS (Regional Ocean Modeling System) sigma-coordinate model was run in a configuration from 5°N to 35°S, including both Peru and Chile basins to 99°W, to study the origins of the PCUC (Peru-Chile UnderCurrent) and coastal upwelling waters. To allow computation on that large spatial domain, resolution was limited to 1/6° and time period to 2000 - 2004. The model was forced with daily QuikSCAT winds and boundary conditions prescribed by ECCO (Estimating the Circulation and Climate of the Ocean) model results.
To compute trajectories, an offline algorithm allowing backward calculation [Blanke and Raynaud, 1997] was used on the mean state and climatology derived from that interannual simulation. Particles were initially located along the Peru and Chile coasts in the core of the PCUC and at the surface. A backward integration then permitted to evaluate the particles origins. 3 sources were identified: the SSCC (South Subsurface Counter Current or Tsuchiya jet), the lower part of the EUC (Equatorial Under-Current) below 100 meters, and a subsurface current coming from the south of the region. This current is probably part of the south-east gyre return branch and is characterized by an extremely low salinity. This water mass has the properties of the Eastern South Pacific Intermediate Water (ESPIW) [Schneider et al, 2003]. Transport was computed to quantify the relative contribution of each source. The EUC brings about 1.8 Sv of water which mainly upwells along the Peru coast. The Southern branch brings around 0.4 Sv; only along the Chilean coast at about 30°S. The SSCC is the main source of water with more than 3 Sv. Part of this water upwells along the Peru coast but another part (0.7 Sv) flows south of 18°S in the Peru Chile undercurrent. Moreover, 2 distinct cores were identified in the SSCC, (around 4°S and 8°S at the western boundary of the model) in agreement with previous observations [Rowe et al 1999]. The first core (4°S) mainly feeds the Peru upwelling whereas the seconds (8°S) also feeds the Chile undercurrents and upwelling.

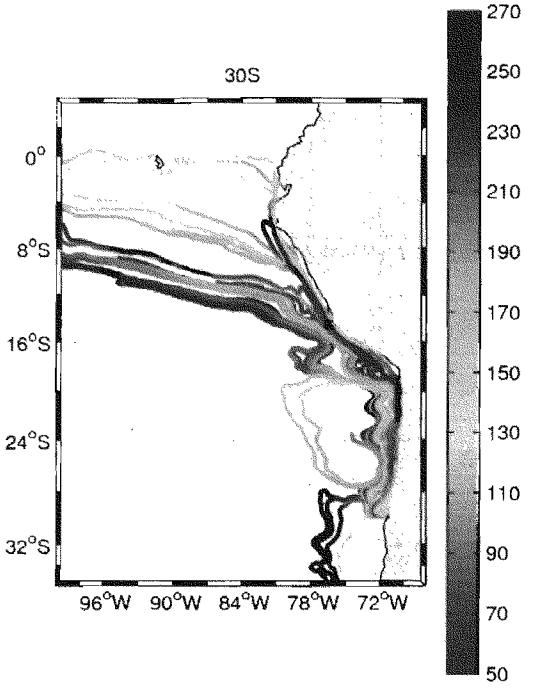

Figure 1: Backward trajectories of particles initially positioned in the PCUC core at 30°S. Colours represent depth.

HCS095 - Statistical study of mesoscale characteristics in the Eastern-South Pacific. A review based on different approaches

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Keywords: Eastern South Pacific; Mesoscale characteristics; Satellite altimetry; Lagrangian drifters; Spatio-temporal variability.

Based on nearly 15 years of satellite altimetry measurements and 25 years of Lagrangian surface drifters data, this study investigates the mesoscale characteristics of the Eastern South Pacific (ESP). Three different vortex identification techniques (sea level anomaly contours, Okubo-Weiss parameter based on satellite surface geostropic current fields, and surface drifter loops) are used to provide the mean kinematics properties of the ESP eddies and their main characteristics (length scales, rotation period, swirl and translation velocities).
The "Chile-Peru Current eddies" have a typical diameter of order of 30 km, smaller than the typical Rossby radii observed in the region. They are principally formed near the South American coast and propagate seaward with a translation velocity varying from 3 cm s^{-1} at 40°S to 6 cm s^{-1} north of 15°S. Long-lived anticyclonic eddies propagate northwestward (Figure 1a), whereas cyclonic vortices propagate westward (Figure 1b), consistent with the vortices propagation theory on a β-plane. The radial distribution of the swirl velocity shows that the Chile-Peru Current eddies have a maximum diameter of order of around 200 km with a swirl velocity of around 14 cm s^{-1} and a rotation period of 50 days. No significant difference is observed between the tangential velocities of cyclonic and anticyclonic eddies.
The good temporal coverage of satellite altimetry observations also allows investigating the seasonal and interannual variations of eddy generation, in particular along the Peruvian coasts. The number of coastal eddy centers is 35-45% higher during autumn than during spring (Figure 1c), probably associated with the seasonal variation of the thermal upwelling front. Eddy activity strongly increased during the 1997-1998 El Niño period but also throughout the study period with an increase of 60% between 1992 and 2004 (Figure 1d). Off-shore mesoscale activity being associated to the upwelling rate at the coast, the data collected during the IMARPE cruises of 1992-2005 are also interpretated in the light of the above analysis.

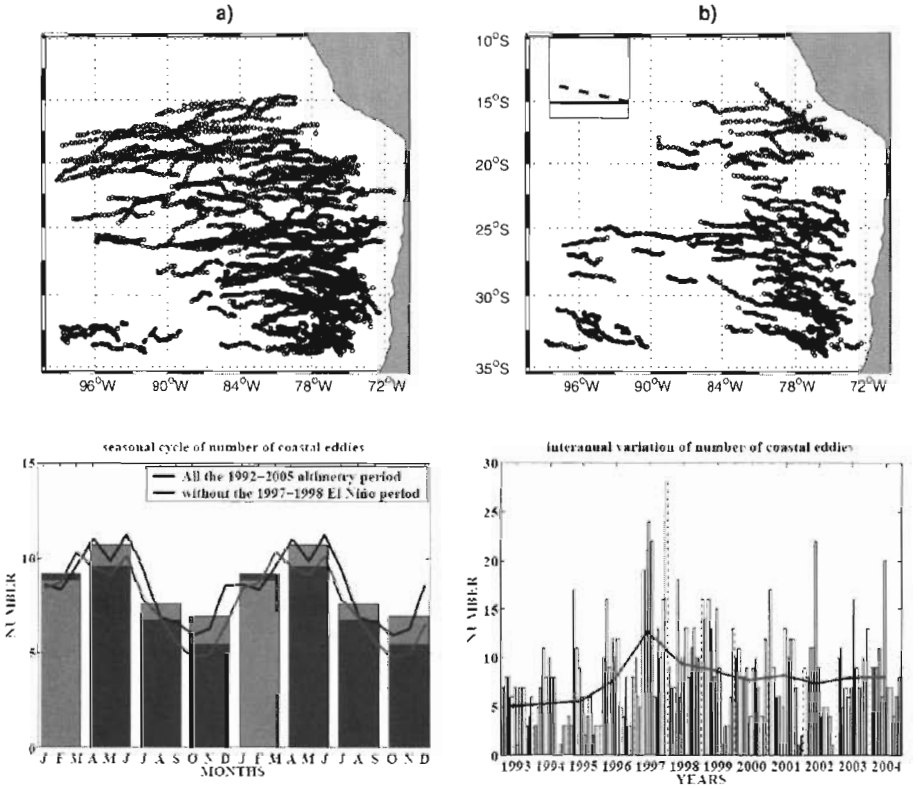

Figure 1. Propagation pathways for (a) cyclonic and (b) anticyclonic eddies tracked with altimetry data for more than 3 months. The inset in Figure 3b shows the mean propagation direction of the cyclonic (solid line) and anticyclonic (dashed line) eddies. Seasonal cycle (c) and interannual variations (d) of the number of coastal eddies in the Peruvian region [5°S-20°S; between the coast and 4° offshore

HCS193 - Some evidences of physical-biological coupling between jack mackerel larvae and mesoscale structures off central Chile

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Keywords: jack mackerel, spawning area, larvae distribution, mesoscale variability, physical-biological coupling

Chilean jack mackerel (*Trachurus murphyi*) is a highly migratory pelagic species that inhabits the Southern Pacific Ocean, constituting the most important fishery for Chile. Jack mackerel is a key component of HCS that exhibits a strong seasonal migration pattern, showing an offshore migration to the spawning oceanic habitat in early austral spring, and an onshore migration during the summer for feeding purposes.
Here we use jack mackerel larvae data obtained from annual cruises carried out by 8-10 fishing vessels simultaneously, in the oceanic (76°-92° W) spawning area off central Chile. These cruises were developed in 6-12 days during the maximum spawning period from 1999 to 2005. Spatial distribution of jack mackerel larvae was modeled using geostatistical techniques. These data were analyzed with satellite sea surface temperature, sea surface wind stress and geostrophic current field obtained from altimeter data.
It is observed a broad spatial distribution of jack mackerel larvae in the oceanic waters off central Chile beyond 80°W. Stratified larval samples showed a clear association to surface layer (< 50 m). The geostrophic field currents show a spawning area characterized by strong mesoscale eddies and meanders as well as relatively weak wind stress. The spatial distribution patterns of larvae appear related to these mesoscale structures. Lower (higher) larval densities were associated to the center (edge) of cyclonic (anticyclonic) eddies. The integration of geostrophic current field with the wind-driven surface current improves the spatial relation between jack mackerel larvae and mesoscale variability. Finally, we discuss the mechanisms involved in the physical-biological coupling in the spawning area off central Chile.

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HCS113 - Seasonal cycles of oceanographic variables offshore central Chile by means of ROMS.

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Keywords: central Chile, coastal upwelling, mean circulation, numerical simulation, seasonal cycles.

Long term seasonal means, or climatologies, are essential measures to estimate inter annual and low frequency variability in the oceans and represent the expected climatic conditions of a region of interest. Today yet there are global climatologies available which reproduce the mean seasonal state of the global ocean, but their relatively low spatial and temporal resolution makes it difficult to address important coastal processes like coastal upwelling and meso-scale processes in general. Here we present a numerical seasonal simulation of oceanic variables offshore central Chile by means of a Regional Ocean Modeling System (ROMS), which is based on the primitive equations of motion and continuity, is hydrostatic, applies a free surface, uses vertically Sigma-coordinates, and horizontally an orthogonal coordinate system. Our study focuses on the eastern South Pacific Ocean off central Chile, confined by 32-40°S and 71-80°W. The model is initiated with Simple Ocean Data Assimilation (SODA) temperature and salinity climatologies, uses ETOPO-2 bathymetry, and is forced by mean monthly winds (QuickScat), surface heat fluxes and evaporation minus precipitation balance (COADS). We choose a horizontal resolution of 5 km, a time step of 15 minutes, and 30 vertical Sigma levels. The model output consists of 3-dimensional fields of temperature, salinity, velocity, sea surface height and other variables. After a spin-up period of 2 years the model was run for 6 years from which seasonal climatologies were computed. The results then were validated with oceanographic measurements stemming from ARGO, WOCE, Blue Earth Global Expedition (BEAGLE, Uchida & Fukasawa, 2005), and World Ocean Atlas 2001 climatologies (WOA01). The model reproduces well the annual mean state and the seasonal cycles of the regions oceanographic variables. ROMS's horizontal and vertical temperature and salinity pattern are in good agreement with observations, although slight differences were noted in absolute values and positions of fronts.
Annual means of temperature, salinity and meridional velocity from the model's simulation along 32.5 °S are shown in Figure 1 for the upper 1000 m of the water column and within the first 500 km from the coast. A strong vertical thermal stratification in the upper 200 m and a shoaling of the isotherms towards the coast is obvious, typical for coastal upwelling throughout the year. The same holds for salinity. The upper 200 m of the water column are occupied by low saline Subantartic Surface water and the well known upper salinity minimum, typical for the region, is well reproduced. Below 300 m water depth the isotherms decrease towards the coast, a feature also present in the hydrographic BEAGLE transect along the very same latitude. Along the continental slope, centered at around 270 m, a core of high saline Equatorial Subsurface Water, which is associated with low dissolved oxygen concentrations, also is well simulated,

although underestimated by about 0.1 PSU. The model simulation also reproduces an offshore core of Antarctic Intermediate Water, between 500-850 m, linked to an intermediate salinity minimum < 34.4 PSU. Within this water mass, however, a slight overestimation of 0.1 PSU has to be noted, nevertheless its vertical position in the water column agrees well with observations (WOCE, BEAGLE). General circulation pattern shows an amplified equatorward flowing current, the Humboldt Current, with surface velocities in the order of 8 cm/s. Closer to the coast the current is only shallow but deepens offshore to more than 500 m, with of course decreasing speeds. Equatorial Subsurface Water, located along the upper continental slope, flows poleward, as confirmed by several publications (e. g. Shaffer *et al.*, 1999), with flow speeds being in the order of 4-6 cm/s, which, however, seems to be an underestimation. Below the Equatorial Subsurface Water, along the coast a narrow equatorward flowing current of about 2 cm/s is observed, which also is well documented in the literature (Shaffer *et al.*, 1999). The general flow pattern along 32.5 °S, associated with the subtropical gyre circulation and the extention of water masses is well reproduced by our simulation.

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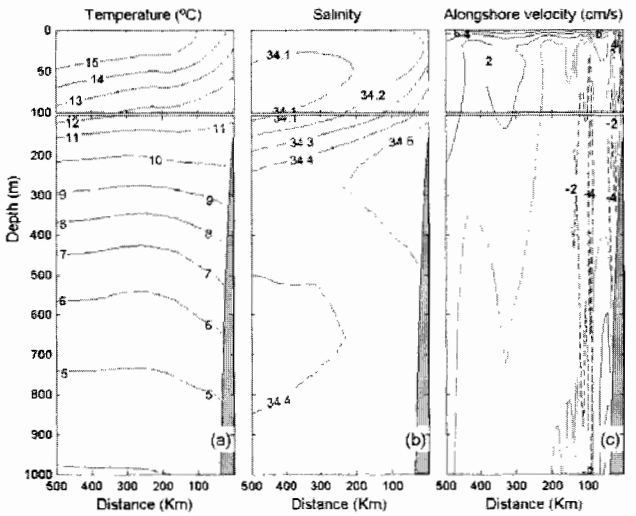

Figure 1. Annual means of temperature (a), salinity (b) and meridional velocity (c) from the model's simulation along 32.5 °S.

HCS173 - Iron and denitrification in the Peru upwelling Regime

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Intense upwelling off the Peruvian coast results in high productivity, with the formation of an oxygen minimum zone in the underlying intermediate waters. Within this zone is an important region for denitrification. Denitrifying bacteria have a high Fe requirement associated with the metalloenzymes for nitrate reductase and nitrite reductase, which contain Fe, and can be readily Fe limited in culture. We studied the distribution of Fe along the Peruvian coast in October 2005 on the R.V. Knorr. Here, we show that within the secondary nitrite maximum, where denitrification rates are the highest, much of the dissolved Fe is present as Fe(II). Fe(II) distribution is tightly coupled to nitrite, rather than oxygen; it is absent below the secondary nitrite maximum, even though oxygen is very low. Fe(II) is much less particle reactive than Fe(III) in seawater, so these local maxima may reflect an elevated residence time of Fe within this horizon. Fe(II) is thermodynamically unstable, even at submicromolar concentrations of oxygen, leading us to conclude that that it is maintained by kinetic processes. The correlation of Fe(II) with nitrite suggests that active biological reduction of Fe(III) by denitrifiers is a plausible hypothesis. East-west transects reveal that this process may be an important mechanism for transporting Fe from shelf waters into highly Fe depleted waters offshore.

HCS135 - N_2O consuming processes in the upwelling ecosystem off Peru

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A profound knowledge of the N_2O sources and sinks in the ocean is required to determine its oceanic role in climate change and to predict the consequences of possible changes of some ocean properties (e.g., temperature, dissolved oxygen) on, for example, N_2O recycling. A certain number of studies have paid attention to N_2O producing processes, but much less emphasis has been laid on N_2O consuming processes. Until now, total denitrification has been considered the unique process responsible for N_2O consumption through des-assimilatory reduction to N_2. Therefore, this is the only process accounted in the global balance of this gas (Codispoti et al., 2001). Here, we explore for the first time the assimilative N_2O reduction or N-fixation as a process that consume N_2O. Nitrogenese enzymatic system is able to use different substrate, among them N_2O, and several mechanisms have been proposed for nitrogenase bind with an N_2O molecule.

The eastern South Pacific off Peru (3°S - 16°S) is an ideal open system for studying N_2O consuming processes, because it has a permanent oxycline (redox gradient) in the water column and often shows the overlapping photic and suboxic zone that defined a Oxygen Minimum Zone (OMZ) where nitrite is accumulated (see Figure 1-a), enhancing conditions required to sustain reductive processes.

We measured des-assimilative N_2O reduction, using the acetylene method. Also, we measured assimilatory N_2O reduction or N-fixation (as an alternative pathway able to transform a gas into organic particle), using a highly sensitive isotope tracer technique ($^{15}N_20$) at different depths between the surface and the 100 m depth. N_2O was offered as a substrate during the experiments with water in order to evaluate the magnitude and relative importance of N_2O fixation and how they vary in response to variable oxygen conditions.

N_2O des-assimilatory reduction rates ranged between 0.7 and 11.2 nmol L^{-1} d^{-1}, and took importance in water associated with the upper oxycline as well as in the core of the OMZ, where oxygen concentration drop to 4.6 uM and nitrite accumulates. N_2O assimilative reduction was detected from the surface water to the core of the OMZ in rates fluctuating from 0.02 to 0.23 nmol L^{-1} d^{-1}. Thus, we simultaneously detected N fixation and denitrification at same depth (Fig 1-b), processes that are dramatically opposed in the N bio-available balance and usually regarded as independent and separate by space if not by time (Gruber and Sarmiento, 1997). Although removal of N_20 by denitrification exceeded fixation rates, assimilative processes accounted for 5% of lost N by red-assimilatory reduction (Fig 1-b).

This evidence calls to put attention on the qualitative and quantitative importance of N-based green house gas removal on global budgets, but it also suggests a novel and alternative reaction as a proccess that can fix N_20 and transform it into bioavailable N. Fixation of N in the form of N_20 suggest nitrogenase activity at the core of the OMZ as an input of N to the water column and it complements the recent finding of biological fixation of N_2 in the euphotic layer and down to the upper oxycline in the same area (Fernández et al, 2006).

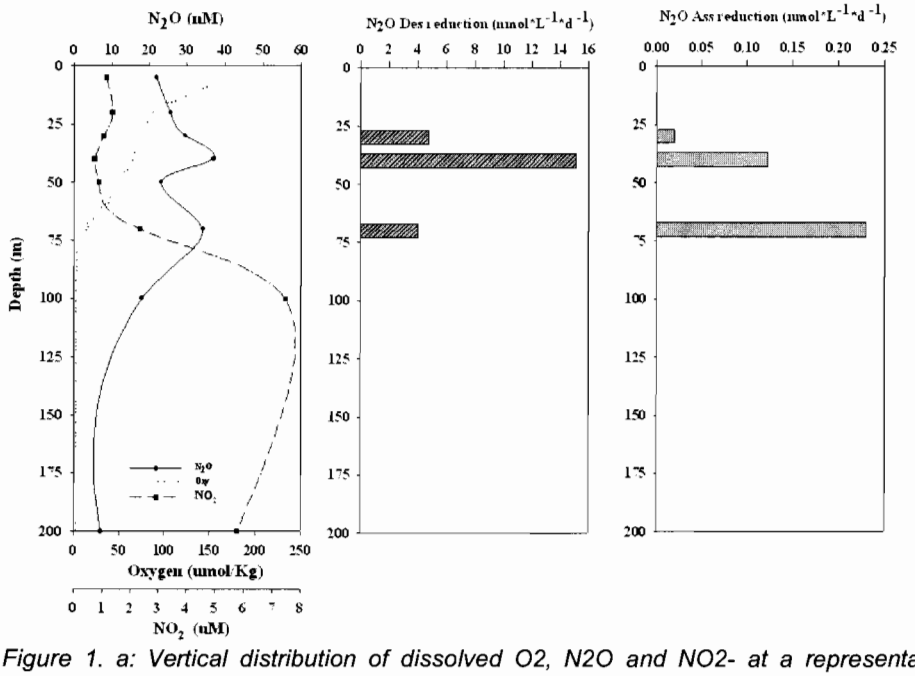

Figure 1. a: Vertical distribution of dissolved O2, N2O and NO2- at a representative station off Peru (15.51° S) and, b: rates of des-assimilative and assimilative N2O reduction obtained from incubation experiments a t the same station.

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HCS146 - Chemical Shift Characteristics in the Sea Along the Peruvian Coast, During El Niño 1997-98

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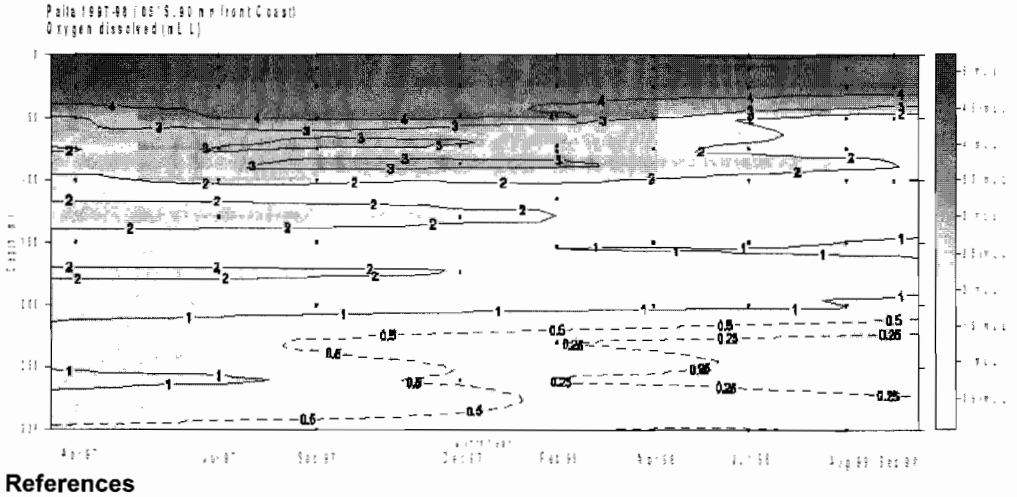
Keywords: El Niño, dissolved oxygen, nutrients, Perú

During El Niño (EN) events there are drastic changes in the physicochemical characteristics of the upper ocean off Peru. El Niño events occur irregularly and are associated with an increase in temperature and dissolved oxygen as well as a reduction of nutrients and chlorophyll-a, throughout the water column of the eastern Pacific. Other characteristics of EN events off the coast of Perú are increases in precipitation and migrations of birds. The main events were those of: 1891-92, 1925-26, 1940-41, 1957-58, 1965-66, 1972-73, 1976-77, 1982-83, 1987-88, 1992-93 and 1997-98, with the events of 1982-83 and 1997-98 being the most severe.

The warming El Niño 1997-98 event began in April of 1997 with sea surface thermal anomalies of + 3°C. During September the conditions appear relatively "normal" but in December of 1997, when Tropical Surface Waters (TSW) advanced up to the 4°S in front of Cabo Blanco, the highest anomalies were present reaching values of + 7°C. These TSW had concentrations of less than: 0.40 µmol/L of phosphate, 2.00 µmol/L of silicate, 0.50 µmol/L of nitrate and, 0.08 µmol/L of nitrite. The Equatorial Surface Waters (ESW) intrudes down to 12°S with typical values smaller than: 0.50 µmol/L of phosphate, 3.00 µmol/L of silicate, 2.00 µmol/L of nitrates and 0.20 µmol/L of nitrites. The south area of Callao was dominated by Subtropical Surface Waters (<0.80 µmol/L of phosphates, <4.00 µmol/L of silicates, <3.00 µmol/L of nitrates and <0.30 µmol/L of nitrites), 7 to 10 times lowers than the concentrations present during normal conditions. Centres of reduced coastal productivity were observed with low concentrations of nutrients and relatively high values of dissolved oxygen (~4.40 mL/L).

Our data suggest that the 1997-98 El Niño event had more anomalous chemical conditions than the 1982-83 event (Guillén *et al.* 1985, Sanchez *et al* 2000), in that the oxycline and the nutricline were located deeper than observed in December of 1982 (Guillén 1985). The vertical distribution of oxygen changed drastically, oxygen concentrations of 1.00 mL/L were located at an average depth of 30-50 m (north of Punta Falsa) in 1981, while the same was found below 200 m in 1997. In relation with the nutricline, during EN event 1997-98 was two times deeper than in 1982-83 (Ledesma *et al.* 1998). The following concentrations of nutrients were detected throughout the upper 100 meters during the EN of 97-98: 1.00 µmol/L of phosphates, 5.00 µmol/L of silicates and 5.00 µmol/L of nitrates. During 1982-83, these concentrations were present in the upper 50 meters (Guillén *et al.* 1985). With respect to the El Niño event of 1987 (weaker intensity) these concentrations were limited to the upper 35 meters (Guillén *et al.* 1989). Therefore, our data show along the Peruvian coast a strong chemical shift in the water column during El Niño 1997-98 conditions; and a significant relationship between the oxycline a nutricline position in the water column and the intensity of the El Niño event.



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HCS003 - The interplay between microbial and classical food webs in coastal upwelling areas off the Humboldt Current System off Chile

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Keywords: upwelling area, herbivore food-chain, microbial food-web, omnivory

The simple herbivore-dominated food chain has long been assumed as a major feature in productive coastal upwelling ecosystems (Ryther 1969). Here we present a complete analysis of seasonal variations of the trophic pathways of carbon in two highly productive coastal upwelling regions in the northern (23° S) and central (36° S) Humboldt Current System off Chile. In northern Chile, upwelling is intermittent throughout the year, whereas in Central Chile, upwelling events are seasonal, mostly concentrated during the spring/summer months. During upwelling events, the water column is characterized by the presence of a shallow (30 to 40 m depth) oxygen minimum layer (OML), where chain-forming diatoms grazed by small zooplankton and h-dinoflagellates comprise most of the autotrophic biomass. Our results show that, heterotrophic nanoflagellates (HNF) were the principal consumers of bacteria, exerting a substantial removal of their daily biomass (> 100 %). Protozooplankton biomass removed a significant fraction of h-nanoflagellate production (12 to 96 % d^{-1} of its production). Thus, the microbial food web could transfer bacterial carbon to protozooplankton and thereafter to zooplankton. The impact of small zooplankton on primary production (PP) was relatively low both in coastal areas of northern and central Chile. Copepods and appendicularians removed between 0.6 to 6 % of PP d^{-1}. Appendicularians were the only zooplankton able to graze on bacteria, but grazing impact was not sufficient to regulate bacterial biomass. Ctenophores exhibited their strongest predation impact on small copepods (0.5 to 5% d^{-1}).
The results suggest that a substantial part of the photosynthetically fixed carbon can be channelled through the microbial food web, and only a small part directly towards copepods through the herbivore food chain. Thus, the microbial food web transfers bacterial carbon to protozooplankton, and then to zooplankton, especially during non-upwelling conditions of autumn/winter. A fraction of this carbon channelled though the microbial food web is also available for the gelatinous predators (i.e., siphonophores and ctenophores). The food web structure in both embayment of northern and central Chile can be classified as multivorous (*sensu* Legendre & Rassoulzadegan, 1995), where herbivorous and microbial grazing has an important role in carbon export. Our findings further suggest that the carrying capacity for larger omnivorous and carnivorous metazoans, and even for commercially exploitable pelagic fishes, might be considerably higher than that expected from a simple herbivore-dominated food chain in coastal upwelling areas.

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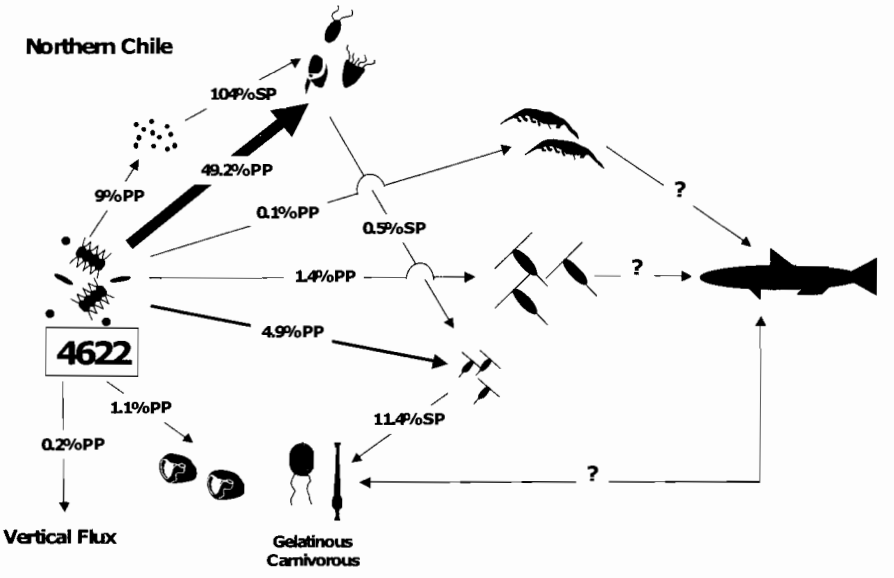

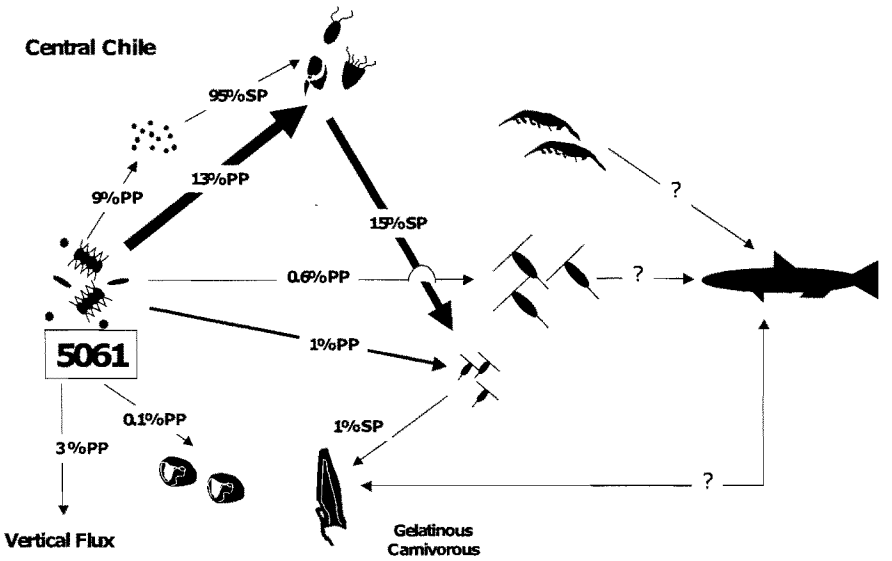

Figure 1. Main carbon fluxes during the spring season in the coastal upwelling areas of northern (23° S) and central Chile (36° S). Mean values were integrated for an euphotic layer of 25 and 35 m, respectively. The number in the box represents mean integrated primary production (mgC m^{-2} d^{-1}). PP: Percentage of primary production removed daily, SP: Percentage of secondary production removed daily.

HCS082 - A satellite study of the oceanic surface circulation in the southeastern Pacific

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Keywords: Circulation, Climate & Interannual Variability, Eastern Boundary Currents, Numerical Models

Aspects of the surface circulation of the SE Pacific are described using two primary types of satellite data: sea surface temperature (SST) fields from the Pathfinder (1985-2003) and Reynolds (1982-2005) data sets; and sea surface height (SSH) fields from the JPL along track SLA and the gridded AVISO SSH and velocity data sets (1993-2005). Results from the satellite analyses will be compared with results from a numerical simulation of the circulation (see abstract by Matano et al). If time allows, comparisons to the NE Pacific will also be presented. Seasonal cycles and interannual anomalies will be presented to describe El Niño, La Niña and "neutral" periods. The typical fields include evolving SST and SSH fields; differences between SST at the coast and offshore (an upwelling index); variances of SSH, geostrophic velocity and SST; wavenumber spectra of SSH and SST; etc. At some locations, comparisons to detailed climatologies are possible, for instance off northern Chile, where 30 years of hydrographic data have been analyzed.

HCS109 - Is the nutrient flux into the euphotic zone the driving mechanism of fish abundance in eastern boundary currents?

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Keywords: Benguela – Canary – Humboldt upwelling current systems, comparative approach, coupled physical-biogeochemical modelling, small pelagic fish

Upwelling ecosystems are characterized by short food chain length. Apex predators forage on small pelagic fish which feed on plankton which grows on the nutrient rich waters newly brought to the surface by the strong upward nearshore vertical velocity. If bottom up processes control small pelagic fish populations we can expect a rather direct relationships between nutrient supply and fish abundance. Here

we propose a proxy which might reflect fish abundance and test it in different upwelling ecosystems: the Canary, the Benguela and the Humboldt Current systems. In each system the Regional Oceanic Modeling System (ROMS) with an eddy-permitting resolution coupled to a biogeochemical model (Nitrate-Phytoplankton-Zooplankton-Detritus - NPZD) has been run over the last 30 years in order to investigate ecosystem changes at a decadal scale. ROMS is forced by NCEP reanalysis at the surface and SODA at the open boundaries of the regional oceanic domain. The three-dimensional outputs of the ROMS-NPZD model (temperature, salinity, turbulence, food and nutrients) are used to link latitudinal distribution of fish biomass to its environment variability.

HCS105 - Photosynthesis and fish production in the Peruvian upwelling system

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In a seminal paper entitled Photosynthesis and Fish Production in the Sea Ryther (1969) explained why coastal upwelling systems could produce almost half of the world fish catch while comprising only ~1% of the area of the global ocean. While many of the basic concepts from that paper are correct several discoveries and advances have occurred since the paper was published. Here we review those advances together with the details of the oceanographic processes along the coast of Peru which might impact fish production on seasonal, interannual and multi-decadal time scales.

HCS018 - Downward fluxes of particulate organic carbon and carbonate in coastal and oceanic areas off Chile: the contribution of functional groups of the plankton

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The contribution of key species and functional groups of the plankton to vertical fluxes of particulate organic carbon (POC) and carbonate (CaCO3) to the deep sea were studied in sediment trap samples deployed in the oceanic area off Coquimbo, Chile during 1993-1998. The mean C-organic / C-carbonate ratio was 0.09 at 2,300 m depth in the central Humboldt Current System (HCS) off Chile, indicating a potential net export of carbonate to the deep-sea.
The carbonate flux was dominated by foraminifers and secondarily by coccolithophorids, contributing with 55 and 102% of total carbonate flux. The contribution of the carbonate flux to the total carbon flux (POC + carbonate) was 91%. This suggests that the deep-water delivery of biogenic CaCO3 is the main pathway by which carbon is removed from the upper ocean biosphere in the central HCS off Chile.
The POC flux at 100 m depth was studied by using drifting sediment traps along the central-northern HCS during the period 1997-2005. The POC flux was dominated by diatoms and faecal material of zooplankton during the spring/summer and winter/autumn periods, respectively. Key groups contributing to this flux are chain-forming diatoms of the genera Chaetoceros, Skeletonema and Thalassiosira, and the faecal material produced by euphausiids and appendicularians. During the non-productive period (mean primary production (PP) ~1000 mgC m-2 d-1), the POC flux was dominated by faecal material and a relatively high proportion (~24%) of the PP was exported below 100 m depth. By contrary, during the productive period (mean PP ~7000 mgC m-2 d-1), the POC flux was equally composed by faecal material and phytoplankton and a relatively low proportion (~5%) of the PP was exported below 100 m depth.

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HCS121 - Lagrangian description of the connection between Equatorial Pacific and Peruvian current system in a high-resolution numerical model

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Keywords: Lagrangian description, numerical floats, Peru-Chile Undercurrents, Regional ocean model system.

Historically patterns of the ocean currents in the eastern south tropical Pacific have been deduced from eulerian current measurements or geostrophic flow estimates that lack spatial/temporal resolution to provide a reliable description of true Lagrangian pathways. As a result, limited information exists regarding the connections between equatorial currents and the Peruvian current system. Making use of the Lagrangian submodel developed for ROMS model outputs, we investigate these connections under climatological conditions (Penven et al, 2005). Preliminary results show that the model reproduces the two main branches of the eastward zonal flow that are of interest to us (Fig. 1). The first branch is the Equatorial Undercurrent (EUC) located between 1 °N and 1 °S. The second one is the South Extension of EUC (SEEUC) located between 3 – 4 °S. Both extend to depths of 50 to 150 m and are present year round which is consistent with existing observations. Most importantly, a first set of Lagrangian trajectories suggests that the subsurface poleward currents off Peru (Peru-Chile Undercurrent – PCUC - and Peru-Chile Countercurrent - PCCC) are both fed not only by the SEEUC, but also directly by the EUC.

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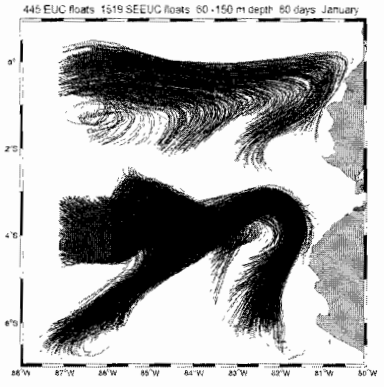

Figure 1. 60 days trajectories for 1964 floats released in January. Red points represent initial positions of the floats. The ensemble of trajectories illustrates the main subsurface pathways.

HCS126 - Modeling the egg and early larval anchoveta (*Engraulis ringens*) transport/retention in the southern spawning area of the Humboldt Current

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Keyword: IBM, eggs, larvae, anchoveta, spawning, Humboldt Current.

The anchoveta (*Engraulis ringens*), a multiple spawner, reproduces in the central-south region off Chile (34°–41°S) during winter and early spring. In this area, seasonal and shorter time scale fluctuations in the winds patterns through the year contributes to the upwelling variability and trigger changes in oceanographic conditions such as mixed layer depth, oxygen concentrations, temperature, mesoscale features (filaments and fronts) and circulation patterns (advection and retention). These changes in oceanographic conditions, when interacting with the biological characteristics (eggs buoyancy and quality) and temporal and spatial characteristics of the spawn (location, depth, and timing of the spawning) modulate the overall distribution and survival of the early stages of this species throughout the spawning region (Parada et al., 2003; Llanos-Rivera & Castro, 2004). In this study we assess the variability of oceanographic conditions and characteristics of the spawn in two locations in the central-south spawning area: the Talcahuano area (34° - 37°S) and the Lebu-Corral area (37.5° - 40.5°S) during winter-early springs 2004 and 2005. Egg density and distribution given by egg surveys carried out during 2004 and 2005 were used to initialize an individual-based model of anchoveta early stages coupled to an hydrodynamic model of the area to study the transport/retention patterns from two spawning locations to potential nursery areas.
The overall oceanographic conditions varied during the anchoveta reproductive season. In winter (main spawning peak) north winds northerly winds (>50km/h) dominated and freshwater from precipitation and

river outputs influenced the coastal areas. Salinity was low at the surface (<34psu), and higher at deeper layers (34.58psu). The mixed layer was homogeneous down to 40 m, with temperature <13 °C, and high oxygen levels (4–6 ml/l). During early spring (end of the spawning season), the strengthening of south and south-westerly winds intensified upwelling (surface temperature <13°C). The mixed layer depth was shallower (15m) at the coast with high oxygen concentrations (4.16 a 6.78ml/l). Beneath this layer, oxygen concentrations decreased <1ml/l. In mid spring, the water column was more stratified with higher temperatures (13.67°C) at the surface and lower temperatures at 80 m (9.4°C); the thermocline was located around 20 m. An oxygen deficit zone occurred at mid depths (40 m). Salinity was lower (34.44psu) at the surface than in deeper water (34.6psu). In terms of potential horizontal transport processes, during spring the south and south-westerly winds induced upwelling and surface seaward water movement by which part of the egg and larval population can be exported offshore. In winter, instead, the north north-westerly winds induced downwelling at the coast and a shoreward movement of surface water where eggs and larvae could have been retained. Two localities of maximum egg concentrations were observed in both years. During the spawning peak, the eggs distribution was more variable in Talcahuano than in the Lebu-Corral locality (Fig 1). Egg and yolk-sac larvae abundances in winter 2005 were higher (6605 eggs/0.05m^2; 721 yolk-sac larvae/100mm^3) than in 2004 (3604 eggs /0.05m^2; 1439 yolk-sac larvae/100mm^3). Using the oceanographic data and the biological and spatial and temporal characteristics of the spawning, an individual-based model (IBM) was run to simulate the transport of early stages of anchovy in the spawning locations. The IBM modeled the development of anchovy from egg up to first-feeding larvae. The processes modeled included vertical movement of eggs buoyancy-mediated, egg development and early larval growth as a function of temperature, and explicitly defined biological and spatial and temporal properties of the spawn (egg buoyancy; spawning location, depth and date). The IBM was initialized with the spawning patterns observed from the data obtained in 2004 and 2005. The model assessed the proportion of larvae in pre-feeding stage that were maintained/left the spawning/nursery locations. The IBM was coupled to the hydrodynamic model ROMS (Regional, Ocean, Model System) for the region (32° a 41°S). Initial ROMs configuration included outputs every two days and a 5x5 km spatial resolution. The aim of the IBM simulations is to track individuals in space and time, and to identify the fate of individuals in both spawning/nursery areas identifying transport success given differential initial conditions of spawning (based on egg survey for two years). IBM simulation using ROMS outputs are under progress.

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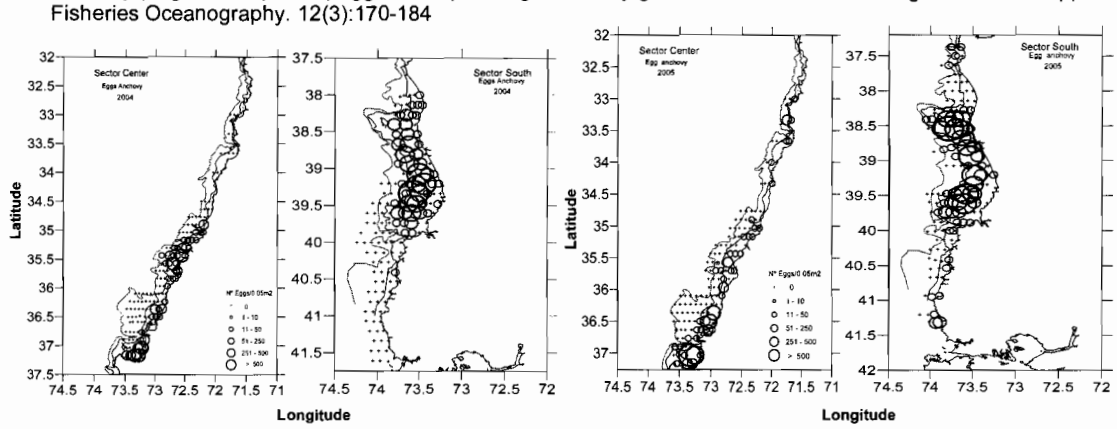

Figure 1. Anchoveta egg distribution at the Talcahuano (left panel) and Lebu-Corral (right panel) locations in 2004 and 2005. (blue line: 50m; red line: 100m).

HCS086 - *Euphausia mucronata* a keystone herbivore and prey of the Humboldt Current.

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Key words: Euphausiids, food-web, fish-prey, purse-seine fishing, *Trachurus*.

Zooplankton in a collective context is assumed to be the intermediate link in the transfer of photosynthetic production to higher trophic levels; a role which is also attributed to small pelagic fish (e.g. sardine, anchovies etc.) to explain their high stocks particularly in upwelling regions. Some peculiar euphausiids among the zooplankton occupy this role in highly productive ecosystems (e.g. Antarctic krill). An intermediate and crucial position in the food web such as this are attributes of a keystone species (Paine, 1969) and a wasp-waist community structure (Rice, 1995; Bakun, 1996). Different lines of evidence suggest that a similar situation may occur for *E. mucronata* in the Humboldt Current System.

The objective of this work is to present some lines of evidence to emphasize this role for this endemic which is so well adapted to live in such a peculiar ecosystem. A re-examination of its geographic distribution, its morphological and physiological adaptations to vertically migrate into the Oxygen Minimum Layer (Antezana, 1978, 2002) together with results based on food and feeding of E. mucronata (and of jack-mackerel off Chile) suggest a significant impact of this krill population upon primary production. Estimated high ingestion rates (ca. 300 ng Chl eq./ind*hr or ca 500 ugC/ind*d) which is equivalent to a daily ration of 13% of its body weight (Table 1 and 2) are discussed and compared to scatter published results (e.g. Gonzalez et al 2000).

It is also suggested that actual densities are much larger than assessed in historical fishery resources oriented plankton surveys, and probably overlooked according to frequent reports on the frequency and dominance of the species in the diet of many and most abundant fishes (e.g. jack mackerel).

The role of *E. mucronata* as a keystone key is emphasized as well, based on occasional reported findings together with results based on jack mackerel feeding off Central Chile. *E. mucronata* makes about 60% in weight and for about 80% of jack mackerel during fishing operation 1989-1991 off southern Chile 34-39ºS, with no significant changes during seasons and years.

Changes in the stomach content between successive purse seine sets and throughout fishing events (Fig 2) suggest not only a very opportunistic behavior of the fish, but a high variance in the distribution of *E. mucronata*, emphasizing its aggregative behavior.

Daily ration of jack mackerel varied enormously, and according to stomach content and assumed evacuation rates jack mackerel eats about 1% of its BW. Q/W also varies widely and was independent of body length. The projected annual consumption of *E. mucronata* by jack mackerel population alone amounts to 7-30 million tons (Table 3).

Implications of the predation pressure of several fishery resources are examined according to the distribution of landing off Peru and Central Chile, as two distinct subsystems of the Humboldt Current. Alternative scenarios associated to changes in the stocks and their predation pressure upon *E. mucronata* (fig 3) are discussed with regard to food web structure and its mesoscale changes (e.g. decades), under the assumption that euphausiid are a keystone component of the food web as it has been suggested (Curi et al, 2000) and in recent mass balance modeling efforts (Neira and Arancibia,2004).

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Table 1. *Representative values of stomach content and ration of E. mucronata in the Humboldt Current in winter 1974. (Assumed constants of stomach clearance rate = 2.76/hr, feeding period =12 hr at night; C:Chl ratio = 50).*

Body length	Wet W	Dry W	Stomach content		Ingestion rate	Ration / BW ratio
Mm	G	g	ng Chl-eq. /ind.	µg C/ind	µg C/ind.* d	% µg C / µg C
20	0.05	0.01	0.316	15.8	523	13

Table 2.- *Population consumption and Grazing Impact of E. mucronata at representative densities upon phytoplankton production. (Average density from coastal localities in winter 1974. Swarm density as reviewed by Ritz (1994) for other euphausiids . Depth of integration for average densities :0-50 m and for swarm densities :0-10 m. Average ingestion rate: 10.45 µg Chl -eq/ ind. Chl:C ratio: 50. Primary production: 3 g C/m2 * d from Walsh (1981)).*

	E. mucronata Biomass wet	*E. mucronata* Density		Population consumption		Impact on Pri. Prod.
Average	g/1000 m3	#/m3	#/m2	mg Chl-eq. /m2 * d	g C/m2*d	%
	100	2	2000	20.91	1.04	34%
Swarming	g/1000 m3	#/m3	#/m2	g Chl-eq/m2*d	g C/m2*d	%
	500	10000	100000	1.04	52.25	1733

Table 3. *Projected annual consumption of E. mucronata by jack mackerel in the Talcahuano-Coronel fishing region. Fish size 40.1 cm, 700 g. Clearance rate 0.22 from Pillar and Barange (1998). 28% fish with empty stomachs. E. mucronata share of the diet in weight, 75%.(* from Arancibia et al, 1995)*

		Sto. W/1 fish	Daily ration	Daily ration on E.m		Consumption of landed fish	
	Annual	wet	Clear. R. 0.22 / d	75 % of Sto.W	28 % non feeding fish	12 month	9 month
	*1000 t	g / fish	g / fish	g / kg fish	kg / t fish	*1000 t E.m.	
Catch 91	2330	2.71	14.3	15.3	11.0	9200	6900
Total 91*	6825	2.71	14.3	15.3	11.0	27100	20300
Catch 94	4150	2.71	14.3	15.3	11.0	16500	12400
Virtual**90	8300	2.71	14.3	15.3	11.0	39700	29800

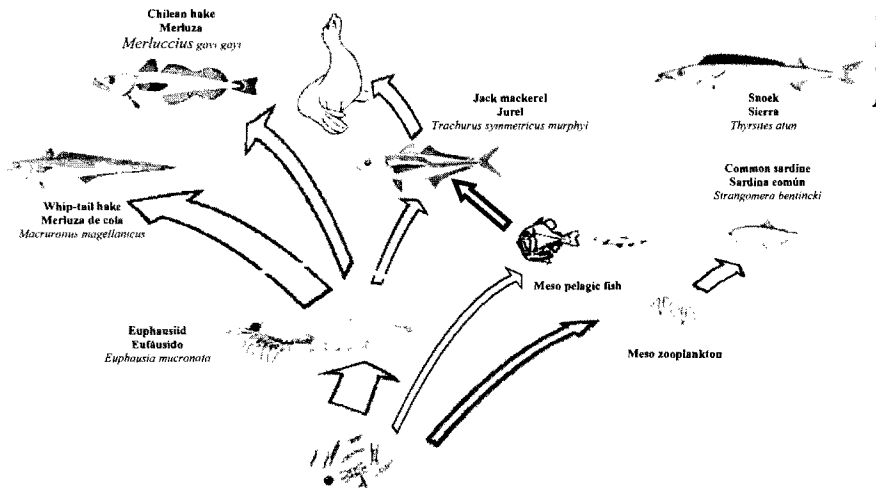

Figure 1. Conceptual model of the food web off Central Chile in a low jack-mackerel year.

HCS084 - Relating the distribution and abundance of zooplankton in the Peruvian Humboldt Current System from 1983-2005 to environmental factors, including the proximity of major fish predators

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Predator prey dynamics play a major role in upwelling-based coastal marine ecosystems, yet direct effects of predation through prey reduction are difficult to observe over larger areas due to the patchy nature of biological distributions and the difficulty of separating predation and production effects while transecting these systems. Our study combines data from zooplankton sampling and acoustic observations on fish from 40 pelagic surveys conducted by the Peruvian Marine Research Institute (IMARPE) along the Peruvian coast from 1983 to 2005. We modelled zooplankton bio-volume as a function of location (latitude and distance from the 200-m isobath), environmental (sea surface temperature; SST), temporal (year, month and time of day) and biological (acoustic anchovy and sardine biomass within 5 km of each zooplankton sample) using classification and regression trees (CART) and generalized additive models (GAM). CART results showed a strong impact of anchovy but not sardine biomass on zooplankton bio-volume, with significantly reduced levels of bio-volume for higher levels of anchovy in the region. This effect was the most important for zooplankton bio-volume. Additionally, zooplankton bio-volume was higher offshore than on the shelf and was higher when SST was above 21.2°C (for some years and months). GAM results corroborated the CART findings, also showing a clear diel effect on zooplankton bio-volume, probably due to diel migration.

HCS128 - Life cycles of the copepods *Calanus chilensis* and *Centropages brachiatus* in the northern coastal upwelling Chilean of the Humboldt Current system

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Keywords: Cohorts, Humboldt-Current, Life-cycles, Upwelling

Life cycles of copepods have become a critical issue to assess the role of dominant zooplankton in the functioning and productivity of the highly productive Humboldt Current ecosystem. Based on time series study, we analyzed the annual life cycles of *Calanus chilensis* and *Centropages brachiatus*. These species are very abundant in the coastal zone, comprising an important fraction of the zooplankton biomass. The study was based on weekly sampling during 2002 at fixed coastal station (90 m depth) off Mejillones Bay (23° S) in which upwelling may occur year round. Zooplankton samples were obtained along with data on the oceanographic variables temperature, salinity, dissolved oxygen, Chlorophyll-*a*, nutrients and phytoplankton composition. All copepod stages (including eggs), for both species, were analyzed to describe their life cycles, identify the reproductive events and cohorts, and to estimate generation time (GT) and the expected number of generations a year (GY).

The oceanographic variability of the whole water column reveals a weak seasonal signal, from a warmer, more stratified period during spring/summer, to a slightly colder and more mixed water column during the winter but this changes however take place only in the upper 20 m. Variation in salinity showed two distinct periods revealing a potential change in the water mass in the zone. The DO in the water column indicated that poor oxygen waters prevail in the area during most of the year, with an upper limit of the OMZ (1 ml O_2 l^{-1}) as shallow as 10 m (average depth of the OMZ was 26.6 m) The OMZ depth fluctuated in association with changes in the thermocline depth, and positive association between depth of the OMZ and SST ($r = 0.4$, $P < 0.05$), indicating that rising of the OMZ occurred along with surface cooling due to upwelling. Nauplii and copepodids of *C. chilensis* and *C. brachiatus* were present throughout the year and the phytoplankton community was diverse in terms of functional groups diatoms, dinoflagellates and naked flagellates. The analysis of relative abundance at different phases of the cohort development was used to elucidate the annual cycle (Fig. 1). The relative abundance of eggs and naupliar stages can show the period when the population initiated a new cohort (upper panels). The initiated cohorts able to develop can be represented by relative abundance of copepodids (mid-panels), whereas the relative proportion of adults with respect to copepodids, can shows the cohorts completed by reaching adulthood (lower panels). *C. chilensis* presented many events at which the population initiated a new cohort, as revealed by the time when naupliar stages were dominated (>50 %) by N1. The peaks in egg abundance coincided with high proportions (> 80 %) of N1 (Fig. 1a) and the most of the cohorts were able to develop (Fig.1b) and the relative proportion of adults with respect to copepodids, shows that at least 15 cohorts were completed by reaching adulthood (Fig. 1c). The generation time, estimated from the average time intervals between adult peaks, was in the range of 14 to 35 days with a mean value of 20 days. *C brachiatus* showed many reproductive pulses, as reflected in peaks of egg abundance and the increase in N1 proportion also revealed many events of new cohort initiation (Fig. 1d). A high number of cohorts developed during the year in according to relative abundance of copepodids (Fig. 1e), and at least 15 cohorts completed their development as indicated by the increases in proportion of adults (Fig. 1f). An estimate of the generation time was in the range of 10 - 28 days with a mean value of 19 days.

Both species showed a very similar annual life cycle. Reproduction was continuous with GT ranging between 19-20 days and nearly 15 GY. More than 9 cohorts a year could be observed for *C. brachiatus*, whereas *C. chilensis* exhibited cohort overlapping, but having periods or more intense reproduction.

Our results showed a close association between abundance and reproduction period of both species revealing the strong link between their life cycles and upwelling variability. The continuous upwelling, promoting high food (Chl-*a*) year-round, should be the key process that allow *C. chilensis* and *C. brachiatus* to reproduce, grow and develop throughout the year, giving rise to a multigenerational of populations and should yield a high secondary production during a year cycle in the coastal upwelling of the Humboldt Current System.

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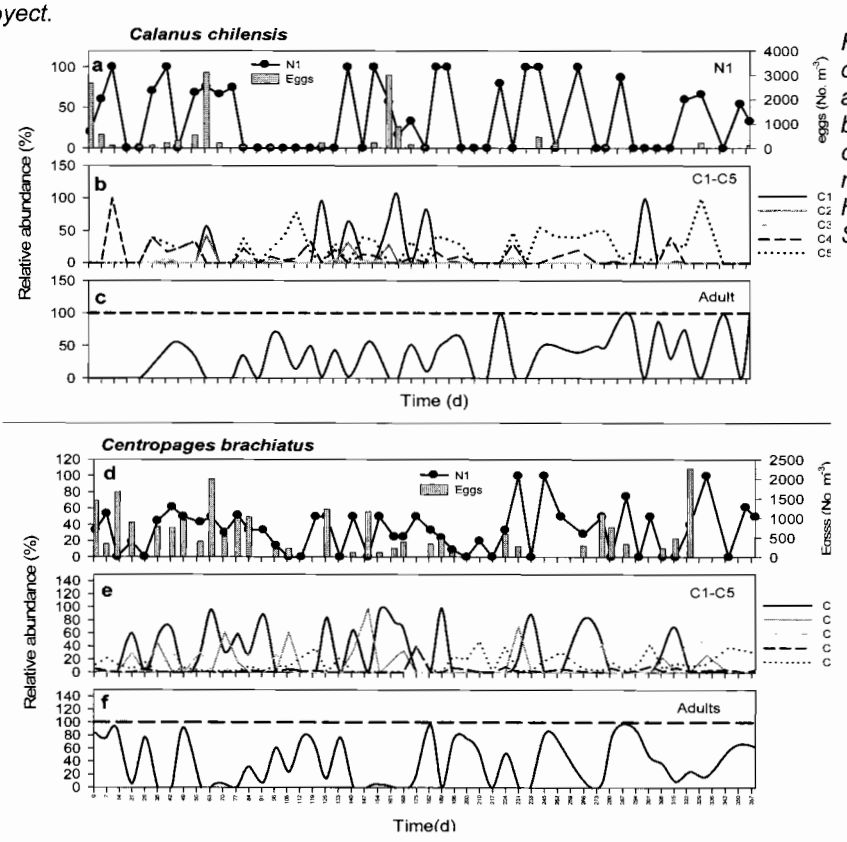

Figure 1. The life cycles of Calanus chilensis and Centropages brachiatus in the coastal upwelling of the northern Chile in the Humboldt Current System.

HCS051 - C and N pools of metazooplankton in the northern upwelling region off Chile: implications for vertical fluxes

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Keywords: Oxygen Minimum Zone, Northern Chile, Vertical Migration, Zooplankton

Zooplankton in the coastal upwelling zone of the Humboldt Current may play a significant role in the cycling and flux of freshly produced organic C and N. Key components linked to vertical flux of these elements are chemical composition of zooplankton biomass, community structure, vertical distribution, and diel vertical migration (DVM). In the upwelling zone an additional component should de added, and this is the interaction with a shallow (<50 m) oxygen minimum zone (OZM). In the present work, the metazooplankton community was studied in coastal waters off northern Chile. Two upwelling sites (off Iquique 21° S and off Chipana 22° S) were studied during the ZOMEI cruise in October 2005 onboard the RV Vidal Gormaz. At each place a cross-shelf transect (120 nm from shore) allowed the analysis of hydrographic conditions in term of temperature, salinity, fluorescence and dissolved oxygen. In one of the stations (20 nm from shore) and intensive zooplankton sampling was carried out. For this a Hydrobios Multinet, 0.5 m opening diameter and 200 μm mesh size was used. Day and night samples were obtained for 5 depth strata from 700 m to surface, as to cover deep Antartic intermediate water, the equatorial subsurface water (associated with the OMZ) and the upper subantarctic and subtropical waters. Zooplankton samples were fractioned onboard to obtain measurements of dry weight, C and N contents by mass spectrophotometry and taxonomic composition .

The zooplankton community was mostly composed by copepods and the dominant species were *Eucalanus inermis*, *Calanus chilensis*, *Acartia tonsa*, *Paracalanus parvus*, *Oncaea conica* and *O. venusta*. The euphausiid *Euphausia mucronata* was also abundant in some cases. The analysis of vertical distribution and DVM showed a marked differential distribution of species over the entire water column. The copepods *C. chilensis, P. parvus*, *A. tonsa* and *Oncaea* spp. appeared restricted to the upper (<50 m) well-oxygenated layer, whereas the larger copepod *E. inermis* exhibited an intermediate (60-200 m) distribution, performing DVM to near-surface water at night (Hidalgo et al., 2005). Meantime *E. mucronata* was performing extense DVM from the upper layer down to 600 m. The C and N contents of the whole biomass were in the range of 0.01–37 mg m^{-3} and 0.005-7.5 mg m^{-3} respectively, with an average C/N ratio of 5.6. The biomass in terms of dry weight ranged between 0.1 and 72 mg m^{-3}. Most zooplankton biomass was concentrated in the upper 30 m layer and increased substantially at night due to DVM performed by *E. mucronata* (Fig. 1)

We estimated that about 80% of total zooplankton is daily movilized from the upper photic zone to deep into the OMZ. This means that nearly 5 and 1 mg of C and N respectively are daily transported as zooplankton biomass to the OMZ. This active transport of organic matter may substantially accelerate its vertical fluxes. Metabolic analysis of fractions of this biomass in deep (>200 m) water indicates that about 20% of the zooplankton is comprised by dead animals. If we add to this C and N released from respiration, egestion, excretion, egg production and moulting, then active transport of C and N mediated by zooplankton may largely surpass passive fluxes, estimated as 20-119 mg C m^{-2} in this region (González et al., 1998). This significant role of zooplankton in contributing to vertical flux of C and N has not been considered before and deserves further attention.

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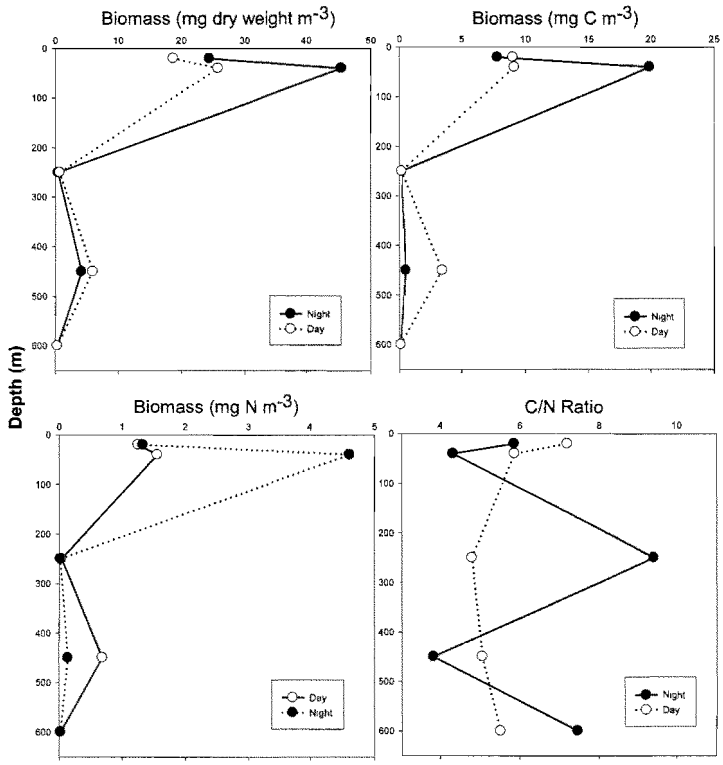

Figure 1. Vertical distribution of zooplankton biomass, C and N contents and the C/N ratio in the coastal upwelling zone off northern Chile in October 2005. Data were averaged from two locations and 2 days sampling at each site.

HCS148 - Revising previous hypothesis on the trophic position and ecological role of the Peruvian anchovy (*Engraulis ringens*)

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Keywords: anchovy *Engraulis ringens*, carbon content, diel feeding behaviour, diet, Peru Humboldt Current system, plankton

The Peruvian anchovy (*Engraulis ringens*) forages on plankton communities and is the main prey of various predators including marine mammals, seabirds, fish, and fisheries. It is therefore a key element of the marine food web in the Humboldt Current system (HCS). In this work, we present results of anchovy stomach content analysis from 1996-2003. Samples came from 23 acoustic surveys and a total of 21,203 stomach contents of anchovy ranging from 3 to 18 cm in length were analyzed. Prey items were identified to the highest taxonomic level possible, then converted to carbon content (µg) and expressed as percent. From 1996-2003, variability in stomach fullness was examined with respect to the taxonomic composition, time of the day, distance from the coast, sea surface temperature (SST), and latitude using generalized additive models (GAMs). Results showed that mean fullness (stomach contents weight expressed as percentage of total fish wet weight) was 0.68% and varied between 0.29% in February-March 1999 to 1.23% in August-September 1999. Phytoplankton largely dominated anchovy diet composing 99.52% of number of prey items. The portion of copepods accounted only the 0.07% and euphausiids the 0.003%. This view of anchovy's diet dramatically changes when considering the carbon content of prey items, whereby zooplankton is by far the most important component (98.0%) with a strong dominance of euphausiids (65.9%) followed by copepods (28.0%). This general view of anchovy diet based on carbon content varied with time but no seasonal trend could be identified. Carbon content of phytoplankton reached its highest level in August-September 1996 with 40.5% and a minimum in June-July 2000 (0.07%). Euphausiids carbon fraction reached as much as 90.1% in August-September 1999, a La Niña period (lower value was 5.4% in November-December 1998) when the maximum proportion of copepods occurred at the end of the El Niño event 1997-98 (87.6%) and the lowest value was observed in November-December 1996 (2.2%). GAMs computed on all surveys showed that main feeding activity occurred during daytime hours, between 07 and 18 hours (Fig. 1). This general pattern was observed for most surveys although nighttimes feeding behaviour made substantial contribution to the total ingestion. Stomach fullness varied with latitude (Fig. 1), with higher values encountered in Northern (< 6°S) and Southern Peru (>13°S), but latitudinal patterns could not be assessed since we obtained some of the highest fullness values in the central part of Peru. Stomach fullness increased with distance from the coast (Fig. 1) and often reached maximum values at sampling stations positioned more than 120 km from the

coast, but strong variability was also observed, e.g. high fullness levels were observed in very coastal areas when anchovy was distributed close to the coast, particularly during the 1997-98 El Niño event. Finally, anchovy stomach fullness had a negative relationship with temperature (Fig. 1) and reached lower values around 22°C. However, the range of temperature varied seasonally, and its effect on stomach fullness can only be partially explained.

In contrast with previous studies, our results show that zooplankton (in particular euphausiids and copepods) is the major component of anchovy diet. Most previous studies concluded that diet of Peruvian anchovy was mainly based on phytoplankton or that phytoplankton and zooplankton played a similar role. However, these works were mainly based on qualitative descriptions of anchovy diet, frequency of occurrence, and percent by numbers rather than carbon content. In terms of diel feeding activity, our results differ from those from Pauly et al. (1989) and Jarre et al. (1991) for the period 1953 – 1982. This difference cannot be related to different methodology i.e., GAM vs. Sainsbury's method. Applying this last method to our data does not change the results.

In summary, the analysis of 21,203 stomach contents shows that zooplankton make up most of the energy for anchovy even though significantly more phytoplankton prey items are ingested. These results put into perspective our current knowledge on anchovy diet, its position in the trophic foodweb, and thus, the trophic models that were build in the HCS.

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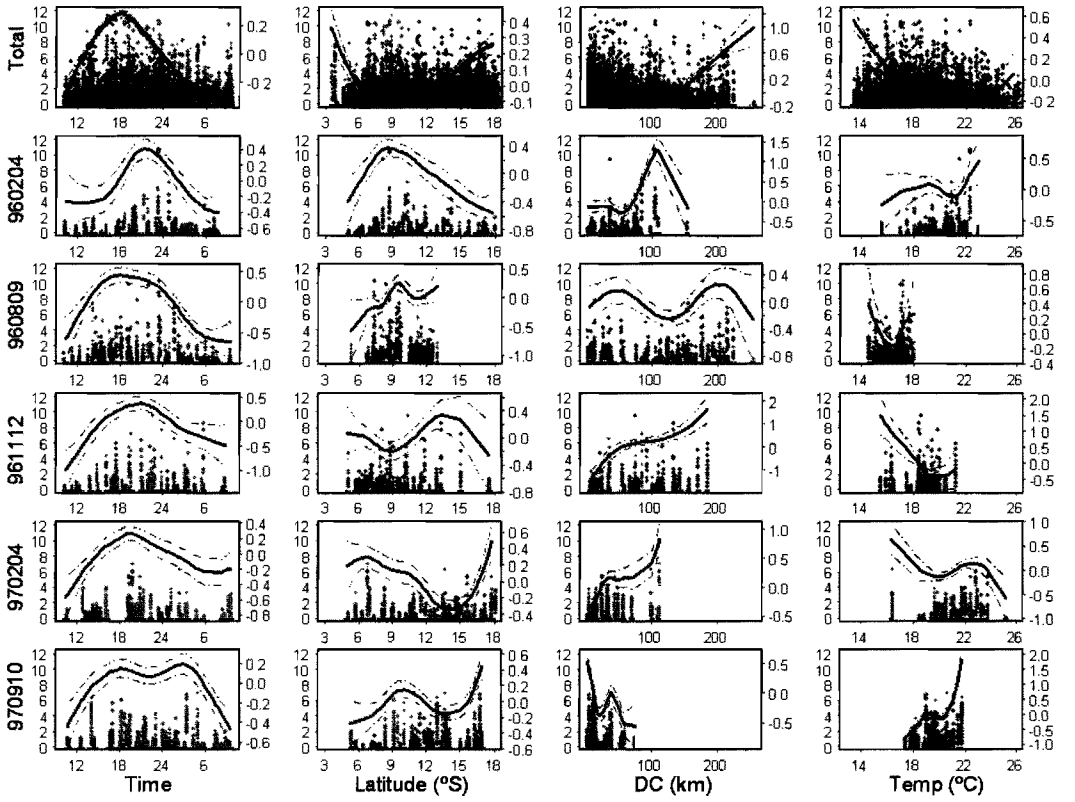

Figure 1. Scatter plot (grey dots) and cubic spline smoothers fits (black solid lines) of GAM models based on fullness on anchovy stomach fullness according to time of day, latitude, distance from the coast (DC) and sea surface temperature (°C) for the complete set of 21,203 stomach contents. Also shown are the fits for 5 of the 23 surveys from which stomach contents were analyzed. The black dotted lines show the 95% confidence limits of GAM models. Left y-axis shows stomach fullness in percent. The right y-axis are in relative scale, they correspond to the spline smoother that was fitted on the data, so that a y-value of zero is the mean effect of the variables on the response.

HCS093 - Comparative trophodynamics of small pelagic fish species in the Benguela Current and Humboldt Current upwelling Systems

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Keywords: Benguela, Humboldt, small pelagic fish, trophodynamics

Abundant populations of co-existing small pelagic fish species that show periods of alternating dominance are a defining feature of upwelling ecosystems and have been the focus of considerable research, including that directed at investigating their trophodynamics and elucidating their respective trophic roles. In this presentation we compare the trophodynamics of some these co-existing species from the Benguela Current and Humboldt Current systems, and assess whether observed species alternations may be trophically mediated. Information collected from morphological, field and experimental studies is described, and species examined include anchovy (*Engraulis encrasicolus*) and sardine (*Sardinops sagax*) in the northern and southern Benguela; anchovy (*E. ringens*) and sardine (*Sardinops sagax*) in the northern Humboldt; and anchovy (*E. ringens*) and common sardine (*Strangomera bentincki*) in the southern Humboldt.
Aspects of trophic morphology compared include length-related changes in gape size of anchovy and sardine larvae in the northern Humboldt and in early anchovy and sardine juveniles in the southern Benguela; and length-related changes in the branchial basket structure of anchovy and sardine juveniles and adults in the northern Benguela. Comparative dietary studies are described for larvae, juveniles and adults of anchovy and sardine in the northern Humboldt; larvae, juveniles and adults of anchovy and common sardine in the southern Humboldt; and juveniles and adults of anchovy and sardine in the northern and southern Benguela. Experimental studies conducted to investigate the feeding behaviour of southern Benguela anchovy and sardine and anchovy and common sardine from the southern Humboldt are described, as are laboratory studies investigating energetic costs and assimilation efficiencies of southern Benguela anchovy and sardine. Energetics models for southern Benguela species developed from these experiments are also briefly described.
Consistent differences between anchovy and sardine (*Sardinops*) in the Benguela Current and northern Humboldt Current systems, such as a larger gape size at a given length for early stages of anchovy compared to sardine, and a higher contribution by phytoplankton and/or small zooplankton to the diet of sardine compared to anchovy, are indicative of resource partitioning between the two species. This, together with results derived from experimental studies and energetics models that suggest that sardine maximize their net energy gain when filter-feeding on smaller zooplankton whereas anchovy maximize their net energy gain when particulate-feeding on larger zooplankton, indicate that differently-structured food environments can favour anchovy over sardine, and *vice versa*, and suggest that species alternations between the two may be trophodynamically-mediated. In the southern Humboldt, anchovy and common sardine (*Strangomera*) exhibit a high degree of trophic overlap and resource partitioning between the two species is not obvious, although this may be due to a relative paucity of information and further research on this species pair is required.

HCS123 - Identifying trophic controls in the southern Humboldt system off central Chile

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Keywords: trophic controls, physical forcing, southern Humboldt, central Chile, time series, wasp-waist.

Although fishing is considered the main threat to marine ecosystems, predation mortality is the main source of natural mortality and, in some cases, of total mortality for many stocks. Therefore, trophic relationships play a central role in the way ecosystems are self-organized. Information about who eats whom represents one of the first records of naturalists, however, this classic question been replaced by the more dynamic question of who controls whom in marine ecosystems. The traditional way in which trophic controls in marine food webs have been approached indicates that population dynamics are either controlled by predator's consumption (top-down control) or by resource availability (bottom-up control). However, an important characteristic of some marine food webs is the presence of "waists" where an individual taxon located in middle trophic position passes most of the energy from lower to all higher predators (Rice, 1995). Specifically, in upwelling ecosystems this position is occupied by small pelagic fish. This species are dominant in terms of biomass, and exert a trophic control on both their predators (through bottom-up control) and their zooplankton prey (through top-down control), while their own dynamics is not controlled by predator consumption or food availability, but by environmental forcing (Cury et al., 2000).
The southern section of the Humboldt system (SH) is one of the least studied upwelling ecosystems. Consequently, the existence of trophic controls as well as their effects on food web dynamic is still poorly understood. Consequently, the aim of this paper is to analyze available data series to identify i) possible waists in the system, and ii) main controls operating in the food web.
Following Cury et al. (2000), the number of species across important taxa inhabiting SH is analyzed,

considering the following categories: jelly fish, crustaceans, anelida-polichaeta, mollusks, fishes, sea birds and marine mammals. Fish species were split into the following groups: bony fishes and chondrichthyans. Bony fishes were subsequently split into mesopelagic fish, small pelagic fish, other pelagic fish, and demersal fish.

Later, available biomass time series of small pelagic fish (common sardine, *Strangomera bentincki* and anchovy *Engraulis ringens*), Chilean hake (*Merluccius gayi,* main predator in the system for which time series are available) and copepods (main zooplankton prey for small pelagic fish) were used to analyze relationships that could indicate top-down or bottom-up trophic control between these groups. The time series for small pelagic fish and Chilean hake were collected from official evaluations and correspond to direct estimates of biomass for these species between years 1990 and 2004. Copepod abundance corresponds to *in situ* samples collected during the yearly survey carried out to estimate the biomass of horse mackerel (*Trachurus symmetricus)* in the study area from 1997 to 2004. The *chlorophyll a* data series (1997-2005) for the area 33°S-39°S and from the coast line to 78°W were collected from the SeaWiFS project (http://oceancolor.gsfc.nasa.gov/SeaWiFS/) and kindly processed by Mr. Hervé Demarq (CRH, France).

A "waist" in the number of species along the main animal taxa is observed in the SH system, which is consistent with the pattern observed in the southern Benguela system (Cury et al., 2000) (Fig.1).

Evidence of bottom-up control of small pelagic fish on Chilean hake in the SH system (Fig. 2). On the other side, the short time series for *chlorophyll a* indicates that the bottom (phytoplankton) has not experienced changes (no significant trend found), from 1997 onwards, while copepods are in steep decline in the same period (Fig. 1). These changes have not strongly affected small pelagic fish (waist) or Chilean hake, and therefore it is possible to hypothesize that the system is controlled by changes in the waist.

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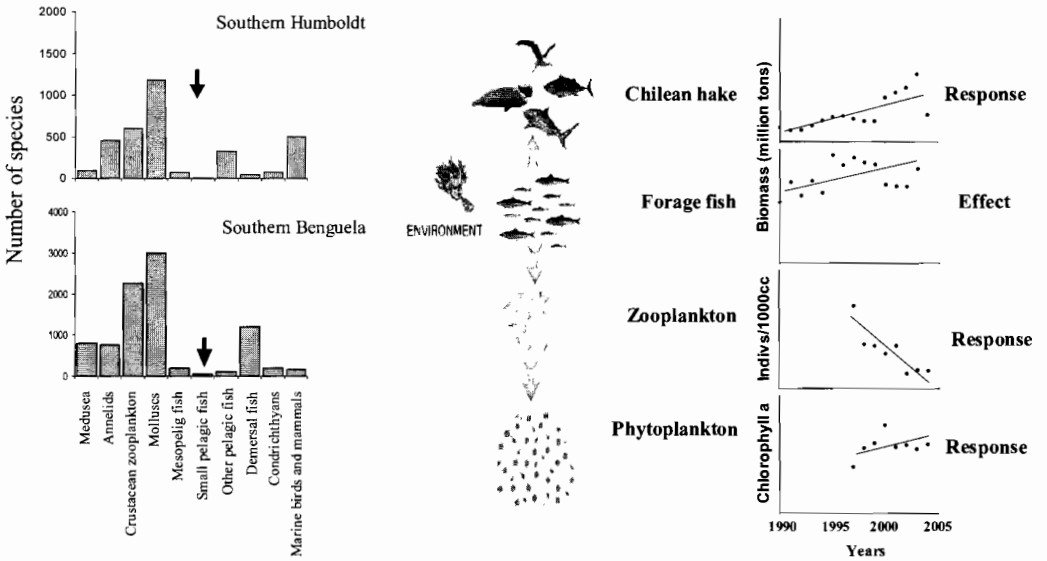

Figure 1. Left, number of species along the most important taxonomic groups in two upwelling ecosystem, Central Chile (Southern Humboldt) and South Africa (Southern Benguela). The arrows indicate the group located in the waist (small pelagic fish); right, relationship between the relative abundance of different groups in the southern Humboldt system.

HCS196 - Trophic flows in the Northern Humboldt Current Ecosystem, Part 1: comparing 1995-96 and 1997-98

J. Tam, M. Taylor, V. Blaskovic, P. Espinoza, R. M. Ballón, S. Purca, E. Díaz, D. Gutiérrez, L. Quipuzcoa, P. Ayón, S. Sánchez, E. Goya, J. Argüelles, M. Wolf, C. Wosnitza-Mendo.

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Keywords: Ecotrophic model, ecosystem indicators, El Niño and the Southern Oscillation, Humboldt Current, Peru.

El Niño 1997-98 was one of the strongest warm events of the past century, related changes in environmental parameters affected phytoplankton species composition, reducing the biomass of the first trophic level along the Peruvian coast. Single responses of main fish resources to this natural perturbation are relatively well known, however echotrophic multispecies models can help studying more global ecosystem response. The development of dynamic trophic modeling tools such as Ecopath with Ecosim (EwE), allows the construction of more detailed models that allow creating more realistic interactions between species or species groups. Drawing from past models for the Peruvian system (Jarre et al. 1991), newer models of other Eastern Boundary Currents (EBC's), and recent trends in Peruvian resources, trophic models for the periods 1995-96 and 1997-98 of the Northern Humboldt Current Ecosystem were constructed to explore temporal changes during the past decade. The model area covered 4°-16°S and extends to 60 nm from the coast. The model includes 32 groups and differs from previous models of the Peruvian system through: 1) division of plankton into groups to account for the feeding preferences between small pelagics, 2) increased detail of demersal groups and life history separations of hake to account for diet changes, 3) incorporation of mesopelagic fish and of the Jumbo squid, which has gained in importance since the last El Niño 1997-98.

Different factors were responsible for the decreased biomass of groups at higher trophic levels (Bertrand et al. 2004). In particular, planktivorous small pelagic fish species such as anchovy and sardine are key elements in the transfer of energy to species of higher trophic levels (mackerel, and horse mackerel), and all four species decreased in biomass through the development of the El Niño event. Changes in prey availability modified diet compositions, switching from normal trophic flows through alternative energy channels, affecting ecosystem indicators such as a reduction in total system throughput and developmental capacity.

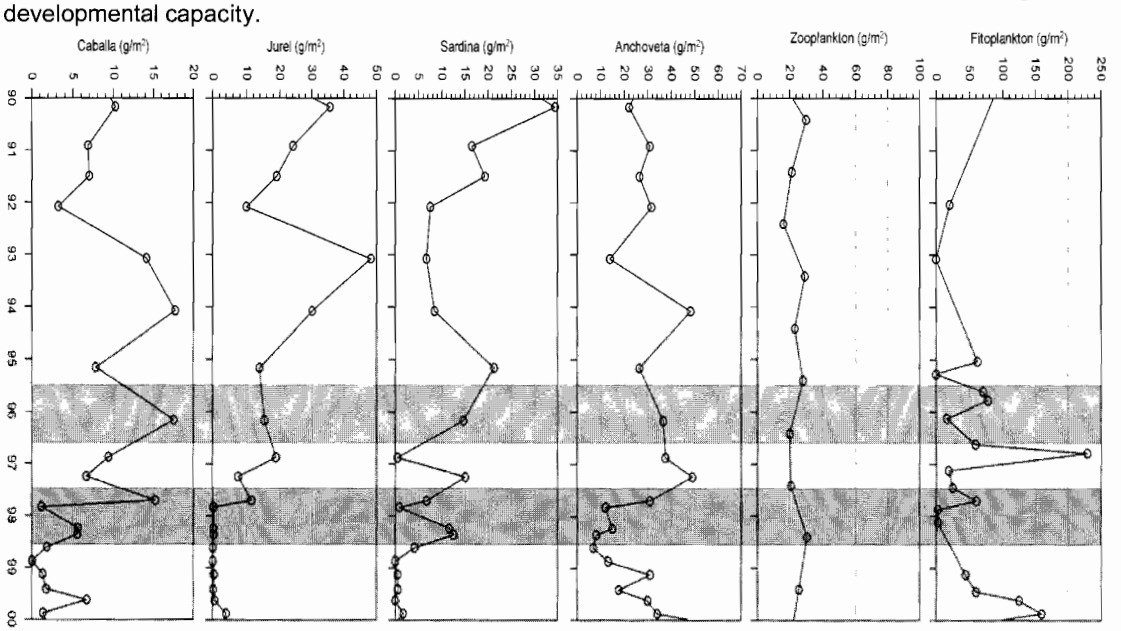

Figure 1. Temporal variation of biomass of phytoplankton, zooplankton and main fishery resources in the Northern Humboldt Current Ecosystem. Modeled periods are shadowed.

