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Small Pelagic Fishes And Climate Change Programme

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Report of a GLOBEC-SPACC/ IDYLE/ ENVIFISH Workshop on Spatial Approaches to the Dynamics of Coastal Pelagic Resources and their Environment in Upwelling Areas
(6 - 8 September 2001, Cape Town, South Africa)

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It is co-sponsored by the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC).

PREFACE

This report documents a meeting held by the SPACC/IDYLE/ENVIFISH Working Group entitled "Spatial Approaches to the Dynamics of Coastal Pelagic Resources and their Environment in Upwelling Areas". The meeting was hosted by Marine and Coastal Management, Department of Environmental Affairs and Tourism, and was held in Cape Town from 6 -8th September 2001. The meeting was aimed at synthesizing the state of the art concerning recent theoretical achievements, analysis techniques and modelling tools used for the integration of spatial structures in the study of the dynamics of marine populations and their environments. Meeting convenors were P. Fréon, C. Roy, M. Barange, C. Van der Lingen, L. Nykjaer, F. Shillington, L. Castro and M. Gutierrez, and meeting sponsors were GLOBEC International, IRD, JRC, MCM, UCT, and SCOR. This document should be cited as:

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LIST OF ACRONYMS

BCLME	Benguela Current Large Marine Ecosystem.
BENEFIT	Benguela Environment Fisheries Interactions and Training.
BEP	Benguela Ecology Programme.
CICIMAR	Centro Interdisciplinario de Ciencias Marinas, La Paz, Mexico.
ENVIFISH	Environmental Conditions and Fluctuations in Recruitment and Distribution of Small Pelagic Fish Stocks.
FAO	Food and Agricultural Organisation of the United Nations.
GLOBEC	Global Ocean Ecosystem Dynamics.
ICES	International Council for the Exploration of the Sea.
IDYLE	Interactions and Spatial Dynamics of Renewable Resources in Upwelling Ecosystems.
IFOP	Instituto de Fomento Pesquero, Valparaíso, Chile.
IIM	Instituto de Investigaçao Marinha, Luanda, Angola.
IMARPE	Instituto del Mar del Perú.
IMR	Institute of Marine Research, Bergen, Norway.
IOC	International Oceanographic Commission.
IPIMAR	Instituto de Investigação das Pescas e do Mar, Lisboa, Portugal.
IRD	Institut de Recherche pour le Développement, Paris, France.
JRC	Joint Research Centre, Ispra, Italy.
MCM	Marine and Coastal Management, Cape Town, South Africa.
MFMR	Ministry of Fisheries and Marine Resources, Swakopmund, Namibia.
NORAD	Norwegian Agency for Development Cooperation, Bergen, Norway.
PML	Plymouth Marine Laboratory, Plymouth, UK.
SCOR	Scientific Committee on Oceanic Research.
SPACC	Small Pelagic Fishes and Climate Change Programme.
UC	Universidad de Concepción, Concepción, Chile.
UCV	Universidad Católica de Valparaiso, Valparaiso, Chile.
UCT	University of Cape Town, Cape Town, South Africa.
UNESCO	United Nations Education, Scientific and Cultural Organisation.

COLOR PLATE LEGENDS

Plate 1. An example of the surface structure of the temperature and currents (arrows) in the Southern Benguela region simulated by the medium-resolution configuration of the 3D hydrodynamic model. This snapshot of the surface structure on the 1st September of the second year of the simulation shows the main oceanographic features of the region, including the warm and intense Agulhas Current flowing westward in the southern part of the domain, and coastal upwelling off the West Coast. Upwelling filaments off the West Coast, a shear-edge eddy on the eastern part of the Agulhas Bank, and eddy shedding in the vicinity of the Cape Peninsula, are examples of the mesoscale activity simulated by the model. See contribution by Roy *et al.* "A regional hydrodynamic model of the Southern Benguela upwelling" for details.

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ABSTRACT

A SPACC/IDYLE/ENVIFISH Working Group meeting on the incorporation of spatial approaches to the dynamics of marine populations and the environment was held in Cape Town, South Africa, over the 6th-8th September 2001. The aim of the meeting was to provide a synthesis of the state-of-the-art concerning recent theoretical achievements, analysis techniques, and modeling tools used for the integration of spatial structures in the study of the dynamics of coastal pelagic resources and their environment in upwelling areas. Fifty-five scientists from fifteen countries participated in the meeting and whilst many presentations described research from the Benguela and Humboldt current systems, the Canary and California current systems were also represented as was research from the Bay of Biscay and the Iberian Peninsula.

Three scientific topics were selected for the meeting, including quantification and modeling of the spatial dynamic of the environment and the development of new tools and techniques to do this; descriptions of the spatial dynamic of pelagic fish resources and their interactions with the environment; and characterisation of the spatial dynamic of spawning and nursery grounds, the coupling between spawning and the environment and linkages between recruitment and the environment. To address these topics, the meeting was divided into four sessions, with the first three sessions comprising presentations and the last a general discussion and synthesis session. The use of tools such as satellite-derived data, 3D hydrodynamic models, artificial neural networks and self-organising maps (SOMs), individual-based models (IBMs), generalized additive models (GAMs) and general linear models (GLMs) in quantifying and describing spatial aspects of pelagic resources and the environment were described. Descriptions of the spatial and temporal distributions of several small pelagic fish species, and the effects of different biomass levels or environmental conditions on their distribution were also presented. This report contains extended abstracts, including figures and tables, from presentations made during the first three sessions, and a summary of the major points arising from the discussion and synthesis session.

ACKNOWLEDGEMENTS

The convenors and editors would like to extend their appreciation and thanks to Ms M. Terry, Ms D. Merkle (both MCM) and Ms L. Elley (UCT) for their assistance in matters organisational and secretarial both before and after the meeting. Messrs D. Horstman and A. Busby are thanked for their help and hospitality at the Research Aquarium. Funding from GLOBEC, JRC, IRD, MCM, SCOR and UCT is warmly acknowledged.

INTRODUCTION

The value of spatially-explicit information in increasing understanding of the dynamics of marine populations and their environment has long been recognised, since all environmental data has a spatial component and fish populations are very rarely, if ever, distributed randomly. Whilst recognition of the importance of spatial information has been implicit in many cases, it is only recently that understanding the interactions between heterogeneously distributed fish populations and their environment has been identified as a key point for fisheries management. This realisation has resulted in several conferences directed towards understanding the spatial processes of fish populations, ecosystems, and the environment. The most recent of these have been the “International Symposium on GIS in Fishery Science” held in Seattle in March 1999 (Nishida *et al.* 2001), and the “Spatial Processes and Management of Fish Populations Symposium” held in Anchorage in October 1999 (Kruse *et al.* 2001).

The “Spatial Approaches to the Dynamics of Coastal Pelagic Resources and their Environment in Upwelling Areas” meeting represents a continuation of this theme but with a narrower focus than the meetings cited above. In the Spatial Approaches meeting emphasis was placed on the integration of spatial structures in the study of small pelagic fish resources in upwelling ecosystems. Since both the ENVIFISH project and the IDYLE programme are involved in the study of the environment and pelagic resources of the Benguela upwelling ecosystem off Southern Africa, many of the presentations were from this region. Additionally, the meeting was intended to foster co-operation and collaboration between researchers from the Benguela and the other major upwelling ecosystem in the southern hemisphere, the Humboldt. Hence there were several presentations from the Humboldt in addition to studies from elsewhere.

ENVIFISH and IDYLE are both affiliated to SPACC and the Spatial Approaches meeting was the first formal gathering under SPACC Theme 3: Reproductive Habitat Dynamics. This new scientific theme groups the activities of the various Process Studies Working Groups of SPACC, including WG6 – Daily growth and zooplankton, WG7 – Spawning habitat quality and dynamics, and WG8 – Spawning habitat dimensions and location (Hunter and Alheit 1997). By using a comparative approach, Reproductive Habitat Dynamics aims to explore how key mesoscale physical processes within the spawning and nursery grounds can affect population growth, and to evaluate the hypothesis that changes in productivity are caused by changes in the dimensions of the spawning habitat as well as its location.

The Spatial Approaches meeting was held from the 6^{th}-8^{th} September 2001, with the first two days comprising scientific presentations and short discussions relating to spatial dynamics of the environment and fish populations from various locations. The third day included updates on regional programmes relevant to SPACC as well as a discussion session in which the future of possible collaborative work between participants from the Benguela and Humboldt systems was explored within a SPACC framework. This report contains the extended abstracts of presentations made at the meeting in addition to a summary of the major points arising from the final discussions.

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An empirical test for the existence of a generation-time-dependent mechanism for the rapid adaptive response of fish populations to variations in ocean climate, predation or fishery exploitation

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Evidence is accumulating that many types of fish populations may change their locations of operation within their ocean habitats, not only in annually-repeated seasonal cycles, but also in an evolving progression over much longer multi-annual time scales. This has extremely important implications for the way that we may view marine resource stock assessment and population dynamics. It might also open opportunities for new ways for conceiving innovative adaptive management actions designed to properly balance fishing and environmental pressures so as to maintain the resource populations within, or return them to, their most productive geographical configurations (Bakun 2001).

The non-stationarities introduced into the system by adaptive feedbacks may invalidate the assumptions of long-term system stationarity that usually underlie conventional empirical analyses of long data series. For example, correlations established between marine environmental and biological time series have been notorious for suddenly breaking down, often immediately after being established. This has led to embarrassment to the researchers involved and a general distrust and distaste of such relationships among fishery scientists. However, in many cases, the breakdown of established correlations might not signify a "scientific failure" in any way, but may be an important clue to the non-stationary dynamics with which our science needs to come to grips. Accepting real system non-stationarities as a fact of life, and addressing those as key ecological issues, seems one logical next step to try in seeking a scientific solution to the overall fish—environment problem.

One potential mechanism for such non-stationarities is the hypothetical 'school-mix feedback' process suggested by Bakun (2001). School-mix feedback could provide a tangible mechanism for:

- Withdrawal of more rapidly responding (due to shorter generation times) mobile prey populations from their slower responding (longer lived) predators;
- Withdrawal of fish populations from sites of major fishery exploitation;
- Coherent movement of fish populations to exploit new opportunities;
- Lagging of major "marine ecosystem regime shift" responses to "climatic regime shifts" of one to several generation times of the major "wasp waist" population; and
- Explosive growth of a wasp waist population along a decadal scale climatic trend (e.g., mid-1970s to mid-1980s).

As one illustration of the powerful implications of such a rapidly acting adaptive mechanism for fishery resource management, Bakun (2001) presented a particular hypothesis for the durable 'regime change' in stock productivity that has characterized the Namibian pilchard (sardine) fishery over the past few decades, where modern management methods (Boyer 1996) have been ineffective in raising the stock abundance and fishery landings to levels much greater than about ten percent of those in the 1960s. According to this hypothesis, an adaptive reaction of the pilchard population to massive fishing pressure in their traditional reproductive habitat may have been to "withdraw" and concentrate spawning in the adult feeding habitat in the zone of the Angola-Benguela Front situated to the north. This suggested a potential management "experiment" of perhaps restricting fishing in the traditional reproductive zone, and concentrating it elsewhere.

However, the idea of the existence of a rapid adaptive mechanism is not part of the current conventional paradigm of fisheries science. Consequently, it is unlikely that a government agency would try such an experiment without some demonstration that such a mechanism may be actually operating. But it is difficult to conceive of a way to produce such a demonstration in any specific marine ecosystem. Nevertheless, it may be possible to test the idea through a comparative retrospective analysis of time-series data from different fish populations from a number of regional marine ecosystems. This could be based on an analysis framework that depends on two concepts. The first is the fact that the ocean-atmosphere system is characterized by a "red noise" variability spectrum (Fig. 1a), where any natural environmental variation tends to be superimposed on other variations of longer time scale and greater amplitude. This, over a number of different regional situations, should provide a good sampling of a rather continuous spectrum of time scales of variability with which to test for the action of a rapid adaptive mechanism.