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HCS067 - Trophic flows in the Northern Humboldt Current Ecosystem, Part 2: elucidating mechanisms of ecosystem change over an ENSO cycle by simulating changes in low trophic level dynamics

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Keywords: Bottom-up control; Ecotrophic model; Humboldt Current; Peru

In Eastern Boundary Current Ecosystems (EBC's), small pelagic fish have long been recognized for their importance not only in terms of fishery catches, but also as an important prey group to higher trophic

levels. 'Small pelagics' are planktivorous, and are susceptible to changes in species composition, production and biomass that occur in the plankton in response to changing environmental conditions. As a result, the Northern Humboldt Current Ecosystem is highly dynamic – experiencing change on various time scales (seasonal, interannual – ENSO, and decadal). ENSO conditions typically involve an overall decrease in primary production due to upwelling of less nutrient-rich waters as a result of a lowered thermocline. Large diatoms that make up a major portion of the dominant small pelagic – the Peruvian anchovy – decrease in abundance and the anchovy is seen to both retreat to the few remaining productive areas and to consume at higher trophic levels from zooplankton of suitable size. Anchovy biomass was seen to decrease in response to these changes over the past ENSO of 1997-98, yet while its recuperation in the following years was fairly rapid, higher predators dependant on it as a food source have been slower to recover. Dynamic simulations using the trophic modeling program Ecopath with Ecosim, explore forcing between predator/prey trophic connections through the application of vulnerability search routines to time series of changing biomass and fishing pressure. Using these estimates, we explore the importance of fluctuations in lower trophic levels during an ENSO event – specifically, a decrease in large phytoplankton fractions (primarily diatoms) – on small pelagic dynamics. Trophic models described by Tam et al. (this conference) for the periods 1995-96 and 1997-98 provide ecosystem states for before and during an ENSO event by which to measure to simulation's performance.

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HCS057 - Comparing internal and external drivers in the southern Benguela and southern Humboldt Upwelling ecosystems

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Trophic models of two upwelling ecosystems, namely the southern Benguela (South African) and southern Humboldt (Chilean), have been fitted to catch and abundance time series. Three drivers were considered during the model fitting: internal forcing by means of the trophic flow controls between the various interacting species groups, and two kinds of external forcing, namely fishing and the environment. The southern Benguela model was fitted to time series data from 1978-2005, and the southern Humboldt model to data from 1970-2004. Fishing has been relatively carefully managed in the southern Benguela during the period modelled and previous studies found that most of the resource variability was attributed to internal forcing and to environmental forcing rather than to fishing. By comparison, fishing has been shown to have played a relatively major role in driving ecosystem changes observed in the southern Humboldt model. Bearing in mind the different roles played by each of the drivers in these ecosystems, two hypotheses were tested. Firstly, flow controls between interacting species groups, which improved the fits of both models, were compared across the two ecosystems to determine to what extent the two models supported the hypothesis that upwelling ecosystems function as wasp-waist systems. Secondly, environmental forcing was examined in an attempt to uncover the processes that may be involved in linking the environment to observed ecosystem dynamics and changes in these two upwelling ecosystems. The hypothesis tested was that although completely different physical drivers and conditions act in each of the ecosystems, the processes whereby these effects are transferred through the ecosystems and manifest themselves as ecosystem changes and observed resource dynamics are essentially similar in both upwelling systems.

HCS-110 - Egg quality and yolk Sac Larval trait variations of the anchoveta *engraulis ringens* along the central and southern zones of the Humboldt Current

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A number of reproductive strategies have been proposed for species living in different environmental conditions. Among them, anchovies have been traditionally shown to have rapid growth rates, young age of maturity, high fecundity associated with the production of abundant but small and energetically cheap eggs, and high mortality rates during the early life stages. However, recent evidence suggests that these

species may also show variations in other life history traits to enhance their offspring survival under contrasting habitat conditions. Examples of these are traits are egg size, larval hatch size and yolk sac reserves that vary with latitude, between populations, or along the spawning season (Castro et al. 2002, Llanos-Rivera & Castro 2004, Llanos-Rivera & Castro 2006). These finding, therefore, suggest that, besides high fecundity, alternative mechanisms may take place to counteract, for instance, harsh environmental winter conditions during the spawning season. The anchoveta, *Engraulis ringens,* a species from the Humboldt Current that form some of the largest small pelagic fish stocks of the world, is distributed along a wide latitudinal range (4 - 42 ^{s}o). Within this wide range, the environmental conditions such as temperature, wind stress, upwelling intensity and turbulence, change markedly among the major spawning areas. Similarly, because of the protracted spawning season in all these zones, the environmental conditions also change throughout the reproductive period, which might finally modify the chances of survival of the early life stages of the anchoveta at different times of the year.

In the present study we assess how the early life history traits of the anchoveta vary between populations separated widely in latitude (13-15 degrees of latitude) and also throughout the spawning season. First, we determined whether differences in egg size at the beginning and also during the rest of the spawning season occurred between the two main spawning areas in northern and central Chile (Iquique, 22oS, and Talcahuano, 37oS). Secondly, we determined whether changes in biochemical composition of the eggs occurred between localities and along de spawning season. Third, we assess changes in hatch success between stocks and along the season and finally, we explored whether these differences between individuals of both areas also propagated to the yolk sac larval stage. Our results from our analyses during 2003 and 2004 reproductive seasons show that eggs spawned by the southern populations were larger, contained a larger amount of proteins and lipids per egg than eggs spawned by the northern females. Egg size, lipid content and protein concentrations decreased as the spawning season progressed. However, when standardized by egg dry weight, only lipids show the trend of decrease along the season. Hatching success also decreased along the spawning season, especially in the southern population. Results from experiments carried out previously had shown that larval size and yolk sac volume at hatch were also larger in the southern population. The analysis of environmental conditions during the spawning season show that temperature is lower and turbulence is maximum at the beginning of the season and also that conditions differ between the northern and southern spawning areas. In summary, our results suggest that larger egg sizes and higher lipid content in the eggs, along with the larger sizes at hatch and bigger yolk sac volumes, may be beneficial especially for recently hatched larvae in southern latitudes and also at the beginning of the spawning season in mid winter, when the environmental conditions for young larval survival may be harder.

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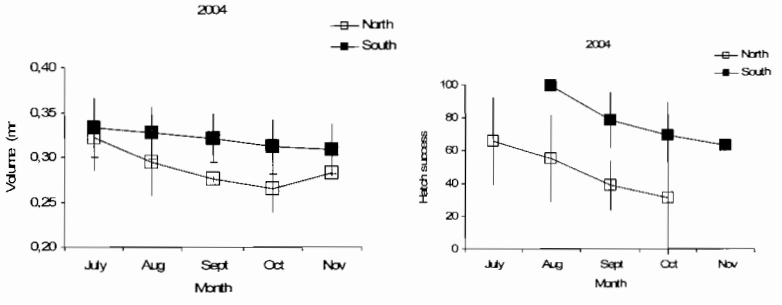

Figure 1. Egg volume and larval hatch success in anchoveta during the spawning in Northern and Southern Chile, 2004.

HCS049 - Simulating ecosystem transition from upwelling to El Niño conditions: the case of Independencia Bay, Southern Peru

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Keywords: Independencia bay, Peru, ecosystem transition, ENSO cycle

The study aims at understanding the mechanisms leading to changes in the trophic flow structure of the Bahía de Independencia ecosystem (Southern Peru) over the cycle of a strong El Niño (1997/1998). Observed changes comprised a strong proliferation of scallop and octopod biomass, a significant decrease in macrophyte, crab and polychaete biomass and several minor changes in other system compartments. Based on survey-, landing- and catch per unit of effort data (CPUE) of IMARPE (Instituto del Mar del Peru), trophic steady state models were constructed for the years 1996 (normal upwelling) and 1998 (El Niño conditions) (see Taylor et al., this conference) and used along with monthly series of relative biomass (as estimated from CPUE) for several groups over the period 1996-2003 to simulate the observed ecosystem changes over the ENSO cycle. We also used monthly temperature time series to simulate scallop recruitment using a previously constructed empirical model. The results of a series of simulations suggest: 1) the main cause for the scallop outburst and for the reduction in crab and macrophyte biomass is a temperature dependent population response (increase in scallop recruitment, mortality in crabs and macrophytes) during the El Niño warming period. The scallop proliferation is substantiated by the fact that the model responded to the temperature mediated scallop recruitment variation with (the observed) eighty fold increase in adult scallop biomass during 1998, followed by a substantial rise in (the also observed) octopod biomass. 2) Other observed changes can well be explained by trophic interactions as suggested by our ECOSIM simulations, when the model was forced to respond to time series of scallop, crab, phytoplankton and macrophyte biomass. The model predicted the following observed changes quite well: an El Niño caused decrease in the groups of benthic detrivors, miscellaneous filter feeders, polychaetes, small carnivores, herbivorous gastropods, and an increase in sea stars, octopods and littoral fish. 3) The time of onset and intensity of the scallop pulse fishery heavily influence the development and magnitude of the scallop stock and the bulk of the total catch during the El Niño, but does not greatly impact the general flow structure of the bay.

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HCS033 - Abrupt environmental shift links with changes in fish spawning in the southern Benguela

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Cape anchovy (*Engraulis encrasicolus*) is an economically-important small pelagic fish in the southern Benguela, which, together with sardine (*Sardinops sagax*), is the target of a medium-sized purse-seine fishery that has shown average annual catches of just under 400 000 tonnes over the past six decades. Interannual changes in abundance and distribution patterns of South African anchovy have been assessed bi-annually via acoustic surveys conducted since 1984. Data collected during summer surveys indicate that anchovy spawners have shown an eastward shift in their distribution (fig. 1), from being located primarily over the western Agulhas Bank (to the west of Cape Agulhas) to being located primarily over the central and eastern Agulhas Bank (to the east of Cape Agulhas). This shift in distribution occurred abruptly in 1996 and has persisted since then, with around two-thirds (on average) of the anchovy spawner population found to the east of Cape Agulhas during subsequent surveys. This eastward shift in spawning appears to have resulted in improved anchovy recruitment success.

In this communication, we present a brief review of the biological facts that best illustrate the change in the spatial dynamics of anchovy spawning, and changes in the spatial distribution of other pelagic species during the same period are also briefly described. Environmental variability over the Agulhas Bank since the early 1980's is then documented using sea surface temperature data in different regions of the bank. These data show that the inner-shelf of the Agulhas Bank east of Cape Agulhas suddenly became colder than the mid-shelf region in 1996 (Fig. 1). A signal, coherent with the 1996 shift recorded in SST is also found in atmospheric surface pressure data. Increased wind-induced coastal upwelling east of Cape Agulhas is thought to be the main driver of the enhanced cooling of the coastal region. The synchrony between the environmental and biological signals, and evidence of favourable feeding conditions for adults on the eastern side of the bank compared to the western side of the bank, have led to the development of the following hypothesis: the anchovy eastward shift was environmentally-mediated through a coupled ocean-atmosphere process, and arose from a change in environmental forcing that altered the relative favorability for spawning of regions to the west and east of Cape Agulhas.

Our results highlight how a relatively minor change in the environment can lead to a drastic spatial reorganization of the life history of one component of an ecosystem. The opening in 1996 of an environmentally-driven window of opportunity for spawning on the eastern Agulhas Bank, and its

persistence since 1996, allowed that region to become the dominant anchovy spawning ground, and that dominance has persisted since then. In the context of Global Climate Change, this example can be used to infer the response to changes in the environment of similar species in other upwelling ecosystems.

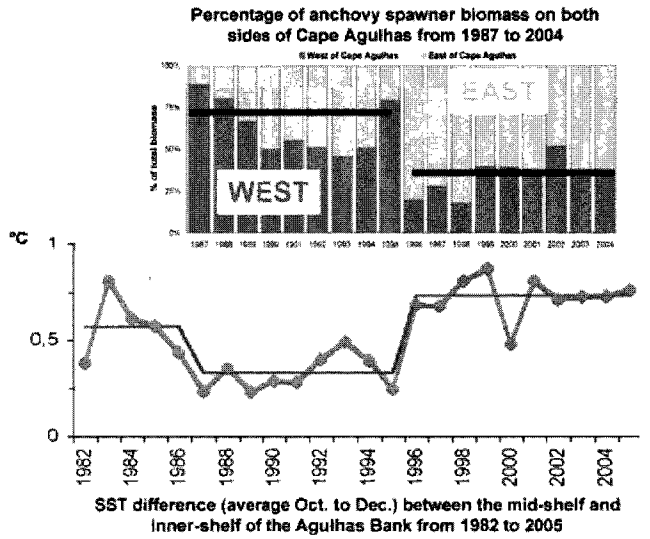

Figure 1: Environmental variability over the Agulhas Bank (bottom) and percentage of anchovy spawner biomass located on both side of Cape Agulhas (top). The abrupt shift of the spawner biomass to the east of cape Agulhas in 1996 corresponds to a sudden increase of the SST gradient between the mid-shelf and inner-shelf regions of the bank. Data on anchovy egg distribution dating back from the early eighties provide also evidence of enhanced anchovy spawning on the eastern Agulhas Bank in 1983.

HCS080 - The relationship of anchovy and sardine to water masses in the Peruvian Humboldt Current Ecosystem from 1983-2005

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Keywords: Peru-Humboldt Current system, El Niño Southern Oscillation, time series, pelagic fish spatial aggregation, water masses, upwelling water, anchovy, sardine.

Although the large fluctuations in abundance of anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) off Peru have been well documented (e.g. Alheit and Niquen, 2004; Bertrand *et al.* 2004; Gutierrez et al., in press) little is known about the functional processes underlying these dynamics in relation to ENSO events and/or decadal regimes. It has been hypothesized that colder upwelling waters provide favourable habitat (hydrologic and feeding conditions) for anchovy while sardine appear to be favoured by warmer oceanic waters habitat. In this work we use water masses as a proxy of habitat conditions. Data from 44 acoustic surveys conducted off the Peruvian coast from 1983-2003 by the Peruvian Marine Institute (IMARPE) provide an unique opportunity for testing the hypothesis of a relation between the range of distribution of these water masses and the abundance of these species. If such a relationship can be established it may suggest that the expansion and contraction of sardine and anchovy populations tracks expansion and contraction of the range of colder upwelling and warmer oceanic waters in Peruvian coastal waters. To monitor changes in water masses composition we constructed an algorithm for determining water masses based on temperature and salinity ranges but also on season and latitude ranges. Classification and Regression Trees (CART) using recursive partitioning, modelling sardine and anchovy presence-absence as a function of year, water mass and latitude showed that anchovy were primarily found in cold and mixed waters, while sardine were more ubiquist relative to water masses. This result was supported by Generalized Additive Model (GAM) analysis of anchovy and sardine abundance versus temperature and salinity as well as spatiotemporal variables. The predominance of cooler, upwelling associated water masses since 1999, can help to explain the absence of sardine and the more pervasive nature of anchovy in the Humboldt Current System. The extension-contraction of the range of distribution of these species according to the availability of each water masses is discussed.

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HCS170 - How habitat suitability does shape the 3D spatial organisation of anchovy across scales?

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Keywords: fish schooling behaviour, habitat suitability, integrated approach, pelagic ecosystem functioning, predator-prey relationships, spatial patterns.

Functional relationships in marine ecosystems are profoundly constrained by the spatial structuring of the physical landscape and by the way living organisms distribute themselves. The relative influence of these two determinisms is thought to depend on the spatiotemporal scale of the processes. Then, to improve our understanding of ecosystem functioning, we need to observe *in situ* the interactions between physical and biological features at different scales. For that purpose, the Peruvian anchovy (*Engraulis ringens*) is an interesting case study. This species supports the highest worldwide landings and is known to present very high population, distributional and even biological dynamics at different spatio-temporal scales (e.g. Bertrand *et al.*, 2004). Until now, most of the studies concerning this species focused on large and medium scale patterns (e.g. Chavez *et al.*, 2003). However, upwelling systems are spatially and temporally very heterogeneous, exhibiting a mosaic of nested dynamical physical structures at meso and sub-meso scales such as the frontal zones between coastal rich and oceanic poor water masses, plumes, filaments, eddies, internal solitary waves and other. Oceanographic and trophic conditions can therefore strongly differ from one place to another in a same zone and from one moment to another in a same place. In other words, anchovy habitat suitability varies according to the place, the scale of observation, the diel period, the oceanographic forcing or the predation pressure. In such context, the objective of this paper is to address the following questions: (i) how the physical environment forces organisms' distribution across scales? (ii) what is the relative importance of social vs. environmental forcing in the formation of fish 3D collective structures? (iii) how does the diel cycle structure and unstructure organisms' distribution and organisation?
For that, a specific behavioural ecology survey was performed in Central Peru, in November 2004. From a series of observation tools (SST and CO2 sensors, Niskin, CTD probes, zooplankton sampling, stomach content analysis, echo-sounder, multibeam sonar, birds and mammal observations) we assessed interactions between fish and the landscape features (both oceanographic and biotic) possibly driving its behaviour. Survey design consisted in 28 hours long series of square transects, 2 nmi large (1 nmi=1852 m), runs.
We could link levels of fish organisation (layer, school, shoal, cluster) to different oceanographic and biological features: upwelling area, plankton patches, solitary internal waves, predators and others, varying in space and in time, particularly according to the diel cycle. At a large scale (100s km), experiments took place in the core of anchovy distribution with abiotic factors ranging inside anchovy ecological niche. At a smaller scale, experiments were performed inside rich upwelling area corresponding to meso-scale oceanographic features (10s of km). The presence of a shallow oxycline limited the vertical range of anchovy and preventing any fish diel vertical migration. Plankton was very abundant and unevenly distributed. Where no specific sub-meso-scale features were present, plankton was distributed in 'classic' sound scattering layer. During the day, part of zooplankton migrated down and was less available to anchovy. Furthermore high predatory pressure by seabirds and sea lions also affected the habitat suitability. Anchovy was then distributed in schools with strong interactions with predators and a rather erratic horizontal distribution. During the night the upward migration of zooplankton associated with the lower predation pressure (no more seabird attack) increased the habitat suitability. Where no specific sub-meso-scale features were present, anchovy was distributed in loose shoals and scattered fish. Sub-meso-scales features (100s m – kms) had a strong impact on habitat suitability and anchovy 3D spatial distribution. Convergence lines concentrated plankton and locally deepened the oxycline, increasing the vertical range of habitat for anchovy. Plankton patches were observed during the night with anchovy concentrating inside. Anchovy cluster size was directly related to patch size. This argues in favour of a fish clustering related to the patchiness of the environment rather than to pure social behaviour or population aspects. Plankton patches were no more observed during the day. This does not mean that oceanographic feature responsible for patch formation changed but that plankton dispersed and migrated below the oxycline. A last aspect concerning these patches relates to the impact of plankton and fish concentration on the chemical characteristics of the habitat. Inside the patch, dissolved CO2 increased. We assume that this pattern is related to organism respiration. Therefore the suitability of these patches may decrease if 'too' many fish are concentrated in. To synthesise this complex panorama we adapted the basin model framework from MacCall (1990) to propose a conceptual model of environment impact on occupation of space by fish. We also propose a conceptual view of the relative contribution of behavioural vs. environmental process on the patterns of aggregation of anchovy according to the scales of observation.

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HCS186 - Ecological niche and patterns of distribution of munida (*Pleuroconodes monodon*) off Peru, and overlapping with anchovy (*Engraulis ringens*) between 1999 – 2006

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Keywords: anchovy Engraulis ringens, ecological niche, horizontal and vertical distribution, munida Pleuroncodes monodon, overlapping

Regular monitoring of the distribution, abundance and catch of anchovy (*Engraulis ringens*) has been conducted over the last 50 years in Peru. These parameters vary over several time scales, in particular low frequency cycles of abundance (El Viejo, La Vieja), inter-annual variability (El Niño, La Niña) and seasonal variability. Although observations are not as extensive as for anchovy, the crustacean munida *Pleuroncodes monodon* (range of distribution 7°S - 43°S) is also an important component of the Peruvian ecosystem. Large amounts of munida were occasionally reported during the last 50 years, mainly in the southern part of Peru. Older reports indicate that munida was an important prey item of the diet of apex predators such as tunas during the 1930's and 1940's. Munida has become highly abundant along the Peruvian coast, since the 1997-1998 El Niño event. Acoustic estimates indicate that munida biomass ranged between 0.6 and 3.4 $x10^6$ t from 1998 to 2005. This large amount of munida is mostly restricted to coastal areas and has for a large impact on ecosystem function and trophic dynamics. Munida is now a very important prey for seabirds, mammals and coastal predatory fish including anchovy, that predates on munida's zoea. Also, munida can forage on eggs and larvae of fish, and thus be a predator of the early stages of some of its own predators. Despite its ecological importance, knowledge on munida patterns of distribution and ecological niche is scarce in Peru. Most published works on munida come from Chile where this organism is basically benthic (e.g. Gallardo et al., 1992). In contrast, munida is primarily pelagic in Peru

In this work, using a series of 22 acoustic surveys performed along the Peruvian coast from 1999 – 2006, we describe horizontal and vertical distributions of munida and associated ecological niche based on oceanographic parameters using spatial analyses and a generalized additive modelling (GAM) approach. As anchovy and munida were the two dominant small pelagic organisms during this period we also studied possible interactions between them and estimated the vertical and horizontal overlap between these two species.

Results indicate that munida distribution is strongly related to the cold coastal waters and ranges vertically between the oxycline and the surface. High horizontal overlapping exists between anchovy and munida (Fig. 1), although munida is more restricted to the coastal zone than anchovy. In the vertical plane, overlapping depends on the diel period. During daytime anchovy schools are distributed above the layer (or swarm) of munida with occasional overlapping. During the night anchovy and munida are dispersed and share the same vertical layer. The role of munida in the ecosystem is discussed with special consideration to potential competition for space, and food between anchovy and munida.

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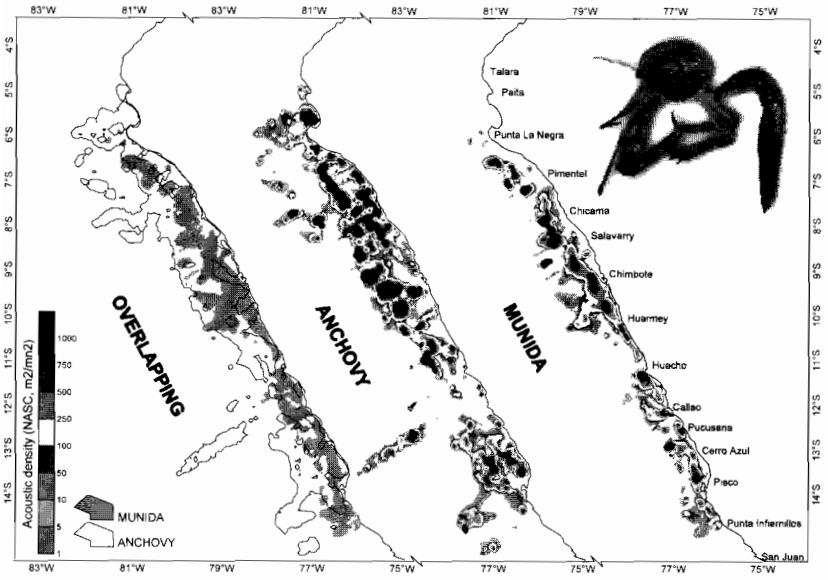

Figure 1. Example of relative distribution and abundance of munida (Pleuroncodes monodon) and anchovy and their horizontal overlapping in Austral winter 2004.

HCS183 - What can be inferred on spatial structure of Peruvian anchovy (*Engraulis ringens*) distribution from spatially explicit fishing data?

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Keywords: anchovy, *Engraulis ringens*, purse seine, spatial structure.

Peruvian purse seine industrial fleet has the ability to remove up to 4.7 million tons of anchovy in less than 4 months. Such an extracting capacity must have strong impact in terms of fish local depletion, and according to density dependent models of space occupation (e.g. MacCall, 1990; Petitgas, 1994), it should also affect deeply fish distribution. But direct observation on fish depletion and spatial re-organization at this spatio-temporal scale is not available. By other means, based on previous works (e.g. Bertrand *et al.* 2005), we know that, at least for this particular fishery, fishers permanently adjust their spatial strategy to fish spatial re-organizations, which make fishers' movements a good indicator of fish distribution. Unlike fish distribution, fishers' movements can be observed at a very fine spatio-temporal resolution and in a time continuous manner thanks to their tracking through Vessel Monitoring System (VMS).
In such context, the aim of this work is to analyze the way fish re-organize its distribution under a high fishing pressure, as inferred from the changes in movement strategy developed by fishing vessels. The study area (between 7 and 10 degrees South) was selected for containing usually a high proportion of the anchovy stock biomass. The periods analysed corresponded to fishing seasons (autumn, from March to July and spring, from October to December) of the years 2000, 2001 and 2002. For this zone and this period, we could rely on (1) Vessel Monitoring System observations, which corresponds to one position per hour for each of the industrial fleet vessels operating in this zone (about 350), (2) data recorded from observers at sea for a sample of about 10 vessels, giving for each sampled set an exact position as well as the composition and weight of the catch, and (3) for each vessel operating in this zone, the catch by trip for all the studied period.
From the VMS observation, we identified probable fishing set position, using as a preliminary criteria a speed comprised between 0.2 and 1.6 knots. From the observer data, we could build a statistical distribution of catch by set, as a function of a total number of sets by trip. Having an estimation of fishing sets position, the total catch by trip and a statistical distribution of catch by set for a trip, we proceeded to an exhaustive spatial re-allocation of catches for these studied zone and period. This spatially explicit and exhaustive information on fishers' catches was analysed following different steps. First, in order to have an idea of the general distribution of the fish in this zone, we computed on a daily basis and at the fleet scale (1) the centre of gravity of the catches, (2) the spatial extent of the catches and (3) the spatial patchiness of the catches (Salthaug and Aanes, 2003).
Second, with the purpose of estimating the size and duration of the fish aggregations exploited by fishers, we analysed these spatially explicit CPUE (catch by set) according to a methodology proposed by Vignaux (1996). A general linear model (GLM) is fitted to the CPUE data in order to remove as much as possible of the CPUE variability due to vessel differences and seasonal or time of day effects for instance. The residuals from this linear model are then analysed for spatial and temporal correlations. The thresholds of distance and time above which correlations in residuals are not significant any more, are interpreted as being the size and the duration of the exploited fish clusters. Spatial and temporal correlations are

analyzed both (1) through Spearman rank correlations computed by pairs of fishing sets, ordered by distance and by duration and (2) through variograms.
The day to day evolution of the centre of gravity, the spatial extent and the spatial patchiness of the catch positions exhibited a very high variability which may be related to fish re-organization and/or variation in local environmental conditions. The analysis of CPUE residuals showed that the fish aggregations exploited by purse seiners had an order of magnitude of 20 nm in size and 1-2 days in duration (Fig.1). The evolution of these variable are then put in relation with 2 indicators of the local oceanographic conditions: SST and sea surface elevation. We discuss finally on the possibilities opened by the growing availability of spatially explicit fishing data for monitoring fish distribution and completing then the information provided by scientific survey.

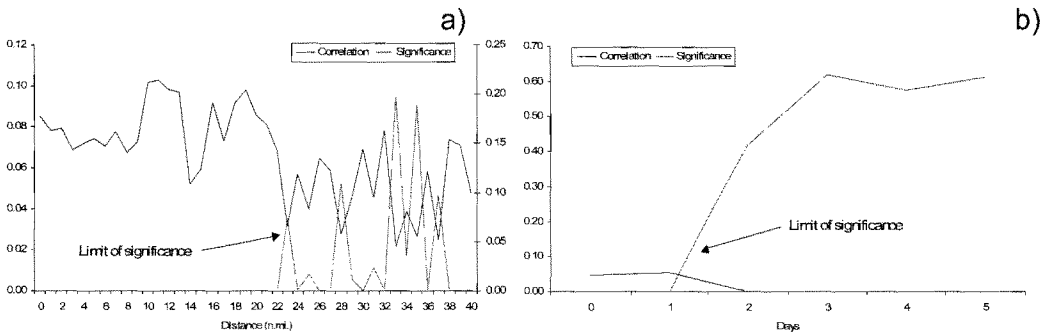

Figure 1. CPUE residual analyses for autumn of 2000. a) Level of correlation (blue line) and corresponding level of significance (red line) between CPUE residuals as a function of the distance separating the fishing sets; b) Level of correlation (blue line) and corresponding level of significance (red line) between CPUE residuals as a function of the duration separating the fishing sets. Spatial correlation is significant up to about 20nm and temporal correlation, up to about 1 day.

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HCS140 - The alternation in spatial distribution of sardine and anchovy in the Humboldt Current: effects of climate, behavioral interactions, or data misunderstanding?

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Keywords: pelagic fish, spatial distribution, alternation, behavioral ecology, catch data, fisheries acoustics.

Anchovies and sardines are known to occupy alternately a given space, especially in upwelling areas. In the case of the Humboldt Current and the Peruvian fishery, the Peruvian anchovy (*Engraulis ringens*) is certainly the most important exploited stock, reaching up to 10 million tons of catch in the years of major productivity. It is also one of the most variable stocks and it may collapse almost completely, as happened during and after the "El Niño Southern Oscillation (ENSO)" events in the early 70s and 80s. The other major pelagic species, the sardine (*Sardinops sagax*) is also present over the Peruvian shelf and may represent the most important biomass when dominating the ecosystem, as It happened during the decade of the 80s, where the catch represented around 3 million tons. These populations of anchovy and sardine display successive and alternate phases of dominance and co-occurrence. Two major reasons are given in the literature explaining such pattern: the role of decadal climatic changes and the behavioral characteristics of schooling fish. In the first case we may cite Chavez et al (2003) who describe the effects of decadal changes in sea temperature (periods "El Viejo" y "La Vieja"); in the last case we could cite as an example the "School trap" hypothesis (Bakun and Cury, 1999) according to which the change in the dominance would be facilitated by behavioral constraints of pelagic fish which have to live in schools and may be "trapped" in school of other species when they are dominant, which implies for them non optimal biological conditions.
The Peruvian coastal pelagic ecosystem presents a particular interest from this point of view, because it represents the world largest fishery, the fisheries statistics show a clear alternation in the catches, usually in phase opposition (figure 1a), and the stocks are constantly monitored by various methods (catch analysis, acoustic surveys, eggs and larvae, etc.), thus many environmental information is available.

Another interesting point is that the same fishing fleet can be adapted for one or the other of these two species: following the great collapse of anchovy in 1972 most of the unemployed anchovy fishing vessels were adapted for the sardine fishery. There was no important fishery dedicated to sardine before the collapse of anchovy and practically no catch existed before the 70s. Then during the "low anchovy production" period, the sardine catches increased regularly (1977-1990) with important interannual variations, began to show a slight decrease in 1989 and collapsed slowly from 1991 to 1999. Sardine fishery has become marginal in Peru after the late 90s.

The paper analyses the different spatial strategies of the two species, and evaluates the possible effect of one species over the other through competition, coexistence, etc. An important question prior to validate any hypothesis is whether information from catch data may give a proper image of these changes through which sardines and anchovies may collapse so suddenly and alternate synchronously. We assume that, despite of its own limitations, acoustics, being a direct source of observation, is more reliable than fishery data for describing the dynamic changes in the population levels of the two species along the last decades, and can be used as reference information. The spatial distributions of the two species are compared in time and space through the analysis of 17 years of acoustic surveys (1985-2000). The respective effects of fish spatial strategies and climatic conditions are considered. The role of fishing data in determining a possible alternation of species is scrutinized. From these results the following conclusion were drawn: (i) no obvious competition for space is visible since spatial overlapping along the studied period is rather small (Figure 1b); (ii) in the places where anchovy and sardine co-occur the acoustic densities of each species are positively correlated; (iii) fishing activity existed during the 1997-98 El Niño, and were directed towards mixed schools of juvenile sardines and adult anchovies; (iv) the major reason for alternation and dominance of one species on the other is climatic, and not behavioral (Bertrand et al, 2004) ; (v) the apparent competition of species during co-occurrence periods (e.g. 1985-1999) is artificially magnified by the catch data (figure 1c).

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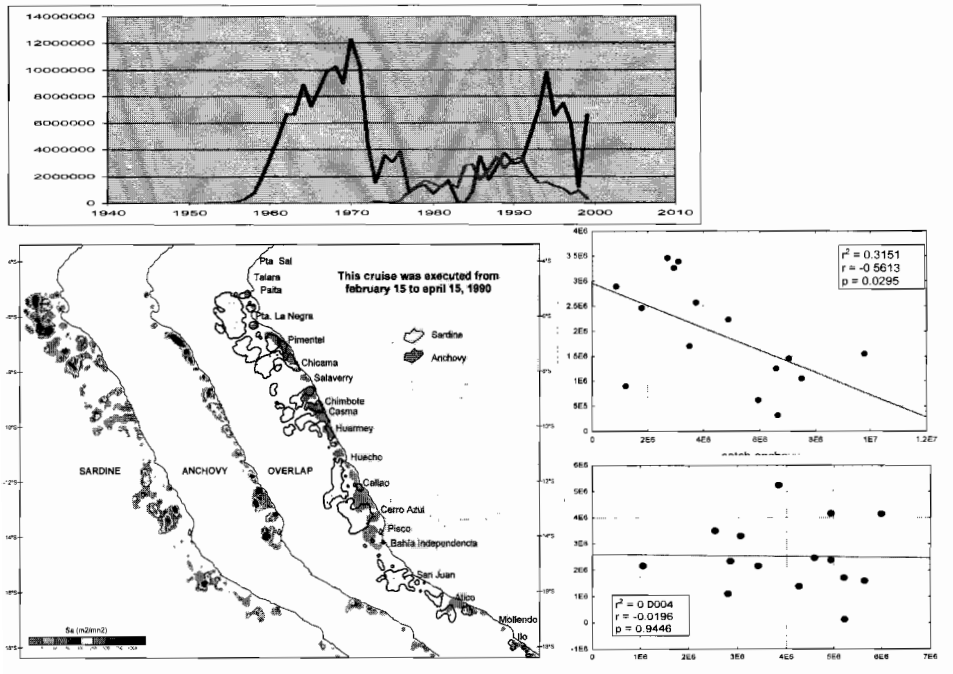

Figure 1. Description of alternation between anchovy and sardine along the Peruvian coast:

- ⇒ *1a (above): annual catches of sardine (blue) and anchovy (red) from 1952 to 2000. Catches in tons. This figure shows the evidence of alternation at decadal scale.*
- ⇒ *1b (below left): example of overlapping in areas occupied by sardine and anchovy in 1990, year of maximum co-occurrence, as observed through acoustic surveys. The figure shows that overlapping is weak, sardine being offshore and anchovy remaining closer to the coast*
- ⇒ *1c (below right): comparison of correlation between catches of anchovy (x axis) and sardine (y axis) catches (above), and between anchovy (x axis) and sardine (y axis) biomasses (below) during period 1985-1999, corresponding to the longest period of co-occurrence where acoustic data were available. The negative correlation observed between catches does not appear with the biomasses, demonstrating that correlation is more related to fishery strategies (a vessel chooses to catch sardine OR anchovy) than to species behavior.*

HCS098 - Spatial re-organizations in the coastal Humboldt Current ecosystem under oceanic climate forcing: portraying contrasted ecological scenarios

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Keywords: climate forcing, ecological scenarios, fish distribution, fishers' movements, Kelvin waves

One of the main sources of the climatic variability in the Humboldt Current system consists of the arrival of the coastal Kelvin waves, themselves being forced at the equator by the equatorial Kelvin waves (Pizarro *et al.*, 2002). The equatorial Kelvin waves are generated along the Equator, in the mid Pacific (180°W) by an anomaly of the wind flow and then propagate Eastwards across the oceanic basin. According to the kind of wind anomaly (under-pressure or over-pressure), the equatorial Kelvin wave may be of downwelling or upwelling type. When these waves hit the South-American continent, a portion of their energy is transmitted along the coast as 'coastal trapped' or 'coastal Kelvin' waves. Because these coastal waves introduce background energy for the turbulent flow in the coastal ecosystem, they are likely to produce deep impacts on a variety of components of the coastal ecosystem. On a physical point of view, a downwelling wave produces an intrusion of oceanic poor and warm waters in the coastal ecosystem and then a warm scenario (El Niño like scenario, Pizarro *et al.*, 2002). On the contrary, an upwelling wave favours cold and rich water resurgence and then the extension of the coastal water domain (a cold, La Niña like scenario).
In that context, the aims of this paper are (1) to describe the spatial re-organisations of living organisms in the Humboldt coastal ecosystem under the effect of the arrival of the costal Kelvin waves, (2) to formulate hypothesis on the particular processes that drive the re-distributions of the organisms, and (3) to build functional portraits of the scenarios of space occupation in the Humboldt coastal ecosystem. To characterise the equatorial Kelvin waves, we used an oceanic linear model of the tropical Pacific (Dewitte *et al.*, 2002). The model allows estimating the amplitude of the equatorial Kelvin waves in the eastern Pacific for the most energetic barocline modes, from wind data (QuickSCAT). The outputs of a high-resolution regional model (ROMS) simulation are also used to characterise the local mesoscale circulation. To describe anchovy distribution (*Engraulis ringens*, the main coastal pelagic resource), we analysed the distance to the coast, the depth and the size of the fish aggregations thanks to data collected both during scientific surveys and by observers at sea onboard fishing vessels. From these data, we also computed a spatial concentration index and a patchiness index (the fractal dimension) of the anchovy distribution. To describe fishers' spatial behaviour, we used positioning data from satellite vessel monitoring system. A synthetic index, calculated through a Lévy random walk modelling approach (Bertrand *et al.*, 2005), describes the sinuosity of the fishing trip trajectory and the area explored (diffusion). To explore the statistical connections between the dynamics of these different ecosystem components, we used linear statistics, GAM modelling and time series analysis.
Thanks to this approach, we could quantify and portray, on a spatial point of view, the ecological scenarios associated with the large scale climatic forcing. A downwelling wave generates in the coastal ecosystem a deepening of the thermocline and a reduction of the upwelled waters panache. Anchovy distribution concentrates in very coastal waters in dense and large aggregations. The high fish concentration allows fishers to explore smaller areas (high sinuosity, reduced diffusion). An upwelling wave, on the contrary, generates a rising of the thermocline in the coastal ecosystem, and an extension of the upwelled waters. Anchovy distribution is looser (less concentrated, patchier). Fishers need to explore wider areas to find enough anchovy (low sinuosity, high diffusion). Moreover, we evidenced a positive and significant correlation between the amplitude of the equatorial Kelvin waves and the fishers' spatial behaviour, with a 6 months lag. This last result may have important implications for management purposes as it could mean an ability to anticipate the dynamics of the coastal ecosystem.

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Invited paper: HCS145 - Structure, carrying capacity, and vulnerability to climate change of NE and SE Pacific marine ecosystems

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Keywords: carrying capacity, climate change, North Pacific marine ecosystems, primary productivity, trophic spectra

PICES, the North Pacific Marine Science Organisation, has studied climate change and carrying capacity of the North Pacific for the past decade as part of its regional GLOBEC program. Much has been learned about the responses of the North Pacific and its marine ecosystems to climate variability (Regime shifts), to changes in their carrying capacities for marine organisms, and the potential impacts of climate change. In this presentation, we build on this knowledge to examine and compare the structure and productivity of the regional marine ecosystems of the North Pacific, in particular the NE Pacific, with the marine ecosystems of the SE Pacific. We contrast the carrying capacities of these systems for commercial fish and invertebrates, taking account of their specific oceanographic properties. We place a specific focus on examining the carrying capacities for small pelagic fishes in the California and Humboldt Current systems, and identifying potential drivers of changes. We conclude with an analysis of the vulnerabilities of these NE and SE Pacific marine ecosystems, and their dependent human communities, to climate change.

HCS212 - Changes in the distribution and abundance of jumbo squid *(dosidicus gigas)* in Peruvian waters between 1991-2005

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Keywords: Distribution, *Dosidicus gigas*, Fisheries, Jumbo Squid, Peru

Distribution of oceanic squid is related to currents and thermal fronts that influence nutrients and productivity (Caddy, 1983). *Dosidicus gigas* is an endemic species of the Eastern Pacific and its habitat is in highly productive areas in the peripheral zone of the coastal upwelling (Nesis, 1983). *D. gigas* is a eurithermic species, inhabiting waters with a wide range of temperatures, between 15-28°C, reaching up to 32°C in equatorial water (Nigmatullin et al. 2001).
Changes in distribution and abundance of *D. gigas* were analysed, using catch and effort data from jigging and artisanal vessels operating within the Exclusive Economic Zone (EEZ) of Peru between 1991 and 2005, and compared with environmental data (temperature, salinity, oxygen and currents) from pelagic research cruises in that period. Besides, sea surface temperature anomalies (SSTA) data from the Peruvian Marine Institute (IMARPE) and Southern Oscillation Index (SOI) from the Bureau of Meteorology, Australian Government, were used and related to distribution and abundance. This study broadens knowledge on the distribution and concentration of *D. gigas* obtained previously, and includes the analysis of new environmental data.
Annual landings of *D. gigas* ranged between 56 t in 1998 and 230,000 t in 2004. Two periods of high abundance were observed, one in 1991-1995 and the other in 2000-2005, and one of low availability in 1996-1998 and these were reflected in both the artisanal and industrial fisheries.
The average catch per unit effort (CPUE) varied between 1.99 and 3.10 t/trip in the artisanal fishery, and from 0.02 to 2.27 t/h in the industrial fishery. The analysis of SSTA and CPUE showed that the availability of the jumbo squid is affected by the strong thermal variations during the 1996 La Niña event and the extraordinary 1997-1998 El Niño event. However, other cold or warm events of lower intensity, did not appear to affect the availability of the resource, which maintained abundance levels comparable with 2002-2005 (Fig. 1).
D. gigas was distributed widely along the Peruvian coast, and the highest concentrations were observed between 4° to 9° S and 13° to 17° S up to 100 nm off shore. During the period examined, high concentrations of the resource were associated with zones of mixed Subtropical Surface and Cold Coastal water masses. An inverse relationship between the SOI and CPUE was observed and this is consistent with the earlier observation that there is a negative correlation between *D. gigas* abundance and the SOI the previous February (Waluda et al. 2004)
Variability in recruitment and abundance of the *D. gigas* can be explained by variability in the oceanographic conditions (Rodhouse, 2001). We conclude that oceanographic characteristics during moderate cold and moderate warm events off the Peruvian coast favour growth of *D. gigas*, because of greater food availability and better development of the early life stages, which contribute to recruitment

success. Whereas during intense cold or warm events, recruitment is affected by lower survival of paralarvae and/or migration of spawning adults to other areas. Abundance of *D. gigas* is apparently strongly influenced by mesoscale oceanography linked to ENSO, with low levels of upwelling leading to low catches of squid off Peru (Waluda and Rodhouse, 2006). Variability in upwelling primary production is likely to be a key factor in influencing the abundance of *D. gigas* in the eastern Pacific.

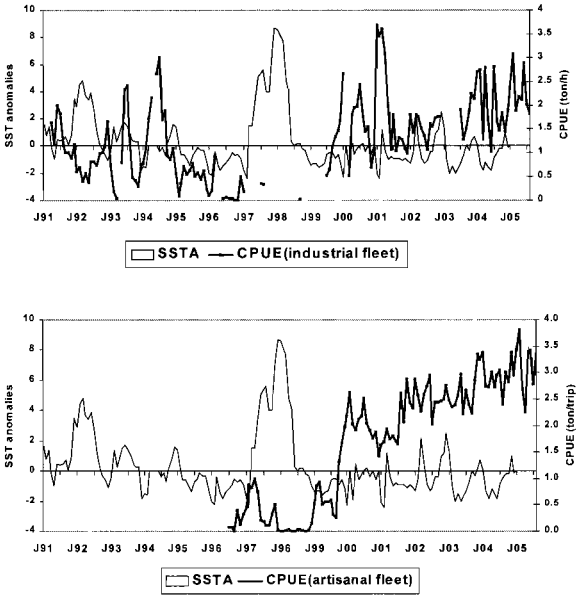

Figure 1. Monthly CPUE of jumbo squid and sea surface temperature anomalies in Peruvian Waters between 1991-2005.

HCS005 – El Niño and the distribution of horse mackerel (*Trachurus murphyi*) in the open part (outside 200-mile zone) of the South-Eastern Pacific Ocean

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Keywords: Age group, El-Niño, fishery, horse mackerel, South Pacific.

The data have been collected in 1978-1991 outside a 200-mile zone of Peru and Chile by results of large-scale fishery of USSR and scientific vessels. Formation of horse mackerel *Trachurus murphyi* aggregations outside 200-mile zone from 5° to 20°S (North subarea) is determined by two factors. Firstly, by the condition of these species stocks in the coastal zone including the entire economic zone of Peru. Secondly, the hydrologic conditions, which facilitate the species migration into the open ocean waters.

For the Northern subarea a seasonal pattern of commercial fish aggregations formation is characteristic. They are forming from May - June to November - December. A necessary condition, promoting occurrence of commercial fish aggregations is the outflow of relatively cold waters of the Peruvian current outside the Peruvian economic zone boundaries. These aggregations stability is determined by the spatial - temporary stability of outflows. The basic locations of cold water penetration outside the economic zone boundaries are between parallels 8-10°, 14-15° and 17-20°S. Water temperature in the fish aggregation regions varies from 16 to 23° C, while the more intensive migrations are found at the temperature of 18°C. The cold waters penetrate westwards on distance up to 400 miles from the coast and fish aggregations are distributed mainly within 100-mile band from Peruvian zone. In a southern part of the Northern subarea, in the field of the Peruvian current, divergence the centres of water upwelling are forming which also contribute the formation of a high productivity zone.

More than ten-year experience of the fishery has shown, that in years of maximum El-Niño development (1982-1983; 1987-1988) in the Northern subarea commercial aggregations of horse mackerel outside 200-mile zone are actually absent (1983; 1987). In the years, when El-Niño development occurred (1982) and in the subsequent years (1984, 1985) the scales of aggregations migration from the zone were insignificant. In these years the area of horse mackerel aggregations is smaller than in other fishing periods. The period 1978-1981 may be considered as a favourable one for commercial aggregations outside the Peruvian zone, when horse mackerel catch depended only on the level of fishing effort. The catch in 1981 amounted to 403,500 tons while available to fishery biomass was up to 4.3 mln.t. Horse mackerel distributed along the entire zone of Peru (from 6° up to 17°30') and up to 20°S. The average effective years of fishery were 1982, 1988-1990. Horse mackerel catches in these years were within 97,500 -125,400 tons, while available commercial biomass varied from 0,8 mln.t in 1982 to 2,7 mln.t in 1988 (the catch rate was 15,8 and 4,3% respectively). In the same years horse mackerel distribution is characterized as a continuous one along the sea zone.

In 1984-1985 after one of the most intensive El-Niño for the latest decades, the catches constituted less than 30,000 tons (23,400 and 27,900 tons respectively) with insignificant areas of fish concentration and total biomass of 0,6-1,2 mln.t.
The highest value of horse mackerel biomass, and catch in the ocean part of the subarea, corresponds to the maximum values of this stock estimated by the Institute of the Sea of Peru (IMARPE) on the basis of echosurveys in 200-mile zone. From 1978 to 1983 maximum biomass were 8.9 mln.t for horse mackerel, 1.8 mln.t for mackerel and 4.8 mln.t. for sardine. During 1988-1990 in "zonal" waters the observed high values of these species stocks were – horse mackerel biomass 7.5 mln.t, mackerel 1.5 mln.t, sardine 8.5 mln.t.
According to IMARPE data in the "zonal" part of the area after El-Niño events of 1982-1983, in 1984-1985, the reduction horse mackerel and mackerel biomass was noted (Muck, Sanchez, 1987). These data agree with the information on fish aggregations that migration outside the zone based on the fishery results in the ocean part of this subarea (in these years the total annual catch of these species did not exceed 28,000 tons) and peculiarities of fish aggregations distribution and available fishing biomass in the grounds of the Soviet Union fleet operation.
When arranging fishery research, special attention should be paid to the time of fish migration into the open sea areas accessible to fishing vessels. The data of figure 1 show, that fish aggregations in the ocean part are forming in May - June or July - August. Formation of fish aggregations in May - June 1980 and 1981, 1985 and 1986, is evidently caused by the cool Peruvian current strengthening. These years are characterized by negative SST anomalies (-1°) in the area 5-10°S during the first half of the year and are not related to the strong El-Niño events (Climate Diagnostics Bulletin, 1991). Formation of fish aggregations in July - August (1979, 1984, 1989-1991) coincides with a situation when in the first half-year positive SST anomalies or their alternation with insignificant (up to – 0.5°) negative anomalies are observed. The years of intensive El-Niño ending (1983, 1988) are the exceptions. Prediction of events, determining migration of fish aggregations outside the zone is the element of El-Niño forecast.
Thus, the time of pelagic fish's migration into the open part of the subarea and the area of fish aggregations is determined by the fish stocks size within 200-mile zone of Peru and hydrologic conditions. The prediction of periodically repeating strong El-Niño is of special importance.
On the basis of AtlantNIRO research data, horse mackerel observed outside Peruvian zone and horse mackerel distributing off Chilean zone belong to different groups. The observed genetic heterogeneity of horse mackerel is caused by reproduction separation of the groups (Alekseev, 1985; Koval, 1981; 1984).
Distribution of horse mackerel in the region located southwards of 25° S outside Chilean 200-mile zone (South subarea) insignificantly depends on the phenomenon El-Niño. El-Niño events in 1982-1983 resulted in water temperature increase by 1° C in this region during 1983 as compared to the average long-term level. This is obviously related to penetration of modified water mass of subtropical origin into the location at 30-35° S. It is possible to consider the occurrence of juvenile horse mackerel of age 1+ together with fish of age 2+-5+ at 37-43°S as a consequence of the above said events. After El-Niño, in 1984, at the same latitude no fish of age 1 + were observed. It is possible to assume, that fish of this age group were distributed further northwards.
Distribution of eggs, larvae and spawning fish during spawning season 1983/84 and up to 1988/89 is shown. It is evident, that westward of 85°W in 1983/84; 1984/85 the spawning occurred in more southern locations. Besides, the analysis of horse mackerel age structure in commercial catches for 1979-1991 based on VPA has shown the absence of strong year-classes after spawning in 1983/1984 and 1984/1985. The strong year-classes appeared after spawning season 1985/1986. Presented data on distribution of various age groups during different quarters of 1983 and 1984, as well as ichthyoplankton and spawning fish distribution show, that in the open sea area southwards of 30 °S horse mackerel at all life cycle stages distribute and these fish are able to provide recruitment for its reproduction. These data allow defining the horse mackerel status in this area as one large population with the distribution area from the coast of Chile to New Zealand, and horse mackerel from different parts of the area contribute the stock reproduction.

HCS100 - Taxonomic composition, diel patterns and ecological importance of the micronecktonic community related to the oxygen minimum zone off Peru

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Keywords: acoustics, diel vertical behaviour, Humboldt Current system, mesopelagic community, pelagic ecosystem functioning, *Vinciguerria lucetia*

The Humboldt Current system (HCS) is characterized by the presence of an intense oxygen minimum zone (OMZ), similar to that in other regions (i.e. Arabian Sea, Northwest Pacific, Southwestern Africa) but with a larger extend and a shallower distribution. The intensity and extent of OMZ increases southward of Equator, due to enhanced physical and biological processes like mixing and re-mineralization. The OMZ

has strong impact on the vertical structuring of pelagic ecosystems in particular for the mesopelagic community. Here we aim at describing organism diversity, abundance and distribution related to the OMZ.
The study is based on three sources of data collected during three acoustic surveys performed off Peru during austral springs 2001-2003: acoustics, pelagic trawls and hydrographic profiles. Species composition was dominated by organisms adapted to low oxygen concentration (Table 1), in particular (1) the fish Phosichthyidae *Vinciguerria lucetia,* Myctophidae *Diogenichthys laternatus* and *Lampanyctus* spp., Bathylagidae *Leuroglossus* spp.; (2) the crustacean Euphausidae, *Euphausia mucronata* and (3) cephalopods Octopoteuthidae. *Vinciguerria lucetia*, the most abundant species undertakes vertical migrations being distributed in layer and patches in the core and the upper part of the ZMO during the day and in surface layer during the night. This diel behaviour allows *Vinciguerria lucetia* and associated species escaping most of their predators (e.g. jack mackerel, tuna, piscivorous mesopelagic fish) during the day and being distributed in the rich surface layer during the night, when most of organisms are concentrated in shallow water. *Vinciguerria* lucetia interacted with the community adapted to low oxygen during the day and with the whole pelagic community during the night.
Similar to others mesopelagic fish in other highly productive areas (e.g. *Benthosema pterotum, Notoscopelus japonicus, Electrona antartica*, see Gjøsaeter, 1984, and Brodeur and Yamamura, 2005), we can assume that *Vinciguerria lucetia* is a significant component in the oceanic region of the HCS. In particular for trophic relationships as it is an abundant predator for macro-zooplankton (e.g. copepods and euphausids) and prey for apex predators (e.g. giant squid, tuna, jack mackerel, piscivorous mesopelagic, seabirds). *Vinciguerria lucetia* and other species adapted to ZMO can be considered as key organisms as they participate to the vertical transport of organic matter (biological pump) in the water column in highly stratified areas.

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Table 1. *Taxonomic composition of micronekton captured by pelagic trawling off Peru*

Family	Species	Total catch (g*trawl min^{-1})	Family	Species	Total catch (g*trawl min^{-1})
Pisces					Crustaceans
Phosichthyidae	*Vinciguerria lucetia**	115 559.0	Euphausidae	*Euphausia mucronata**	71 610.9
Myctophidae	*Diogenichthys laternatus**	9 836.0	Pasiphaeidae	*Pasiphaea* sp.	445.4
	*Lampanyctus idostigma**	3 002.5	Galatheidae	*Pleuroncodes monodon*	40.0
	*Lampanyctus omostigma**	2 870.7			Cephalopods
	*Lampanyctus sp.**	678.2	Octopoteuthidae*		460.0
	Myctophum aurolaternatum	393.1	Enoploteuthidae		2867.7
	Myctophum nitidulum	328.4	Cranchiidae		254.5
	Triphoturus oculeus	715.6	* Species adapted to low oxygen concentration		
	Hygophum reinhardti	100.2			
	Hygophum proximum	49.1			
	Gonichthys tenuiculum	20.3			
Bathylagidae	*Bathylagus berycoides*	419.1			
	*Leuroglossus stilbius**	243.9			
	Leuroglossus urotranus	1 444.1			
Melamphaeidae	*Melamphaes* sp.*	297.0			
	Scopeloberyx sp.*	67.3			
Sternoptychidae	*Argyropelecus affinis**	48.0			
	*Sternoptyx obscura**	12.5			
Paralepididae	*Paralepis* sp.	417.3			
Serrivomeridae	*Serrivomer sector*	53.5			
Scopelosauridae	*Scopelosaurus* sp.	79.4			
Stomiidae	*Stomias colubrinus**	15.0			
	Stomias sp.*	105.4			
Nemichthyidae	*Nemichthys fronto*	46.3			
Scopelarchidae	*Scopelarchoides nicholsi**	72.8			
Gonostomatidae	*Polymetme* sp.	25.2			
	Gonostoma elongatum	7.7			
Chauliodontidae	*Chauliodus* sp.*	10.0			
Idiacanthidae	*Idiacanthus* sp.*	9.1			
Astronesthidae	*Astronesthes* sp.*	0.4			

HCS205 - Long-term changes in population size of Peruvian guano-producing seabirds

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Keywords: Peruvian guano-producing seabirds, population trends, distribution, diet, seabirds as indicators, fishery effects

Peruvian guano-producing seabirds are an important component of the Humboldt Current System. These seabirds feed primarily on Peruvian anchovies (*Engraulis ringens*). The proportion of anchovy found in the diet of cormorants and boobies is strongly correlated with anchovy biomass (Jahncke y Goya 1998). Peruvian guano-producing seabirds have shown large population changes over time. The population decreased dramatically in the last century from 16-20 million birds in the 1950s to less than one million birds during El Niño 1982-83. Currently, this population is at a critical size (2.5 million birds) and no

significant increase has been reported during the last 6 years. In this study, we analyze trends in annual population size of adult guano-producing seabirds (Guanay Cormorant, *Phalacrocorax bougainvillii*; Peruvian Booby, S*ula variegata* and Peruvian Pelican, *Pelecanus thagus*) in relation to oceanographic perturbations and fisheries.

Temporal variability in environmental conditions can lead to major ecosystem changes that affect even the higher trophic levels. Seabird populations are severely affected by oceanographic perturbations like El Niño, which causes breeding failures and high mortality of birds. These semi regular catastrophes must have exerted tremendous selection pressure on the seabird populations, favoring their ability to increase rapidly after each crash. Our data suggest that this ability may have decreased after the development of the anchovy fishery. The guano-producing seabirds had failed to reproduce once oceanographic conditions returned to 'average' conditions. Seabirds, had never recovered population levels prior to the fishery. The reason for this seems to be that the anchovy fishery has taken up the superabundance of food on which the guano-producing seabirds depended on to come back after the recurring crashes induced by the oceanographic perturbations. Our data indicates that adult reproductive rate has decreased in recent years. Many studies have shown that adult reproductive rate and reproductive success decreases during low food availability periods, because of a trade-off between lifetime reproductive success and actual adult survival.

Guanay cormorant and Peruvian booby have shown different responses to El Niño. We found there are differences in time needed for both populations to recover, as a result, changes in the proportions of species composition have been registered during the last ten years. Peruvian booby population is recovering faster than the other species after the last El Niño 1997-98. Before El Niño 1997-98, Guanay cormorant was the most abundant seabird species off the Peruvian Coast. Peruvian booby feeds almost exclusively on anchovy; and in contrast to the Guanay cormorant, this species is able to spread widely and shows also a broader breeding frequency. On the other hand, the Guanay cormorant is gregarious not only in their foraging but also on their breeding behaviour. This species is an opportunistic feeder, and preys on large schools of small pelagic fish, and shows higher synchronicity in their breeding.

Our results suggest that the combination of higher frequency of El Niño events and persistent competition for food with the anchovy fishery have reduced the resilience of guano-producing seabirds. Studies on seabirds and other top predators will improve our understanding of the long-term dynamics of the Humboldt Current System. We propose the use of these predators as indicators of the 'state' of the system as we move towards an ecosystem based management approach.

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HCS208 - The Pacific Decadal Oscillation and its influence on the latitudinal distribution of Peruvian hake (*Merluccius gayi peruanus*)

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Keywords: hake Merlucius gayi peruanus, latitudinal pulsing distribution, Pacific Decadal Oscillation index, Cromwell underwater current, regime shift

The Peruvian hake (*Merluccius gayi peruanus)* is the main demersal species of the sub-system of the Northern Humboldt Current System (NHCS) in term of economic importance. We hypothesize that its linkage to NHCS is more geographical than oceanographic. Indeed its distribution over the adjacent continental shelf along the Peruvian coasts is the product of the influence of the oceanic equatorial system where the sub-surface Cromwell current, injects oxygen to the demersal domain favoring hake whose range of distribution is closely related to the Pacific Decadal Oscillation index (PDO).

From a conceptual point of view we support the idea that the north-south latitudinal variation in hake distribution is an opposed function to PDO, which means that a markedly distribution of the fish toward the south of the equatorial line is an answer to a positive PDO. In the same sense, a negative PDO would lead to a displacement of the demersal sub-system towards the north (Fig. 1a). This pattern would be related to the one of regime shift described by Chavez et al (2003) who linked the positive PDO with El Viejo warm long term events, and negative PDO with La Vieja or cooler decadal regime, which last period started during the mid 1990's.

During the 1970 and 1980 decades the Peruvian hake showed a distribution that can be qualified as "standard", i.e. from the south of Ecuador to Huarmey (10ºS) with seasonal fluctuations that were described in detail by Espino and Wosnitza-Mendo (1988). They showed that hake distribution was reduced towards the north during winter-spring while extended southward during summer-autumn. During El Niño events hake extended its distribution toward the South, then the magnitude of the extension

depends on the intensity and duration of the event. For example, in the case of the El Niño of 1982-83, hake catches extended until Southern Peru – Northern Chile. This pattern of Southern extension is typical to the one observed during positive PDO (Fig. 1b).

During a negative PDO (as the one that is underway since the mid of the 1990's), hake latitudinal range of distribution shift toward the north (Fig. 1C). Such decadal change has had an effect on the local fishery of hake based in the Paita's harbor. Indeed the mean size of catch was smaller than before the regime shift. According to our results, the southern "tail" of hake distribution was mostly composed by juveniles distributed between 08 to 10°S during the last positive PDO. Then, after the regime shift the juveniles were distributed further north, being the target of the Paita's fishing fleet (05°S).

As described by Chavez et al (2003) the basic reason for the positive dominance of PDO since mid the 1990's would be the intensification of the sub-Antarctic system while the equatorial and tropical systems are relaxed and retired to north. Clear evidence is the increased abundance and northern distribution of anchovy (*Engraulis ringens*) and munida (*Pleuroncodes monodom*) since mid the 1990's, as previously observed during 1930's to 1960's. After these last periods a regime shift occurred with the dominance of a positive PDO together associated with higher abundance of hake in the demersal system and that of sardine in the pelagic one. Recent studies of paleoceanography performed by the Peruvian Marine Research Institute (IMARPE) on sedimentary scales collected in the zone of Paracas would confirm this observation.

An alternative hypothesis, that is not based upon an environmental component, has been elaborated by Wostnitza-Mendo and Guevara-Carrasco (2000) based on biological and fishery data, which explain the reduction of mean size of catches by a complex effect of overfishing, cannibalism, diet composition, maximization of fecundity and behavioral adaptation of hake, which changed from being a type ***K*** strategist (longer growth with smaller fecundity) to a ***r*** one (smaller growth with increased mortality). The two hypotheses might be in agreement since the southern fraction of the population can effectively respond to the fishing pressure by a change in the life history strategy without denying a general change of distribution to north as the variation of PDO strongly suggests.

In conclusion, the decadal variations of PDO would explain the apparent resilience or persistent smaller mean size of catches of hake in the NHCS by a latitudinal northward change of the overall distribution of hake since mid the 1990's. The continuous catches of large hake since late the 1990's in Ecuador, Colombia and Panama supports our hypothesis of a overall northward latitudinal change of the demersal sub-system without denying the possible existence of a change in the life strategy of the southernmost fraction of the population as a response to fishing pressure. Therefore they have been performed statistical analysis on latitudinal fishing, biological, oceanographic and abundance data of pelagic and demersal systems obtained by IMARPE during 1960 to 2006, as well as fishing data collected in Ecuador, Colombia and Panama in recent years.

Fig. 1a. CONCEPTUAL MODEL OF THE LATITUDINAL CHANGES OF THE AREA OF DISTRIBUTION OF HAKE

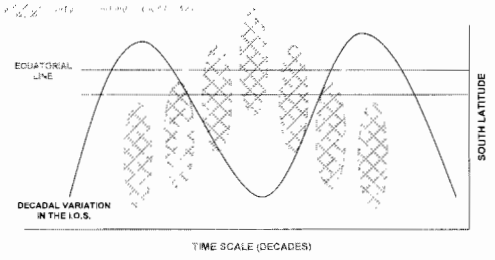


Fig. 1b. IDEALIZED DISTRIBUTION OF HAKE WITH A POSITIVE P.D.O.

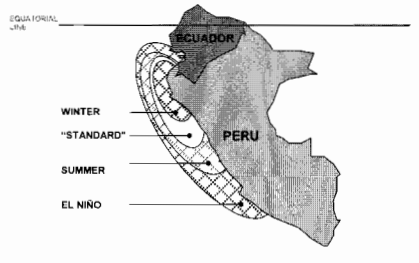
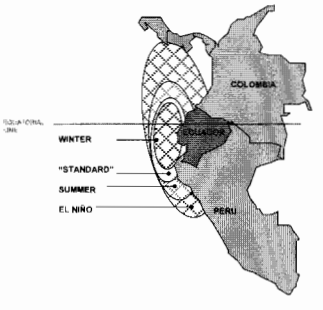


Fig. 1C. IDEALIZED DISTRIBUTION OF HAKE WITH A NEGATIVE P.D.O.



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HCS189 - Changes in the distribution area of Peruvian hake: effect of fisheries

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Keywords: Fishing pressure, hake, interaction with anchoveta, spatial distribution

The distribution of hake (*Merluccius gayi peruanus*) off the Peruvian coast is characterized by two patterns. One is determined by changes over the seasons and inter-annually in phase with El Niño events, due to the actual extension of the Cromwell Current. The second pattern is related to a size depending distribution by latitude, larger individuals being found to the north and smaller ones to the south (Del Solar et al., 1965).
During the 1980s and 1990s Peruvian hake's distribution was assumed to comprise mainly the area between the Ecuadorian border and 10° latitude south. This area was determined taking into account exploratory surveys carried out in the late 1970s and early 1980s. Relying on these findings, swept area surveys covered generally the mentioned area to determine hake biomass.
From the start of the heavy trawl fishery in 1973, Peruvian hake has experienced changes in its population structure and a first considerable reduction in biomass in the late 1970s. Hake population, as it shrinks, tends to concentrate again and occupy the northernmost areas of its distribution range (Wosnitza-Mendo et al., 2004).
For this study we used length frequency and biological data collected by the Peruvian Marine Institute (IMARPE) in Paita (5°S), Chimbote (9°S) and Callao (12°S). A separate treatment of the length measurements from the different ports allowed us to reconstruct mean length values over time for the three landing areas (Fig 1). We show that during the whole 1970s decade large hake with mean length >40 cm were present as far south as Callao.
This result illustrates that before the full development of the fishery by factory trawlers, the range of hake distribution was much larger than assumed. We also show the direct effect of combined trawl and purse-seine fisheries on the reduction of hake biomass and hence the range of hake distribution. Possible indirect effects due to changes in the ecosystem species composition and/or environmental long term changes are discussed to explain why hake did not recover the lost range.

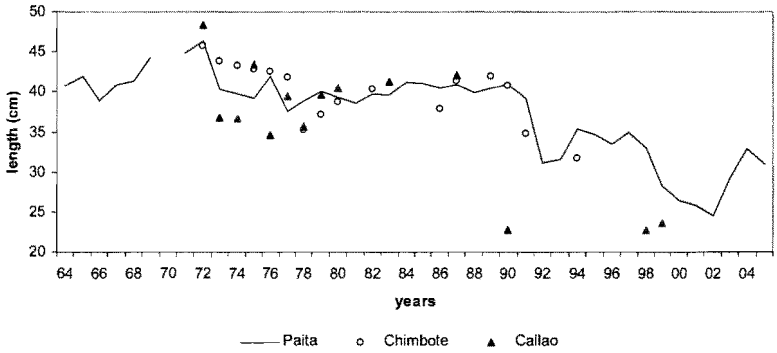

Figure 1. Mean length of Peruvian hake by year and ports (from north to south).

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HCS191 - Trend in relative investment of energy in growth and/or reproduction by Peruvian hake from 1972 – 2004: an issue of length dependence

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Keywords: Gonadosomatic index, Fulton's K condition factor, Peruvian hake, El Niño Southern Oscillation, Selective fishery impact.

Peruvian hake (*Merluccius gayi peruanus*) is the most abundant commercial demersal fish species of Northern Peru. Intensively exploited since the early 1970's, this species has experienced drastic declines in biomass leading to the closure of the fishery in 2002. The fishery was reopened in 2004 and total allowable catches and individual nontransferable quotas were implemented to control hake's exploitation. The evolution in biomass was accompanied by biological changes, particularly in size structure and length

at maturity. These changes are assumed to be related to the combined effect of the trawl fishery and El Niño events (Wosnitza-Mendo et al., 2004). However, the effect of fishing pressure and physical environment on hake is still unclear. In this work we study the physiological response of hake to changes in their physical environment and population structure from 1972-2004. In particular, we check for changes in the relative investment of energy in growth and/or reproduction.

Our study relies on 55000 female hakes sampled from commercial landings. Each individual was assigned to a 5 cm interval length group (range: 20 - 50 cm), and condition factor (Fulton´s K), gonadosomatic and fullness indexes were calculated. Generalized Additive Models (GAM) were applied to examine potential relationships between condition factor, gonodosomatic, and fullness indexes and sea surface temperature (SST) anomaly, population structure (biomass, sex ratio) and time.

Large positive SST anomalies (>2°C) were related to low condition factor, gonadosomatic index and, to a lesser extent, fullness index, suggesting a negative impact of El Niño on hake. We found that condition factor and gonadosomatic index had rather similar fluctuations over time with higher values during the mid 1980s, lower values during the mid 1990s and then an increasing trend (Fig.1). When the analysis was repeated by length class a different picture emerged. Condition factor and fullness indexes for large hake (>35 cm) increased after El Niño 1991-93 reaching their highest values during the 2000s, whereas the gonadosomatic index had its highest values in mid 1980s decreasing thereafter and staying at a low level despite the high condition factor and fullness index. Small hake (<35 cm) showed a different trend with increasing values of condition factor, fullness and gonadosomatic indexes since the mid 1990s. In comparison to large hake, small hake spent more energy in reproduction after the mid 1990s, coinciding with a reduced length at maturity. Additionally, the sex ratio shifted toward females (reaching almost 100% for fish larger than 35 cm) during that period. We discuss the results regarding the influence of the fishery, density dependent effects, prey abundance, and physical environment and hypothesize that the low investment of energy in reproduction by large female hake might be related to the lack of large males, due to a selective sex-related fishery and El Niño impact.

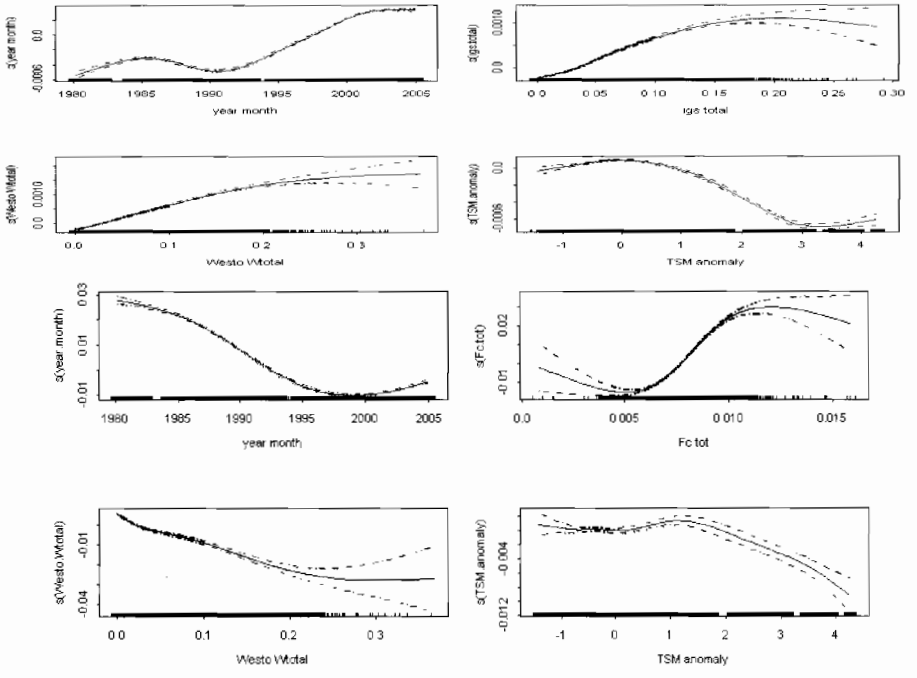

Figure 1. Cubic spline smoothers fits (black solid lines) of GAM models based on condition factor (a) and gonodosomatic index (b) of female hake according to time, condition factor (CF), gonodosomatic index (GI), stomach fullness and sea surface temperature anomaly (SST anomaly) for the complete set of data. The black dotted lines show the 95% confidence limits of GAM models. The y-axes are in relative scale, they correspond to the spline smoother that was fitted on the data, so that a y-value of zero is the mean effect of the variables on the response.

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HCS203 - Size distribution of Peruvian hake (*Merluccius gayi peruanus*) and its dependence on Cromwell Current Southern Extension

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Keywords: Cromwell Current, hake, remote sensoring.

In terms of abundance and habitat range a strong influence of the Cromwell Current Southern Extension (CCSE) on Peruvian hake *(Merluccius gayi peruanus)* has been well documented (Samamé *et al.*, 1983). Independently a north – south segregation by age has been also proved e.g oldest hakes located in the north and the youngest ones in the southern range habitat (Del Solar, 1968).
According to this increasing CCES intensity allows hake to expand its habitat and decreasing intensity reduces hake's habitat. Then if 05°S and 06°S are classic fishing grounds, and taking into account the spatial age segregations, the first scenario would result in a higher availability of older ages and the second one in a higher availability of the younger ages. In other words CCES intensity could be proposed as an environmental indicator of hake availability, while mean length could be proposed as a indicator of hake population structure. Unfortunately the actual system of oceanographic monitoring does not allow us to get a continue series (e.g. monthly) of CCES progress.
The goal of this work is to propose a technically easy and continue indicator of CCES development and to analyze the connection between CCSE intensity and size composition of Peruvian hake caught by the trawling fleet from 1995 to 2005 in order to prove if CCES intensity changes (assumed as habitat changes) force migrations by size.
Unable to monitor the CCSE extension and intensity at a regular basis by surveys we are able to monitor the intensity of CCSE by using the remote sensoring tool. In order to construct a real time CCSE intensity indicator we used the sub – surface temperature satellite images provided by NOAA – TAO buoys which are lined up along 95° W, from 12° N to 08° S and from the surface to 500 m depth, providing a cross section image of water masses arriving form mid Pacific Ocean to South Eastern Pacific Ocean. The area comprised between 14° and 16° C isotherms was used as CCSE intensity indicator. Monthly mean area and standard deviation time series was quantified and modeled using the Standardized Anomaly Time Series Method (12 means and 12 standard deviations corresponding to each month of the year were estimated, then every value of CCSE intensity was subtracted from this mean and divided by the corresponding standard deviation) (Purca, 2005). Monthly mean length time series of hake caught by the industrial trawling fleet at 05°S and CPUE by age group were also estimated in order to know what age group was present in the proposed area (assumed to be a fixed station) and the relative biomass. Finally all time series were overlaid and correlated.
A strong relationship ($p<0.01$) between standard deviation of CCES intensity and mean length of hake from mid 1997 onwards (just when El Niño 1997 – 1998 started) was clearer than the preceding period (1995 – mid 1997). From 1997 to 2005 three scenarios were identified, a declining CCES intensity and mean length from 1997 to 2000, a steady low level of CCES intensity and mean length from 2000 to 2002 and an ascending CCES and mean length period from 2002 to 2005 (Fig. 1). Also age 2+ CPUE was proved to be the most related to CCSE intensity.
We showed that 1) CCES intensity has proved to be an interesting real time indicator of hake's habitat range and as a consequence of hake's availability and 2) the dynamic of CCSE strongly forces migration. While high CCES intensity induces a southward stock movement added to a relative spatial age segregation leading to older hakes more available to the trawling fleet at 05°S. We also discuss the mismatch between CCES intensity and mean length of Peruvian hake between 1995 and 1997.

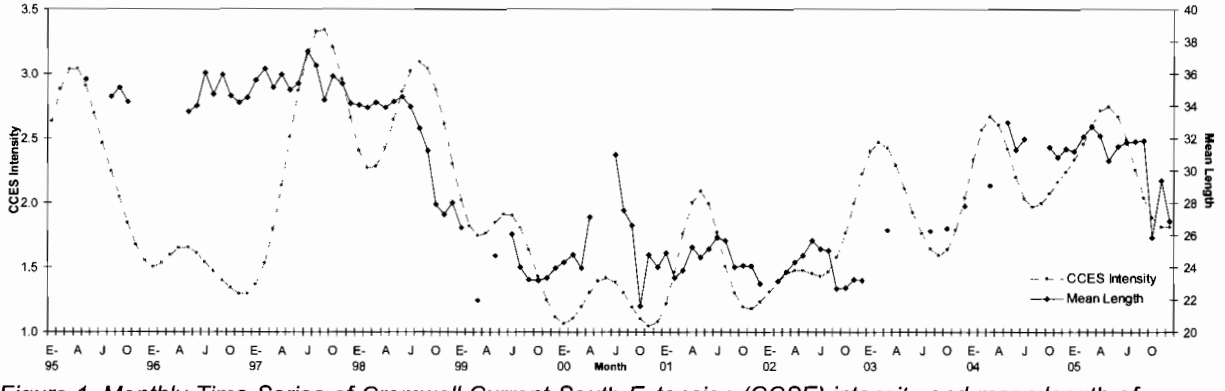

Figure 1. Monthly Time Series of Cromwell Current South Extension (CCSE) intensity and mean length of Peruvian hake (Merluccius gayi peruanus). Notice the strong relationship between CCSE intensity and mean length after El Niño 1997 – 1998.

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HCS047 - Integrated Modeling of Peru – Chile anchovy (*Engraulis ringens*) and The Humboldt Current System

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Keywords: Humboldt Current System, Peru – Chile anchovy, ENSO, El Niño – La Niña South Oscillation, Climate Variability, Fisheries Management, Socioeconomic Impacts.

El Niño South Oscillation is frequently occurring along Chilean-Peruvian coast of the Humboldt Current upwelling system, with severe impact on the anchovy fishery and coastal environment (FAO, 1997b). ENSO phases generate different challenges for the local ecology, socio-economy and infrastructure (Pinochet and Villagrán, 2004). So, a profound knowledge and understanding of functioning of coastal communities and ecosystems under extreme stress as during ENSO can help to develop recommendations and advices to manage natural marine resources by recent climate oscillation (Chávez et al 2003).

The research hypothesis considers the high importance of environment on productivity of Humboldt Current System to explain dynamics population and landings of Peru-Chile anchovy how a respond of Pacific Decadal Oscillation and ENSO could explain very well the spatial-temporal fluctuations of anchovy to the fishing fleet. Both factors could be determinant in socioeconomic effects of climatic variability.

This work uses inductive modelling based on early life stages of anchovy, biomass estimates and environmental indexes. They can predict very well the ENSO socio-economic impacts, Fig. 1 (Rodríguez y Pinochet, 2004). Artificial neuronal networks were used to model and adjust captures and biomass of anchovy. The environmental indexes explored correspond to regional variables such as temperature and its anomalies in El Niño 3.4 Area and the Southern Oscillation Index (SOI); and local indexes such as sea level (SL) and sea surface temperature (SST), indices of larval Index and indirect anchovy biomass both in Chile and Peru. The analyzed period extended from 1984 to 2006.

The advances and results obtained can be considered as highly satisfactory with a good cost-effectiveness relationship, concluding that the explicit incorporation of biological and environmental indexes can be usefully tool to fishing management and mitigations of negative impacts.

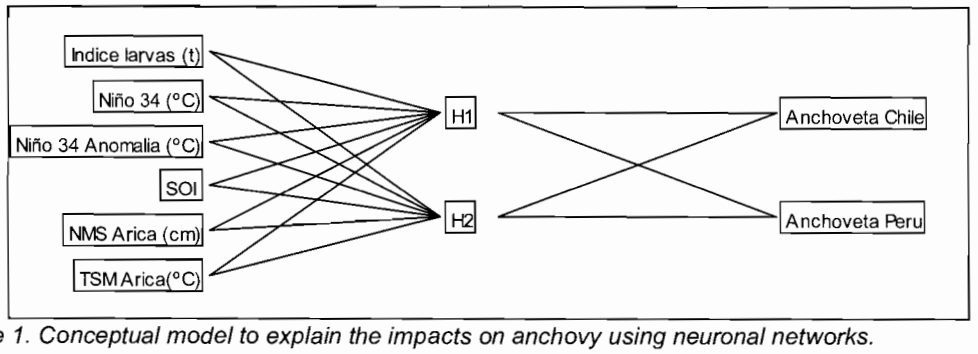

Figure 1. Conceptual model to explain the impacts on anchovy using neuronal networks.

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HCS119 - Knowledge and Research on Chilean Fisheries Resources: Diagnosis and Propositions

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Keywords: cognitive system, knowledge building blocks, sustainability.

The Chilean Fisheries Authority is in great and urgent need of systematizing both information and knowledge to design and implement a fisheries research program in support of fisheries management. In 2005, the Chilean Fisheries Research Fund (FIP) decided to support a research project (Project FIP 2005-25) aiming at diagnosing the current state of main fishery resources in Chile, which was conducted in 2005-2006 by joint team of researchers from Pontificia Universidad Católica de Valparaíso and Universidad de Concepción.

Three specific objectives of this project were: (i) to develop a Knowledge Matrix of main fishery resources, (ii) to conduct a comprehensive literature review upon which to base a diagnostic of the current state of knowledge related to the main fishery resources of Chile and (iii) propose a research program to support future management of these resources, based on past experiences and a prospective vision of fisheries management and related research.

The approach adopted to conduct the research project is based on two main principles. On the one hand, fisheries management and related research must contribute to the attainment of sustainable development of Chilean fisheries and on the other hand, fisheries management and research must be based on a process applying a common language and framework between the government, the private sector and the public in general, enabling the attainment of areas of mutual interest upon which to build political-social-economic feasibility for sustainable fisheries development.

To accomplish the above, a seven step process was conducted. First, expert judgment techniques were used to define a Conceptual Vision or Model of fisheries system structure and functioning under sustainable development conditions. From this model a set of four Clusters of Minimum Knowledge (CMK) or Knowledge Building Blocks (KBB) required to understand the fisheries system, beyond the Ecosystem Approach for Fisheries, were defined (Figure1). Second, a Cognitive System comprised of a set of 126 was identified and defined. Third, a structural matrix analysis of the elements previously defined, based on driving-dependency analyses was performed to identify Key Driving Forces of knowledge in the Chilean fisheries system. Fourth, a validation of the conceptual model and the knowledge elements defined was conducted through a discussion workshop with participation of government officials and a extended group of national fisheries experts. Fifth, a parallel literature review was conducted to identify current status of knowledge and research on 31 fishery resources. Sixth, knowledge and research gaps were identified through a comparison of results from the literature review and conceptual model adopted (CMK/KBB and their specific constituting elements). Seventh, a research agenda and needs were systematized through the proposal of fisheries research program.

The conceptual model adopted along with the structural matrix analysis and results are briefly presented. The current status of knowledge and research on Chilean fisheries resources is presented and implications for future research directions are also discussed. Current partial results of the matrix analysis showed in the fisheries system it is possible to identify thirty (30) knowledge elements as forcing variables or drivers. In addition, other seventeen (17) elements have been identified as having driving-dependent nature. Among the above it is possible to highlight Upwelling, Rossby waves, ENSO, fish mortality, solid wastes, rate of interest, primary productivity, nominal fishing effort, product price and marginal cost, among others.

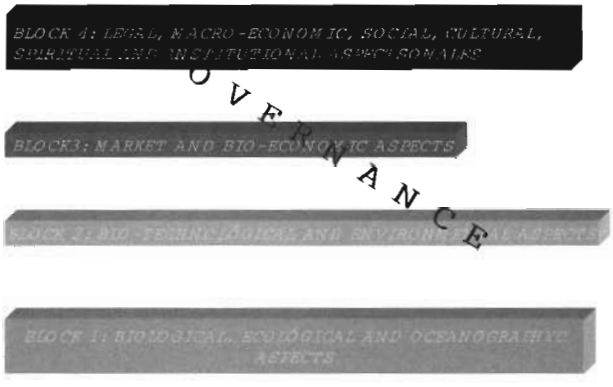

Figure 1. CMK or KBB in the fisheries system.

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HCS062 - Social – Ecological Complex Adaptive Systems, Simulation modeling and the Humboldt Current System

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Keywords: complex adaptive systems, Humboldt Current, simulation, social ecological systems

Social Ecological Systems are linked complex systems of people and nature that co-evolve in the biosphere. In 1968, von Bertallanffy originally defined a "system" as a complex of elements standing in interaction; and developed the notion of "general systems theory" which is concerned with the exploration of wholes and wholeness. According to this theory, understanding comes from the examination of how parts of a system operate together and not from the examination of the parts themselves in isolation. More recent definitions of systems include the work of Mandel (2001), who states that "a system is a family of meaningful relationship among the members acting as a whole" (Mandel 1994). According to Berkes *et al.* (2003) a complex system often has a number of attributes not observed in simple systems, including nonlinearity, uncertainty, emergence, scale, and self-organization. Many of these attributes apply to both social and natural systems.
A "complex adaptive system" is a complex system that includes *planner* units, i.e., units that are goal-directed and that attempt to exert some degree of control over their environment to facilitate achievement of these goals (Auyang 1999). This paper considers the Humboldt Current System as a complex adaptive system and describes its principal characteristics from this standpoint. We also propose the methodological approach of simulation modeling as a tool for understanding behaviour of the system and discuss the potential applications in the development of participatory decision-making processes as an example. Finally we discuss the prospects of the interdisciplinary work between social, ecological and computer scientists in the field of simulation modeling to support the management of the Humboldt Current System.

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HCS130 - Assessing the socio-economic impacts of climate variability on artisanal fishing communities: A Peruvian case study

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Keywords: adaptive management, artisanal fisheries, climate variability, El Niño, livelihoods, socio-economic impacts

Understanding the livelihood impacts of climate variability and change and the resulting vulnerability of fisherfolk is essential for the appropriate design of policies and management strategies in the fisheries sector (Allison et al., 2005). The purpose of this paper is to present the socio-economic impacts of inter-annual climate variability on fisherfolk livelihoods in Peru. At the local scale an adapted version of the sustainable livelihood approach (SLA) is used to establish a typology of impacts to El Niño-Southern Oscillation (ENSO) events. People can access, build and draw upon five types of assets: human, natural, financial, social and physical (Allison & Ellis, 2001), and this research investigates how each can be affected by ENSO events. A comparison is made between a reference state (Non-ENSO) and a disturbed state (ENSO) and for each asset a set of indicators (quantitative and qualitative) is developed. Preliminary results are presented from a set of in-depth interviews, focus groups, secondary data and surveys conducted in two coastal regions located respectively in the North and the South of Peru. The livelihood framework provides a useful insight into the complex range of assets and activities affected by climatic events and the response of fishing communities which ranges from prey switching, migration and diversification of livelihood strategies.

While both regions are located within the Humboldt Current System (HCS), there are significant differences on how they are affected by ENSO. In Sechura (North), El Niño is synonymous with devastating floods and negatively affects scallop fisheries while favouring fishermen extracting migrating tropical species. In Pisco (South), the same climatic event results in a scallop boom, causing a short-lived economic wellbeing for diving fishermen while small pelagic ones are negatively affected. Climate variability can thus results in "winners" as well as "losers", these differences being accentuated by differential social, economic and political environments. However the research findings suggest that common attributes to the response of communities can be identified across study areas even though impacts might differ. These attributes are not only related to what people actually did in terms of their changing livelihood practices, but also to the role of institutions and social networks in promoting or inhibiting adaptation to climate variability. The research provides one of very few detailed studies on the impact of ENSO events on artisanal fishing communities in Peru and the results presented will contribute to the challenge of designing adaptive management strategies in a highly fluctuating and uncertain environment such as the HCS. This research is part of the project CENSOR which aim is to understand the implications of climate variability on the artisanal fishing sector in Peru and Chile (www.censor.name).

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HCS060 - Sustainable fisheries through improved management and policies

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Peru's fisheries resources support one of the country's most important economic activities and provide fundamental environmental services. The Peruvian anchoveta remains the largest single stock fishery in the world. The occurrence of El Niño Southern Oscillation drives extreme fishery resource volatility. Combined with the expansion of fishing and processing capacity and deficient sector governance, this volatility has resulted in resource depletion, extensive marine ecosystem change, widespread environmental degradation and dissipation of resource rents and loss of socials and economic benefits. Meeting these challenges will require an open and transparent participatory process to: i) substantially increase net benefits from the sector by reducing capacity and effort in the fishing sector in line with natural productivity and maximum economic yield; ii) improve sector governance and equitable benefit distribution; iii) issue effective environmental regulations with independent oversight of enforcement; iv) strengthen the sectors research capacity to support an ecosystem approach to management of fisheries and coastal resources; v) establish a system of Marine Protected Areas; and vi) revise and modernize the sectors regulatory framework.

Invited paper: HCS216 - Interdecadal variability of anchovy abundance and overcapacity of commercial fleets in Peru

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Keywords: Fishery management; fishing effort; overcapacity, interdecadal scale

Historical data of catches and conventional stock abundance estimates during the last decades indicate that pelagic fish populations inhabiting upwelling ecosystems undergo large interdecadal variations in abundance which amplitude is equal, if not higher, than the amplitude of interannual variability. Paleontological records of scale deposition in anaerobic sediments indicate that this interdecadal variability existed long before exploitation. The pattern of variability displays alternation of periods of high and low abundance that were termed "pseudo-cycles" because their periodicity is irregular. The mean period varies between 20 and 90 years according to the population (species and region), and for a given population the internal variation of the period is in the order of 30%. In the case of the Peruvian anchoveta population, the mean duration of the cycle is 40 years but it varies at least between 30 and 60 years. This cycle to cycle variability is difficult to estimate and even more to predict because 1) few realisation of the pseudo-cycles are available (here only 3); 2) the process(es) responsible for this pattern of variability are largely ignored; 3) the recent global warming might impact on the anchovy population dynamics.

Small pelagic fisheries, as any other fisheries, suffer from overall overcapitalisation due to many factors such as the tragedy of the common and the positive feedback between overexplotation and overcapitalization (Ludwig's ratchet - Decrease in abundance due to exploitation requires more effort,

therefore more capitalization, to catch the remainder of the stock, which then declines further, and so requires more effort (Ludwig, 19xx; Mangel et al. 2000). But small pelagic fisheries suffer from an additional overcapitalisation problem, which is the phase displacement between investment and fish abundance (Fig. 1). Because there is a lag between profit and actual realisation of investment (accumulation of benefits, decision making process, factory or boat building delay), investment remains very high when the exploited stock enter in the declining phase of their interdecadal pseudo-cycle. At that time, a large part of the heavy investment are not yet redeemed and must be either reformed, sold at low coast or maintained at expense in expectation of a better period that is likely to be waited for decades. Here we document this situation in the case of the Peruvian anchoveta fleet from a bibliographical review of economical reports on investment/disinvestment and from the presentation of new evidences of overcapacity of the fleet and processing factories (indices).

Presently the anchovy stock of Peru is a state of high abundance since the end of the 80s, despite some strong interannual variability due to El Niño events. Therefore a decrease in abundance is expected within the next few years. Due to the present overall overcapacity of the pelagic fleet worldwide (including Peru at present time), it will be difficult this time to sell boats to other countries as during the previous stock collapse during the 70s. Therefore a crisis with high economical and political tensions is expected. In order to limit its effect a drastic reduction of the fishing and processing capacity is recommended. Ideally this capacity should be at least halved. The minimum but urgent measure is to prevent new investment.

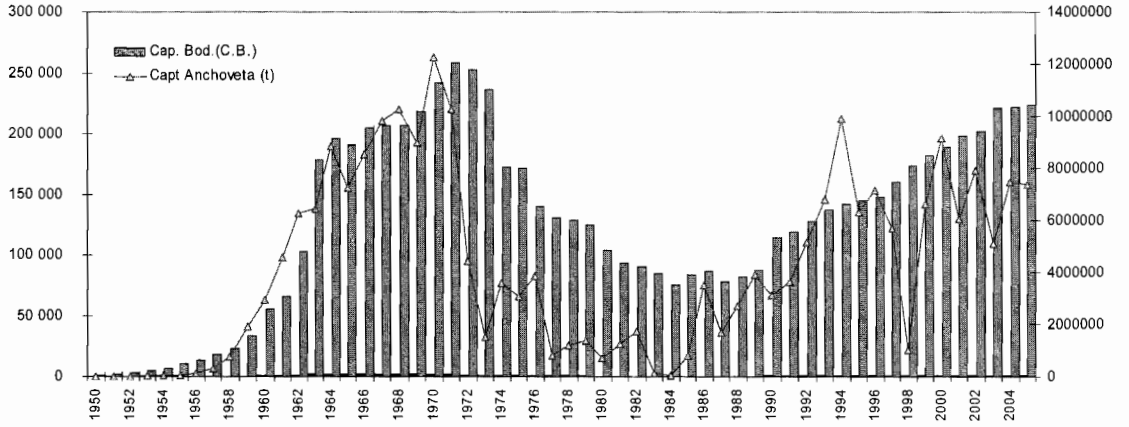

Figure 1. Time series of anchovy catches and fleet loading capacity (CB).

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Posters

Part 1

Monday afternoon

HCS001 - Decadal changes of the western boundary currents affected spatio-temporal variation of the copepod community in the western North Pacific.

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Keywords: copepods, Kuroshio, Oyashio, Pacific Decadal Oscillation, regime shift

The Oyashio in the subarctic and Kuroshio in the subtropical are the western boundary currents in the North Pacific, and the Transition zone (the Mixed Water Region) lying between the two currents shows the highly variable, complex environments. Dynamics of the Oyashio and Kuroshio greatly influence biological production in the western North Pacific. Hydrographic conditions of both currents have been reported to vary in a decadal scale corresponding to the North Pacific Decadal Oscillation, which are closely related to the behavior of the wintertime Aleutian Low (AL). After the intensification of the AL in 1976/77 (known as the major Regime Shift), enhancement of sub-arctic circulation induced a southward shift of the Oyashio domain, and also a strengthening and northward shift of the Kuroshio. We have been studying the long-term ecosystem change in the western North Pacific since FY2003, using the Odate Collection, a 50 yr zooplankton collection maintained by the Tohoku National Fisheries Research Institute. In this presentation we report the decadal change in geographical distribution pattern of copepods in the Oyashio and Transition zone, which was associated with the latitudinal shift of the Oyashio and Kuroshio currents.

To see the temporal variation in the lower trophic levels in the Oyashio domain and Transition zone (36-43°N, 142-150°E) for 1960-1999, we applied the principal component analysis (PCA) on the annual abundance (May-Sept average) of major copepods species. The first principal component (PC1) accounted for 21% of the interannual variation in copepods community. The "jump" of the PC1 value was detected in 1976 and 1988 based on the differences between 5-year means before and after a given year, both of the jumps coincided with the years of major and minor climatic Regime Shifts in the North Pacific. Copepods species with interannual variation have a significant positive correlation with the PC1, which mainly consisted of ~~the~~ large-sized, cold-water calanoid copepods, dominating in the Oyashio domain (water temperature < 5°C at 100 m deep), PC1 time-series mirrored the interannual variation of the abundance of "Oyashio assemblage" copepods. The second principal component (PC2) accounted for 15% of the variation, and the jump year was observed in 1982. Copepods species with a significant positive correlation with the PC2 time-series mainly consisted of the small-sized, warm-water species including cyclopoids and poecilostomatoids. As these species frequently occurred at the Transition zone stations (water temperature > 5°C at 100 m deep) but absent or only occasionally observed in the Oyashio domain, they were defined as the "Transition zone assemblage" copepods.

Geographical distributions of the Oyashio assemblage and Transition zone assemblage were compared before and after the jump year(s). The distribution center of the Oyashio assemblage shifted southwestward after 1976, clearly responding to the southern intrusion of the Oyashio. It further shifted west toward the Japanese coast after 1988, presumably due to the northern intrusion of the Kuroshio. There was no clear change in the geographical distribution of the Transition zone assemblage before and after 1982. However, an increase in its abundance was manifested, indicating the influence of the northward shift of Kuroshio. Interestingly, increase of the geostrophic transport and northward shift of the Kuroshio occurred around 1982 several years after the southward shift of the Oyashio. Therefore, the distribution pattern of the copepod community in the Oyashio and Transition zone was determined by the combined effects of both lagged and un-lagged hydrographic variations which were closely related to the North Pacific Decadal Oscillation.

This finding implies the possibility of the spatial match-mismatch between the lower and higher trophic levels in a decadal scale. For instance, the Transition zone is known for the nursery ground of Japanese sardine (*Sardinops melanostictus*), and thus food availability there is crucial for the recruitment success of this species. Previous study did not sufficiently explain the paradox of the high standing stock of Japanese sardine during the 1980s when zooplankton biomass declined. Our study suggests that abundance increase of the small, warm-water species in the Transition zone after the 1982 might have improved prey encounter rate for the juvenile sardine.

This study was financially supported by the Global Environmental Research Fund of the Japanese Ministry of the Environment.

HCS015 - Siliceous productivity changes during the last ~350 years in an upwelling center off Concepción, central Chile (36°S)

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Keywords: Chaetoceros, Diatoms, Humboldt Current Sistem, sediments, upwelling

Silicon is the second most abundant element in the earth's crust; and it enters the ocean by means of river inputs, wind transport and hydrothermal sources.
This element is used by organisms such as diatoms that incorporate silicon into the structure of their cell wall.
The fate of biogenic silica, which is produced in the euphotic layer, is determined by competition between dissolution in the upper layers and export to the bottom. Siliceous material preserved in the sediments can be used as a proxy of upper layer productivity as well as for reconstructing climate and oceanographic conditions in the past (Ragueneau et al., 1995).
The coastal zone off Chile has one of the highest productivities of the world because of strong upwelling. Paleoproductivity studies based on diatoms and silicoflagellates have been conducted on surface sediments (Romero & Hebbeln 2003) and long sedimentary records en compassing the last 19000 years (Mothadi et al., 2004).
Fluctuations in siliceous export production for the last ~350 years were reconstructed from one boxcore off Concepción (COPAS Time Series Station 26: 35º25´S, 73º23 W, 120 m water depth; core length= 35cm) and compared with other proxies (e.g. total organic matter, alkenones). Biogenic silica and total organic matter fluxes fluctuated between 1.4-4.2 mg $cm^{-2}y^{-1}$ and 3.3-9.5 g $cm^{-2}y^{-1}$, respectively (Fig. 1A); biogenic silica and total organic matter were inversely related (r^2=0.179; p=0.031). We estimated using alkenones that mean sea surface temperature was12.5 ±0.4ºC (Fig. 1A); this variable was directly related with TOM (r^2=0.340; p<0.002) and inversely correlated with microsiliceous organisms (r^2=0.341; p<0.0017).
Diatoms were the most abundant siliceous group ($2x10^4$ - $3x10^6$ valves $cm^{-2}y^{-1}$) (~94-99% of the total); whereas the contribution of other siliceous groups (e.g. silicoflagellates) was ~4 order of magnitude lower. In addition, 130 diatom taxa were recorded (H' = 1.87±0.22) and silicoflagellates were represented by 3 species: *Dictyocha mandrai*, *Distephanus speculum* and *D. pulchra*. The upwelling group, characterized by *Skeletomena costatum* and the resting spores of the genus *Chaetoceros* (*Ch. radicans/cinctus*; *Ch. constrictus/vanheurckii*, *Ch. debilis* and *Ch. diadema*) dominated the diatom assemblage. Other important groups were coastal planktonic diatoms, temperate and cosmopolitan (1.1-27.2%), benthic (0.3-16%) and oceanic and warm-temperate (0.1-2.9%) (Fig.1B).The freshwater group was constituted by 16 taxa, reflecting the influence of the Bio-Bio and Itata rivers.
We observed a pronounced drop in siliceous productivity during the last 80 years. A concomitant decrease is observed for biogenic silica, total diatoms and upwelling diatoms (Fig. 1). This generalized drop in siliceous production coincided with a gradual increase in Sea Surface Temperature (Fig. 1A), which could be related to a general scenario of global warming and/or stratification of the water column which attenuates the upwelling of nutrient-rich water favorable to the development of microplankton, especially diatoms.

Acknowledgments: FONDAP-COPAS Center, Graduate School University of Concepcion, UCO 0214 – MECESUP Project, and University of Concepcion.

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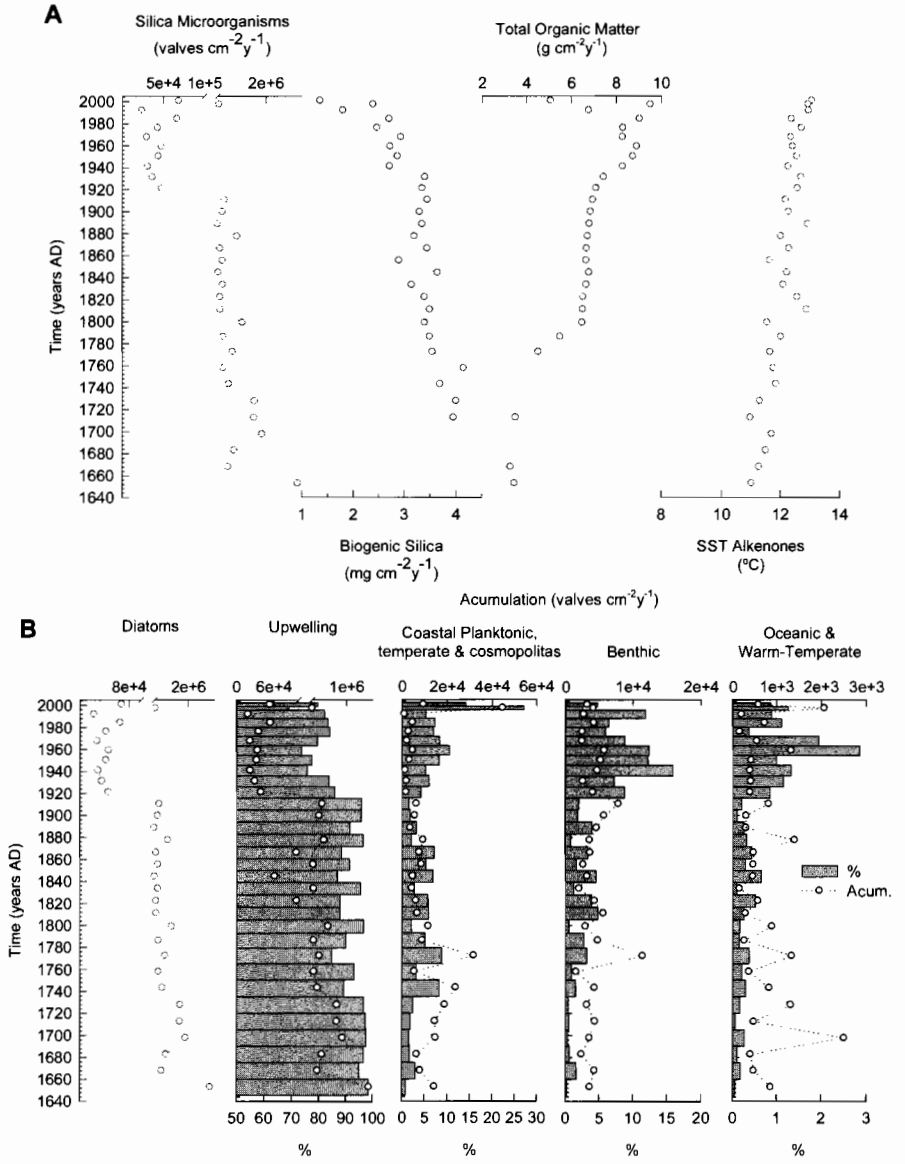

Figure 1. Downcore variations of A) Siliceous microorganisms, total organic matter, biogenic silica and Sea Surface Temperature from alkenones; B) Total diatoms and other diatoms group. Gloria E. Sánchez.

HCS026 - Numerical study of the response of the ocean to a northerly wind-jet in the equatorial eastern Pacific

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Keywords: Eastern Pacific; equatorial waves; linear ocean model; Panama Wind Jet

The response of the ocean circulation to an anomalous northerly wind jet in the Gulf of Panama in March, 2002, that crossed the equatorial line from 6°N to 6°S [Mosquera, 2004], and the subsequent effects on the west coast of America were studied using a linear numerical ocean model. Two experiments were made: one, without boundaries and the other with an eastern boundary at 81°W, representing the American continent. The spatial and temporal structure of the imposed wind anomaly, represented using idealized mathematical functions, was quite similar to that of the real jet. The duration of the wind jet was six days and the maximum intensity occurred at day three.

The results of these two experiments, after the duration of the wind jet, were the following:

1) The first simulation shows 3 types of disturbances: one moves towards the west, slowly, like a packet of Rossby waves [McCreary, 1989], other whose displacement is towards the east and has the mixed Rossby - gravity (MRG) waveform, and the last is an eastward perturbation faster than the second that has an eastward inertia-gravity waveform.

2) The second simulation shows that when the eastward inertia-gravity wave initially reaches the eastern boundary, they excite downwelling and upwelling coastal Kelvin waves that propagate southwards and northwards, respectively. Four days later, other group of Kelvin waves of the opposite sign, and stronger than the previous ones, are excited when the MRG reaches the boundary. At the end, five days later, another group of Kelvin waves, with the same sign and intensity of the first group, were excited.

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HCS034 - Benguela Edge Exchange Processes

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Keywords: Benguela system; Biogeochemistry, Carbon export; Shelf edge exchange

The world ocean is pivotal in the global carbon cycle, and its ability to sequestrate atmospheric carbon via the biological pump is a key link between these reservoirs. While a large proportion of previous carbon fixation work has focused on the open ocean, a mounting body of evidence suggests that the ocean margins may in-fact be zones of significant carbon sequestration (Monteiro, 1996). In particular, coastal upwelling systems such as the Humboldt and the Benguela, with their high f-ratios represent the most significant global sources of export production by area (Schlitzer et al, 2003). However the ability of these systems to sequestrate carbon in the long term is dependent on the export of detritus from the shelf recycling domain to the depo-centres of the deep ocean sediments.
A preliminary study aimed at identifying such export processes off the west coast of South Africa, showed that benthic accumulations of Particulate Organic Carbon (POC) and Particulate Organic Nitrogen (PON), were occurring at the shelf break. In addition sediment samples from the study area revealed that the slope sediments of the region were unusually high in organic carbon, reaching values of over 4%. Together these encouraging results prompted the formulation of a more comprehensive sampling program aimed at elucidating the cross shelf transport of carbon from the shelf to the slope sediments in the Southern Benguela upwelling system. This current effort has been termed the Benguela Edge Exchange Processes (BEEP) project.
The working hypothesis of the BEEP project is that a significant amount of the carbon fixed through primary production over the continental shelf in the southern Benguela system is transported to the adjacent continental slope, where its sedimentation below the permanent thermocline leads to the long term sequestration of the organic material. A conceptual model of carbon export in the system (see figure) indicates that the exchange processes are regarded to occur in several steps, which are likely to be inhomogeneous in both space and time. Following the fixation of carbon through primary production in the euphotic zone, a series of biogeochemical and physical processes determine the fate of the organic material. Oxidation and recycling may occur in the water column or on the shelf sediments, reducing the amount of phyto-detritus available for export. Alternatively, turbulent resuspension and advection (1) could lead to the subsequent deposition of the carbon rich organic material in quiescent zones found within the benthic boundary layer (2). Following several such resuspension/advection events, the phyto-detritus may finally be deposited and sedimented in the permanently quiescent zone associated with the continental slope (3), resulting in the long term sequestration of the associated carbon.
Two principal avenues of research are currently being undertaken to investigate and quantify the carbon transport of the southern Benguela system:

1) Biogeochemical Evidence of carbon export and
2) Physical mechanisms associated with resuspension and cross shelf flow

The biogeochemical component is based on a suite of measurements taken on a monthly sampled long term monitoring line (St Helena Bay Monitoring Line – SHBML) transecting the shelf-slope environment off the west coast of South Africa. During several research cruises on this line in 2006 water samples from discrete depths throughout the water column were filtered for later POC, PON and stable light isotope ($\partial^{14}C$ and $\partial^{15}N$) analysis. Patterns evident in POC/PON concentrations highlight the role of the benthic boundary layer in the cross shelf transport of organic material with a surface origin. Preliminary results on the isotopic character of the filtered samples indicate that slope based benthic organic material has a $\partial^{14}C$ and $\partial^{15}N$ signature consistent with a contribution from an inshore source. In addition to these recent specialized measurements, a historic data set comprising six years of monthly continuous Fluorescence-Conductivity-Temperature-Depth-Oxygen (F-CTDO) data, as well as discrete nutrient data for the SHBML exists. Each individual SHBML transect from the historic data set is currently being analyzed to search for evidence of bottom accumulations of phyto-detritus, including *inter alia,* benthic fluorescence and turbidity

maxima, low oxygen waters, and signs of water column nutrient recycling. Preliminary results show clear indications of a preferential accumulation of phyto-detritus in the benthic layer near the shelf break, despite surface productivity being concentrated further inshore. Monthly means of all relevant variables are also calculated for the historic data to provide insight into the seasonality of bottom accumulations and potential export of phyto-detritus. The collection of sediment cores for Total Organic Carbon as well as isotopic analysis to complete the sampling is planned for the later half of 2006. The biogeochemical approach will ultimately provide insight into whether 'oxidation and recycling' or 'resuspension and advection' are the dominant processes controlling the fate of phyto-detritus on the continental shelf of the southern Benguela.
Systems such as the Benguela are traditionally dominated by alongshore geostropic flows. Several potential mechanisms could achieve the cross shelf flows required for the export of shelf based organic material, including *inter alia,* turbulent processes (downwelling), veering of the poleward undercurrent, topographic effects (capes and canyons), offshore rings and eddies, and oscillating motions such as Coastal Trapped Waves (CTW) tidal currents and inertial flows (Brink, 1998). To investigate the presence and relative importance of these physical mechanisms, as well as those associated with benthic resuspension (internal tides) historical Recording Current Meter (RCM) and Acoustic Doppler Current Profiler (ADCP) data for the southern Benguela are currently being analyzed. The records are divided into their alongshore and cross-shore components in order to assess the relative significance of the respective flows, and the likelihood of cross-shore transport. A Continuous Wavelet Transformation (CWT) is applied to each of the records, and provides the frequencies associated with variability in the data. This analysis provides insight into which physical mechanisms are responsible for generating significant cross-shelf flows, and therefore the possible export of organic material to the slope.
The Benguela, like the Humboldt, is a highly productive upwelling system which has the potential ability to sequestrate photosynthetic ally fixed primary production, through the export of photo-detritus from the shelf to the continental slope. Through analyzing the biogeochemical modification of shelf based organic material as well as the physical characteristics of resuspension and cross-shelf flow, the Benguela Edge Exchange Processes project aims at quantifying the potential significance of organic carbon export from the system and its subsequent long term sequestration. This work has important implications for JGOFS and other global carbon flux studies.

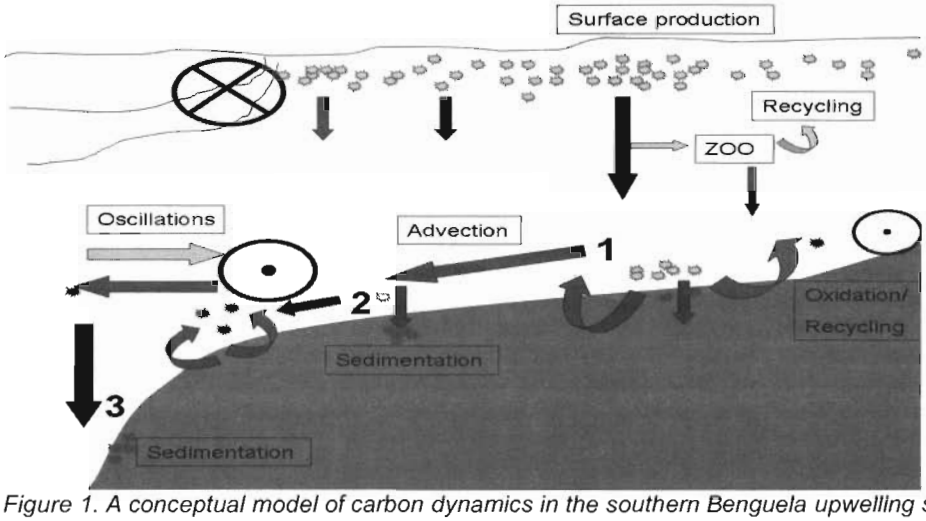

Figure 1. A conceptual model of carbon dynamics in the southern Benguela upwelling system

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HCS040 - A numerical study of the oceanic circulation in the Southeastern Pacific

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This presentation discusses the results of a numerical simulation of the oceanic circulation in the southeastern Pacific using the ROMS model. The model domain extends from 5°S to 50°S and from the South American coast to approximately 95°W. The model has 30 vertical s-levels and a variable horizontal grid with a maximum resolution of 3 km near the coast. The bottom depths were derived from the Etopo2 topographic data and the temperature and salinity fields were obtained from the World Ocean Data (Boyer

et al., 2001). At the open boundaries the model was nested to POCM (Parallel Ocean Climate Model), experiment 4-C. We discuss three experiments, the first was forced with NCEP climatological atmospheric forcing and the other two were forced with atmospheric forcings corresponding to El Niño and La Niña years.

HCS059 - Impact of bottom topography smoothing on the modelled circulation in the Humboldt Current System

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Keywords: Mesoscale circulation, modelling, upwelling, vertical coordinate

Several modeling studies of Humboldt Current System (HCS) have been able to reproduce adequately the main dynamical features of upwelling system, such as the equatorward surface current, a subsurface undercurrent and a transition zone of high mesoscale variability (Penven et al., 2005). However, theses studies have shown that some biases remain such as the failure to reproduce correctly the spatial patterns of turbulence in the area (Echevin et al., 2006). In the present work, two models ROMS and NEMO are used to compare the impact of the bottom topography on the dynamics of the system. In the ROMS model, the so called "s" vertical coordinate requires smoothing of the bottom topography of the shelves and slopes to reduce numerical errors of the horizontal pressure gradient. In the NEMO model, the "partial step" vertical coordinate allows to represent unsmoothed bottom topography. In a series of numerical experiments we compare the mean HCS circulation, the vertical structure of the upwelling, and the characteristics of the mesoscale circulation. Both regional models are forced at their open boundaries by outputs of the ORCA OGCM at ½° resolution, and at the surface by winds and heat fluxes of the ERA40 reanalysis.

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HCS071 - Small-scale patchiness of plankton in Peruvian coastal and shelf habitats as detected by using PELSS (Particle and Environmental Parameter Logging and Sampling System)

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Keywords: zooplankton, new technologies, spatial distribution, small-scale patchiness, Peru

PELSS (Particle and Environmental Parameter Logging and Sampling System) was tested for the first time under in situ conditions off Peru in May 2006. This array of sensors, with a LOPC (Laser Optical Plankton Counter, VNIRO Model Trap 7a, Technopole, Russia) and a plankton net in its center, was specifically designed to be used on small boats without a conductor wire, and may be handled even manually by two people. Additionally, it contains an Oxygen Optode, a CTD probe, and a fluorescence probe. All data are stored and pre-processed in a built-in submersible autonomous Datalogger (ISITEC, Bremerhaven, Germany).

The LOPC uses optical electronic sensors measuring 128 size classes in the range of 0.0 to 1.6 mm on the base of the shadow method. Particles within this range in the water column are considered to represent living plankton organisms. Plankton particles pass between the emitter and the photo receiver of the LOPC, their shadow sizes are recorded on the photo receiver. The associated software allows calculating biomass using the equivalent spherical diameters and shape coefficients for mass species. The LOPC is intended for the estimation of zooplankton concentration and size as part of CTD-probes mounted on undulating towed vehicles like PELSS. Besides, the LOPC may work autonomously mounted on buoys or platforms.

First investigations with LOPC within PELSS have been performed off Peru in May 2006 in the context of the CENSOR project (www.censor.name). The specifications of PELSS and first results regarding spatial distribution and small-scale patchiness of plankton are shown (Figure 1).

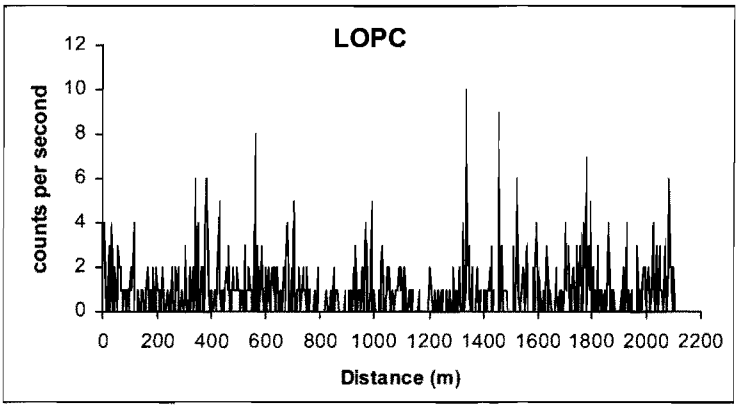

Figure 1: Example of LOPC data generated during a 20-minute subsurface (3 m) horizontal tow along a transect of approximately 2100 m inside Independencia Bay, Peru, in May 30, 2006.

HCS078 - Variations in benthic and planktonic foraminifera from laminated sediments off the coast of Peru

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Keywords: Dissolution, Foraminiferal record, Laminated sediments, Oxygen minimum zone, Peru margin.

Variations in abundance of foraminifera preserved in marine sediments provide a record of environmental and ecosystem change in the ocean that extends beyond instrumental records. The development of dysoxic environments generally favors the preservation of the calcium carbonate tests of benthic and planktonic foraminifera as well as the temporal sequence of sedimentation in the form of laminated sediments. PALEOPECES is a multidisciplinary group of researchers aiming to reconstruct past changes in ocean and ecosystem structure from sediment cores taken off the coast of Peru. We present results of variations in abundance of foraminifera from a box core taken off Pisco, Peru in 2004 (at 299 m. depth) (Fig. 1) and discuss the implications for reconstructing environmental changes.

Foraminifera were quantified from the >125 um fraction of vertical sampling intervals ranging from 0.2-0.7 cm based on the laminated structures of the sediment. The record of foraminiferal abundances is dominated by periods of presence or absence of planktonic and benthic foraminifera for periods of several sampling intervals to sections of the core spanning over a century in duration (Fig. 1).

A major portion of the variability in the abundance of foraminifera can be attributed to effects of dissolution for several reasons: 1) direct observations of dissolution in parts of the tests of benthic and planktonic foraminifera, 2) periods of absence or nearly total absence of all planktonic foraminifera, which are known to be abundant in surface waters off of Peru, 3) periods of absence or nearly total absence of all benthic foraminifera, although several taxa are abundant in dysoxic waters, 4) observations of varied abundances within a sedimentary slump that represents an instantaneous deposit but later had differential exposure to pore waters.

Intervals of foraminifera preservation show noteworthy variations in species composition. There is a trend of increasing relative abundance of *Bolivina seminuda* throughout the period of enhanced preservation since about 1850. Because *B. seminuda* is well adapted to low oxygen concentrations (Bernhard and Gupta, 2000; Paez et al. 2001) this trend suggests a continued decrease in oxygen concentrations throughout the 20th century. Such a trend of decreasing oxygen is consistent with other proxies indicating increasing productivity, such as total organic carbon shown in Fig. 1, and decreasing oxygen since an apparently abrupt change in the mid 19th century. Furthermore, the enhanced preservation after about 1850 is also best explained by reduced oxygen concentrations in bottom waters.

The shift from total dissolution of foraminifera towards preservation, followed by a continued trend of decreasing oxygen concentrations suggests an important shift in the interstitial chemistry of sedimentary pore waters that can vary with water mass and changes in acidity, alkalinity, and oxygen associated with organic carbon flux. This change occurs at the same time as a multitude of other proxies of surface productivity and sedimentary characteristics (Fig. 1). Thus the foraminiferal record provides an additional line of evidence from the PALEOPECES effort indicating that centennial-scale shifts can occur in the biogeochemical environment of the Peruvian coastal upwelling system.

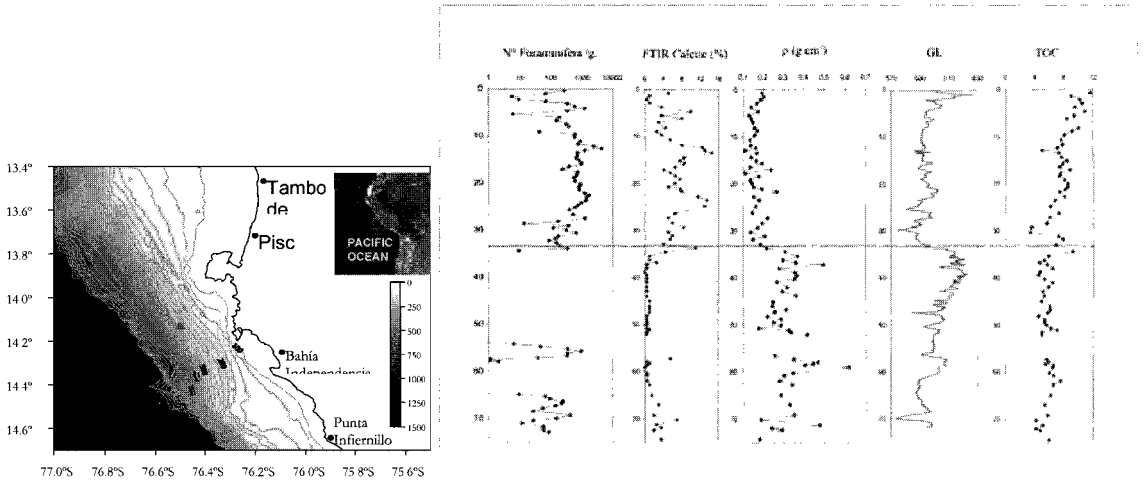

Figure 1. Left, Location of boxcore B0405-06 (red triangle, 14°07.90 S, 76, 30.10W, 299 m depth) off the central-south Peruvian coast. Bathymetric contour lines are in 25m intervals from 100m to 500 m, and in 100m intervals from 500m to 1500m depth (Gutiérrez et al., 2006); right, Downcore time series of total number of foraminifera (benthic and planktonic), % Calcite from FTIR (Fourier Transform Infrared spectrometry), dry bulk density (ρ (g cm^{-3})), grey level (GL), and total organic carbon (TOC), in the boxcore taken off Pisco.

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HCS097 - Investigating Internal Variability in the Northern Benguela Current Region – A Modelling Approach

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Keywords: Benguela Current System, Comparable systems, Internal variability, Ocean modelling

This study focuses on the internal variability of the Northern Benguela Current System and the Angola Benguela Front (ABFZ) using a regional model run for 32 years and forced with monthly climatologies of QuikSCAT winds and NCEP/ NCAR reanalysis fluxes. The ABFZ is an important system boundary separating the tropical current system from the Benguela upwelling system. Any changes in the intensity or meridional shifts of the front may potentially affect local fisheries and/ or rainfall variability over the bordering land masses.

Model results suggest that anomalous northward (southward) positions of the Angola Benguela Frontal Zone are connected to anomalous intensities of the front. A mechanism is suggested whereby anomalous northward shifts of the Angola Benguela Frontal Zone are associated with an anticyclonic circulation pattern in the area that shifts the frontal system towards the north. This anomalous circulation also forces changes in coastal upwelling that in turn drive anomalous upper ocean temperatures, which act to enhance the meridional temperature gradient. This mechanism appears to be most effcient during austral spring and summer.

Interannual variability within the front is investigated and is found to be connected to periodic westward propagating anomalies of the large scale sea surface height. It is suggested that oceanic instability processes are mainly responsible for this wave-like motion. A comparison between internal variability near the Angola Benguela FrontalZone and other modes of variability suggests that internal variability could at times account for the same amount of variability induced by El Niño-Southern Oscillation, and for up to 20% of the variability apparent during major warm events in the South East Atlantic such as Benguela Niños.

HCS099 - Heat balance of the oceanic surface layer in the Eastern South Pacific and Panama Bight areas

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Keywords: Eastern South Pacific; Heat balance; Mixed layer; Panama bight; Seasonal cycle; Sea surface temperature.

Introduction- The seasonal cycle of heat budget contributes much to the total variance of oceanic and atmospheric variables and is one of the essential keys for understanding the evolution of the global climate system. Yet little attention has been paid particularly for investigating the terms of heat balance of the oceanic surface layer (net surface heat flux across the air-sea interface, short wave radiation that penetrates through the base of the mixed layer, net longwave radiation, advective heat fluxes in zonal and meridional direction and vertical heat advective fluxes) in the Humboldt Current and Panama Bight areas. We complete this need by investigating the changes in the heat balance of the oceanic surface layer, at seasonal time scales, in order to explain the sea surface temperature (SST) and gain an improved understanding of their characteristics and spatial patterns. In this text, we only presented the annual mean climatolology as an advance of the work.

Data and methodology- The area under consideration goes from 9°N-to-40°S and extends eastwards from 100°W to coastal South America. The data used for this analysis is as follows:
-Monthly climatologies of the heat fluxes and meteorological variables published by da Silva (1994) and the Southampton Oceanography Center (Josey et al., 1999), hereafter referred as DaSilva and SOC, respectively. Both databases comprise in situ data and their horizontal latitude x longitude grid resolution is 1° x 1°.
-Surface currents with a horizontal grid resolution (lon x lat) of 1° x 1° based on monthly composites from 1993 to 2005, from NOAA's Ocean Surface Current Analysis - Real Time (http://www.oscar.noaa.gov). This data includes geostrophy, Ekman dynamics, and buoyancy effects. Monthly climatologies of the surface currents were computed over this time period.
-Monthly climatologies of vertical attenuation coefficient (downward irradiance at 490 nm, K490) on a horizontal resolution 4-km from http://oceancolor.gsfc.nasa.gov/SeaWiFS/ and monthly climatologies of the mixed layer depth on a regular 2°x 2° grid published by Montégut et al. (2004). Both datasets were interpolated to1° 1° x 1° grid.
The processes that control SST will be investigated by estimating the heat budget (air-sea processes) of the surface and mixed layer. The mixed layer heat balance equations are:

$$Q_t = \rho_o C_p H \frac{\delta T}{\delta t}, \quad (1)$$

$$Q_o = Q_{short} + Q_{lon} + Q_{lat} + Q_{sen} \quad (2)$$

$$Q_{adsorb} = Q_o + Q_{pen}, \quad (3)$$

$$Q_{pen} = -0.45 Q_{short} e^{-\gamma H}, \quad (4)$$

$$Q_u = -\rho_o C_p H U T_x \quad (5)$$

$$Q_v = -\rho_o C_p H U T_y \quad (6)$$

$$Q_{ocean} = Q_u + Q_v + Q_w \quad (7)$$

$$Q_w = Q_z + Q_{ent} \quad (8)$$

When the ocean gains heat, the surface flux terms are positive. The density of seawater, ρ_o, is 1022.4 kg m^{-3}, and the heat capacity, C_p, is 3940 J kg^{-1} $°C^{-1}$. Here, Q_t, is the rate of heat storage, and H, the mixed layer depth. The net surface heat flux across the air-sea interface, Q_o, and the net surface heat flux absorbed by the mixed layer, denominated absorbed heat flux, Q_{adsorb}, will be computed according to equation (2) and (3), respectively, where Q_{pen}, is the short wave radiation that penetrates through the base of the mixed layer. Here, Q_{short}, is the shortwave radiation that enters the mixed layer, Q_{lon}, is the net flux of longwave radiation, Q_{lat}, is the latent heat flux, and, Q_{sen}, is the sensible heat flux and will be obtained from the databases. Q_{pen}, will be estimated by applying equation (4), where, γ, is the k490.
The computation of the advective heat fluxes in zonal direction Q_u, and in meridional direction Q_v, requires the knowledge of the temporal horizontal temperature gradients T_x and T_y, as well as the horizontal flow field (*U, V*). Temperature gradients will be computed from SOC and DaSilva databases. The oceanic terms, Q_{ocean}, are the sum of advectives terms (7), where Q_w, is the vertical advective flux and representing entrainment, Q_{ent}, and vertical diffusion, Q_z, and will be estimated as a residual between the Q_{absorb}, Q_t and Q_{ocean}.

Results- The annual mean climatology analysis of the surface heat fluxes show that in average in the study area, Q_o, only contributed to a warming of the mixed layer (43 W m^{-2} in average) with a maximum in the equatorial band between 0°-5°S (~100 W m^{-2}). On the other hand, if we performs a ranking of the surface heat flux that contributed to the cooling the mixed layer, it is lead by the vertical advective flux (40% that correspond to -24 W m^{-2}), followed by the penetrative heat flux (38% that correspond to -23 W m^{-2}), the advective zonal heat flux (14% that correspond to -8 W m^{-2}), and finally the advective meridional heat flux (8% that correspond to -5 W m^{-2}). Q_{pen} was minimum (~-30 W m^{-2}) in the Panama bight area, the equatorial band and approximately in the area occupied by the South Pacific Anticyclone (centered about

28-31°S, west of 85°W). For the rest of heat fluxes showing areas of cooling and heating; Q_v presents a very interesting and particular minimum (< -50 W m^{-2}) close to the coast about 5°N and between 20°S-to-30°S,while Q_u is loosing heat (about -40 W m^{-2}) in a extensive band between 5°S to 25°S. Q_w is nearly a mirror of Q_o, and presenting also here an interesting maximum close to the coast about 5°N and another close to the coast between 20°S-to-30°S (Fig. 1).

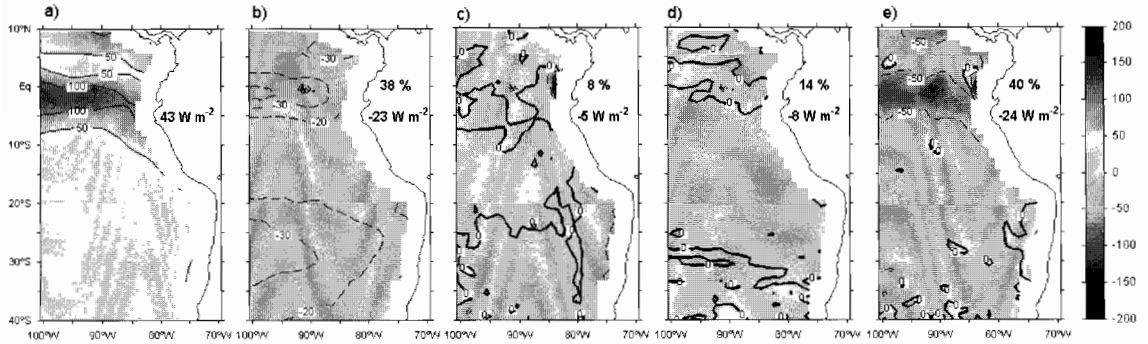

Figure 1. Annual mean climatology of the heat balance of the oceanic surface layer in the Eastern South Pacific and Panama Bight areas. a) Q_o (SOC database), b) Q_{pen} (SOC database, c) Q_v, d) Q_u, and e) Q_w. Units are in W m^{-2}; the right color bar applies to all panels. In the right of the panels b), c), d), and e), are showed the mean surface fluxes area with their respective mean percentages when contributed to cooling the mixed layer, and in a) only the mean surface flux area.

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HCS108 - How interannual-to-decadal changes of the Humboldt Current are associated to large-scale changes of the Pacific ocean/atmosphere?

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Keywords: El Niño, Decadal, Subtropics, TOPEX

Sea level and wind observations between 1980 and 2005 are used to study the relationship between the changes in the Humboldt Current and the Pacific ocean/atmosphere system. Depending on the strength and eastward extension of the El Niño events along the equator, warm waters propagate along the coast of South America and weaken the Humboldt Current. For the 1997-1998 strong event, the weakening of the cold current is quite clear at 15S (Fig1). It is even visible as far South as 40S. A simple coupled model of the tropical Pacific Ocean atmosphere is used to study how each El Niño event observed since 1980 is unique. When the model is forced by observed winds (FSU), it reproduces remarkably well the warming event and the associated weakening of the Humboldt Current.

This model was actually used to study the series of El Niño/La Niña events observed since 1980 as a large scale ocean/atmosphere system. The 1986-87 event was not a coastal event; the sea level rise which hardly reached the Peruvian coast was much weaker and did not go further south. The 1991-92 event was not coastal either: the relaxation of the trade winds took place in the central Western Pacific, the 1993 event aborted while a major event developed in 1994 in the Indian Ocean. The 1982-83 event is another case of strong coastal Niño event which affected the Humboldt event. By contrast to the 1997-98 event which was triggered from the West, the 1982-83 event started from the eastern Pacific. Before TOPEX launch in 1992, we use the surface dynamic topography relative to the 400dbar level as a proxy to sea level.

Data and model over the period 1980-2005 are used to study the large scale processes which make El Niño events be strong and coastal like in 1982-83 or 1997-98 and what makes them start from the East or from the West. It was found that the specificity of each event is a function of the charge and discharge of the equatorial Pacific by the subtropics (Perigee and Bollinger, 2006). The charge/discharge, measured by the sea level averaged over the whole basin between the eastern and western boundaries of the Pacific, in the North (5N-20N) or South (5S-20S), gets accumulated in time and it is the combination of Westerly Wind Bursts with the decadal oceanic trends that triggers or not events from the Western Pacific (Perigee and Cassia, 2000). The variations of the time accumulated charge of the North Pacific are clearly opposed to those of the South Pacific between 1980 and 1998. It was found that this is no longer the case since 1998: while the North is accumulating charge between 1998-2005 that resembles that of the 1982-1990

period, the South keeps on increasing charge significantly more than ever. The strong rising trend of the South started back in 1990.

In addition to the charge signals derived from the XBT-TOPEX data, we computed the sea level in Sverdrup balance with the FSU winds. Results are quite clear. There is a remarkably good agreement between the two charge signals (XBT-TOPEX with FSU) in the North for the entire period 1980 to 2006, and in the South for the period 1980 to 1998. This is all the more remarkable as the two charge signals come from totally independent data sets. Starting 1998, the South is charging very drastically according to TOPEX, whereas it is discharging according to the FSU winds. Why is that so? Part of the departure from the Sverdrup balance is explained by the oceanic exchanges between the Indian and the Pacific oceans via the Indonesian Throughflow, the variations of the latter do impact on the growing or collapsing of El Niño events (Florenchie and Perigaud, 2001). But the strong present trend needs an additional explanation. Can it be due to what is happening South of the tropics in the Pacific?

Actually for the strong 1997-1998 event, TOPEX allows to trace the signature of the equatorial event further South than the tropics, it can be traced as far South as 40S. In addition to the interannual signal associated to El Niño, TOPEX/Poseidon/ERS/Jason/ENVISAT data allow to study the region in detail. Results indicate that the Humboldt Current South of 20S undergoes a significant weakening trend since 2000 (Fig1 bottom). QuikSCAT winds are being investigated both locally and over the entire Pacific ocean to find an explanation for this trend which is not of equatorial origin. We know from the coupled tropical model that depending on the large-scale ocean/atmosphere balance between winds and sea level in the South and North subtropical Pacific, warm events develop and extend southward to impact the Humboldt Current or decay before reaching the coast of America. But in return, does the Humboldt Current South of the tropics contribute to the sea level trend of the South Pacific (Fig3 bottom)?

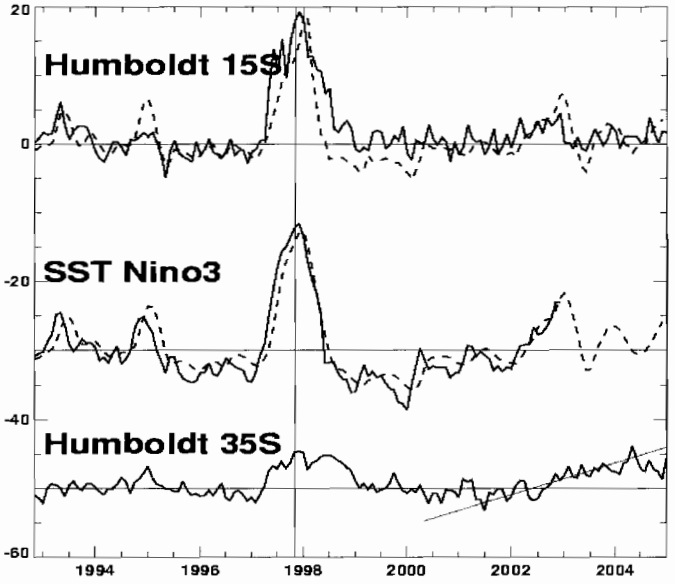

Figure 1. Times series of (Top): sea level anomalies across the Humbold current at 15S from observations in plain or model in dashed. (Middle): SST Niño3 index, observations in plain and model in dashed, (Bottom): Sea level anomalies across the Humboldt Current at 35S from TOPEX/Poseidon/Jason/ERS/Envisat.

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HCS132 - A modeling study: Does high frequency ocean-atmosphere interactions do affects intraseasonal oscillations?

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Keywords: El Niño, intraseasonal oscillations, MJO

In the present work, intraseasonal oscillations, emphasizing the MJO and the Rossby wave, are studied, by coupling an intermediate complexity model named QTCM (QuasiEquilibrium Tropical Circulation Model) with a slab mixed layer ocean model (SMLOM). The SMLOM was used to rectify the time evolution of the specified sea surface temperature (SST) as a function of the Heat Flux balance. This rectification was done at the atmospheric model integration time step, at every twenty minutes. In this way, high

frequency correction allows us to have a systematic ocean-atmosphere interaction at time scales shorter than Equatorial inertial period (~1.5days) at this assymptotic limit the coupling by Heat Flux balance is consistent. Experiments are conducted with the coupled/non-coupled model integrated for a period that runs from January 1990 to December 1999, so the El Niño 1997-98 was included in the simulations. Several Convectively Coupled Equatorial Waves were isolated with the use of the space-time spectral analysis. A common metric between model results and observations is ensured by using the same spectral regions, equivalent depths and noise/signal separation used in previous observational studies. The general results showed that the coupling here used is a modulating factor acting mainly over intraseasonal scales without altering so much the mean. The coupling acted preferentially in the representation of the intraseasonal modes with eastward propagation, increasing its variability and its propagation mainly over the Maritime Continent. It is suggested that the very efficient way of the QTCM to project vertically atmospheric boundary layer perturbations was the responsible of the effect of the coupling on intraseasonal time scales.

HCS138 - Intraseasonal to annual propagating variability in a medium-resolution regional model simulation of the South Eastern Pacific

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Keywords: Extra-tropical Rossby wave, OMZ

The oceanic variability of the South-Eastern Pacific is peculiar in that the coastal variability off Peru and Chile connects the equatorial Kelvin waves to the extra-tropical Rossby waves at a variety of timescales, from intraseasonal to interannual. The off-shore propagating variability may participate to the extension of the Oxygene Minimum Zone (OMZ) in this region know to be the most productive of the world. Here, we present the results of a medium resolution, eddy permitting regional model simulation for the eastern south Pacific. The model is forced with observed climatological fluxes during 5 years. Our objective is to investigate the intraseasonal to annual propagating signal in the model and understand how the energy is transmitted both from the open boundaries along the coast and to the inner basin and from the coastal zone to the off-shore ocean. Assuming O_2 concentration as a passive tracer, we also wish to estimate to which extend the OMZ variability can be related to the zonal advection of O_2 concentration by the extra-tropical Rossby wave.
Comparison with available observations indicates that the model mean state is realistic enough to further investigate the characteristics of the propagating variability along the coast and off-shore. The simulated sea level anomalies are first compared to the TOPEX/POSEIDON satellite derived data. Despite mesoscale features are not well resolved by the model, the simulated variability has a pattern in rather good agreement with the observations with a comparable decrease of the variability from the coast to the open ocean and southward. A vertical mode decomposition of the simulated pressure field is then carried out. Results indicate that the sea level variability projects to a large extend on the first three baroclinic modes, with an eastern extension of the variability from the coast for the gravest mode of the seasonal cycle (figure). The semi-annual cycle associated variability is more concentrated near the coast and exhibits less consistent off-shore propagating characteristics than the annual cycle. The intraseasonal variability display peaks in the inner basin between 33°S and 15°S and a minimum in a 'shadow zone' just off-shore, between 27°S and 17°S. The higher the mode order, the more to the North the location of maximum variability consistently with the triggering of extra-tropical Rossby waves equatorward of the critical latitudes. Analyses of the seasonal propagating variability indicates that it is forced both locally by the annual cycle and remotely at semi-annual timescales by the equatorial variability. On the other hand, westward propagating characteristics of the intraseasonal variability results to a large extent from wave interactions processes and modal dispersion. Results of sensitivity experiment to the wind stress and boundary forcings indicate that a large part of the off-shore intraseasonal current variability off central Chile is associated to the equatorial forcing. It is suggested that the seasonal westward expansion of the OMZ in that region is associated to the advection of low O_2 concentration by the extra-tropical Rossby waves.

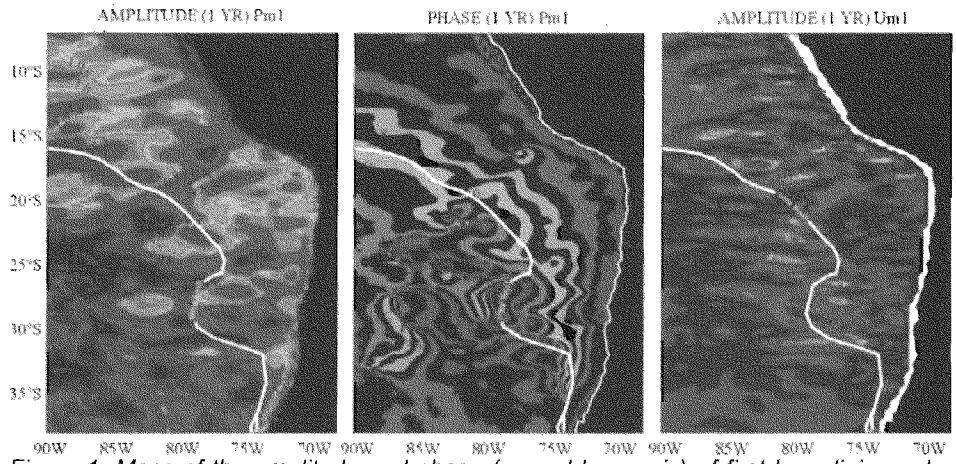

Figure 1. Maps of the amplitude and phase (annual harmonic) of first baroclinic mode contribution to the simulated sea level anomalies (units is cm). The amplitude of the annual harmonic of the corresponding zonal currents is displayed on the right panel (unit is cm/s). The thick white line correspond to the mean position of the O_2=1 mL/L iso-line at 300 m.

HCS157 - Fish scale preservation and Scale Deposition Rate during the last two hundred years in a coastal upwelling system of northern Humboldt Current, Mejillones bay, Chile

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Keywords: Fish scales, Marine sediment, Upwelling, Mejillones Bay, Chile

The Punta Angamos upwelling system (23°S) is known as one of the most productive marine regions off the Chilean coast. Mejillones del Sur Bay, which forms part of this system, acts as a center of sedimentary deposition for the abundant biological productivity of the zone. This bay is located off the world's driest desert (Atacama), and thus material of continental origin which reaches coastal sediments in the area is limited solely to wind-transported particles. Primary productivity measurements in this bay have given average annual production of 1070 g C m^{-2} y^{-1}, while dissolved oxygen profiles measured over an annual cycle showed that, at depths greater than 50 meters, oxygen is depleted which strongly restricts the presence of benthic macrofauna (Gonzalez et al., 1998). These factors have favored the rapid accumulation of diatomaceous organic-rich sediments, in which there is very little bioturbation. These characteristics are ideal for the reconstruction of local paleoceanographic conditions at the scale of the last centuries and millennia (Ortlieb et al., 2000).
In this environment, fish scale records were analyzed from both a spatial distribution (12 surface sediment samples recovered between 15 m and 120 m water depth) and a temporal perspective (42 cm sediment core). Biogenic remains were sorted, using a batch of sieves from 63 to 500 microns mesh size. Fish scales were identified and counted from the material retained in the 500 micron mesh size sieve. The chronology of this core was established from a CF-CS model based on excess ^{210}Pb profiles and further confirmed by radiocarbon ages corrected for local reservoir effects, yielding an average sedimentation rate of 1.67 mm y^{-1}; and an estimated age of 1740 AD for the base of the core. Based on sedimentation rates, scales abundance and area of sample we estimate the Scale Depositional Rate (SDR) which permits to interpret variation in term of fish population abundance.
In general, were observed a good preservation of scales in sediments of Mejillones bay and the dominance of three species; anchovy (*Engraulis ringens*), sardine (*Sardinops sagax*) and jack mackerel (*Trachurus symmetricus murphyi*). The former are the most abundant, in superficial sediment as well as downcore. Bathymetric segregation was observed in scales preservation within Mejillones bay. Sardine scales were more abundant in shallow zone (between 10m and 60 m water depth) while anchovy scales were more abundant in deeper zone (> 60 m water depth) (Fig. 1, left). Possibly, this situation is related to a more coastal behaviour of sardine population distribution and a more pelagic distribution of anchovy populations. The nearly anoxic conditions of the water column and the hydrodynamic conditions of the bay (Valdes & Ortlieb, 2001) favored the preservation of fish scales in the sediments, with higher surface abundances at the same depth stratum where the sediment core was collected.
Figure 1 shows the SDR records for anchovy, sardine and jack mackerel from the Mejillones sediment core, which marks a secular increase of fish scales, probably linked to a more intense upwelling activity which generated nutrient availability. The change in biomass, starting by an increase of sardine

abundance at 1850, followed by an increase of anchovy abundance at 1860, may reflect a decrease of SST reaching colder conditions around 1860. A short period with moderately enhanced SDR also took place just before the secular shift, from ca. 1830 to 1850.
Since 1860 the anchovy SDR followed a multidecadal pattern of variation, with periods around 30 years until the present, and the highest SDR were reached in the late nineteenth century, overlapping partially with the period of highest anchovy SDR. Low SDR values followed this period until 1975, and then SDR values increased again up to the present.

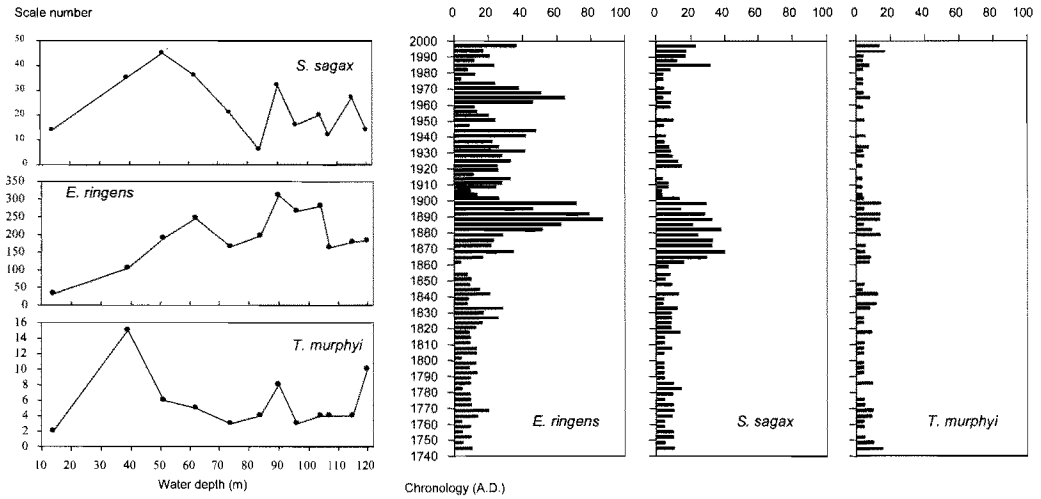

Fig. 1: Abundance of scale in surface sediment (left) and SDR in core sediment (right), in Mejillones bay.

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HCS162 - Regional atmospheric circulation simulations in Chile during October 2000: upwelling impact of mesoscale wind variability forcing a regional ocean model

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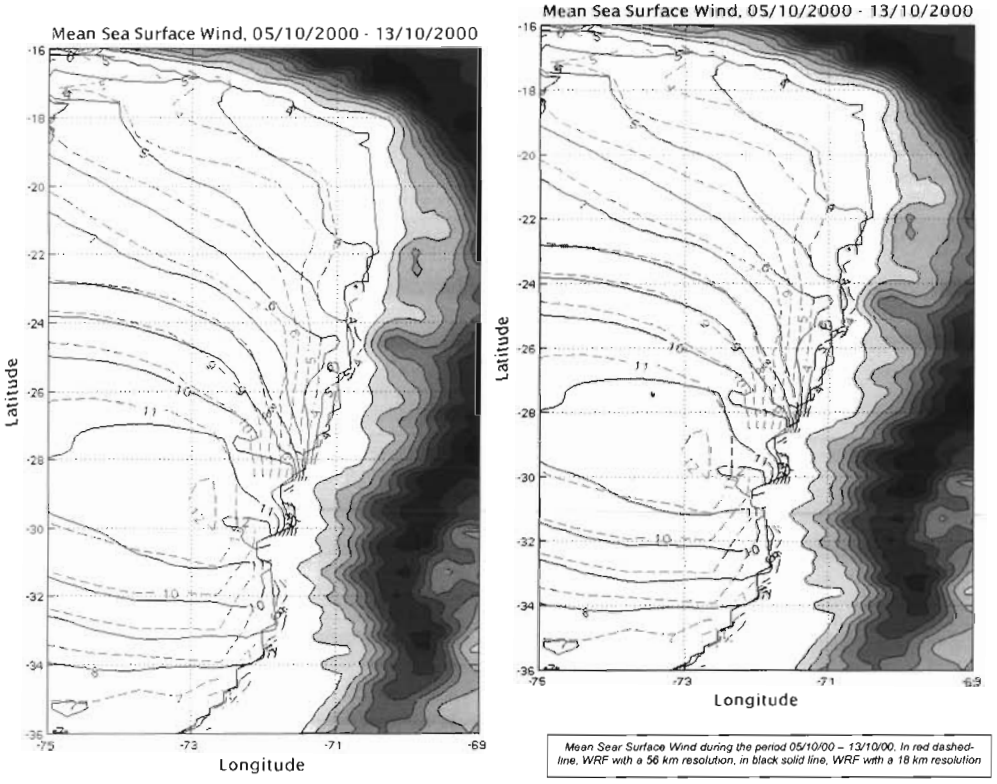
Keywords: Atmospheric circulation, Coastal Jet, Mesoscale, Regional Models, Upwelling

The study of regional oceanographic processes has undergone considerable development in recent years due to the expansion of in-situ observation networks, the increasing availability of satellite data, and the development of high resolution numerical models. Coastal zones are of special interest in regional applications as they are often the place of intense ocean mesoscale circulations which play a key role in coastal and deep-ocean exchange. In the case of the South American (SA) coastline, the regional wind-driven upwelling is modulated by ocean disturbances originally in the equatorial Pacific. Thus, an accurate representation of the atmosphere is likely to be important in studies seeking to evaluate coastal to deep-ocean transfer and to clarify the mechanisms associated with coastal wind variability.
In this study we use the WRF (Weather Research and Forecasting) regional atmospheric model to simulate the near surface atmospheric circulations along the SA coast between 15°S - 40°S using a multiple nested domain with grid spacing as low as 6 km. Simulations were performed for a sustained coastal jet event in October 2000 during which there was significant atmosphere-ocean interaction. A comprehensive validation of the model against in-situ meteorological and QuikScat satellite observations show that WRF was able to adequately simulate the low level winds in the vicinity of the coastline. However, while the model was capable of producing a well developed marine boundary layer (MBL), the

altitude of the MBL was significantly underestimated, as has been noted on prior studies using the MM5 model (Muñoz and Garreaud, 2005 ,Garreaud and Muñoz, 2005). The spatial and vertical resolution was found to have a significant impact on the accuracy of the simulations, with higher resolutions generally giving superior results. We also present the results of preliminary experiments in which atmospheric fields produced by WRF at various resolutions were used to force the ROMS (Regional Oceanic Modelling System) ocean model in simulating coastal upwelling processes.



Mean Sear Surface Wind during the period 05/10/00 – 13/10/00. In red dashed-line, WRF with a 56 km resolution, in black solid line, WRF with a 18 km resolution

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HCS165 - Introducing a 3-D Visualization tool for Oceanographic and Marine data

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Keywords: 3-D visualisation, oceanographic data,

Marine ecosystems represent a complex network of numerous interconnected physical and biological components. Results from different field investigations and modelling studies provide us with a special challenge when several components are to be understood and seen in relation to each other. Visualising the interplay between different aspects of an ecosystem more holistically adds a complementary perspective to the more specialised, detailed and quantified knowledge scientist possess. Even with only three components like plankton distribution, temperature and ocean currents the understanding of how these components link up in tree dimensional space is not trivial. Statistical analysis can provide quantitative knowledge of correlations and interconnections but managers and scientists working multidisciplinary would often benefit from a more intuitive and synthesised representation of data. The use of visualization tools can help scientists and managers better achieved this and thereby improving the overall understanding of the ecosystem.

We present here such a visualisation tool (MareMaid3D) utilizing the Silicon Graphics Open Graphics Library (OpenGL) to display various oceanographic and marine data sets in tree dimensional space. The software can run on an ordinary modern laptop computer and requires no expert user level. MareMaid3D is interactive and enables the user to move around and close into the various data sets, changing the camera view and perspective. The camera can be set to fly along survey lines or user defined paths. The main purpose of MareMaid3D is to visualise various oceanographic and marine data sets within a common 3-D geographical framework based on latitude, longitude and depth in order to directly and intuitively view spatial and temporal relationships. MareMaid3D is able to animate data sets through time, synchronised in

accordance with their date and time of day. The system is scale independent, where the scale is given by the resolution of the data sets provided. Given latitude and longitude positions, data of any part of the world oceans can be displayed. The different type of data which can be visualised include bathymetry, CTD measurements, acoustic measurements, survey trajectories or paths of tagged fish/mammals, model data of plankton/fish distributions and a number of oceanographic data including temperature, salinity, current, ice and several biological distribution fields. In Figure 1, three different examples of three different data types at three different scales (1000 km, 100 km and 10 km) are shown. The left image simply shows a large-scale representation of the bathymetry west of Peru. The second image show a line of ctd stations in relation to bathymetry and temperature fields from oceanographic models. The third image shows an acoustic survey. The three examples illustrate how MareMaid3D can be used in its simplest form, plotting one type of data, and in an integrated way synthesizing different data sets. We will present this software as a general visualization tool for different marine ecosystems, providing examples from the Humbolt current ecosystem and other oceans. We will put focus on how different data within the same area at the same time of year can be visualize in order to better shown their relations and dependencies.

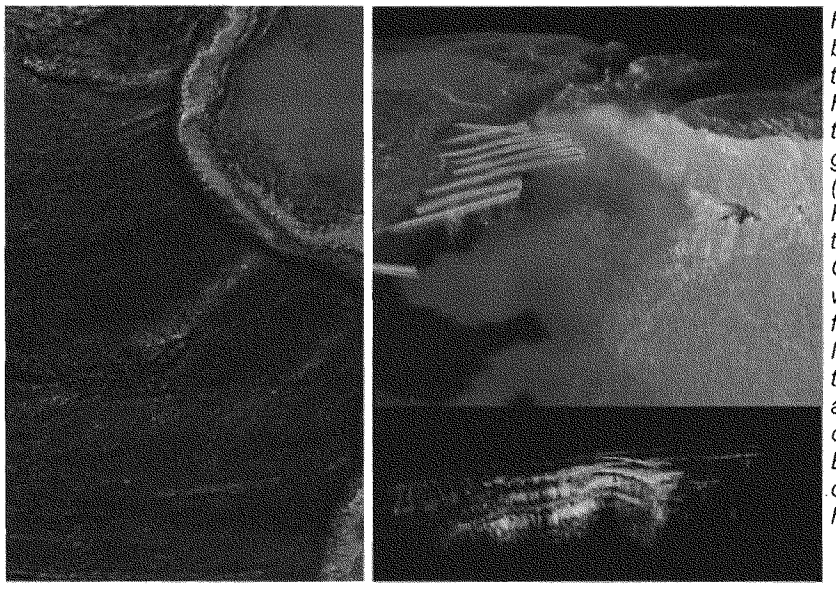

Figure 1. Left: The bathymetry west of Peru in the northern part of the Humbolt current, based on the "etopo2" 2-minute gridded global relief data set (www.ngdc.noaa.gov). Top Right: Example of temperature profile from CTD measurements together with modelled temperature field at 400 m in May in the Norwegian Sea, seen from the North. Values above 3°C are masked away to be completely transparent. Bottom Right: Visualisation of an acoustic survey on herring without bathymetry.

HCS198 - Modelled and observed variability of the atmospheric circulation the Peruvian Current System: 2000-2005

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The coastal upwelling of the South Eastern Boundary systems is critically dependant on the characteristics of the local equatorward atmospheric circulation. Resolving the mesoscale variability of the heat and momentum forcing is a top priority issue for modeling the oceanic regional circulation in these regions. Here we analyzed the outputs of two regional atmospheric models, the Fifth-Generation NCAR / Penn State Mesoscale Model (MM5) and Weather Research and Forecasting (WRF) that were run over the Peruvian Current System (PCS) [0N-19°S; 83°W-68°W] from November 2000- October 2005. Wind data as derived from the satellite QuickSCAT was used as a benchmark to assess the realism of the simulations for a variety of timescales: daily, monthly, seasonal, annual and interannual. The focus was on how the models resolve the cross-shore gradient of the surface circulation, which is directly related to the upwelling rate, and the along-shore propagation of the curl anomalies. The MM5 models simulate a realistic southwest mean flow throughout the coastal zone (figure 1) with a marked semi-annual cycle (maximum amplitude in summer and winter). Wind stress curl estimates are comparable in the models and the observations. However the amplitudes are smaller by ~25% for the models for the coastal (open ocean) zone as compared to the observations. These differences are attributed to the mesoscale dynamics resolved by the models but not by the Quickscat data (½ ° of resolution, figure 1). In particular, the observations exhibit a purely anticyclonic circulation near the coast, whereas the models simulate an anticyclonic circulation over the off-shore ocean and a cyclonic circulation near coast. This results in a more realistic coastal circulation as revealed by the comparison with meteorological *in situ* measurements. A 2-D spectral analysis shows that the spectral power density of the observations is comparable to the model outputs, with a dominant peak at the annual period and weaker contribution at periods of 2,5-3

months. The comparison between the two model simulations indicates the coastal mesoscale atmospheric circulation should intensity coastal upwelling variability.

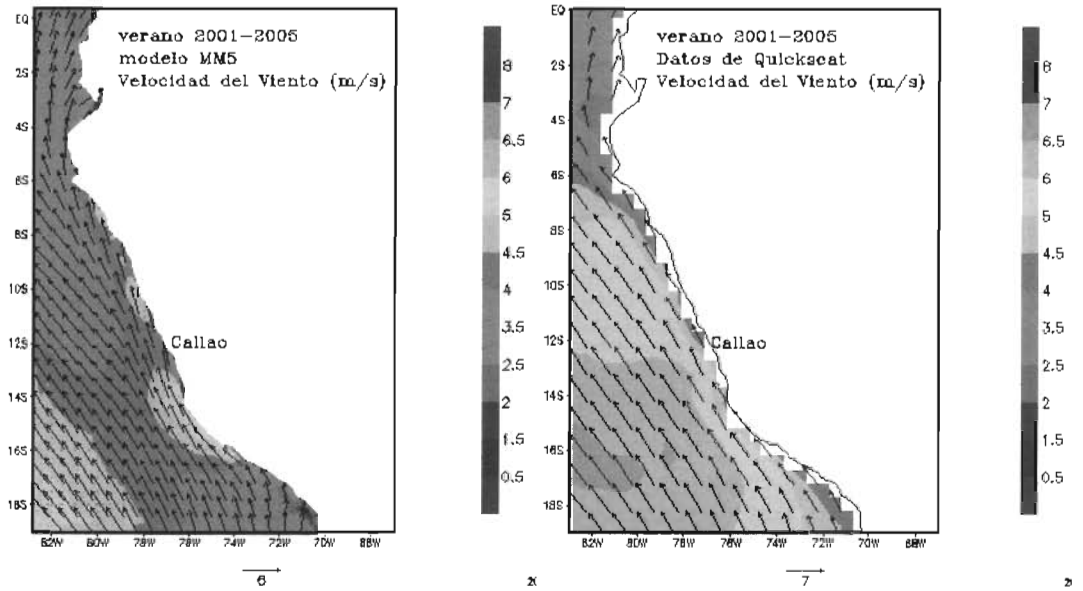

Figure1. Left, wind speed average, MM5 model; right, wind speed average, Quickscat.

HCS202 - Southward subsurface flow off the Peruvian coast (southward extension of the Cromwell Current)

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Keywords: Southward Extension of the Cromwell Current, El Niño events, Perú coast

The southward subsurface flow off the Peru coast, is related with the Southward Extension Subsurface of the Cromwell Current (ESCC), among the 3 - 14° S, inside the 60 nautical miles, based on geostrophic calculations, the time series of the mean depth the 15°C isotherm (1961-2005) and of the mean oxygen (1980-2005).The geostrophic flow toward the south, calculated in the sections off Paita, Pta. Falsa, and Chicama, shown clear changes mainly summer and autumn seasons of the South Hemisphere, with a surface flow superimposed in the summer related with the propagation toward the Peru of the equatorial Kelvin waves more evident during the El Niño events. The time series the mean depth of the 15° C isotherm, along the coast, shows the biggest depth in January and May-June and being more surface in October-November; depths bigger than 100m are strongly associated with the ESCC, and with oxygen range1.0-2.0 mL/L; besides the presence of the 15° C isotherm, is associated with the demersal fishing between 3-8° S.

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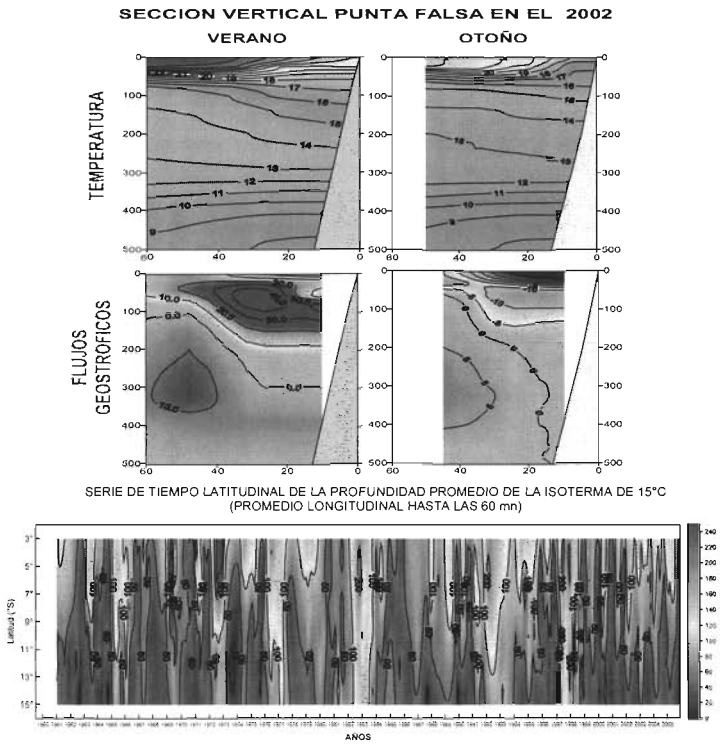

HCS206 - Monthly sea surface salinity by marsden squares off the Peruvian coast (1960-2004)

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Keywords: Equatorial region, Oceanic area, Salinity, Subantartic region.

In this study, data of sea surface salinity (SSS) from all the national and international cruises that were performed from 1960 to 2004 between 03° and 18° S and between the coast and 86° W were analyzed. Maps of monthly and seasonal averages per Marsden Squares (MS) were prepared, as well as latitudinal and longitudinal time-series charts. The results of the analyses indicate that the surface layer off the Peruvian coast presents the following water masses: a) waters from the Equatorial region, which normally are located north of 05° S; b) waters from the northern boundary of the Subantartic region, that feed the Coastal Cold Waters, which are projected from south to north between 20 and 60 nm off the coast; and c), and waters from the subtropical region, which approach to the coast mainly in summer. On average, the Peruvian SSS present values from 33.2 to 35.6 ups in summer and from 33.8 to 35.4 in winter, that can vary significantly due to ocean-meteorological events, topographical effects, fluvial input, etc.

In terms of seasonal averages, during summer low salinity waters (<34.0 ups), generally located north of 03°30' S, show a moderate projection to the south, surpassing the 04° S (Máncora). Meanwhile the Equatorial Surface Waters (<34.8) can reach the 06° S (Punta Falsa). By the other hand, lower Salinities than 35,0 ups, related to Coastal Cold Waters are present in a coastal fringe between 18° and 8° S; north of 8° S these waters are projected to the west. The Surface Subtropical Waters (35.1-35.5 ups), are present in the oceanic area south to 07° S.