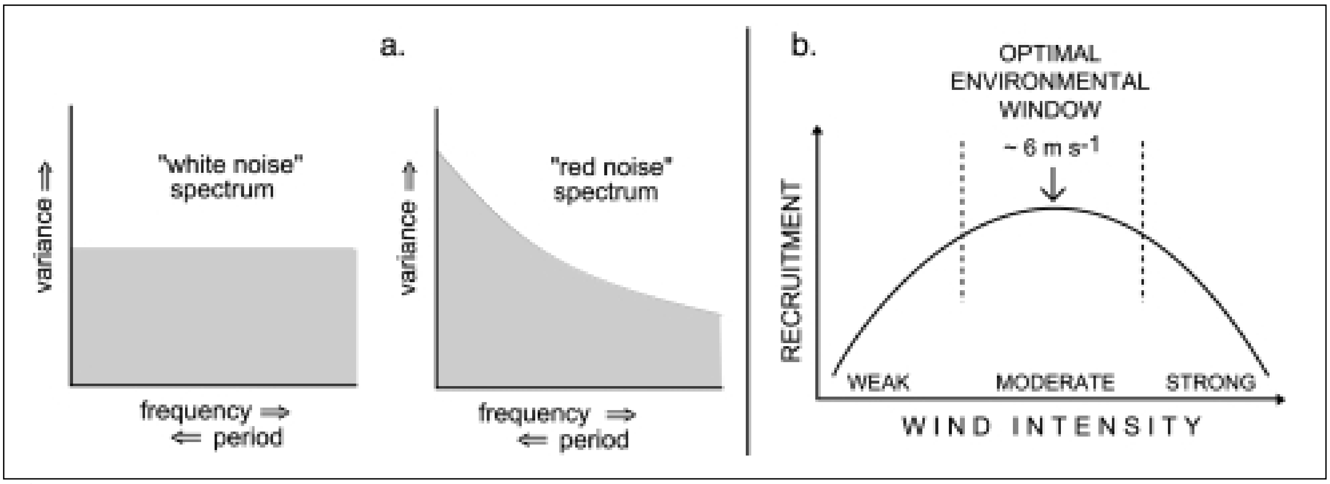

Fig. 1

The second concept is the expectation of an "optimal environmental window (OEW)" (Fig. 1b) type of biological response. That is, in order to maximize the probability of successful reproduction, a fish population would tend to position its spawning in situations where "normal" conditions (*i.e.*, those near the center of the frequency distributions of controlling environmental variables) will correspond to the conditions most conducive to reproductive success (and where less frequent anomalous extremes would tend to be correspondingly less conducive to reproductive success). Note that while Cury and Roy (1989), and the associated follow-on studies (*e.g.*, see Durand *et al.* 1998), used nonlinear statistical methods to establish their famous OEW result, a similar test could be performed by employing more easily applied and interpreted linear statistical methods, by simply transforming the independent variable series to anomaly series, and then using the absolute values of the anomalies rather than the actual (positive or negative) anomaly value.

The actual empirical analysis would proceed as follows:

- Select controlling independent variables by performing a "climatological analysis" of the ecological system (characteristic biological behaviours and associations versus characteristic seasonality and geography of environmental processes) employing various pattern recognition methodologies such as GIS, coupled hydrodynamic/IBM modeling, etc;
- Construct time-series indicators of variability in these controlling environmental processes;
- Assume the response of reproductive success to controlling variables is of a nonlinear "optimal window"-type (*e.g.*, linear response to absolute value of anomalies);
- Construct a set of time series of anomalies from a range on different band-passed filterings of the raw time series. Transform this into a series of absolute values of anomaly magnitudes by changing the signs of negative values to positive;
- Perform a corresponding set of empirical tests to identify the "best fit" adaptive time scale;

- Repeat the previous five steps for a large number of different fish/environment systems; and
- Identify informative patterns in the "best fit" adaptive time scales with respect to species type, generational time scale, etc. (For example, a significant positive relationship found between inferred adaptive time scales and characteristic generational time scales for the given species may be considered evidence of the operation of an adaptive mechanism similar to the school-mix feedback type.)

Note that this approach is not expected to be useful in constructing explicit predictive relationships in specific regional situations. The increased range of choices of explanatory variables represented by the different filterings of the anomaly series only increases the already overwhelming problem of spurious relationships. It is only the global comparative process that will be useful in providing the understanding that will lead to specific predictive capability.

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Figure Legends

Figure 1. (a) A "white noise" spectrum where variance is spread rather evenly over the frequency range (left), and a "red noise" spectrum characterizing non-seasonal variability in the coupled ocean-atmosphere system (right). (b) The optimal environmental window (Cury and Roy 1989) where reproductive success (recruitment) is highest at an intermediate wind intensity level and declines at both higher and lower intensity levels.

A REGIONAL HYDRODYNAMIC MODEL OF THE SOUTHERN BENGUELA UPWELLING

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To explore the environmental processes affecting fish recruitment in the Southern Benguela, an eddy resolving, coastal hydrodynamic model has been implemented in order to simulate the circulation over the main spawning and nursery grounds. Within the wide range of numerical models available, we selected the Regional Ocean Model System (ROMS). ROMS is a community model shared by a large user group and developed at Rutgers University and the University of California Los Angeles (Haidvogel *et al.* 2000).

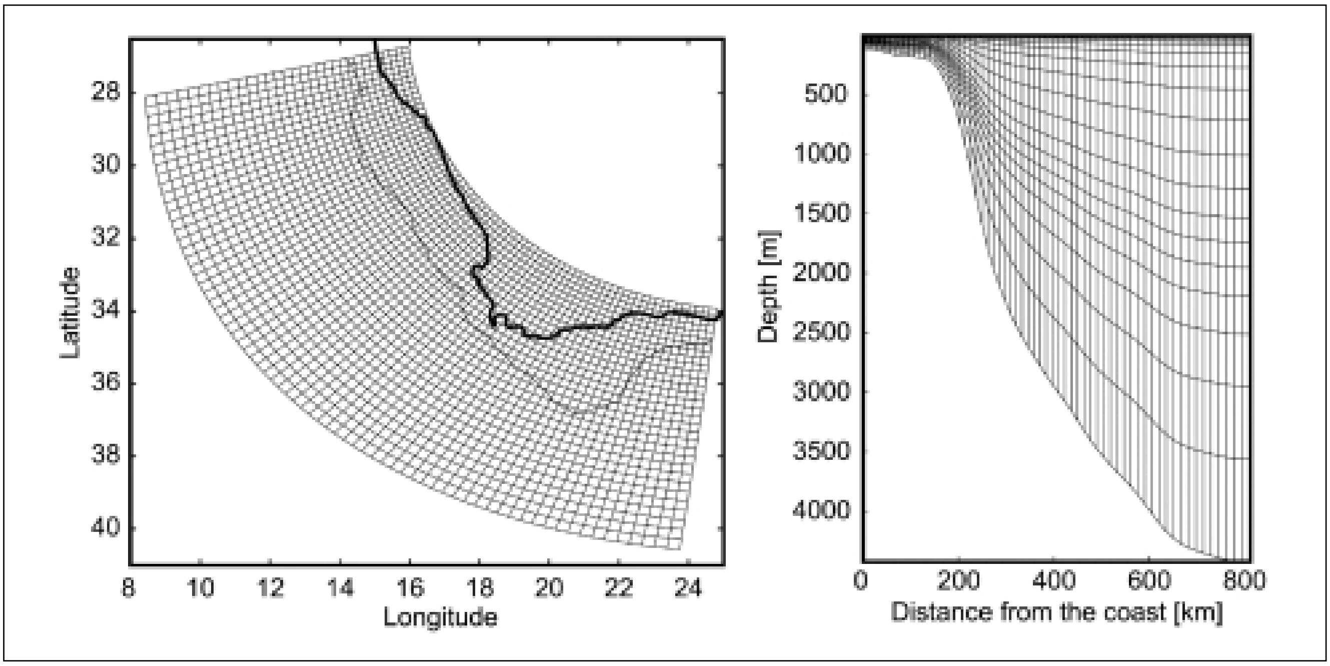

Fig. 1

ROMS incorporates advanced features allowing the efficient resolution of mesoscale dynamics. ROMS solves the free surface, hydrostatic, primitive equations of the fluid dynamics over variable topography using stretched, terrain-following coordinates in the vertical plane, and orthogonal curvilinear coordinates in the horizontal plane. Active open boundaries, connecting the regional model with the open ocean, are implemented (Marchesiello *et al.* 2001). A pie-shaped grid that follows the south-western corner of the African continent from 40°S to 28°S and from 10°E to 24°E was developed. The topography is derived from the ETPO2 database, and both a low-resolution and a medium-resolution grid are implemented (Fig. 1). Along the vertical plane, the twenty levels provide enhanced resolution at the surface while preserving an adequate resolution in the deeper layers. The model is forced with winds, heat and salinity fluxes extracted from the COADS ocean surface monthly climatology (Da Silva *et al.* 1994). At the three lateral boundaries, an implicit radiative boundary scheme, forced by a seasonal climatology computed from the AGAPE basin scale ocean model (Biastoch and Krauss, 1999), connects the model to the surroundings.

The highly energetic and meandering Agulhas Current flowing westward in the south-east corner of the domain necessitates the implementation of a specific open boundary scheme.

The medium-resolution configuration has a resolution varying from 9km at the coast to 18km offshore. Having a realistic topography, this configuration should adequately resolve the topographically-controlled features over the continental shelf. A high level of mesoscale activity is observed during a 10-year simulation, including the generation of Agulhas rings, and the shedding of cyclonic eddies starting from the southern tip of the Agulhas Bank, the Cape Peninsula and Cape Columbine (Plate 1). Off the West Coast, the upwelling front shows an important variability, developing a series of meanders, plumes and filaments in a realistic manner. In the southern part of the model domain, the cyclonic eddies that appear in the simulations in the lee of the Agulhas Bank are in agreement with observed features (Penven *et al.* 2001). The main discrepancy appears off the West Coast region during summer, where simulated SSTs are significantly lower than observed SSTs from satellites. In the monthly climatology used to force the model, the high frequency variability (from days to weeks) of the wind is smoothed out. This results in a continuous and persistent upwelling-favorable wind forcing, in contrast to the characteristic pulsing pattern of the local southeasterly wind, which results in a succession of relaxed and enhanced upwelling. It is thought that both the low temporal and spatial resolution of the climatological wind used to force the model contribute to intensify the input of cold water over the continental shelf in our simulations.

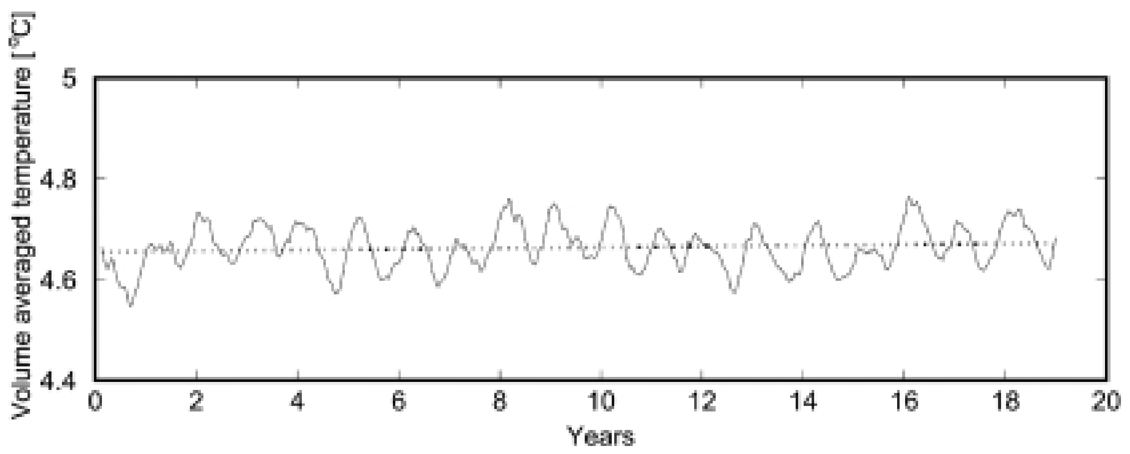

Fig. 2

Although the model is forced by repeated climatology, there are pronounced differences in the simulation outputs between individual years (*e.g.* the thermal structure and current fields of year 4 are significantly different from those of year 3; Fig. 2). The intense mesoscale activity is the main contributor to this inter-year variability (Penven 2000). This indicates that local, intrinsic oceanic instability processes are able to produce variations in the dynamics in the absence of added, forced variability by synoptic and inter-annual atmospheric fluctuations. How the inter-year variability observed in the model outputs compares to the inter-annual variability resulting from contrasted atmospheric forcing (such as a relaxed or intensified southeasterly wind regime) is still an open question.
Analysis of the 10 year model run is currently being carried further by focusing on the structure and variability of the West Coast upwelling, and on shear edge features along the Agulhas Bank. New experiments are in progress to investigate the response of the Peninsula jet and of the West Coast upwelling to high frequency wind forcing, as well as to an abrupt relaxation of the upwelling-favorable wind. This latter experiment is aimed at simulating the relaxation of the wind observed in December 1999, and investigating its impact on the successful transport of anchovy eggs and larvae to the West Coast nursery grounds (Roy *et al.* 2001).

Acknowledgements

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Figure Legends

Figure 1. The low-resolution horizontal (left) and vertical (right) grids used in the regional configuration of ROMS in the Southern Benguela.

Figure 2. Twenty year time-series of volume-averaged temperature using the low-resolution configuration.