During winter, the Equatorial Surface Waters (<34.8 ups) are found around the 04°30' S (north of Talara), while the low salinity waters (<34.0 ups) are only found, if present, off Caleta La Cruz (3°30' S). This pattern is mainly due to the intensification of the South Trade Winds in winter that also causes a displacement of the isohalines to the west, resulting on the 34.4 ups isohaline as the one of highest value south to 12° S.

There were determined monthly haline anomalies during some El Niño (EN) events off the Peruvian coast, especially the 1982-83 EN and the 1997-98 EN. During these two events, there were recorded anomalies between 2.0 and 3.0 ups around 06° S, due to the strong projection of low salinity waters to the south. These anomalies diminished during the advance of the waters to the south. There were also recorded high positive anomalies in the previous and following months to EN events, when the Subtropical Waters are present very close to the coast.

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HCS219 - Simulations over the Peruvian Andes using a Regional Climate Model with Sub-Bats scheme

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Keywords: Regional climate models, sug-grid aggregation, peruvian Andes, precipitation, air temperature

One of the limitations of the numerical models with medium resolution is their restrained ability to represent the physical processes in the surface layer in regions with complex topography. For these cases, it would be required to run the model with high resolution, which involves a greater computacional cost. For this reason the implementation of sub-grid scheme (Giorgi et al 2003) could represent a solution to improve the ability of the regional climate model (RegCM) to reproduce regional aspects of the climate, even with a meddium resolution, for domains with sharp ocean-land contrasts or with very complex terrain.
The temperature and water vapor disaggregation over the Alpes (Giorgi et al. 2003), using subgrid-scale topography and land use scheme, showed some improvement in the simulation of the rain and snow. The application of RegCM3 with sub-BATS scheme over Peruvian Andes, the Caribbean and East Europe are discussed in Fernadez et. al (2006), where the model with sub-BATS scheme showes better result for the Alps.
In present work, we analyse with more detail the effects of using sub-grid topography over the peruvian Andes, where the RegCM3 default configuration usally produces wrong output, specially in the precipitation field, generating a lot of grid point storms.
The main objective of this paper is to test the regional climate model (RegCM3) ability to reproduce the air temperature and precipitation fields with medium resolution (50km) over the Andes using sub-BATS scheme. The initial and boundary conditions were taken from the NCEP/DOE reanalysis II data sets. Preliminary results of one month simulation over the Peruvian Andes are iscussed.
In this study we used the RegCM3 model, which is a hydrostatic limited area model, with finite-difference discretization and sigma vertical coordinate. The main characteristics of the model are described in Pal et al., (2006).
The Cumulus Parameterization Scheme (CPS) used was Grell with Fritsch-Chappell (Gfc) and with Arakawa-Schubert (Gas) closures; over the ocean the Zeng PBL scheme was used to calculate the near surface fluxes. The horizontal resolution was chosen as 50km, covering 71 (E-W) by 54 (N-S) grid points in Rotated Mercator projection, and 18 vertical sigma levels until 80 hPa (top of the model. Two set of simulation were compared: (a) the default that use BATS surface scheme; with the model horizontal resolution of 50km; (b) the sub-BATS scheme where the near surface variables (air temperature, moisture and precipitation) were desagregated in 5 grid points, implying a 10 km horizontal resolution for the surface scheme.
The initial and boundary conditions were taken from NCEP/DOE reanalysis II. Sea surface temperature was obtained by interpolating the monthly averaged values of Reynolds. The monthly climatology of air temperature and precipitation, developed by the Climatic Research Unit (CRU) of the University of East Anglia and GPCP were used to verify the model results. The experiments were done for the year defined as extreme cases of drought and very rainy periods which caused some impacts in the Peruvian Andes. The total period of simulation was one month including the model spin up. We choose January 1992 (dry year) and Juanuary 1994 (wet year).
The analysis of simulations were done for 3 subdomain: all domain, central and southern part of the domain (centered over the Titicaca Lake). The Figure 1c, using sub-BATS scheme, shows greater orographic effect over the tempeature than in BATS scheme (Figure 1b), that presents a somoothed temperature field.However, in the precipitation field Sub-BATS (Figure 2c) increases the systematic errors over the Andes of the BATS (Figure 2b), and more grid point storms are genereted. Almost the same results were obtained for the dry period (Juanuary 1992, Figure not shown).
In the future, more specific analysis for the Andes using different cumulus and PBL parameterization schemes will be done. Problaby it will be necessary to make some changes in the sub-grid scheme to get more realistic results.

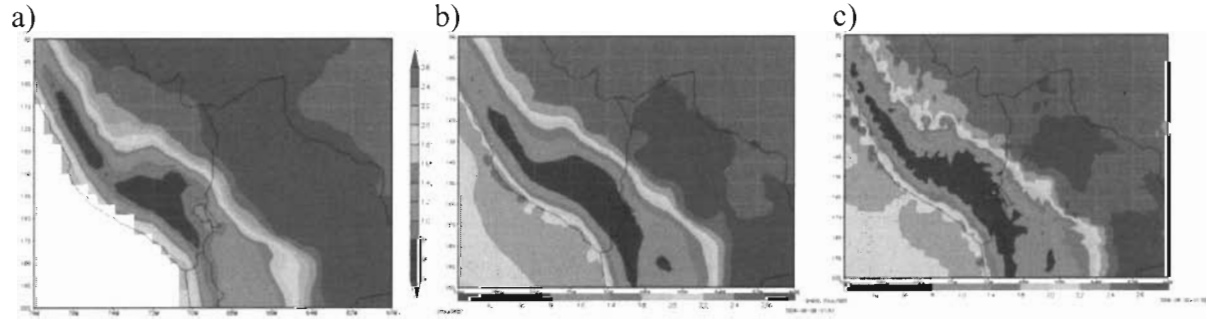

Figure 1. Monthly mean air temperature (ºC) for the southern peruvian Andes region for January 1994. a) CRU; b) BATS and c) Sub-BATS.

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Tuesday morning

HCS021 - The effect of oxycline and other oceanographic features on the vertical distribution of main species of coastal ecosystem off Peru during summers 2002-2006

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Keywords: school, anchovy, white anchovy, jack mackerel, munida, catfish, coastal pelagic ecosystem, diel vertical distribution, acoustics, patterns.

The coastal region or continental shelf along the Northern Humboldt Current System is characterized by the presence of a shallow oxycline. Accordingly the marine life on the sea bottom off Peru is constrained to very shallow waters where the ocean-atmosphere dynamics provide good conditions for a high biological diversity. However, offshore, the diversity is limited just to pelagic species such as anchovy (*Engraulis ringens*), white anchovy (*Anchoa nasus*), jack mackerel (*Trachurus murphyi*) and pelagized bento-demersal species such as catfish (*Galeicthys peruvianus*) and the crustacean munida (*Pleuroncodes monodom*).

The diet distribution of the above listed species is vertically limited by the presence of the zone of minimum oxygen that often corresponds with the oxycline. Thus dissolved oxygen is likely to be the main determinant abiotic parameter in fish vertical distribution and spatial organization (Bertrand 2006). Other oceanographic features can also play a role in explaining the dynamics of diet vertical migration, like temperature and salinity. The largest contrasts between the characteristics of water masses regarding vertical distribution of studied species occur during summer when the highest nearshore contrasts are observed in temperature and salinity.

To study these aspects we used the acoustic information collected from scientific echosounders operating at two frequencies (38 and 120 kHz) during summers from 2002 to 2006. Acoustically observed fish schools have been identified and classified using image processing methods, species composition of trawls surveys and other identifying characteristics. Their morphological features were measured and associated with their geographical location. Additionally, the vertical structure of the ocean (oxygen, temperature, salinity) has been measured along key-transects periodically surveyed in Puerto Pizarro (3°20'S), Paita (5°S), Point Tur (6°S), Chicama (7°30'S), Chimbote (9°S), Punta Bermejo (10°30'S), Callao (12°S), Pisco (14°S), San Juan (15°30'S), Matarani (17°S) and Ilo (18°S).

The results show that during summers a vertical latitudinal stratification of oxygen exists, with the zone of minimum oxygen deeper in the north, and shallower in the south. Accordingly, the vertical distribution of anchovy tends to be wider in the north, while mania change their vertical distribution on a seasonal pattern particularly southward during summers, due to a strong dependence on the ox cline. Like these, other results have been obtained using statistical analysis like GAM and multivariate statistics, which confirm that oxygen, is the most important parameter to explain changes in the vertical distribution of some species though other oceanic features and intrinsic characteristics (like depth and distance from the coast) have a clear effect as well.

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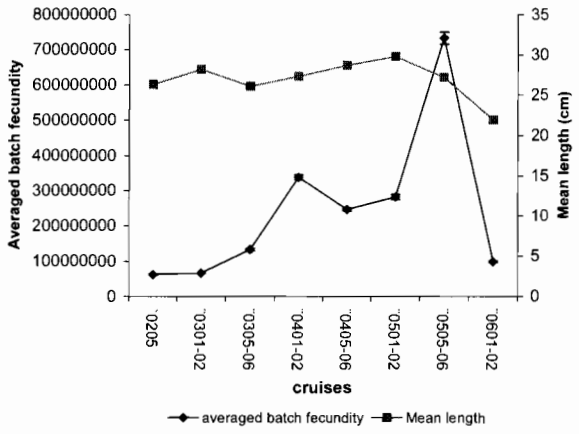

Averaged batch fecundity an mean total length of Peruvian hake *Merluccius gayi peruanus* (mature females) in different research cruises

HCS031 - Circulation in Paita Bay (Peru): a nested model study

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The Humboldt Current System is one of the most productive of the eastern boundary currents. The Peru Current system (PCS) ends on its northern part at approximately 5°S where the bay of Paita is located. This zone experiences the confluence of two important current systems: from the south, the Peru coastal current (PCC) flows equatorward, and from the north the Equatorial Undercurrent (EUC) flows eastward and poleward when it reaches the coast. This impacts the local circulation and consequently may affect the fishery and the anchovy nursery, despite the sea temperature is not as cold as in the rest of the Peruvian upwelling. Furthermore, this region is also a site of potential pollution, which requires active surveillance.

In order to investigate the physical processes associated to the regional circulation in the bay of Paita, the nesting of a high resolution model (ROMS, Regional Oceanic Model System) is designed. A fortran subroutine, AGRIF (Adaptive Grid Refinement in Fortran) was implemented to ROMS (Penven et al. 2006) in order to refine the grid and work with nested models up to 1/81 of a degree.

Such a high resolution configuration requires an adapted bathymetry which has been interpolated with Gebco data (1 minute of degree resolution) and some in situ data from local marine database.

In a first step the model is used to characterize the mean circulation inside the bay and its seasonal variability. Then the impact of the eddies located inside the bay on the retention or expulsion of water mass in the bay is investigated, using offline Lagrangian diagnostics. This allows, in particular through the observation of spatial and temporal evolution of passive tracers, to document the regional circulation and associated processes.

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HCS032 - Dissolved and particulate ATP in the Humboldt Current System off Chile

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Keywords: DATP, deep ocean, Humboldt Current System, microbial community, PATP.

This research is the first report of the vertical distribution of dissolved ATP (DATP) below 1000 m (down to 5555 m) in the oceans and the first comprehensive spatial report of particulate ATP (PATP) and DATP in the Humboldt Current System (HCS) off Chile. Our results indicate a heterogeneous vertical distribution of

DATP with an extensive high concentration layer at about 2500 m. All sampling was conducted during four oceanographic cruises between March 1999 and October 2000 in the HCS off northern and central-southern Chile. Samples were collected with Niskin bottles and subsequently filtrated; ATP concentrations were measured by the bioluminescence assay. PATP concentrations averaged 28.9 ± 52.0 and 14.9 ± 15.6 ng ATP L^{-1} off northern and central-southern Chile, respectively. DATP averaged 76.8 ± 97.9 ng ATP L^{-1} in the northern zone and 42.8 ± 40.2 ng ATP L^{-1} in the central-south zone. The highest concentrations of vertical PATP distribution were found in superficial strata to approximate depths of 100 m. A second PATP peak was found within the oxygen minimum zone coinciding with the secondary fluorescence peak and the DATP peak. DATP, on the other hand, showed higher variability across the water column and was the dominant ATP fraction in practically all strata. There is a trend to increase the concentration of integrated DATP in deep strata from the coast towards the oceanic zone, especially in the northern zone. A similar coastal-oceanic gradient was observed for PATP concentrations in surface waters of the central-southern zone. When all data from the HCS was analyzed as a whole, associations were observed between PATP and temperature and between DATP and salinity. In the surface stratum association between DATP and PATP were observed in the northern and central-southern zones. High correlations were found between PATP and autotrophic biomass (i.e. Chl - *a*, fluorescence) in the surface waters of the coastal zone off northern Chile. The Nazca Ridge (ca. 20° S and 80° W), could be playing an important role in determining DATP distribution in deep waters in the northern zone of the HCS. A conceptual model of the main processes involved in the release and removal of DATP in the water column of the HCS is proposed (Figure 1).

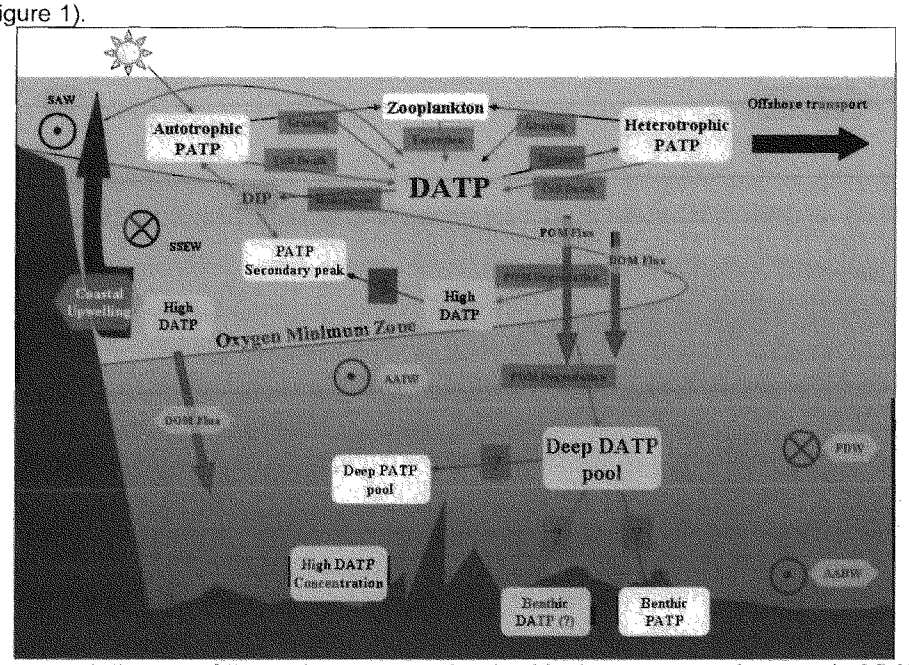

Figure 1. Conceptual diagram of the main processes involved in the release and removal of DATP in the water column of the HCS. Rectangles with rounded corners = standing stocks of compounds and biomass; Rectangles = processes involved in each of the arrows crossing them; Hexagons = physical processes or water masses; Black arrows = physical transport; Blue arrows = output processes; Red arrows = input processes; Green arrows = vertical transport of organic matter; DIP = standing stock of dissolved inorganic phosphorous. Question marks correspond to unknown or poorly quantified processes. For the sake of diagrammatic simplicity, the following DOM removal and release processes are not shown: polymer formation and uptake by metazoan, release by metazoan death, release from pellets or decomposition products from metazoan, and prokaryote lysis due to viral infection. SAW = Sub Antarctic Water; SSEW = Subsurface Equatorial Water; AAIW = Antarctic Intermediate Water; PDW = Pacific Deep Water; AABW=Antarctic Bottom Water.

HCS061 - Comparison of the functioning of the first trophic levels of the Benguela and the Canary upwelling system: A modelling study

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Keywords: Upwelling ecosystem, Canary, Benguela, plankton, modelling

In upwelling ecosystems, the food chain is relatively short with small pelagic fish (sardine, anchovy) feeding on plankton. With similar forcing and apparent similar primary production, the fish production (acoustic biomass evaluation) can differ a lot from one upwelling system to the other. The goal of this study is to investigate the role of the first trophic levels in these differences. How does transfer efficiency from autotrophic organisms to small pelagic fish might differ from one upwelling system to the other?
To bring insight towards this particular questioning, we use the Regional Oceanic Modeling System (ROMS) coupled to a biogeochemical model of phytoplankton and zooplankton to compare the functioning of the first trophic levels within two of the major eastern boundary currents, i.e. the Benguela and the Canary Currents. The sensitivity of the distribution and of the production of these oceanic regions has been tested with respect to the boundary conditions, the resolution, the atmospheric forcing as well as to the parameterization of biogeochemical processes. The differences between the two subregions will be discussed with regard to fisheries issues.

HCS077 - On the origin and maintenance of low oxygen waters along the coast of Peru

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The largest area of low oxygen in the world lies under the thermocline in the eastern tropical Pacific. The area of low oxygen extends from Central and northern South America across the eastern tropical Pacific as a tongue to either side of the equator. These tongues are divided by the higher oxygen water of the Equatorial Undercurrent (EUC) that flows eastward, underneath the SEC, on the equator. The oxygen minimum is formed by at least three processes: (1) Lack of ventilation, isolation from the atmosphere, and low oxygen content of source waters. It has been suggested that the meridional overturning circulation controls rate of ventilation of the eastern Pacific oxygen minimum, which is low during interglacial periods as at present. A permanently strong pycnocline and shallow mixed layer further isolate sub-thermocline waters from the atmosphere. Modeling studies suggest that the EUC contributes reduced oxygen source waters to the oxygen minimum because EUC oxygen levels decrease while crossing the Pacific; (2) Long residence time, with cumulative oxygen depletion. The eastern Pacific is an area of generally weak wind and is not penetrated by the subtropical gyres. As a result, residence time is long and oxygen depletion cumulates; (3) Decay of biological production sinking from overlying surface waters, depleting oxygen. In surface waters organic particles are created by photosynthesis, phytoplankton growth and the consumption of phytoplankton by animals. A fraction of these particles sink and decay below the thermocline. Decay depletes oxygen, and in the absence of ventilation, oxygen levels can fall to zero. Here we investigate the role of the EUC in the origin and maintenance of the low oxygen waters along the coast of Peru using observations from a set of cruises in the equatorial Pacific.

HCS083 - Non-linear univariate forecast of anchovy (*Engraulis ringens*) catches in the north area of Chile. A first non-seasonal approach.

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Keywords: fisheries, non-linear modelling, neural network, time series.

Taking into account the economic importance of the fisheries, it is necessary to know as much as possible about fish populations, which can undergo many changes in response to the commercial fishing. These include changes of abundance, total biomass, size-frequency distributions, age-structure, and spatial distributions. Fisheries science can use a wide set of mathematical and statistical methods for characterise these processes in attempts to understand the dynamics of exploited populations. The underlying assumption is that if we can understand the response of fish populations to different perturbations then we should be able to manage the fisheries according to our chosen objectives.
Forecasting biomass available for a fishery is a very interesting topic, because it plays a central role in management of stocks, preceding decision making (Makridakis et al., 1983). In fisheries management policy the main goal is to establish the fishing effort applicable in a concrete area during a known period keeping the stock replacements. For achievement of this aim, it is necessary to predict uncontrollable events, such as abundance changes. Forecasting of abundance changes is possible if catch past quantitative data are available and if the "assumption of continuity" is considered, that is to say, if some aspects of the past pattern will continue into the future. Apart from methods based on biological principles,

a variety of statistical techniques have also been used to fisheries forecasting. These methods are oriented towards the following: a) modelling on the basis of deterministic, regression techniques that explain changes in fishery variables in terms of changes in various biotic and/or abiotic variables, b) modelling on the basis of univariate time series techniques that treat the system as a black-box, viewed as an unknown generating process, and c) methods that synthesise the above mentioned two general approaches (Stergiou et al., 1997).

Significant progress in the fields of non-linear pattern recognition and system control theory have recently been made possible through advances in a branch of non-linear system theoretic modelling called artificial neural networks (ANNs) (Lek et al., 1996). In recent years, ANNs have attracted increasing attention from both academic researchers and industrial practitioners. Basically, the reason for their popularity is the powerful pattern recognition and flexible non-linear modelling capacity. ANNs have a great capacity to fit highly scattered data, far from normality, and produce powerful models from few data, thus providing reliable predictions.

In this paper, the principal aim is evaluate the ANN models for anchovy catch forecasting, analysing for it the general characteristics of fishing time series and identifying the possible error source in the model. Only non-seasonal autorregressive ANN models were used.

The anchovy monthly catches data are from the data base of the Fondo de Investigación Pesquera (FIP) de Chile project N°2003-33. The data show monthly catches during the fishing period from January of 1963 to December of 2002.

The best estimate was obtained when the catches of six five previous months were used as inputs, with two hidden layers and 10 nodes in each hidden layer. In this case, all the error magnitudes used were significantly good (R^2=0.83; Error mean=854.49; RMSE=21337.8; %SEP=38.7). Figure 1 shows the best ANN model regression between anchovy catches observed and estimated in the validation phase.

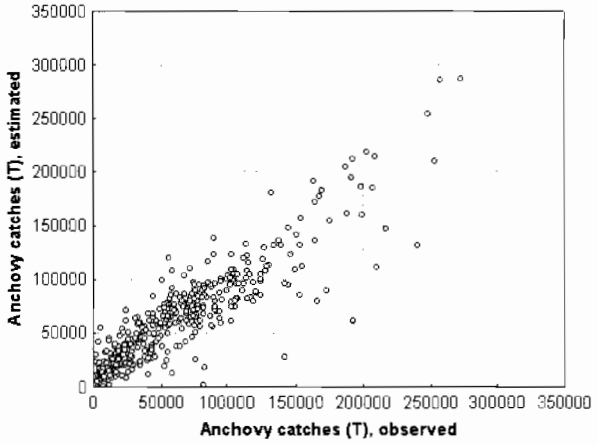

Figure 1. Regression between anchovy catches (Tons) observed and anchovy catches (Tons) estimated.

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HCS102 - Microbial biomass production and the metabolic relationship with the dissolved organic carbon of low molecular weight in the Humboldt Current System off Concepción (Chile)

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Key words: ATP-P, dehidrogenases, metabolism, microplankton, ZMO

The Humboldt Current System (HCS) corresponds to one of the most productive areas in the world oceans (Daneri 2000). This system is characterized by the presence of upwelling events and a permanent subsurface oxygen minimum zone (OMZ). During coastal upwelling events, the OMZ reaches the surface, generating cold filaments stretching over 100 nm long into the open ocean (González et al., 1998). Heterotrophic areas with high microplanktonic respiration (up to several times more than the carbon fixed by primary production) have been described in connection with these filaments (González et al. 1998). The

grounds for this uncoupling between primary production and the microplanktonic community respiration, as well as the metabolic-enzymatic adaptations of microplankton (< 100 µm) to these low oxygen conditions, remain unknown. This work shows results of two years of research in the metabolism of microbial community and its enzymatic response to dissolved organic carbon of low molecular weight (DOClmw). We determined the rate of microbial biomass production using the ATP-P production (Adenosine Tri Phosphate – Particulate; 0.22 µm < ATP-P < 100 µm) as a proxy and its relationship with the specific enzymatic activity of dehydrogenases involved in the catabolism of the microbial community inhabiting the water column off Concepción (36° 41'509 S; 73° 00'908 W), under oxic, suboxic (laboratory) and *in situ* incubation conditions. ATP-P production was induced using four carbon sources as DOClmw in logarithmic concentration (dose-response): glucose (carbohydrate), glycine (glucogenic amino acid), leucine (ketogenic amino acid), and oxaloacetate (carboxylic acid). No significant differences were found between incubation under oxic and suboxic conditions (laboratory) except in the case of leucine. For this amino acid, the induction of ATP-P synthesis was higher under suboxic than oxic conditions. The data sets of all the substrates used showed greater potential ATP-P production under suboxic than oxic conditions but the amount of ATP-P production seems to be more related with the initial inoculums used for incubation experiments than the chemical nature of the substrates used. The results of the potential enzymatic activities suggest that malate dehydrogenase (MDH) has the highest signal of NADH (Nicotinamide Adenine Dinucleotide reduced form) oxidization activity in the microbial assemblage. Furthermore, for all experiments, MDH activity had a significant relationship with ATP-P production. These findings suggest that the microbial community inhabiting the oxygen minimum zone has the same or greater potential growth than the community inhabiting more oxygenated strata of the water column and that MDH is the activity that best represents the metabolic potential of the community. Furthermore, the data set of specific activities of all dehydrogenases has a negative relationship with the ATP-P production (Fig. 1). When the equation in Fig. 1 is used to estimate the ATP-P production at t0 using the enzymatic activity at t0 in the original sample from the water column, and these values are transformed to carbon unit, the microbial production biomass integrated in the water column for the period winter-spring summer (2005-2006), rise to 1.65 kg C m-2 y-1 corresponding to 117% of the annual average of carbon fixed by primary production (PP) in the area reported by Daneri et al. (2000) (0.93 Kg C m-2 y-1). Our estimation of microbial biomass production is very close to the reported by Troncoso et al. (2003) of 1.82 kg C m-2 y-1 but using metil-3H-timidina. The values reported by Troncoso et al. (2003) corresponding to 24 % of PP in off Concepción area and until 94% of PP off Antofagasta area (northern Chile). Finally, the rates of microbial biomass production estimated using this new methodology are consistent with the uncoupling between primary production and the microplanktonic community respiration reported in this area of the HCS (González et al., 1998).

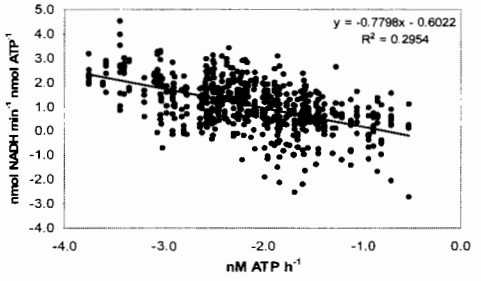

Figure 1. Relationship of the ATP-P production and the specific activity of dehydrogenases in the enrichments experiments ($p < 0.05$).

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HCS111 - Influence of physical and biogeochemical mechanisms on N_2O vertical distribution and its exchange towards the atmosphere in an upwelling zone

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Keywords: N_2O fluxes; upwelling system; nitrification, denitrification

N_2O concentrations and several physical and biogeochemical variables in the water column have been measured since August 2002 to April 2006 in a station off central Chile subject to a seasonal coastal upwelling during the austral spring and summer. In order to determine the physical and biogeochemical

component that result in N_2O fluxes towards the atmosphere, the water column was divided in three layers according to its physical and chemical structure (i.e., surface, middle and bottom water). Surface layer N_2O concentrations ranged from 6 to 130 nM, which 75% of the year presenting supersaturation (up to 1457% saturation) specially after a strong favourable-upwelling wind stress and instauration during the most of the winter. The middle layer (~20 – 40 m depth) generally associated with the oxycline have up to 250% of the surface N_2O concentration (up to 245 nM at 30m depth). This layer had a clearly seasonal cycle that was divided in 3 stages according with N_2O contents from low N_2O concentrations in austral winter (stage I) through "hotspot" of N_2O concentrations during spring and summer (stage II), coinciding with the lowest O_2 concentrations (ranged from 4 to 28 µM) and enhanced NO_2^- and NH_4^+ concentrations (up to 3.97 µM and 4.6 µM, respectively), to diminishing N_2O concentration in the early autumn (stage III). According with the AOU - N_2O and N_2O – NO_3^- correlations (r2 = 0.65 and 0.59, respectively), N_2O seems to be produced by nitrification, although a denitrification contribution is probably when the O_2 is less than 20 µM. Bottom waters also exhibited a seasonal pattern, different to the middle layer with high N_2O concentrations in winter (up to 48 nM, stage I), apparently driven by the sediment behaviour; an increasing N_2O concentration from spring to summer (stage II), and culminating in a N_2O consumption at the late summer and early autumn (stage III). Thus high unsaturations found near to the sediment (up to 40%) coinciding with periods of high organic matter accumulation and peaks of $S^=$ on surface sediment and anoxia (< 7 µM) in the water column could indicate a N_2O consumption by denitrification in the water column or even in the sediment. The N_2O production along the year seems to be responding to the oxygen concentration and the N_2O consumption is also responding to the O_2 concentrations but to N/P ratio too. These biogeochemical variables are driven to upwelling index and primary production. Consequently with the seasonal pattern of N_2O, the estimated air-sea N_2O fluxes presented low or negative fluxes during the winter (ranged from –9.8 to 20 $\mu mol \cdot m^{-2} \cdot d^{-1}$) and an increasing fluxes during the spring and summer (up to 195 $\mu mol \cdot m^{-2} \cdot d^{-1}$). The results presented here confirm the area as an important source of N_2O to the atmosphere with a mean N_2O flux of 31.8 $\mu mol \cdot m^{-2} \cdot d^{-1}$.

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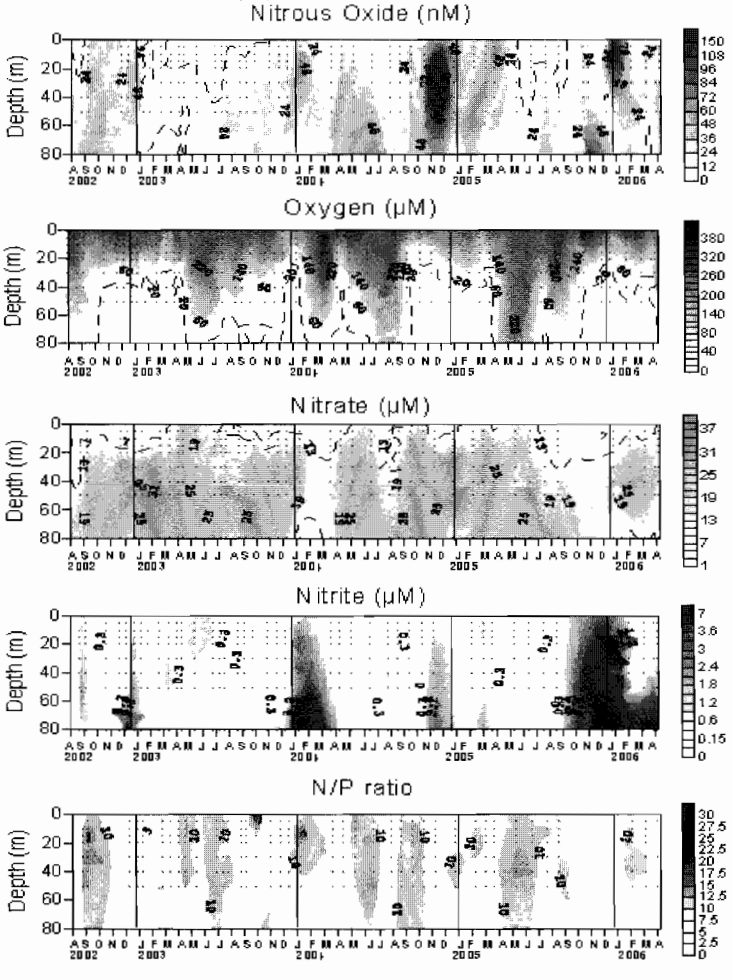

Figure 1. Temporal variability of vertical distribution of : a) N_2O concentrations (nM), b) oxygen concentration (µM) with 22.3 µM O_2 concentrations shown (dashed line); c) NO_3^- concentrations (µM); d) NO_2^- concentrations (µM); and e) N/P ratio at station 18. Data since August 2002 to April 2006.

HCS112 - Association between the SST bidecadal patterns and small pelagics biomass in the Humboldt Current Ecosystem

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Keywords: SST, Bidecadal, Humboldt Current Ecosystem, small pelagics.

El Niño Southern Oscillation (ENSO) is the most important mechanism of the coupled ocean atmosphere system in the Eastern Tropical Pacific (ETP). Links between ENSO and fisheries has been broadly established. However, biomass and climatic data are assumedly linked to changes over decadal variation. In that context, we explore an association between the SST bidecadal patterns and small pelagics biomass in the Humboldt Current Ecosystem. Monthly sea surface temperatures (SST) along the Peruvian coast between January 1950 and December 2005, and acoustic biomasses of anchovy (*Engraulis ringens*), sardine (*Sardinops sagax sagax*) and mackerel (*Scomber japonicus*) were analyzed. Links between ETP and Central Tropical Pacific have been found between the first principal component of coastal SST and the Oceanic Niño Index. We observed a significant relationship between low pass filtered indexes (0.33 in lag -37 months).Two variability periods: 1960-1980 and 1980-2000 in the ocean atmosphere system could determine change periods in the Humboldt Current Ecosystem (HCE). On the other hand, anchovy biomass data presented a high variability period in 1985-present. While 70-84 was a period of decline of anchovy, in contrast 1985-present was a period of recovery (Niquen and Alheit 2004) (Figure 1). The HCE is a complex arrangement of organisms and biogeochemical cycles in the spatial and temporal dimensions, where ENSO cycle is imposed over the interannual variability of HCE. Identification of low frequency physical signals could elucidate mechanisms supporting the abundance of anchovy in the long term. A bidecadal control in the HCE and in the abundance of anchoveta is suggested.

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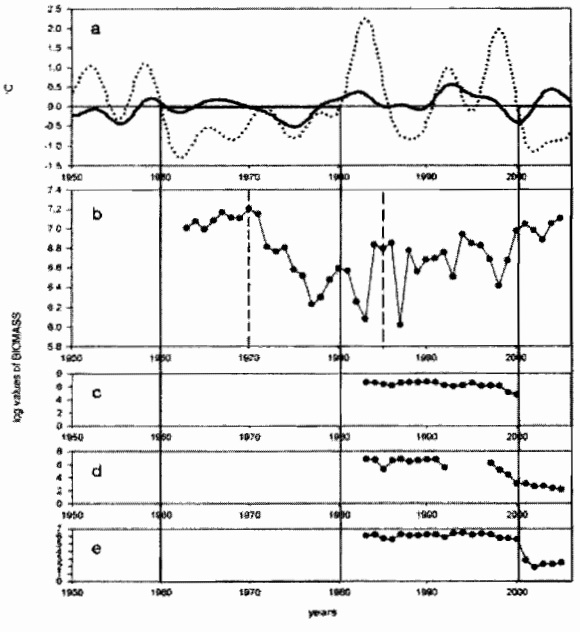

Figure 1. a. Low pass filter for Oceanic El Niño Index (solid line) and fist principal component of SST =86% of total variance for SST along Peruvian coast (dashed line). Log values of biomass of small pelagic: b. Engraulis ringes. c. Sardinops sagax sagax. d. Trachurus picturatus murphy. e. Scomber japonicus. The years of changes indicated by solid blue line for climatic frame and dashed blue line for anchovy biomass (sensu Alheit and Niquen 2004).

HCS116 - Succession and Coastal Nutrients Concentrations in Ancón Bay, Peru

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Keywords: anthropogenic effects; nutrients; Peru; rocky intertidal; succession.

Introduction- Anthropogenic nitrogen inputs to coastal zones from terrestrial sources have already resulted in the eutrophication and degradation of many coastal ecosystems (e.g., estuaries, bays, and inland seas) worldwide. This increase in nutrient loading is generally associated with shifts in the abundance and functional diversity of primary producers. Using an interdisciplinary approach (Menge, 2000), linking community processes to coastal oceanographic chemical parameters, we tested the hypothesis that even

in rich nitrogen areas, anthropogenic inputs may exert a major influence in intertidal community structure, and this influence is associated to the amount of the impact. To evaluate this hypothesis we described and compared the succession of intertidal benthic communities in four areas in a bay subject to urban anthropogenic impact, and assessed its degree of eutrophication.

Methods- Experiments were conducted in the rocky shore located at the south of Ancón Bay (11º46 S, 77º11 W), a protected bay in the central coast of Peru from November 2005 to February 2006. Part of sewage produced by the town of Ancón is discharged by a tube directly to the bay, in the intertidal rocky shore. Four sites were selected in the bay: Desagüe (Des), in the wastewater outfall, Punta Cruz (PC) ~300 m west, Playa Hermosa (PH) ~300 m east, and Muelle San Martin (SM) ~600 m northeast. In each site, 18 plots (12 x 12 cm) were cleared in the mid intertidal. Plots in each site corresponded to 6 replicates of three treatments: one complete exclusion of motile herbivores (made by a barrier 1 cm width of epoxy putty, painted with antifouling paint), one half barrier (an L-shaped partial barrier, as a control for the presence of barrier) and one un-manipulated open area. The percent cover of sessile invertebrates and algae and the density of motile animals were determined at the end of the experiment. All plots were photographed with a digital camera. To determine percent cover we used a digital grid with 64 evenly spaced dots covering the central 8 x 8 cm area of the plots images. We recorded the sessile algae, barnacles and mussels occurring under each dot. For motile invertebrates, we estimated densities by censoring four randomly placed 2 x 2 cm subunits in each plot image. All organisms were identified to the lowest possible taxonomic level. Some algae and invertebrates could not be identified to the species level and were combined into larger groups for some analyses. For statistical comparisons we chose the 6 most abundant groups: the green algae *Ulva* spp., the barnacle *Jehlius cirratus*, mytilids, two red algae, *Gelidium* spp. and *Chondracanthus chamissoi*, and bare space. To evaluate differences in the amount of nutrients between sites, three replicates of seawater samples were taken weekly from November to January at each site. Water samples were filtered (50µm) in the field and frozen. Nitrate, phosphate, nitrite and silicate were later analyzed.

Results- There were no differences in nutrients concentration among sites during the nine weeks sampled (Kruskal-Wallis test, $P>0,05$ for all comparisons). However, at each site, differences were found in nutrient concentration among weeks (Kruskal-Wallis test, $P<0,05$ for all comparisons), except for silicate at Des and SM (Kruskal-Wallis test, $P>0,05$ for both comparisons). No differences were found among sites neither treatments in the number of taxa established (two way Anova, $P>0,05$). At each site, there were no differences in percent cover of each group among treatments (Kruskal-Wallis test, $P>0,05$, data arcsin transformed). Differences were found in the percent cover among sites for all groups except for *Gelidium* spp. (Kruskal-Wallis test, data arcsin transformed, $P<0,05$ for all comparisons). For *Ulva* spp. percent cover in PH was lower than other sites. For mytilids, percent cover in PC was higher than other sites. For *J. cirratus*, the lowest percent cover in SM was different from PC and PH. Furthermore PH was different from Des, with intermediate percent cover. PH was the only site without *C. chamissoi*, this site was different from Des and PC. PH was the site with the lowest values of bare space, and was different from SM and Des (non parametrics Tukey-type test, $P<0,05$ for all comparisons). Three species of motile herbivores were found. *Tegula atra* was only present at Des, with a mean density of 12,21 ind/m^2. *Scurria* spp. was found at all sites except Des, with mean densities of 17,36 ind/m^2 at PH, 5,79 ind/m^2 at PC, and 10,81 ind/m^2 at SM. *Siphonaria* spp. was found at PH with a mean density of 3,86 ind/m^2 and in the same density at PC. Most of these herbivores were found in un-manipulated and partial exclusions areas, although *T. atra* entered in excluded plots at Des, as *Siphonaria* at PC.

Conclusions and Discussion- The lack of differences in nutrient concentrations obtained in the different sites may be due to water mixing that operate, in the scale of few hundreds meters, homogenizing water masses. The bay is object of an intense use by residents who recollect several intertidal invertebrates and algae species for consumption. This may lead to a decrease in herbivory pressure, and would explain the lack of differences in cover between herbivores excluded and non-excluded plots within each site. Nevertheless interactions among organisms may explain between-sites variations. The direct effect of limpet grazing in limiting algal abundance would explain the lowest *Ulva* spp. cover and the absence of *C. chamissoi* at PH, where the density of *Scurria* spp. was the highest. This can lead to the dominance of *J. cirratus*, released from inter-specific competition for settling space. PC and Des are proportionally more exposed to wave action than the other sites, and in PC was found the highest cover for mytilids. High wave exposure is a factor that have been pointed as beneficial for mytilids settlement. Another physical factor that distinguish PC and Des from PH and SM is the substratum nature, while PC-Des are rocky shores, PH-SM are seawalls. Although it is not clear yet how the type of substratum affects early colonization. Some other factors that control key ecological processes, as larval transport and particle delivery should be assessed at small scale to fully explain the observed differences among sites. Several species of the genus *Ulva* have been characterized in the literature as opportunist algae, proliferating in eutrophicated shores. In our study *Ulva* spp. was the alga with highest cover, this suggest that the intertidal assemblage of Ancón Bay is subject to an intermediate degree of organic enrichment (Díaz et al 2000).

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HCS125 - Nitrogen fixation in upwelling areas of the Eastern South Pacific (3°S - 16°S)

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Keywords: Nitrogen fixation, nitrogenase activity, Upwelling

The Humboldt Current System (HCS) and particularly the coastal area off Peru possess unique characteristics for studying the biogeochemical transformations of nitrogen due to the presence o fan intense upwelling regime able to sustain high primary production rates (Minas et al, 1990). In addition, this geographical area presents a permanent oxygen minimum zone (OMZ), reaching the euphotic layer.
Nitrogen (N_2) fixation was recently included among the sources for new production in oceanic waters. In the last decade, it has been linked to a wide variety of microorganisms including cyanobacteria and chemoautotrophic bacteria. Due to the high energetic cost of nitrogen fixation compared to NH_4 or NO_3, its study in marine environments has been restricted mainly to surface oligotrophic waters and no data exists for eastern continental margins in the southern hemisphere. The occurrence of nitrogen fixation in productive waters like coastal upwelling areas has been considered improbable, due to the high nutrient concentration and the possible role of NH_4 as a repressor for nitrogenase enzymatic system.
We performed experiments in the eastern South Pacific (15 Oct – 10 Nov 2005; (3°S - 16°S) using a highly sensitive isotope tracer technique ($^{15}N_2$) at different depths between the surface and 100 m depth. Samples were inoculated with $^{15}N_2$ (99%) and incubated on deck for 24 hrs. Incubations were terminated by filtration and filters recovered and dried at 60°C. Once in the laboratory, filters were analyzed by mass spectrometry (Finnigan delta-S mass spectrometer).
Nitrogen fixation experiments revealed measurable rates from the surface and down to 100 m depth (Fig. 1a, b), in presence of surface nitrate concentrations ranging between 1 and 20 □M and oxygen conditions going from 30 to 200 □M L^{-1}. Furthermore N/P ratios were generally well below Redfield values. Lower, although measurable, rates were obtained from dark-conditions experiments (Fig. 1a), supporting previous observations of N_2 fixation during the night (Montoya et al, 2004). Integrated N_2 fixation rates ranged between 3 □moles m^{-2} d^{-1} and 0.35 □moles m^{-2} d^{-1}, and represented up to 50% of N_2 fixation obtained in an oceanic station in the tropical north pacific (1.5 °N; 273.8°E). Gathering all data, fixation rates obtained represent up to 0.6% of global estimations for N_2 fixation and can sustain up to 3% of nitrogen lost by denitrification in the area (Codispoti et al, 2001).
This is the first report of nitrogen fixation rates in suboxic conditions, as well as the first report of this process in upwelling productive regions in the eastern South Pacific Ocean. We anticipate our observations to be a starting point in a re-evaluation of the distribution of nitrogen fixation in previously overlooked ecosystems, which can have significant influence in global N budgets. Our work will contribute to understanding how N_2 fixation can be involved in N budgets, even in one of the most productive region in the world which can sustain up to 10% of the world's fisheries industry.

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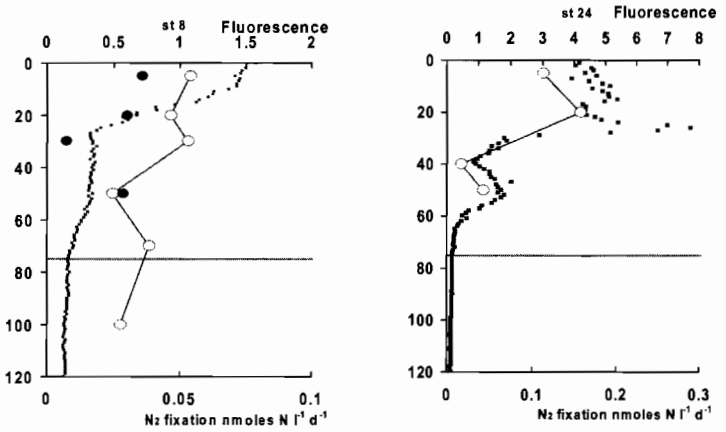

Figure 1. Vertical distribution of N_2 fixation rates at a) st 8 located near the coast (15.54°S; 285.35°E) and b) st 24 located offshore (12.25°S; 280.7°E). Grey line represents the base of the upper oxycline at the OMZ. Green squares represent fluorescence values. Open circles: N_2 fixation rates. Filled circles: N_2 fixation rates obtained from dark incubation experiments.

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HCS129 - How the Eastern South Pacific (ESP) Oxygen Minimum Zone (OMZ) off Chile could be maintained in the modern ocean?

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Keywords: Oxygen Minimum Zone (OMZ); Biogeochemical activity; Oxycline; Local maintaining; Low O_2 data; Chile.

Influenced by both climatic changes and environmental perturbations, the OMZs could extend during the next 100 years as a response to the increasing anthropogenic activities. The ESP-OMZ covering a surface of 5.9 millions of km^2 and representing more than 18% of the global OMZs, has been very little documented. Physical and biogeochemical processes maintaining this impoverished oxygen subsurface layer in an open extended oceanic area remain a mystery.
This study reports ultra low oxygen (O_2) data along the ESP-OMZ off Chile obtained during four cruises (North, 21°- Center, 30°S) and a fixed-point monitoring (South, 36°S) between years 2000 and 2002. These O_2 data allow the characterization of the Chilean OMZ vertical structure in the open ocean and the seasonal variability on the continental shelf. With a thickness of ~700±50 m and O_2 concentrations reaching values so low as <1 µM in the OMZ core, the Chilean OMZ in the three studied areas appears to induce a total O_2 deficit near the surface 2.5 and 1.5 times higher than for the more known OMZs of East Tropical North Pacific and Arabian Sea, respectively.
The maintaining of the intense Chile OMZ would be due to two mechanisms: i) a strong local remineralization, twice as large as found in the oxygenated ocean and which could contribute to the OMZ maintaining from 25% to 50%; ii) a preformation associated to a regional dynamical transport of O_2-impoverished (<40-80 µM) subsurface waters by the Peru-Chile Undercurrent (PCU). Because the O_2 consumption is 3 times higher in the oxycline than in the core, the oxycline is proposed as the engine of the local OMZ maintaining where most part of the remineralization takes place.
This oxycline role should be more important off Chile, because these OMZ is shallow between 5-20 m and 750 m, 5 times less deep than the Arabian Sea OMZ. The shallow oxycline intercepts the euphotic layer allowing a more efficiently O_2 consumption system probably due to simultaneous aerobic, anaerobic, photic and aphotic biogeochemical processes. The OMZ maintaining, at the oxycline, would be mainly due to aerobic processes, 70% of remineralization and 20% of nitrification, and 6% of photosynthesis and 4% of anaerobic re-mineralization only.
But, this OMZ biogeochemical maintaining at the oxycline could be intermittent. The highest biogeochemical O_2 consumptions, associated with the active OMZ phases, paradoxically occur when the oxygen is higher (ie the oxycline is less intense: <1 µM/m) and surface biomass is low (Chl-a<0.4 mg/m^3), as offshore. At the opposite, the O_2 consumption at the oxycline is low, or passive phases, on the shelf and in spring and fall, when O_2 availability is low (oxycline is strong: >4 µM/m) and carbon biomass is higher (Chl-a>1 mg/m^3). These results suggest that the OMZ intensity could be controlled by the O_2 availability, instead of the surface carbon biomass and productivity such as proposed in previous studies. This O_2 control helps to understand why, if the OMZ is observed in the three Chilean studied areas, its structure: i) off northern and center Chile, remains so intense and thick offshore even thought the biomass is 3 times less intense than at the coast; ii) on the continental shelf, forms in spring and persists until its erosion in the end of fall. The regional contribution of the OMZ preformation and destruction by dynamical transport needs both, ultra low O_2 data covering all the ESP area and to improve our knowledge about PCU, upwelling and low ventilation of the intermediate waters.
The highlighting of the different aerobic/anaerobic and photic/aphotic processes coexistence, more efficient for the O_2 consumption, has to be the first step to be performed in the future biogeochemical studies of the ESP-OMZ. This identification is that much more important since it will also contribute to the OMZs analysis as persistent traces of the primitive anoxic ocean in which the life appeared.

HCS133 - Variability of the community of macrobentos of soft bottom of the Peruvian Coastal Upwelling Ecosystem

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Keywords: EN, macrobenthos.

The purpose of this study is to determine the level of influence of the sign of El Niño (EN) upon interannual variability of the principal community parameters of soft bottom macrobenthos in a shallow area of Ancon Bay during 1981 to 2005.
To determine the level of influence of the sign EN upon the variability of density and biomass of macrobenthos of Ancon Bay, lineal regression was used, (previous filter of 13 months), between the first

components of PCA of density (1DEN), biomass (1BIOM) and of the average of sea surface temperature (TSM) from Paita, Chicama, Callao, Pisco and La Vieja Island (Ica). The first component of SST (1TSM) was analyzed previously by spectral analysis in order to identify significative variability cycles and to extract seasonal sign. The software PAST was used for the analysis.
Spectral analysis on 1 SST, previous extraction of seasonal sign showed that the sign of 4.98 years (p<0,01) was the most intense. Lineal regressions were significant for 1TSM and for 1DEN (r^2=0,42; p=0) as for 1TSM and 1BIOM (r^2 =0,46; p=0). It has been demonstrated that in the Pacific Ocean, the frequency of ENOS interannual sign is between 3 and 5 years (Tourre *et. al.* 2001) and that EN induces significant changes in the soft bottom macrobenthos of the central coast of Peru (Tarazona y Arntz, 2001). Nevertheless, only now we can demonstrate that EN sign would explain up to 40% of variability induced over density and biomass of macrobenthos community. This fact would suggest that EN sign also might modulate strongly temporary variability of other communities.
It is concluded that EN sign modulate strongly interannual variability of soft bottom macrobenthos. Besides, only long time biological series could allow us to explore modulation of biological response of this and others oceanographic variability cycles of low frequence reported for Peruvian Coast.

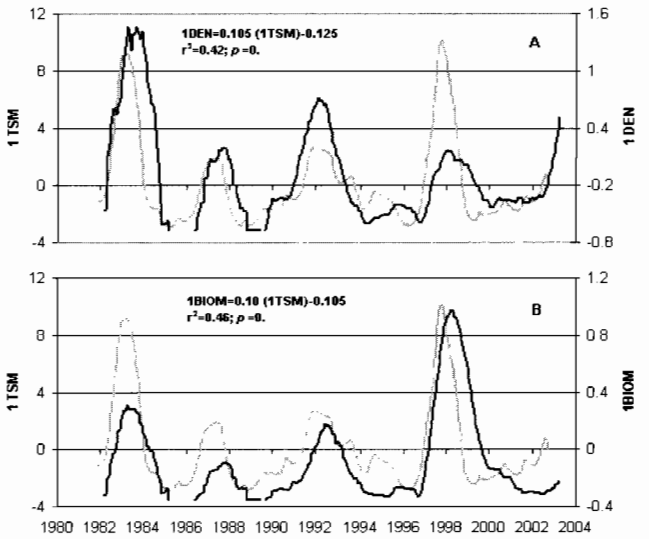

Figure 1. Modulation of the EN sign (1TSM: gray line) over (A) variability of density (1DEN) and (B) biomass (1BIOM) during the period 1981 to 2003.

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HCS142 - Spatial patterns and interannual variations of Dissolved Oxygen, Temperature and Salinity in Bahía Independencia, Pisco (Peru) during 1995-2004

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Keywords: oxygen, temperature, salinity, interannual variability, Bahía Independencia, Perú

Bhatia Independencies (14° 06'- 14°20' S, 76°00'-76°18' W) is a large (ca. 21 km long and 6.5 km wide), shallow bay situated within the Paracas national park in Pisco, Perú (Fig. 1a). This bay has an irregular sea-floor topography with a variety of habitats that provide spawning and nursery areas, including seagrass beds, sandy sediments, and rocky bottoms. Additionally, tidal mixing with open coastal waters rich in nutrients and high run-off of nutrients from guano bird colonies at La Vieja Island are key factors leading to high primary productivity in the bay. This high primary productivity results in high marine resources biomasses (e.g., Avalon, Mussels) and in important fisheries in the area. Understanding the effects of climate variability (e.g., El Niño) and resulting environmental changes is important for the sustainable use of natural marine resources. In this context, we describe hydrographic characteristics of Bahía Independencia from 1995-2004, including the large 1997-1998 El Niño.

Methods- Dissolved oxygen, nutrients, temperature and salinity data in surface and bottom waters were collected from surveys of the project "Evaluation of Concha Abanico (*Argopecten purpuratus*)" carried out by the Direction of Marine Invertebrates Evaluation (DEIM) from the Instituto del Mar del Perú (IMARPE). A total of 49 stations, which are distributed throughout the Bay with an average distance of 1 mn between stations (Fig. 1), were systematically sampled during the study period. Exploratory Data Analysis (EDA) was performed to identify stations having common patterns in time (Id stations, Fig. 1a).

Results- We present the results from the austral summer and early autumn's surveys in Figure 1b. The comparison between years in Fig. 1b shows that temperature ranged from 13.8 and 25.8 ºC in the surface waters. The average temperature in the surface was 18.75º C (18.37-19.13, 95% CI). The temperatures decrease in the bay from north to south, with a similar range in the bottom waters. The average temperature in the bottom waters during all the sampling period was 16.44 º C (16.08-16.80, 95% CI). The northern bay (North of 14º 13', including the influence of Laguna Grande) consistently had higher temperatures (> 20 ºC), than the south. Low bottom temperature and salinity values (35.085 ups, 35.070-35.100 95% CI) during most of the study period reflect an influence of Cold Coastal waters-CCW (34.8-35.1 ups, Zuta & Guillén, 1970). The highest temperatures (up to 25.8ºC) were observed during February 1998, in both surface and bottom waters. These high temperatures were coincident with high salinity values (between 35.275 ups and 35.494 ups) indicating the presence of Subtropical Surface Waters (SSW).

Dissolved oxygen, Fig. 1b also shows a clear spatial and temporal pattern reflecting the influence of local and large-scale processes. The dissolved oxygen concentrations ranged between 0.14–8.78 (mL L^{-1}), the average in the surface was 4.48 mL L^{-1} (4.21–4.75, 95% CI) and in the bottom waters 1.42 mL L^{-1} (1.26–1.60). Surface dissolved oxygen values in the north of the bay (up to 8.5 mL L^{-1}) indicate saturation conditions and are considerably higher than in the south (~3ml L^{-1}), which could result from different physical properties (temperature), biological influences as a higher productivity rates in the north. Oxygen levels in bottom waters are generally characterized by low concentrations (hypoxic conditions <0.5 ml L^{-1}) that could reflect the influence of CCW, and the oxygen deficiency that characterizes the coastal upwelling system. However, during austral summer period of 1998, as is expected under the influence of El Niño conditions, bottom oxygen levels increase (oxygen up to 2 mL L^{-1}). A positive significantly correlation was observed between oxygen and temperature values, temperature and water depth and also between temperature and salinity (v-p <0.05).

In summary, the chemical and physical results suggest:

- A clear spatial pattern appears which two different areas: the north with higher temperatures and oxygen concentrations and the south.

-A regular influence of coastal upwelling processes in the area. Temperature and salinity values during most of the study period reflect an influence of CCW, and the oxygen deficient conditions in the bottom waters that characterized the coastal upwelling waters off Perú.

-A strong influence of the 1997-1998 El Niño events, which resulted in drastic changes in the oxygen conditions, temperature and salinity in the area and show the presence in these latitudes of the Subtropical Surface Waters (SSW) influence.

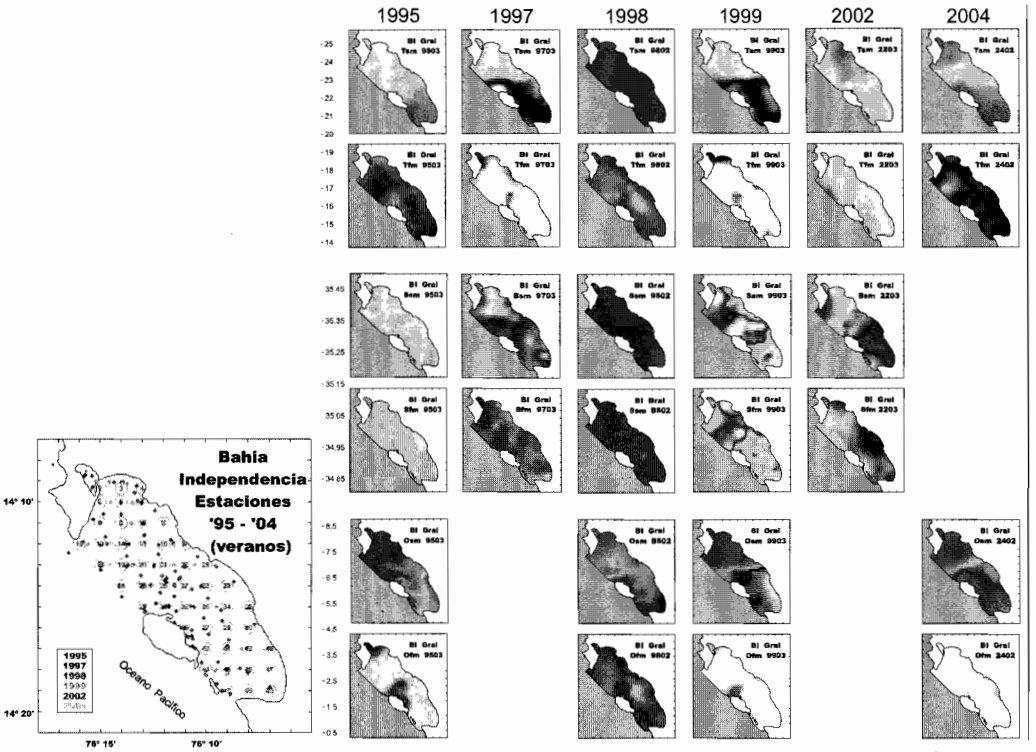

Figure 1. Study area - Temperature (º C), Salinity (ups), and Dissolved oxygen (mL L^{-1}) distribution in the surface (upper plots) and bottom waters (lower plots) at Bahía Independencia during 1995-2004 summer periods.

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HCS158 - Upwelling fronts and jets along the coast off Central Chile

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Keywords: Coastal Upwelling, Coastal Jet, Peru-Chile Current System,

Upwelling fronts are one of the most distinctive features along the Eastern Boundary Current Systems. During upwelling seasons these fronts are associated to a surface thermal contrast between cold, recently upwelled, coastal waters and warmer oceanic waters. These contrasts are clearly visible in satellite images of sea surface temperature (SST), which allow analyzing spatial and temporal variability. The upwelling front, together with an alongshore jet that commonly is associated to the front, acts as an important dynamical and biological boundary between coastal and oceanic waters. It may define a natural offshore boundary for the coastal ecosystem in upwelling regions.
In this work, SST images from NOAA satellites were used to study the seasonal variability of the sea surface thermal fronts associated with upwelling off central Chile (33°-40°S). Additionally, geostrophic velocity fields derived from satellite altimetry and cruise data were also used to analyze the structure of the coastal jet during spring 2004.
The mean offshore boundary of the upwelling front presents, in general, alongshore changes related to the width of the continental shelf. But between 35°-37° —a region characterized by the presence of a seasonal filament— the upwelling front extends several tens of kilometers seaward. Near the offshore boundary of the upwelling front Chlorophyll-a concentration decay to values smaller than 1 mg m^{-3}, while typical coastal values remain larger than 5 mg m^{-3} during the complete year. Mean SST distribution showed that Concepción bay, and especially Gulf of Arauco, both equatorial facing bays, facilitate the development of upwelling shadow areas.
An alongshore jet is present in both, satellite altimetry and cruise data and its location and estimated speed are quite consistent in both data sets. The jet is surface-intensified but is clearly visible near 200 m in the southern hydrographic transects (38°-37°S) and below 400 m in the northern transects (35.5°-36°S), where surface speeds are smaller. This jet advects low salinity waters toward the north, reducing the salinity of the saltier coastal water recently upwelled.

HCS159 - Seasonal and Interannual Variability of the Peru Undercurrent

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Keywords: Current Measurements, Model simulations, Peru Undercurrent, Satellite Altimetry, Seasonal and Interannual variability

Historical hydrographic cross-shelf sections data (1990-2006) from 5°S to 18°S off Peru, combined with coastal sea level, satellite altimeter data, Acoustic Doppler Current Profiler data and an equatorial Kelvin wave model are employed to investigate the seasonal and inter-annual variability of the Peru Undercurrent and its relationship to the equatorial Pacific. Three distinctive hydrographic features associated to the PUC are used, along with dynamic topography, to trace the mean path of the Equatorial Undercurrent and to investigate aspects of its seasonal variation. These features are the 13°C thermostad, the high-salinity core, and the high dissolved oxygen concentration.
In situ sea level data from 6 mareographic stations distributed alongshore Peru and temperature and salinity hydrographic data collected from the surface to 500 m depth in the 350 km band adjacent to the coast was used. Monthly and seasonal current fields were obtained using geostrophic approximation. These results were compared to ADCP measurements collected during some cruises of 2006 in order to validate the geostrophic calculation. These *in situ* data sets combined to the altimetric sea level are interpreted in the light of the estimates of the Kelvin wave amplitude along the equator as derived from linear model simulations and the SODA reanalyses. Results indicate that the propagating features as revealed by the *in situ* data are associated to the equatorial Kevin wave impinging at the eastern boundary of the tropical Pacific. The southward extension and amplitude of the PUC variability varies with the frequency of the equatorial forcing, the 1997-1998 El Niño imprinting the most dramatic change in the structure of the PUC. These changes superpose to some extent on the O_2 concentration pattern that exhibits a marked latitudinal heterogeneity; suggesting that the PUC participates to poleward transport of dissolved oxygen.

HCS172 - Atlas of Dissolved Oxygen, Nutrient, Chlorophyll and Primary Production off Peruvian Coast

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Keywords: dissolved oxygen, nutrient, chlorophyll, primary productivity, Perú

The South East Pacific region and the currents system in front of the Peruvian coast dynamics is closely related to the macro-scale circulation (atmosphere-ocean). Among the main characteristics there are the seasonal upwelling, intrusion of warm oligotrophic oceanic waters, the presence of a minimum oxygen zone, a high variability on circulation and the water masses influence during el Niño events as well as the cold periods, La Niña. In consequence, the study of the environmental variability in these areas is a key topic and the historical data may be a useful tool for the description and determination of this variability, and to obtain patterns on chemical and biological features of this region based on the retrospective analysis. The study of the chemical variables started at Institute of Marine Resources in Peru in 1961 aboard of vessels of the Armada Peruana BAP/Bondy (1960-1963), BAP/Unanue since 1964 and IMARPE scientific ships BIC/ SNP-1 since 1969, BIC/Tareq II (1973-1975), BIC/Humboldt (1980), and BIC/ J. Olaya (1998). Chlorophyll and primary production measurements were performed later, at the middle old the sixties. The information from those years progressively increased until to reach four decades (1960-2000) although with some limitations in frequency and coverage area. The gathering of information was done in 26 708 hydrographic and surface stations corresponding to 400 national cruises and from join research cruises in international programs. Data were included from the tracks between coastal line and 86 W. In the data processing base, monthly and seasonal averages for oxygen and nutrient were calculated for each decade and for the whole period. The data analysis was made at sea surface, 50m, 100m and for 0-50 and 0-100 layers. For vertical distribution of chlorophyll and primary production data were adjusted to a Gaussian curve using a computer pack Graphpad Prism. The analysis were accomplish for surface and integrated values (0-25, 0-50, 0-100 layers) and to the euphotic zone. The resultant curves from fitting between the modelled and in situ data were considered acceptable with the major coefficient of 0.6. It was obtained 2 394 profiles of chlorophyll and 134 of primary production. Processing data was made at the Bedford Institute of Oceanography, Canada. The data was organized in an atlas designed for use as a working document. Its content had been divided in two sections:
1. Horizontal distribution of oxygen and nutrients. Monthly and seasonal charts of averages at the sea surface, 50m and 100 levels for each decade and for the whole period. Sea surface chlorophyll and primary production maps.
2 a. Vertical distribution of oxygen and nutrients. Monthly and seasonal averages charts of 0-50 m, 0 - 100m layers and for the minimum oxygen zone at each decade and for the whole period. Chlorophyll and primary production in the euphotic zone.
2b. Vertical sections. Seasonal profiles of oxygen, phosphate, silicate, nitrate and nitrite in selected areas.
2c. Chlorophyll and primary production in the euphotic zone.
The compiling represents a former and long effort to build a data base of dissolved oxygen, nutrients (phosphates, silicates, nitrates, nitrites) chlorophyll and primary production for the Peruvian coast. Additional and selective analyses of this data will allow advancing in different fields relevant for future research.

HCS174 - A Numerical Study Of Oceanic Circulation Along The Peruvian Coast Using Princeton Model (Pom) During 1991-2000

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Keywords: Upwelling, Numerical model, Ekman dynamic, Peruvian Coastal Current.

Tunning numerical model of Princeton University (Princeton Ocean Model-POM) for to study oceanic circulation and Ekman dynamic along the peruvian coast when occur La Niña and El Niño events during 1991-2000 period. The Peruvian Coastal Current, the drag force of the southwestward trade winds and the subsuperficial current establish the mechanism which maintains the coastal upwelling. Upwelling occurs along a coastline when surface wind stress produces offshore Ekman transport or when wind stress curl produces upward motion at the bottom of the Ekman layer. In order to do this, the POM was applied forced by the wind stress climatology of the CERSAT/IFREMER reanalysis and by the Levitus 94 salinity and temperature climatology. In strong wind events, the thermocline rises and the sea level height is lower. Conversely, when the trade winds are weak the thermocline sinks and the sea level height is higher. The analysis confirm that when occur strong El Niño event, the meridional wind stress has a role essential in the intensivity of coastal upwelling. During the El Niño, speed of Ekman pumping was nearly 4 times larger than the normal speed of Ekman suction and offshore Ekman transport nearly doubled.

HCS207 - Synchronicity in anchovy catches in the Humboldt Current Ecosystem

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Keywords: pelagic fisheries, time series analysis, temporal patterns, synchrony, anchovy

Interdecadal synchrony in pelagic fish stock abundance have been largely investigated since the seminal work of Kawasaki (1983) on the large, long-term changes experienced by *Sardinops sagax* in different parts of the world, but the reasons of these synchronies are still debated (Klyashtorin, 2001). Global synchrony in pelagic catches is even questioned whereas basin scale synchrony seems more likely to represent real simultaneous changes in abundance (Fréon et al., 2003).
In order to investigate this issue in the Humboldt ecosystem, time series of >50 years of catches of anchovy in the Humboldt ecosystem (Fig. 1a) were analyzed, subdividing the dataset in three large areas: northern Peru, southern Peru, northern Chili (southern Chili will be added). The methodology consists in smoothing first the annual data with a loess function with a low span value (0.5) in order to extract the low frequency signal in each series and compare them (Fig. 1b). Then the residual values were extracted (Fig 1.c), representing the interanual signal and were compared using correlations. Finally, these residuals were correlated to proxies of the ENSO signal at the basin scale (MEI) and on the continental shelf (SST).
The results suggest that there is a strong synchrony in the signals, both at the interdecadal and at the interanual scales (r>.70). The correlation of the times series from northern Chile and southern Peru is weaker than between Northern Chile and Northen Peru despite a larger distance between areas in the second case. The interannual variability of the time series of catches was correlated with the ENSO proxies. Several interpretations are proposed including the effects of large scale environmental forcing and synchronous exploitation due to the globalization of the fishmeal and fish oil markets.

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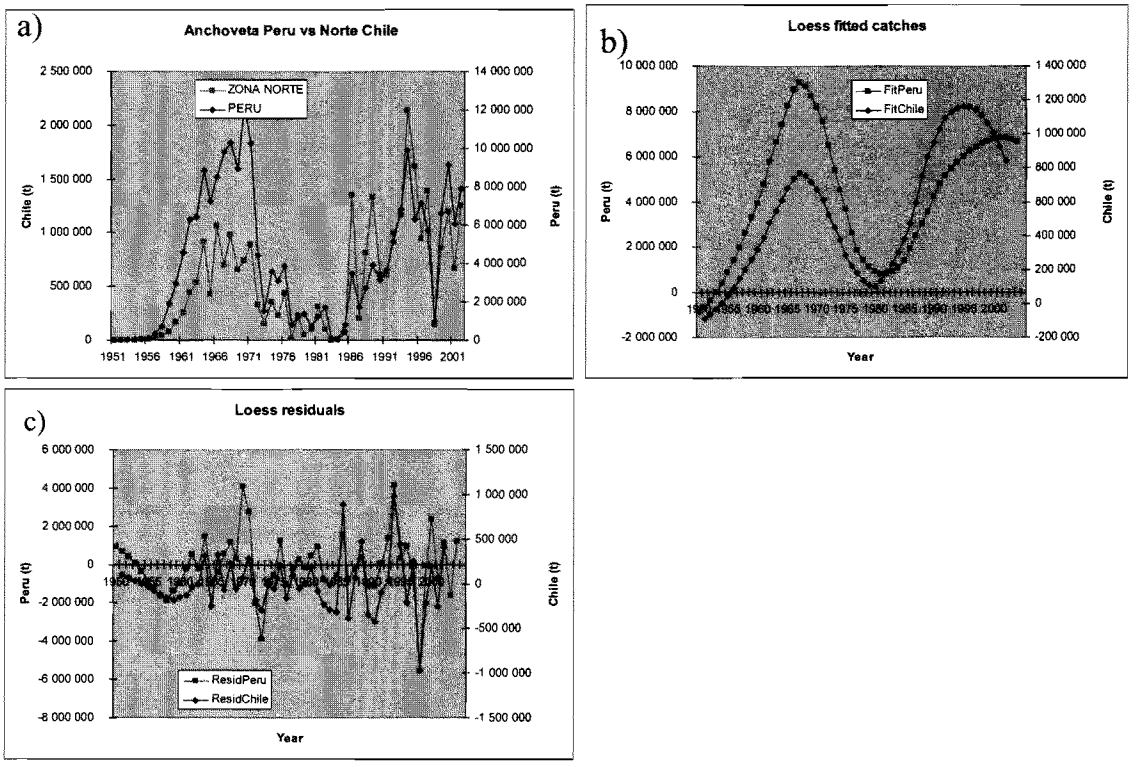

Figure 1. Example of time series (here northern Chile contrasted with central Peru + northern Peru aggregated): a) annual time series; b) loess function (span 0.5); c) residual of the loess function.

HCS210 - Retrospective analysis of temporal variability of pelagic resources catches and abundances in Peruvian waters

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Keywords: Pelagic resources, distribution and abundance, Peru, seasonality

Off the Peruvian coast, the climatic and oceanographic conditions present a large spatio – temporal variability that expressed at short (seasonal), medium ("El Niño" – "La Niña") and long term (cold period – warm period) scales. The main pattern in the Peruvian waters is the presence of cold water masses and important upwelling areas that allow the development of large populations of anchovy *(Engraulis ringens)* that support the Peruvian pelagic fishery (Csirke, et al 1996). Other pelagic fish species are Jack mackerel (*Trachurus murphyi*), Pacific mackerel (*Scomber japonicus*) and Sardine *(Sardinops sagax)*.

Data used in this work came from the monitoring of the pelagic resources performed by the Instituto del Mar del Peru (IMARPE) since 1950. In particular we used catches distribution disaggregating juveniles and adult fish, biomass estimates from VPA stock assessment and from acoustic surveys.

Catches of anchovy in the northern-central region of Peru showed two periods of high levels, one in the sixties and the other from 1992 until 2005, that matches the trends in abundance estimated from VPA and acoustics (for 1983-2005; Fig. 1). For the second period, following El Niño phenomenon of 1982-83, the anchovy biomass increased dramatically, as did the caches that reached a maximum yield of 9.1 million tonnes in 1994. Nonetheless, due the change in target species (sardine) the increase in catches was delayed compared to the increase in biomass, and the exploitation rate (not shown) was lower than during the first period.

In southern Peru, the peaks of higher catches occurred in 1970 and 2002, and in contrast to the northern-central region, the decline in biomass after 1972 was not so abrupt and recruitment remained substantial until 1982. Maximum catch of other pelagic resources occurred between 1984 and 1992, sustained by high biomasses varying between 4 and 14 million tonnes (Fig 1).

The average biomass of anchovy in periods of high abundance fluctuated between 14 and 18 million tonnes for the northern-central region and between 10 to 16 millions tonnes for the south Peru – north Chile region. From the interpretation of these results, the debated question of the anchovy stock unit(s) is discussed.

The second increased anchovy population can be interpreted as a variation in the species composition of the pelagic ecosystem, with a tendency towards the dominance of this specie, as was the case in the 'sixties, under the influence of a period of normal and/or cold conditions in the coastal environment, and sustained by good recruitment indices between 1964 – 1970, 1992-1994 and 2002-2005 (Chavez et al. 2004).

Highlights points of the changes on pelagic resources through 60' to 2000 were:

1960'	1970'	1980'	1990'	2000'
Anchovy Dominance	Decrease Anchovy Decrease Guano birds Increase Sardine	Dominance Sardine & others Pelagic Appears Giant Squid	Decrease Sardine Increase Anchovy Increase Giant squid Appears pelagic squat lobster	Anchovy Dominance

Acoustic assessment performed between 2000 and 2006 showed that the gravity center of anchovy distribution fluctuated between 07ª - 11ª S, with a northerly position at 7º40`S (Chicama) in summer 2003, followed by a trend to establish near to Huarmey (10ª S).

In this context, the development of the pelagic fishery in the short to medium term is closely related to the fluctuations in the abundance and availability of anchovy, and research should be intensified in order to attain an appropriate management of these resources.

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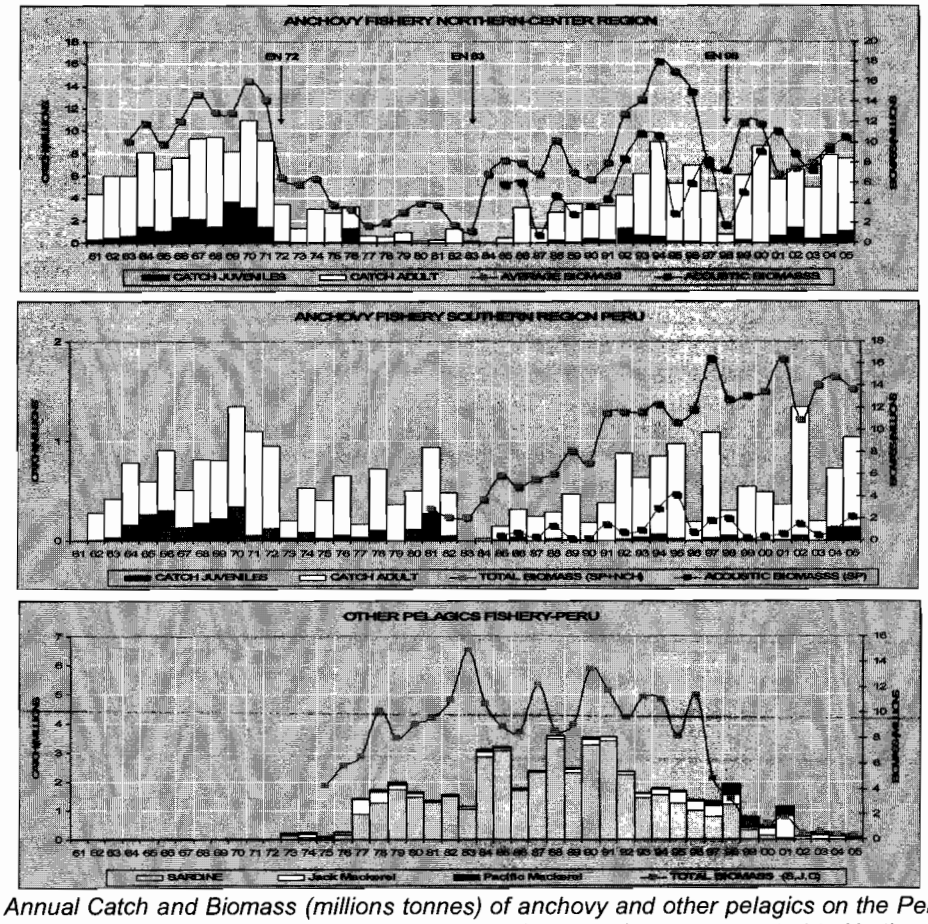

Figure 1. Annual Catch and Biomass (millions tonnes) of anchovy and other pelagics on the Peruvian sea during 1961-2005. For the southern region, Peruvian catches are shown, contrasted to Northen Chile and Southern Peru biomass. The red bar shows juvenile catch and yellow bar shows adult catch of anchovy. EN = El Niño.

Tuesday afternoon

HCS008 - Fish productivity and ocean dynamics in the Humboldt Current region

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Anchovy and sardine catches in the Humboldt Current region reach some 13 and 6 mill. t., respectively. The corresponding time series for 35 years (1953-1988) makes it possible to address possible links between the long-term changes in the Ocean dynamics and fluctuations of fish productivity.

The average upwelling index and primary productivity index vary in a similar manner, since the level of primary production depends mainly on the nitrate content in the euphotic layer, which, in its turn, depends on the upwelling rate. During 1953-1988, the both indices underwent ~10 years synchronous oscillations, and the level of primary productivity and upwelling index for the 35-years period increased by 25% on the average. The biomass fluctuations and catches of basic commercial species (anchovy and sardine) do not depend on the variation of the primary productivity.

Correlation between the level of primary production and zooplankton biomass for the 35-years period (1964-2001) was rather low (r = 0.51). During 1964-1982, however, these indices were correlated much better (r = 0.71), while in 1983-2001 no significant correlation between the primary production and zooplankton biomass was found (r = 0.32).

Strong El Niño events of 1982-1983 and 1998-1999 caused drastic drops in the anchovy biomass, though did not impact zooplankton biomass. The sardine catches in the region reached their maximum in 1982-1984, and a strong El Niño event of 1982-1983 that almost eliminated the anchovy population had no visible effect on the sardine population ad catches.

Thus, no reliable correlation between the upwelling index, primary production, zooplankton biomass, and fish productivity in the most productive oceanic regions has been revealed.

Further studies and analysis of longer time series of relevant observations are needed to answer the question on possible influence of atmosphere dynamics, upwelling index, and turbulence mixing on the long-term dynamics of fish productivity in the Humboldt Current region.

HCS009 - Fluctuations of Peruvian anchovy biomass and strong El-Niño events

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Biomass and catches of Peruvian anchovy reaches 19 and 13 mill. t., respectively. The dynamics of biomass and catches are rather tightly correlated (r = 0.79). The anchovy population undergoes catastrophic drops in abundance and biomass due to strong El-Niño events, which use to repeat every 8-12-year. A strong El-Niño event of 1956-1957 reduced anchovy biomass from 10 to 3 mill.t , but the biomass increased up to 12 mill in 2 years and up to 17 mill. t. after one more year. The strongest El-Niño event of 1982-1983 reduced the anchovy biomass drastically from 9 mill.t. to its age minimum of 1 mill.t., but again the biomass increased up to 7 mill.t. in the first year and up to 8.5 mill.t. after two years after the event. The second strong El-Niño event of 1997-1998 caused drop in biomass from 18 to 7 mill.t., which result in catch shrinkage up to 1.7 mill.t. The biomass and catches reached 12 and 9 mill.t., respectively, as soon as one year after the event (Fig .1). A capability of anchovy population for quick restoration after strong El-Niño events was clearly demonstrated in the 1955-1970s and 1980-2000s. The drastic drops in anchovy populations caused by strong El-Niño events can be considered as a kind of «natural model» of non-regulated catches causing catastrophic decrease in commercial stock. Almost total elimination of the anchovy population due to strong El-Niño events, however, do not cause irrecoverable loss of population — the fish abundance completely restore during the life cycle of one or two generation of anchovy, so that in a few years the biomass reaches 7-10 mill. t.

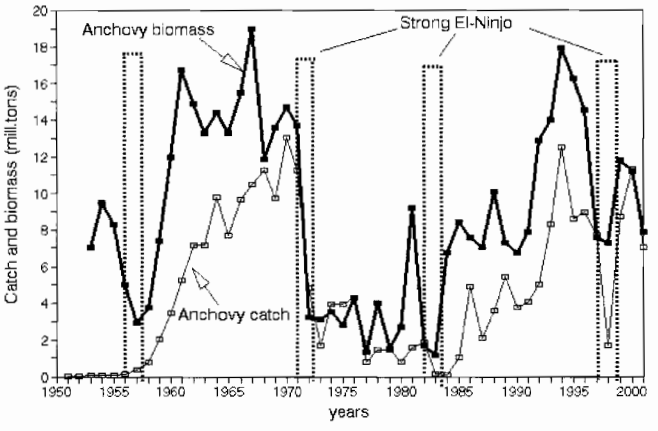

Fig.1. Comparative dynamics of Peruvian anchovy biomass (bold line), anchovy catch (white squares) and strong El-Niño events (bars), 1950-2000.