PREDICTING THE SHAPE OF CHLOROPHYLL PROFILES USING SOME NOVEL QUANTITATIVE APPROACHES

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Introduction

Information on the vertical chlorophyll structure is important not only for estimating integrated chlorophyll, but also as input to analytical models of primary production which require depth-dependent chlorophyll values for estimating global primary production from satellite data. To estimate global primary production, Longhurst *et al.* (1995) and Sathyendranath *et al.* (1995) partitioned the ocean into four primary domains, which were further subdivided into 57 secondary biogeochemical provinces with each province characterized by a single seasonal profile. One province within the coastal domain is the Benguela Current Coastal province, which includes the Benguela upwelling region.

The aim of this study was to characterize and parameterize the shape of chlorophyll profiles of the southern Benguela upwelling region and the Agulhas Bank. A type of a neural network called the self-organizing map (SOM), which is a semi-quantitative technique, was used to highlight variability in vertical chlorophyll structure. Other novel quantitative techniques such as generalized additive and generalized linear models (GAM and GLM) were also used to model and predict the shape of chlorophyll profiles from environmental information. The temporal and spatial variability of parameterized chlorophyll profiles in relation to a range of environmental parameters (*e.g.* sea surface temperature, surface chlorophyll concentration and water column depth) was then investigated. Finally, this study aimed to predict chlorophyll profile shape from pertinent environmental parameters that are known or can be easily measured (*i.e.* from satellites). The methodology outlined in this study will allow improved regional primary production estimates in the Agulhas Bank and Benguela upwelling system.

Data

Vertical chlorophyll profiles were collected during research cruises off the west and south coasts of South Africa. The analysis was restricted to shelf waters (depth <300 m). A shifted Gaussian curve was fitted to each profile to estimate four parameters that defined the shape of the curve: the background chlorophyll concentration (B_0), the total chlorophyll concentration beneath the curve (h), the width of the peak (σ) and the depth of the chlorophyll maximum (z_m). This four-parameter function is expressed as (Platt *et al.* 1988, Platt and Sathyendranath 1995):

$$B(z) = B_0 + \frac{h}{\sigma\sqrt{2\pi}} e^{-\frac{(z-z_m)^2}{2\sigma^2}}$$

Identifying characteristic profiles

Profile parameters from the shifted Gaussian curve were used to characterize chlorophyll profiles in the SOM analysis. A 6x4 SOM was chosen, which managed to summarize the data and still capture sufficient detail of *in situ* chlorophyll profiles (Fig. 1). Patterns changed from low subsurface chlorophyll concentrations (~1 mg.m^{-3}) at the bottom left of the map to high surface chlorophyll concentrations (>10 mg.m^{-3}) at the top right of the map. The width of the peak also changed across the map, with narrower near-surface maxima situated at the top left corner and broader deeper chlorophyll maxima at the bottom right corner of the map. Total chlorophyll concentration within the peak increased from a minimum at the bottom left to a maximum at the top right corner, and the background chlorophyll concentration decreased from a maximum (1.4 mg.m^{-3}) at the top left to a minimum (0.1 mg.m^{-3}) at the bottom right part of the

SOM. The SOM technique produced a continuum of patterns in all directions of the SOM output, with every pattern representing profiles from input data with no discontinuities in profile parameter values. The analysis highlights the variability in chlorophyll profiles across all directions of the map.

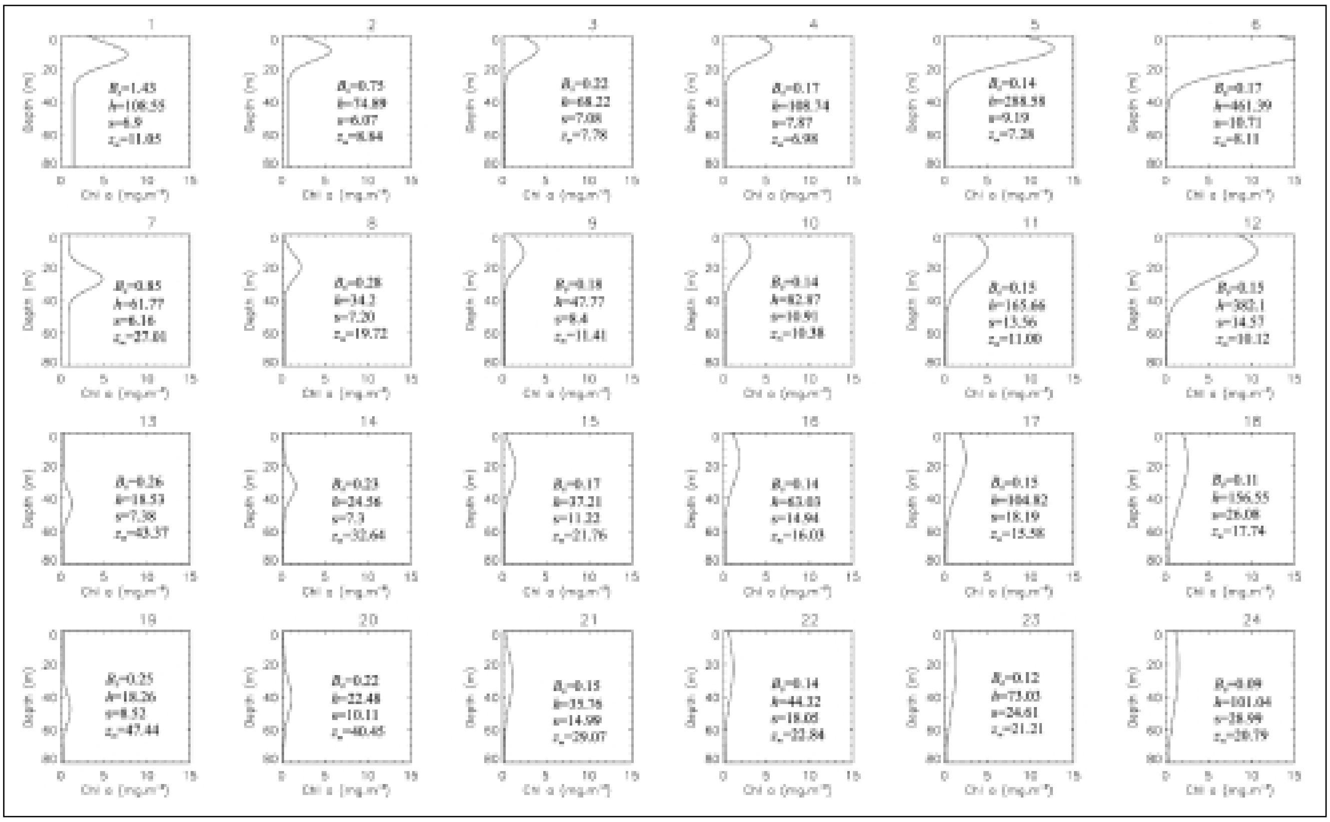

Fig. 1

The phytoplankton pigment structure varies on the Agulhas Bank and West Coast regions during different seasons, as well as under different environmental conditions. Therefore, changes in the shape of chlorophyll profiles at these regional and seasonal scales, and variability in phytoplankton biomass structure in different environmental categories was investigated. Variability in chlorophyll patterns in these two sub-regions and seasons (autumn, spring and summer) was highlighted by the SOM analysis. The West Coast was characterized by large surface chlorophyll maxima, whereas the Agulhas Bank had a mixture of chlorophyll profile shapes. A mixture of chlorophyll profiles with near-surface and subsurface maxima were common in spring, with summer having two different patterns; surface and deep chlorophyll peaks. Phytoplankton biomass structure differed with environmental conditions; large surface peaks dominated newly upwelled waters with cool SSTs and high surface chlorophyll concentrations inshore, whilst chlorophyll maxima shifted to subsurface layers in offshore waters characterized by warm SSTs and low chlorophyll concentrations at the surface.

Predicting profile shape

Separate GAMs were constructed for each profile parameter. Chlorophyll peak width and total chlorophyll concentration beneath the curve were log and square-root transformed respectively to improve normality and homoscedasticity when developing models. The form of the relationship between each profile parameter and environmental variables was identified visually from GAM plots, and then used to develop predictive equations through the development of GLMs. A number of parametric relationships including piecewise linear regression, quadratic, log and exponential fits were used in GLM development, with significant environmental variables only from the GAM being included in the GLM. Predictive equations for each profile parameter are given in Table 1, and the GLM for depth of the chlorophyll maximum (z_m) is shown in Figure 2. Correlations between observed parameters from the shifted Gaussian curve and predicted parameter values from GLM equations were significant for total chlorophyll concentration beneath the curve (h; r^2=43%) and depth of the chlorophyll maximum (z_m; r^2=61%), but weak or not significant for the other two parameters.

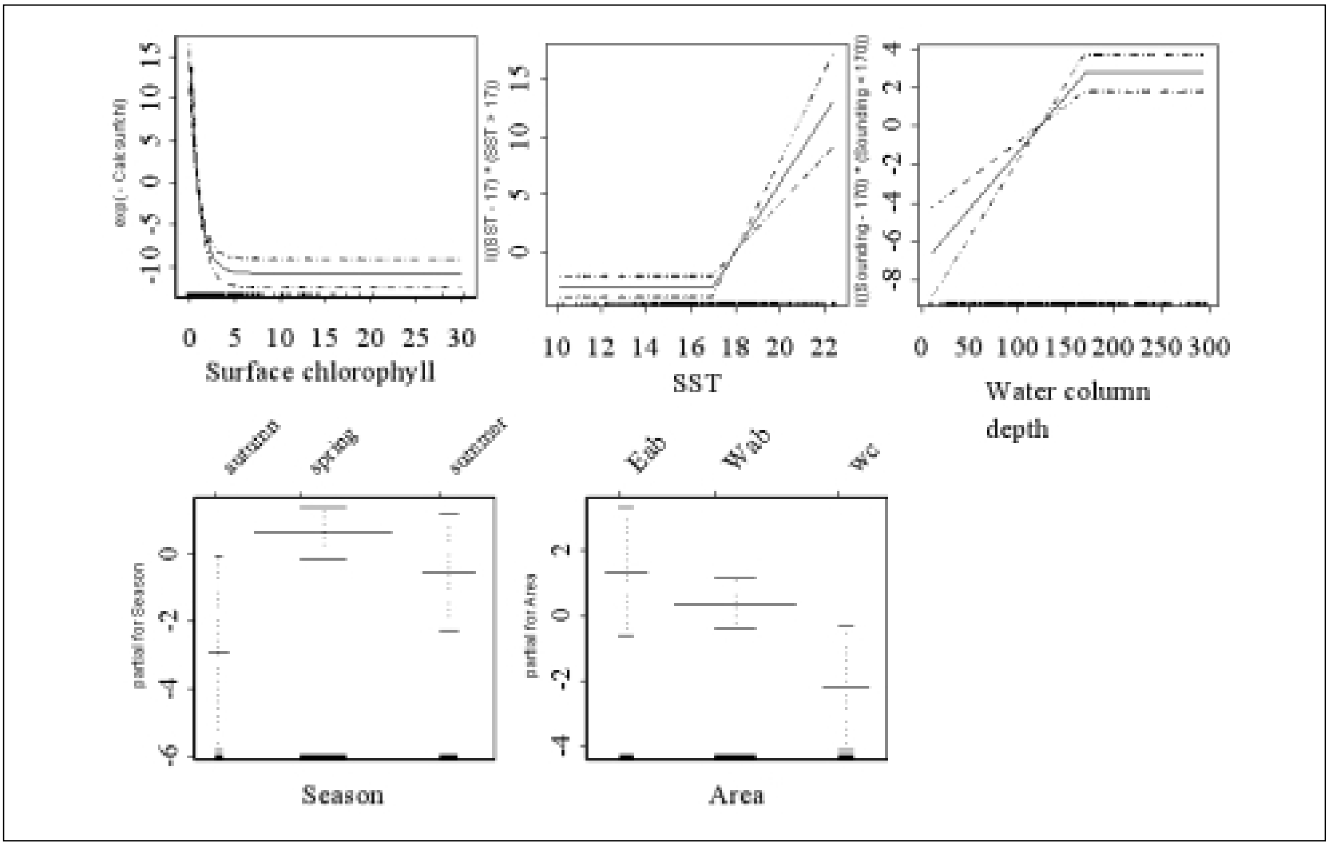

Fig. 2

The results from this study have highlighted variability in phytoplankton biomass structure in the Agulhas Bank and southern Benguela. This suggests that an ideal typical profile, as used in the framework of biogeochemical provinces, may not be applicable to this dynamic upwelling system. In addition, only h and z_m profile parameters have been successfully predicted from environmental parameters. This study forms part of an ongoing project to predict profile shapes from satellite measured SST and surface chlorophyll in an attempt to improve regional estimates of the Benguela Current primary production from satellites. Moreover, the methodology outlined in this study provides a framework that can be used for estimating subsurface chlorophyll structure in other coastal domains and biogeochemical provinces.