HCS012 - Factors responsible for the differences in satellite-based chlorophyll a concentration among the major global upwelling areas

B. Patti, C. Guisande, A. R. Vergara, I. Riveiro, I. Maneiro, A. Barreiro, A. Bonanno, G. Buscaino, A. Cuttitta, G. Basilone, S. Mazzola

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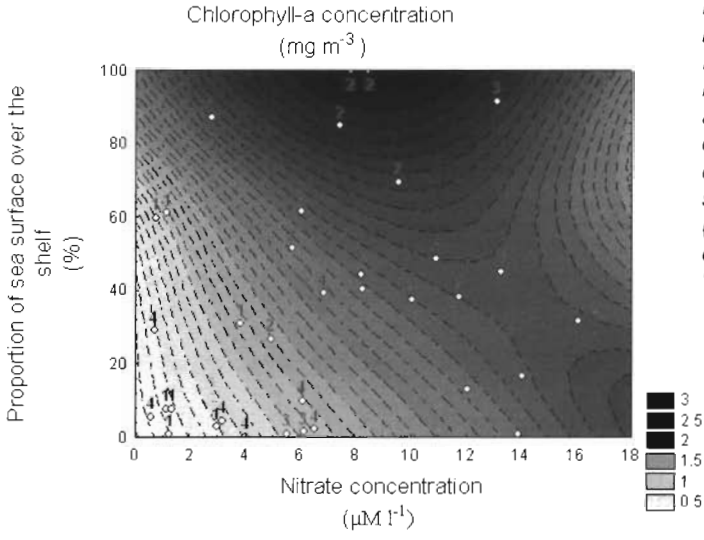
Keywords: Chlorophylls, Ekman transport, Eastern boundary currents, Upwelling.

The aim of this study was to identify the driving factors responsible for the differences in chlorophyll a (Chl-a) concentration observed among California, Canary, Humboldt and Benguela eastern boundary ecosystems, using *in situ* and satellite "climatologic" information mainly collected over the period 1998-2004. Monthly mean values of Chl-a concentration obtained from satellite images (SeaWiFS data; Feldman & McClain, 2002) revealed that chlorophyll was higher in the Benguela system than in the other areas. Upwelling intensity (derived from ICOADS data; Woodruff et al.,1998) was higher in the Benguela and Humboldt regions and, for the same upwelling intensity; chlorophyll was higher in Benguela than in the other regions. There was a negative relationship between Chl-a concentration and temperature, which may be due to cold deep water brought to the surface by upwelling, thus enhancing primary production. There was a significant positive relationship between turbulence and Chl-a concentration, but this was also due to the relationship between Ekman transport and turbulence. Upwelling intensity appears to be able to drive chlorophyll densities through nutrient supply (data obtained from World Ocean Atlas 2001; Conkright et al., 2002), as nutrients are correlated to offshore Ekman transport. A linear regression model including the fraction of sea surface over the shelf in each site (1°x1° boxes) and nitrate concentration explained the 72.8% variance in Chl-a concentration between the areas. Differences in offshore Ekman transport explained the lower Chl-a concentration observed in the Canary and California regions with lower upwelling intensity and the higher chlorophyll density observed in Benguela and Peru-Humboldt with higher upwelling intensity. A small continental shelf and low water column stability also contribute to

reducing phytoplankton pigment biomass in the Canary and California areas. The differences between Benguela and Peru-Humboldt are due to wider extension of the continental shelf in the Benguela region compared with the Humboldt-Peru region.



B. Patti , C. Guisande, A. R. Vergara, I. Riveiro, I. Maneiro, A. Barreiro, A. Bonanno, G. Buscaino, A. Cuttitta, G. Basilone, S. Mazzola: Contour plot of average (1998-2004) chlorophyll a concentration as a function of nitrate concentration and proportion of sea surface over the shelf in different sites (1°x1° boxes) of four eastern boundary ecosystems (1 = "Canary", 2 = "Benguela", 3 = "Humboldt", 4 = "California").

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HCS013 - Mesoscale eddies and jack mackerel (*Trachurus murphyi*) distribution in the eastern South Pacific

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Keywords: Mesoscale eddies, Jack mackerel, fish biomass, Peru-Chile current system

An integrated analysis of acoustic fish biomass, logbook fishing sets, oceanographic sections, satellite sea surface height anomalies and satellite chlorophyll concentration, provides evidence indicating that the jack mackerel spatial distribution is affected by both mesoscale eddies and meanders. Off the South American west coast, higher jack mackerel (*Trachurus murphyi*) landings levels occur mainly off the central-south Chile region, which accounts for about 85% of the total annual catches. There, recurrent mesoscale eddies and energetic meandering currents define a region of high mesoscale variability, located between the coastal and deep ocean dynamics zones. This region has an offshore extension of ~600-800 km and corresponds to the Coastal Transition Zone (CTZ). In the CTZ, satellite and *in situ* data show that chlorophyll concentration enhancement is strongly association with mesoscale structures. Mesoscale eddies have a coherent vertical structure up to ~600 m depth and generate an offshore transport of $2x10^6$ m^3 s^{-1} which extends the rich nutrient waters beyond the zone directly affected by coastal upwelling. During the fishing season, the spatial distribution of significant fishing sets and enhanced acoustic biomass index are both strongly associated to mesoscale eddy edges and to strong coastal meandering currents. This good spatial pattern agreement may be associated with high prey availability as a result of physical-biological enrichment processes linked to eddy pumping and westward advection of upwelled waters.

HCS016 - "Latin America-Europe School of Oceanography", a network of institutions under European Union-Alfa program.

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Several universities in the world have successfully developed curricula in Oceanography and/or related Marine Sciences, while others are in the process of developing or modifying existing ones. International

quality standards in curricula can be achieved through exchange of information, contents, students and teachers.
With the general aim of initiating and sustaining a network of cooperation between Latin American and European educational institutions, "Latin America Europe School of Oceanography" (www.udec.cl/laeso) was established in July 2005 and is currently functioning under the auspices of European Union, (http://europa.eu.int/comm/europeaid/projects/alfa).
Specific objectives of LAESO today are to share concepts, planning and implementation actions in education, to define agreements on cooperation in institutional management and mobility, and to promote joint scientific research and sharing of resources.
European partners are: Goteborgs Universitet, Sweden; Universitat Kiel, Leibnitz-Institut fur Meereswissenschaften, Germany; University of Plymouth, England; Universidade de Vigo, Spain. Latin American partners are: Universidad de Costa Rica, Costa Rica; Universidad de Bogota Jorge Tadeo Lozano, Colombia; Escuela Nacional Tecnica del Litoral (ESPOL), Ecuador; Universidad Nacional Agraria La Molina, Peru and Universidad de Concepcion, Chile, which coordinates the network.
These objectives of initiation search of agreements and basis for further cooperation are in brief associated with the following activities: Curriculum Harmonization, Curriculum Development, Certification of Degrees and Diplomas and Administrative Management of Education in Oceanography.
Information has been exchanged and consensus reached on several key concepts such as Oceanography and Applied Ocean Sciences, Undergraduate Prerequisites for Oceanography, Core graduate courses in Oceanography, Credit Transfer System and others resulting from the Bologna Process analysis. The following previously drafted White Papers were examined and approved at the First Meeting of the Network in Costa Rica last December: 1.- Undergraduate Curricula in Oceanography, 2.- Pre-requisites Courses for graduate studies in Oceanography, 3.- Core Courses in Oceanography, 4.- Certification of Courses, 5.- Credit Transfer System, 6.- Harmonized M.Sc. in Oceanography, 7.- Harmonized Ph.D. in Oceanography. They are being edited and will be made available to the public.
A Second Network Meeting was held in Gothenburg, Sweden on 23-31 August 2006. The meeting was attended by partners and by invited observers from University of Southampton (UK) and Cicese (Mexico). Working Groups were re-organized, White Papers were completed, information was exchanged and consensus reached on an "Optimal Ph.D. Curriculum in Oceanography and Applied Marine Sciences". Consistently with agreement at the Costa Rica meeting to expand and extend the network the "Joint Declaration of Goteborg" was signed by representatives of 9 institutions of LAmerica and Europe, and a " Memorandum of Understanding for Academic Cooperation in Oceanography and Applied Marine Sciences" was prepared to be signed by partners institutions in the next months.
We trust that scientific and educational cooperation and the implementation of networks between both regions will significantly improve development and stability in our societies and in the world.

HCS022 - Seasonal shipboard transect monitoring in St Helena Bay in the Southern Benguela, 2000-2005

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Key words: chlorophyll a, decadal, mesozooplankton, oxygen, pelagic fish, seasonal,

Two oceanographic transects (12 stations and two stations) in St Helena Bay (32°S) were sampled monthly from April 2000 to April 2005 , as part of a BENEFIT initiative to monitor changes in the Benguela Upwelling system at three ecologically important sites. The other sites included Walvis Bay (23°S) in Namibia and Namibe (15°S) in southern Angola. Standardized sampling protocols were applied to all three areas. These sites are important at different stages in the life history of some of the commercially important fish stocks in the three countries and the shipboard transects were complemented by remote sensing, buoy data, mesoscale fisheries surveys and process-orientated cruises in order to determine variability at different time and space scales through the Benguela Upwelling Ecosystem. The data also contribute to long-term data sets on dissolved oxygen and zooplankton, while providing information on seasonal changes. Inshore-offshore thermal gradients peak during summer months when maximum upwelling intensity inshore coincides with advection of water of Agulhas origin onto the west coast. Phytoplankton concentrations are high (100-150 mg chlla/m^2) throughout the year, with a slight decrease during winter months. Internal variability is not marked. Dissolved oxygen concentrations are high in the upper mixed layer but low (<2 ml/l) throughout the bottom mixed layer inshore, particularly in late summer and autumn, when extreme low oxygen conditions may induce rock lobster stranding and mass mortalities and affect hake recruitment grounds. Intense mixing events during winter, or downwelling during summer, results in intermittent periods of increased oxygen concentrations. Prolonged periods of low oxygen have occurred in 1982/3, 1994-2000 and extensive low oxygen water is currently prevalent in the southern Benguela. Mesozooplankton biomass exhibits strong seasonal variability, despite the consistently high phytoplankton concentrations. A reversal of the long term upward trend in zooplankton in autumn months is not reflected in the peak summer values, which continue to increase. Predation by

pelagic fish may be a powerful factor in years when high recruitment occurs. Changes in pelagic fish condition appear to reflect food availability and will reduce energy reserves for the migration and subsequent spawning on the Agulhas Bank.

HCS027 - Modelled and observed interannual variability of the circulation and mesoscale dynamics of the Peruvian Current System

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[2] *IRD/LOCEAN. LOCEAN, UPMC, Boite 100, 4 place JUSSIEU. Paris, France.*
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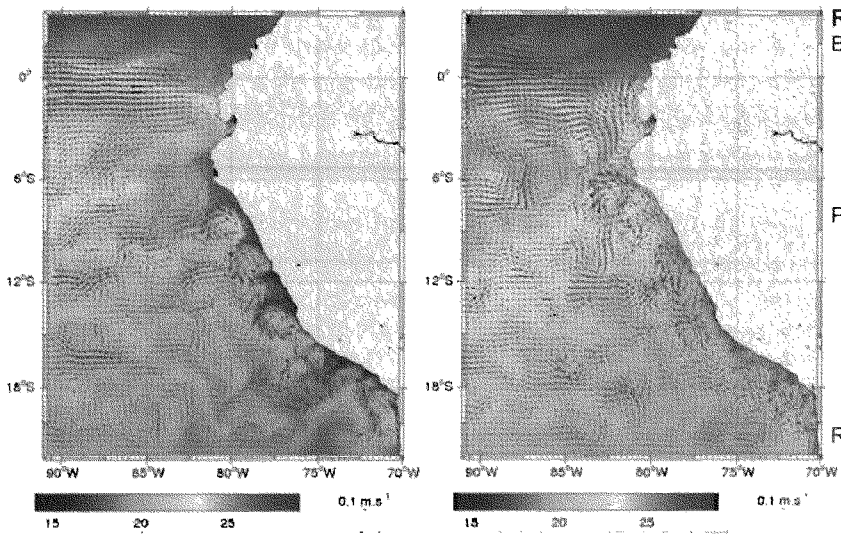
Keywords: Model, Circulation, Boundary Current System, equatorial cold tongue, El Niño, water masses

A configuration of high-resolution (isotropic grid of 1/9°x1/9° and 32 discrete vertical levels) of the Regional Oceanic Modelling System (ROMS) was run on the period 1992 to 2000 over the domain extending from 5° N to 25° S. The study area is part of the Eastern Boundary Current System that it is located in the South-eastern Pacific Ocean, known as the Humboldt Current System (HCS). A predominantly alongshore strong wind stress forces a strong coastal upwelling, that occurs throughout the year and creates a narrow coastal region of colder coastal SST that expands and connects to the equatorial cold tongue, these features convert the HCS in a unique area with the most productive fishery. There are five types of water masses: Subsurface Equatorial Waters (AESS) coming from of the Equatorial Undercurrent, Tropical Surface Waters (TSW), Cold Coastal Waters (CCW) associated to the Peruvian Coastal Current, Template Waters of the Sub arctic Region (TWSR) and Antarctic Intermediate Waters (AIW). The main objective of this work was to investigate the structure and dynamical mechanism and mesoscale physical variability in the interannually varying circulation. We focused on the period from 1997 to 1999 encompassing the occurrence of strong El Niño and La Niña events to analyze of interannual variability on the coastally trapped waves. Four experiments were performed: first the model was run using ten years of mean months wind stress combined from the ERS and QuickSCAT Data Set corresponding period (1992-2000); a second experiment consisted in climatological wind stress; the third experiment used forcing with climatological boundary, and finally the fourth experiment is developed using interannual boundary. On the other hand, remotely-sensed satellite data observations of sea surface anomaly, wind stress and sea surface temperature are used to examine space-time propagation characteristics of the mesoscale eddy activity, to obtain a more complete view of the surface circulation. The results presented here show that the model is capable of simulating some of the general features and patterns of interannual variability of the circulation. We found that the wind contributes to the development of interannual sea surface temperature (SST) anomalies due to seasonal variations of the winds stress. The comparison of mean Eddy Kinetic Energy (EKE) simulated and observed, show that in the model the EKE is relatively low compared to the satellite data. The model can capture the features and variabilities of the sea surface temperature. Elevation sea level showed a complex field of onshore and offshore intrusions combined with the effects of mixing along the upwelling front. Furthermore, aspects of the large-scale circulation and associated energetic structures, as the warm water tongue which extends from the equator to northern Chile, confirmed that the role of baroclinic instability of upwelling alongshore currents is the primary eddy generation mechanism of eddies whose diameter follow a equatorward increase and strongly correlated to the Rossby radius of deformation.



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HCS037 - Variability of phytoplankton biomass in upwelling systems: a comparative approach

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Keywords: Ocean colour, phytoplankton, remote sensing, upwelling systems, biomass index

The spatio-temporal variability as well as trends in phytoplankton biomass in three upwelling systems (Humboldt, Benguela and Canary ecosystem) are investigated over a nine year period using SeaWiFS ocean colour data and a model of vertical profile of chlorophyll. Composite reconstructed images of chlorophyll a revealed that the surface concentration always reach maximum values near the coast and decreased in an offshore direction, allowing observation of the spatial extent of phytoplankton distribution in relation to coastal upwelling. A vertically integrated index of chlorophyll biomass is estimated as the integration of the chlorophyll a concentration from the coast to an offshore minimum level of 1 mg·m-3and a maximum depth of 100 m and was used to examine the average seasonality and annual variability in phytoplankton biomass as well as temporal trends during the period investigated.
Ekman offshore transport is computed to estimate the part of the variability of the biomass due to the local forcing of the upwelling compared to other sources of variability. The data indicates that the level of biomass seems globally higher than previous estimates and that the interannual and seasonal variability is generally very high but also quite variable between systems as well as within every system. The different patterns of variability depicted could be partly explained as a combination of different planktonic structure associated to different modes of forcing of the upwelling. Our biomass index appears to be robust and generic enough to be applied to various upwelling systems. As a reasonably good index of variability in phytoplankton biomass, it provides an important and necessary step towards a reliable estimation of the primary production of these systems, that also requires a better understanding of the differences in the structure and the functioning of the planktonic communities (for example important differences observed in P/B ratios) that could explain large differences observed further in the trophic chain and therefore in the global efficiency of the upwelling systems.

HCS073 - Using Argo data to document water masses variability in the Humboldt Current System

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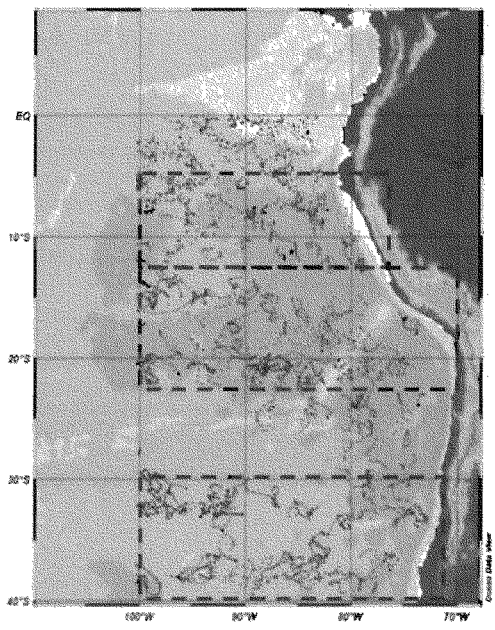
Keywords: Argo, variability, water masses

The Argo program, formally endorsed by CLIVAR, aims at providing an enhanced real-time capability for measurements of temperature and salinity through the upper 2000 m of the ocean and contributes to a global description of the seasonal cycle and internal variability of the upper ocean thermohaline circulation. To achieve this goal, the deployment of 3000 profiling floats throughout the world ocean should be reached in 2006. The increasing number of floats already deployed in the Eastern South Pacific (ESP) can already provide information on the variability of upper ocean water masses (0-1000m) in the area. The ESP present a specific structure of water masses, some originating from the tropical Pacific, and some from the Southern ocean. In the near surface layers (0-200m) warm and salty Subtropical Surface Water (STSW) and colder and fresher Sub-Antarctic Surface Water (SASW) are transported by various branches of the Humboldt Current System and meet around 30-35°S [*Stramma et al., 1995; Chaigneau & Pizarro, 2005*]. Around that location, low salinity water at 150-250m forms the Eastern South Pacific Intermediate Water (ESPIW), of still badly known origin [*Schneider et al., 2003*]. In subsurface (200-1000 m) are found salty and oxygen-depleted waters (Equatorial Subsurface Water, ESSW) and fresher, oxygen-rich Antarctic Intermediate Water (AAIW) [*Mc Cartney, 1977*]. All available Argo temperature/salinity profiles between equator and 40°S and East of 100°W (more than 4000 for 2000-2006) are first quality controlled by reference to existing climatology. Because of some still uneven distribution of profiles, they are grouped in 3 latitude groups, allowing a description of the main characteristics of water masses; depending on available data, in some of the groups, seasonal variability can be apprehended. This work is focused mainly on the Oxygen Minimum Zone (OMZ) associated with ESSW, and on the salinity minimum of the ESPIW at 30-40°S. Argo data and outputs from a regional circulation model are also compared, in terms of main structure and seasonal variability. This preliminary study shows that since 2003-2004, the network of Argo profilers provides enough coverage to study upper ocean water masses and their variability. With a continuing effort of countries participating in Argo to maintain the full network coverage, interannual variability in the Humboldt Current System will be also accessible in a few years.



Distribution of Argo profiles for 2000-2006. The dashed line delimits the area under study: from north to south, the core of the OMZ, a transition zone, and the area of ESPIW water.

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HCS075 - Predicting anchovy recruitment in the southern Benguela: comparing rule-based and statistical approaches

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Keywords: Anchovy, Benguela, expert system, recruitment, robustness

The South African anchovy fishery on anchovy (*Engraulis encrasicolus*) is a recruit fishery, the management of which can benefit from a prediction of recruitment as early as possible into the fishing season. An expert system developed by Miller and Field (2002), designed to predict above median, median, likely below median and highly likely below median recruitment, proved robust to the large changes in abundance observed in 1999/2000. In view of additional recent changes in the distribution of small pelagic fishes in the southern Benguela, we update this expert system with recent input data, and explore its sensitivity to changes in input data series. Finally, we compare the semi-quantitative prediction of the expert system to quantitative prediction of anchovy recruitment using generalised linear and additive models.

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HCS076 - Physical and biological processes associated to mesoscale structures identified by satellite images in the Humboldt system off northern and central-south Chile

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Keywords: Chile, Humboldt, mesoscale structures, remote sensing

In the eastern boundaries margins, such as the Chilean Humboldt Subsytem (CHS), the presence of mesoscales structures is a recurrent phenomena. This oceanic structures generate a high variability zone between the continental shelf and the open ocean, known as the Coastal Transition Zone (CTZ).The CTZ is the transition zone between the physical process that dominate the coastal dynamics, i.e. the coastal upwelling, and the processes that dominate the oceanic dynamics, i.e Rossby waves. This zone extends from coast to 800 km offshore and can be separated in two latitudinal regions with particular conditions of kinetic energy and wind stress (Hormazabal *et al.*, 2004). The first region (northern zone), between 19ºS and 29ºS, is characterized by low eddy kinetic energy and weak but persistent equatorward wind stress. In this area, the upwelling process occurs the whole year round, either in focal points or bands that covers a great part of the coast, whereas the eddies occur only in summer but are not frequent. In contrast, the second region (central-south zone), between 29ºS and 39ºS, is characterized by high eddy kinetic energy and strong but variable equatorward wind stress. The upwelling process in this area is highly seasonal (Sept-Mar), and a high mesoscale eddy activity is observed. The difference between the mesoscale processes in both zones is mainly due to the wind stress, kinetic energy and other factors less studied, like the bottom topography, coastline shape, planetary waves influence, etc.

The most common mesoscale features in the CTZ are the frontal structures resulting from the coastal upwelling. Upwelling contributes to the nutrient enrichment, thanks to the pumping and offshore transport of deep cool rich-nutrients waters that are upwelled into the euphotic zone, as a result of the dominant along-shore winds forcing. The intense biological productivity in CTZ supports one of the most productive fisheries in the world, mainly composed by pelagic species. It is worth noting that different pelagic species dominate each zone, with similar catch levels, being the anchovy the dominant species in the northern zone and the jack mackerel in the central-south zone. The upwelling seasonality and the importance of eddies generation in the central-south zone change the plankton distribution and abundance of the dominate species. Indeed, Hormazabal *et al.* (2004) found a spatial relationship between the jack mackerel fishing zone and the edge of cyclonic eddies in the central-south CTZ.

Different data types, such as remote sensing, *in situ* data and model simulations, are available to assess the mesoscale structures. Remote sensing offers the advantage of providing synoptic observations of surface parameters, such as sea surface temperature from AVHRR/NOAA, chlorophyll-a from SeaWiFS/SeaStar and sea level anomalies from altimers of TOPEX/Poseidon, the trend being to use multi-sensor satellite data. Given the big volume of satellite data available for the oceanic studies, an automatic system for the images processing is necessary. Some methods have been developed to detect mesoscale structures, mainly based on the detection of horizontal gradients or boundaries between different water masses. The Cayula-Cornillion method has been the most widely and successfully applied. The technique to detect fronts on individual daily images, then combines the fronts located over a week or month with weighting factors based on front gradient, persistence and proximity to other fronts (Cayula & Cornillon, 1995).

The construction of mesoscale activity indices is relevant to study the marine ecosystems in order to resume and transfer into a quantified information the long-term time series of satellite data,. The indices developed till now are generally based on large scale features. However, in order to understand the fish response, it could be more useful to analyse the mesoscale ocean dynamics from the detection and tracking of the mesoscale structures over long periods of time. This mesoscale approach has begun to develop. In fact, the Workshop on the Indices of Mesoscale Structures (WKIMS) developed by an ICES Group in February 2006 is a first intent to define mesoscale indices. Indices such as gridded index (i.e. density of fronts) and structure index (length, position, advection path, etc) are proposed to describe the fronts. For the eddy activity two types of indices may be considered: the structures indices such as eddy size, rotational direction, lifetime, etc., and aggregated indices such as spatial map of eddy density averaged over a time period, eulerian map of eddy mean transport direction and velocity, etc. The researchs in this field are challenging especially to construct and to automatize the mesoscales indices, which have as ultimate goal to relate the time-series of mesoscales indices with time series of fish populations. This approach should allow understanding how the physical processes are related with the enrichment, concentration and retention mechanisms of the lower levels of the food web in the CHS.

In this work, we proposed to implement automatic front detection tools on a sequence of satellite images in order to characterize oceanic mesoscale structures in coastal upwelling areas and to explore some interactions between physical and biological processes. Maps of Sea Surface Temperature fronts and chlorophyll are presented, derived from a sequence of high resolution NOAA/AVHRR and SeaWiFS data. The Cayula & Cornillon algorithm and other edge detector algorithms are implemented using the Interactive Data Language (IDL) and applied to a set of satellite images from the CHS. A comparative approach between the northern and central-south zones off the CTZ will be carried out. A preliminary result shows the interest of combining conventional gradient-based methods and more modern edge detector methods whose advantages are largely complementary and should bridge the gap between multiple frontal detections and automatic pattern recognition.

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HCS090 - Viability of Microbial Community from Free-living and Sediment Associated Bacteria Assayed by Respiratory Activity and Growth from a Coastal area of the Current Humboldt System.

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Keywords: Bacteria, Respiratory Activity, Culturable cells, Free-living, Surface Associated.

The Humboldt Current System of northern Chile is characterized by its high autochthonous productivity and its bottom depleted oxygen condition. In this zone, it is located Semillons bay (23° S), which is part of one of the most productive upwelling centre off northern Chile (Punta Anamosa), where biological and geochemical processes are influenced by natural and anthropogenic factors, Although Semillons del Sure has been studied in the last years specially from a oceanographic and geochemistry perspective (Valdes et al, 2005), little is know about temporal or spatial variability in the proportion of colourable vs. nonculturable or active bacterial communities in this particular ecosystem. It is now generally held that the number of active or viable cells in environmental samples changes in relation to the total number of cells in the population, because a large fraction of the total cell count consist of either dead or dormant bacteria. The well established fact that a small percentage (i.e., <1%) of the total observable bacteria in environmental samples can be readily cultured has led to increase emphasis on the use of cultivation independent methods for assessing microbial community understanding. The value of studying these dynamics is depending on the ability to assign general ecological characteristics to culturable and nonculturable types. These temporal and spatial study approaches would be necessary to understand a successional microbial process for microbial communities from free-living and surface associated cells. Actually new methods for distinguishing live from dead cells or active from inactive cells are being investigated. Some techniques combine methods for enumerating total bacteria with assays for directly visualizing the active or live fraction of a population such as 5-cyano-2,3-ditolyl tetrazolium chloride (CTC) based on the formation of insoluble formazan precipitate inside cells when reduced. Here we explore the relationship between total bacterial abundance, and their proportion of active and culturable bacteria for samples obtained from Mejillones del Sur (23°S) bay. For these purpose water and sediment samples were collected in winter and summer period from eight different sampling stations along the bay, for total direct count (TDC), vital staining (CTC) and culturable bacteria by counting of Colony Forming Units (CFU). The preliminary results revealed that culturable bacterial rates for the different sampling periods were less than 1% of the TDC values for free-living and surface associated bacterial cells (Table 1). Respiring active bacteria using CTC showed that free-living and sediment associated cells represents in general about 10% of the TDC values, these is about 50 to 100 fold higher than culturable rates (Table 1). The statistical analysis using a Statistica software (version 5.0) revealed differences on bacterial activity (CTC) between free-living and sediment associated bacterial cells (ANOVA, $F=4.1$; $P<0.05$). Differences between sampling stations also were observed on the different sampling periods (ANOVA, $F=4.1$; $P<0.05$). This behaviour could be related to the system productivity found in cold season, when there is a higher availability of nutrient on column water with a low production of chlorophyll product of a decrease in solar radiation with the consequence of low utilisation of nutrients by phytoplankton. These results suggest that bacterial cells capable to reduce CTC are likely to be involved in bacterial production with the turn over of energy. Conversely, the higher proportion of non-colourable cells reported in this study (Table 1) could be associated with latter succession states since these bacterial cells direct less energy into growth and/or have a specific type of growth requirements that may not be readily provided in artificial media.

Acknowledgements: This research was supported by a INNOVA Chile Grant N°04CR7IXM-04.

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HCS094 - Near-inertial surface currents observed from Lagrangian drifters

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Keywords: Eastern South Pacific; Global distribution; Near-inertial currents ; Satellite-tracked drifters ; Wind energy flux.

Together with the tides and wind-work at lower frequencies, near-inertial waves generated by wind-stress fluctuations represent an important mechanism for internal mixing of physical and biogeochemical

properties in the deep-ocean. Based on more than 6000 satellite-tracked drifter trajectories, this study investigates the surface current characteristics associated with high frequency movements.
We first start with a regional spectral analysis in the Eastern South Pacific (ESP) which shows slightly enhanced energy for frequencies corresponding to diurnal and semidiurnal tides (K1 and M2 respectively) whereas strong energy maxima are observed at near-inertial frequencies (NIF). In the NIF band, movements are strongly polarized, with spectral energy being largely stronger for anticyclonic motions (Figure 1a-b). In the ESP, important meridional variations of spectral energy are observed: a quasi-linear increase between 10-30°S, a local maximum at 30°S where there is resonance of the NIF with K1, and quasi-constant level of relatively high energy between 30-50°S. Averaged over the region, the inertial energy is higher during summer than during winter. Using the extended complex demodulation technique we reconstruct the 2-D distribution of the velocity amplitude for anticyclonic movements at NIF (Figure 1c). The spatial distribution shows higher amplitudes in the south of the ESP but also along the coastal transition zone. Mean counterclockwise velocity amplitudes increase from around 5-10 cm s^{-1} North of 25°S to 10-15 cm s^{-1} south of 40°S (Figure 1c), corresponding to inertial motions with radii of 1-3 km (Figure 1d).
We then present for the first time a global map of the near-inertial current amplitudes (Figure 1e). In contrast to what is observed in energetic areas such as the Kuroshio or Gulf Stream regions, but in agreement with the other eastern boundary current regions, the ESP inertial currents are relatively week. Using these observations and a high-resolution blended wind product we finally provide a global map of wind energy flux into mixed-layer inertial motions.

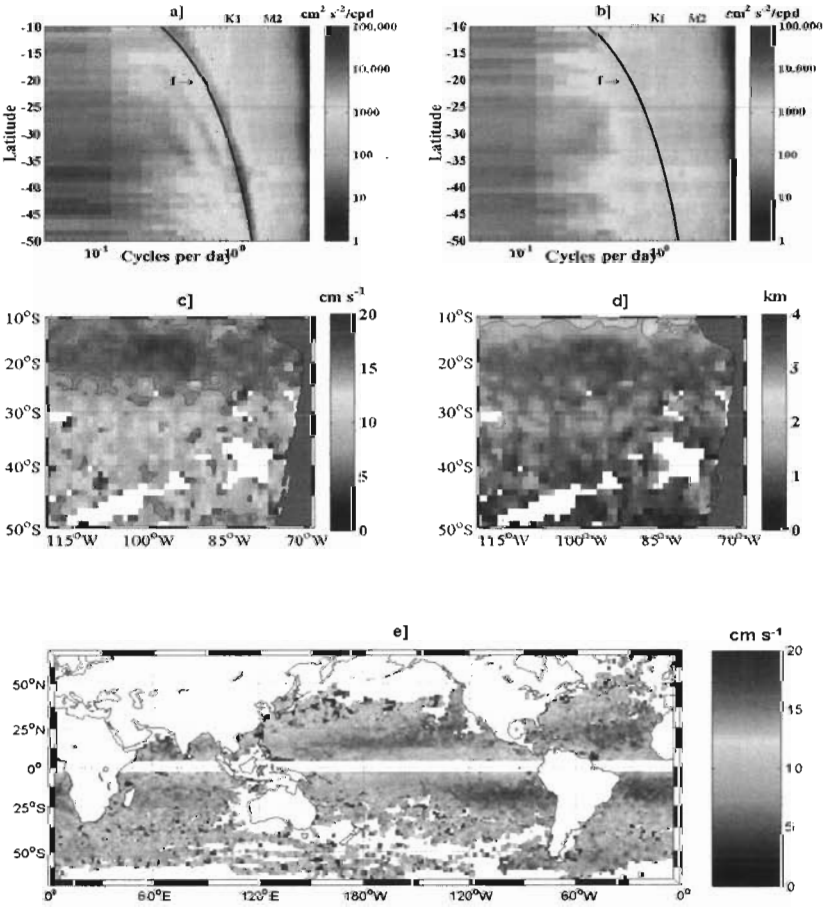

Figure 1: Characteristics of near-inertial currents in the Eastern South Pacific and in the world oceans. a-b] mean spectral energy for each latitude band of the ESP for (a) anticlockwise and (b) clockwise motions. c-d] Mean distribution of (c) near-inertial currents amplitude and (d) and corresponding radii in the ESP. e] Global map of near-inertial currents amplitude.

HCS104 - Coastal trapped waves off the west coast of South America during El Niño

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Keywords: coastal trapped waves, intraseasonal oscillations, wavelet transform

Evidence of coastal trapped waves off the west coast of South America, during the El Niño 1991-92 and 1997-98, is examined by applying wavelet analysis over sea level and alongshore wind stress time series. Wavelet transform reveals the existence of intraseasonal variability and Cross wavelet transform allows us to discriminate the sources in terms of remote and local forcings. Temperature and salinity profiles from an

oceanographic cruise realized during 1992 (El Niño year) were used to compute phase speed of theoretical coastal trapped waves and to compare with estimated phase speed from wavelet spectra.
For the studied El Niños phenomena, we found the existence of intraseasonal oscillations with periods between 20-90 days, between latitudes 2°S and 27°S. We detected oscillations with strong correlation between sea level and local wind, with periods of around 10 days, wich could be associated with "coastal lows", which are atmospheric trapped waves. These oscillations were more intense during El Niño 1991-92. At the peak of the El Niño events, between 6°S e 15°S, we found observed perturbations probably associated with remotely forced internal kelvin waves wich propagate, with periods between 6-50 days with phase speeds between 180-340 km/day. In the region comprised between 12°S and 15°S, we also identified perturbations probably associated barotropic shelf waves propagating southward with velocities between 110 and 150 km/day and periods between 30 and 40 days.
These poleward propagating intraseasonal perturbations off the west coast of South America probably are linked with equatorial wave dynamics, especially during El Niño events, and can have a significant influence in modulating the upwelling system and primary productivity in the region, which is one of the most productive all around the world.

HCS160 - Intraseasonal to annual variability at Paita (5°S) during 1999-2006

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Keywords: Coastal trapped waves, Equatorial Variability, Intraseasonal and near-annual oscillations, Model simulations, Peru Undercurrent, Vertical structure variability

A combination of *in situ* data, satellite data and regional model simulations are used to investigate the vertical structure variability off Paita [Peru, 5°S]. The focus is on the connexion with the equatorial variability at intraseasonnal and near-annual timescales considering that the high-frequency forcing from equatorial origin, although with a weaker amplitude than ENSO events, can also drastically impact marine resources. The observing system at Païta consists in a coastal automatic ocean-meteostation and microscale and mesoscale cross-shelf sections at 20 nm and as far as 200 nm off-shore that continuously measures temperature and salinity on the shelf and in the upper 500 m layer on the continental slope. The comparison between the two sites reveals a contrasted vertical structure variability which corresponds to different dynamical regimes. Whereas the vertical structure variability on the slope is directly influenced by the equatorial variability through coastal-trapped wave activity, the variability on the shelf is dominated by mesoscale recirculation. Combined to altimetric sea level data and an estimate of the equatorial Kelvin wave amplitude from SODA Reanalysis, the *in situ* data and regional atmospheric and oceanic model simulations (ROMS and WRF) are used to document the Peru Undercurrent (PUC) variability in the intraseasonal frequency band off Paita.

HCS161 - Seasonal to decadal variations of the macrobenthic biomass and diversity in the upper Peruvian continental margin influenced by the Oxygen Minimum Zone (1976 – 2005)

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Keywords: benthic communities, ENSO, Oxygen Minimum Zone, Peru margin,

Introduction- Large scale circulation patterns and high regional primary productivity in near-surface waters result in an intense oxygen minimum zone (OMZ; O_2 < 0.5 ml L^{-1}) that intersects the upper continental margin (50 – 600 m depth) off the coast of Peru. Oxygen concentrations have a strong influence on benthic communities in the continental shelf and upper slope, especially where high concentrations of organic matter deplete sedimentary oxygen levels. As a result, there is a strong bathymetric zonation of the macrobenthic communities (Arntz et al., 2006). Moreover, the influence of the less hypoxic Equatorial Undercurrent near the equator results in a latitudinal gradient of the macrobenthic biomass and diversity.
The subsurface oxygen content undergoes significant interannual variability driven by the ENSO cycle, with the OMZ deepening during El Niño (EN). In shallow sublittoral areas, macrobenthic biomass and diversity responses to EN vary in sign and intensity, according to latitude and the sedimentary environment (Tarazona et al., 1988, Gutiérrez et al., 2006). Temporal variability at other time-scales and the dynamics of the deeper sublittoral and bathyal macrobenthic communities is poorly known. For example, it is

unknown if there have been changes in the benthic subsystem associated with the shift from low to high anchovy biomass in the pelagic subsystem off Peru in the last decades. Higher anchovy biomass may increase the export production by increasing the vertical flux of fecal pellets to the seafloor. Increased export may decrease oxygen levels of bottom waters and, in turn, reduce the metazoan benthic biomass and diversity.

Our main objective is to analyze the temporal variability of the sublittoral and bathyal macrobenthic communities off the coast of northern Peru within the last 30 years. We examine seasonal, interannual and decadal variations of macrobenthic biomass and diversity taking into account latitudinal and bathymetric patterns, as well as the temporal variations in oxygen content during the same period.

Methods- A database of 1330 stations from 27 research cruises from 1976 to 2005 was analyzed, covering a study zone from 03°20' to 10°00' S and from 30 to 500 m depth (Fig. 1). The cruises were classified according to season (spring, summer and autumm), ENSO phase (El Niño –EN, La Niña –LN and neutral) and decadal period (low anchovy biomass period prior to 1995, and high anchovy biomass period from 1995 onwards). The Oceanic Niño Index (ONI), which is based on SST anomalies in the EN 3+4 region (http://www.cpc.ncep.noaa.gov/products/), was used to classify the ENSO phase for a given cruise date. The majority of the cruises were performed during autumn (10) and summer (11), and during EN (8) and neutral periods (13). For all the cruises the macrobenthic organisms were classified, counted and weighed by large taxa, and an index of 'phyletic diversity' was estimated based on the number of large taxa determined. In a subset of the cruises the species richness and abundance was determined. Biomass and abundance measurements were log-transformed for analyses. Factorial ANOVA and covariance analyses were used to test for seasonal, interannual and decadal changes of both abiotic and biotic factors under varying latitude and depth.

Results and Discussion- In general, higher oxygen concentrations in bottom waters were observed during (austral) autumn, suggesting a greater influence of the Equatorial undercurrent. Seasonal differences were greatest from 5 to 8°S and from 50 to 200 m depth. As expected, higher oxygen concentrations characterized El Niño periods compared to neutral or La Niña periods. On the other hand, lower (higher) oxygen concentrations were observed during EN (LN) periods after 1994 at 5 – 6°S, although cruises generally occurred during weaker phases of EN and LN events after 1994.

The highest average macrofaunal abundance and biomass were observed from 6-8°S and 5-8°S, respectively. Macrofaunal phyletic diversity and species diversity decreased with latitude, particularly south of 6°S. The correlation between these two diversity indices was significant ($r=0.59$, $n = 582$; $p<0.001$).

Seasonal and interannual differences by latitude with depth as a covariable accounted for ~25% of the total variance of macrofaunal abundance and biomass. Macrofauna tended to reach higher levels of abundance and biomass during autumn, particularly in the latitudes of maximum concentration, suggesting a peak period in recruitment. In terms of interannual variability, macrofaunal abundance tended to increase during EN periods, especially from 5 – 6 °S. Interannual differences were weaker for macrofaunal biomass, but higher values generally occured during EN periods at the same latitudinal range. Seasonal and interannual differences accounted for 45% of the total variance of species richness and 25% of the variance in phyletic diversity. Excluding spring that was undersampled for species richness, higher species numbers were determined during autumn or during EN periods north of 6°S. Phyletic diversity tended to follow the same pattern after excluding spring cruises.

Higher values of abundance and biomass after 1994 could result from the use of a finer mesh size (0.5 mm versus 1 mm before 1994). However, macrofaunal abundance and biomass were lower after 1994 during LN periods within 5 – 8°S. In addition, when season or ENSO are tested versus decadal differences in phyletic diversity, a stronger statistical effect is found for decadal changes, indicating lower phyletic diversity after 1994. This trend is supported by estimates of species richness, which are limited but indicate lower diversity after 1994 during neutral ENSO periods.

In conclusion, seasonal, interannual and decadal variations of macrobenthic biomass and diversity have been documented. Seasonal and interannual changes are clearly associated with oxygen concentrations (with more oxygenated conditions in autumn and EN years favoring the communities). A decadal shift towards lower biomass and diversity after 1994 coincides with an increase in anchovy biomass in the upwelling ecosystem and can not be explained by a decadal change in the near-bottom oxygenation with our available data.

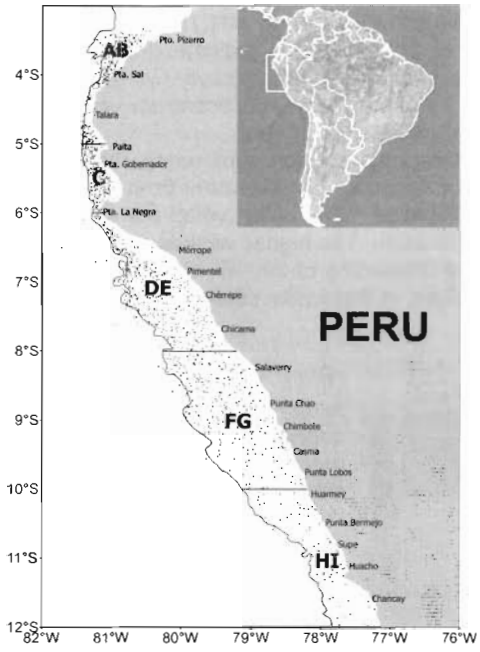

Figure 1. Map of benthic stations surveyed from 1976 to 2005. Latitudinal areas were grouped according to the distribution patterns of oxygen and macrobenthos.

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HCS166 - Impact of the oceanographic variability in the phytoplankton community and the anchovy vertical distribution in front of Callao (12° S) Perú during 1997-2000

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Keywords: oceanography, plankton, anchovy, El Niño, Callao-Perú

The Humboldt upwelling ecosystem is characterized by the occurrence of coastal upwelling events. The coastal upwelling areas are under the influence of a significant oceanographic variability (e.g., local, remote forcing) a different time scales (seasonal, interannual, decadal) with one of the most strong El Niño South Oscillation (ENSO) signals. The upwelling events carry up to the surface rich nutrients and oxygen deficient subsurface waters that promote high primary productivity and the availability of abundant pelagic resources in front of Perú. The main pelagic resource is the anchovy (*Engraulis ringens*), representing 95% of the total landings in Perú (6.8 millions tons per year). However, anchovy production can vary widely from year to year. The variations in the distribution and biomass of this resource were apparently caused by environmental changes but not still totally understood.

This work explores the relationship and impact of the oceanographic conditions in front of Callao (12°00' S) in the phytoplankton community and vertical distribution of the resource anchovy during 1997-2000 years, including the large El Niño 1997-1998. There were analyzed salinity, temperature, dissolved oxygen, nutrients, chlorophyll a, superficial bio-volume and composition of phytoplankton and vertical distribution of anchovy in the water column in two stations St 3 and 4 (13-20 nm from the coast). The data show in the area a significant deepening in the 15° C isotherm below 80 m from April 1997 until June-July 1998. This was coincident with changes in the oxygen minimum conditions (< 0.5 mL/L) and its upper boundary position (1 mL/ L, Fig. 1). In consequence, the 1997-1998 period was characterized by a well oxygenated and warmer (18-23° C) water column as is expected during El Niño event. Furthermore, the chlorophyll a concentrations integrated in the water column showed a significant reduction (< 82.40 mg/m^2 Fig 1.), that matches up with a reduction in the phytoplankton volume (e.g. 0.009 mL/m^3 November 1997) and/or changes in the dominant species, the presence of warm waters diatoms (*Planktoniella sol, Rhizosolenia styliformis, Detonula confervacea, Guinardia flaccida* and *Streptotheca thamesis*) and/or a higher frequency of thermophyllic dinoflagellates (*Ceratium gibberum V. dispar, C. buceros, C. candelabrum, C. contortum* v. *karstenii, Pyrocystis fusiformis* and *Goniodoma polyedricum*).

In contrast, during 1999 and 2000 years considered a non El Niño period the water column was characterized by a very shallow 15° C isotherm (30-40 m) and low oxygen concentrations (below 20-30 m, Fig. 1) indicating the presence of coastal cold waters. A positive correlation appear between temperature and dissolved oxygen concentrations (R^2 0.65). The water column chlorophyll a values and phytoplankton

volumes were significant higher than in 1997-98 period, with concentrations up to 301.75 mg/m^2 (Fig. 1) and up to 5 mL/ m^3 respectively. The composition analyses of phytoplankton indicate dominance of diatoms characteristics of coastal upwelling events (*Chaetoceros affinis, Ch. compressus, Ch. curvisetus, Ch. didymus* and *Coscinodiscus perforatus*) and cosmopolitan dinoflagellates (*Prorocentrum gracile, P. micans, Ceratium furca*).

Furthermore the changes in the oceanographic conditions and the phytoplankton community, the vertical distribution of the anchovy in front of Callao evidence a significant resource displacement from surface (> 20 m, Fig 1) to deeper layers, reaching up to 40 m during May-June of 1997. Later, when the conditions were "normalized" the anchovy distribution was mostly between 10-25 m. The higher vertical distribution in the water column of this resource during 1997 match up with the deepening of the 15° C isotherm, lower chlorophyll a and phytoplankton volumes and the oxygen increase in the water column with a positive correlation with the oxygen minimum zone distribution (R^2 0.379).

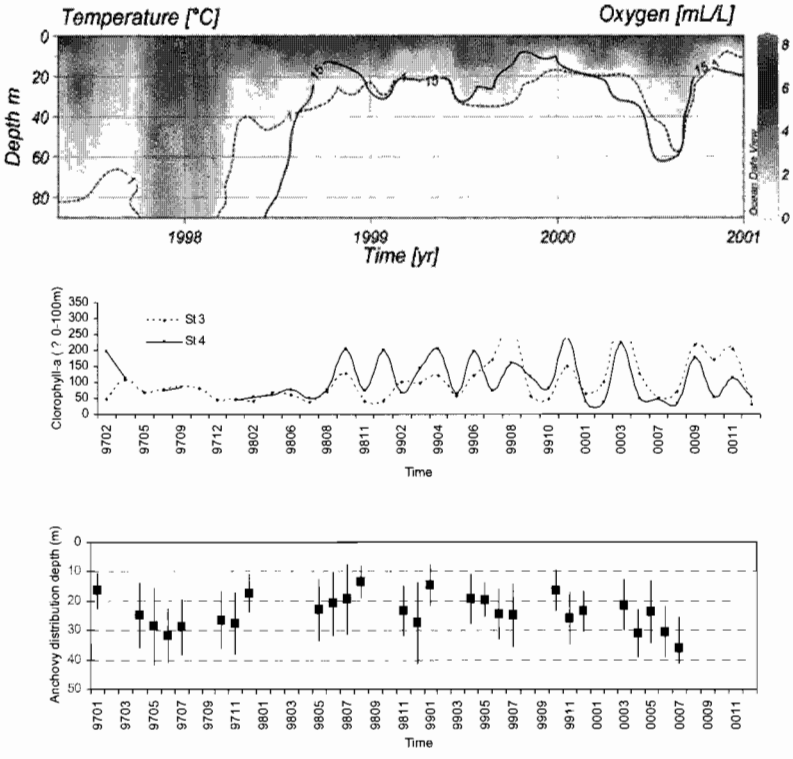

Figure 1. Time series of (upper panel) dissolved oxygen concentrations, dotted line represents the 1 mL/L dissolved oxygen concentration and solid line the 15° C isotherm; (middle panel) water column chlorophyll a concentrations (Σ 0-100 m) and (lower graphic) anchovy vertical distribution depths in front of Callao during 1997-2000 years.

HCS180 - Interannual variability of oceanographic conditions and phytoplankton in the upwelling zone off Pimentel (06° 50´ 05.5" S, 79° 56´11.04" W), Perú (2001 – 2006)

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Keywords: El Niño; interannual variability; Kelvin waves; Lobos de Afuera islands; northern Perú.

Interannual changes of oceanographic and biological conditions in the water column are studied using time series of temperature, salinity, oxygen, and phytoplankton data in an upwelling area (Morón, 2002), off Pimentel (06° 50´ 05.5" S, 79° 56´11.04" W). Cold Coastal Waters (CCW) were typical conditions and prevailed on period, except in summer 2001, summer/autunm 2002 (related to positive anomalies of El Niño), winter 2003, spring 2004, autumn 2005 and summer 2006, characterized by the presence of Surface Equatorial Waters (SEW) (Fig. 1). During winter 2002 and in summer 2005 were observed a mixing of CCW and Surface Subtropical Waters (SSW). The conditions in January - February of 2006 were similar to those of 2001. After the warm episode 2002, the Kelvin waves that impacted in the South American coast in winter 2003, spring 2004 and autumn of the 2005, was reflected off Pimentel as trapped waves, affecting the depth layer of 20 m (August - September 2003). In this context, such waves reached depths of up to 50 m, a distance of 30 nautical miles offshore, in September - December of the 2004 and April of the 2005, indicating a strong impact in the coast, north of the 7°S. In January - February 2006, the presence of SEW in Pimentel was not due to the Kelvin waves, but to a strong projection of SEW.

The concentration of dissolved oxygen in the under layer showed mixing conditions between the ACF and the oxygenated waters of the Southern Extension of the Cromwell Undercurrent (SECU). The SECU

showed a strong projection toward the south in May - July 2001, while in the 2002 it approached to the coast and became deeper during 2005.
In the study area the 15°C isotherm does not get deeper in the north area (Paita and Punta Falsa) as normally do due to the convergence of the SECU with the CCW, but high oxygen contents are observed in autumn.
The species richness of phytoplankton registered in May of 2003 and February of 2002 varied between 22 and 100 species, respectively. In a temporal scale, the number of diatoms species was superior to that of the dinoflagellate, and the biggest species number in both cases was observed in February 2002 with 57 and 41 species, respectively, due to the addition of species from equatorial waters to upwelling waters. It is postulated that the presence of waves Kelvin associated with the SECU, was responsible for the low phytoplankton volumes in the studied area. The diatoms and dinoflagellate organisms were more frequent in some months of 2001, 2002 and 2004, coinciding with the displacement of warm waters.
The results indicate that the period of study was dominated by the presence of an event EN (2002) and coastal trapped waves, contrary to the marked seasonality of the SECU (1998-2001) reported by other authors (Gutierrez *et al.* 2005).

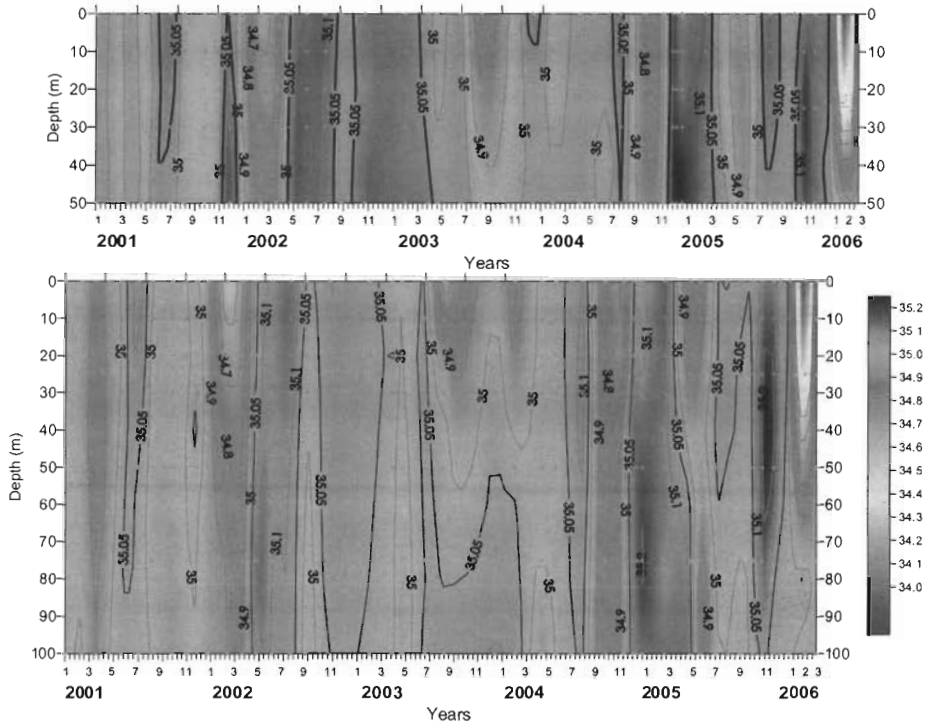

Figure 1. Times series of salinity at the station 4; 58 m of deep (a) and at the station 7; 124 m of deep (b), in the section San José - islas Lobos de Afuera, 2001 - 2006.

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HCS181 - Observing the Dynamics of the Humboldt Current with Coastal HF Radars

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A network of 60 SeaSonde coastal HF radars is being brought on line to map surface currents along the coast of California in real time. Ten of these form the outer span of a nested grid, reaching beyond the continental shelf to a distance of 200 km. Thus they observe the California Current, which is the Northern counterpart to the Humboldt Current system off South America. Analogously, ten such systems along the coast of Peru can map its dynamics, including upwelling activities and regional jets. We show a depiction of the Peruvian area coverage from such a network.
We have been developing methods to "pre-condition" the radar data -- both the raw polar radial velocities as well as the 2D total horizontal velocities -- before assimilation into others' numerical circulation models (e.g., ROMS, POM). Those models include temperature, salinity, and other conservative quantities of interest, and can forecast conditions into the future. We present details of these pre-conditioning methods, including use of a Navier-Stokes equation constraint that extends the coverage to regions

where only one radar can see. The works of others who have been using SeaSonde radar data in this regard are reviewed also: for example, the use of Normal Mode Analysis (NMA) nowcasts to determine fates of floating fish larvae. Finally, we show accuracy improvements realized by others to numerical modeling based on assimilation of SeaSonde HF radar measurements over this important, expansive, and continuous upper ocean boundary.

HCS211 - Surface circulation in the eastern South Pacific derived from satellite altimetry data

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Keywords: Eastern South Pacific; Humboldt Current; Subtropical Gyre.

Satellite-borne mean sea level anomalies were blended with mean dynamic topography to obtain seasonal climatologies of the eastern South Pacific Ocean's surface circulation. The Humboldt Current could clearly be identified in all climatologies, although it was most pronounced in austral summer, when the equatorward current extended from 38 - 20° S, with maximum speeds of about 20 cm s^{-1}, and confined to a narrow band of roughly 250 km in width. The current streamed closer to the coast in its southern section (76° W) and diverted slightly to north-northwesterly directions around 30°S; further north, it flowed along 80°W. A bifurcation took place at 24° S, creating one branch towards the coast (Arica) and the other directed towards the South Equatorial Current. The Arica branch was stronger in winter, whereas the latter was stronger in summer. A retention zone was sustained between both branches throughout the year which also is present in Kessler's (2006) mean surface circulation of the eastern tropical Pacific derived from surface drifters. After crossing the Nazca Ridge, the seaward branch of the HC spun to the west (at around 85° W) in both seasons. It then continued to meander north, somewhat weaker in strength than off central Chile, to finally join the South Equatorial Current.
The main seasonal differences in circulation strength were found in the westward South Equatorial Current (5-15° S). The southern portion of this current was strongest in austral summer, whereas the northern portion was strongest in winter. We relate this seasonal shift to the Intertropical Convergence's meridional movement across the seasons. Although somewhat weaker, the Humboldt Current maintained its position during El Niño 1997/98, whereas the South Equatorial Current came to a complete standstill with virtually no westward flow at the onset of the strong El Niño 1997/98.
Within the eastern portion of the South Pacific subtropical gyre, besides by means of the Humboldt Current, equatorward surface transport took place in several bands (e.g. 90° W and 115° W), although in smaller quantities, thereby creating different recirculation cells. The South Pacific Current appeared as a weaker and less organized meander-like flow separated into several bands turning northward east of 90°W. Similar results were obtained by Stramma et al. (1995).

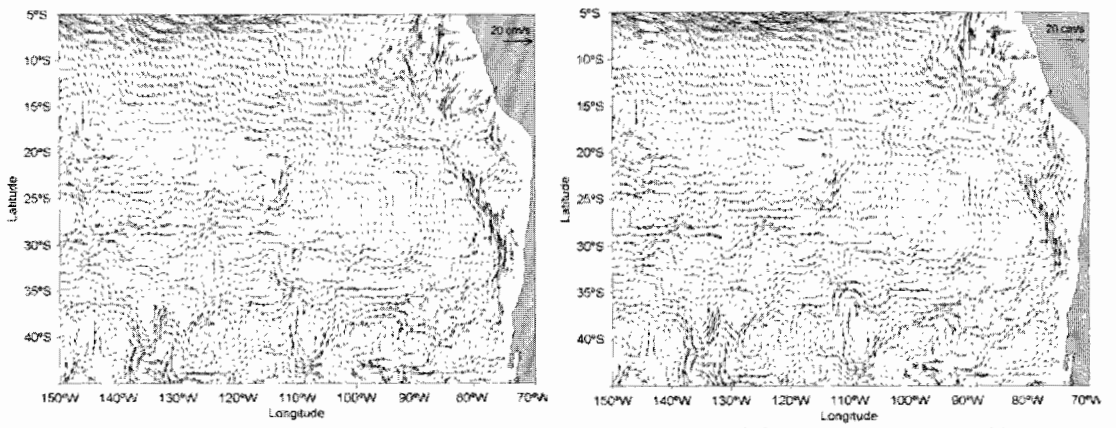

Figure 1. Seasonal climatologies 1992-2003: Geostrophic velocities a) for austral summer without El Niño 1997/98; b) for austral winter without El Niño 1997/98. A scale vector for velocity is shown in each upper right panel.

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Part 2

Wednesday afternoon

HCS002 - Day-night differences in zooplankton biomass in the Eastern Tropical Pacific. Results from historical data

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According to our recent results in the eastern tropical Pacific (ETPac), no day-night differences in near surface (0-200m)zooplankton biomass have been found during summer or winter cruises (Färber-Lorda et al. 2004b and Färber Lorda et al, 2006). Trying to better understand these results and considering the special features of this wide area, we examined historical data to determine whether these differences were real or just the consequence of limited or highly variable data. Historical data from the EASTROPAC cruises and other cruises were utilized. An ANOVA comparing night and day zooplankton volumes obtained with a 330 µm mesh net, showed significant differences. Other statistical tests separating season, or bimester showed significant differences with a multiple way ANOVA. Even if significant differences were found, probably due to the great variability of the results, large areas of the ETPac show a night/day zooplankton volume ratio close to 1, these are areas, in general characterized by a shallow oxygen minimum layer (40 -100m), in which oxygen is lower than 1 ml/l, and cover a wide area in the northern hemisphere between 5 to 15° N and around the Costa Rica Dome. A smaller set of data of samples obtained with a 505 µm mesh net, also showed significant differences. It is hypothesized that low oxygen is limiting the vertical migration of zooplankton. A comparison with the California Current zooplankton volume data from the CalCOFI program, showed no differences for samples obtained with a 505 µm mesh net, night/day ratios seem to be higher in the ETPac, however, night/day ratios of less than 1 were very almost absent in the CalCOFI area. Further studies are in course to better understand this phenomenon.

HCS014 - Effect of feeding ration on gonad maturation and fat accumulation in Peruvian anchovy (*Engraulis ringens* JENYNS).

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Keywords: Anchovy, reproduction, fat, feeding, energy.

Laboratory experiments are commonly used to give complementary information on fishery resources, in regards to surviving and processes such as growth and reproduction of aquatic organisms. In this context, the effect of the feeding ratio on the gonadal development of Peruvian anchovy *E. ringens* in captivity was analyzed, with the main objective of understanding and explaining its reproductive biology, which is important to make an adequate fishery management.
The use of partial condition factor (Bradford, 1993) allowed us to determine where the energy provided by food was directed; i.e. gonad weight gain, somatic weight gain or body fat storage. The maturation of the gonad and the rates of oocyte atresia were studied using histological analysis.
The interval to pass from immaturity to maturity was less than 45 days, under feeding conditions similar to natural environment (46.1 cal*g^{-1} body weight*day^{-1}). Individuals fed with 138.3 cal*g^{-1} body weight*day^{-1} matured the gonads in 30 days and although the food was excessive they did not increased their muscle mass. In the other hand, oocytes from fishes fed with 46.1 cal*g^{-1} body weight*day^{-1} had restarted atresia faster than oocytes from fishes fed with 138.3 cal*g^{-1} body weight*day^{-1}. We also observed variations in the rates of atresia between treatments, and discuss the possible effects that feeding could have.
Although feed supply was appropriate, females did not spawn during the experiment. In males, food availability is shown to speed up or slow down spermatogenesis, but the gametes expulsion was conditioned by the presence of mature females.
Energetic requirements of Peruvian anchovy published by different authors are considerably variable, probably because they have not taken into account the maturity stage of the fish. According to our observations, this is an important factor to be considered for energetic requirement calculations.

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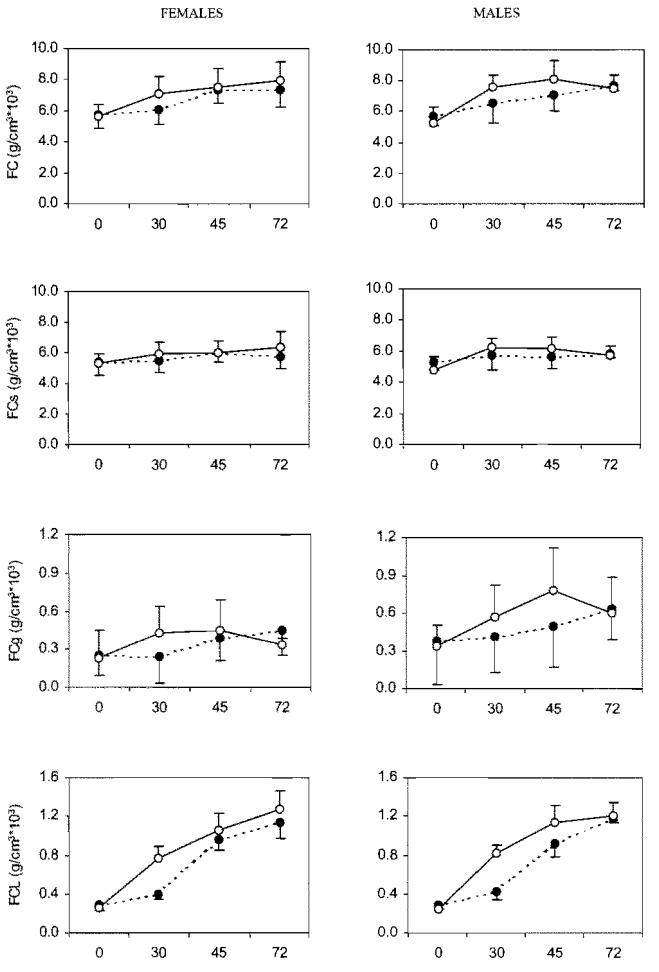

*Figure 1. Factors of partial condition of individuals of Peruvian anchovy in captivity. FC: Total condition factor; FCs: somatic condition factor; FCg: Gonad condition factor; FCL: Lipid condition factor. Black circles correspond to individuals fed with daily portion of 46.1 cal*g^{-1} body weight*day^{-1} and white circles to individuals fed with 138,3 cal*g^{-1} body weight *day^{-1}.*

HCS017 - Preliminary studies of zooplankton in the Peruvian sea, using a combined methodology of multifrequency acoustics and plankton multinets.

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Key words: Multifrequency, TAPS, zooplankton

The present work reports preliminary results on the zooplankton abundance and its distribution in size classes, deduced from the use of multifrequency acoustic methods, combined with plankton stratified sampling by means of a multinet device.
Data were collected during a survey performed on board the R/V Olaya, off the Peruvian coasts, from April 23rd to May 2nd 2006. Two types of multifrequency data were acquired: first continuous data along transects from an EK60 echosounder working at four frequencies (38, 70, 120, 200 kHz), second vertical profiles acquired in stations from a TAPS™ (265, 420, 700 kHz, 1.1, 1.85 and 3 MHz). Plankton samples were systematically caught after each TAPS™ profile through the multinet (mesh size, 300 µm).
Each type of acoustic data provides complementary information as they scan different zooplankton size structure. The TAPS™ has been designed particularly to focus copepods but detects also euphausiids, amphipods, chaetognaths, etc ... that is organisms with an equivalent radius from about 0.05 to 4 mm. The equivalent radius (ER), radius of a regular shape, sphere or cylinder, presenting the same volume as the organism, is the size parameter provided by the acoustic data processing. The echosounder detects the larger parts of the zooplankton partly including the same organisms than the TAPS (for example large euphausiids or krill) but detects also everything larger until the fish.
The specific information on the populations was provided by the plankton nets. From shapes and sizes, species can be distributed into classes of equivalent radii that are comparable to the output sizes provided by acoustics. According to the knowledge of the main species present, a choice of zooplankton model has been done to process the data (Figure 1, Stanton *et al.* 94, Stanton 89, Holliday 92). In both cases (TAPS and echosounder data), results were expressed in terms of "the more representative population according to the acoustic scattering measured". This population is described by an organism model (shape and material type), an ER distribution and a corresponding biovolumes distribution.

Processing of echosounder data was performed with the software Movies+ which includes an "inversion" functionality allowing classifying the detection types from multiple frequency data. TAPS data were processed through a dedicated program in Matlab.
The descriptions of the biologic components of the sampled area provided by both types of acoustic equipments are compared and their complementarity is discussed. The relationship between the acoustic results and the biological samples captured by net is also studied.
The combination of the three sampling tools, that is multiple frequency echosounder, TAPS and stratified plankton nets, allowed a rather exhaustive description of the biotic components of the ecosystem (fish and zooplankton). Oppositely to plankton nets that give punctual information, continuous data are available through acoustic equipments. The TAPS provides a vertical continuity in the quantitative estimates of the biomass and of the size distribution of the small zooplankton, with a fine vertical resolution (of the order of 2 meters high). The echosounders provide continuous data in both vertical and along ship horizontal dimensions. This combined approach is therefore a help for a direct study of generally predator-preys and more particularly fish-zooplankton relationships.

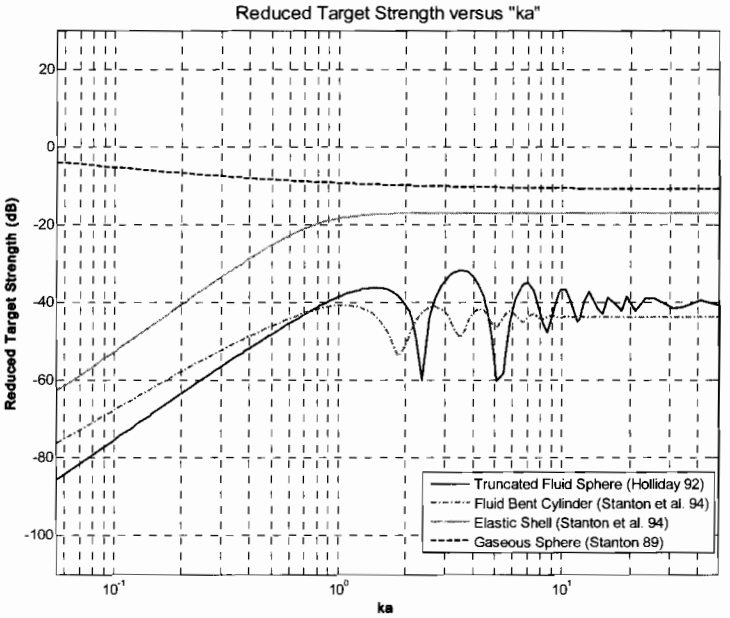

Figure1. Frequency responses used to model four main types of zooplankton: fluid sphere for the copepods, fluid bent cylinder for the euphausiids, elastic shell for the gastropods and gaseous sphere for the gaseous inclusion of some siphonophores.

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HCS035 - *Nodilittorina peruviana* (Gastropoda: Littorinidae) effects on epilitic biofilm abundance and on barnacle settlers survival in a rocky intertidal of central Peru

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Keywords: barnacle, biofilm, grazing, intertidal, *Nodilittorina peruviana*.

Introduction- Littorinid gastropods are cosmopolitan and ubiquitous in intertidal marine ecosystems. Most high shore Littorinidae feed on the epilithic biofilm of micro-algae, but also on ephemeral filamentous or foliose algae and macro-algae; influencing both primary production and overall community structure. They can also affect directly and indirectly recruitment and survival of sessile organisms, such as barnacles, while grazing.
In the Peruvian rocky shores, the high zone is dominated by the littorinid *Nodilittorina peruviana* (Paredes, 1974). There, the vertical distribution of *N. peruviana* ranges from the bare substrate in the higher zone, to the barnacle belt of *Jehlius cirratus* and *Notochthamalus scabrosus* lower in the shore, overlapping its distribution with that of barnacles. In this study we evaluated the effects of *N. peruviana* grazing on the abundance of the epilithic biofilm of micro-algae of the mid-high intertidal zone and on the settlement and survival of the barnacles *J. cirratus* and *N. scabrosus*. The study was conducted on a rocky intertidal next to the Ancón bay (11°46'S, 77°11'W), in central Peru.

Methods- To investigate the grazing effects of *N. peruviana* on the abundance of micro-algae and barnacle recruitment, 10 x 10 cm plots in which snails were excluded (exclusions) were compared with plots where snails were allowed to enter (controls and experimental controls). Experimental plots were established at two heights of the shore: in the upper limit of distribution of barnacles and within the barnacle belt (herein after the "high" and "low" zones, respectively). The vertical distance between the two heights was ~35 cm. Eight plots were assigned to each treatment. To homogenize initial conditions, each plot was previously scraped and sprayed with oven-cleaner (NaOH, which degrades to NaCl and water when in contact with seawater) to ensure the elimination of all organisms. Exclusions were bordered with a thin coat of epoxy putty and a copper based antifouling paint was applied directly on the epoxy when it was still wet. Experimental controls were also bordered with the epoxy, but only with two opposite sides painted. This allowed testing for possible effects of the epoxy border in retaining water, creating little pools; and for the effects of the antifouling paint on the biofilm and barnacle recruiting and survival. Control plots were marked with epoxy putty in two diagonally opposed corners. Exclusions were controlled at regular intervals, removing any snail that could be entered, and painting if necessary. Experiments were set up on October 2005.
Biofilm abundance was assessed indirectly by means of the chlorophyll *a* (Chl *a*) content of the rock. Forty-five days after starting the experiments, 1 to 10 rock chips, with a total mean area of 4.69cm^2, were extracted from each plot and Chl-*a* was measured with the cold methanol method (see Thompson et al. 1999). In March 2006, density of barnacle recruits was estimated either visually or from digital pictures taken from four sub-sampled quadrants (2 x 2 cm) of each plot.

Results- Chl-*a* abundance was higher in the low intertidal zone than in the high zone (two-way ANOVA, $p < 0.001$, $\log_{10}$ transformed data); and was consistently higher in exclusions than in controls and experimental controls for both intertidal zones (ug_{Chla}/cm^2 (mean, SD); E-L: 1.84, 1.08; EC-L: 1.28, 0.55; C-L: 0.84, 0.33; E-H: 0.70, 0.14; EC-H: 0.65, 0.39; C-H: 0.40, 0.18. "H" refers to high zone, "L" to low zone; "E" are the exclusions, "EC" are the experimental controls, and "C" the controls), despite significant differences among treatments within zones were only found between exclusions and controls from the low zone (Two-way ANOVA, Tukey HSD test, $p = 0.01$). Barnacle recruits density was markedly higher in the exclusion of the low zone, while there were no differences in the rest of the treatments (N recruits/4 cm^2 (mean, SD): E-L: 9.47, 11.01; EC-L: 0.22, 0.25; C-L: 0.12, 0.27; E-H: 0.06, 0.11; EC-H: 0.09, 0.13; C-H: 0.03, 0.09; Two-way ANOVA, Tukey HSD test, $p < 0.01$ for all comparisons).

Discussion- The copper based antifouling paint combined with the epoxy putty was a successful method to exclude *N. peruviana*, and did not have evident negative effects on the biofilm abundance, neither on barnacle recruitment nor survival. *N. peruviana* grazing reduces the abundance of the epilitic biofilm at both the high and low shore. However, longer emersion times in the high shore might reduce biofilm abundance and therefore littorinids would have little impact on it. Barnacle settlers survival was markedly enhanced in the exclusions in the low shore, and were nearly absent in low shore controls and in all the treatments in the high shore. This shows that settlers' survival is reduced by grazing in the low shore. Grazing can affect barnacle recruitment either directly by consumption, bulldozing or crushing of new settled individual; or indirectly through the removal of the epilithic biofilm, which in turns may facilitate cyprids settlement (Thompson et al, 1998). Higher in the intertidal, however, desiccation stress or a lower number of larvae, as a result of shorter immersion times, may control recruits settling and survival. Our results suggest that the relative importance of littorinid grazing decreases with increasing tidal height in the high shore, and even a ~35cm vertical height difference may cause a considerable difference in community dynamics, especially given the narrow vertical tidal range in the central coast of Peru.

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HCS042 - Changes in the long-term distribution of zooplankton in the Humboldt Current Ecosystem off Peru 1963-2005

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Keywords : Humboldt Current Ecosystem, Time series, Zooplankton

We examine changes in the distribution and bio-volume of zooplankton from 1963-2005 and their possible relationship to seasonal, environmental (temperature and salinity), temporal (day-night and year) and

geographical parameters (north-south and on-off shelf) using a data set, assembled by the Instituto del Mar del Peru (IMARPE), Using classification and regression trees (CART) we showed that the zooplankton distribution can be divided into four time periods: prior to 1974.5, 1974.5 to 1989.5, 1989.5 to 1997.5 and since 1997.5. These periods differ in overall bio-volume, but more importantly in the relationship with various parameters. Offshore-onshore, seasonal, diel and north-south patterns are all apparent in the temporal changes observed in zooplankton distribution. In the early period, zooplankton bio-volume was high throughout the Peruvian Humboldt current ecosystem and showed enhanced abundance in all seasons but winter. After 1974.5 the bio-volume was considerably lower. There was, in general, an increased difference between the shelf (lower volume) and offshore (higher volume), with a significant day-night effect detected offshore, due to the effect of diel migration on both distribution of zooplankton (since samples were only taken in the upper 50 meters of the water column) and possible increased net avoidance during daytime. After 1989.5 seasonal effects were observed and bio-volume appeared to be higher in the winter in the northern region (north of 9°S) than in other regions of the coast. In other seasons the bio-volume was on average double during night than during daytime samples, but higher during the daytime farther offshore (greater than 65 km offshore of the 200-m isobath) and during the night higher after 1997.5 than before. We suggest here that biomass shifts in zooplankton have been accompanied by various distribution shifts.

HCS050 - Feeding and reproduction of two pelagic copepods in the Chilean northern upwelling system: effects of abrupt changes in the diet

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Keywords: Copepods, ENSO, food, metabolism, population's demography.

Changes in the community structure of the pelagic system in the Chilean northern upwelling zone are some of the consequences of El Niño Southern Oscillation cycle (ENSO). During the warm phase of ENSO (El Niño conditions), the phytoplankton assemblages are dominated by small diatoms and autotrophic flagellates, whereas large chain-forming diatoms prevail under normal upwelling, cold conditions (Iriarte *et al.*, 2000). The highly abundant pelagic copepods in the upwelling zone and feeding on this phytoplankton must adjust their diets as a response to such changes. Little is known for this system about the ecological consequences of changing diet for copepods. In studies from other regions is known that demography of copepod populations is related with reproductive success, which may strongly depend of food quality. In this context, an interesting discussion has taken place to elucidate if food limitation, nutrient- deficient o inhibitory metabolites can affect copepod reproduction (Lacoste *et al.*, 2001). Altered fecundity can result from changes in dietary composition, particles concentration and species succession with different chemicals signals. Therefore, females capable to use more nutritive and/or less toxic food, will exhibit reproductive advantages (Lacoste *et al.*, 2001). Accepting that phytoplanktonic species successions involve changes on the physic-chemical properties of the available energy; and also because food utilization could be different within the copepods community, comprised by co-existing species with similar trophic niche, we would expect to find differences in the metabolic efficiency of populations exposed to these natural perturbations. In this work we examine the responses of two dominant copepods species of the upwelling system of the Chilean northern coast to changes in food resources. These changes are assumed as representing a simulation of altered food items upon an El Niño event.
Studies were conducted in two upwelling sites of the Chilean northern coast, Mejillones (23ºS) and Chipana (21ºS). Experiments consisted in incubations of the copepods *Acartia tonsa* and *Centropages brachiatus* in natural diets, in the food fraction of <20 µm. We found significant differences in egg production rate (EP) (egg female^{-1} d^{-1}) and fecal pellets production rate (FP) (pellet female^{-1} d^{-1}) between species and sites. Both rates showed a similar tendency as incrementing with time of exposition to a diet, implying acclimation to either food or experimental conditions. The EP obtained in Mejillones for *C. brachiatus* in the first 24 h of incubation was 10.7 ± 2.1 increasing at 17.3 ± 2.2 at 48 h, whereas FP varied between 12 ± 2.1 and 17 ± 2.0 towards the end of the experiment. On Mejillones the EP rate of *A. tonsa* varied between 3.4 ± 0.8, increasing to 11.2 ± 0.4, whereas in Chipana the EP was between 3.3 ± 0.4 and 16 ± 1.0. The ingestion of *A. tonsa* increased in Mejillones from 4.4 ± 0.7 at 8.7 ± 1.5 and in Chipana varied between 3.1 ± 0.3 and 13.5 ± 0.9. A strong and positive relationship between FP and EP (r^2=0.96;p<0.05) was found indicating lack of saturation or inhibotory effects of food. The phytoplanktonic distribution and biomass were notably distinct in both. Phytoplankton was characterized by near-surface peak (10 mg Chlo-*a* m^{-3}) in Mejillones and subsurface weak peak (5 mg Chlo-*a* m^{-3}) in Chipana. The phytoplankton composition was dominated by dinoflagellates (>60% abundance contribution) and small diatoms at depths below the photic zone, with abundances in the order of 10^6-10^7 cell l^{-1}.
A. tonsa is an opportunistic species that responds rapidly to changes on food conditions, and is capable to utilize a wide dietary spectrum (size-composition). Females of this specie do not store reserves, but they

rapidly invest the food in EP, diminishing its fecundity when the food is not suitable (Roman 1984). *C brachiatus* is omnivorous and can use phytoplanktonic diets as well as others zooplankters. The fecundity shown by these species in our study is consistent with other works, although with values relatively lower, suggesting that diet quantity-quality or the efficiency of its utilization was not optimal to sustain maximal metabolic outcome (EP). However the comparison of these results suggest that both species can use quickly and efficiently different fractions of the food that usually dominate under normal conditions on the pelagic system of the Chilean northern upwelling centers. This capacity would allow them to sustain stable rates of egg production and thus contribute to maintain stable population demographies. In fact both species are dominant and abundant in either normal upwelling or during El Niño conditions.

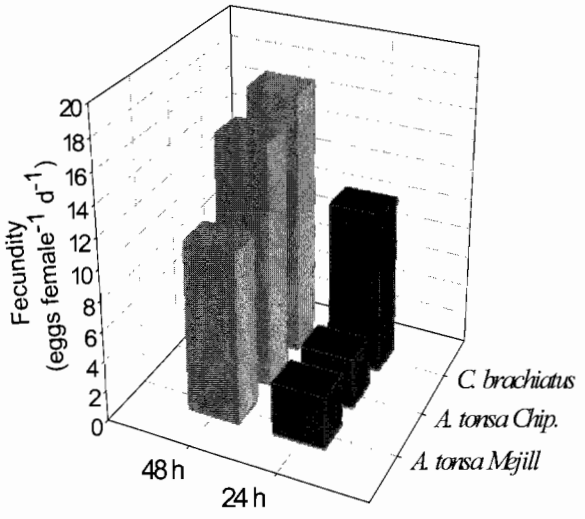

Figure 1. Eggs production rates of Acartia tonsa and Centropages brachiatus, collected and incubated whit nature diet <20 µm from Chilean north coast during summer 2006.

This work is a contribution of CENSOR Project.

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HCS052 - Seasonal secondary production of small copepods in the Upwelling System off Central Chile (36° S): Effect of feeding behaviour and food quality

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Keywords: upwelling area, copepodites, secondary production, fish recruitment

The Humboldt Current System (HCS) have been recognized as some of the areas with the highest biological production in the oceans, which has been usually attributed to the occurrence of coastal upwelling (Alheit & Bernal 1993). The coastal upwelling area off Central Chile (~36° S) constitute one of the sites with highest biological production within the HCS, where high zooplankton biomasses are observed practically year-round. Commonly, copepods are considered as a major component for zooplankton secondary production in coastal marine ecosystems. The spawning of many fishes coincides with the maximum food availability in terms of copepod secondary production for their larvae. In fact, eggs and early larval stages of small copepods constitute major food items for larval and fish juvenile, specially during the first feeding period, when larval fish are highly vulnerable to starvation (Richardson et al. 2003). An important aspect of both copepod population dynamic and their role in biogeochemical cycles is their growth rate and secondary production (Hirst et al 2005). In Central Chile, small copepods constitute one of the more abundant zooplankters, with the copepod species *Acartia tonsa* and *Paracalanus parvus* as numerically dominant component over the continental shelf. There are scarce studies about the feeding behaviour, reproduction and copepod growth, and therefore, on the dynamic population of these species in coastal upwelling areas of the HCS. Antecedents from the coastal upwelling area off Central Chile suggest a scenario where the contribution of small cells, large algal cells and protozoan to the food assemblages may exhibit strong seasonal variation as a response to a very dynamical upwelling regime. It is known that quantity and quality of food are important factors for copepod growth. The quality of the ingested food, in

addition to other factors such as temperature or prey selection, seems to be essential variable to model the dynamic population of these organisms in the planktonic food web (Touratier et al. 1999). Therefore, seasonal changes in copepod food composition suggests a high variability in the food quality available for copepod feeding and growth. Here we report estimates of copepodite feeding selectivity, growth rate and secondary production in response to seasonally changing phytoplankton characteristics measured in a highly productive coastal upwelling area off Central Chile. During seasonal cruises, detailed analyses of phytoplankton and protozoan community, size-fractioned pigments, and fatty acids composition of seston, were conducted to evaluate the food quality available for copepodite growth in the numerically dominant species *Acartia tonsa* and *Paracalanus parvus.* Copepodite growth rates were assessed through application of direct measurements of growth based on the estimate of 'moulting rates' by short-term incubations under natural conditions observed during the seasonal cycle. For secondary production estimates, egg production rate in mature females of *A. tonsa* and *P. parvus* was estimated in parallel over the seasonal cycle.