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Table 1. Predictive equations from the generalized linear models for the shifted Gaussian parameters. The proportion of the variance explained (r2) in linear modelling of each profile parameter is also included. B0 = background chlorophyll concentration; s = width of the peak; h = total chlorophyll concentration beneath the peak; zm = depth of the chlorophyll maximum; Dep = depth of the water column; Chl = surface chlorophyll concentration; Aut = autumn; Spr = spring; Sum = summer; EAB = eastern Agulhas Bank; WAB = western Agulhas Bank, WCO = west coast; and SST = sea surface temperature.

$B_0 = 0.163 - 0.0068 \times \left\{ \begin{matrix} (Dep - 90) & , \text{if } Dep < 90 \\ 0 & , \text{if } Dep > 90 \end{matrix} \right\} + 0.064 \times \left\{ \begin{matrix} 0 & , \text{if } Chl < 10 \\ (Chl - 10) & , \text{if } Chl > 10 \end{matrix} \right\}$ r^2~15%
$\log\sigma = 2.51 + 0.005 \times \left\{ \begin{matrix} 0 & , \text{if } Dep < 170 \\ (Dep - 170) & , \text{if } Dep > 170 \end{matrix} \right\} + \left\{ \begin{matrix} 0 & , Aut \\ 0.557 & , Spr \\ 0.216 & , Sum \end{matrix} \right\} - 0.038 \times (Chl - 3) + \left\{ \begin{matrix} 0 & , EAB \\ 0.031 & , WAB \\ -0.147 & , WCO \end{matrix} \right\}$ r^2~21%
$\sqrt{h} = 27.73 + 1.020 \times \left\{ \begin{matrix} (Chl - 20) & , \text{if } Chl < 20 \\ 0 & , \text{if } Chl > 20 \end{matrix} \right\} + 0.024 \times \left\{ \begin{matrix} (Dep - 140) & , \text{if } Dep < 140 \\ 0 & \text{if } Dep > 140 \end{matrix} \right\} + \left\{ \begin{matrix} 0 & , Aut \\ 0.524 & , Spr \\ 2.085 & , Sum \end{matrix} \right\} - 0.629 \times \left\{ \begin{matrix} 0 & , \text{if } SST < 15 \\ (SST - 15) & \text{if } SST > 15 \end{matrix} \right\}$ r^2~74%
$z_m = 7.487 + 25.33 \times e^{-Chl} + 2.975 \times \left\{ \begin{matrix} 0 & , \text{if } SST < 17 \\ (SST - 17) & \text{if } SST > 17 \end{matrix} \right\} + 0.059 \times \left\{ \begin{matrix} 0 & , \text{if } Dep < 170 \\ (Dep - 170) & , \text{if } Dep > 170 \end{matrix} \right\} + \left\{ \begin{matrix} 0 & , Aut \\ 3.573 & , Spr \\ 2.416 & , Sum \end{matrix} \right\} + \left\{ \begin{matrix} 0 & , EAB \\ -0.994 & , WAB \\ -3.571 & , WCO \end{matrix} \right\}$ r^2~70%

Figure Legends

Figure 1. A 6x4 self-organising map showing the characteristic vertical chlorophyll patterns representing the *in situ* chlorophyll profiles used as inputs.

Figure 2. A generalized linear model of the depth of the chlorophyll maximum (z_m) modelled as a function of surface chlorophyll, SST, water column depth (sounding), season and area. The y-axis is modelled as an exponential regression for surface chlorophyll concentration and as a linear regression for SST and water column depth. Season and area are categorical variables.

INVESTIGATION OF INTERANNUAL VARIABILITY IN SEA SURFACE TEMPERATURE IN THE ANGOLA-BENGUELA REGION

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The main aim of this study was to analyse the interannual variability in sea surface temperature in the Angola-Benguela region off the west coast of Africa. Prior to this study it was not known whether warmer and cooler than average years occur sporadically, or whether they group into more persistent events. It is anticipated that a technique defining warm or cool years, and finding the similarities and differences between them, will be of use in fisheries oceanography.

The monthly satellite-derived ENVIFISH sea surface temperature data set, with a spatial resolution of 4.5 km and covering the area off Angola and Namibia (6-29˚S and 10-16˚E), was investigated using an artificial neural network technique known as the Kohonnen self-organising map (SOM). The SOM analysis used data collected over an 18 year period (1982-1999) comprising monthly SST composites from three regions; off Angola (6-17˚S and 10-16˚E), off Namibia (17-29˚S and 10-16˚E), and for the whole area (called the Angola-Benguela region, 6-29˚S and 10-16˚E). The SOM analysis for each region provided three different 5x3 output maps of typical and rare SST patterns, and also provided three sets of annual trajectories for the three regions. Individual annual trajectories followed similar cycles in the SOM pattern space (nodes). By undertaking a further SOM analysis of the output trajectories, similar years can be grouped in a small number of categories.

The first approach partitioned the trajectories into two different categories: warm and cold. The SST time-series showed significant variability in both the Angolan and Namibian regions, which have different dominant atmospheric forcing regimes. For the Namibian region, the 1980s were generally cooler than the 1990s, while for the Angolan region and for the Angola-Benguela region this separation of years was not as distinct. The variability of the Angola-Benguela region appears to be strongly affected by the dominant forcing of either of the Angolan or Namibian regions.

A second approach was undertaken to get more detailed information about possible grouping of the years. Three categories of trajectories were generalised; intermediate, warmer than average and cooler than average. For the three regions the cool, intermediate and warm years were grouped differently (Table 1). Persistently warm years for all three regions were 1984, 1995, 1996, and 1999, while cool years were 1982, 1983, 1985, and 1992. 1994 was the only year where all the three regions had intermediate SSTs.

The second approach also showed that in the Namibian region, the 1980s were generally cooler than the 1990s, which were intermediate to warm. For the Angolan region this separation was not as distinct. For the Angola-Benguela region, the early 1980s were cool and the late 1990s were warm, while the years between (1986-1991) were intermediate. For the Namibian region, the period 1982-1988 was cooler than average, with the exception of 1984 which was warmer than average. The period 1989-1999 was intermediate to warm, with the exception of 1992 and 1997, which were cool years. For the Angolan region, the period 1982-1994 was cool or intermediate, with exception of 1984 and 1988, which were warmer than average. The period 1995-1999 was warm with exception of a cold 1997. For 1986, 1989, 1991 and 1998, the Angolan region, and in 1990 the Namibian region, acted in concert with the Angola-Benguela region (see Table 1).

The year 1993 was difficult to place in perspective. It was cool off Angola, intermediate for Namibia but warm for whole Angola-Benguela region. This anomalous result may be due to the pattern recognition procedure adopted. The years 1987 and 1997 are also interesting, since for Angola and Namibia they appear as cool years but for the Angola-Benguela region they appear as intermediate years. 1988 also appeared as an intermediate year for the Angola-Benguela region, but during this year the influence of the Angolan and Namibian regions was averaged (it was cold for Namibia but warm for Angola).

Acknowledgements

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Table 1. SOM grouping of years into three generalized categories. The shaded boxes show years grouped in each category (warm, intermediate and cool) for the specific regions: A&N stands for the Angola-Benguela region, A for the Angolan region and N for the Namibian region

Years	*Region*	*'82*	*'83*	*'84*	*'85*	*'86*	*'87*	*'88*	*'89*	*'90*	*'91*	*'92*	*'93*	*'94*	*'95*	*'96*	*'97*	*'98*	*'99*
	A&N			■									■		■	■		■	■
Warm	*A*			■				■							■	■		■	■
	N			■					■		■				■	■			
	A&N					■	■	■	■	■	■			■			■		
Intermed.	*A*					■			■		■			■					
	N									■			■	■				■	
	A&N	■	■		■							■							
Cool	*A*	■	■		■		■			■		■	■				■		
	N	■	■		■	■	■	■				■					■		

RELATING SARDINE RECRUITMENT IN THE NORTHERN BENGUELA TO SATELLITE-DERIVED SEA SURFACE HEIGHT USING A NOVEL PATTERN RECOGNITION APPROACH

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Sea surface height data are currently providing new insights into oceanographic problems. In this study we aim to assess the usefulness of this data for investigating fisheries oceanographic problems using a novel application of a neural network pattern recognition technique.

Historically, sardine *Sardinops sagax* (formerly *ocellatus*) was the dominant species in the Namibian small pelagic fishery. Like other small pelagic fish populations around the world, its abundance is highly variable. A high sardine biomass was observed during the 1950s and 1960s, but since then the stock has generally been in a depleted state. Although overfishing has undoubtedly played a role in the decline of the sardine stock, the environment is also thought to have been a major contributor to this population variability (Boyer *et al*. 2001).

In the Northern Benguela, sardine spawn over the central and northern Namibian shelf between September and April, with peaks in September-November and February-April (Le Clus 1990, Kreiner *et al*. 2001). They have planktonic egg and larval stages, which last for 50-100 days before metamorphosis (Shannon 1998). Only after this period are fish able to swim against currents and actively forage. Thus, during the planktonic period, environmental conditions can strongly influence larval survival.

The dominant oceanographic processes along the northern Namibian coast are upwelling of cold, nutrient-rich water and intrusions of warm, nutrient-poor Angola Current water. According to the ocean triad theory (Bakun 1996), three main factors are required for successful recruitment: nutrient enrichment, concentration of food particles and retention of larvae. We postulate that, in central and northern Namibia, moderate upwelling produces 'favourable' conditions for recruitment by providing inshore enrichment, retention and concentration. Conversely, strong or weak upwelling during the spawning season reduces the probability of successful recruitment by disrupting enrichment, retention and concentration. This is consistent with the optimal environmental window theory of Cury and Roy (1989). The intrusion of Angola Current water into the coastal area is also detrimental to recruitment success because it reduces enrichment and concentration. Additionally, for recruitment to be successful, 'favourable' conditions must be present for the planktonic period of the sardine's life history, *i.e.* a period of greater than 50 days from spawning.

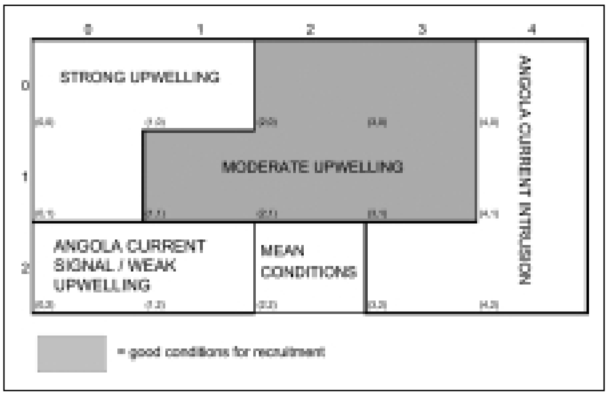

Fig. 1

Seven years of satellite-derived sea surface height (SSH) and sea surface temperature (SST) data are used to investigate variability in oceanographic processes that influence ocean triad factors. A neural network approach, known as a self-organising map (SOM; Kohonen 1997), is used to reveal the dominant oceanographic processes and to investigate their spatio-temporal variability.

The SOM output patterns for SSH differences along the northern Namibian coastline are shown in Plate 2. There is a continuum of change across the SOM output map, from patterns with generally low SSH on the left to patterns with generally high SSH on the right. Most patterns also show an inshore-offshore gradient in SSH. Mean SST difference patterns (not shown), corresponding to each SSH difference pattern, were used to show the thermal signature of the patterns identified by the SOM. Cooler temperatures correspond to lower SSH and warmer temperatures to higher SSH. Interpretation of the patterns in terms of known oceanographic processes is given in Figure 1. Processes identified are strong, moderate and weak upwelling and Angola Current intrusion. Moderate upwelling conditions, defined *a priori* as 'favourable' for recruitment, are indicated.

Monthly frequency maps show that strong upwelling occurs most frequently between June and August, which is outside the spawning season. Angola Current water intrudes most frequently around March, but may also influence a relaxation of the upwelling around October/November. Moderate coastal upwelling is most frequent in January, although this can occur anytime throughout the year. Annual frequency maps, taking the year from August to July to correspond with the spawning year, show a large amount of interannual variability in the frequency of SOM patterns.

To assess if favourable conditions were present during periods of peak spawning, a range of spawning dates were estimated for each cohort sampled during assessment surveys over the study period by back-calculating from the mid-survey date using von Bertalanffy growth parameters. These estimated spawning periods were then used to determine oceanographic conditions during spawning for each year from the SOM patterns. The number of consecutive days of 'favourable' conditions after spawning was calculated for each cohort, and are given in Table 1. Only two cohorts were spawned during periods of 'favourable' conditions that lasted longer than 50 days, and these were in 1995/96 and 1996/97. Comparison of these results with recruitment data over the study period (Fig. 2) showed that these were also the only two years with above average recruitment.

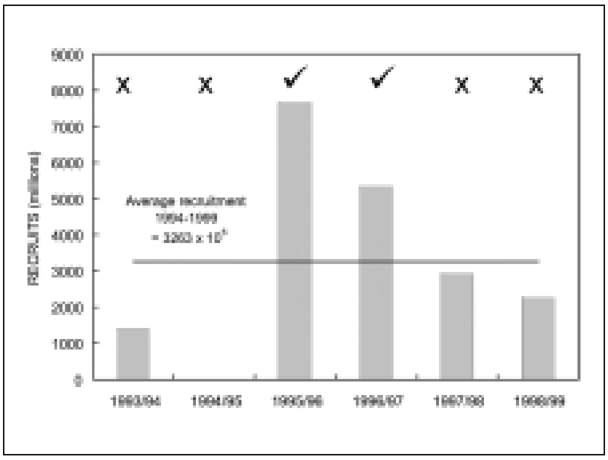

Fig. 2

In conclusion, the use of an SOM to analyse sea surface height data has provided a clear description of the main surface oceanographic processes in the region. Additionally, a comparison of interannual variability in these processes with recruitment data supports the initial hypothesis that persistent periods of moderate upwelling during the spawning season provide the required ocean triad factors, and hence increase the probability of successful recruitment. In contrast, influxes of Angola Current water and strong upwelling events disrupt the ocean triad and reduce the probability of successful recruitment. However, the short period of overlap between time series of sardine recruitment and sea surface height make the relationship observed suggestive, but not conclusive.

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Table 1. Duration of 'favourable' oceanographic conditions after spawning

Year	Cohort	Window of 'favourable' conditions (days)
1993/94	1	40
	2	40
1994/95	?	10 ?
1995/96	1	60
1996/97	1	80
	2	0
1997/98	1	0
	2	0
1998/99	1	20
	2	20

Figure Legends

Figure 1. Classification of the SOM output grid patterns into oceanographic processes. Moderate upwelling conditions, identified *a priori* as favourable for recruitment, are shaded.

Figure 2. Comparison of expected recruitment success from oceanographic conditions (ticks represent successful recruitment and crosses represent unsuccessful recruitment) with observed recruitment data (columns).

SEASONAL AND INTERANNUAL VARIABILITY OF THE BENGUELA COASTAL UPWELLING

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Seasonal and interannual variations in Benguela upwelling were studied using satellite-derived data of both wind and sea surface temperature (SST). Based on weekly (ECMWF: 1982-1997) and monthly (ERS-1: 1992-1995) wind field composites, a time-series of the offshore-directed Ekman volume transport per unit length was derived from the alongshore wind component, and used as an indicator of the forcing for coastal upwelling. Spatial patterns along the coastline were resolved by division into one degree of latitude.

Interannual variability in offshore Ekman transport is described, and anomalies detected in the wind forcing are related to sea surface temperature (SST). Monthly maps of SSTs from satellite (AVHRR) are used to describe the variability of Intense Benguela Upwelling (IBU) between 1982 and 1999. IBU is defined from satellite images as the size of the total area of cold water between the coast and the 13º isotherm, for the domain 9-34°S and 8-20°E. Within-season the size of this area shows average values of $30x10^3$ km^2, an alongshore extent of 1600 km (equivalent to the alongshore extent of the south-east trade wind), and an offshore extent of about 20 km (equivalent to the first mode baroclinic radius of deformation).

The seasonal cycles of offshore Ekman transport and IBU are shown in Figure 1. Along 11°E, offshore Ekman transport exceeds 1.25 m^2/s between 18°S and 23°S during June-August, and between 18°S and 20°S during October-December. Peak IBU values occur in August but dramatically relax during the rest of the year. Due to permanently released subinertial waves (coastal Kelvin waves and topographically trapped Rossby waves), the main upwelling area is located somewhat to the south of the wind forcing area. Consequently, the IBU shows regional peaks at two coastal zones, near 26°S (the Lüderitz cell) and 29°S (the Namaqua cell).

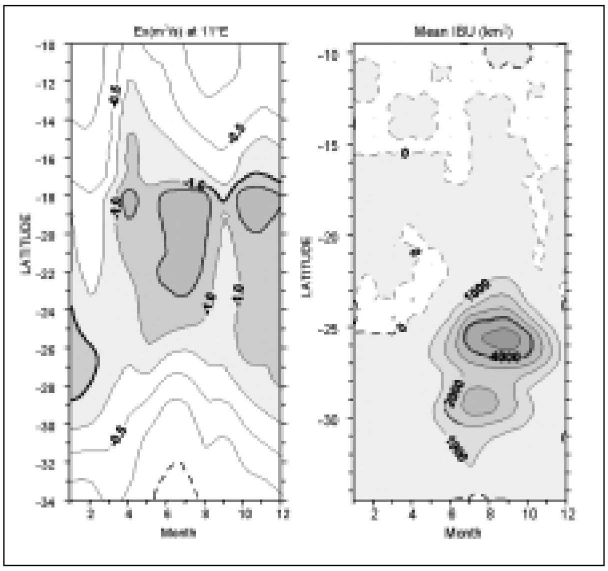

Fig. 1

The Lüderitz and Namaqua cells form giant upwelling filaments with a mean offshore extent of 210 km and 130 km respectively. The offshore extent of these filaments changes dramatically between strong and weak upwelling years. Removing the mean seasonal cycle of the IBU, strong, moderate and weak upwelling years are easily identified by peak values in resulting anomalies. Concerning the SSTs, this procedure also removes the influence of seasonally occurring heating and cooling processes. The resulting mean seasonal cycle of extreme upwelling years clearly shows that drastic changes in IBU reach values of $\pm$ $20x10^3$ km^2 (Fig. 2) during exceptionally strong (1982, 1985, 1990, 1992) and weak (1984, 1993, 1996, 1997, 1999) upwelling years. Interannually, the cold-water belt of the Benguela current regime reveals an 18-year lasting tendency for decreasing upwelling intensity (Fig. 2).

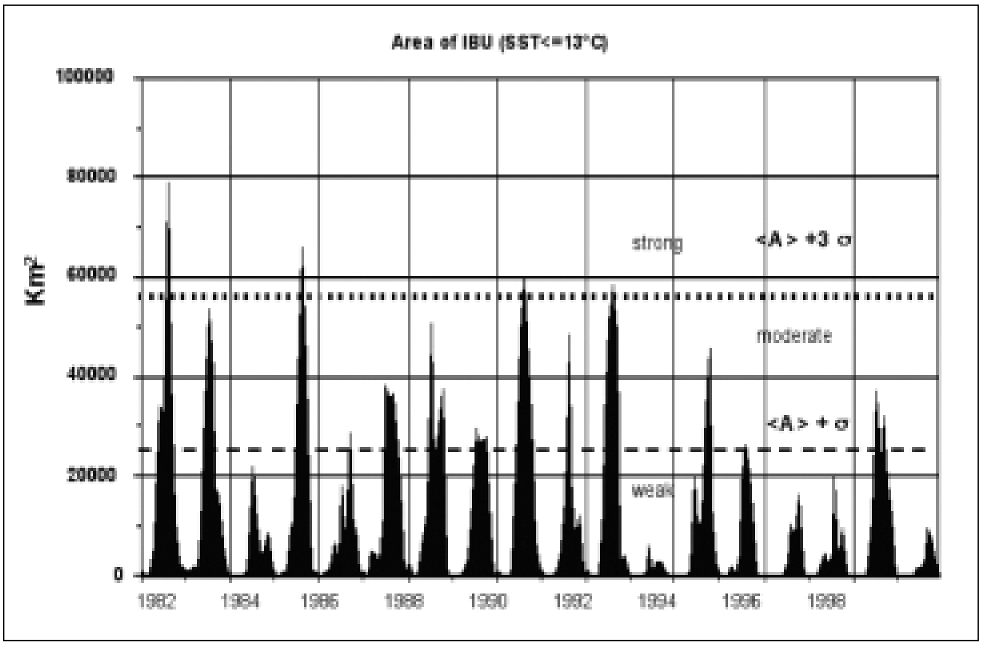

Fig. 2

Figure Legends

Figure 1: Mean monthly (1992-1995 average) Ekman offshore transport (Ex, m^2/s) along 11°E, from 10°S to 34°S, calculated using wind data from the ERS-1 satellite (left panel), and mean monthly (1982-199 average) IBU (km2) from 10°S to 34°S and 8°E to 20°E (right panel). Cold coastal waters occur between 24°S and 30°S during the austral winter in reaction to peak values of Ex; thus the seasonal response time of coastal upwelling (IBU) on changes in the forcing (Ex) is of about two months and the detected southward displacement of the main upwelling center is probably caused by dynamics of coastal Kelvin waves and topographically trapped Rossby waves.

Figure 2. Monthly time series of Intense Benguela Upwelling (IBU) from 1982 to 1999. IBU is defined as the size of the area with SST lower or equal to 13°C in the coastal region between 9-34°S and 8-20°E. Years of Intense Benguela Upwelling (IBU) exceed the mean value $<A>$=10 543 km plus three times the standard deviation (3σ; dotted line) while those of drastically relaxed upwelling fluctuate beneath the level of $<A> + \sigma$ (dashed line).

SATELLITE IDENTIFICATION OF HYDROGEN SULPHIDE EMISSIONS

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Introduction

Outbreaks of toxic hydrogen sulphide toxic gas are a recurrent feature in the near-coastal shelf environment off Namibia. These outbreaks have a significant economic and societal relevance because of their effects on the biota in one of the world's largest upwelling regions, fisheries being the third largest source of revenue for Namibia. Until recently, hydrogen sulphide events were considered to be of local geographical extent and forced by a combination of high biological productivity and reduced advection of oxygenated ocean water. New evidence from remote sensing suggests a far larger geographical distribution than previously assumed, and ship-borne surveys in 2000 suggest a significant contribution by eruptions of biogenic gas accumulations in organic-rich diatomaceous oozes on the shelf.

Background

Strong upwelling off Lüderitz results in massive downstream primary production. Dead and decaying phytoplankton cells accumulate on the sea bottom in a metres-deep muddy diatom ooze, which is exceptionally thick and azoic. The "azoic zone" bottom water suffers from chronic hydrogen sulphide concentrations, and is devoid of fish life, although copious fish remains are present. In the sediment, anaerobic sulphate-reducing bacteria convert sulphates to sulphides, ultimately producing hydrogen sulphide. During an hydrogen sulphide event, hydrogen sulphide gas is liberated into the water column. While some gas escapes into the atmosphere, hydrogen sulphide in the water column oxidises to microgranules of elemental sulphur, giving the surface a milky-green discoloration.

In addition to its direct toxic impact, hydrogen sulphide has the secondary effect of stripping oxygen from the water, so that extensive surrounding areas suffer from severe anoxia and hypoxia. The catastrophic loss of two billion young Cape hake, *Merluccius capensis*, during austral summer of 1992-93, was blamed on an anoxic outbreak (Woodhead *et al*. 1998a). About half of the recruit population of Namibian Cape hake was estimated to have died as a result of being trapped by widespread anoxia in shelf bottom waters, with cumulative mortality of surviving hake in 1994 being estimated at 84% (Woodhead *et al.* 1998b).

Satellite identification of hydrogen sulphide emissions

Recently, a potential boon to the scientific study and eventual management of the possible effects of hydrogen sulphide outbreaks has emerged. We are now able to detect and monitor such anoxic phenomena via satellite remote sensing. An example is shown of an episode, observed over a two-week period during March–April 2001 (Plate 3), that affected an area of ocean surface exceeding 20,000 km^2. Plate 3 displays a series of visible-band, quasi-true colour images from the OrbView-2 SeaWiFS satellite during this episode. On 18th March (image a), a massive sulphide emission event was evident in the turquoise-coloured patch stretching northwards more than 200 km along the Namib Desert coast from the vicinity of Lüderitz almost to Conception Bay. Images for 12th and 13th March showed only small isolated spots of milky coloration localized against the coast between Ichaboe Island and Hollams Bird Island, indicating that minor precursory eruptions seem to have commenced at that time.

Fortunately, NATMIRC personnel were on the scene during the major outbreak, taking measurements and collecting samples for analysis. They were able to demonstrate the presence of intense hydrogen sulphide emissions in that zone, and to confirm that the peculiar milky turquoise colouration of the water occurred simultaneously as viewed from the satellite. This discoloration consistently occurs during hydrogen sulphide events along the Namibian coastline, and is due to the highly reflective microgranules of sulphur (oxidised sulphide) suspended in the water column. Oxygen samples from surface waters showed very low concentrations (<0.7ml l^{-1}; K. Noli-Peard, NATMIRC, unpublished data) indicating that a knock-on impact of sulphide is widely felt throughout the water column.