The results of copepodite feeding on naturally food assemblages during winter evidenced that both copepod species preyed actively on small autotrophic, heterotrophic nanoflagellates and dinoflagellates, which corresponded to numerically dominant food items at winter time. Under such diet copepodite growth rate was ~0.04 µgC copepod^{-1} d^{-1}. During spring, when chain-forming diatoms were abundant at upwelling blooms, copepodites ingested not only flagellates and dinoflagellates, but also chain diatoms such as, *Thalassiosira* sp., *Skeletonema costatum* and *Chaetoceros* sp. Size-fractioned fatty acid composition showed that during the spring polyunsaturated fatty acids (PUFA) were abundant in the microplankton > 20 µm fraction (2,2– 5,3 µg L^{-1}), mostly dominated by diatom chains, and which resulted in higher growth rates (0.19 µgC copepod^{-1} d^{-1}). Similar conditions were observed during summer, with a high contribution of dinoflagellates and chain-forming diatoms to the copepodite diet. The highest copepodite growth were observed during this season, with mean rates of 0.26 µgC copepod^{-1} d^{-1}. In autumn, diatom abundance was very low, as well as, the total PUFA concentration (0.04 µg L^{-1}). Copepodite diet was based mostly in small dinoflagellates, and growth rate averaged ~0.08 µgC copepod^{-1} d^{-1}. Maximum egg production was also observed during the spring/summer period (~40 to 60 eggs female^{-1} d^{-1}), whereas a low egg production occurred at autumn/winter time (< 10 eggs female^{-1} d^{-1}). Integrated secondary production of small copepods in the upper 35 m depth ranged between 7.2 in winter to 172.8 mgC m^{-2} d^{-1} during summer. Depending on the food availability, diets had different effects on copepod growth rates and secondary production. High HUFA/PUFA availability in diatom-based diets may play an important role determining the highest copepod production during spring/summer, which coincide with the spawning of many species of pelagic fishes in coastal upwelling areas.

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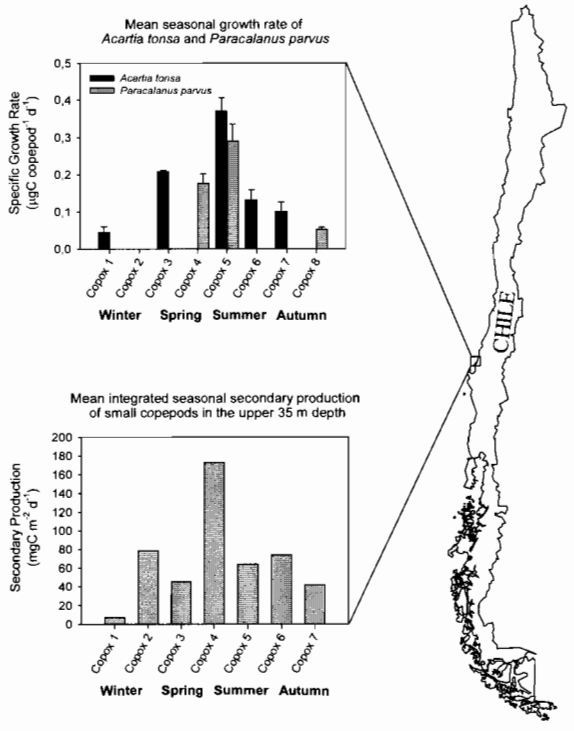

Figure 1. Mean seasonal growth rate of the small copepods Acartia tonsa and Paracalanus parvus, and mean integrated seasonal secondary production of total small copepods in the upper 35 m depth of a coastal upwelling area off Central Chile (~36° S).

HCS054 - Distribution of meroplanktonic larvae of crustacean decapods in the Colombian Pacific. Period 18 sep – 8 oct 2004

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Keywords: Meroplankton, crustaceans decapods, composition, spatial distribucion, moon phases, nictimeral migration,

The spatial distribution of meroplanktonic larvae of the crustacean decapods families in the Colombian Pacific Ocean (CPO) was studied, based on the analysis of 25 zooplankton samples, obtained during the period 18.Sep-08.Oct.04, as a part of the "Estudio Regional del Fenómeno El Niño (ERFEN)". Circular surface samplings with a conical net (opening 50 cm, length 1.43 m, pores 363 µm) were performed. The abiotic variables temperature, salinity, nictimeral variation, and moon phases were considered. Although in the CPO a moderate to weak El Niño event was reported ((Braun *et al.,* 2005), surface abiotic data did not revealed it. The highest organisms concentration, in general, trended to take place in the nearest stations to the coast (Fig. 1). Larvae of 24 families were identified, eight of which are of fisheries importance in the CPO (Fisher *et al.*, 1995), being Portunidae, Palaemonidae and Penaeidae more relevant in the present research by its abundance (3192, 95 and 39 ind./100 m^3, respectively), and spatial distribution (14, 8 and 10 stations, respectively). However the highest abundance (46779 ind./100 m^3) corresponded to Majidae and was registered at the station 07 relatively near to the coast, where mangroves are abundant (CCCP, 2002), indicating a probable moment and spawning area. The only previous study on this group of organisms in the CPO (Jaramillo, 1978) had one year duration but embraced only the area, where the station 07 is located. Over there, this author registered a general abundance of hardly 2600 ind./100 m^3 in September and October, being Majidae y Portunidae the more abundant families. This suggests that these families use that area to spawn, perhaps by its proximity to the mangrove systems. In the nictimeral period the highest averages of general abundance were observed by night (2865 ind. /100 m^3 *vs.* 23 ind./100 m^3 by day). Related with the moon phases, the highest abundance (12552 ind./100 m^3) was registered in new moon (*vs.* 217, 34 y 8 ind./100 m^3, in the last quarter, first quarter and y full moon, respectively). It suggests night spawning and vertical migration to the surface during the night, with intensification in new moon. Surface temperature and salinity did not show statistical correlations with the larval abundances.

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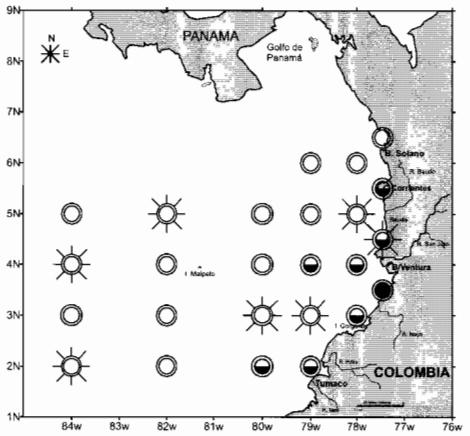

Figure. 1. Distribution of meroplanktonic larvae of crustacean decapods in the colombian Pacific. Period 18.sep – 8.oct.04. O Low (<50/100 m^3) ◒ Half (50 – 5000/100 m^3) ● High (>5000/100 m^3), ☾ Day O night.

HCS065 - Sublittoral soft-bottom communities and diversity of Mejillones Bay in northern Chile (Humboldt Current upwelling system)

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Keywords: macrozoobenthos, community analyses, feeding modes, Mejillones Bay, El Niño

The macrozoobenthos of Mejillones Bay (23°S; Humboldt Current) was quantitatively investigated over a seven years period from austral summer 1995/96 to winter 2002. 78 single van Veen grab samples taken at six stations (5, 10, 20 m depth) provided the basis for the analysis of the distribution of 60 species and 28 families as well as their abundance and biomass. Mean abundance (2119 ind. m^{-2}) was consistent with previous estimates by Zúñiga et al (1983) (2762 ind. m^{-2}). Mean biomass was 966 g formalin wet mass m^{-2} and ranged between 72 g m^{-2} (5 m) and 1521 g m^{-2}, (10m). Thus, the mean value exceeds prior estimations (396 g alcohol wet mass m^{-2}) mainly due to the dominance of the bivalve *Aulacomya ater*, which reached a maximum abundance of up to 2400 ind. m^{-2} at the 10 m stations in summer 2000 and occurred along the whole depth range sampled. This bivalve was not a dominant faunistic element in earlier investigations (e.g., Zúñiga et al 1983). A possible explanation is that the regime shift to warmer conditions in the 80ies and 90ies (Arntz et al. 2006) created more favourable conditions for this bivalve off northern Chile. 43% of the taxa sampled inhabited the complete depth range. Mean taxonomic Shannon diversity (H´, Log e) was 1.54 ± 0.58 with a maximum at 20 m (1.95 ± 0.33), evenness increased with depth (Fig. 1). The fauna was numerically dominated by carnivorous gastropods, polychaetes and crustaceans (48%). Echinoderms occurred only in low numbers, 15% of the species were suspensivorous, 13% sedimentivorous, 11% detritivorous, 7% omnivorous and 6% herbivorous. Cluster analyses showed a significant difference between the shallow and the deeper stations. Gammarids and the polychaete family Nephtyidae characterized the 5-m-zone, the molluscs *Aulacomya ater*, *Mitrella unifasciata* and gammarids the intermittent zone, while the gastropod *Nassarius gayi*, *Nassarius gayi* and *Mitrella unifasciata* and the polychaete family Nereidae were most prominent at the deeper stations.

The communities of the three depths did not appear to be limited by hypoxia during non-El Niño conditions. From Figure 1 it is obvious that although oxygen concentrations rose at all depth the signal was by far not as clear for the fauna of Mejillones Bay as off Peru and in observations of deeper living communities of Concepción Bay (Chile). Therefore, no typical change in community structure occurred during El Niño 1997/98. This suggests that EN-induced enhanced oxygen levels significantly increase diversity only in those communities, where abundances and species richness are normally limited due to oxygen stress and thus, unfavourable settling conditions for larvae (Arntz et al. 2006). Oxygen limitation explains the low diversity during non-EN years at deeper bottoms throughout the Humboldt Current Ecosystem. When physiological tolerance limits are no longer exceeded due to improved oxygen concentrations in the bottom water (Arntz et al. 2006) previously excluded species may extend their distribution to lower and greater depths or proliferate strongly ("opportunists"). This is in line with observations of Tarazona et al. (1996) who state that very strong or very prolonged EN events may produce favourable conditions only in hypoxic study areas, reflected in considerable community changes but never reaching the species numbers of comparable bays favoured generally by better oxygenation. Although the 1997-98 EN might be one of the strongest on record, according to some physical indices, the biological impact off northern Chile was not as catastrophic as generally expected. This does not only hold true for the analysed soft-bottom community, but also for the pelagic ecosystem of the same area. Differences in the impact compared with previous events may furthermore be attributed to the distinct seasonal onset (Arntz et al. 2006): while EN 1982-83 started in austral spring, just before the reproductive season, EN 1987-98 commenced in late austral autumn (and thus in the northern hemisphere reproductive season).

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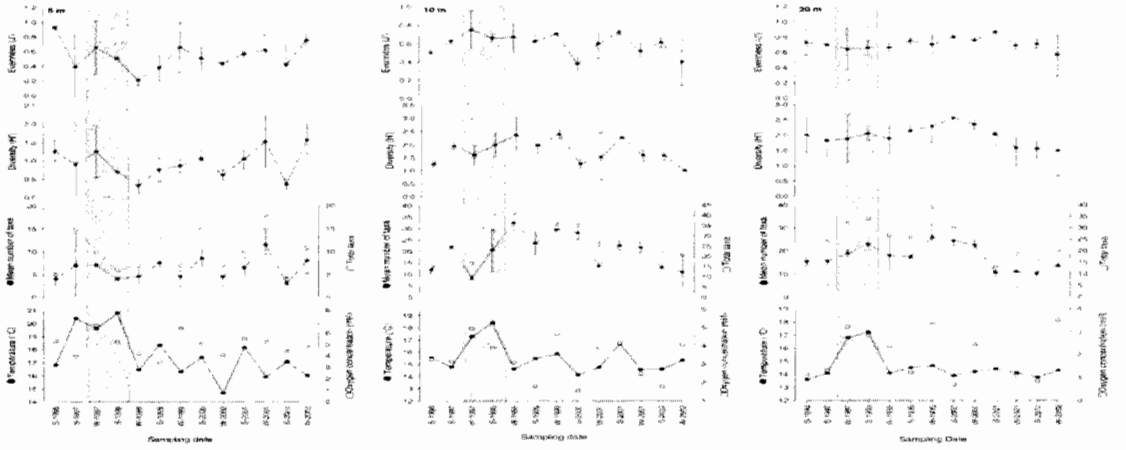

Figure 1: Temperature and oxygen concentration, mean and total number of taxa, Shannon diversity (H', Log e) and evenness (J') of soft bottom macrobenthos of three different depths (5 m, 10 m and 20 m) from Mejillones Bay in northern Chile. Striped bars indicate El Niño 1997/1998.

HCS068 - Temporal and spatial variability in copepod abundance, distribution and community structure off Walvis Bay in the Northern Benguela Current, 1979-1981

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Keyword: abundance, biomass, community structure, copepod, Walvis Bay, zooplankton

This study investigates variability in the temporal and spatial distribution of total zooplankton (non-gelatinous) biomass, total copepod abundance, as well as copepod community structure along a transect off Walvis Bay (23° S), over the period 1979-1981. Included in the data set are sea surface temperatures (SSTs) and surface salinities, allowing for spatio-temporal trends in the hydrology of this region to be examined. A clear seasonal pattern in the cross-shelf distribution of SST and salinity was observed in 1979-80. There was an existence of cool inshore surface water from mid-winter to mid-spring, warming up into summer and extending offshore, which was indicative of a typical upwelling cycle off Walvis Bay. Cross-shelf distribution of zooplankton biomass exhibited multiple peaks, mostly bimodal, attributable to the effects of coastal upwelling. However, variability in total copepod abundance was not necessarily reflected in total zooplankton biomass. This pointed to the changes over time in the taxonomic composition of the zooplankton, which, in general, does not remain constant, as the zooplankton comprises other taxa in addition to copepods. Cluster analysis revealed that four calanoid copepod species were mainly responsible for the structuring of copepod communities, namely, *Calanoides carinatus*, *Centropages brachiatus*, *Metridia lucens* and *Rhincalanus nasutus*, which displayed some specific distribution characteristics. Finally, biomass and abundance data from this study are discussed in the context of long-term variability – over the period 1959-2004. An increasing trend in both bio-volume and total copepod abundance was observed. Moreover, this trend was also reflected in the abundances of *C. carinatus* and *M. lucens*, but not *C. brachiatus* and *R. nasutus*, suggesting long-term changes in community structure. In other eastern boundary current systems (e.g. the Californian, Guinea, and Humboldt Current systems) where there has also been large-scale intensification in coastal upwelling, a long-term decline in zooplankton has been reported (Carrasco and Lozano 1989, Mensah 1995 as cited in Verheye 2000).

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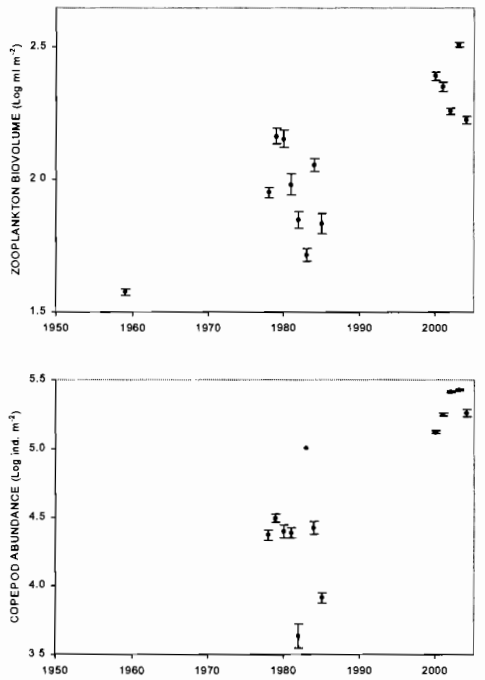

Figure 1. Time-series of annual means of (a) zooplankton biovolume and (b) total copepod abundance measured within 30 and 70 n. m. off the coast of Walvis Bay (23° S), respectively.

HCS070 - Small-scale patchiness of plankton in Peruvian coastal and shelf habitats as detected by using PELSS (Particle and Environmental Parameter Logging and Sampling System)

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Keywords: zooplankton, new technologies, spatial distribution, small-scale patchiness, Peru

PELSS (Particle and Environmental Parameter Logging and Sampling System) was tested for the first time under in situ conditions off Peru in May 2006. This array of sensors, with a LOPC (Laser Optical Plankton Counter, VNIRO Model Trap 7a, Technopole, Russia) and a plankton net in its center, was specifically designed to be used on small boats without a conductor wire, and may be handled even manually by two people. Additionally, it contains an Oxygen Optode, a CTD probe, and a fluorescence probe. All data are stored and pre-processed in a built-in submersible autonomous Datalogger (ISITEC, Bremerhaven, Germany).
The LOPC uses optical electronic sensors measuring 128 size classes in the range of 0.0 to 1.6 mm on the base of the shadow method. Particles within this range in the water column are considered to represent living plankton organisms. Plankton particles pass between the emitter and the photo receiver of the LOPC, their shadow sizes are recorded on the photo receiver. The associated software allows calculating biomass using the equivalent spherical diameters and shape coefficients for mass species. The LOPC is intended for the estimation of zooplankton concentration and size as part of CTD-probes mounted on undulating towed vehicles like PELSS. Besides, the LOPC may work autonomously mounted on buoys or platforms.
First investigations with LOPC within PELSS have been performed off Peru in May 2006 in the context of the CENSOR project (www.censor.name). The specifications of PELSS and first results regarding spatial distribution and small-scale patchiness of plankton are shown (Figure 1).

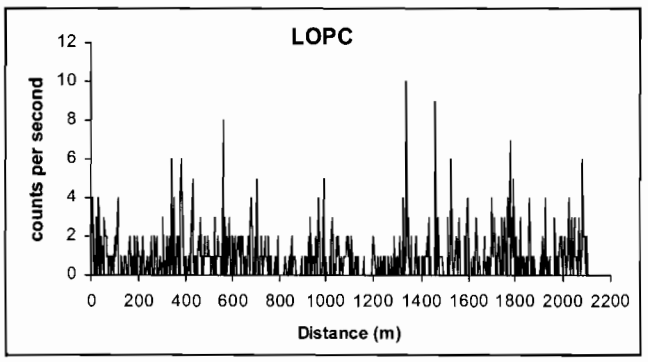

Figure 1: Example of LOPC data generated during a 20-minute subsurface (3m) horizontal tow along a transect of approximately 2100 m inside Independencia Bay, Peru, in May 30, 2006.

HCS091 - Copepods (crustacea, zooplankton) in the northern boundary of the Humboldt Current system during La Niña.

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Keywords: Biological indicators, Copepods, Humboldt Current

After the exceptional warm event El Niño 1997-1998, oceanographic conditions of La Niña were developed since 1999 which remained with slight alterations during 2000-2001. Aboard the BAE Orion from the Oceanographic Institute of the Navy (Ecuador) was carried out an oceanographic and biological cruise during September 2001. On September 2001, conditions of La Niña were intensified; negative anomalies were reported in Ecuadorian waters, specially related to the equatorial upwelling west of the Galapagos Islands, as well as the equatorial front between the Galapagos and the continental Ecuador.
These cold conditions of La Niña were also enhanced by the strong influlence of the northern boundary of the cold Humboldt Current in the equatorial Pacific.
The composition and distributions of copepods in the plankton of the equatorial part of the Pacific were studied. In the Southern part of this area, species of copepods related to cold waters were dominant such as: *Calanus australis*, *Eucalanus inermis*, *Paracalanus parvus*, *Acartia tonsa*, *Oithona plumifera*, *Oncaea conifera*, *Corycaeus giesbrechti*.These species are very common in the Humboldt Current System .
Finding some species related to Subantartic waters as *Paraeuchaeta antartica* and *Haloptilus austini*, in the equatorial band, probably related to the strong influence of La Niña which contributed to the advection of these species of copepods to ecuatorian waters.
Once again the carefully taxonomy studies of the plankton communities will bring surprising information of the oceanic variability related to the ENSO event.

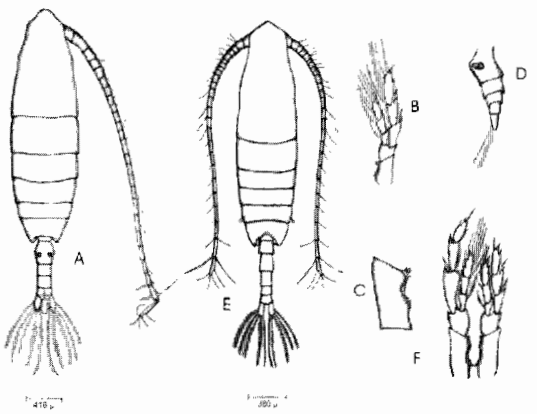

Figure 1. Calanus Australis. Female: A Dorsal view, B fifth legs, C first basipod of the fifth legs, D Lateral view of urosome. Male: E Dorsal view, F fifth legs.

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HCS107 - Temporal variability of the mesozooplankton community in the Humboldt Upwelling System off Central Peru

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Keywords: Central Peruvian Coast, Hydrography, Multivariate analysis, Zooplankton assemblages.

Bimonthly samples were taken from February to December 2005 at four stations off Callao (~ 12° S), central Peru, to assess temporal and spatial variability of the zooplankton community and oceanographic conditions. Temperature and salinity profiles were obtained with a Seabird CTD. Water samples for oxygen, chlorophyll a (Chl-*a*) and nutrients (phosphate, nitrates, and silicate) were taken at 0, 10, 25, 50, 75, and 100 m depth. Biological sampling was performed at daytime with oblique tows with a 300 µm Bongo net for five minutes at three knots. The net was equipped with a calibrated Hydro-Bios flow-meter. In the laboratory, all organisms were identified, sorted and counted. Salinity (34.8-35.1 ups) and temperature data showed the presence of cold coastal waters (CCW) at all stations and sampling months. Oxygen minimum concentrations (< 0.5 ml/L) were observed. The bottom depth of the oxycline varied between 10 and 75 m, being deeper at offshore stations. Average Chl *a* concentrations above the oxygen minimum layer (< 0.5 ml/L) ranged from 2.6 to 18.5 µg/L. Total zooplankton density, bio-volume and biomass varied from 0.39 to 39.20 ml/m³, and 0.0026 to 0.40 mg/m³, respectively. A total of 209 taxa were identified in the present study. The 10 most abundant taxa were: *Acartia tonsa* (55%), *Centropages brachiatus* (14%), *Paracalanus parvus* (10%), eggs (5%), *Eucalanus inermis* (1.8%), Cirripedia cypris (1.4%), Magelonidae larvae (1.4%), *Calanus australis* (11%), *Pleuroncodes monodon* zoeae (1.1%), *Pleopis plyphemoides* (0.9%). *A. tonsa* represents the most abundant taxon in all the stations and time periods. Maximum densities were observed onshore during February and April (St. 1 and 2), and offshore during August (St. 3 and 4). *C. brachiatus* and *P. parvus* increased their abundances during the Austral winter season at all stations. Diversity showed minimum values during April (0.33, St 2) and a maximum during August (2.53, St. 1 and 2). During winter, maximum diversity was observed onshore (St. 1 and 2). Spearman rank correlation analysis showed a significant ($p < 0.05$) positive correlation between oxygen and Chl *a* concentrations ($R^2 = 0.51$). Several positive and negative correlations between taxa were also found. The most significant correlations were found among *C. brachiatus*, *P. parvus*, *C. australis* and Magelonidae larvae. Also they showed significant correlation with oxygen minimum layer depth. *A. tonsa* did not show correlations with any taxon or variable tested. Finally, Multi-Dimensional Scaling (MDS) (Fig1) indicated seasonal changes in the community composition, while there was not a clear pattern regarding spatial variability.

The time resolution of this study shows temporal pattern of the mesozooplankton community not only related to phytoplankton availability (Chl *a*), but also to the oxycline and oxygen minimum layer position in the water column. The data suggest a significant impact of the oxygen concentrations in the structure of the mesozooplankton community off central Peru, Callao. Maximum density and biodiversity observed onshore during the austral winter (August) was related to a deeper oxycline, while the opposite was observed in periods dominated by a very shallow oxycline and oxygen minimum conditions.

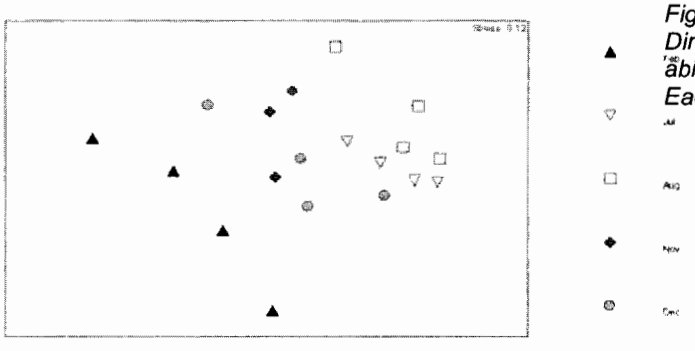

Figure 1. Multidimensional Scaling Dimension (MDS) for all species and abiotic variables off Callao during 2005. Each symbol is a sampling date.

HCS117 - Epibiontic Macrophytes on the Mole Crab *Emerita analoga* in a Bay in the Central Coast of Peru

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Keywords: Emerita analoga; Enteromorpha *spp.; epibiosis; Peru; sandy beach.*

Introduction- The mole crab *Emerita analoga* is one of the most abundant decapod of the Peruvian sandy beach communities. They play an important role in secondary production as prey for many crustaceans, fishes, birds, and even humans (Alvitres et al. 1998). Its geographical distribution in the Pacific Ocean extends from Alaska (58° N) to the Beagle Channel (55° S). In Ancón Bay (11°46' S, 77°11' W), a small bay close to Lima in the Peruvian central coast, the mole crab inhabits all sandy beaches, and they have been found with epibiontic macrophyte. Until now, such interaction had never been reported. Epibiosis is one of the closest possible associations between different species. Through direct and indirect interactions, this association has major effects on the species involved and on community dynamics (Wahl & Mark, 1999). In this study we described the epibiosis, assessed its occurrence in the population and tested its effects in *E. analoga* burrowing abilities.

Methods- Based on rostrum individual percent cover by algae, a 3 levels qualitative scale was designed: level 0 (no epibiontic algae observed), level 1 (algae covering 0 to 50% rostrum surface), and level 2 (algae covering 50 to 100% rostrum surface). Classification was tested by weighting dry biomass of epibiontic algae from fouled individuals collected in San Francisco Grande (SFG), a beach of Ancón Bay, in October 2005. To analyze *E. analoga* population characteristics and epibiosis occurrence, we performed, in February 2006, samplings in two beaches of Ancón Bay: SFG and Las Conchitas (LCB), and one south of the bay, in Huaquillo beach (HB). Samplings were performed in three transects parallel to the shore, corresponding to saturation, resurgence and retention zones. To assess direct effects of epibiosis, in March 2006 burrowing ability experiments were performed at HB, where burrowing time and depth were measured. We collected variously sized *E. analoga* with and without epiphitic macrophytes. For statistical analysis only ovigerous females were considered, as they were the only group with enough fouled and non-fouled individuals to make measurements comparable. The burrowing times of individual crabs were timed from the initiation of burrowing to the disappearance of the crab under the sediment surface. Burrowing speed was calculated as the rate CL / burrowing time. Maximum burrowing depths, were estimated by measuring the length of a nylon string glued to the carapace, from the sediment surface to the tip of the rostrum.

Results- The epibiontic algae found on *E. analoga* was identified as *Enteromorpha* spp., and was settled mainly on the rostrum, but was also found on primary and secondary antennae and maxillipeds. In some cases, *Polisiphonia* spp. has been also found under *Enteromorpha* canopy. Algae dry weight ranged from 0,0004 to 0,0091g for epibiosis 1 and from 0,0062 to 0,1899 g for epibiosis 2. These values of algae dry weight corresponding to categories 1 and 2 of our visual-based scale were significantly different (T-test, $P<0,001$). In SFG the density was 433 ind/m^2, the male:female ratio was 6,75:1, and 0,8% of individuals had epibiosis 1. In HB the density was 1091 ind/m^2, the male:female ratio was 4,63:1; 0,32% of individuals had epibiosis 1 and 1,76% epibiosis 2. In LCB the density was 284 ind/m^2, the male:female ratio was 1,81:1, and there weren't fouled individuals. Ovigerous females with epibiosis 2 spent more time in burrowing than ovigerous females with epibiosis 0 and 1 (ANCOVA, $P<0,001$ Tukey post hoc test, $P<0,001$ for both comparisons). Burrowing speed was significantly lower for ovigerous females with epibiosis 2 than for ovigerous females with epibiosis 0 and 1 (ANCOVA, $P<0,001$; Tukey post hoc test, $P<0,05$ for both comparisons). The degree of epibiosis had no effect on the maximum burrowing depth of ovigerous females (ANOVA, $P>0,05$).

Conclusions- The designed scale resulted to be effective in assessing the degree of fouling. Densities and sex rates resulted consistent with other studies in the Peruvian coast. Our results show that epiphitic algae modify *E. analoga* burrowing ability, slowing their escape activity. This may play an important ecological role in their population dynamics by modifying their availability to predators, mainly seabirds and fishes; although further studies are necessary to assess how epibionts affects *E. analoga* in recognition and handling by predators. *Enteromorpha* has been characterized as opportunist algae, proliferating in eutrophicated shores, therefore we conclude that the interaction reported in this work should occur in other impacted areas of the large distribution of *E. analoga.*

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HCS127 - Transport of squat lobster larvae on the continental shelf of the Humboldt region off Central Chile inferred from both observed data and individually-based modelling techniques

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Keywords: bio-physical model, crustacean larvae, larval tracking, sea surface advection, spatial distribution.

The squat lobster *Pleuroncodes monodon* (Crustacea: Galatheidae) is a dominant benthic species of the continental shelf in South-Central Chile. The southern population (35 to 37° S) has been subject to strong fishing pressure since the mid 60s. Catches, biomass, and latitudinal range of the population have undergone large contraction/expansion cycles in the last 3 decades. This population occurs in two adult branches stemming from the same nursery ground over the Itata terrace (about 36.5° S). The northern branch has been cyclically depleted by fishing and recovered once fishing has decreased or ceased. The relative contribution of each population branch to the population renewal is unknown as well as the interaction with physical transport processes at the larval stage that allow recruitment to the nursery ground. In this study, we analyzed the spatial distribution and the potential transport of the squat lobster larvae in the coastal upwelling area of south-central Chile (35-37°S), by means of bio-physical field sampling and simulations. Field sampling was conducted during November 2001 and March 2002 between 35 and 37ºS on the R/V Abate Molina, when larvae are being released and juveniles recruited respectively. Each hydrographic survey comprised 11 equally spaced meridional transects of 6/7 stations each. At each station, CTDO data and stratified zooplankton samples were gathered. Stage larval distribution was mapped and analyzed with geostatistical methods. Geostrophic current estimates were adjusted for shelf areas. Two sections of current velocity (transects I and IX) were obtained with an Acoustic Doppler Current Profiler (ADCP). Surface current fields were obtained twice a day from November through March from sequential thermal satellite images following the maximum cross-correlation method (Emery et al., 1986). Larval tracking experiments were conducted using three different physical templates and approaches: 1) 2D simulations based on mean current measurements and their standard deviations at three different depths from literature (Sobarzo and Djurfeldt, 2004); 2) 2D simulations based on estimated surface current fields from SSTs (valid for the mixed layer); 3) 3D simulations based fields from the Regional Ocean Model System (ROMs). Output was configured for a fine grid (1.5 km) with a domain between 34-37ºS in the Chilean coast, forced with daily winds. This fine resolved ROMs configuration is nested to a coarser one (5km resolution, 31-40ºS, climatological forcing), the coarse grid output has already been validated. In addition, the individual based biological model used in (2) and (3) included a temperature dependent growth and development algorithm.

North of 36°S, coastal upwelling and a conspicuous shelf break front was evident during both cruises; geopotential anomalies indicated a northward surface flow intensified at the shelf break front; these features were also evident in the subsurface. Geopotential anomaly followed bathymetry. In the mouth of the BioBio canyon during November water flowed northward while the flux was southward in the head, the southward flux was intensified in the sub-surface. During March, upwelling was evident even over the inner shelf of the Itata terrace, and in the Biobio canyon the northward flow was only evident at the mouth. ADCP data from the March survey was congruent with geostrophic velocity patterns. Larval abundance was 2 orders of magnitude larger during November than in March; zoea I and IV dominated during November (no juveniles found). In March, juveniles and megalopae dominated the pool of *P. monodon* pelagic stages. Zoea I occurred in larger quantities in sub-surface (southward flowing) waters, while later stages dominated at the surface (northward flowing) ones (Fig. 1). Zoea II seemed to be transported south in sub-surface waters; later stages showed larger abundance in shallower strata and larger concentrations in the northern sampled area, were larvae were always circumscribed between the coast and the shelf break front. Megalopas and juveniles vertically migrated daily, ascending during night hours. In March (austral autumn), juveniles and megalopas were only found over the wide shelf at the nursery zone (Itata terrace). Larval retention areas where all larval stages were aggregated were identified over the Itata terrace. Simulation experiments that tracked larvae in the studied area and forced with mean current velocity data from literature (approach 1) indicated that the layer located at mid depth (ca. 50m) had the highest potential for larval retention, and that maximum exportation should be expected in surface waters. Larval tracking simulations forced with surface advective velocity fields (approach 2) showed that both northern and southern branches of the population were contributing to next year recruits, but the three historical spots furthest north, did not. Successful recruitment was affected by the period of larval release and the place of larval release. Also, developmental time and weight at molting to megalopa were dependent on release site (due to temperature influence on growth and development). Larval tracking over ROMs template (approach 3) will be conducted in order to compare the 3D results with the 2 methods mentioned above.

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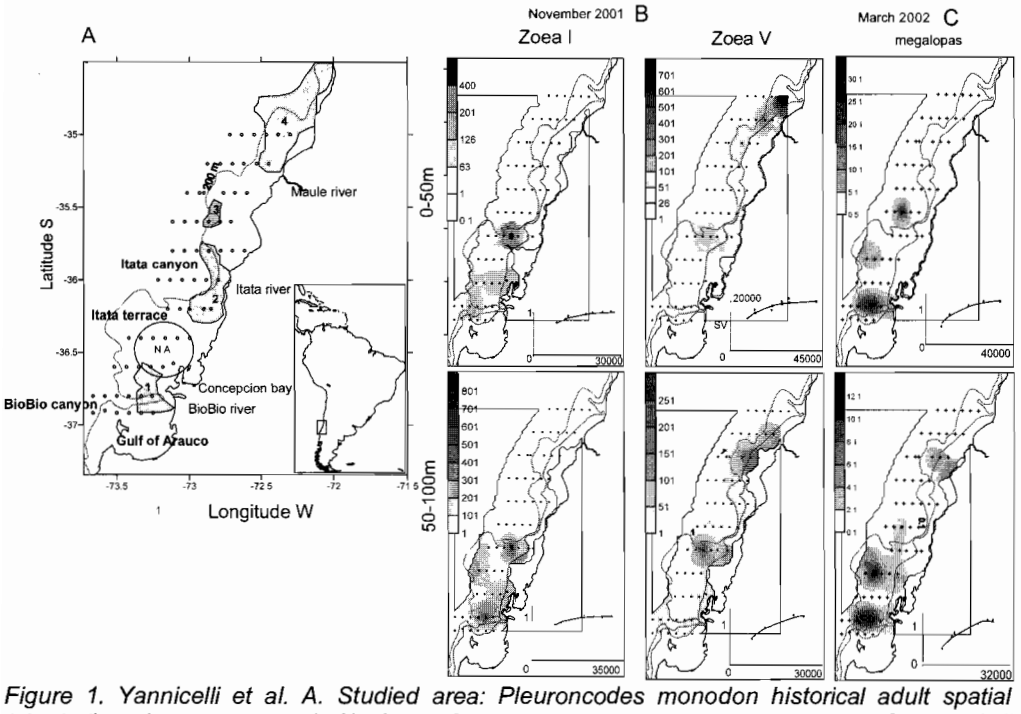

Figure 1. Yannicelli et al. A. Studied area: Pleuroncodes monodon historical adult spatial distribution (shaded) and nursery area (NA). Areas 3 and 4 area actually depleted. B and C Spatial distribution of squat lobster (Pleuroncodes monodon) zoea stages I and V (November 2001) and megalopas (March 2002) respectively, off central Chile in two depth strata (0-50 and 50-100m), as inferred from geostatistical analysis. Shaded areas represent depth-integrated number of individuals per m^{-2}. Variogram models are shown as inserts (x-axis is the range in m, and the y-axis, the variogram estimation). Data for Novembre 2001.

HCS134 - Response of hard bottom subtidal macrobenthic fauna to the 1997-1998 El Niño in an area of The Peruvian Upwelling System

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Keywords: El Niño 1997-98, hard bottom, macrobenthos, subtidal, upwelling.

Hard bottom subtidal macrobenthic fauna were sampled monthly (n=6 *replicates per* month) from September 1996 to December 1998 to a depth of 12 meters in Independence Bay, Peru (14°19'S, 76°10'W). We analyzed variation in the composition and abundances of macrobenthic invertebrate communities between non-El Niño (EN) periods and an EN period (1997-1998).

Species composition and density of species responded differently than biomass during EN 97-98. With the first increase (April 1997 - June 1997) of Sea SurfaceTemperature (SST), the species number and density showed immediate increases, reaching maximum values of up to 66 species and 2622 ind. x 0.0625 m^{-2}, respectively, which later decreased in the following months. In contrast, biomass (1550 g ww x 0.0625 m^{-2}) did not show important variations throughout the entire studied period. At the onset of the second increase (December 1997– February 1998) in SST (which was more intense than the first one), species number and density increased only slightly (56 species and 361 ind. x 0.0625 m^{-2}, respectively), while biomass showed a significant decrease (568 g ww x 0.0625 m^{-2}).

Jaccard and Bray – Curtis indices of similarity indicated that macrobenthic community structure was significantly different after the first increase of SST, during the EN 1997-1998 period. Time series analysis by means of linear regression between the similarity matrixes and SST showed that community structure was significantly different five months after the beginning of EN 1997-98 (Jaimes, 1999).

Although the 1982-83 EN event was similar in intensity to the 1997-1998 EN (Soenens, 1985, Tarazona *et al.*, 1999), the biological impact on hard bottom macrobenthic communities was minor in the latter event.

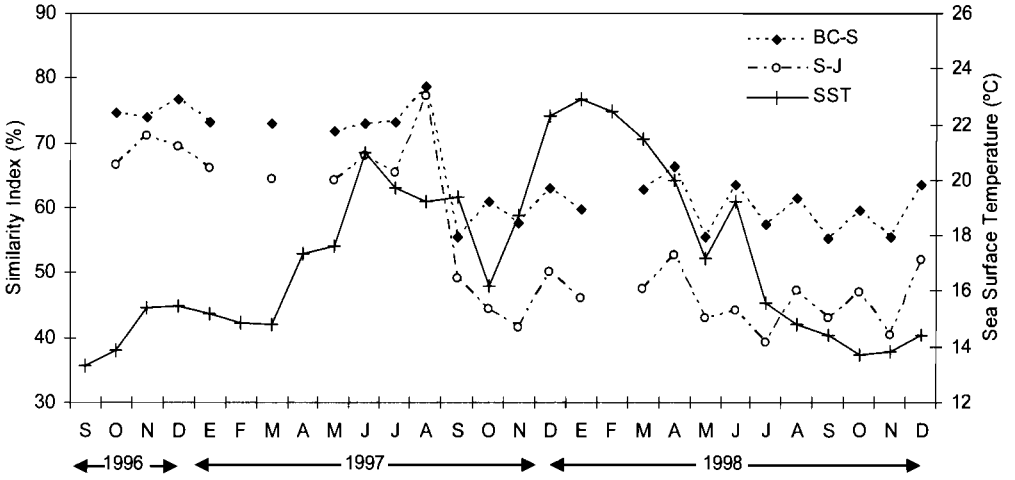

Figure 1. Monthly variation in Jaccard (J-S) and Bray-Curtis (BC-S) similarity indicies (%) obtained from analysis of hard bottom macrobenthic invertebrates, and sea surface temperature (°C – SST) obtained from September 1996 - December 1998, in Independence Bay, Peru.

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HCS143 - Patterns and effects of the infestation of the surf clam *Mesodesma donacium* (bivalvia, Mesodesmatidae) by *Polydora bioccipitalis* (Polychaeta, Spionidae) in Northern Chile

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Key words: Infestations, *Mesodesma donacium, Polydora bioccipitalis*, Polydorids, Surf clams, symbiosis.

Although the surf clam *Mesodesma donacium* is one of the most important species for shellfisheries in Chile and Peru and infestation by the symbiotic polychaete *Polydora bioccipitalis* reaches 31.4 %, we lack relevant biological and ecological information on this interaction. Burrowing polydorid worms, also called blister worms, are a known pest, which can seriously affect mollusks, both cultivated and living in natural ecosystems (e.g. Handley 2000, Leonart et al. 2003). A sample of 80 clams covering the whole size range was collected monthly from Hornitos (22°54.998´S; 70°17.416`W), northern Chile, to study (i) the temporal variability of the infestation, (ii) the relationship between the prevalence of infestation and the length of the host and (iii) the effects of infestation on growth, body condition, gonad cycle and digging ability of *M. donacium*. Clams were measured and classified into a qualitative scale of infestation levels (level 0-III). Body condition index (BCI), gonado-somatic index (GSI) and thickness of blisters (TB) formed in the valve to isolate the worm were measured to estimate the duration of the infestation. In addition, a laboratory experiment was performed to compare growth rate and digging time between clams with different infestation levels.

The relationship between the host-size and the prevalence of infestation was explained by a logistic-regression model (r^2 = 0.959); the smallest infested clam was 34 mm whereas the shell length of clams at 50% infestation was 73.6 mm. Mean TB differed between months (ANOVA: $F_{11, 371}$ = 2.388; p = 0.0072) showing a bimodal pattern throughout the year. Shifts in mean TB were observed between October and November 2006 and in April 2006 (Fig 1A). At these times we consider the infestations of *P. bioccipitalis*, supported by the decline of the GSI, which drops after spawning events. Body condition between clams with distinct infestation levels was different (ANCOVA: $F_{3, 175}$ = 8.606; p = 0.00002). Multiple comparisons revealed that BCI of "non-infested", "level I" and "level II" clams did not differ significantly, whereas only those infested at level III differed to non infested clams. Temporal variability in GSI and BCI are given in

Fig 1A-B. Growth and digging time under laboratory conditions significantly differed (ANOVA: $F_{3,27} = 5.35$; $p = 0.005$; $F_{3,32} = 3.14$; $p = 0.038$, respectively) between infection levels, the level III explaining the observed differences (Fig 1C-D).

A strong relationship between host-size and the prevalence of infestation was observed. Clams are infested only above 34 mm shell length, which seems to be a common feature of *Polydora*-infestations (Davis 1967). A rapid increase in prevalence was observed between 40 and 70 mm shell length, which could be related to an ontogenetic migration from the intertidal sandy beach (juvenile clams) to the lower subtidal (post-juvenile and adult clams). Spawning events of bivalves seem to be coupled to infestation events of *P. bioccipitalis*. This suggests that infestation takes place during energy-demanding periods of the host after spawning events. The infestation by *P. bioccipitalis* affected growth, body condition and digging activity, however, this was only considerable after severe infestations (level III). The surplus energy allocated to face the infestation (e.g., secrete extra calcite and conchioline layers, adaptation to space restrictions) may explain the observed negative effects. Under normal conditions host species may be able to support the presence of their parasites, attaining a certain level of equilibrium (Margalef 1980). Those effects, however, may dramatically increase if the host is stressed due to adverse environmental conditions or other stress sources, reflected that individuals are more prone to diseases, other parasites and predators (Kent 1981, Newell & Barber 1988). The infestation of *P. bioccipitalis* could, therefore, play a role in explaining natural mortality events in *M. donacium* (Arntz et al 1987) thus providing an alternative explanation to the notion that mass mortalities are due to environmental factors.

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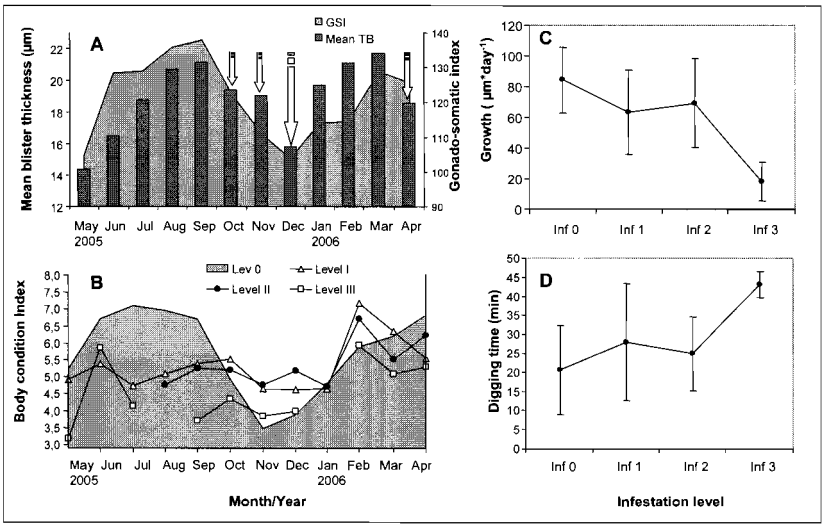

Figure 1. A. Changes of mean thickness blisters (TB) and mean GSI of the surf clam Mesodesma donacium between May 2005 and April 2006; arrows indicate infestation events by P. bioccipitalis. B Seasonal oscillation of mean body condition index (BCI) of M. donacium. C-D. Mean growth and digging time of M. donacium with different infestation levels revealed from laboratory experiments.

HCS144 - Deviations from large-scale geographical patterns in the reproductive biology of the isopod *Excirolana braziliensis*: possible effects of upwelling

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Key words: *Excirolana braziliensis,* Isopoda, latitudinal patterns, reproduction, sandy beach, upwelling

Excirolana braziliensis (Isopoda: Cirolanidae) numerically dominates the macrofauna of tropical, subtropical and temperate Pacific and Atlantic sandy beaches of the Americas (Dexter, 1977). Strong latitudinal patterns in the reproductive traits of *E. braziliensis* have been observed throughout its distribution range (Cardoso & Defeo 2003). Patterns in life history characteristics of a species assume that

latitudinal gradients in environmental conditions occur along the distribution range (Cardillo, 2002). However, distinct environmental conditions in local or regional scales may give rise to deviations from large-scale patterns. The intertidal and upper subtidal of upwelling ecosystems in the Humboldt Current Ecosystem are typically well oxygenated and influenced by huge food import (Wulff & Field, 1983). To test the effect of upwelling on the reproductive biology of *E. brasiliensis,* two subpopulations were studied, one at Chipana (21°, 18`S; 70° 03`W) and one at Hornitos (22°54`S; 70°17`W), Northern Chile, between June 2005 and May 2006. Three replicated sediment samples (0.16 m^3 each replicate) were taken along an across-shore transect every four meters using an open ended push-corer. The sediment was sieved through a 1-mm mesh. Retained *E. braziliensis* were counted, measured (cephalon-telson length) and classified as juveniles, adult male, adult ovigerous and non-ovigerous female. Sea surface temperature, salinity and chlorophyll *a* concentrations were registered at the study locations.
Results show deviations from the latitudinal reproductive patterns reported in the literature: Ovigerous females and juveniles were found throughout the year while the latitudinal pattern of the breeding season predicts a regeneration phase of up to three months. The female to male ratio was roughly the same at Hornitos and Chipana (1.84). This also deviates from the predicted latitudinal pattern stating that the sex ratio linearly increases with latitude, which would correspond to a value between 0.75 and 1.25 at our study sites. Size at maturity ($L_{50\%}$) was 5.8 mm for both locations, while the latitudinal pattern predicts a size between 6.5 and 7.5 mm.
Ecotypes constitute groups with well-defined morphological (e.g. body size) and physiological (e.g. growth and reproductive traits) characteristics determined by genetic differences between conspecific populations, reflecting local matches between organisms and the environment (Begon et al., 1996). The observed divergence from the predicted patterns in the reproductive biology of *E. braziliensis* might reflect two ecotypes locally adapted to their environment. Coastal areas between 21° and 23°S are characterized by upwelling activity throughout the year, and high primary production of up to 10g C $m^{-2}d^{-1}$ (Danery et al, 2000). High and constant food availability might promote a reproductive strategy with breeding (and thus ovigerous females and juveniles) throughout the year. Reduced breeding periods in temperate beaches tend to be counteracted by increasing predominance of ovigerous females with largest sizes (Cardoso & Defeo, 2003). Conversely, breeding throughout the year could promote predominance of ovigerous females with smaller sizes, thus explaining the lower $L_{50\%}$ observed, which resembles that of tropical zones. In conclusion, the observed reproductive characteristics may reflect local reproductive strategies to optimize fitness, enabling local populations to adapt to favorable environmental conditions.

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HCS163 - Growth and production of *Argopecten purpuratus* in Tortuga's Bay, Perú

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Keywords: *Argopecten purpuratus*, growth, production, Tortugas Bay, Peru

Argopecten purpuratus is one of the most important commercial resources in Tortugas Bay located in Casma (350 km northern Lima). The scallop bank is exploited by the artisanal fishermen using HOOKA diving equipment and their economic profit is variable and depending on abundance and somatic production. As the first step to achieve adequate management measures of the scallop bank and as a contribution to trophic flow studies, abundance, length-weight relationships, growth and somatic productivity of scallop was determined.
Between October, 2001 and October 2002, four systematic evaluations were done, dividing the Bay in transects. An average of 198 stations was sampled for each evaluation and in each station scallops were removed from 2 square meters, counted and returned to their habitat. Monthly length frequencies distribution (5 mm size class) was recorded and analyzed using the routine ELEFAN I in order to obtain von Bertalanffy growth parameters. Shell height and total weight from 30 to 60 scallops were recorded monthly. Gonad and somatic tissue were removed from each individual carefully and weighted separately to the nearest 0.01g. Values for somatic, gonad and shell weight relationships with shell heights were fitted and used to obtain mean weights and calculate production estimates for each age class (MacDonald and

Bourne, 1987). Production of somatic and shell component was estimated by the mass specific growth method (Crisp, 1984).
Growth parameters were estimated as Loo= 109.6 mm, K=1.0/year and to=0.02. Mean annual scallop abundance was 2.20 ind.m^{-2}, which represented a mean annual biomass of 104.09 g.m^{-2}. Total annual production was estimated to be 187.68 $gm^{-2}y^{-1}$ (243.80 $kJm^{-2}yr^{-1}$) and the mean annual turnover rate, 1.80. Somatic weight decreased during autumn and winter and began to increase in spring, showing maximum values in summer. On the opposite, shell weight decreased during summer, started to increase during winter and registered the maximum value in spring. Gonadic weight showed two peaks, one in December (summer) and the other in autumn (May). The ANCOVA showed significantly heavier somatic tissue in spring and summer ($p<0.001$), while gonadic tissue showed significant differences between the four seasons ($p<0.001$). Shell tissue showed significant differences between seasons ($p<0.001$), except for autumn and winter ($p>0.05$). According to its production, *A. purpuratus* is likely to play a significant role in the trophic web of Tortugas Bay.

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HCS178 - IBM for the anchovy in the Northern Humboldt Current Ecosystem: identification of processes affecting survival of early life stages.

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Keywords: Anchovy, fish larval survival, Humboldt Current, Individual based model, Peru, transport.

We focus on the northern/central stock of anchovy (*Engraulis ringens*) in Humboldt upwelling region off Peru. We use an Individual Based Model (IBM) of the first stages of life coupled with a hydrodynamic output from the Regional Ocean Model System (ROMS) model to investigate the factors driving eggs and larval survival rates variability.
Our approach consists in a Pattern Oriented Modeling (POM) of the spawning time and locations. Environmental parameters influencing larval survival are added one by one to the model. Both climatological and interannual hydrodynamic outputs are used, to study independently the seasonal and interannual effect on (pre)recruitment.
In a first time we define the spawning success with a coastal retention criteria, and investigate the spawning tactics to approach the observed patterns. We found that (1) observed real spawning date and areas relatively match variations in coastal retention rate, with an exception during the summer peak of spawning; (2) the depth of spawn and the vertical behavior of the larvae have a great influence on coastal retention time, and the best place to enhance retention is the deepest that the oxycline allows; (3) Finally, the ENSO didn't have a great influence over the coastal retention rates, suggesting a biggest importance of temperature mortality effect.
Our modeling approach produced a set of hypothesis on spawning locations and larval behavior that could be tested empirically by collecting new data.

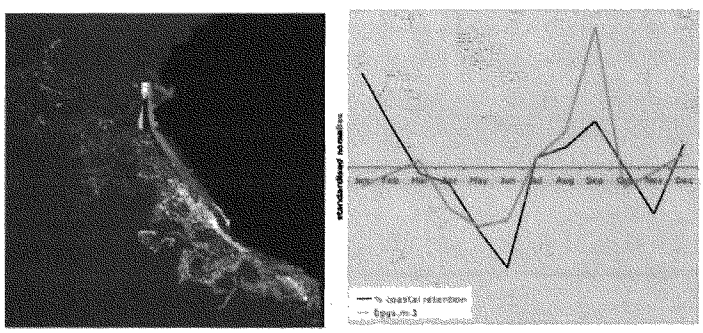

Figure 1. left, Simulated transport of anchovy eggs and larvae; right, Coastal retention (%) and egg concentracion (ind.m-3).

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Thursday morning

HCS007 - Winter trophic conditions off the southwest coast of Mexico

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Samples from a line of stations obtained during winter in the eastern Pacific off México, from the Gulf of Tehuantepec to the tip of the Baja California Peninsula are used to describe the trophic conditions in the diverse environments encountered. Hydrography showed the presence of frontal areas around Cabo San Lucas, Cabo Corrientes and in the middle of the Gulf of Tehuantepec. In the middle of the Gulf of Tehuantepec, low sea surface temperatures and high productivity were found, caused by intense vertical mixing under the strong trans-isthmic wind jets present in the area during autumn and winter. These conditions produce frontal areas of higher primary and secondary productivity. A comparison between a transect from the Gulf of Tehuantepec (Färber-Lorda et al. 2004b) to Cabo San Lucas (intergulf-GC), with the Gulf of Tehuantepec, showed higher zooplankton biomass and Particulate Organic Matter (POM= protein+carbohydrates+lipids) in the Gulf of Tehuantepec, during a period with mild wind (Leg I). The lower biomass and POM was present in the intergulf- GC area. Tehuantepec samples taken after a strong wind event (Leg II), showed still higher values than the intergulf- GC area, but lower than the Leg I period. For zooplankton biomass, no significant differences were found between Leg I and the intergulf- GC area, but the mean was more than two times larger during Leg I period. Euphausiid mean abundance was 10 times greater in the Gulf of Tehuantepec than in the intergulf-GC area. Between areas and sampling periods, zooplankton biomass differences were more marked than POM differences; this is attributed to the grazing impact of zooplankton populations, being higher during higher productivity periods. A significant regression with positive slope between particulate lipids and krill lipids was found, while a significant regression with negative slope was found between zooplankton biomass and POM. The first is attributed to a krill response to better trophic conditions, and the second to active grazing by zooplankton. Local events seem to control productivity in the eastern tropical Pacific, as shown here and suggested by Fernandez-Alamo & Färber-Lorda (in press).

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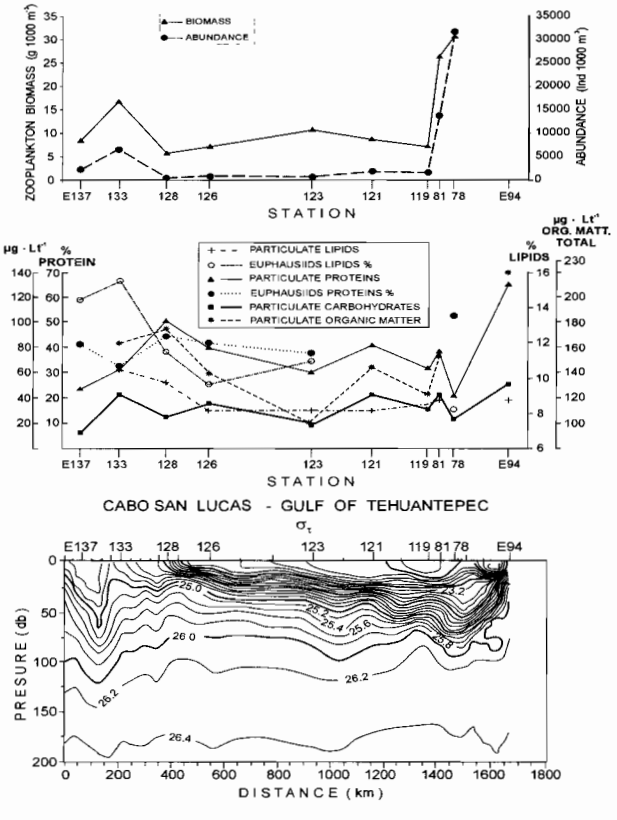

Figure 1. Zooplankton biomass, krill abundance and trophic conditions in a transect from the Gulf of Tehuantepec to the entrance of the Sea of Cortés, corresponding to two upwelling regions at both ends.

HCS010 - Genetic distances between *Donax marincovichi* and *Donax obesulus* confirmed by morphological features

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Keywords: Donacidae, genetic taxonomy, sperm morphology, surf clams.

Surf clams of the genus *Donax* exist worldwide. They dominate sandy beaches in dense populations, occupy an important ecological role and are subject to artisanal and recreational fisheries in many countries. The taxonomy of Donacides is controversially discussed resulting in 45 to 64 described species. High variations might be due to the large variability in shape, size and colour of the respective species. The taxonomic status of the two Pacific American Donacides *Donax marincovichi* and *Donax obesulus* is also not clear. Furthermore, little is known about the larval dispersal allowing gene flow among populations of these two "species". To clarify the taxonomic status and to obtain information on the genetic drift clams were collected at nine different Chilean and Peruvian exposed sandy beaches along their distributional range (18°27'53.8"S 70°18'24.3"W to 3°33'57"S 80°27'5"W). As a reference additionally *Donax asper* was collected from northern Peru and *Donax hanleyanus* from northern Argentina. 35 clams per beach were conserved with opened valves in 80% ethanol. A part of the muscle of the food was taken for DNA extraction using a commercial "Qiagen Dneasy" kit. Amplification was realized by partial cytochrome oxidase I (COI) sequences in order to estimate genetic distances between both putative species and to estimate the intraspecific gene flow along the coastline. Gained sequences were verified by BLAST-search in the gene bank (http://www.ncbi.nlm.nih.gov/blast/). Sequence data from the COI proved to be useful for species discrimination within the genus *Donax*: The taxonomic status of *D. asper* and *D. hanleyanus* is well supported (> 15% sequence divergence among each other and the two putative Humboldt Current species). However, there is no indication of reproductive isolation between *D. marincovichi* and *D. obesulus* from the COI data. With only up to 1.2% sequence divergence, the divergence between the latter is in the order of known intraspecific variability in the COI gene (Held 2000). Therefore, the taxonomic status of two species must be questioned. No genetic differentiation between the geographically separated "*D. marincovichi*" populations could be observed from the sequence data indicating gene flow in-between populations. In the future, molecular markers with higher resolving power (e.g. AFLP, Microsatellites) should be analysed.
Morphological features like shell length (anterior-posterior), height (ventral-dorsal) and width (left-right) (Laudien 2003) or sperm morphology deliver good possibilities for taxonomic investigations (Introíni 2004). The comparison of these features can confirm the genetic results of this study.

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HCS019 - The relationship between Peruvian anchovy reproduction and feeding; considerations of time and space in the feeding condition of reproducing anchovies

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Keywords: anchovy, feeding condition, reproduction, spawning

In this study we consider the relationship between the reproductive condition of the Peruvian anchoveta and stomach fullness, under the hypothesis that periods of higher reproduction reflect better feeding conditions for anchoveta. We explored data at two levels of spatial and temporal resolution; data on stomach contents and reproductive condition of anchoveta sampled during scientific surveys in summer 2000-2002 throughout the entire Peruvian coast and stomach contents and percentage of spawning females over three separate coastal regions (Paita, Chimbote and Callao), continuously collected between 1999 and 2004. Analysis of the first data set suggested an inverse relationship between stomach fullness and reproductive condition of females, which did not support the initial hypothesis. However, comparison of percentage spawning females and stomach fullness in each of the regions sampled suggested a possible time lag between periods of high stomach fullness and high reproductive intensity; although a

statistically significant time lagged correlation could not be found. Also, when the seasons were divided into reproductive (above a threshold level of spawning females) and non-reproductive periods, stomachs were significantly fuller during the reproductive periods suggesting that they reflect better feeding conditions. Establishing significant relationships between feeding and reproduction in continuous breeders such as anchoveta is a challenge and may require new methods of sampling, some of which are suggested here.

HCS024 - Predicting weight composition of fish diets for trophic foodwebs: converting frequency of occurrence of prey to relative weight composition

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Keywords: fish diets, weight composition, frequency of occurrence

The growing importance of ecosystem-based assessment as a complementary approach to traditional single-species assessment has emphasized the importance of the availability of diet composition data. Diet compositions expressed in weight are essential to determine the trophic relationships between the compartments within a system. However, many fish diet composition studies provide the frequency of occurrence of prey in diets (often the case in historical studies), which is the percentage of fish stomachs analysed containing a particular prey item irrespective of the amount (in weight or numbers). In order to make use of such studies for modelling purposes, the objective of this study was to explore empirical relationships between the frequency of occurrence and the preferred index, relative weight composition.
Diet composition data from stomachs were compiled from a number of sources (62102 stomachs), covering four broad areas such as the Northwest Atlantic, South Africa, West Africa and the Azores Islands in order to evaluate the general applicability of the results. The relationship between frequency of occurrence and relative weight was modelled using Linear Models (LM), which was highly significant and explained 74% of the variance in the data. Data were grouped according to categories (factors) such as the area, predator habitat, feeding type, predator size group, and prey type to study the effect of these factors in the empirical relationship. All factors were found to be highly significant except for predator habitat. Nonetheless, the value of including these factors was questionable, as they contributed to only small increases in explanatory power (less than 2% of variance explained). The clear exception to this is prey type, which should clearly be included in the empirical relationship. Various conversion equations are presented by prey type, which can be used as rough estimates of weight composition in fish diets, if the only available information is frequency of occurrence.

HCS036 - Predation by oystercatcher *Haematopus ater* in a rocky intertidal of central Peru

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Keywords: oystercatcher; Peru; predation effects; rocky intertidal

INTRODUCTION: Predation is nearly a universal pressure affecting the structure of many intertidal communities. Most of the works have focused on the predatory effects of the more abundant and easily manipulating marine invertebrate species; however, terrestrial predators, particularly birds, may also exploit intertidal species. Because they often occur in small numbers, bird interaction strength has received comparative less attention. These vertebrates have fast metabolic rates, and their ability to exploit prey over large areas may be greater than that of slower-moving invertebrate predators; therefore, birds can play a significant role in structuring rocky intertidal communities, even when present in low abundance.
In this work we investigated predation of the oystercatcther Haematopus ater in a rocky intertidal of central Peru. The aims of this work are to identify the feeding preferences of oystercatchers, to estimate their predation rates, and to evaluate their potential effects on their prey populations.
METHODS: The study was conducted from May 2005 to March 2006 in a rocky intertidal of the Ancón Bay (11°46'S, 77°11'W), in central Peru. To determine foraging rate by oystercatchers, focal observations were performed using a 16 X 50 binocular. Data were collected from the early morning to the afternoon (before sunset) and saved in a portable tape recorder. Each bird was observed during 5-15 minutes identifying

captured items and handling time (i.e. the time elapse between prey capturing and swallowing). To further evaluate birds feeding, at the end of each day of observation, prey remains (those with small fresh flesh remnants inside) were collected, identified and measured. To calculate the daily mean number of birds foraging in the beach, we recorded the number of individuals foraging or resting in the intertidal at hourly intervals along each sampling day. To evaluate the effects of oystercatchers feeding on the mussel bed (the most common prey; see Results), the size frequency distribution of mussels sampled from vertical surfaces accessible to birds foraging were compared to that of non-accessible vertical surfaces.

RESULTS AND DISCUSSION: Focal observations were conducted for a total of 11 hs. The number of oystercatchers present in the intertidal during the censuses ranged between 0 and 6 (mean (SD) = 1.13 (1.01) individuals day-1). On average, they spent 41% of their time feeding or searching for food, while the other 59% of the time were resting. Mussels accounted for the 68% of the prey consumed (67% corresponding to Semimytilus algosus and 33% to Perumytilus purpuratus). Other common food items were snails (mainly Tegula atra and Crassilabrum crassilabrum), the keyhole limpet Fissurella spp., urchins (mainly Tetrapygus niger), and chitons (Chiton granosus and C. cumingsii). Handling times did vary among prey species consumed, being the shortest for S. algosus (mean (SD) = 11.37s (18.33)), and the largest for urchins (mean (SD) = 104.23s (45.7)).

Individual oystercatchers are able to consume 0.29 S. algosus and 0.14 P. purpuratus min-1, what yields a total consumption of 88 S. algosus and 43 P. purpuratus day-1. Calculated predation rates were comparable to that obtained in other studies (e.g. Wootton 1997, and references therein) where important impacts on the abundance of their prey have been documented.

S. algosus consumed by oystercatchers were larger than those from both accessible and non-accessible surfaces; moreover, S. algosus from non-accessible surfaces were larger than those from accessible ones (shell length [mm] (mean, SD): consumed: 32.63, 4.62; accessible: 11.63, 7.02; non-accessible: 17.83, 9.91). Our data indicates that despite their relative low abundance compared to other intertidal predators, oystercatchers could control the size distribution of their main prey, by consuming the larger individuals. However, further evidence (i.e. manipulative experiments, size and distribution of prey, prey abundance) is still necessary to assess their impacts on the entire intertidal community.

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HCS038 - Gelatinous carnivorous zooplankton: Ecological significance in pelagic food web in coastal upwelling areas off Chile

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Keywords: Gelatinous carnivorous, predatory impact, upwelling zone, copepods.

The Humboldt Current System (HCS) is one of the most productive marine ecosystems worldwide, where its high primary production (PP) is driven by strong seasonal upwelling that enables the development of important pelagic fisheries including anchovies, sardines, and hakes. The spawning of these fish in coastal areas coincides with the maximum food availability in terms of copepod production for their larvae. However, gelatinous carnivore zooplankton, such as, medusae, siphonophores and ctenophores exhibit rapid individual and population growth rates and have been shown to be major consumers of copepod production and early life stages of fish, which give them an important role as predators as well as competitors with pelagic fish populations. Despite their importance to the coastal upwelling areas, there are substantial gaps in our knowledge of basic ecology, and environmental responses, even for many of the dominant species.

Under this context, we have compiled information about the significance of gelatinous carnivorous zooplankton in the upwelling zone off Chile. The northern region off Chile (23ºS) has an intermittent upwelling that supports a high productivity through all the year, supporting also a large abundance of gelatinous zooplankton. Even for this area a "gelatinous food web" was proposed as an alternative way of carbon flux, instead of the "classic food chain", and it could be more relevant under certain environmental conditions (González *et. al.* 2004). On the other hand, the coastal area off Central Chile (36ºS) has a strong seasonality, with peaks of PP in spring/summer, supporting a large zooplankton secondary production, including gelatinous carnivorous. Throughout experiments with *Pleurobrachia bachei* (Ctenophora) in northern Chile and with *Muggiaea atlantica* and *Sphaeronectes gracilis* (Siphonophora) in central Chile, predation rates were determined using *Acartia tonsa* and *Paracalanus parvus* (CIV-CV) as prey because of their high abundance during these studies. To estimate the predatory impact of these species on secondary production of small copepods, the results were extrapolated to the field using the

predator abundances of each one of the carnivorous species. Results show that the predation pressure of these species of carnivorous jellyfishes on small copepod secondary production is relatively low (2.8 - 8.2%). Nevertheless, if we consider the predation effect by the whole gelatinous carnivorous zooplankton at mesoscale level, this impact is be important (19.6 – 57.4%). Since other predators, like chaetognaths, might remove near 6% of the standing stock of copepods in spring in the northern (21°S) zone (Giesecke & González, 2004) gelatinous predators could modulate the population dynamic of small copepods in some periods of the year. Copepods represent the most important prey for many fish larvae and juvenile of pelagic fish. Recent evidence (Arai, 2005) suggests a strong top down control between pelagic fishes and gelatinous zooplankton (Arai, 2005), thus the interplay (predation/competition) between these two important groups of the plankton are discussed.

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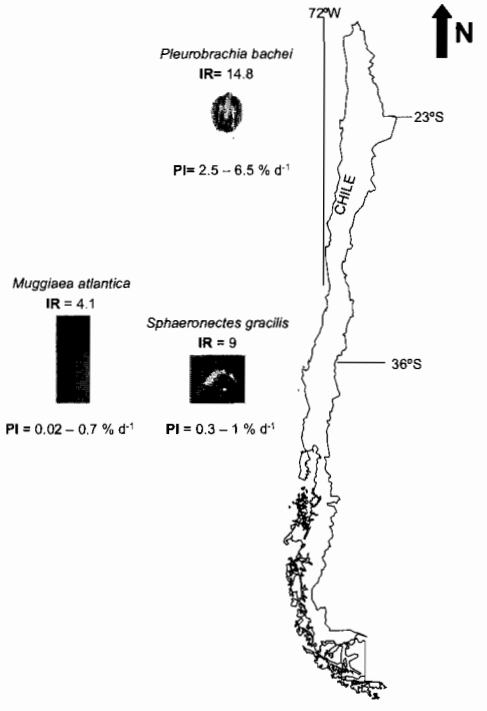

Figure 1. Predatory impact of dominant species of gelatinous carnivorous zooplankton, in northern and central area off Chile. ***IR=*** *Ingestion rates (copepods predator^{-1} day^{-1}).* ***PI=*** *Predatory impact (% secondary production of copepods removed daily).*

HCS064 - Comparative analysis of trophic flow structure between normal upwelling and El Niño periods for Bahía Independencia, Peru

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Keywords: Argopecten purpuratus; Bahía Independencia, Peru; Ecotrophic model; El Niño; Humboldt Current

Along the Peruvian coast El Niño causes a lowering of the thermocline and, as a result, the upwelling of cool, nutrient-rich water is decreased. During the strong El Niño event of 1997/1998, Independence Bay showed a ca. 10 °C increase in surface temperatures, higher oxygen concentrations and overall clearer water conditions due to decreased phytoplankton concentrations. Many benthic species groups suffered under these almost tropical conditions (macroalgae, Cancridae crabs, polychaetes, and others), while others benefited (scallop – *Argopecten purpuratus*, sea stars, sea urchins) (Fig. 1). The most obvious change is the strong recruitment success and subsequent proliferation of the scallop *A. purpuraus,* whose biomass increased eighty-fold during the past El Niño event of 1997/1998. In order to observe the changes in trophic flow structure that occur during El Niño, steady-state models of Bahía Independencia were constructed for a normal upwelling year (1996) and at the height of the following El Niño event (1998).

Inputs into the model were based on survey and landings data of IMARPE (Instituto del Mar del Perú). Results indicate that while the total system size (Total Throughput) is reduced by more than one-third (mainly as a result of decreased total primary production) total biomass remains largely unchanged despite considerable shifts in dominance of functional groups (e.g. scallops replace polychaetes as the dominant consumer of plankton/detritus). Under normal upwelling conditions, strong predation by snails and crabs utilize the production of their prey species almost completely (high Ecotrophic Efficiencies, EE, of prey groups), resulting in a higher Mean Transfer Efficiency (TE) and Predatory Cycling Index (PCI) than during El Niño. However, during El Niño, the proliferation of the scallop *A. purpuratus* combined with an overall decrease in phytoplankton production resulted in a much higher overall utilization of primary production and is reflected in reduced exports both overall and as a proportion of Total Throughput, and a higher Finn's Cycling Index (FCI). Other system statistics point to the El Niño situation as that of a more mature ecosystem, such as the ratio between primary production and total respiration coming closer to 1.0, an indication of maturity (1.28 vs. 2.52); however, this interpretation must be taken with caution given that many of the functional groups are reduced as a result of physiological stress and these statistics seem to largely reflect the scallop – phytoplankton flow. El Niño perturbations in Bahía Independencia may be considered an ecosystem enhancing event on a longer time scale as key benthic predators recover and are able to feed on the newly available scallop biomass.

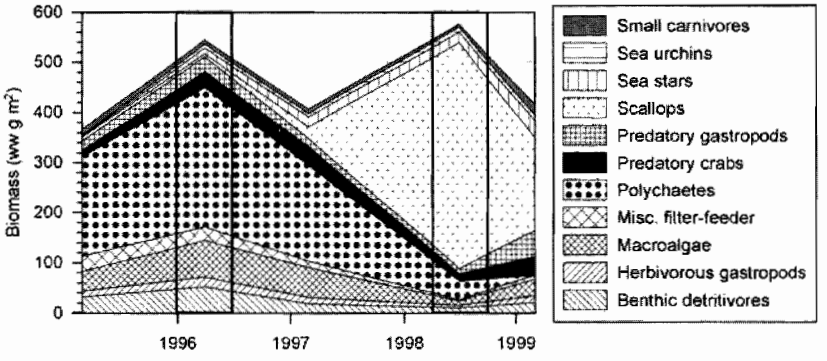

Figure 1. Biomass changes of benthic macrofauna in Independence Bay from 1995-1999 (IMARPE). Boxes indicate model periods.

HCS122 - Comparing ecosystem status in the southern Humboldt and the southern Benguela systems before and after heavy fishing

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Keywords: Food web models, fishing impacts, Humboldt, Benguela, Upwelling systems

Since fishing activities have degraded many marine ecosystems, stock rebuilding and ecosystem reconstruction are considered central goals for ecosystem-based fisheries management. However, information on historical stock biomasses and evolution of fishing effort are not enough to accomplish this goal, because ecosystem effects of fishing include changes in community structure, trophic interactions and the paths through which energy is circulated in marine food webs. Therefore, sound representations of past ecosystems are useful in assessing present status of ecosystems, understanding the mechanisms by which fishing (and other forcing factors) alters ecosystems, and identifying future ecosystem-based strategies for reconstructing ecosystems, or at least, alleviating negative effects of fishing and other forcing at the ecosystem level.

The upwelling ecosystems of southern Humboldt (SH) and southern Benguela (SB) are among the most productive areas of the world ocean. Consequently, important fisheries have been operating in these systems targeting pelagic, demersal and benthic species. Although food web models are available for SH and SB representing relatively recent periods of exploitation (i.e., already altered by fishing), no models have previously been constructed to represent the food web during the pristine and early fishing periods in these systems. As a result, changes occurred in SH and SB before and after heavy fishing are still poorly understood.

Although community structure and the assemblages of species are similar in both upwelling systems, fishery exploitation has been more intense in the SH compared to the SB, as revealed by recent collapses of important fishery resources in SH. Therefore, we test the hypothesis that ecosystem effects of fishing are more noticeable in the SH than in the SB.

We test this hypothesis by assessing and comparing changes in community structure, trophic interactions, energy flows and biomass changes in key species in SH and SB during three main periods of exploitation, using food web modeling. Historical data on biomass, production and consumption rates, catches and

other key population parameters are used to construct food web models representing SB and SH during the following periods: pristine, moderate fishing exploitation and present (altered after heavy industrial fishing). Following Moloney et al. (2005), models are constructed using a standard structure in terms of number and type of functional groups and the Ecopath with Ecosim software (version 5.1). Each model includes the following functional groups: the fisheries, cetaceans, sea lions, marine birds, cephalopods, large-sized pelagic fish, medium-sized pelagic fish, small-sized pelagic fish, demersal fish, benthic invertebrates and other groups such as zooplankton, phytoplankton and detritus. Input data were gathered from published and unpublished (grey) literature.
Following Bundy (2004), an analysis of uncertainty was conducted to examine the effects of uncertainty on model estimates. Later, intra- and inter- system comparisons were conducted based on indices of community structure, trophic interactions and energy flows, which were calculated using network analysis routines incorporated in EwE. Changes that are robust to uncertainty are discussed in the light of ecosystem effects of fishing and the ecosystem approach to fisheries management in both systems.

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HCS124 - Analyzing recent and past changes in the southern Humboldt sub-system off Central Chile using ecosystem indicators

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Keywords: ecosystem effects of fishing, ecosystem indicators, Southern Humboldt, central Chile,

Nowadays, managers, users and scientists, among other stake holders, agree on the principle that wider ecosystem considerations have to be formally implemented in fisheries management if fisheries are to be sustainable. Accordingly, the ecosystem approach to fisheries (EAF) has moved from the definition state to the action state. Indicators play a central role in any serious fisheries management system and, consequently, several fisheries agencies are implementing EAF as a gradual evolution from the current single-species indicators towards community- and ecosystem-based indicators. As no big input of monetary resources is expected for ecosystem scale research in the short-term, a practical step-by-step ecosystem approach is needed, i.e., to include metrics that can be calculated using available information, meanwhile more data on other ecosystem components, as well as insight about ecosystem mechanisms and processes are progressively gained. The starting point for an ecosystem-based management plan is the definition of a working list of ecosystem indicators.
In this paper, we select and calculate a working list of indicators based on the recommendations of the SCOR working group on quantitative ecosystem indicators for fisheries management. However, since the comparative approach plays an important role in validation, we also take into account whether selected indicators are being implemented in the analysis of other ecosystems around the world. The available data and ecological significance in the southern Humboldt system are also considered when selecting indicators. In this paper present ecosystem indicators that cover catch composition, biomass of the main target species, average size of the community, trophodynamics and environmental indicators, among others. Consequently, the aim of this paper is to understand the effects of fishing in the exploited community in the southern Humboldt ecosystem. The specific objectives are: i) Assess historical ecosystem trends and forcing using a list of ecosystem indicators (what is the history of the ecosystem?); ii) Determine the status of the ecosystem in the present (where is the ecosystem relative to where we want to be –or at least to the state we were before fishing?).
Results indicate that big mammals have disappeared from the catch and may present low abundances in the system. Long-term (decadal) fluctuations (biomass and catch) of the main exploited stocks are observed. An unusual and apparently high presence of jumbo squid has been recorded in the system in last years. Environmental factors indicate the presence of two main "conditions" in the system in terms of sea surface temperature and upwelling index (Fig. 1a). From 1970-1985 the system appeared to be characterized by a relatively warm period of reduced upwelling. From 1985-to early the 2000s the system appeared to be characterized by a relatively cold period with increased upwelling and PP. The switch between these two periods in the SH system occurred at approximately mid 1980s.
In terms of aggregated indicators, it is possible to say that, in the present state, the exploited community is dominated by species that present small body size, short life span, high turnover rate and low trophic level (Figs 1b to 1f). In addition, the system could have lost some food web attributes associated to maturity and

stability. This information leads to the hypothesis that in the present state, the system is less resilient to external forcing such environmental variability and fishing effort.
Finally, all this information is used to discuss deficient areas of knowledge about ecosystem process and mechanisms by which fishing (and environmental variability) have altered the exploited community in the southern Humboldt.

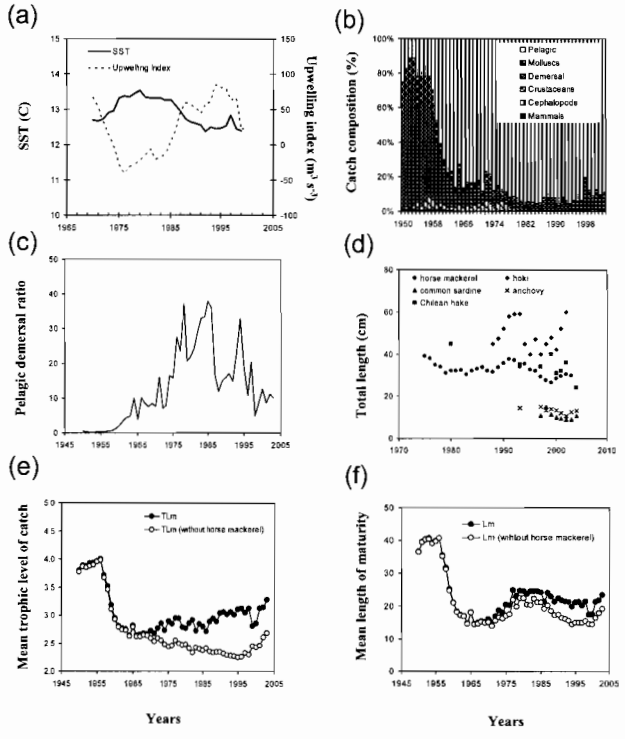

Figure 1. Ecosystem indicators calculated for the southern Humboldt system off Central Chile.