In the days to follow (images b-f), the feature was advected further northward and offshore in the prevailing equatorward geostrophic current, as well as exhibiting some spreading due to turbulent diffusion. Finally, in the image of 3rd April (image f), even while the earlier offshore feature continued to maintain a coherent identity, another totally new hydrogen sulphide emission event was observed to have abruptly commenced within the coastal upwelling zone north of Lüderitz. “Milky turquoise waters” were again reported from Ichaboe Island, which is amongst Namibia’s most important lobster fishing grounds. Dive surveys showed dissolved oxygen levels to be exceptionally low, forcing the lobster stock right inshore (C. Grobler, NATMIRC, personnel communication).

Additional recent episodes have likewise been definitively associated with coastal sulphide emissions and associated anoxia, although the possibility of some degree of involvement of coccolithophores in the offshore signatures cannot be discounted at this point. If so, such a relationship to sulphide/anoxia is previously unreported and in itself would be of great ecological significance. The conventional view has been that the sulphide emissions that are recurrently observed from the shore in this region are very local features, and thus must have only rather limited ecosystem-scale consequences. The recent satellite observations appear to dramatically overturn that view. In the case of the March-April episode, the initial coastal outbreak can be seen (Plate 3 image a) to stretch continuously along nearly two and one half degrees latitude. The zone of rather intense coloration in the later images (images b-f) extends over an expanse of sea surface more than 20,000 square kilometers in total area.

Conclusions

Hydrogen sulphide occurrences are seen to be far larger in spatial extent, and more frequent and longer lasting, than was previously supposed. Implications of these phenomena to the local ecology may be profound, and the relevance to the valuable but extremely variable fishery of the region is likely to be high. This capability for identifying and monitoring from satellite the incidence, position and extent of ocean areas affected by toxic hydrogen sulphide emissions and associated anoxic/hypoxic conditions promises to be a major asset for fisheries management in the Namibian waters.

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Acknowledgements

We wish to acknowledge the contributions of all the members of the NATMIRC “Sulphide Team”, the French-South African IDYLE Project and the regional BENEFIT Project. We also wish to express special thanks to Dr. Gene Feldman of NASA (USA) for his continuing generous interest and assistance in affording the benefits of SeaWiFS technology to southern Africa.

Spatio-temporal distributions of anchovy and sardine ichthyoplankton in the Benguela Jet Current from 1995 to 2001: Six years of monitoring off the Cape Peninsula

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Introduction

Small pelagic fishes such as anchovies and sardines are prone to large fluctuations in population abundance. This has been particularly evident in South African waters, with considerable interannual variability in spawner and recruit biomass estimates during the 1980s and 1990s. A number of variables are thought to affect recruitment, including temperature, wind, food availability, transport/retention, turbulence/stability, predation/competition, population density, gross egg production and both localised and widespread oceanographic events. In the late 1980s, the international Sardine/Anchovy Recruitment Project (SARP) was initiated by IOC/UNESCO and FAO in order to investigate biological and physical oceanographic processes governing recruitment fluctuations in marine fish stocks, particularly factors causing mortality of early life stages. South African SARP (SA SARP) was initiated in 1993, and comprised monthly cruises from spring through autumn to investigate within-season variability in factors thought to affect recruitment. Up to 12 cross-shelf transects, covering the west coast and the western Agulhas Bank, were sampled each cruise, with many environmental and biological parameters measured. SA SARP extended over 2 years (1993/1994 and 1994/1995; Painting *et al.* 1998).

Since 1995 a new sampling approach has focussed on providing increased temporal coverage of the transport of early life history stages by the Benguela jet current. The shelf-edge jet current has been shown to be instrumental in the concentration and transport of eggs and larvae from the western Agulhas Bank spawning grounds to the west coast nursery area (Shelton and Hutchings 1989). Sampling along the "SARP Monitoring Line", which crosses the jet current off the Cape Peninsula, began in August 1995 and is ongoing. Sampling frequency is effectively bi-monthly. Stations were 3 nm apart and extended 34 nm offshore during the first year of sampling, which was increased to 40 nm offshore in following years, and occasionally to 60 nm to investigate potential offshore losses beyond the routine transect (Fig. 1). Parameters measured include SST, current vectors, vertical temperature and fluorescence profiles, and eggs and larvae of anchovy (*Engraulis capensis*), sardine (*Sardinops sagax*) and roundherring (*Etrumeus whiteheadii*).

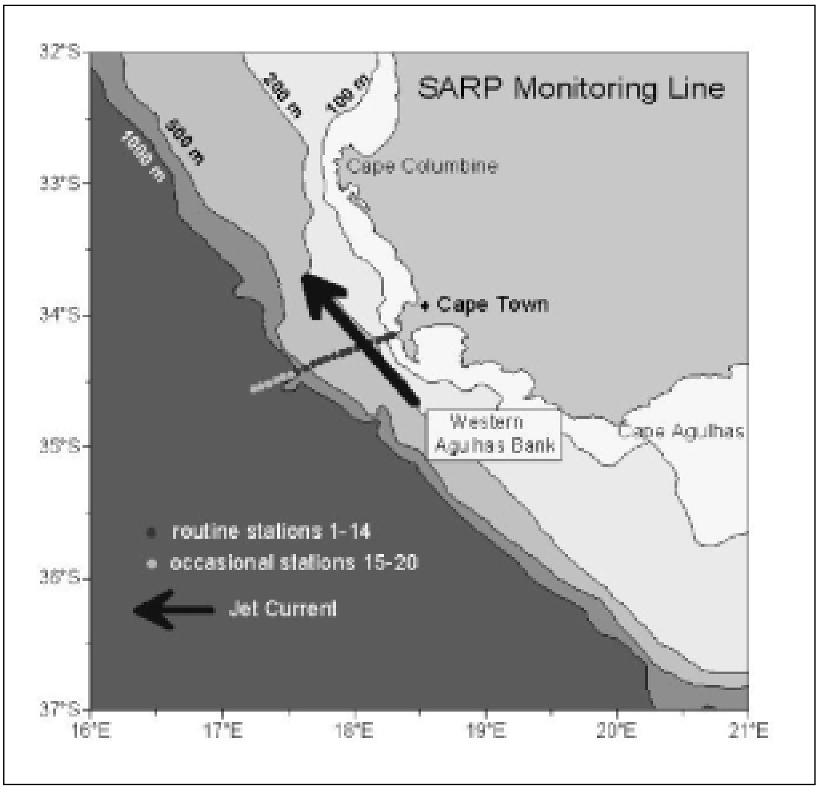

Fig. 1

Within season variability

Results from the first six years of sampling indicated considerable within-season variability in all parameters measured. Warm (≥20°C) Agulhas Bank water extended shorewards over much of the monitoring line during summer, penetrating up to 7 nm off the coast. Coastal upwelling resulted in patches of cool (10-13°C) water inshore, particularly from late spring to autumn, extending up to 7 nm offshore during autumn. SSTs from May to October (late autumn to mid-spring) were less variable, generally 15-18°C. The equatorward jet current showed considerable variability in strength and position, usually situated close to the coast in spring and moving further offshore in early summer. Summer and autumn were characterised by variable current patterns, with poleward flow a surprisingly common feature, generally located inshore of the equatorward flow. Mean equatorward flow over the time-series was 37.4 $cm.s^{-1}$, but current speeds exceeding 100 $cm.s^{-1}$ were recorded with a maximum of 128.8 $cm.s^{-1}$ measured in March 2001. Anchovy eggs were most abundant from October to December, while anchovy larvae were found from October to March. Patches of sardine eggs were found between August and March, while sardine larvae were collected from July to April. All showed different patterns of abundance from year to year.

Mean monthly anchovy (Aug. – Mar.) and sardine (Sep. – Feb.) egg abundances from the first year of sampling (1995/1996) were significantly correlated ($p < 0.05$) with the estimated birthdate distribution of the 1996 recruits (Huggett *et al.* 1998). Unfortunately, a lack of ageing and growth rate data has hampered the further pursuit of such relationships.

Interannual variability

Useful comparisons may be drawn between years of low and high anchovy recruitment. Low anchovy recruitment in the winter of 1996 was preceded by a brief warming period along the monitoring line during the summer of 1995/1996, and a narrow window of anchovy eggs and larvae from late October to early December (Plate 4). In contrast, high anchovy recruitment in winter 2001 was preceded by an extended period of warm water along the monitoring line, and greater and more persistent abundance of anchovy larvae in particular, as well as eggs, which were associated with the warm water (Plate 4).

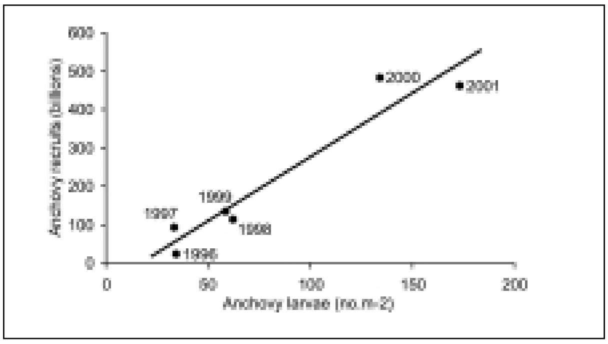

Fig. 2

Annual indices of mean egg and larval abundance ($no.m^{-2}$) along the monitoring line were calculated by dividing the total number of eggs and larvae found from September to March by the number of stations sampled. Positive linear correlations were found between eggs, larvae and eggs + larvae and the subsequent number of recruits for both anchovy and sardine over the 6 years sampled. Whereas most correlations were not significant, there was a significant correlation ($p < 0.05$, $r^2 = 0.92$) between anchovy larvae and recruits (Fig. 2).

Generalized additive models (GAMs) were constructed using log transformed values of anchovy and sardine eggs and larvae ($no.m^{-2}$) as dependent variables, and year, month, station (*i.e.* distance offshore), SST, and longshore and cross-shelf current strength as independent variables. Results indicated both anchovy eggs and larvae were most abundant during 2000/2001, the year of highest recruitment during the 6 years of monitoring. Maximum anchovy egg and larval abundance occurred during November, with eggs peaking at station 5 (13 nm offshore, beyond the shelf-edge) and larvae increasing in abundance with distance offshore. Both eggs and larvae were positively related to temperatures >16°C. Egg abundance was correlated with equatorward and cross-shelf current strength, whereas larvae were unrelated to longshore flow but positively correlated with onshore flow. Maximum sardine egg and larval abundance in the GAMs did not coincide with peak sardine recruitment, probably because significant sardine spawning also occurs on the west coast, which is not detected by the SARP monitoring line. Sardine eggs were most abundant at stations 5-6 (13-16 nm offshore), slightly inshore of peak sardine larval abundance at station 7 (19 nm offshore). Both egg and larval abundance increased with increasing temperature. High egg abundance was associated with strong alongshore and cross-shelf current strength, suggesting a concentration effect. Larval abundance was not related to current strength.

The SARP Monitoring Line Programme is proving to be a valuable time-series of both environmental and biological data, providing timeous results that supplement the annual more broadscale surveys of pelagic fish.

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Figure Legends

Figure 1: Map showing the location of the SARP monitoring line off the Cape Peninsula, South Africa.

Figure 2: Positive linear correlation between mean abundance of anchovy larvae (no.m^{-2}) across the monitoring line from September to March (1995/1996 to 2000/2001) and subsequent anchovy recruitment.

PREDICTION OF PROBABLE FISHING GROUNDS IN NORTHERN CHILE FROM PELAGIC FISHERIES DISTRIBUTIONS AND ENVIRONMENTAL CONDITIONS

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Introduction

Small pelagic fishes support economically valuable purse seine fisheries in the South East Pacific, and are one of the major contributors to world fish production (FAO 1997). Since the distribution and abundance of these resources are strongly influenced by environmental conditions (Yáñez *et al.* 2001), the fishing industry should adapt a fishing strategy that takes into account the environmental changes occurring at different spatial and temporal scales. The objective of this study was to develop an expert system to generate probable fishing ground (PFG) charts in northern Chile. In the context of a fishery management policy, such a system aims to decrease the searching time and hence fisheries operational costs. The PFG charts were calculated from remotely sensed satellite data and a decision support analysis using the IDRISI GIS.

Methodology

The period (1987-1997) used to determine resources-environment relationships and to evaluate the model corresponds to a period "positive" for anchovy and "negative" for sardine (Fig. 1). Therefore the model was built to focus on anchovy in northern Chile (18-24ºS and 70-73ºW).