HCS011 - Pacific sardine shoaling behaviour related to tidal front dynamics and related to fishing activities in a coastal lagoon in the southern part of the California Current System

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Pacific sardine shoaling behaviour as inferred by acoustics and related to the dynamics of the pelagic ecosystem was investigated in a tidal dominated coastal lagoon in the southern part of the California Current during the summer of 2004. Observations were done during spring and neap tide using a split beam echosounder (Simrad EY-60, 120 kHz), underwater video-camera, several continuous sub-surface sensors (temperature, oxygen, fluorescence) and zooplankton samples. During spring tides, dense zooplankton aggregations concentrated along tidal fronts that separate the continental shelf mass from the bay's water mass. Pacific sardine and other predators gather to feed along the tidal fronts. During neap tides tidal fronts were less evident and the homogenization of water temperature, dissolved oxygen and fluorescence was observed. Acoustic data shows that during spring tides fish shoal density and fish shoal size increases. During neap tide Pacific sardine groups were smaller, scattered and they tend to swim closed to the sea bottom. However, total fish abundance as calculated by acoustics did no vary significantly. Accordingly, the hypothesis that fishing on these species would be more profitable during spring tides was established and tested using 2004 fishing statistics. Results show that daily fishing trips from the local sardine fishery increased from 30 to 150 when the interval between successive spring tides was minimum and tide range was at the maximum. Moreover, tidal status and spring tide occurrence were calculated for two decades (1990-2010). Results show that the occurrence of successive spring tides varies along the seasons and along the years. Discussion is focused on the significance of the timing of this 'window of opportunity' to the fishery related to the California Current variation and strength in the area along the years. We conclude that Pacific sardines adjust their behavior to the dynamics of tidal regime by modifying shoaling parameters and that these behaviors have a direct relation to fishing activities.

HCS045 - Abundance and distribution of small pelagic fish and their eggs in the southern Benguela ecosystem: a comparison of two decades of acoustic and egg surveys

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Hydro-acoustic surveys to assess the biomass and distribution of anchovy *Engraulis encrasicolus* and sardine *Sardinops sagax* spawners in the southern Benguela have been conducted annually since 1984. Ichthyoplankton samples are also routinely collected from CalVET net samples during these surveys, and together with the acoustic data, have provided a wealth of information on how the abundance and distribution of these species has changed through time. Biomass estimates derived from these surveys are used for stock assessment purposes and to set annual total allowable catches (TACs) for both species. Anchovy spawner biomass has shown immense variability arising from the high recruitment variability shown by this species, with spawner biomass estimates ranging from 180 thousand tons to almost 7 million tons. Of note is the substantial increase in spawner biomass over the period 2000-2003. Sardine has shown a steady increase in spawner biomass over most of the time-series, despite high recruitment variability. The biomass of sardine increased from under 100 000 tons in 1984 to a high of over 4 million tons by 2002, although most recent surveys indicate that the population trajectory is now decreasing. The distribution of anchovy eggs during surveys coincides with the distribution of anchovy adults, and anchovy egg data were used in the successful implementation of the daily egg production method (DEPM) to estimate anchovy spawner biomass between 1984 and 1993. These comparative biomass estimates (DEPM) were essentially unbiased and therefore used to "tune" the acoustically-derived anchovy spawner biomass estimates so as to improve the accuracy of the acoustic estimates in the light of several unknowns such as target strength uncertainty. For sardine, however, areas of high egg and adult densities are disparate, possibly arising from inadequate sampling of sardine eggs by the CalVET net or from age-specific differences in egg production whereby larger females produce substantially more eggs per spawn, and over the entire reproductive season, than do smaller females. This mismatch may be a complicating factor in the planned implementation of a DEPM estimate of sardine spawner biomass. We show how, over a period of more than two decades, distribution patterns of spawners and eggs have changed both geographically and in relation to biomass, and we highlight a recent eastward shift in the distribution of both sardine and anchovy spawners which has been broadly mirrored by a shift in egg distributions of both species.

HCS101 - Natal origin, migration patterns and potential subpopulation structure of *sardinops sagax* inferred from otolith δ^{18} o measurements

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Keywords: Isotope ^{18}O, otoliths, Pacific sardine, temperature

Introduction- The ecosystems associated with the Humboldt and California Current Systems share common characteristics in their physical-chemical attributes, such as coastal upwelling events that occur throughout the year and marked latitudinal gradients in temperature. These systems are also characterized by elevated productivity and the presence of a large biomass of fishes like anchovy, sardine and mackerel. The sardine (*Sardinops sagax*) is one of the more important species in terms of abundance and fishery catches in both ecosystems. It is likely that there are more than one stock of sardines in both ecosystems inhabiting their area of distribution (Serra & Tsukayama 1988, Felix *et al.* 2004). However, there is limited information regarding the natal origin of different potential subpopulations and their movement patterns.

A methodology that has recently proven useful for examining population structure and migration of fishes is the isotopic composition of otoliths. Otoliths are composed of $CaCO_3$ that is deposited throughout the life of the fish. The stable isotopes of oxygen in otolith carbonate ($\delta^{18}O_{oto}$) can be used to reconstruct some of the environmental characteristics to which individuals were exposed during their life. There is an inverse relationship between temperature and otolith $\delta^{18}O$ values that can be used to back calculate the temperature regime experienced by an individual during its life (Campana 1999). Fishes that have grown at different temperatures can potentially be identified based on the otoliths $\delta^{18}O$.

We measured $\delta^{18}O_{oto}$ in sardines captured in various locations within the California Current region and the Gulf of California to reconstruct temperature histories of individuals and evaluate whether $\delta^{18}O_{oto}$ can be used as a natural tracer of natal origin, migration patterns and to discriminate among populations. We describe the method and results here as a potential tool to investigate population structure of sardines and others pelagic fishes in the Humboldt Current.

Methods- Otoliths were extracted from fishes collected at nine locations along the Pacific coast of Baja California and in the Gulf of California (Mexico) between May 2004 and May 2005. Otoliths were cleaned following standard methods. For $\delta^{18}O$ analysis, otoliths were reacted with phosphoric acid to convert aragonite to CO_2 for analysis in an isotope ratio mass spectrometer. Isotopic values are reported in standard δ notation relative to VPDB standard. Ageing was performed to estimate the time period over which otolith $\delta^{18}O$ reflected the temperatures to which sardines were exposed during their life. The mean sea surface temperature (SST) to which each fish was exposed based on its age, was obtained for each location from the NOAA's CoastWatch satellite service. We used the Campana (1999) equation to back-calculate temperature (T_{oto}) from $\delta^{18}O_{oto}$ and water (δ_w) isotopic measurements: $\delta^{18}O_{oto}-\delta_w = 3.71-0.206(T_{oto})$. δ_w values for each region were obtained from the literature.

Results and Discussion- The average age of sardines ranged between 8-16 months. There were no significant differences between all Pacific and Gulf $\delta^{18}O_{oto}$ values (p=0.1). However, there were significant differences among locations within each region. There was an inverse correlation between $\delta^{18}O_{oto}$ values and SST estimates for all fishes collected in the Pacific (r=-0.48), which agrees with theoretical predictions. There was a slightly lower correlation between SST and $\delta^{18}O_{oto}$ values for the Gulf samples (r=-0.44). There was a large amount of variability in $\delta^{18}O_{oto}$ from individuals captured simultaneously (Fig.1), suggesting that the sardines were exposed to different temperatures during their life and that horizontal mixing had occurred.

Comparison of T_{oto} and SST estimates for Ensenada suggest that those samples come from the so-called Northern subpopulation (centered off Alta California, USA). Cedros samples are identified with a subpopulation (centered off central and southern Baja California) that exhibits seasonal northward movement along the Pacific coast of Baja California (Felix et al. 2004). In contrast, there were discrepancies between SST estimates and T_{oto} for Bahia Magdalena.

Sardines collected in Bahia Magdalena do not appear to be permanent residents of that bay system. Comparison of T_{oto} with SST's within the region of study suggests that sardines may migrate from Cedros Island to Bahia Magdalena in the fall and from the Gulf to the bay during the summer. This agrees with previous observations based age-length relationships and otolith morphometrics.

Estimates of T_{oto} for Gulf samples were generally lower than average lifetime SSTs, suggesting the preferential use of colder temperature habitats. Sardines are able to inhabit deeper, colder waters during warmer periods, which may explain the differences between SST and T_{oto} for some Gulf locations.

In conclusion: 1) SST estimates provided an approximation to the temperature history to which young sardines may have been exposed during the course of their lives, although T_{oto} is a more accurate estimate of temperature history if δ_w measurements are available. 2) The oxygen stable isotope composition of sardine otoliths could potentially be used to characterize natal origin and migration patterns within the range of distribution of this species within the Mexican Pacific.

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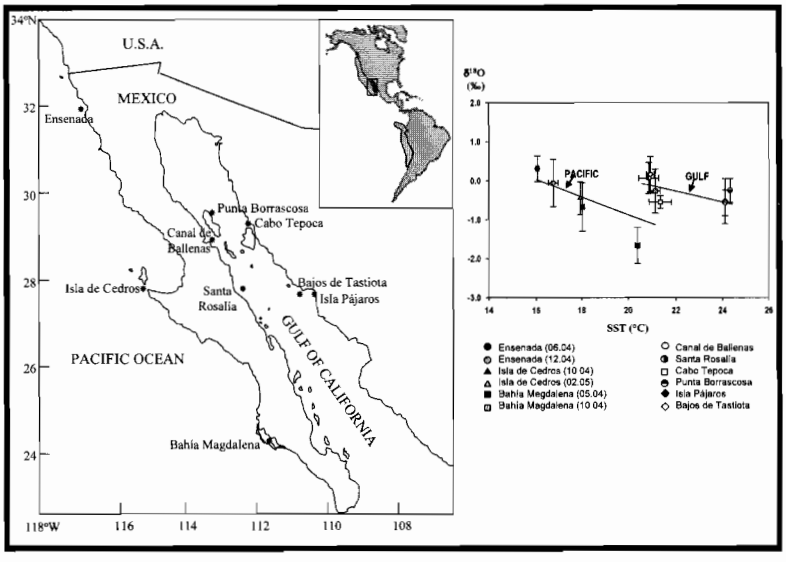

Figure 1. Left: Map of Baja California showing sampling areas at the Pacific off Baja California and Gulf of California, Mexico and distribution of Sardinops sagax in the Humboldt and California Currents. Right: Relationship between $\delta^{18}O_{oto}$ values of sardine otoliths and the temperature (SST).

HCS103 - Utilization of energetic susbtrates in early stages of anchoveta *Engraulis ringens* in the Southern area of the Humboldt Current.

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Keywords: egg, *Engraulis ringens*, fish eggs, free aminoacids, proteins, survival

Engraulis ringens is a key specie in the transference of energy from the primary producers to the trophic web and also an important fishing resource. However, the information on how egg quality can affect development and survival of anchoveta embryos is scarce. Recents studies on this species have demonstrated that differences in egg size and yolk sac content of recently hatched larvae depend on season and latitude, among other things. Eggs of oviparous teleosts accumulate lipids and a large amount of yolk proteins, as a nutrient storage required by developing embryos. Along the southern Humbodt Current System area, the anchoveta spawning season is uncoupled with the season of maximum upwelling. Therefore, substrates and energetic requirements for larval development storaged in the eggs should be enough to guarantee survival. In this study we have determined the availability of energetic substrates (lactate, free aminoacids, proteins and lipids) in the early stages of anchoveta and their utilization through out the main spawning period in the South of Humboldt Current.
During August 2003, ichthyoplankton samples were collected from the field and transported to the Dichato Marine Biology Station (University of Concepcion), where anchoveta eggs were separated and incubated at 12ºC. During the experiment, samples of eggs and young larvae were obtained from the incubators at different times in order to obtain groups of eggs in different developmental stages along with 1, 3, and 5 days old larvae. Egg Group I was defined as eggs without embryo, Group II defined as eggs with early embryo and Group III eggs with late embryo. Each egg and larval sample was frozen at -20ºC for later analyses. The total amount of egg proteins were determined by Lowry et al (1951) and SDS-PAGE electrophoresis by Laemmli method (1970). During August and November 2004, oceanographic cruises were carried out in Coliumo Bay (36° 32'S; 72° 57' W) where ichthyoplankton samples were collected and gently transferred to 3.5 L containers and then transported under controlled temperature (12°C) to the laboratory. Eggs were sorted and classified in three groups according as their developmental stage. Samples of each developmental stage were quickly frozen and maintained at -20ºC. Finally, in October 2004, two sets of experiments were performed under controlled temperature (12ºC), in which eggs were incubated and collected at different times during the incubation in order to obtain the 3 different developmental stages described. After the collection, all samples were storage at -20ºC until analysis. For all August and November egg samples and also for the eggs from the October 2004 experiments, the total amount of proteins of fish eggs were determined by Lowry et al (1951) and SDS-PAGE electrophoresis by Laemmli method (1970). Lipid content was extracted by Blight & Dyer method (1957) and measured gravimetrically. Triacylglycerides (TAGs) and Total cholesterol were determined in the reconstituted dry lipid samples with 300 μL isopropanol p.a. (Merck) and analyzing by using an enzymatic TG PAP 150 (Biomérieux) and CHOD-PAP (Spinreact) kits respectively. The lactate was quantified using a modified protocol of the colorimetric-enzymatic. Lactate dry fast kit (Sentinel diagnostics). Free aminoacids contend (FAAs) were determined by RP-HPLC.
During the study, lipid concentrations ranged from 4.5 (July 2004) to 9.5 μg egg^{-1} (August 2004). There was no evidence of decrease in lipid concentration through the three analyzed developmental stages. TAGs showed a range from 0.168 to 2.69 μg egg^{-1} with a maximum value in August and there were no significant differences during the egg developmental stages. The total amount of cholesterol ranged from 0.04 to 0.4 μg egg^{-1} and decreased with the egg developmental stages in four of the five months that the study lasted. The average concentration of proteins in eggs was 8.3 μg egg^{-1} and no significant changes occurred in the studied period. Nevertheless, SDS PAGE electrophoresis of fish eggs and larvae obtained from experiments during 2003, showed a decrease of intensity and number of bands of 79.8, ~65, 24 y 22 kD and an increasing presence of low molecular weight fragments from egg stages to larval stages. The two experiments performed in October 2004 showed a significant decrease in concentration of FAAs as the eggs developed. Samples from the field showed the same pattern. FAAs measured in eggs from a first experiment showed concentration of 4.7 ± 0.19 (Group I), 3.0 ± 0.09 (Group II) and 2.5 ± 0.06 (Group III) μg egg^{-1} respectively. Eggs from a second experiment showed higher FAAs concentrations: 6.1± 0.31 (Group I), 5.3 ± 0.22 (Group II) and 3.9 ± 0.16 (Group III), μg egg^{-1}. The first experiment and the field collected eggs had higher concentration of leucine and lysine than the second experiment where lysine, phenylalanine and methionine showed higher concentration. Essential and no- essential FAAs concentration decreased during development but no difference occurred between the two types. FAAs could be produced by partial cleavage of yolk proteins as showed SDS- PAGE electrophoresis. These proteins are used as energetic substrate and have a documented role in regulation of floatability during the

egg development. We observed a decrease of lactate concentration in the eggs collected from the field through the study period. The concentrations ranged from 14.4 ng egg^{-1} in July to 5.6 ng egg^{-1} in October in eggs of Group I. During July and October, lactate concentration was 4 and 8 times higher respectively in Group III than Group I. Lactate accumulation could be attributed to a potential use of glycogen as energetic substrate by anaerobic pathway during the egg phase.
The results from these observations show that the different potential energetic substrates present in the early egg stages are not equally utilized during the rest of the development of the anchoveta eggs and larvae and that some differences might arise along the spawning season. These results are one of the first contributions to the study of energetic balance during the early life stages of pelagic fish species and the potential effect of the energetic substrates on their survival in upwelling systems.

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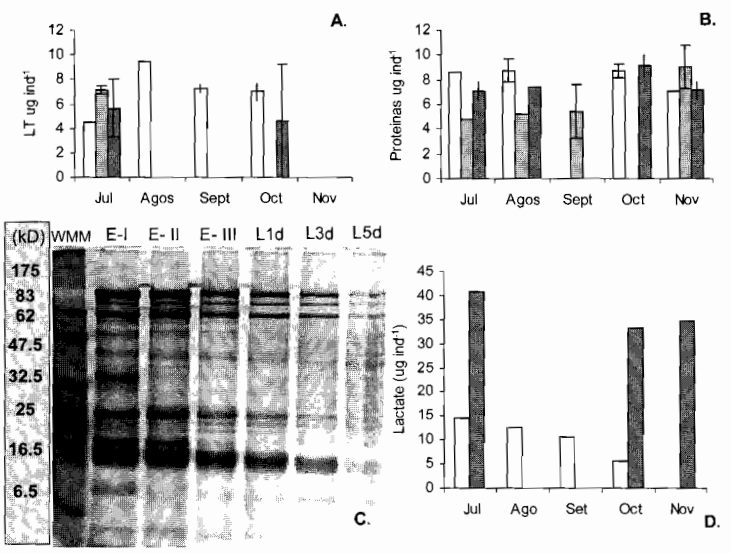

Figure 1. a. Total lipids (A), Total proteins (B) and Lactate concentration (D) in anchoveta eggs. Bars: white: Group I, Light gray: Group II and Dark gray Group III. C. SDS-PAGE gel showing proteins from E-I at III: egg group I at III; L1d to 5d: Larvae of 1 day to 5 day old.

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HCS131 - Artisanal Fishery of Anchovy (*Engraulis ringens*) in the zones of Caldera and Coquimbo (26° – 30° S), Chile, 2000 –2005

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The main biological and fishery variables that characterize the anchovy artisanal fishery in the zones of Caldera, III Region and Coquimbo, IV Region, Chile, during the fishing seasons 2000 – 2005. The relative abundance estimator (*CPUE*= ton/trip with capture (twc)) was standardized with a GLM which considered the influence of factors as: fishing ground, month, trimester, semester and fishing vessel's hold capacity. In Caldera, the available information covers only the 2002 to 2005 period, and catches were limited to the latitudinal limits 26°08'21''S and 27°39'31''S, and to 10 nm from the coast. The catches taken by the artisanal fleet increased through the study period. The relative abundance index showed an important variation through time, with 4.14 ton/twc for 2002 to 11.83 y 37.36 ton/twc during years 2003 to 2005. In Coquimbo, the available information includes one semester of 2000, the 2003 – 2004 period, and the 2005 season, and catches were limited to the latitudinal limits 29°16'56''S and 30°21'38''S, and to 10 nm from the coast.. As in Caldera, the mean *CPUE* showed the lowest values during 2002, increasing the following years with 31.61 to 42.85 ton/twc (Fig.1).
The biological data analyzed includes monthly and yearly size range and structure (Total Length, LT, cm), Gonadosomatic Index (GI) and Condition Factor (CF). In Caldera, the minimum and maximum size values were found during the 2003 and 2004 fishing seasons, respectively, with an important proportion of recruits (< 11.5 cm LT) during 2003 (Fig. 1b). The anchovy GI showed the highest values during July and October every year in both regions (Fig. 1c), although in Caldera, a second smaller peak was detected

during December 2004 - 2005. During years 2003 and 2005, the GI was higher in Coquimbo than in Caldera. The anchovy CF showed the highest values during the last two years and in both regions, with 159.2 g/cm in Caldera and 151.2 g/cm, in Coquimbo (Fig. 1d).

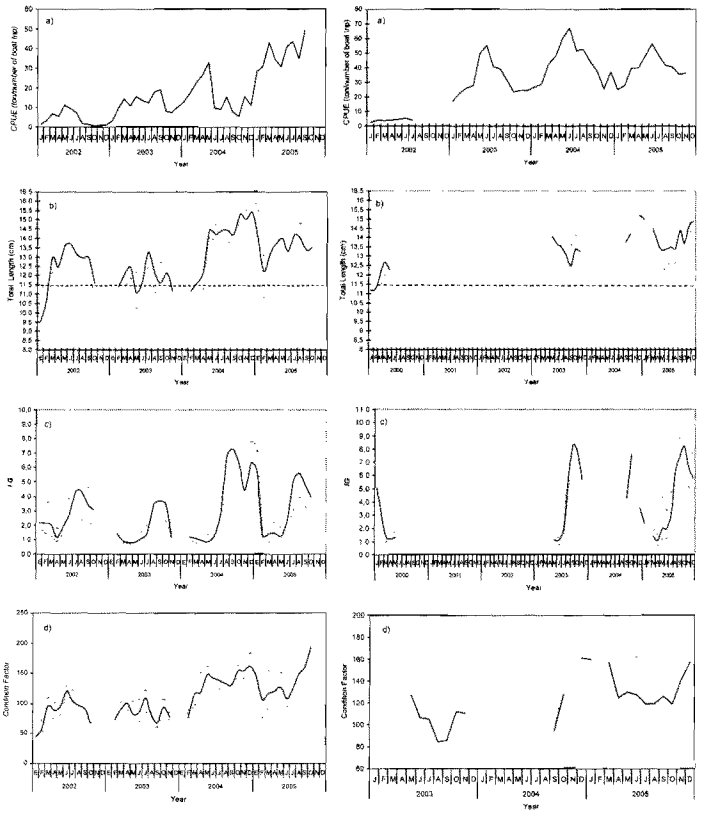

Figure 1.Time series of CPUE (a), median total length (b), Gonadosomatic Index (GI) and Condition Factor (CF) of Anchovy in Caldera (left) and Coquimbo (right), 2000 - 2005.

HCS139 - Morphological aspects of fish schooling: which traits are general across ecosystems, and which are local adaptations?

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Keywords: anchovy, Behavioural ecology, Clupeoids, herring, schooling, school morphology

Small pelagic fish, such as Engraulids, Clupeids and Carangids generally form schools throughout most of their life cycle. Structural patterns are common to all schooling fish species with e.g. coherent, synchronized movements and inter-individual attraction. Nevertheless, the overall morphology and structure of schools are extremely variable in shape and dimensions. What factors that determine the morphology of schools is an important issue in marine ecology, as school morphology could be used as an indicator of the population response to changing environmental conditions.

To explore the schooling phenomena we compare schooling patterns in two very different Clupeids: the Peruvian anchovy (*Engraulis ringens*) in the Humboldt Current ecosystem and the North Atlantic herring (*Clupea harengus*) in the Norwegian Sea ecosystem. These two species have distinct biology and behaviour, while living in exceedingly different environmental conditions in terms of temperature and oxygen range as well as interacting predator and prey species. However, they share an identical position in the middle of the food web being very effective planktivores and by far the most abundant and successful fish species within their respective ecosystems.

This study compares the morphology and structure of geographically distant and unrelated anchovy and herring schools in order to distinguish between common and differently evolved and specialised school characteristics. Quantitative data on important school features like dimension, shape and density has been collected from several acoustic surveys from Peru and Norway using similar methods with vertical echo sounders and multi-beam sonars linked to the physical and biological environment. The morphological differences between schools within and between species allow us to define those schooling patterns that typically vary from one species to the other and those which may be more basic and considered universal. We discuss the schooling concept by comparing two different ecosystems and we evaluate the use of school types as environmental indicators.

HCS141 - Circadian connection between fishing activity, fish schooling and feeding behaviour and planktonic food availibity: the Peruvian Anchoveta *(Engraulis ringens)* case

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Keywords: anchovy, circadian, *Engraulis ringens*, feeding, fishing, planktonic availability, schooling.

In the context of an ecosystem approach to fisheries, we need to improve our understanding of the trophic and behavioural interactions governing the ecosystems dynamics. Many studies have addressed the question of the co-variation of two ecosystem components (e.g. fish and birds, Davoren *et al.*, 2003; fish and fishers, Mathisen, 1989). But, commonly because of lack of data, very few studies proposed to shed light on the trophic and behavioural connections between more components of the ecosystem.
In that context, this work aims at a preliminary exploration of the relationships between fishers, fish and plankton behaviours on a daily basis, as observed in the Peruvian upwelling ecosystem. For that purpose, we used data from (1) onboard observer program for the fishing activity, (2) a specific scientific survey dedicated to the study of anchovy trophic and schooling behaviour performed during November 2004. The studied area is the central zone of the Peruvian coastal ecosystem (between 10 and 16° South) and the studied period is spring of 2004.
As a first step of the analysis, we modelled by a non parametric function (moving average or spline smoother) and as a function of the time of the day (1) the number of fishing sets, (2) the filling rate of the net and (3) the time of leaving port, as indicators of fishing activity; (4) the acoustic index of fish local abundance and (5) the number of schools by surface unit as indicators of schooling behaviour; (6) the filling rate of anchovy stomachs as indicator of feeding behaviour and (7) the number of copepods by unit of volume present in the 25m upper layer, used as an index of plankton food availability. All the studied variables showed a clear day-night pattern. As far as fishing activity is concerned, the higher number of fishing sets is performed at dawn, when filling rate of the net is high. After dawn is the period when anchovy is more densely packed as showed by the diel pattern of the volume backscattering strength (Sv in dB re 1 m-1) of anchovy echoes-traces and low number of schools, i.e. fish is condensed in dense schools. The stomach filling rate of anchovy is higher at dusk, when copepods (as an index of plankton) migrate upward in the water column becoming more available. This co-evolution of the variables all along the day illustrates clearly the facts that (1) fishers take advantage of anchovy schooling at dawn for maximizing catch per set (although in a smaller scale of a few hours there was not a clear match what will be discussed) and (2) anchovy disaggregate at dusk for feeding on plankton which becomes more available by migrating upwards in the water column. We popose the following pattern according to a bottom-up scheme: "copepods become available at dusk and during the night to anchovies. In order to feed actively on copepods, anchovies have disaggregated at dusk and remain scattered during all the night. They begin to aggregate in schools at dawn. Fishers, whose gears are fitted for catching schools, leave the ports at midnight to be present at dawn on the fishing grounds, at the precise moment when anchovies are present in schools. This cycle is completed every 24 hours". We discuss about a "bottom – up" control of behavioural interactions, smaller scale mismatch between them and the advantage of integrating information from diverse sources to try to explain functional relationships between some components of the Peruvian upwelling ecosystem.

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HCS150 - Biological and environmental factors conditioning spatial distribution of the "pejerrey" Odontesthes regia regia in the Pisco area, Peru

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Keywords: "pejerrey" *Odontesthes regia regia*, spatial distribution, seaweeds.

The occurrence of the artisanal fleet oriented to the "pejerrey" (*Odontesthes regia regia*) fishery in the main fishing zones in the Pisco Port in Peru is analyzed. For that purpose we analyzed the spatial-temporal variations in pejerrey distribution related to the reproductive cycle and the environmental conditions. We used CPUE data of the artisanal fleet in the main fishing areas during 2002-2005. Correspondence analysis (ANACOR) was applied to identify patterns of spatial-temporal distribution using occurrence of the fleet per zones. The relationships between the reproductive processes of pejerrey and its distribution

pattern were presented when data obtained by SCUBA diving allowing to identify the extension of seaweeds fields and the incidence of the "pejerrey" eggs in Paracas Bay were available. The environmental data was obtained from the NAO/NOAA and Oceanographic-Fishery Monitoring in Selected Areas (MOPAS – Pisco). Our results suggest a migratory displacement of pejerrey schools according to the seasons and the spawning periods. Indeed, the ANACOR allowed defining two periods with specific well defined distribution areas that alternate during the year and a third period related to rather variable and poorly defined zones (Fig. 1).

During the first period, between November and April fish were located south of the Paracas Peninsula and extending from Lagunillas Bay to the Mendieta beach (sector 1).

From, May to September, i.e. the pejerrey spawning period, fish were mainly distributed close to Punta Pejerrey, Talpo and Punta Corazon (sector 2).

These shallow areas are appropriate to spawning thanks to the presence of seaweeds fields (mainly *Macrocystis piryfera, Rhodymenia spp* and *Gracilariopsis lemanaeformis*).

Between October and November the area of distribution of "pejerrey" was not well-defined (sector 3). Most of the records were located north of the Paracas Bay (Petro Perú, San Andres and La Puntilla) but other records were observed in the central and southern part of the study area.

The analysis of the environmental conditions illustrated clear differences between the north and south part of the Paracas Peninsula. In the north, sea surface temperatures were higher, usually above 16,5°C, and associated to low levels of dissolved oxygen (between 1 – 2 ml.L-1) and higher salinity than in the south.

The variations in the occurrence of the artisanal fleet in the "pejerrey" fishing grounds located north of the Peninsula suggest a seasonal displacement of pejerrey schools to more appropriate spawning areas during autumn and winter seasons. This illustrates the close relationships between migratory movement, environmental conditions and reproductive process. This is also corroborated by the presence of pejerrey eggs in the seaweeds fields north of the Paracas Peninsula and by the biometrics sampling of adult fish showing larger individuals and overall better condition indexes than south of the Paracas Peninsula.

The differences in environmental conditions between north and south areas of the Paracas Peninsula condition the seasonal distributions. During summer "pejerrey" are located south of the Peninsula where cold waters are registered. In the middle of autumn and beginning of winter the migration to the north of the Peninsula is initiated until spring when the spawning occurs, especially in the Paracas Bay where appropriate substrate with seaweeds for fixation and protection of eggs is available. This period ends in spring when pejerrey schools disperse to concentrate again south of the Peninsula in summer.

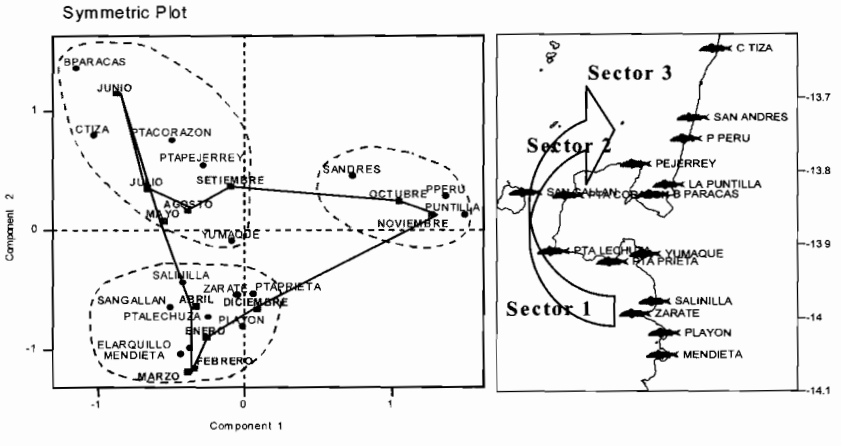

Figure 1. Migratory displacement of the schools of Odontesthes regia regia associated to the seasons of the year and spawning.José Zavala, Daniel Flores, Héctor Sarmiento, Jorge Zeballos

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HCS156 - A not conventional method to estimate the sample size in acoustics survey of three pelagic species in northern Chile.

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Keywords: Systematic sampling, acoustic survey, relative error, ratio estimator, simple size, spatial structure, surface occupation index, pelagic species.

The conventional method for obtaining a sample size equation makes use of an analytic variance expression. We propose a not conventional method to estimate the sample size in acoustic survey design.

We analysed information from the schools of sardine *(Sardinops sagax)*, jack mackerel (*Trachurus murphyi*) and anchovy (*Engraulis ringens*) in the winter season of 1984-1990. A surface occupation index of the schools was used to measure the space covered by the species in the study area. It was found that the three species shown different distribution patterns and the surface occupation index behaved as a measure of the homogeneity of the resources in the study area. The changes in the distribution patterns shown by the species between successive years do not permit to establish pre-stratification criteria to evaluate three different species simultaneously. In this paper we obtain a relationship between the relative error of the density estimations of the species and an index of intensity of sampling (degree of coverage) corrected by the index of surface occupation by species (DCM). Values over the threshold DCM=0,015 indicate a low gains of precision for the acoustic survey design. The sample size expression obtained depends on the parameters of the adjusted equation, the relative error of the density estimates, the area of study and the surface occupation index of the species. It was found that to greater value of the surface occupation index of the species, then smaller the sample require to reach a determined level of precision.

HCS168 - Evolution of acoustic methodologies in Peru and their use in the analysis of distribution and abundance of main pelagic species along Peruvian coasts between 1983 and 2006

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Keywords: abundance, acoustic, biomass, distribution, ecosystem, gravity center.

Acoustic methods are now commonly used for detection, quantification and studying behavior of marine pelagic populations. Acoustics have been used to investigate the main pelagic resources of the Northern Region of the Humboldt Ecosystem beginning in 1961 when the Institute of Marine Resources (IREMAR, Callao, Peru) performed the first systematic surveys for qualitative monitoring of the aggregative patterns of anchovy (*Engraulis ringens*). In 1966, the Peruvian Marine Research Institute (IMARPE) continued this type of research through the Eureka Program (Gutiérrez et al, 2000) which made qualitative observations for scientific purposes using echosounders operating from fishing vessels. Between 1975 and 1981, IMARPE established cooperative links with the United Nations Food and Agricultural Organization (FAO) and (Norwegian Agency for Development) NORAD to develop a survey method based on echointegration to obtain estimates of absolute biomass. That method, developed in the course of a research on the Peruvian hake (*Merlucius gayi*) and anchovy (*Engraulis ringens*) involved measuring, acoustic conversion coefficients in a controlled environment, the progressive increase of fish density and echointegration values up a maximum acoustic response level as known amounts of fish were progressively added in a cage, to simulate real densities. The regular use of the methodology, complemented by statistical models for mapping and calculating abundance, was begun in 1983 with systematic monitoring of species such as anchovy (*Engraulis ringens*), sardine (Sardinops sagax), jack mackerel (*Trachurus murphyi*) and mackerel (*Scomber japonicus*), which were the most abundant pelagic species during the 1980's (Gutierrez, 2000).
The use of those conversion coefficients or *constants of calibration* ended in 1992 when IMARPE adopted the use, the by then internationally accepted methodology, of reference targets (spheres) to adjust the echointegrator's settings. The old method was replaced by empirical Target Strength (TS) equations which convert the mean size of fish into its corresponding acoustic reflectivity value (in decibels). Then, the readings of the echointegrator were converted to the number of fish per sampling unit given that the mean fish size was known (this required an adequate TS equation for every species, and a certain number of sampling trawls along the studied area in order to estimate the size and age distribution of assessed fishes). The acoustic equipment remained the basically same between 1975 and 1995 (separate echosounder-echointegrator) in 1996 the first digital system (integrated echo-sounder and integrator) was acquired, which facilitated the data collection and analysis. In 1997 we began a systematic study of the values of acoustic reflectivity (TS) for the main pelagic species and, in 1998, we began recording data in digital format and using post-processing software.
Thanks to the user-friendly features in the new technologies and to software implemented since 1998 it was possible to increase the number of acoustically studied species. Additional species incorporated include munida (*Pleuroncodes monodom*), vinciguerria (*Vinciguerria lucetia*), catfish (*Galeichthys peruvianus*), giant squid (*Dosidicus gigas*), white anchovy (*Anchoa nasus*), hake (*Merlucius gayi*) etc. The acoustic surveys usually covered the whole Peruvian coast to 100 n.mi. on average off shore.. The number of surveys performed was between 1 per year between 1983 and 1995, and an average of 2 or 3 between 1996 and 2006. Thus, a reliable time series of distribution and abundance of anchovy and sardine exists between 1983 and 2006 (23 years). Additionally a more qualitative series for anchovy reaches back to 1961 (Fig. 1). Through this period 51 acoustic surveys devoted to pelagic species were conducted, not counting the surveys for demersal and invertebrate species and short duration surveys. For the purposes of the present study the processing and analysis of the data has been carried out using multivariate statistics and geostatistics to reveal distributional and abundance patterns of the main species. In addition estimates of latitudinal biomass or abundance and area of distribution for all assessed species

are shown. These include the used species specific calibration coefficients (for the 1983-1991 period) and TS-Length relationships (for the 1992-2006 period).
Preliminary results show two processes that co-occur through the 1980 and 1990 decades: (i) the sustained increase of anchovy abundance while sardine, jack mackerel and mackerel declined (Gutiérrez, 2007), and (ii) the increase of giant squid and munida. In terms of distribution and abundance since the last strong El Niño in 1997-98 an almost absolute dominance by anchovy and munida along the coastal ecosystem, and of vinciguerria and giant squid in the open sea, have been observed, while the presence of jack mackerel and mackerel is seasonal, as is the presence of white anchovy and mote sculpin and of demerso-pelagic resources such as catfish and barred sea-robin. Our analysis supports hypotheses suggesting that both decadal changes and composition of plankton communities explain the observed fluctuations in population levels of studied species.

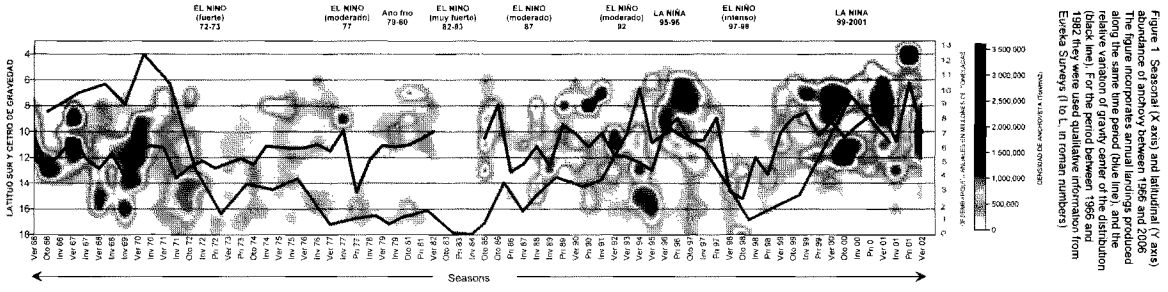

Figure 1. Seasonal (X axis) and latitudinal (Y axis) abundance of anchovy between 1966 and 2006. The figure incorporates annual landings produced along the same time period (blue line), and the relative variation of gravity center of the distribution (black line). For the period between 1966 and 1982, they were used qualitative information from Eureka Surveys (I to L, in roman numbers)

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HCS177 - Dynamic of fish schools and clusters' characteristics over time: description, analysis and comparison for small pelagic fish off Peru from 1996-2003

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Keywords: dynamic, long term series, schools, spatial summary statistics.

When monitored with acoustic devices, the very nature of pelagic fish is probably not well reflected by back-scattering energies integrated over regular space intervals (ESDU) which is however the traditional way of doing. In this case, as integration is performed over the entire water column, fish distribution is considered as a continuous variable in a 2D space and its spatial structure can be described by means of some geostatistical tools. As a summary statistics for such spatial structures, we used the fractal dimension (in the sense of local rugosity) of the 3D surface representing the spatial fish distribution surface areas and generated a time series of this indicator for the 20 acoustics surveys realised off Peru over the past 8 years. Following theoretical concerns (Bruno and Raspa, 1989), we computed the fractal dimension from the order one variogram.
Thanks to still recent technical progress, it is now routine to store acoustic information school by school through a set of variables such as the high and length of the acoustic aggregation, its depth, its shape, its density, and other. In the case of historical data, a visual scrutinising allows extracting similar, even if less precise, information to obtain long time series of information on fish collective structure shape, abundance and distribution. However, the valorisation of that kind of data implies the development of adapted methods. Another objective of the present work is thus to develop and apply summary statistics adapted to this type of information (i.e. marked spatial point processes). School characteristics are available for the four main pelagic commercial species (anchovy (*Engraulis ringens*), sardine (*Sardinops sagax*), jack mackerel (*Trachurus murphyi*) and mackerel (*Scomber japonicus*)), and their summary statistics feed the description and analysis of the impact of environmental changes on fish aggregation behaviour. In particular the compaction of the populations and the synchronic modification of the two main levels of spatial organisation of pelagic fish (the schools and the clusters) are considered.

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Thursday afternoon

HCS182 - The size spatial segregation by sizes in the anchovy population (*Engraulis ringens*) in northern and central part of Peruvian Coast

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Keywords: Peruvian anchovy, spatial segregation, size groups, fishing set, conceptual model, behaviour, size association.

The present work studies the spatial segregation and migratory tendencies related to fish size in anchovy population located in the northern and central part of Peruvian coast. The research takes into account spatial and temporal aspects of two fishery and biological attributes: the relative abundance and the size of individuals. For this reason, multivariate methods for size group determination, traditional methods in fishery biology for cohorts identification were used. Cartography techniques for mapping the distribution of size groups were also applied. Size frequencies and capture data were obtained from fishing sets carried out by commercial purseine fishing vessels and research cruises between 1996 and 2000.
Previously, the optimal effort unit (OEU) was determinated to estimate a spatial index of capture per effort unit (c.p.u.e.). For this, two effort units were evaluated: fishing days and fishing sets. The storing capacity (SC) of the vessels was considered as indicator of fishing power of themselves, for this analysis, the SC was divided in five categories. To face the effect of sampling intensity on the SC, an applied effort rate per vessel (λ) was established. The chosen OEU must show a direct relationship between the λ and SC of vessels. Spatial segregation was measured by Cramer V index (CV), if two groups have the same areas of distribution then the CV is "1", on the contrary, if these areas are absolutely different then the CV is "0". To eliminate possible errors when comparing segregation levels of size groups between years, an standardized index of CV (γ) was established, if γ is negative then segregation exists if γ is positive then spatial segregation of anchovy sizes does not exist. Another studied characteristic was the fish association of different sizes inside the groups, which was measured by a size association index (A_{Gx}).

Results on OEU determination showed the fishing set would be the effort unit more suitable for the estimation of c.p.u.e index if aspects of spatial distribution of relative abundance of anchovy population are required. Also, it was demonstrated the existence of spatial segregation by sizes in the population anchovy, which was characterized by the presence of three size groups in Peruvian coast. The distribution areas of these groups showed a high level of overlapping between 1996 and 1997, intermediate in 1998, and low between 1999 and 2000. These results indicate the spatial segregation not always is notably observed in anchovy population. Furthermore, an indirect relationship was observed between segregation levels and anchovy abundance. Results on association of individuals inside the size groups indicated that this was significantly related to seasonal variations and not to the size of individuals throughout their life span ($p < 0.05$). The major levels of association were observed in spring and summer.
In the other hand, conceptual models built with results obtained from individuals association, superficial distribution and depth distribution of size groups; showed some behavior linked to reproductive and trophic processes of the species: a major level of individuals association of different sizes and movements of anchovy schools (to the coast and to superficial zones in the water column). This behavior was observed from November to December of 1998 and 1999.
Finally, this work concludes that occupation way of the space by anchovy individuals is not at random, but it happens in age related systematic way which is reflected in spatial and temporal migrations by sizes. Also, the presence or absent of spatial segregation by sizes could be considered as indicator of abundance state of anchovy population in a specific period of time. The results obtained in this work give the necessary bases for a future spatial modelation of the most important anchovy population in the East Pacific, being benefited of a better management by fishery administrators and scientists involved.

HCS184 - Changes in the Peruvian marine pelagic biodiversity from 1990 - 2005 related to climate variations and fishery

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Key words: biodiversity indices, ENSO impact, fisheries impact, marine pelagic biodiversity, Peru Humboldt Current system

Change in biodiversity is considered as one of the best indicators of the ecosystem health status. Species diversity indices are therefore classically used to monitor human impact on marine ecosystems. Natural changes of the environmental conditions also lead to dramatic variations in species composition and

biodiversity. This is typically the case of Eastern Boundary Current systems that are strongly affected by climatic variability. These ecosystems support very high fish biomass exploited by extensive fisheries. For these reasons, there is a need to analyze temporal changes in biodiversity according to both, climate and fisheries. Here we study variations in pelagic biodiversity in the Humboldt Current System through classical indices (specific richness, Shannon–Wiener and evenness) to relate them to indicators of environmental conditions (ENSO, SST anomalies) and to the landings of commercial fisheries.

Data came from 40 acoustic surveys, carried out by IMARPE to estimate the biomass and monitor the distribution of the main pelagic species from 1990 - 2005. An average of 200 pelagic trawls per survey was performed for species composition and biological measurement. A maximum of 107 species were identified from these samples. Indices were calculated for each survey as a whole and also according to the diel period, the ecological domain *i.e.* shelf or offshore, and ecological provinces (transitional zone, north of 6°S and Humboldt System, south of 6°S). Besides, multivariate analyses were used to determine species assemblages and their temporal variability.

Results showed that species richness presented a similar trend in time series when considering each survey as a whole or when taking into account the diel period and the ecological domain but different patterns were found between ecological provinces. Spatiotemporal variations in species richness (Fig. 1) show that El Niño 1992-1993 had no apparent effect on biodiversity whereas biodiversity dramatically increased during and after El Niño 1997-1998. The effect of this event lasted more than four years and had strong effects on the dynamics of assemblages during the studied period. No direct impact of pelagic fisheries on pelagic biodiversity could be observed. The period of higher biodiversity (1997-2002) corresponds to very high pelagic landings (mean: 7 million tons). In the specific case of pelagic biodiversity off Peru, changes in biodiversity appear more related to changes in environmental conditions than to direct human activities (even if climate is now affected by human activities).

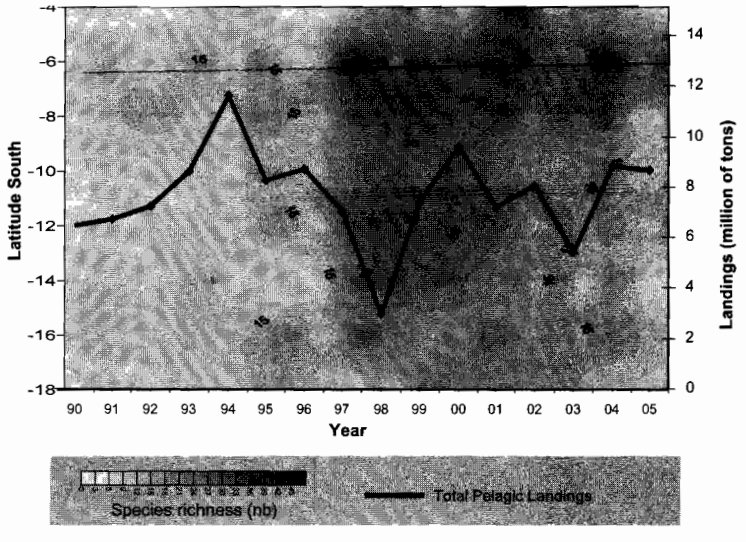

Figure 1. Spatiotemporal variations in species richness and total pelagic fishing landings in Peru from 1990 - 2005.

HCS187 - Influence of the oscillating distribution of water masses on the relative distribution patterns of mesopelagic fishes (*Vinciguerria lucetia* and mictophiids) and Peruvian anchovy (*Engraulis ringens*) off Peru

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Keywords: anchovy, oscillation, seasonality, mesopelagic fish, water masses

The main water masses in presence in the Northern Humboldt Current System off Peru are the cold coastal waters (CCW) and the subtropical surface waters (SSW). Each has a distinct range of temperature and salinity, as well as a specific biological diversity that may change according to decadal cycles. In the present decade, anchovy (*Engraulis ringens*) and munida (*Pleuroncodes monodom*) are the dominant species in the CCW, and *Vinciguerria* (*Vinciguerria lucetia*) and myctophids are the main species associated with the SSW.

In relation with the fluctuating intensity of the upwelling, the relative extent of the CCW and SSW waters exhibit a year-round oscillation. Between these two oscillating water masses exist a mixing zone whose localization varies is particularly attractive to fish due to its high dynamic and productivity. As most of the processes in the pelagic domain, the overall distribution of these water masses is not linked to specific geographic limits, and thus cannot be defined by latitudinal or longitudinal limits, like the continental shelf for instance.

In opposition, and as far as the living organisms are concerned, the presence of the continental shelf is likely to constitute a spatially fixed obstacle to the presence of mesopelagic species such as *Vinciguerria* and myctophids in the coastal shallow waters. Indeed, these fish perform long range diel vertical migration which are not permitted by depths inferior to 180 m (Fig. 1a). On the contrary, the main pelagic coastal species have no specific constraint impeding them to follow a westward extension of CCW.
Between 1998 and 2006 acoustic spatial information was collected on the mentioned species, in most of the cases between 1 and 100 n. mi. off the coast. This spatial window of observation does not allow to describe entirely the CCW-SSW system previously described, but allows to monitor the intrusion of SSW in the coastal ecosystem. Such an intrusion might occur not only seasonally but also in relation with the arrival in the coastal ecosystem of equatorial Kelvin Waves, for instance.
In that context, using non parametric statistical tools (GAM and other), we analyzed the features of the distribution of these fish species in relation with the water masses features and with the presence of potential physical barrier such as depth or distance to the coast. We test the hypothesis that even if anchovy and mesopelagic species are likely to occupy the same geographical areas, the instantaneous overlap is weak if not null (Fig. 1b), because of their attachment to different water masses and the limitation related to the presence of the continental shelf.

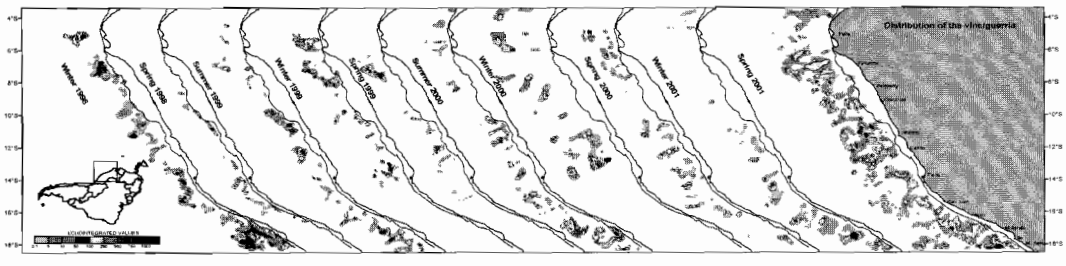

Figure 1a. Distribution charts of vinciguerria (1998-2001). Blue line in all sections represents the isobath of 100 br. It is then evident that the fish does not distribute in waters with less than that depth.

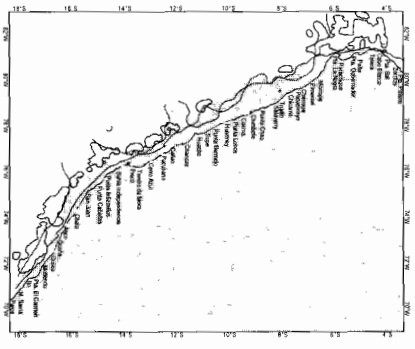

Figure 1b. Overlapping of anchovy and mesopelagics including vinciguerria (summer 2005). Yellow color shows the distribution area of anchovy. Continuos black curves delimited the distribution of mesopelagics. Blue line represents the isobath of 100 ft. In this case the overlapping is minimun. Red line represents the inner limits of the saline line (Subtropical Surface Waters). As it can be seem mesopelagics can distribute in coastal waters where the depth is adequate. However these fishes do not intrude areas shallower than 100 ft.

HCS200 - Population dynamics of *Strangomera bentincki* in central-southern Chile: density-dependent and biological interaction factors

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Key words: Anchovy; density-dependent factors; abundance fluctuations; *R* function; biological interaction; common sardine

The exploitation of small pelagic species in central-southern Chile (34°-40°S) mainly involves *Strangomera bentincki* (common sardine) and *Engraulis ringens* (anchovy). These commercially important resources are caught in coastal waters by both industrial and small-scale fleets. Common sardine landings fluctuate inversely with those of anchovy (Cubillos *et al.,* 1998). In other words, a decrease in *S. bentincki* abundance is accompanied by an increase in *E. ringens* abundance, which decreases concomitantly with the recovery of *S. bentincki*. To date, these relatively opposite fluctuations have only been analyzed in terms of their relationship to environmental variability (Fonseca *et al.,* 1986; Yañez *et al.,* 1990, 1992; Cubillos *et al.,* 1998, Cubillos & Arcos, 2002). Nonetheless, MacCall (1983) suggested that these fluctuations could have other causes, likely to include interspecific competition. This competition or replacement hypothesis has been posed more than once in analyses of the reciprocity of the dominant species' role in the so-called sardine-anchovy complex (Daan, 1980; Pauly &Tsukayama, 1987; Serra & Tsukayama, 1988; Cury & Fontana, 1988). This study generates a foundation for understanding aspects of the population dynamics of common sardine in central-southern Chile. To do so, we analyze the CPUE as a relative abundance index and consider similar biological characteristics and spatial-temporal dynamics for the two species, as well as their joint exploitation. Our results should further understanding of the fluctuations observed in common sardine abundance through ecological bases and classical population dynamic theories.

We represent the population dynamics of the common sardine through a general survival model, individual reproductive processes, and the incorporation of the *R* function, which involves per capita rates of population growth (Berryman & Gutierrez, 1999). Strictly speaking, a family of functional forms was evaluated for ***R***, selecting the one that delivered the best fit for the time series observed for this resource. We used generalized lineal and additive models (GLM-GAM) for this (Hastie & Tibshirani 1990). The most parsimonious models were selected using the Akaike information criterion (AIC) and the order of the feedback structure was explored using the partial rate correlation function (PRCF) (Berryman & Turchin 2001). Table 1 summarizes the procedures of fit for the different models used. The following were determined: i) The population dynamic of common sardine is characterized by a highly negative, non-linear feedback structure of the second order (PRCF -0.5988 lag 2); and ii) the results of the model evaluations suggest that common sardine has a regulatory structure that is highly linked to intra- and interspecific competition mechanisms (AIC = 9.887; R^2 = 0.57); these are expressed by the joint effect of the anchovy abundance over time t_{-2} (positive, non-linear effects) and abundance of the same species from the previous year t_{-1} (negative, non-linear effects) on the current common sardine abundance t (Table 1).
In particular, the intraspecific mechanisms are expressed in the joint effect (negative, non-linear effects) of common sardine abundance observed in the two previous years (t_{-1} and t_{-2}) on the record of current sardine abundance (t). The interspecific mechanisms, however, are shaped by the effect (positive, non-linear) of anchovy abundance observed two years earlier (t_{-2}) on the current common sardine abundance (t).

Models for **Common Sardine**	F	p	R^2	BIC	AIC	ΔAIC
Intraspecific interaction						
R_{st} = *f*(s(CPUEs_{t-1}))	**7.104**	**0.0237**	**0.36**	**16.679**	**15.709**	**0.000**
R_{st} = *f*(s(CPUEs_{t-2}))	4.590	0.0578	0.25	19.237	18.441	2.73
R_{st} = *f*(s(CPUEs_{t-3}))	0.722	0.4155	-0.03	27.034	26.429	10.22
R_{st} = *f*(s(CPUEs_{t-1})+ s(CPUEs_{t-2}))	**8.657**	**0.0080**	**0.58**	**19.113**	**17.658**	**0.000**
R_{st} = *f*(s(CPUEs_{t-1})+ s(CPUEs_{t-3}))	3.484	0.0757	0.31	19.134	17.679	0.021
R_{st} = *f*(s(CPUEs_{t-2})+ s(CPUEs_{t-3}))	3.228	0.0877	0.29	24.589	23.396	6.309
Interspecific interaction (with Anchova)						
R_{st} = *f*(s(CPUEa_{t-2}))	**4.929**	**0.0507**	**0.26**	**13.767**	**12.972**	**0.000**
R_{st} = *f*(s(CPUEa_{t-1}))	3.640	0.0855	0.19	17.354	16.385	3.163
R_{st} = *f*(s(CPUEA))	0.997	0.3417	-0.00	19.790	18.660	5.239
R_{st} = *f*(s(CPUEa_{t-3}))	0.459	0.5132	-0.05	24.055	23.45	12.875
R_{st} = *f*(s(CPUEa_{t-1})+ s(CPUEa_{t-2}))	**3.641**	**0.0694**	**0.32**	**19.574**	**18.119**	**0.000**
R_{st} = *f*(s(CPUEA)+ s(CPUEa_{t-1}))	5.108	0.0329	0.43	0.5620	-1.133	19.696
R_{st} = *f*(s(CPUEA)+ s(CPUEa_{t-2}))	2.383	0.1478	0.20	12.481	10.786	31.615
Intra- and interspecific interaction						
R_{st} = *f*(s(CPUEs_{t-1})+ s(CPUEa_{t-2}))	**8.328**	**0.0089**	**0.57**	**11.342**	**9.887**	**0.000**
R_{st} = *f*(s(CPUEs_{t-2})+ s(CPUEa_{t-2}))	2.503	0.1366	0.21	15.962	14.768	5.453

Table 1. A summary of the evaluation of population dynamics models for common sardine, including intra- and interspecific competition mechanisms. Only models with optimum statistical criteria are presented. The most parsimonious model is selected according to the AIC selection criteria.

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HCS204 - The impact of fishing and climatic conditions on the abundance and population structure of the Sardine, *Sardinops sagax*, from 1978-2005.

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Keywords: Gonadal maturity, Peruvian Upwelling Ecosystem, Sardine, spawning, stocks assessment

The sardine (*Sardinops sagax*), similarly to other species of the same genre in the main upwelling areas of the world, showed important changes in its abundance and population structure in Peru. The analysis of historic series shows that this variability can be related to fishing and climatic conditions. These changes have serious ecological and socioeconomic implications for the country. This resource gained importance after the collapse of the anchovy fishery, *Engraulis ringens* in 1972, when it represented an important part of the capture in the Peruvian upwelling ecosystem.
To analyze the changes in sardine abundance and evolution structure from 1978-2005, we used biological-fishery information coming from the tracking program of the pelagic fishery carried out along the Peruvian coast, and from the pelagic resources scientific surveys. Sardine landings increased in the entire

Peruvian coast since 1973, reaching 3.5 millions tons in 1988. Then, from the beginning of the 1990's, sardine landings started to decrease but were maintained above one million annual tons until 1998. Later on, an abrupt decline was observed on captures with an average of 132 tons in the last three years. The virtual analysis of the population (traditional VPA) performed since 1978 showed that north-centre stock sardine biomass gradually increased since the beginning of the analyzed period to reach a maximum of almost 13 millions of tons in 1987. However, due mainly to the strong fishing effort and environment variability, its population drastically declined to very low levels in the last years. This trend is also supported by the acoustic biomass estimates. The recruiter biomass (age 2) reached almost 3 millions of tons in 1987 to then decline to very low levels in the last years. At the same time, fishing mortality (F4-6) showed a growing trend, reaching its highest values during the 90's, which is indicative of the high fishing pressure on sardine.

The mean length of sardine did not show any important changes during the analyzed period; however, the size and mode range varied. At the beginning of the industrial fishery, in 1978 and 1979, the sizes fluctuated between 5 and 39 cm of total length. This range was maintained during the 80's, while later, in particular in the last years, the maximum length reached 32 cm. In the first years (1978-1979) a polymodal structure was observed at 15, 25, and 32 cm. In the 80's decade, two most important observed modes were at 15 and 27 cm; and in the 90's several modal groups were registered, the main one at 27cm and other secondary ones at 11 and 18 cm. From 2000 until 2005, a structure with a reduced group of sardines with a mode at 27cm was observed, suggesting an unhealthy state of its population.

Throughout the analyzed period, the age structure of sardine captures showed a predominance of fish of medium age (4, 5 and 6 years old), in particular during the period from 1985 to 1990. The arrival of an important juvenile fish or recruiters contingent (sardines with ages of 0, 1, 2 and 3 years old) to the fishery, in increasing order, was observed during the years 1984, 1988, 1998 and 1995. The old fish (> 7 years old) fraction decreased strongly since the end of the 80's, until almost disappear from the capture in the last years, which is another evidence of its population damage (Fig. 1). The mean sizes of gonadal maturity and spawning decreased during the study period. In the first years of the fishery, these indicators were at 30 and 31cm of total length respectively. Then they decreased to 27cm during the 80's, and to 26 cm during the 90's to finally reach 25 cm these last years. This suggests that sardine are maturing and spawning at smaller lengths, which can be considered as a survival strategy. The spawning took place throughout the year during the study period, with two periods of higher intensity: a main one in winter and a secondary one in summer. However, it has been observed this behavior changed during the El Niño events of 1982-1983 and 1997-1998. Indeed during these warm events, spawning intensity was lower; on the opposite it was higher when cold conditions occured, such as the La Niña events of 1995 and 1996.

The analysis of the biological, fishery and population indicators demonstrate the critic status of the sardine population. Sardine fishery is manifestly on a collapse state and it will take years to recover because of the slow renewal rate of its population. These results also point out that sardine populations are not capable of supporting high levels of exploitation and that the climatic conditions have a strong impact on their behavior. These results agree with the sardine population analysis in the altogether stock of north-centre Peru and south Ecuador (Patterson, et al 1992), and fluctuations of these abundance regimens in the four regions of the world oceans (Lluch Belda, et al. 1992).

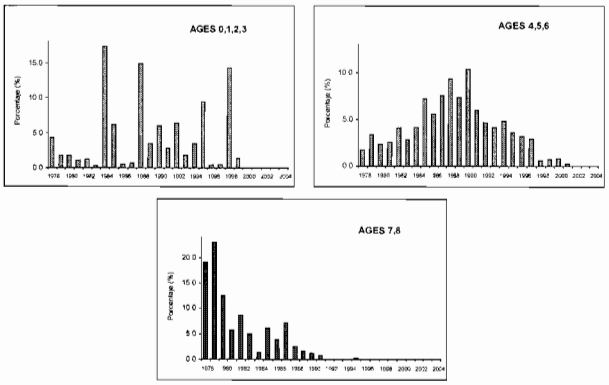

Fig.1 Structure by age groups of Sardine, *Sardinops sagax (Jenyns 1842)* landings, between 1978 and 2004

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HCS215 - Species composition, abundance and spatial distribution of coastal fish and its relation with the habitat structure of north Chilean kelp beds

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Keywords: coastal fish, habitat structure, *Lessonia trabeculata*, macroalgae morphology, *Macrocystis integrifolia*, northern Chile.

Shallow subtidal hard-bottom communities of northern Chile are dominated by two kelp species, *Macrocystis integrifolia* Bory 1826 and *Lessonia trabeculata* Villouta and Santelices 1986. Structure and organisation of the kelp communities are controlled by local upwelling processes and ENSO, resulting in alternative habitats such as *Macrocystis integrifolia* kelp beds, *Lessonia trabeculata* kelp beds, and barren ground (Vasquez 1992, Vega et al. 2005). The preliminary results of a study under way (Villegas et al, ms in prep.) show that *M. integrifolia* and *L. trabeculata* kelp beds provide different habitat structures; *M. integrifolia* plants are longer and produce more stipes as well as wider phylloids. The *L. trabeculata* plants from barren ground were shorter compared with those from *L. trabeculata* kelp beds, but did not show any further differences. We hypothesise that these alternative habitats with dissimilar structures might maintain different composition, abundance and spatial distributions of coastal fish species. The study site is located in Caleta Chipana (21° 19' S, 70° 04' W) in northern Chile. Seasonally (winter 05 until autumn 2006) 15 sampling units (10 m^2) of each studied habitat were assessed using SCUBA diving, to record sporophyte density, fish composition and abundance. The fish species were spatially associated to "rock", "macroalgae", "water column", and "sand". The fish community was classified as "resident species", which are present throughout the year, "seasonal visitors", which are present seasonally, and "occasional species", which show no seasonal pattern of occurrence, but cannot be found throughout the year. In addition, nine sporophytes of each kelp type were collected and transported to the laboratory for individual estimations of i) total plant length, ii) maximal holdfast diameter, iii) stipe number, iv) phylloid width and v) total drained wet mass.

A total of 16 fish species was recorded in the three habitats. The fish assemblage was composed of four resident species in the *M. integrifolia* and barren grounds habitats, while six resident species were found in *L. trabeculata* beds. Three seasonal visitors were recorded in *M. integrifolia* and *L. trabeculata*, in contrast to the six seasonal species on barren grounds. Numerically dominant species were *Isacia conceptionis* and *Chromis crusma* in the *M. integrifolia* habitat. *I. conceptionis* and *Cheilodactylus variegatus* were abundant in the *L. trabeculata* habitat, whereas *Scartichthys* sp. abounded in the barren ground habitat. We did not find differences between the total fish abundances in the studied habitats. However, a seasonal pattern was observed particularly in *M. integrifolia* where the number of fishes was decreasing during the seasons. In the case of *L. trabeculata* the number of fishes showed a similar tendency but was increasing in autumn 2006. A positive correlation between the number of fishes, stipe number and holdfast diameter was found only in the area of *L. trabeculata* kelp. Fish spatial distribution showed a significantly similar use of "rock", "macroalgae" and "water column" in contrast to "sand" in *M. integrifolia* and *L. trabeculata*, however, on barren ground the fish were associated to "rock" and "water column" with a significantly lower use of "macroalgae" and "sand". The number of fishes distributed in "macroalgae" was decreasing during the seasons in *M. integrifolia*, in contrast to *L. trabeculata* where those fishes distributed in "macroalgae" maintained constant abundances during the year. In the barren ground habitat the number of fishes distributed in "macroalgae" was increasing in relation to the sporophytes density. The spatial fish distribution was influenced by morphological variables such as sporophyte density, plant length, stipe number, and holdfast diameter suggesting a clear kelp effect especially with *L. trabeculata* plants. The results suggest that the shrub-like morphology of *L. trabeculata* is optimal for the fish distribution, compared to the arborescent form of *M. integrifolia*. However, physical factors and trophic relations may be important, too. Based on the first results, further *in situ* experiments were designed in order to analyse the effect of specific features of the kelp on the fish community.

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HCS020 - Early maturation and the compensatory effect in the egg production of Peruvian hake (*Merluccius gayi peruanus*)

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Keywords: Fecundity, Hake, maturity, *Merluccius gayi peruanus*, spawning.

The Peruvian hake is the most important demersal resource, with a well developed fishery since the beginning of the 1970s. It has been exposed to a growing and fluctuant fishing activity caused, in part, by changeable environmental factors such as El Niño Southern Oscillation (ENSO). By effect of the fishery or the dynamics of the Cromwell sub-superficial current, to which its distribution is highly related, Peruvian hake has registered notorious changes in its size and age structure (*Wosnitza-Mendo et. al.*, 2004), the maturity size and consequently, the reproductive potential. In spite of its economic importance, there is little knowledge about its reproductive biology. This study presents new achievements, being the most

important aspects for this work, the validation of the macroscopic scale of gonadal maturity, estimations of partial and relative fecundity, spawning areas and vertical stratification of the reproductive activity. In this sense, the importance of this work is the evaluation of the effect of decrease in total length on the reproductive potential. Data on fecundities and early maturation are presented, describing these as a compensatory mechanism in the production of eggs.
Data on fecundity from austral autumn and summer periods, from 2002 to 2006 were used. Peruvian hake's early maturation was first documented by *Perea* et. al. (1998), who estimated it for a specific area. Size at first maturity (21 cm) was lower in comparison to the estimation made by *Canal* (1989), which was 27 cm. Nevertheless, with the purpose to evaluate this parameter for a longer period, data of mean size at maturity (L50) were estimated from the Paita fishery database, (*Wosnitza-Mendo* et. al., in this Symposium), where a decrease of about 14,3 cm was observed from 1973 to 1998. The most relevant fact is that, although the adult stock has been registering smaller sizes, affecting the partial fecundity, the relative fecundity showed an opposite effect, i.e. the smallest females were capable to produce more oocytes than the largest females in relation to corporal weight. It seems to be a compensatory mechanism that influences the production of eggs. The gradual increment of smaller mature individuals in the adult stock through early maturation is perhaps the strongest explanation about why the recruitment or individuals of age 0 has always been maintained through the years with or without ENSO and with fishing pressure, although very fluctuating. In the enclosed figure the average fecundity estimated during the cruises since 2002, shows an increasing tendency until 2005, despite of the seasonal changes and the reproductive moment during the evaluation. These results and the possible effect of having parents increasingly younger in the population are discussed.

HCS028 - Biological aspects and population dynamics of the cuttlefish *Dosidicus gigas* in central-southern Chile

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Keywords: abundance fluctuations; cuttlefish; recruitment pattern; growth parameters; reproductive period

The presence of *Dosidicus gigas* in central southern Chile (34° - 40° S) has increased significantly since the second semester of 2000, and continues to do so at present. The appreciable increase in the presence and abundance of this squid is related to successful recruitment, probably favored by environmental conditions. Nonetheless, cuttlefish recruitment patterns and seasonal abundance changes off central-southern Chile are not known. Here we propose two reproductive periods separated by 6 months (autumn and spring) that generate a seasonal recruitment pattern influenced by seasonal and interannual variability in *D. gigas* relative abundance off the coasts of central-southern Chile. Moreover, we analyze the periodicity of monthly catches in order to corroborate this pattern using the autocorrelation function (ACF). Having determined the recruitment pattern, we estimate the squid's relative abundance using an age-structured population dynamic model that incorporated the Pope approach (1972).
The population structure of *D. gigas* was studied along the coasts of central-southern Chile from July 2003-February 2004 and from May 2005-February 2006. During the first period, two size groups, thus, two cohorts were identified (N = 616): a small group (20-50 cm LM) and a large group (50-100 cm LM); both cohorts were present throughout the entire first period. However, during the second period (N = 337), large sizes (>50 cm LM) were observed throughout the period but small sizes (<50 cm LM) were only recorded in August. Length frequency data from both periods were used to determine the recruitment pattern. Therefore, cuttlefish recruitment presented a seasonal pattern of two pulses every six months. The average recruitment consisted of a first, less intense pulse in autumn (May-June) and a second, more intense pulse in spring (September). Nonetheless, the greatest percentage of recruitment was observed in August (22.39 %) and November (13.85 %).
The abundance index was estimated using the number of casts that included cuttlefish and were made in the area where common hake are typically distributed; data was from August of each year studied (1999, 2000, 2001, 2002, 2004). This index has been increasing since 1999, when only 20 casts included cuttlefish as compared to 70 in 2004. The estimated abundance index was perfectly fit to reports of cuttlefish in common hake catches. The estimation error of the index was used to determine the factor for changes in abundance that, along with the recruitment pattern, model the relative abundance of cuttlefish recruitment along the coasts of central-southern Chile. This factor presents interannual variability and considerable increments from 2003 to date.
The length and weight of the cuttlefish were determined and the age was based on the length-weight relationship from Cubillos et al. (2004) and Von Bertalanffy growth parameters. The estimated length in the first month of life for this species is 8.4 cm LM, which indicates rapid growth. Thus, 50% selectivity begins at two months, when individuals measure about 30.4 cm LM and 100% selectivity begins around 9 months, or 88 cm LM. The exploitation rate estimated with this model increases as the cuttlefish biomass increases, with the greatest percentages of exploitation in 2004 (40%) and 2005 (60%). When considering the distribution frequencies throughout the entire study period in oceanic and coastal zones, corresponding to the different fishing fleets, a seasonal recruitment pattern was found with a maximum in spring and a minimum in autumn. This was corroborated with the autocorrelation of the monthly catches that present

significant coefficients approximately every 6 months. Seasonal recruitment of *D. gigas* was generated in two reproductive periods (autumn-spring), resulting in two cohorts per year, confirming Ibáñez and Cubillos' postulate (in press). Thus, reproductive success influenced seasonal variability of catches and interannual variability of relative *Dosidicus gigas* biomass along the central-southern coasts of Chile, probably favored by environmental conditions.

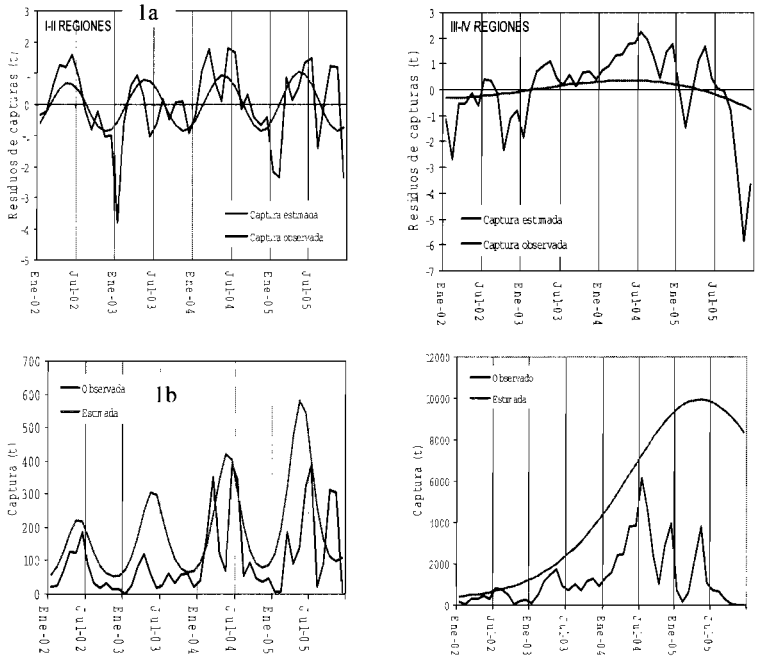

Figure: (1a-2a) Catch residuals and (1b-2b) Catch total; Regions (I – II) (III – IV).

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HCS046 - Use of time and space by different jack mackerel size groups in fishing grounds off Central-Northern Chile.

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The spatial-temporal distribution of the relative abundance of different jack mackerel size groups and their relation to environmental, spatial and temporal factors is determined. The jack mackerel fishery data off Central-Northern Chile between 1999 and 2004 was used. The size structure analysis allowed to establish the following size groups: smaller than 26 cm Fork Length (FL), 26-33 cm FL, 33-49 cm FL and larger than 49 cm FL. Spatial-temporal maps were done for each size group using Generalized Linear Model (GLM) standardized catch rate with a Geographic Information System (GIS). Jack mackerel frequently used coastal areas off the zones of Caldera and Coquimbo. Temporal factors such as Year and Month explained the highest percentage of model variation for all size groups, while environmental factors such as wind stress and SST and spatial factors, although significant, explained a lower percentage of the variation in some groups. A differential use of time and space by different size groups was found. Fish smaller than 26 cm FL showed periodic seasonal fluctuations with the highest abundance at the beginning of autumn for the Zone of Caldera. Fish of 33-49 cm FL were exclusively observed from later spring until the beginning of summer off Caldera and showed inter and intra-annual asynchronous pulses in the Zone of Coquimbo. Fish larger than 49 cm FL were always observed from late spring until the beginning of summer in both zones. The 26-33 size group cm FL showed a higher temporal dynamics for both zones with aperiodic pulses of abundance. Spatial-temporal distributions found are discussed on the basis of the traditional migration hypothesis suggested for jack mackerel from the Southeastern Pacific Ocean.

Sponsors: CERCOPESCA Coquimbo, FREPART-Atacama and Undersecretary of Fisheries, Chile.

HCS058 - South American sea lions as indicators of marine environmental change and prey abundance in the unpredictable Peruvian upwelling ecosystem

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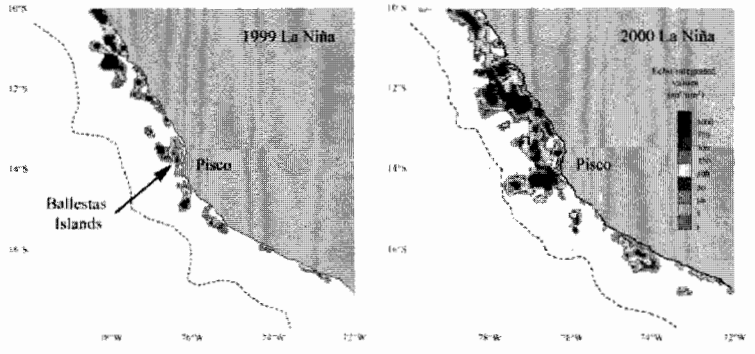
Keywords: South American sea lion, Peruvian anchovy, maternal attendance, diet, El Niño, prey abundance

The Peruvian upwelling ecosystem is one of the most unpredictable productive marine ecosystems in the world. As a consequence apex predators inhabiting the Pacific coast have to endure inter-annual fluctuations in their food supply. Behavioural observations were made of South American sea lions (Otaria flavescens) at the Ballestas islands, Peru, to determine whether changes in their diet and maternal attendance patterns reflected physical changes in the marine environment and alterations in the abundance and distribution of prey. The study was conducted during breeding seasons (1998-2002) that encompassed the strongest El Niño on record (1997-1998) and a moderate La Niña (1999-2001). Observations revealed a strong relationship between maternal attendance patterns of South American sea lions and the abundance of prey and oceanographic features close to the rookeries. Acute prey reduction during El Niño resulted in females increasing the time spent at sea foraging and decreasing the time they spent onshore nursing their pups. In contrast, shorter times at sea and longer times onshore were observed during the favourable conditions of La Niña when their preferred prey (anchovy and squat lobster) were more abundant near the rookeries (Fig.1). Pup mortalities due to starvation increased when females spent more time at sea searching for prey and did not return frequently enough to nurse their pups. Greater numbers of species (particularly demersal fishes) were consumed during El Niño when anchovy and squat lobster were less available. Females appeared to adjust their diets and maternal attendance patterns in response to annual changes in the abundance and distribution of their prey. However, this maternal flexibility was insufficient during the strong El Niño to compensate for the acute prey shortage. These results suggest that diet and maternal responses reflect interannual fluctuations in the unpredictable Peruvian upwelling ecosystem, and imply that South American sea lions may be reliable indicators of relative changes in the distribution and abundance of marine resources. Understanding the behavioural response of sea lions to stochastic changes in the marine environment can help scientists to understand how this species have evolved to cope with rapid changes in the ecosystem. This information could prove invaluable in connecting the complex strands of the marine food web, and in understanding how fluctuations in the marine environment can shape the life history of its apex predators. The fact that behavioural measurements of apex predators may be considered good proxies for the abundance and distribution of prey and oceanographic features is promising and opens new windows for the implementation of research using this species as data collectors.



Soto K.H., Arias-Schreiber M. and Trites A.W.: Fig.1. Distribution and abundance of Peruvian anchovy (Engraulis ringens) in South Peru during La Niña in 1999 and 2000.

HCS063 - Cape fur seal diet: patterns from a long term study

Kirkman, S.P., Oosthuizen, W.H. , Meÿer, M.A. , Kotze, P.G.H, Reynolds, D.M and Boucher, M.

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Keywords: Benguela, Cape fur seal, diet, fisheries, indicators

Cape fur seals *Arctocephalus pusillus pusillus* are abundant in the Benguela ecosystem, which also sustains profitable commercial fishing industries. The recovery of the Cape fur seals population during the 20th century from effects of over-exploitation, led to concern that increased predation by seals might cause fisheries catches to decline (Wickens *et al.* 1992). The feeding habits of Cape fur seals were therefore studied by means of at-sea sampling of seals during research cruises. Morphometric and reproductive data of sampled animals were taken, and stomach contents were analysed by reconstituting the original

mass of prey, using undigested traces (teleost prey only). The time series of sampling along the West coast of South Africa (20 research cruises conducted during 12 years between 1981 and 2001) was analysed to assess temporal trends in the intake of prey groups.
Preliminary results, with all samples pooled within years, indicate (a) that temporal trends exist in the intake of prey groups by seals, and (b) that in the case of the most important prey groups in the diet (anchovy *Engraulis capensis*, pilchard *Sardinops sagax* and hakes *Merluccius* spp), these trends reflected the availability of prey based on the findings of scientific biomass surveys (see Figure). The proportion of pilchards and hakes in the diet were significantly correlated ($P < 0.05$) with biomass survey estimates of the same prey groups (pilchard: $r = 0.90$, $n = 10$ years; hake: $r = 0.78$, $n = 9$ years). The proportion of anchovy in the diet was not significantly correlated with biomass estimates of anchovy in the same years ($r = 0.56$, $n = 10$ years), except when 2001 was excluded from the analysis ($r = 0.80$). This was the only year coinciding with a seal research cruise, for which the biomass estimates of both anchovy and pilchard were high, and seals appeared to favour the latter.
The results, which were achieved in spite of the many biases associated with the technique and the fact that the sampling protocol was not designed with the aims of detecting long-term temporal patterns, support that Cape fur seals are useful indicators of shifts in prey availability. At an individual scale, a General Linear Model is used to explore the effects of sex, age, location, year and time of year on diet.

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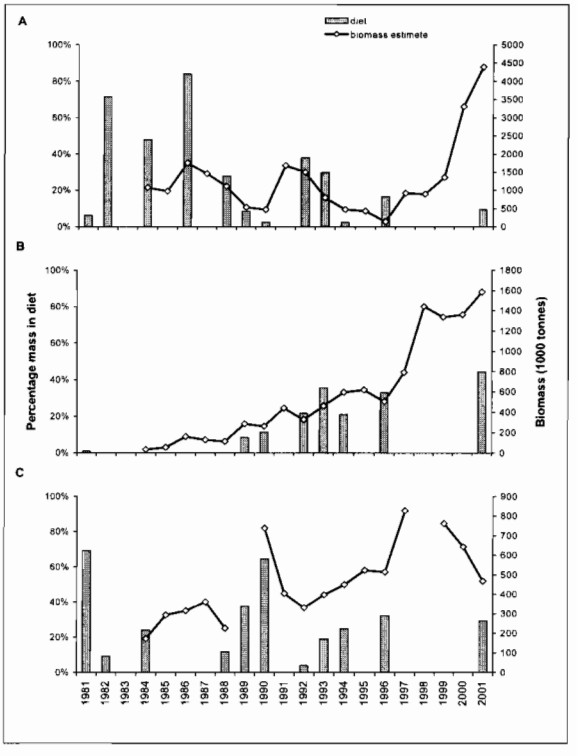

Figure 1. The percentage mass (grams) of (a) anchovy, (b) pilchards and (c) hakes in the diet in study years, and results of biomass surveys of these prey (MCM unpublished data). For pilchards and anchovy, the biomass estimates represent the entire stocks, in the case of hakes, they are an index of stock size.

HCS069 - The Cape fur seal population – trendy and shifty

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Keywords: Benguela, Cape fur seals, environmental variability, population trends, pup counts

Cape fur seals *Arctocephalus pusillus pusillus* occur along the West and South coasts of southern Africa; coinciding with the highly productive Benguela ecosystem, and its lucrative commercial fisheries. They are apex predators that feed principally upon teleost fish, including many of commercial importance. This had resulted in conflict between seals and fisheries that has apparently escalated as the population has recovered in numbers from the over-exploitation prior to the 20th century (Wickens et al. 1992). The recovery of the population under controlled harvesting, and in the face of habitat loss and competition with fisheries, has been touted as a conservation success story (Anonymous 1997). However, there are claims that population has exceeded its pre-exploitation level, and should be reduced in the interests of fisheries and seabird conservation. On the other hand, there have been claims that the seal population has been in

decline in recent years, as a consequence of ongoing harvesting in Namibia, starvation, incidental and illegal killing of seals during fishing operations, and unnaturally high levels of mortality caused by the vulnerability of many of the extant offshore breeding colonies to rough seas.
In recent decades, frequent censuses of the Cape fur seal population have been conducted, to facilitate research and management on issues such as harvesting and seal-fishery interactions. Due to the number and wide distribution of colonies, and the density of seals within colonies, aerial photographic censuses are the only practical means of covering the entire population. Pups are focused upon because they are the only demographic category that are all ashore simultaneously for any period of time, and because their small size and distinct color permit them to be easily distinguished from other age classes in photographs. Pup counts serve as useful indicators of population size, though they should be interpreted with caution. In this study, the time series of pup counts are investigated at population, sub-population and colony levels, to determine temporal trends and regional shifts in population numbers. Possible effects of environmental variability, harvesting and habitat loss are given special attention.