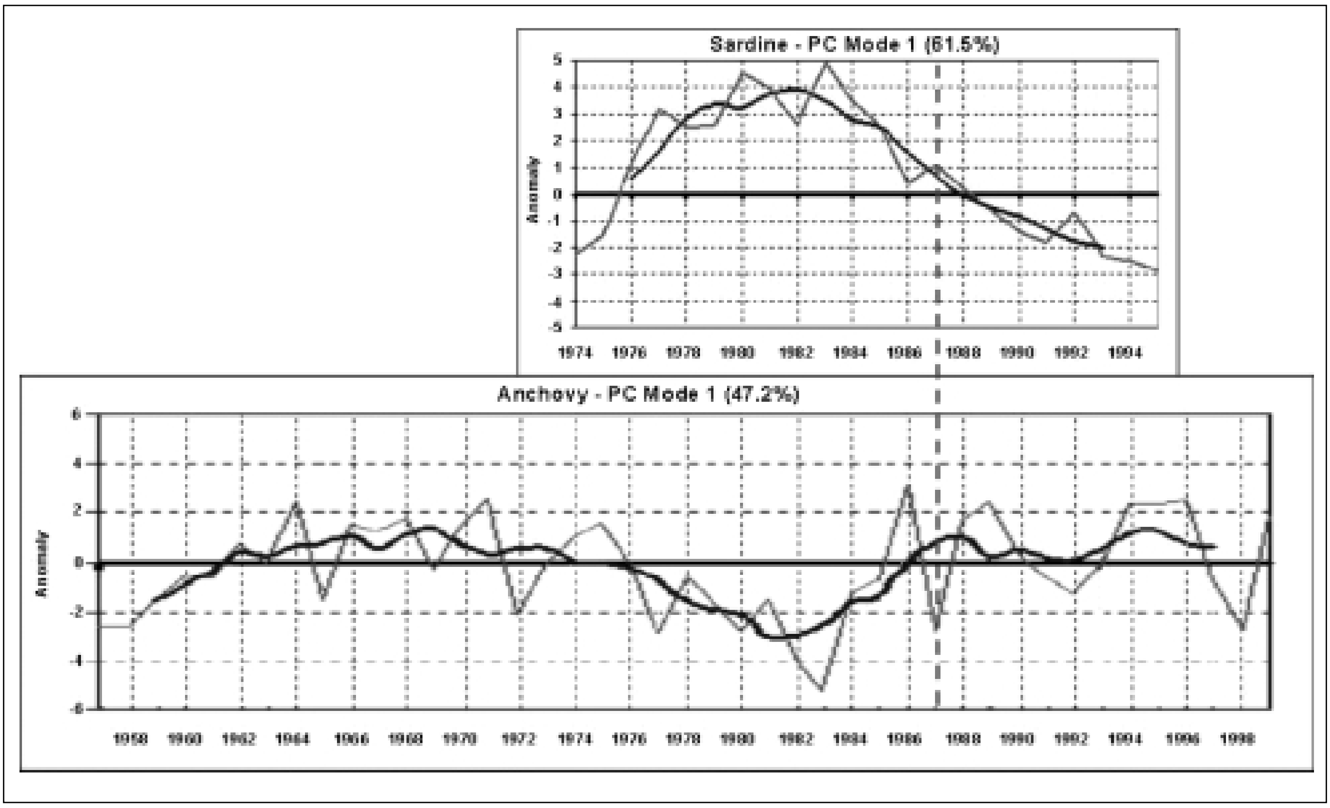

Fig. 1

Environmental data

An historical (1987-1997) satellite SST database comprising a total of 2019 SST images from NOAA/AVHRR satellites, and of thermal gradient (TGR) derived from SST, was analysed. SST images were validated with *in situ* SST data obtained from oceanographic sampling (r=0.9). In addition, a 1999-

2001 database of chlorophyll (Chl) satellite images obtained by the SeaWiFS sensor of the SeaStar satellite are processed and analyzed. Since October 1997, the UCV has a satellite infrared reception system (SIRS) HRPT, allowing real time acquisition of data. The SST images were used to establish resources-SST relationships and as input data for the PFG model.

Fishing data

The historical database (1987-1997) and other information obtained by monitoring of the industrial purse seine fleet during 1999-2000 were analyzed. Data included geo-referenced information on catches, fishing effort per day and vessel characteristics. These data were used to calculate daily anchovy CPUEs, previously standardized using GLM (Yáñez *et al.* 1999), which were then mapped using GIS.

Relationships between SST, TGR, Chl and CPUE

Daily anchovy CPUE distributions were superimposed to SST, TGR and Chl images in order to analyse fishery and environmental variables associations. These data were aggregated monthly to compute *conditional probability distributions* (evidence curves) that were used to determine the optimal ranges of SST, TGR and Chl in the fishing grounds.

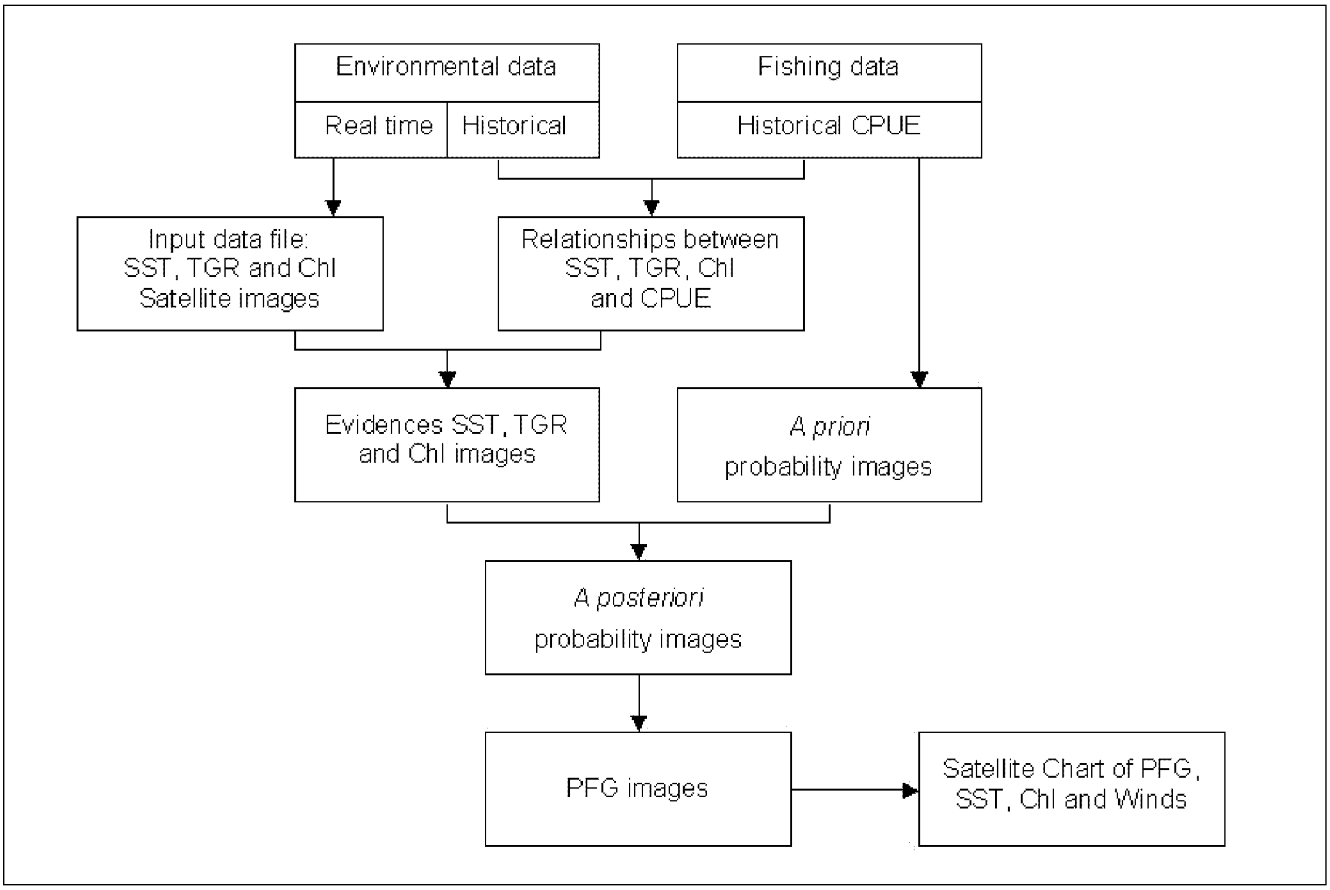

Fig. 2

PFG images

The PFG images were calculated following the methodology proposed by Nieto *et al.* (in press; Fig. 2). Evidence SST, TGR and Chl images were generated by applying fuzzy logic to the input image data according to the corresponding monthly evidence curve. Daily anchovy CPUE distributions were used to determine the *a priori* knowledge of distribution and abundance, and a representative *a priori* probability image was then computed monthly, depending on the abundance level registered in the past weighted by the sampling frequency. In order to obtain a *posteriori* probability images for SST, TRG and Chl, the *a priori* and evidence images were integrated using a Bayesian theory approach. These images were integrated in one PFG image through a weighted linear combination. The PFG model was validated with satellite images and geo-referenced CPUE data collected during 1999.

Results

Anchovy is caught in a wide range of SSTs from 16 to 23ºC, with an optimum between 19 and 20ºC; and in TGR from 0.3 to 3.5ºC/10nm with an optimum between 0.8 and 2.1ºC/10nm. The Chl data compiled in 1999 indicated a range between 0.2 and 6 mg/m^3, and an optimum between 0.3 and 1.3 mg/m^3. However, these ranges vary according to season. Anchovy is found in the frontal zone produced by the convergence of the cold upwelled waters and the warm ocean waters, a situation more clearly noticeable from late spring to early autumn.

An example of the application of the PFG model carried out using SST, TGR and Chl images from October 28th 1999 as input variables is shown in Plate 5. The PFG image is classified in medium (red) and high (yellow) probability values. In this chart high PFGs were observed closer to the coast, but were also distributed throughout various areas of the study zone associated with the frontal area between upwelling and oceanic waters. The analysis of 242 values from 1999 shows that 67% of the actual fishing grids coincided with high probability grids from the PFG model, and 30% with medium probability.

Conclusion

The PFG model was designed to be implemented in a GIS, due to the large amounts of geographical data analyzed and the necessary analysis required to develop the expert system and generate a PFG chart. The PFG model is supported by past evidence of the spatial and temporal distribution of anchovy, and by the optimum ranges of SST, TGR and Chl recorded in fishing zones. In view of this, the model's validation by 1999 data allows us to conclude that it has correctly integrated the environmental variables that influence anchovy distribution.

Proyecto FONDEF D98I1022; http://ecm.ucv.cl/efisat/

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Figure Legends

Figure 1. Principal component 1 of an EOF time series analysis using catches, effort, SST and SOI for anchovy (1950-99), and recruitment, biomass, SST and upwelling index for sardine (1974-95).

Figure 2. Diagram of the PFG model.

AN APPROACH BASED ON ACOUSTIC DATA TO STUDY THE VARIABILITY IN DISTRIBUTION AND ABUNDANCE OF SMALL PELAGICS IN THE HUMBOLDT ECOSYSTEM

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Introduction

Acoustics can be used in the study of ecosystems through the analysis of the spatial changes in biotic and abiotic factors (Holliday 1993). This proposal is under development for its application to the Peruvian fisheries through the study of the aggregative behavior of small pelagics (with special emphasis on anchovy) of the Humboldt ecosystem from the point of view of the spatial distribution of the nautical area scattering coefficient (NASC, formerly known as s_A; MacLennan and Fernandes 2000) and its relation to oceanographic parameters. This study could also lead to a determination of the ecologic balance between the main marine populations in terms of their distribution and abundance. An improved method of analysis of the acoustic information has being carried out since 1996, which has allowed the study not only of the main stocks of small pelagics but also other important marine populations. Currently assessed species are shown in Table 1.

Data collection and analysis

Data used for this analysis was collected during acoustic echointegration surveys that covered most of the coastline (3°20´S to 18°20´S) from 0-120 n.miles offshore over the period 1966-2001. During the surveys EK500 echosounders and Echoview® software were used together in conjunction with intensive fish sampling in order to identify acoustic targets.

Mapping the distribution of assessed species is made through interpolation software contouring values higher than zero (Gutierrez 1997). In this way, an accurate measurement of the total or latitudinal area with the presence of fish can be made, including the determination of any particular NASC range. Three ranges or 'categories of relative abundance' have been defined for this study; Highly Dispersed (HD), Dispersed (D) and Commercially Abundant (CA; Table 2). These categories were arbitrarily defined, but represent an increase of about 5x between Highly dispersed and Dispersed and of about 2x between Dispersed and Commercially abundant. Abundance and biomass calculations were done using GIS and raster analysis was used to associate species-specific NASC with oceanographic parameters.