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HCS114 - Interannual dietary variability of Peruvian hake (*Merluccius gayi peruanus*), 1976-2005

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The Peruvian hake (*Merluccius gayi peruanus*), an important species of the bentho-demersal subsystem, and its accompanying fauna, are associated to the Southern Extension of the Cromwell Current (SECC); presenting intra- and inter-annual spatio-temporal fluctuations in relation to environmental conditions being the strongest the impact of El Niño and La Niña. Several bentho-demersal species form part of the diet of the hake. Due to the opportunistic behavior and cannibalism of hake, observed variations in the trophic units would be related to the availability of the prey.
Historical data from about 20.000 stomach contents were analyzed according to length groups from the area of Paita (5°S) between 1976 and 2005. The samples were taken from the landings of the commercial trawler fleet. The laboratory analyses were carried out by personnel of the Coastal Laboratory of Paita (1976-1994) and by the Trophic Ecology Laboratory (1995 to the date) belonging to the Peruvian Marine Institute (IMARPE). Crustaceans and cephalopods were identified only to the level of main groups, all other cases to the smallest possible level. The contribution of each prey-item in weight (g) in the different size groups of hake with 5 cm intervals was considered. The identified prey items were assigned to one of 13 dietary groups as described by Fuentes *et al.* (1989). A temporaly analysis according to decades was carried out. The trophic groups were classified with a Bray-Curtis similarity analysis.
A total of 140 prey items among fishes, crustaceans, cephalopods, algae and invertebrates (*Gastropoda, Echinodermata, Polychaeta, Pelecypoda*) were counted during the analyzed period.
The contribution of crustaceans in the diet according to size groups in hake <60 cm shows an increasing trend. They dominate in the 20-54 cm interval, especially in 2005 with more than 60% in weight.
In the 1970s two trophic groups prevailed in adult hakes. The first one of 35-49 cm fed predominantly on small sciaenids ("bereches", *Ctenosciaena peruviana* and *Larimus pacificus*) "other" demersal fishes and sardine (*Sardinops sagax*). The second one, of 55-74 cm, distinguished itself by cannibalism and the ingestion of bereche and sardine.
During the 1980s, four trophic units were registered. The first, composed by hake of 25-34 cm, fed mainly on euphausiids and bereche. The second, conformed by hake of 35-49 cm consumed bereche and anchovy (*Engraulis ringens*), especially in the second five-year period of that decade, and "other" pelagic fishes. The third one, hake of 50-69 cm, consumed especially sardines, "other" benthic fishes and bereches. The fourth group of 70-79 cm showed mainly cannibal behavior and in a smaller proportion fed on sardine and "other" pelagic fishes.
During the 1990s, we differentiate two groups. Hake of 25-49 cm were characterized for feeding on "other" pelagic fishes, anchovy and particularly "other" benthic fishes. Hake of 50-69 cm were mainly cannibals consuming "other" benthic and "other" pelagic fishes on a minor scale.
During the first five-year period of the XXI century two trophic associations appear. Hake of 20-34 cm fed primarily on euphausiids, anchovy, caridea and "other" pelagic fishes; and the individuals of 40-54 cm were mainly cannibals aside from consuming giant squid (*Dosidicus gigas*) and crustaceans.
An increment in food consumption in the 1990s was observed associated to an increased number of prey-items due to El Niño 1997-98 (Fig. 1) as indicated also by Tam et al. (2006), and changes in the community structure (Ballón, 2005).

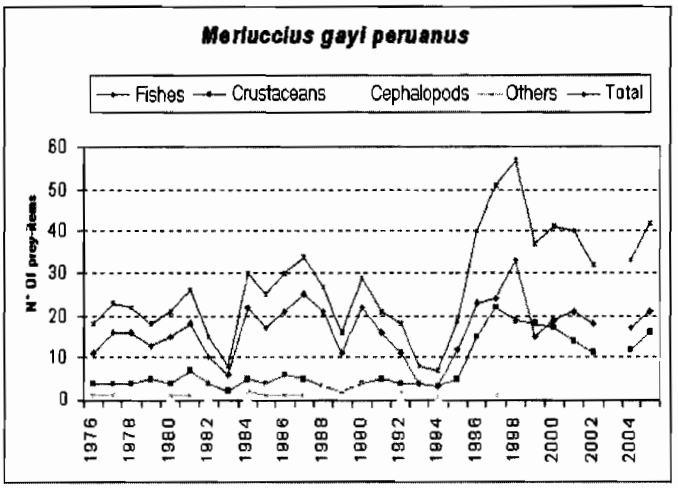

Figure 1 Number of prey- items in stomach content of Peruvia hake (1976-2005).

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HCS136 - Food and feeding modes of *Trachurus* sp indicative of opportunistic strategy to patchy and transient environment.

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Rank order of prey in the diet is associated to either prey availability or selection of the most profitable items. Optimal Foraging Theory predicts that predators maximize their net energy intake by choosing prey according to their relative profitability. Alternatively prey of different profitability would be taken one at a time as they are encountered by an opportunistic predator. Such behavior is shown by a number of pelagic fish (e.g. mackerel, herring, and anchovy) which are able to shift feeding modes according to prey characteristics (Leong and O'Connell, 1969).

This behavior is expected to occur in a patchy and transient environment where the assumption of a complete assessment of prey distribution by the predator is probably violated.

The diet of jack mackerel and indeed of most *Trachurus* species is dominated by euphausiids, followed by fish (mainly myctophids) and by a variety of planktonic organisms (Konchina, 1978; Muck and Sanchez, 1987). It is not clear whether such an order of prey dominance is the result of an active selection of prey among co-occurring prey at any particular feeding event, or it simply reflects prey distribution in the environment as sequentially consumed by the fish. The first aim of this work was to describe the breadth of the diet of *T. symmetricus* and to examine it at a finer sampling resolution (e.g. fishing events, schools) from purse seiners operating in coastal waters off Chile.

The diet was dominated by euphausiids (91%), followed by myctophids, copepods, ostracods, stomatopod larvae and several other taxa encompassing three order of magnitude in length. No prey/predator size relationship was found.

The diet of jack mackerel in the entire region could be expressed as the common rank order of prey characterized by euphausiids as the primary item, myctophids as the secondary item and other planktonic crustaceans such as copepods, *Nematoscelis megalops*, ostracods as tertiary items. A great diversity of other items of much less occurrence is represented by less than 0.1 %. This common rank order is attributed to the dominance of *E. mucronata* in the area and likely to underestimated abundance of myctophids, but also to infrequent occurrence of high concentration of other tertiary items. Deviations of this rank order of prey at several scales (fishing zones, fishing events and schools) are attributed to the assumed uneven distribution of these prey and to the opportunistic behavior of the fish which would feed as prey are encountered. This behavior is supposed to be mediated by their plasticity in their prey capture by shifting feeding modes according to prey size and density. At the scale of a feeding event (e.g. associated to a school during a day time) fish would be opportunistic with regard to prey but transitory selective to adjust the most efficient feeding mode to capture every prey. Testing of this assumption was the second aim of this work which was done experimentally in a large aquarium on *Trachurus trachurus*.

A repertoire of feeding modes, feeding stages and shifts between modes was visually observed and video recorded. Feeding modes fell into three groups namely suction feeding, ram feeding and biting. They are

displayed according to the density and size of the food experimentally provided. The most unexpected mode among particle suction was pump filtration and basal filtration; they are described in detail.
Feeding stages are grouped as pre-feeding, feeding and post feeding according to fish movement and mouth activity. Switching modes are a function of particle size and density and may be observed in several directions. The main trend with decreasing size and increasing density of particles was: biting to 1-particle suction to basal filtration.
The first implication is that an individual fish has the ability to choose from an ample repertoire, the most appropriate feeding mode according to size, density (and probably behavior) of prey to respond to drastic changes in prey availability as in patchy and transient environments, which would explain the high variance of stomach content of fish in nature and despite dominance of euphausiids and myctophids in the diet.
The final implication of a wide trophic spectrum in the diet and feeding modes and plasticity to switch between items and modes is that *Trachurus* spp have (added to greater longevity) greater competitive advantages to variable prey availability compared to other pelagic fish of upwelling regions and to migration over extended biogeographic areas. It may also explain rapid increase and replacement of other pelagics in particular regions.

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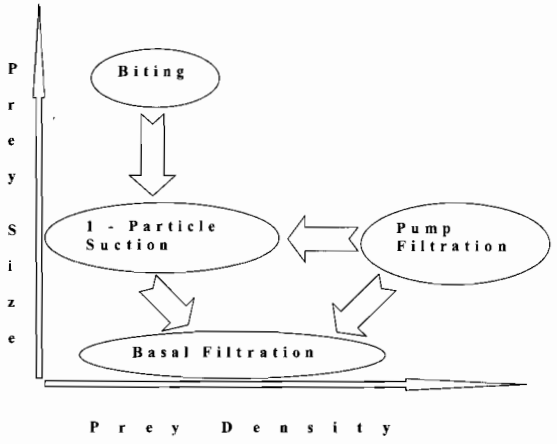

Figure 1. Observed switches between feeding modes in Trachurus trachurus as a function of rank order of prey size and density.

HCS149 - Comparative analysis of the demersal community structure and trophic relations of the Peruvian hake Merluccius gayi peruanus and its by-catch of the years 1985 and 2001

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Keywords: Demersal community structure, Humboldt Curremt system, overfishing, size spectra analysis

The drastic reduction in abundance and mean size of the Peruvian hake (*Merluccius gayi peruanus*) stock due to intense fishing and environmental factors (Wosnitza et al., 2004) during the late 1990s and early 2000s caused the hake stock to be declared overfished in 2002. This overfishing appears to be the main cause for the observed changes in the species composition and demersal community structure, as well as for the changes in biomass and trophic relations of the Peruvian hake and its by-catch for the years 1985 and 2001. It has been found that in the period between these years, the traditional hake by-catch, mainly composed of k-strategists, drastically decreased in biomass and was replaced by other r-strategists fish species and invertebrates (Fig. 1). The community size structure also changed towards small-sized individuals which affected the average diet of hake and its by-catch and was related to a reduction in the mean trophic level of the demersal fish community in 2001. It is suggested that the apparent increase of macrobenthic biomass from 1985 to 2001 was due to the reduction of the traditional hake by-catch, which seems to have a top-down control over the benthic production.

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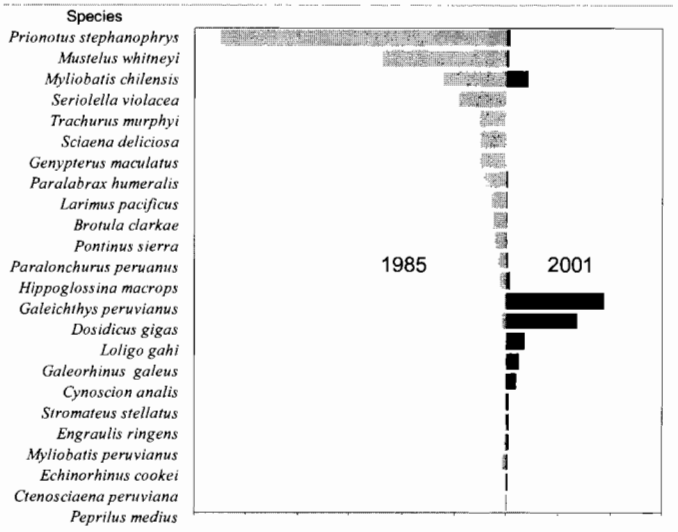

Figure 1. Relative biomass of the most abundant hake by-catch species for the years 1985 and 2001.

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HCS153 - Loggerhead turtles in the Humboldt Current System

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Upwelling ecosystems are considered to be one of the most productive systems in the oceans. How important should the Humboldt Current ecosystem be that species like sea turtles had evolved to cross an entire ocean basis just to feed in this area?
The loggerhead sea turtle *Caretta caretta* is distributed in all the oceans including the Pacific Ocean. Interestingly, in this ocean basis, the rookeries (where sea turtles nest) occur only on the east side of the ocean, in the coasts of Japan and Australia mainly. The populations that nest in Japan and in Australia are considered to belong to different genetic stocks. Loggerhead as most sea turtle undergo different ontogenic stages, soon after hatchlings leave the beaches where they were born, they became oceanic juveniles and remain in this stage for up to 15 years. Later on they move into neritic foraging grounds to keep growing and became adults. The oceanic juveniles that belong to the North Pacific population migrate from Japan to Baja California to feed on the California current ecosystem, specially in the incredible high biomass of pelagic red crab *Pleuroncodes planipes* that occur in that area (Bartlett 1989). Many years later, when the juveniles are big enough to move to neritic environment they will cross again the entire north Pacific Ocean to reclute to the wes pacific coastal areas (Resendiz *et al* 1998). Is there a parallel of this for the South Pacific population? Since 1982 loggerheads were reported to occur in Chilean waters but it was not until 2003 that the presence of this species was confirmed for Peru (Kelez *et al.* 2003). We encounter this sea turtle species during observations onboard longline vessels. It was an unexpected but very interesting finding. They turned out to be the second most common species of turtles captured in this fishery. Results from our observations show that the individuals captured are all in the juvenile stage (mean size 57 cm, range 41-70, n=38). Moreover, genetic analysis of this individuals proved that their share the same haplotype than the Australian population.
It seems that the loggerheads that are born in Australia swing east to catch the currents that will take them all the way to the Humboldt Current system. Apparently this is not a passive process because green turtles born in the same beaches do not reach the currents and remain in the west Pacific Ocean. Further analysis of their diet and oceanic behavior would let us understand how this species is exploiting the Humboldt Current system and which role in the biological system are these juvenile loggerheads performing.

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HCS179 - Spatial-temporal distribution, abundance and habits of catfish (Bagre, *Galeichthys peruvianus)* in the Peruvian coast between 1998 and 2006

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Behavior, catfish, distribution and abundance, ecological interactions, Perú, seasonality

In the Northern Region of the Humboldt Ecosystem (NHCE) live more than 700 taxonomically identified species. However, the knowledge on the abundance, seasonal patterns of aggregation, behavior, spawning seasons, feeding habits, etc, of the commercial value species are mostly unknown. Thus the present document is a contribution in that direction. We present the results on distribution, abundance and fishing and ecological aspects of bagre (*Galeichthys peruvianus)*, a bentho-pelagic fish that is not target of an intensive fishery. Our study started in 1998 as a response to the need for the knowledge of its abundance and biological aspects that could be linked to other species as well. Through out a systematic monitoring of its distribution and of the environmental variables associated to observed changes in seasonal aggregation patterns of bagre we contribute to the study of the niche this species occupies inside the trophic web of the coastal ecosystem. Therefore we can synthesize our study by describing bagre as a fish that inhabits Coastal Cold Waters (CCW) and soft bottoms of shallow coastal waters along the Peruvian coast, particularly inside the first band of 50 nautical miles off shore. The acoustically detected main areas of distribution are comprised among Punta La Negra (06°S) and Chimbote (09°S), where the continental shelf reach out its maximum longitudinal width. Data of acoustic backscattering shows that this fish is distributed in the whole water column according to diel cycles though getting dispersed during night close to the surface. Depending of the depth of the oxycline this fish can go to depths of 140 m. Acoustic assessment performed between 1998 and 2006 shows a maximum abundance level of 2´133 357 t during winter of 1998 (which matches with the end of El Niño event of 1997-98) (Fig. 1). Forthcoming abundance estimates were sometimes significant though of lower levels which might indicate that it exist a certain level of resident population that could have a dynamic role regarding ecological interactions with other coastal species that overlap their spatial distributions. In general terms, warm events like summers and moderated or weak El Niño or Kelvin waves disperse the fish along the coast, though the presence of bagre was null during summer of 1998 and very low during summer of 2004; its presence during winter 2000 was null too, what is the season that supposedly aggregated the fish close to the northern end of NHCE. Furthermore, the minimum assessed abundance was of about 28,000 t during winter 2005. These fluctuations in abundance are rather well reflected in landings of artisan fishery though the fish is not the objective of a sustained catching, what is, its presence in landings is the product of by catch.

To perform this study all available information regarding bagre was gathered though emphasize was given to the main zone of distribution (6° to 9ºS). Biologically bagre has a maximum length till 38 cm of total length while the mean size of catches is 27 cm. The proportion between females and males is 2.31, respectively, for the studied time range. At the same time the fecundity was of 27 eggs per individual during the main spawning season in summer. Its size of first maturity is around 17.3 cm of total length.

Diet of bagre varies seasonally, thus during summer and autumn anchovy is usually its main food in proportions of 62.7% and 53.9%, respectively. The crustacean munida is only part of its diet during spring and autumn (13% and 0.4% respectively). However bagre has a preference for invertebrates, especially polychaeta worms when the fish is juvenile, and prefers other fishes when adult.

The comparison and analysis of distribution areas of bagre, anchovy and munida lead to the conclusion that bagre inhabit zones that are part of the main nursery areas of anchovy. On the other hand, bagre is usually associated in the majority of cases with the landings to adult anchovy, which demonstrates its strong seasonal dependence of the latter. Depending on occasional high densities bagre can behave as a pelagic fish. The distribution of bagre shows seasonal patterns of aggregation rather well defined: during winters the main densities occur, especially in the coastal zone along 7° and 9° S, and during spring its main aggregations are moved down to the area between 8 and 10°S.

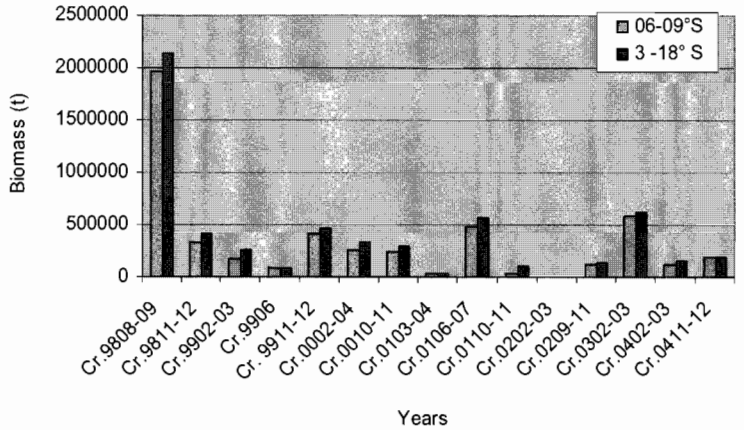

Figure 1. Biomass (t) of catfish (bagre Galeichthys peruvianus) according to degrees of latitude for surveys conduced by IMARPE during 1998-2004. The red bar shows the total abundance (for 3° to 18° S) and blue bar is the abundance for the northern end of NHCE (6° to 9º S).

HCS190 - Spatial separation of spawning units of hake *Merluccius gayi peruanus*

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Keywords: *Hake Merluccius gayi peruanus, maturity ogives, spawning spatial separation*

The logistic curve describing mean length at maturity (Lm50) of female hake (*Merluccius gayi peruanus*) presents "bumps" which only appeared after El Niño 1997-98 (Fig.1). In order to explain this trend we analysed samples from surveys performed by the Peruvian Marine Institute (IMARPE) between 2001 and 2005. Only for that period the sample design has been appropriate to differentiate the spatial distribution of mature hake by latitude in contrast to the data base from commercial fisheries. From the survey of austral summer of 2001 onwards stratified samples of maturity stages per degree of latitude were available, allowing us to draw separate spatial maturity ogives. We identified two size-groups, one comprising small hake, fluctuating slightly from year to year in their mean length at maturity. The second was a group of larger hake, with fluctuating Lm50, too. Both size-groups were involved in spawning.
In relation to the type of logistic curve we found, some description of a similar distribution in proportion mature exists. Trippel and Harvey (1991) subdivided 32 maturity distributions of white sucker (*Catostomus commersoni*) into four types. Their type III distribution, which describes "non-successive increases in proportion mature with increase in age or length", represents what we call "bumps" in this study. We suggest that the occurrence of the so-called type-III maturity distribution like in Trippel and Harvey's study, after El Niño 1997-98 is due to the spatial separation between mature female hake. Small females mature normally to the south and larger ones to the north of their distribution area. During the 2002 and 2003 surveys, when hake biomass and density was very low, all hake matured at very small sizes at all latitudes, and the larger size-group did not enter in a mature stage. After the closure of the fisheries in 2002/03, hake biomass increased and we found larger hake spawning again during the surveys carried out in austral winter of 2004 and autumn of 2005. For management purpose, we recommend to treat the two spawning units separately.

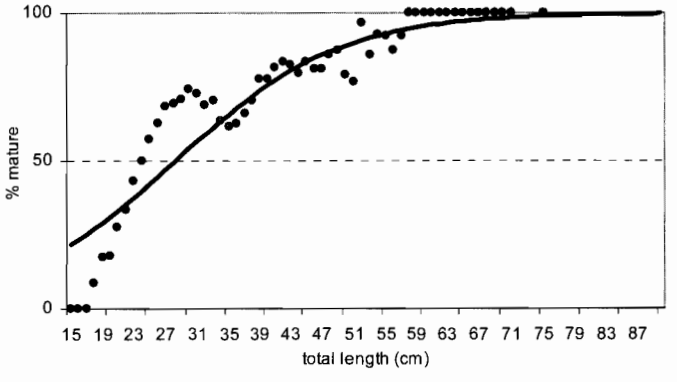

Figure 1. Percentage of mature female hake and resulting logistic curve showing "bump" (period1998 -2002).

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HCS194 - Abundance and population structure changes of jumbo flying squid *Dosidicus gigas* off Peruvian waters during 1989-2004

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Keywords: Abundance, *Dosidicus gigas,* Perú, population structure, squid

The giant squid of Perú and Chile, *Dosidicus gigas* (family Ommastrephidae), is one of the most abundant squids in the world. It plays an important role in the ecosystem of open waters in the southeastern Pacific Ocean (Nesis, 1970). *D. gigas* is a typical schooling nektonic predator, which eats any prey that moves. Myctophids play the main role in the food of squid.
The population structure of *D. gigas* is complicated, hovewer, in the intraspecific structure three groups have been distinguished on the basis of the size of adult males and females: a small group, a medium-sized group, and a large group. The ranges of both the small-and medium- sized groups fully or partially overlap, as do the ranges of the medium-and large-sized groups. Squids of the small-sized group are found predominantly in the near equatorial area, those of the medium-sized group live within the whole species range and those of the large-sized group occur at the northern and southern peripheries of the range (Nigmatullin et al., 2001). The abundance of this specie in Chilean waters is reported through high mortalities in coastal areas (Wilhelm, 1954). Studies made by Russian and Japanese scientists in

Peruvian and Chilean waters have demonstrated that the distribution of *D. gigas* is related to areas of high productivity.

The objective of this work is to show changes in the abundance and size of adult females in Peruvian waters during the period 1989 - 2004, and possible relations to changes in water masses and food supply.

Catch (t) and effort (hours) were registered by Imarpe's technical observer on each squid vessel from 1991 to 2004, and used to estimate abundance (CPUE). Biological data of *D. gigas* were registered during research cruises, artisanal and industrial fisheries during 1989-2004 in Peruvian waters. Mantle length (ML) of adult females by year and areas (northern, central and southern littoral) were plotted using box plot graphics. The time series of biomass of mesopelagic fishes (*Vincingerria* sp) during 1998 -2004 were correlated with the biomass of *D. gigas* estimated during the same period. Sea surface temperature and water masses registered during two periods: El Niño 1997-98 and normal conditions (2000-2001) were used to characterize the abundance and size structure.

The abundance of *D. gigas* (CPUE) presented high annuals variations. Before 1994, the annual mean CPUE ranged between 0.7 and 1.6 t per hour. After this period, the abundance decreased quickly until 1996. During 1998 *D. gigas* was not observed in Peruvian waters. After July of 1999, *D. gigas* abundance increased again, reaching the highest annual mean of CPUE.

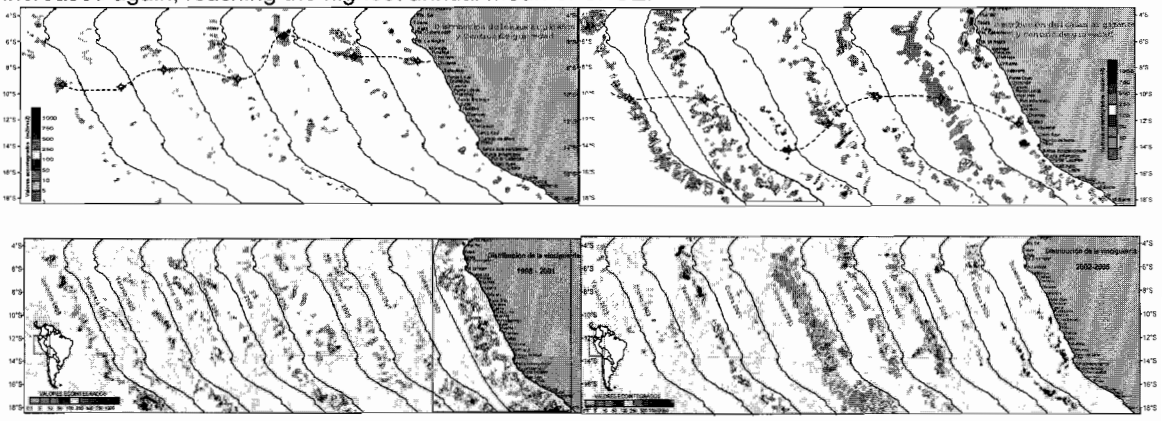

Figure 1. Annual variation in biomass of D. gigas and Vinciguerria lucetia during 1998 – 2004.

Four scenarios were observed during the period of study. In the first, three groups of adult females (small, medium and large) were observed during 1992. The size of adult females ranged from 25-94 cm ML. In the second, small and medium adult females were observed during 1994. The size of adult females ranged from 28-58 cm ML. In the third, only small adult females were observed during 1998. The size of adult females ranged from 28-41 cm ML. In the fourth, only large adult females were observed during 2002.The size of adult females ranged from 58-100 cm ML. Before El Niño 1991- 93 (moderate event), small and medium-sized adult females were observed. During 1992 large-sized adult females were observed principally in the southern littoral. A predominance of medium-and small-sized adult females were observed during 1993-1995, except in the southern littoral during 1993. In 1996 (cold period – La Niña) only the small-sized group was observed. During 1997 small-and medium-sized groups were observed again. During El Niño 1997-98 (strong event), mainly the small-sized group was observed. During that period, sea surface temperature ranged 24-27°C and Subtropical Surface Waters predominated in the littoral. During that period (spring, 98) lower values of mesopelagic fishes were observed. From 1999 - 2004, the large-sized group prevailed. Normal conditions were observed during 2000-2001. The sea surface temperature ranged 16 - 24°C and the prevailing water masses were cold coastal and mixed waters. An increment in the biomass of jumbo squid observed since spring 2001 is positively correlated with an increment in the biomass of mesopelagic fishes, *Vinciguerria lucetia* (Fig.1).

The observed changes in abundance of mesopelagic fishes and prevailing water masses after El Niño 1997-98, could be correlated with changes in the abundance and population structure of *D. gigas* observed during 1997 to 2004. We postulate that before 1997, observed changes in *D.gigas* could be related to the same variables.

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Friday morning

HCS199 - Changes in population size and distribution fur seals, *Arctocephalus australis* and sea lions, *Otaria flavescens,* off Peru, from 1971-2006

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Keywords: Fur seals, sea lions, population size, distribution, El Niño Southern oscillation (ENSO), Peru Humboldt Current system

In Peru, fur seals (*Arctocephalus australis*) and sea lions (*Otaria flavescens*) were almost extinct because of indiscriminate commercial exploitation until 1946. Then, the implementation of some regulations in harvest allowed a certain degree of populations' recover. In 1976 an exploitation ban was established and since this date, populations' fluctuations were mainly determined by density-dependent habitat and food availability factors, which are influenced by "El Niño" and "La Niña" events (Arias Shreiber 2000). Here we aim at evaluating trends in fur seal and sea lion Peruvian populations size and distribution from 1971-2006, as influenced by environmental variability, in particular El Niño and La Niña events.

Data come from counts in the major colonies along the Peruvian coast during the end of the breeding season. There are always a certain number of animals that are at sea and not counted. Thus, the counts are considered as minimum estimates of the number of animals in a particular site and serve as relative indices of population size and trends in abundance.

The most important fur seals population decreases were observed after El Niño 1997-98, when the population declined about 74% (from 24 481 individuals to 6 257 individuals) from the previous year. Since this date, fur seal population has showed slow increases, reaching a total of 14 320 individuals in 2005 (Fig. 1). During the study period, the distribution of Peruvian breeding population mainly ranged between 13° and 18°S The core of the population was distributed between 15 and 16°S before 1997 then between 17 and 18°S.

As with fur seals, the most important change in sea lions population size and distribution also occurred after the "El Niño 1997-98" event. Indeed the population reduced dramatically (81%) passing from 144 087 individuals in 1997 to 27 998 individuals in 1998. Then, the population recovered, reaching 118 220 individuals in the last count conducted in 2006 (Fig. 1). The Peruvian breeding population was distributed almost all along the Peruvian coast (6 -18° S), with higher densities at about 14°S. El Niño events produced latitudinal changes in sea lions distribution. Indeed, the core of the population was distributed at about 11°S after the El Niño 1982-83 and 13°S after the El Niño 1997-98.

Changes in fur seals and sea lions number and distribution observed since 1976 (end of hunting activities) are probably related to the changes that occurred in the distribution and abundance of their principal prey species; the Peruvian anchovy *Engraulis ringens*. Anchovy population variations could have directly affected fur seal and sea lion populations, but also the feeding time investment and dispersal that may have biased the counting performed in colonies. Other factors that could also have affected directly or indirectly the populations are e.g. fishing (competition for prey), illegal direct captures, and human perturbation in colonies.

The different response of fur seal and sea lion population structures to ENSO events can be related to differences in foraging strategies. For example, the sea lion has a different foraging behavior, a deeper diving capability than the fur seal (Arias Schreiber 2003; Gentry and Kooyman 1986). Also, fur seals are specialist feeder on anchovy and sea lions are more generalist. Under normal feeding conditions fur seals are very effective feeders on anchoveta. However, under poor feeding conditions, when anchoveta is too deep or aggregated in some refuge areas (e.g. El Niño) or dispersed (e.g. La Niña) the sea lions appear to feed more effectively on anchoveta than fur seals (Arias Schreiber 2003).

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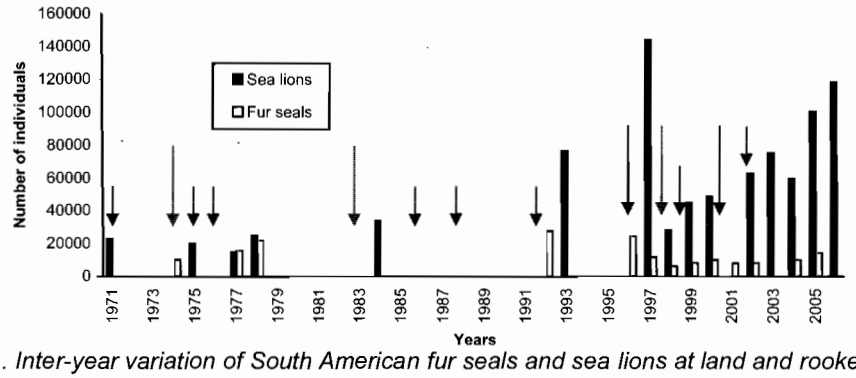

Figure 1. Inter-year variation of South American fur seals and sea lions at land and rookeries sites off the Peruvian coast. Red arrows signal warm events and blue arrows cold events, length indicates intensity.

HCS201 - Small Cetaceans Interactions with the Purse Seine Fisheries off the Peruvian Coast during 2002

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Keywords: small cetaceans, interactions, bycatch, purse-seine, foraging

Several species of small cetaceans are distributed along the Peruvian coast, from inshore to offshore waters (Arias-Schreiber 1996). This wide distribution could potentially generate encounters of several small cetaceans or dolphin populations with the large Peruvian fishing fleet, which has grow in the last decade. Marine mammals, and including small cetaceans are top predators (Pauly 1998), therefore it is of great concern that these encounters result in dolphin mortality indirect effects n the ecosystem (Hall 1998). On-board observers registered the presence of small cetaceans during fishing operations by the industrial purse-seine fleet targeting Peruvian anchoveta and sardine during 7 fishing months of 2002. The sampling effort covered 2% of the fleet. The present study analyzes the fishery-dolphin interaction events and the variables that help to better understand of the foraging behavior of the dolphins during fishing operations, including depth of fish school, fish size, sea floor depth, time of the day, and size of the vessel.
It was also of special interest to find dolphin capture rates to show the magnitude of these interaction problems and evaluate the factors that that influence captures such as set length, net size, time of day, etc. At least 4 species of small cetaceans occurred during fishing operations; the Common Dolphin *Delphinus delphis*, the Long Beaked Common Dolphin *Delphinus capensis*, the Bottlenose Dolphin *Tursiops truncatus* and the Dusky Dolphin *Lagenorhynchus obscurus*. These were present in 299 of 2664 sets made between 4° 40.1' S and 18° 43.7' S Latitude, from 0,5 to 105 nm from shore (Fig. 1). The highest sighting rates were encountered in July and October (17.88% and 20% sets with dolphins respectively). The sightings occurred mostly during daytime (86.95%), from 0600 to 1700 hrs, and anchoveta size ranged from 9.18 cm to 15.18 cm. in schools of 0-44 ftms. depth. Observers reported dolphin school size when conditions made it possible, up to a maximum of approximately 700 individuals.
Around 9% of the interaction events resulted in bycatch, ranging from 1 to 12 individuals captured per set. 93% of the captures occurred in sets that lasted between 1.18 to 2.93 hours. When cetaceans were captured estimated dolphin school size varied from 12 to 300 individuals. A capture rate per set for each month of 0 to 0.11 (average = 0.041; SD = 0.037) dolphins was estimated, with the highest capture rate in January. Since fishing trips could total around 80000 a year, cetacean captures could potentially reach considerable numbers.

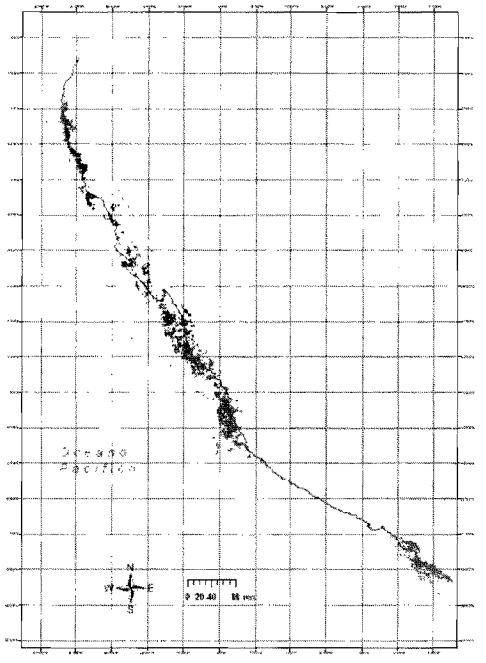

Figure 1. Distribution of purse-seine sets and presence of small cetaceans during 2002.

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HCS213 - Database on Ukrainian research of Chilean jack mackerel Trachurus murphyi in the high seas of the Southern Pacific

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Chilean jack mackerel *Trachurus murphyi* is one of the most important species in the world fisheries. Total catch of this species quickly increased in 1970-1977 from 100000 t to 800000 t fluctuated than at the level of 1 billion t to 5 billion t in 1978-2001 (FAO, 2006). Starting from the 1978 till early 1990-ies this species supported large-scale distant water fisheries of the USSR with total catch more than 1 billion t in 1989-1990 (FAO, 2006). Catch of coastal countries, generally Chilean and Peruvian coastal fleet fluctuated at the level (0.5-4.5 and 0.1-0.7 billion t respectively). Recently, late 1990-ies or early 2000-ies this species also target of distant-water Chinese fisheries (catches unreported to FAO). Despite enormous research effort by former USSR (more that 200 research cruises, according to Elizarov et al., 1992) and numerous Soviet and Russian publications (Elizarov et al., 1992, Grechina, 1998, others...), Chilean research (Serra, 1991; Arcos et al., 2001) and other studies (Bailey, 1989, Parrish, 1989) many aspects of distribution, biology, and life history of this species is unclear, which allow many interpretations of this species status (highly migratory/straddling/oceanic/neritic). Uncertainties in knowledge led to including this at least straddling or even highly migratory species as neritic species in FAO analysis (Garibaldi, Limongelli, 2003), incorrect description of species area and biology at FAO web-site (FIGIS, 2006) misreporting of more than 100000 t of Soviet catch of this species in the Western Pacific as catch New Zealand greenback horse mackerel *Trachurus declivis* (errors originated from fisheries statistical office, which submitted data). The purpose of this presentation is to describe principal results obtained during data rescue project for 40 Ukrainian scouting expeditions to the Southern Pacific, and present general review of available biological information. Database was created in 1999-2003 during YugNIRO/NMFS data rescue project aimed to protect data which were available on paper only and involve these data into analysis using modern technology. Data from 40 scouting/searching cruises to the Southern Pacific Ocean (SPO), which consists a total of 7221 trawl hauls and 6681 positive trawl haul. Total catch from these cruises aggregated by 1-degree squares is presented at the Fig. 1. A total catch in the sampled hauls is 66071 t of fish, cephalopods and other animals. A total of 294 species or higher taxa ware recorded in the catches. Chilean jack mackerel is the principal species in the catch: 62197 t (more than 94% of total catch). Together with two other principal species South American pilchard (*Sardinops sagax*) and chub mackerel (*Scomber japonicus*) these three species accounted more than 99% of the catch. Database consists of more than 165000 individual measurements, weighing and biological analysis for Chilean jack mackerel and more than 2700 bulk size frequency samples. These values for South American pilchard and chub mackerel are 4214/87 and 7400/116 respectively. This database is stored in the YugNIRO and could be available for joint analysis within frameworks of cooperative bilateral or/and multilateral research programs.

HCS214 - Utilization of the North Pacific by Marine Mammals and Others Top Predators: Tagging of Pacific Pelagics: Using Electronic tags to discover Hotspots in the Pelagic Realm

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In an effort to understand and locate biological hotspots in the North Pacific Ocean, the Tagging of Pacific Pelagics program (www.toppcensus.org) is using biologging technology to simultaneously map the location of marine vertebrates including sharks, tuna, albatrosses, seals and whales. Hot spots are regions of high biological activity where linkages occur between physical forcing, primary production, secondary consumers and top pelagic predators. Although it is generally accepted that these hotspots occur and are important, surprisingly little is known about these congregating spots for marine organisms in the open ocean. Our lack of understanding of the aggregating forces in the pelagic ocean ecosystem stems largely from limitations of available technology. Prior studies have focused on single species tracking and few have attempted to examine interactions among top pelagic species. TOPP is coupling electronic tagging data with satellite remote sensing technologies to simultaneously map the movements of diverse pelagic species and link their movements to oceanographic processes. To date we have tagged and tracked mako, salmon and white sharks, elephant seals, bluefin and yellowfin tuna, black-footed and Laysan albatross, California sea lions and leatherback sea turtles. To date our analysis indicates that frontal features associated with the North Pacific Transition zone and the California Current are the major regions of common habitat utilization for these species.
We propose here to evaluate the viability of conducting a similar research program in the Southeastern Pacific, using bio-logging science to understand habitat use by marine vertebrates, integrating biological data collected from electronically tagged organisms with earth-observing satellites and *in situ* data.

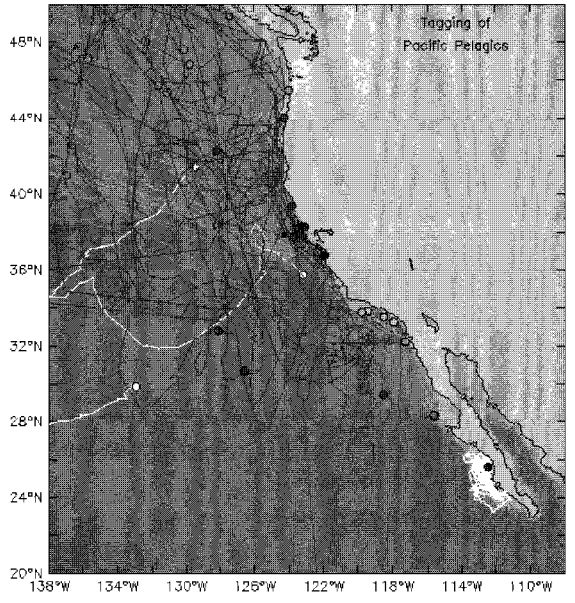

Figure 1. Tracks of TOPP animals across the California Current (Image obtained from www.toppcensus.org).

HCS221 - Incidence of the climatic variability on some highly migratory resources

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Keywords: Dolphin fish, ENSO, environment, jack mackerel, transboundary species, tuna.

This paper reviews the information on the distribution, abundance, fisheries location, landings, size composition and reproductive aspects of the some transboundary species and oceanographic information for a better understanding of the incidence of the climatic variability on these resources. The Peruvian marine area is part of the Peruvian Current system, which is characterised by its high environmental variability. This variability occurs at different scales e.g., seasonal (summer- winter), interannual (El Niño-La Niña) and interdecadal (El Viejo – La Vieja).

In this work I analyse the effects of water masses variations off Peru on some transboundary species such as the South Pacific jack mackerel (*Trachurus murphyi*), the Pacific mackerel (*Scomber japonicus peruanus*), the yellowfin tuna (*Thunnus albacares*), the skipjack tuna (*Katsuwonus pelamis*), the dolphin fish (*Coryphaena hippurus*) and the mesopelagic fish *Vinciguerria lucetia* from the El Niño 1997-98 to present. The incidence of El Niño 1997-98 on these resources is analysed and results indicates that this event was favourable for the pacific mackerel and unfavourable for South Pacific jack mackerel. This event also constituted a turning point between the end of a warm period in July 1998, (with a steady decrease in the acoustic estimates of anchovy biomass during the event) and the beginning of a cold period in August-September 1998. During this transitional period, subantartic water mass spread toward the north reaching 12°S. Simultaneously, superficial subtropical water mass with high salinity invaded the north-central coast between 6°-11°S. This resulted in a higher *Vicinguerria* biomass with an estimate of 11.1 millions tons. Environmental changes were also related to changes in the distribution, concentration, abundance, vulnerability, reproduction and condition factor of these species. An interesting result relies on the fact that the gravity center of jack mackerel and Pacific horse mackerel captures moved from Callao (12°S) to southward instead of Callao to northward as usually observed during warm periods. During this period fish schools were large which increased their vulnerability to purse seines fleet. At the same times dolphin fish and tuna changed their distribution with lower abundance in Equatorial areas, and higher abundances in the Peruvian waters. Finally, from the results we obtained I propose recommendation to reduce the negative effects of fisheries and to take advantage of favourable situations.

HCS006 - Understanding El Niño – an integrated INCO approach on coastal ecosystem research and management (CENSOR)

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Keywords: climate oscillation, ecosystem management, ENSO, artisanal fisheries, Humboldt Current

Marine biodiversity and the sustained exploitation of marine resources in the coastal zone of the Humboldt Current upwelling system are significantly influenced by El Niño-Southern Oscillation (ENSO). Both its warm (El Niño: EN) and cold (La Niña: LN) phase have drastic implications for the ecology, socio-economy and infrastructure of the countries concerned. Local artisanal fisheries represent a major activity for the domestic economy and in consequence a huge amount of studies (published/unpublished) exists aiming at identifying effects of EN. However, most processes and mechanisms causing these effects are not yet known. Especially artisanal fisheries and coastal invertebrate and fish populations suffer from EN effects. The EU-funded international science and technology cooperation (INCO) project (CENSOR, www.censor.name) aims at enhancing the detection, compilation and understanding of EN and LN effects on the coastal zone and its resources, to mitigate damage, better use beneficial effects, and thus improve the livelihood of human coastal populations. In a multidisciplinary approach, including Latin American and European specialists, the consortium is presently developing a comprehensive picture by illustrating the respective response of marine floral and faunal assemblages to the phases of the ENSO. Coastal benthic communities, pelago-benthic exchange processes, riverine input and resource variability are compiled and analysed comparatively. Aquacultural demands to compensate and decrease EN dependence in coastal fisheries are addressed. Integrated database information (Zeller et al., 2005) will enhance the understanding of mechanisms and processes related to life strategies, species interactions and genetics. As one strategic point, indicators to predict EN events are elaborated. We aim to improve the understanding of ecophysiological demands explaining shifts in resource availability, supporting an advanced fishery management. In this frame access to information about past states of the environment and social systems is necessary to cope with the challenges of climate change and over-exploitation of natural resources at the onset of the 21st century. The loss of (historical) data is a major threat to mitigate long-term effects of human activities and anthropogenic changes to the environment. Although this is intuitively evident for old and local literature of any kind, even present-day international publishing of papers without the underlying raw data makes access to basic information a crucial issue. By utilising the world data centre WDC-Mare and Pangaea (Grobe et al., 2006), the CENSOR project is providing access to local and ancient information. We show that indeed local "Grey Literature" is still one of the most important sources of knowledge about natural science research and management of natural resource systems in Latin American countries adjacent to the Humboldt Current. We argue that public archiving of original data of present-day research and old (Grey) Literature and easy public access are important for appreciating today's global environmental challenges caused by human activities, both past and present, and with particular importance in the ENSO context (Thatje et al., in press). All information retrieved through the project is made available at various society levels, including scientists, stakeholders, decision-makers, and coastal human communities (www.censor.name).

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HCS023 - Ecosystem-based management of upwelling systems: the importance of accounting for anthropogenic influences to balance the predator suite

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Keywords: Cape fur seal *Arctocephalus pusillus,* Cape gannet, *Morus capensis,* fledgling mortality, Malgas Island, predation

Predators in upwelling ecosystems include some that are opportunistic and others that are specialised. Generally the opportunistic animals have benefited from human activities, whereas specialists have been disadvantaged by them. For example, the opportunistic Cape fur seal *Arctocephalus pusillus* utilizes fish discarded by fishing boats and also takes fish from fishers from their nets. Following the removal of large predators from much of the southern African coastline, it has formed large mainland colonies. It is possible that its numbers are now higher than before the arrival of Europeans in southern Africa in the 1600s. By contrast, several seabirds, such as the African penguin, are specialist feeders that compete with fisheries for food, had their breeding habitat altered through *inter alia* the removal of deposits of guano for agricultural use, and decreased substantially during the 20th century. Recent interactions between seals and seabirds off southern Africa are exacerbating the population decreases of seabirds caused by human perturbation of the marine ecosystem. At Malgas Island, Cape fur seals killed some 6 000 Cape gannet *Morus capensis* fledglings in the 2000/01 breeding season, 11 000 in 2003/04 and 10 000 in 2005/06. This amounted to about 29%, 83% and 57% of the overall production of fledglings at the island in these breeding seasons, respectively. Preliminary modelling suggests this predation is not sustainable. There was a 25% reduction in the size of the colony, the second largest of only six extant Cape gannet colonies, between 2001/02 and 2005/06. Management intervention is required to ensure conservation of scarce and decreasing predators and ensure a balanced predator suite.

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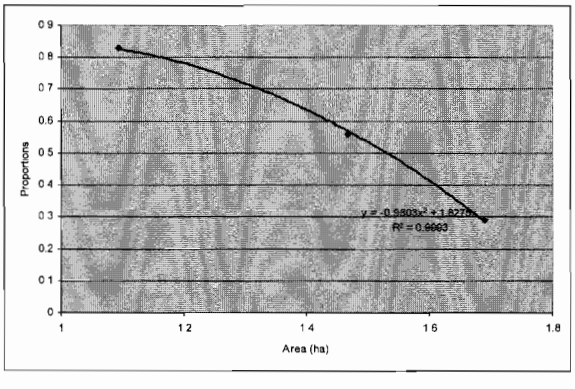

Figure 1.

HCS025 - Ecosystem Indicators and Integrated Conceptual Model: Fisheries Managements Perspective in the South-East Pacific

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Keywords: pelagic fisheries, northern Chile, variability, conceptual model, indicators.

The Chile-Peru Eastern Boundary ecosystem is one of the most productive systems of the planet. This richness takes place mainly by coastal upwelling induced by winds blowing predominantly towards the Equator and by the advection towards the Pole of rich nutrients water. In this ecosystem El Niño events correspond to those of most importance in the interannual variability. Nevertheless, after El Niño 1972-73 a regime shift was observed, and associated to a clear decrease of anchovy fishery after the mid 80's. In as much, from mid 70's a remarkable increase of sardine landings and in lesser quantity of jack mackerel and horse mackerel landings was observed. A second regime shift was observed after 1985, associated mainly by anchovy recovery and sardine decrease.
We develop an integrated conceptual model of different local and large scale phenomena that affects the marine environment and the distribution and abundance of the main pelagic resources of northern Chile (Fig. 1). This model is based on the analyses at different scales of environmental, biological and fishery data. The model describes the inter-decadal (associated to regime shifts) and inter-annual (associated to El Niño events) fluctuations developed in the Equatorial Pacific Ocean, South-East Pacific and northern Chile spatial scales, and the effects in annual cycle, planetary waves dynamics and coastal upwelling . In this framework, the interdecadal fluctuations would be playing an important roll in the sequence of alternating anchovy-sardine-anchovy regimes. An identification and develop of ecosystem indicators proxies is also proposed, in order to support the fisheries management decision making process.

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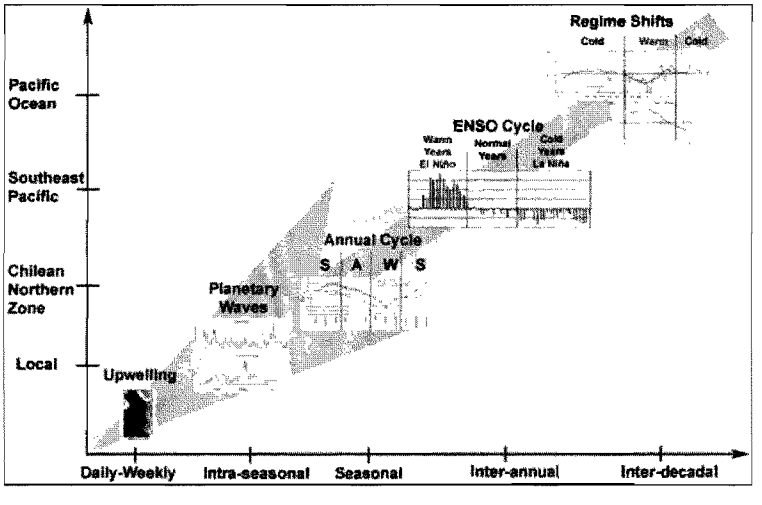

Figure 1. Northern Chile ecosystem integrated conceptual model relates local and large scale events affecting the pelagic resources.

HCS044 - Rule-based approaches to modelling long-term changes in the southern Benguela ecosystem

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Keywords: Benguela, change, ecosystem, model, rule-based

This paper describes how two rule-based approaches are used for detecting and predicting long-term ecosystem changes in the pelagic ecosystem of the southern Benguela region off South Africa. The two approaches are "frame-based modelling", which represents changes between ecosystem states on a decadal time scale, and "expert system modelling", which detects changes within a given ecosystem state (or frame). To implement these approaches, major ecosystem states in the southern Benguela are identified over the period of the past 50 years (mid-1950s to present), based on species compositions and hypothesised ecosystem processes. In the frame-based model, transition rules are defined and are used to change the ecosystem from one state to another. This model is executed to test scenarios of climate change in combination with different management strategies. The expert system model aims to improve our ability to detect real long-term ecosystem change in the short- to medium- term. This model synthesizes our best understanding of signals provided by ecosystem indicators, to provide an early warning of large-scale changes occurring in the ecosystem. The rule-based models rely to a large extent on expert opinion garnered from varied sources, in contrast to fully quantitative approaches, which are data-driven. We argue that the rule-based approaches allow multidisciplinary syntheses of ecosystem information in the absence of extensive data sets, and that the process of developing and maintaining such models allows trans-disciplinary teams to communicate effectively in implementing an ecosystem approach to fisheries management.

HCS055 - Expert systems as decisions support tools in an Ecosystem Approach to Fisheries: Comparing a fuzzy-logic and a rule-based approach

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Keywords :Benguela, decision support, EAF, fuzzy, rule-based

Management for an ecosystem approach to fisheries (EAF) must draw on information of widely different types, and information addressing various scales. Decision support tools, which have evolved considerably during the past two decades, assist in the decision-making process by summarizing this information in a logical, transparent and reproducible fashion. They generally consist of (i) a structured knowledge base storing the underlying information, (ii) an information system accessing and retrieving this information, (iii) a model predicting the outcome of a problem posed, and (iv) a framework that facilitates communication between the users, the decision support system, and the knowledge base. With regard to the modeling component, both rule-based Boolean and fuzzy logic models have been used successfully in such decision support tools, but the relative merits of these two approaches often remain unclear.
Three prototype decision support tools relevant to fisheries management in an EAF have been developed for the southern Benguela. The first is a rule-based expert system for the prediction of anchovy recruitment (Miller and Field 2002, Miller et al. this conference). The second is a fuzzy-logic decision support tool to monitor the implementation process of EAF in the sardine pelagic fishery (Paterson et al. this conference). This study is based on the construction of a fuzzy-logic counterpart for the rule-based model, and a rule-based counterpart to the fuzzy-logic model. We summarize the knowledge gained in this process with specific reference to the third tool, an expert system for predicting long-term ecosystem change (Moloney et al. this conference). We demonstrate the potential merits of both the rule-based Boolean and fuzzy logic models in supporting decision-making in an EAF.

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HCS056 - A fuzzy spin on fishy problems: Development of a fuzzy-logic tool to assist in multicriteria decision-making for an ecosystem approach to fisheries in the Southern Benguela

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Keywords: Benguela, EAF, fuzzy, decision support system

The ecosystem approach to fisheries (EAF) aims to achieve the collective sustainability of all uses and impacts on an ecosystem. Consequently, individual issues cannot be addressed independently because attempts to manage any one issue are likely to have impacts on other issues. This paper presents a prototype fuzzy-logic decision support system to monitor the implementation process of EAF, and to assist decision makers in evaluating the effect and effectiveness of management measures. A prototype has been implemented for the pelagic fisheries in South Africa, using the commercially available NetWeaver and Geo-NetWeaver software. The decision support system consists of a network hierarchy of the factors that constitute an ecosystem approach to fisheries in the southern Benguela and provides intuitive visual outputs to communicate results to managers and other stakeholders. The system successfully combines empirical data and expert opinion, thus providing a rigorous approach for including parameters for which fully quantitative data were not available. The system has the potential to be applied widely in the context of EAF.

HCS081 - Peruvian scallop fisheries management in the context of decentralization, changing property right regimes and climate variability

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Keywords: climate variability, decentralization, fisheries management, institutions, Peruvian bay scallop, property rights

Peru has a centralized government which is reflected through the limited autonomy of regional government agencies to develop and implement institutional arrangements in the fisheries sector that respond to specific regional needs and realities. Additionally Peruvian fisheries are characterized by a *defacto* open access system which in the context of resource fluctuations induced by climate variability further complicates the management of the artisanal fishing sector. The paper explores how this centralized management and property rights regime have influenced responses of the Peruvian bay scallop fishery to El Niño events in two coastal regions. The issue of cross-scale interaction in vertical interplay is given a particular emphasis by examining the historical impact of higher level institutions (national) on local-level ones (regional, community groups) through institutional surveys, interviews and archival research.
The paper then examines how the decentralization process as well as the promotion of community or group-based rights are impacting artisanal fisheries management and what are its implications for future responses to El Niño events. While decentralisation is intended to provide more efficient and locally-responsive service delivery and political representation, the introduction of private property rights into the scallop fishery ("concesiones" and "concesiones especiales") is intended to provide users more control over access to the resource, promoting sustainable use of the latter. The paper argues that decentralization in the context of weak local institutions with low financial and technical capabilities will not lead to adequate management, and stresses that the role of central government agencies as coordinating bodies in emergency response during El Niño should not be down played. The paper also highlights the difficulties in implementing a new property right regime in the light of exogenous forces at different scales such as local and regional economic and social imperatives as well as climate variability and change. It argues that although legal reform to strengthen property rights is necessary, any new rights-based system must enjoy legitimacy among stakeholders if it is to function, and remain sufficiently flexible to respond to future changes.
This research is a contribution to the ongoing debate on decentralization and community-based management as tools for adaptive management. It addresses the issue of scale in fisheries management: local versus regional and national functional and spatial dimensions as well as the issue of institutional fit, that is matching ecosystem properties and property right regime attributes. The research is part of the project CENSOR which aim is to understand the implications of climate variability on the artisanal fishing sector in Peru and Chile (www.censor.name).

HCS085 - Review of the perspectives opened by satellite vessel monitoring system (VMS) data for the study, the monitoring and the fishery management of the exploited marine ecosystems.

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Keywords: Fishing vessels trajectories, Lévy random walk, Peruvian anchovy fishery, VMS.

Vessel monitoring systems are being implemented in a growing number of industrial fisheries over the world. Originally designed for security and regulation purposes, these systems are incidentally providing to fisheries scientists very detailed and time continuous information of the trajectories followed by the fishing vessels. This is a brand new and groundbreaking type of information that can provide to fisheries scientists a new way of looking at the functioning of the exploited marine ecosystems. Indeed, this technology and the data it is providing are definitely opening wide perspectives for spatial approaches to fisheries because: (1) the observation is time continuous and collected at a very fine temporal scale; (2) the observation is exhaustive, in the sense that all the vessel population is monitored, in contrast with observers at sea programs for instance, sampling few vessels; (3) the information is reliable, as it does not depend on fishers' declarations like logbooks programs for example; and (4) the nature of the data opens the possibility of a Lagrangian (individual movement oriented) analysis and modelling of fishers' spatial behaviour, in opposition to classic spatial statistics in fisheries science, which mainly concern discrete point processes (e.g. catch locations and associated catches). The most common approach adopted for trajectory analysis consists in looking for a model of movement (for which mechanistic features are well known). Random walk models are particularly well suited to the study of animal trajectories (Turchin, 1998).

In this work, we analyzed the Peruvian anchovy fishery VMS data from November 1999 to June 2006. By studying the features of the vessels movements (move length and heading probability distribution, diffusion, etc.), we established that they well fitted Lévy random walk models (Bertrand *et al.*, 2005; Bertrand *et al.*, accepted). This family of random walk is characterized by scale invariance, created by a mix of short and long but infrequent moves. Each vessel was fitted a particular Lévy random walk, fully defined by a unique parameter, called μ. Analyzing the μ times series at a vessel scale, at a fleet scale, and in relation with fish spatial distribution or climatic descriptors was very fruitful as it allowed to establish that (1) the scale invariant movement developed by fishers is linked and adapted to the patchiness of fish distribution, (2) the spatial strategy of fishers for searching for fish is strictly comparable to the one of animal predators, (3) the average searching behaviour of the fleet allows to optimize the encounters with fish aggregations, (4) there is a real gradient in the fleet from vessels having in average quite directed movements (low μ) to vessels having in average quite sinuous movements (high μ), (5) when aggregated at the fleet level, the mean μ value characterizes the average fleet spatial behaviour; as vulnerability of anchovy is tightly linked to its spatial distribution and as fishers spatial behaviour reflects to some extent fish spatial distribution, VMS observations could be used by management authorities as warning signal of high anchovy vulnerability, (6) the fishing vessels spatial behaviour responds to the large scale climatic forcing (Equatorial Kelvin waves) with a 6 months lag; this last results shows that fisheries management authorities may anticipate the forthcoming dynamics of the whole coastal system.

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HCS106 - The Peruvian Artisanal Fishery: Changes in patterns and distribution over time

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Since 1996, the Peruvian Marine Research Institute (IMARPE) has been collecting data on landings by species, weight, gear type and region for landings in all major ports of the artisanal fishery. At present, this fishery has exclusive right to commercial landings inside of a region 5 miles from the Peruvian coast. During this period there were significant changes in the composition and spatial pattern of the fishery including a shift in dominance from anchoveta and sardine, to jumbo squid, scallops and dolphin fish. Of particular note was the effect of the El Niño of 1997-1998 which saw a major reduction in the catch of anchoveta and silversides and increases in shellfish (mussels and scallops). While the fishery has undergone relatively large changes in species composition of landings there has been a relatively steady level of CPUE for target species and in numbers of trips in the fishery. To some extent the observed changes reflect changes in environmental conditions, with a warmer period before 1999 and a cooler, higher production period since then. This change was accompanied by the rapid increase of jumbo squid capture, a voracious predator on many commercial fish species, since 1999. However, some changes reflect changes in economic conditions, for example higher oil prices and decreased selling price of many species resulting an increased focus on high value fisheries including the use of long-lines to produce a higher quality end product and the holding of shellfish catches in the sea to increase their size and bring a higher price. The Peruvian artisan fishery features strong seasonal variation in some species, generally sustained landings over a long time period, but strong changes in species dominance reflecting a long-term regime-shift-like pattern in this highly productive region.

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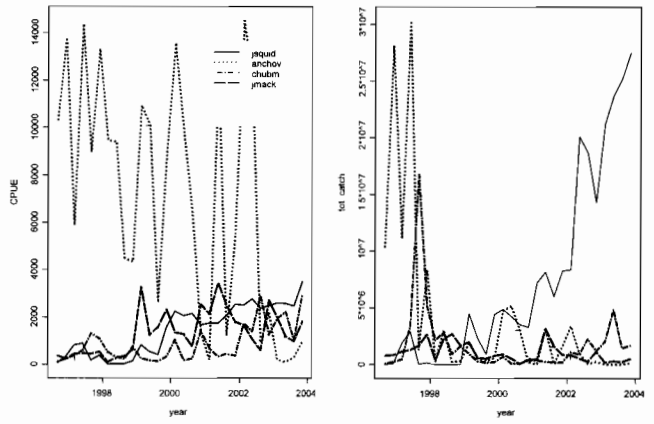

Figure 1. Time series from 1996-2004 of total catch and CPUE (per trip) for the 5 largest (in overall tonnage) artisanal fishery.

HCS120 - El Niño Effects, Recruitment and Risk versus Harvest Trade offs: The Chilean Jack Mackerel Fishery

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Keywords: Fishery; Chilean Jack Mackerel; Pelagic Recruitment

This paper estimates the impact of environmental changes on a Ricker Recruitment function for the so-called *Chilean Jack Mackerel* stock, considering an oceanic measure of the *El Niño* phenomenon. The occurrence of the latter is modelled by estimating a sinusoidal function. Numerically simulated random shocks are then introduced into the *El Niño* generating sinusoidal function, to simulate future possible environmental scenarios. Afterwards, by using an age-structured population dynamics model, the resource biomass' and the aggregate catch's are annually projected, being conditional on alternative harvesting strategies occurring along a 20-year horizon. Indicators of fishing collapse risk are also defined, considering the probability that the biomass falls below some unwanted critical levels. Additionally, other indicators are calculated as proxies for the expected annual fishing yields. Some of the main results are: (i) The oceanic measure of *El Niño* phenomenon obtains a significant and negative sign when it is used as a regressor in the Recruitment function. (ii) The estimated *El Niño* generating function exhibits cyclical behaviour of changing frequency. Based on the latter, historical periods of High versus Low environmental variability are accordingly defined. (iii) Different collapse risk levels are estimated, conditional on alternative exploitation strategies. By doing so, a trade-off relationship between collapse risk measures and expected annual fishing yields is obtained.

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HCS167 - Modelling Fishing Effort's Spatial Decisions at the so-called 'Chilean Jack Mackerel' Straddling Fishery

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This paper performs econometric analysis of the determinants of fishing effort's spatial decisions of the Chilean industrial fleet that has operated in the so-called 'Chilean jack mackerel' straddling fishery along the period 1985-2004. Since the mid 1990s, this fleet has begun to increasingly operate beyond the

Chilean EEZ limit, as a response to perceived changes in the spatial distribution of this highly migratory/straddling fish stock. It has been suggested that this pattern of change in the stock's spatial distribution could had been affected (and indeed intensified) by the occurrence of the strong "El Niño" phenomenon during the years 1997-1998. The return since the early 2000s of Distant Water Fishing Nation (DWFN) fleets at this fishery, currently operating at high seas areas which are nearby or adjacent to the Chilean EEZ, has increased the relevance of having a better understanding about the causes and consequences of the changing pattern in the spatial decisions of the Chilean industrial fleet operating at this fishery.
Our modelling estimates the effects of biological, environmental, regulatory, technological as well as economic factors upon the Chilean industrial fleet's (fishing effort) spatial decisions. We use vessel-specific per trip official data about geo-referenced fishing operations of this industrial fleet along two decades, together with information about changes in resource biomass, oceanic measures of the occurrence of "El Niño" and "La Niña" phenomena, changes in catch regulation regimes, vessels' technological features and economic variables which control for profitability aspects of the fishing business. The panel-data structure of our information about the fleet's fishing operations enables us to test the possible influence of environmental (time series) changes upon fishing effort's spatial decisions. Most previous econometric modelling of fishing fleets' spatial decisions has been developed only within the context of cross-section estimation techniques.

HCS176 - Policy analysis at the Humboldt Current Region (Chile, Ecuador and Peru). Why the current trends in marine management and protected areas?

MSc. (c) Maximiliano Bello M.

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This contribution aims at depicting current management practices and policies in the Humboldt Current (Chile, Ecuador and Peru) with particular focus on Marine Protected Areas (MPAs), by comparing global trends, experiences and knowledge of best practices and sustainable management together with the way these countries have been performing on these topics. Despite the fact that oceans and marine resources are becoming focal points in the international agenda, as can be evidenced by international forums and treaties, the status of world ecosystems, as denoted by the United Nations, points out that more than one quarter of marine fish stocks are overexploited or depleted. However, this is just part of the problem, the state of many other non commercial fish species, i.e. more than 60%, are still unknown. The object of study refers particularly to MPAs, which are recognised as an effective and efficient tool for fishery enhancement, conservation improvement, and planning for many different productive and non productive activities. These trends have been affecting the human society as well as the local ecosystems. This analysis considers a stakeholder analysis, macroeconomics and governance indicators, as well as treaties signed and accomplished by these nations.
The study region is ecologically represented by the Humboldt Current and the coast of Chile, Peru and Ecuador. This area accounts for about 50% of total world catches, a fact of increasing relevance if we consider that such amount is based on 0.1% of total ocean surface representation. The Humboldt Current, therefore, seems to be one of the most productive areas of the world, but at the same time, one of the most fragile because the interspecies relations and trophic web. Over the past 20 years, many important and useful measures have been put into practice to manage existing marine resources under a new tool called MPAs. This particular tool has a wide range of features and objectives, and most of them occur in particular social and ecological contexts. Several authors over the last few years have been successful in recording the evolution of this management tool and particularly in proving how successful they can be. Despite the fact that MPAs are becoming more popular and that they have been clearly helpful in many experiences around the world, they still remain insufficiently multiply in geographical terms for them to b ecological sound, and are very controversial among local communities, governments and the industrial sector. Many management improvements have been implemented in the region; however, unsustainable overexploitation indicators clearly show the trends in the region: bad practices are still deeply rooted in the current management practices of industries and artisanal fisheries.

HCS197 - Decadal Changes in the Purse Seine Fleet Strategies in Perú

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Keywords: *purse seine fleet, pelagic fishery, anchovy*

Studies on fishing strategies, dynamics of the fleet, and fishermen behavior are important issues to understand the functioning of exploited marine ecosystem, but they have not been taken in account enough sufficiently (Hilton, 1985, Vignaux, 1996).

The objective of this paper is to analyze and understand temporal changes in the fishing strategies of the industrial Peruvian fleet, mainly in the purse seine fishery. Since the 50's this fishery has been affected by profound medications, based mainly on anchovy (*Engraulis ringens*) afterward shifted to the others resources like sardine (*Sardinops sagax*), horse mackerel (*Trachurus murphyi*) and Mackerel (*Scomber japonicus*), and nowadays it is based again on anchovy. The study considered the fleet operating area between the northern and the southern of the Peruvian Exclusive Economic Zone. The analyzed time series data belong to the Pelagic Fishery Monitoring Program and an onboard observers program called "Fishing Logbooks" for the periods 1974 – 1980 and 1994 – 2005. From this information different fishery variables were estimated: captures, fishing effort (trips duration, search duration, number of sets, and sets duration among others) and efficiency indicators aiming at characterizing interannual and interdecadal variability.

The time series analysis shows that, during the last decade the trips duration increased in about 1, 4 (± 0,05), greatly influenced by the technological development of the fleet, which allows a greater autonomy in searching for the fish and expanding their fishing areas. The sets duration had in a first period a direct relationship with the fishing master's experience, decreasing afterwards by the use of new detection and operating technologies. During the ENSO events, the fishing vessels changed their strategies, by increasing the searching time in more than 100%, because of the decline of the anchovy biomass (Fig.1). With regard to the time of fishing, during the 70's it was centered on 9:00 – 9:30, while nowadays the time of fishing is earlier. This may be explained by: a) the better knowledge of the fishermen about the hour when the anchovy form the larger aggregations, getting to the fishing ground as early then can to perform more sets while the fish is aggregated, and b) the implementation of modern fishing equipments. Multivariate analysis, performed on several fishing efficiency variables, allowed to identify significant differences in the fleet behaviour in time according to the effective effort and characteristics of the vessels.

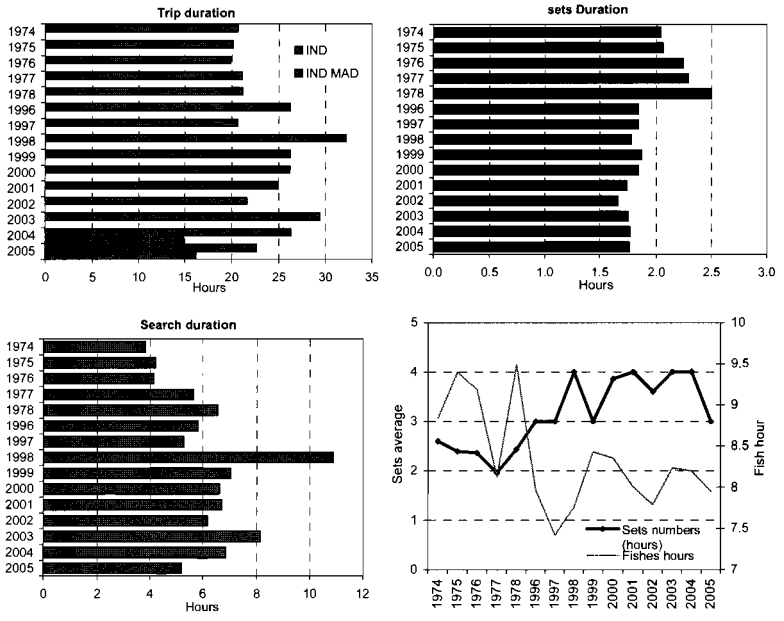

Fig. 1 Temporal changes in different fishing effort measurements of the Peruvian purse seine fleet.

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HCS217 - Conservation ecology of Galapagos rocky shores in the face of human disturbance and climate change

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Keywords: Bottom-up, climate change, Galapagos rocky shores, ENSO, marine iguanas, top down

The Galapagos rocky shores harbour some of the most remarkable ecological and evolutionary treasures of the planet, including marine iguanas, penguins and flightless cormorants. However, the unique endemic flora and fauna of the Archipelago are under severe natural and anthropogenic threats. In spite of its uniqueness we understand very little about the forces that shape the diversity of this system. Here I report on a series of manipulative experiments to investigate the role of consumers (top-down effects) and productivity (bottom-u effects) on the maintenance and diversity of algal communities. Marine iguanas, fish

and crabs had important herbiovory (top-down) effects by reducing the diversity of algae to few grazing resistant forms. However, the effect of consumers was time dependent and accounted for less that 5% of the variability observed in the system. More important effects were associated with El Niño event of 1997-1998. Low levels of nutrients and high temperatures reduced primary productivity and facilitated the invasion of a species of brown filamentous algae that replaced edible species of algae, including *Ulva* sp. and filamentous red algae. At this time high mortality of marine iguanas and other marine organisms were observed. In the aftermath of El Niño and subsequent la Niña low temperature and high nutrient levels promoting algal growth and the recovery of marine iguana populations. Further experiments at sites that experience different levels of productivity suggest that the system is strongly influenced by bottom-up effects. My results provide new insights into the function of tropical rocky shores and the likely consequences of climate change on this unique system.

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HCS218 - Integrating age-structured and ecosystem-based approaches for the management of the Monterey sardine, *Sardinops caeruleus*, fishery in the Gulf of California, Mexico.

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The sardine (*Sardinops caeruleus*) fishery is one of the most important fish activities within the Gulf of California. Fishery management has been based on single stock models, through actions such as fishing premises control, a minimum legal size and a close season; all of them aimed to control fishing rates to avoid growth and recruitment overfishing. Integration of single stock and ecosystem based approaches for management purposes is recognized as one of the necessary steps towards a sustainable use of marine fish stocks. In this contribution our analysis is based on 20 fishing seasons. Management scenarios of a single age-structured model that considers age-dependent natural mortality and catchability variations with age, stock size, and time, are integrated with scenarios from an ecosystem trophic model that incorporates a number of functional groups, forcing factors and interaction between fleets. Age-structured model provides information about variable fishing rates, vulnerability to fishing, stock size and their patterns of variation for sardine stocks. Based on the ecosystem-based approach and the age-structured analysis we explore management scenarios under the framework of viability analysis, where we identified, previous to simulations, viable management scenarios based on the current state of exploitation of the main fish stocks, assuming fleets control and considering economic, social and ecological-ecosystem criteria. Management scenarios are analyzed for the complete period of time as well as by sub-periods defined by the fluctuating environment-biomass dynamics.

HCS188 - Remotely - driven temporal variations of the subsurface dissolved oxygen content and responses of the continental shelf benthic subsystem off Central Peru

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Keywords: Remote forcing, Peru margin, benthic communities, oxycline, OMZ

The upwelling system off the central Peruvian coast (8 – 14° S) is characterized by a higher biological production and a thicker and more intense oxygen minimum zone (OMZ) than other latitudinal areas of the system. The combined high export production and water-mass oxygen deficiency results on very low subsurface oxygen contents near the coast and on chemically reducing sedimentary conditions. Consequently sublittoral macrofaunal populations can only develop if sustained oxygenation occurs, allowing succesful recruitment and survival in the sediment surface. In addition suboxic sediment conditions and high nitrate contents near the bottom are favourable for the development of mats of the large nitrate-reducing and sulphide-oxidising bacteria *Thioploca* spp., while oxic or totally anoxic conditions are unfavourable for these species. Since oxygenation events or anoxic periods are key for the behavior of the benthic subsystem, in this research we aim: i) to analyze the time variability of the coastal subsurface oxygen content off central Peru in relation to remote (equatorial) oceanographic anomalies; and ii) to analyze the coupling, sign and duration of biomass and/or diversity responses of the macrobenthic fauna and macrobiotic bacteria (*Thioploca*) to temporal changes in the oxygen regime.

Methods- We analyzed monthly time-series from an oceanographic station located at 94 m depth (12°02.8' S, 077°17.1' W), 10 miles off Callao, central Peru. Temperature, salinity and dissolved oxygen were determined at standard depths. Macrobenthos (> 0.5 mm) was sampled using a 0.04 m^2 Van Veen grab. Biomasses of macrofauna and *Thioploca* spp. were determined as wet weight. 'Mats' of *Thioploca* are defined as wet biomass (trichomes + sheaths) values higher than 30 g m^{-2}. We used linear interpolations to extract the depths of the iso-oxygens 1 ml L^{-1} and 0.5 ml L^{-1} and of the isopycnals σ_t =26 kg m^{-3} and σ_t =26.5 kg m^{-3}.The 5-day averaged and monthly time-series of the dynamic height at 95ºW on the equator (TAO project buoy, http://www.pmel.noaa.gov/tao) were employed to track the propagation of sea level anomalies (associated with equatorial Kelvin waves) and their impact on the local water column conditions. For coastal winds we analyzed a high-frequency time-series from Chucuito, Callao within the period 1995 – 1997 (source: Dirección de Hidrografía Naval del Perú, DHN), from which weekly and monthly upwelling indexes were computed. We computed cross correlations between the local and remote variables.

Results and Discussion- The oceanographic time-series record clearly the impact of the extreme 1997-98 El Niño (EN) that deepened the oxycline/OMZ and the vertical density structure in general (Figs. 1a, 1b). It also records the 1998 – 2000 La Niña (LN) and the subsequent neutral ENSO years until 2002, characterized by shallow positions of the pycnocline and oxycline. This period was also characterized by a stronger seasonality of the subsurface dissolved oxygen, which was minimal during summer/early autumm periods. During the warmer period 2002-2003, the oxycline was moderately deepened and showed a high variability. The correlation between the 95ºW equatorial dynamic height and the subsurface (≥ 50 m) density and dissolved oxygen, and with the analyzed isopycnal and iso-oxygen depths was significant ($p<0.001$) with a one-month lag. The lag period is consistent with the poleward propagation of coastal trapped waves, that are forced by the impinging of Kelvin waves on the coast (Ulloa et al., 2001).The variance unexplained by this relationship was higher for the subsurface dissolved oxygen (52 – 56%) than for density (28 – 34%). Similarly, the portion of unexplained variance was higher (~ 57%) for the iso-oxygen depths than for the isopycnal depths (~ 40%). The difference arises from the role of local processes (as coastal upwelling, local surface circulation, particle export and respiration) in the modulation of the subsurface dissolved oxygen content, especially during periods of low or intermediate equatorial sea level. An example occurred in February 1997 (Figs. 1e, 1f), when the oxycline reached near to the surface (< 20 m). The intense hypoxia near the surface was possibly due to the parallel intensification of coastal upwelling, disturbing the response of the coastal environment to the remote forcing.

On the other hand, the benthic time-series exhibited interannual variability triggered by the changes in the subsurface oxygen regime (Figs. 1c, 1d). Three different states were identified during the study:

I) A macrofaunal biomass dominance over *Thioploca* spp. This state was triggered after the first 1997 – 98 EN coastal trapped wave reached Callao and continued until 1999. It is explained by the oxic environment that predominated during the 1997-98 EN (O_2 values up to 3.2 mL L^{-1} near the bottom), which was unfavourable for *Thioploca*. The prolonged survival of macrofauna after the end of EN and during part of the 1998 – 2000 LN can be explained by the colonization of bioturbating species that contributed to oxidise the surface sediment even with very low oxygen concentrations (Gutiérrez et al., 2002). In turn, the abrupt switch to LN conditions resulted on severe subsurface hypoxia, in which nitrate availability was reduced by denitrification (Graco et al., submitted), not allowing a succesful colonization of *Thioploca*.

II) Parallel defaunation and nearly absence of mats (e.g. 1999 – 2000, 2004 – 2005). This state occurred during a period with a lower energy of positive sealevel anomalies at 95ºW, that resulted on a sustained development of strong hypoxia (O_2 values: 0.0 – 0.3 mL L^{-1} near the bottom) and lower nitrate availability in the water column off Callao, possibly due to the intensified coastal upwelling and denitrification, such as during the 1998 – 2000 LN.

III) Well-developed *Thioploca* mats that dominated the macrobiotic biomass (2002 – 2003). A coastal trapped wave reached Callao at mid-2000, resulting on a moderate oxygenation of the water column that was associated to an increase of the subsurface nitrate content. This event allowed the bottom colonization by *Thioploca*, which by the 2002 – 2003 period had fully developed in mats. During these two years, the conditions were characterized by a moderately deep oxycline and average high nitrate contents in the bottom waters, but still hypoxic conditions near the bottom (O_2 values: 0.1 – 0.6 mL L^{-1}) limiting the macrofaunal colonization.

Our results highlight the importance of timing, intensity and duration of oxygenation or hypoxic events for the following development of the benthic macrobiota. In this regard, remote forcing is the main factor controlling the oxygen regime in the coastal environment off central Peru, which in turn, is the master variable for the benthos. However, local physical, biological and biogeochemical processes can disturb or amplify the remotely-driven signal, influencing on the benthic response.

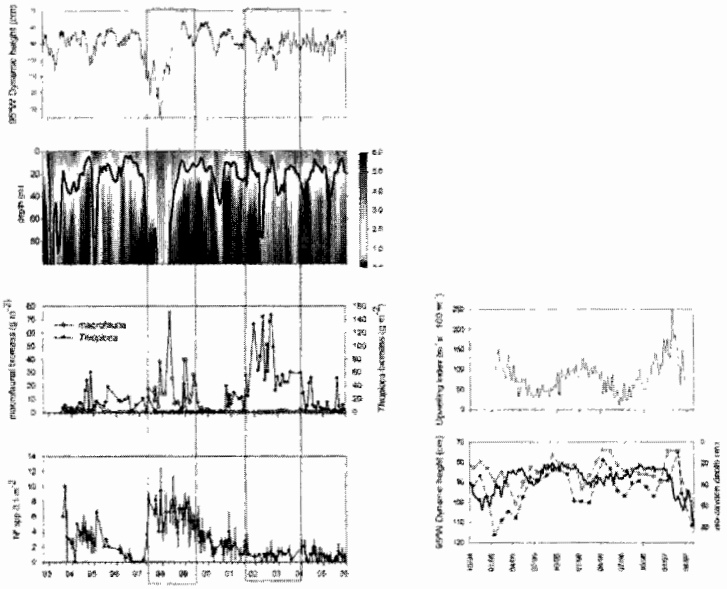

Figure 1. Time-series of equatorial sea level at 95°W and oceanographic and benthic variables off Callao (12°S): a) 5-day averaged ecuatorial Dynamic Height (DH) at 95°W (scale reversed); b) Temporal variability of dissolved oxygen (coloured) and of the 26 kg m^{-3} isopycnal depth (black line); c) Biomasses of Thioploca spp and macrofauna; d) Macrofaunal species richness (error bars = 1 SD); e) Weekly upwelling index from coastal wind records (Chucuito; 1994 – 1997; f) 5-day averaged DH (black, scale reversed), and 3-month running mean (1-2-1) of the 0.5 mL L^{-1} (blue) and 1.0 mL L^{-1} iso-oxygen depths (1994 – 1997). Red and green boxes envelope the periods of macrofaunal-dominated and Thioploca-dominated benthic states.

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