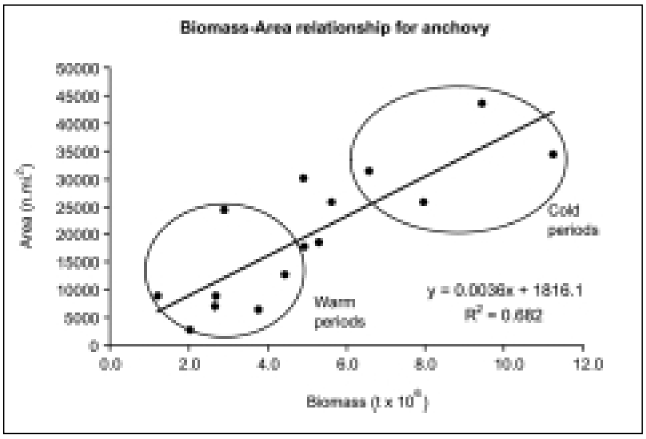

Fig. 1

Theoretical background: the case of anchovy

Muck *et al.* (1989) put forward the hypothesis that changes in the spatial parameters (alongshore extent and onshore-offshore distance) of the cold and warm water habitats off Peru control, or at least influence, the migration and concentration patterns of anchovy, mackerel and horse mackerel. This results, for example, in changes of anchovy vulnerability to predation, to egg and larval cannibalism and to the fishery. This hypothesis was supported by Ware and Tsukayama (1981), who noted that anchovy concentration increases with positive temperature anomalies. A direct relationship between water temperature and anchovy density has also been shown to exist and a relative balance between anchovy and sardine abundance has been established (Ñiquen and Gutierrez 1998).

Relationship between anchovy abundance and its area of distribution

A positive correlation between anchovy biomass and the area of its distribution has been observed (Fig. 1), as has a negative correlation between anchovy density and distributional area (Gutierrez *et al.* 2001). This mechanism is an obvious response to oceanographic changes and it is independent of the fishery and predation. These relationships have allowed the construction of a model that permits an estimation of the relative abundance of anchovy without conducting frequent and expensive acoustic surveys. The model has been applied to back-calculate the abundance of anchovy during the history of the Eureka Programme (1966-1982) and the results obtained appear to be coherent (Gutierrez *et al.* 2001).

An approach for the acoustic modeling of anchovy abundance

From acoustic observations, the size of the anchovy population seems to be dependent on the available area or volume of water with appropriate conditions for their survival. To demonstrate this, anchovy abundance estimates were compared with the area of Cold Coastal Waters (CCW) plus the mixture of CCW and Surface Subtropical Waters (SSW) for the 1996-2001 Surveys. Volume calculations were made by multiplying the area of appropriate condition water by a layer whose thickness was estimated from the equation of Muck and Vilchez (1988). In that equation there is the possibility of using salinity instead of temperature to improve that formula. A strong relationship between salinity and the presence of anchovy has been shown to exist, with anchovy being mostly distributed inside salinity limits of 34.8-35.1 PSU. This range is that covered by CCW plus mixed CCW-SSW waters.

Patterns of seasonal aggregation

Analysis of seasonal changes in terms of the covered area by the NASC ranges permits an examination of the space-time fluctuations in the abundance of the anchovy population. The percentage of the area of anchovy in the Dispersed category remained more or less the same between seasons (cold or warm), at least for the 1996-2001 period (Fig. 2). If the Dispersed area remains approximately constant through time, then this observation could allow modeling of the abundance of anchovy according to different levels of fishing effort. An improved Eureka Program could help to determine the area of distribution of the fish (Villanueva 1971) and, through it, get relative estimates of anchovy abundance. However geostatistics and CPUE indices would have to be incorporated to provide more consistency to the proposed model.

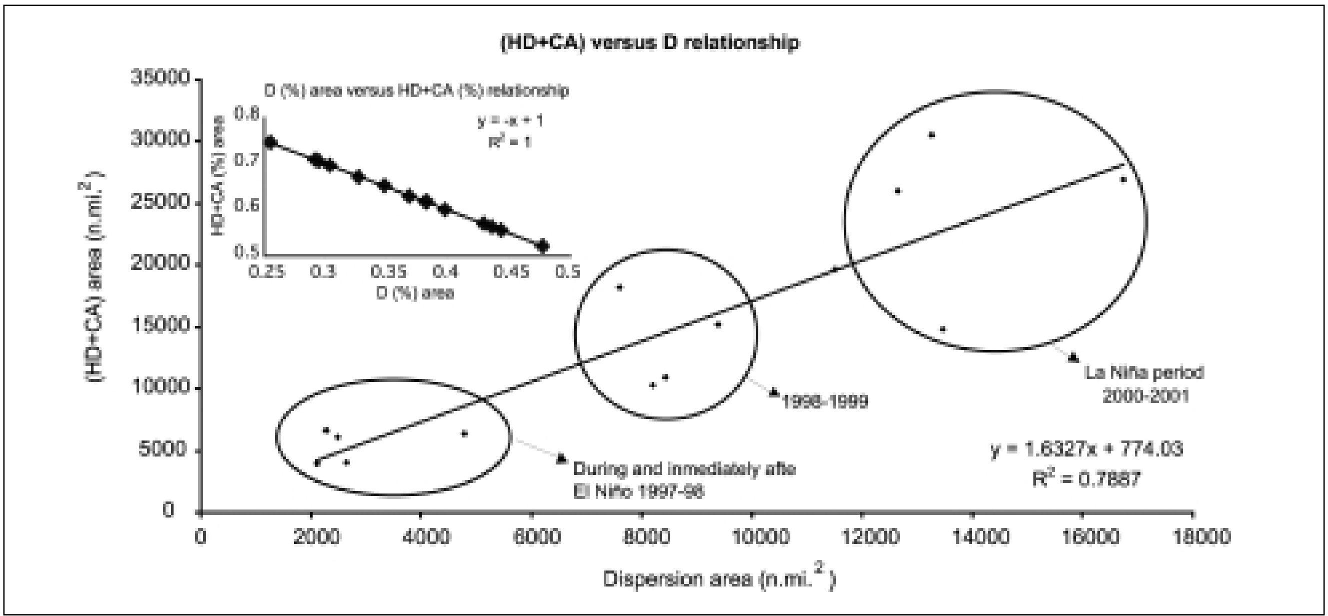

Fig. 2

Ecological balance

In August 2001 it was found that the contribution of CCW to the mixed waters was becoming progressively smaller and that of SSW to the mixture bigger. This increased presence of SSW could stop the growth of the anchovy population. At this stage it would be useful to review the ecological balance between a fish like anchovy, the main inhabitant of CCW, and a mesopelagic species like vinciguerria, the main inhabitant of SSW waters, to try to understand the seasonal changes in the structure of the water masses.

Indices of acoustic distribution

Figure 3 shows the variation in the NASC index in terms of the distribution of anchovy from 1998 to 2001 compared with that for vinciguerria. It is clear that a negative correlation between the distribution of these species exists, and a similar effect occurs in the case of the abundance indices. Therefore it is possible to acoustically measure their balance and through this to analyze the trends of their respective aggregative patterns. Figure 3 also shows that the anchovy distribution area tends to be smaller when that for vinciguerria tends to be bigger. Therefore, spatial distribution of the NASC values can also indicate oceanographic changes and the ecological balance as appears to be occurring in the Humboldt ecosystem. Monitoring the composition of the water masses will be essential for any acoustic model intended to predict the abundance of small pelagics.

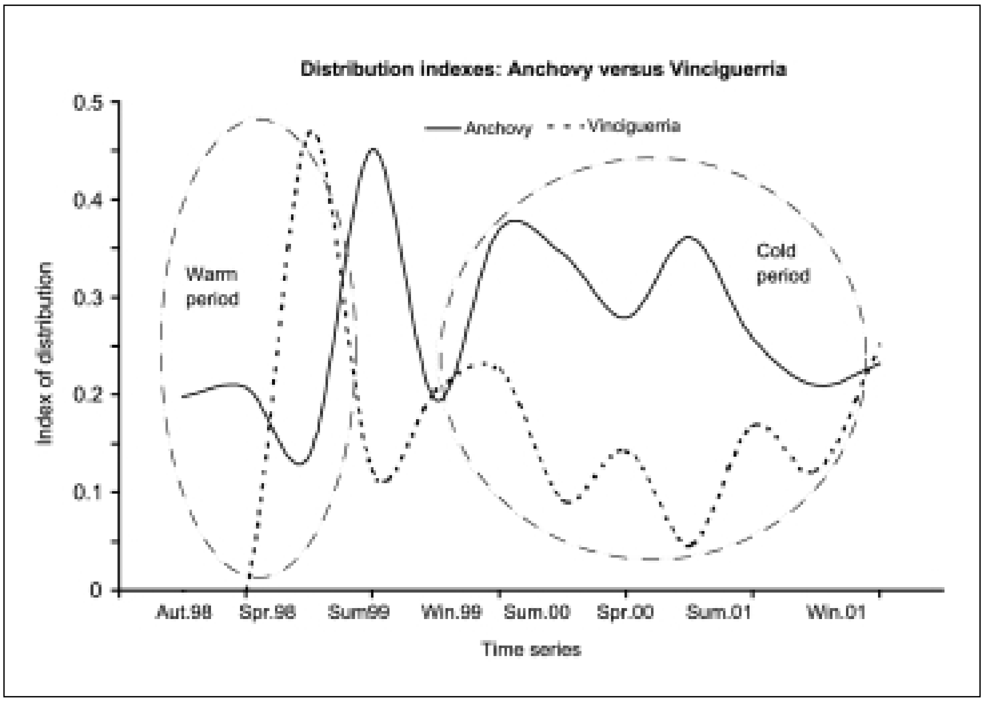

Fig. 3

Conclusions

Acoustics can effectively contribute to studies of the ecosystem through analysis of abundance and distribution indices based in the spatial distribution of NASC values. Hence it is possible to acoustically establish an ecological balance between the abundance and distribution of the main marine populations. Finally, an accurate calculation of an ideal available volume for the distribution of a particular species could be incorporated as a regular predictive tool of fish availability, at least in the case of anchovy, using a new Eureka Programme.

Table 1. Main marine populations in terms of their abundance in Peruvian waters.

Small Pelagics		Mesopelagics		Cephalopods	
Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Anchovy	*Engraulis ringens*	Vinciguerria	*Vinciguerria lucetia*	Giant squid	*Dosidicus gigas*
Sardine	*Sardinops sagax*	Bregmaceros	*Bregmaceros spp.*	Demersals	
Horse mackerel	*Trachurus murphyi*	Myctophids	*Myctophiids spp.*	Common name	Scientific name
Chub mackerel	*Scomber japonicus*	Crustacea		Hake	*Merluccius gayi*
White anchovy	*Anchoa nasus*	Common name	Scientific name	Lumptail searobin	*Bellator loxias*
Bighead	*Diplectrum euryplectrum*	Munida	*Pleuronectes monodon*	Catfish	*Cathorops fuerthii*
Tape fish	*Lepidopus fitchi*				

Table 2. NASC ranges according to types of aggregation.

Category by NASC range (m2/nm2)	Highly Dispersed "HD"	Dispersed "D"	Commercially Abundant "CA"
1	0.1 - 5.0	50.0 - 100.0	500.0 – 750.0
2	5.0 - 10.0	100.0 - 250.0	750.0 – 1000.0
3	10.0 - 50.0	250.0 - 500.0	> 1000.0

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Figure Legends

Figure 1. Area-abundance relationship for Peruvian anchovy.

Figure 2. The relationship among Dispersed (D) area versus Highly Dispersed (HD)+Commercially Abundant (CA) area for Peruvian anchovy.

Figure 3. The variation in acoustic distribution indices for anchovy and vinciguerria off Peru.

IMPACT OF ASSUMPTIONS ABOUT THE DYNAMICS OF MACKEREL SPAWNERS ON THEIR BIOMASS ESTIMATION IN THE BAY OF BISCAY, 2001

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Mackerel and horse mackerel egg surveys have been carried out triennially since 1977 in the NE Atlantic with multinational participation in order to relate the quantities of freshly spawned eggs to the number of parental animals, thus rendering a direct estimate of the spawning stock biomass. As recommended by the ICES Working Group in charge of these surveys, the German cruise completed in March/April 2001 in the Bay of Biscay was divided into two legs. The first leg lasted 3 weeks and surveyed every second transect, while the second cruise lasted 2 weeks and surveyed as many of the skipped transects as time allowed (Fig. 1). Plankton samples collected during the survey were sorted on board during the cruise. Extending each sample to its area of influence shows that the estimation obtained from the first leg alone ($3.3x10^{13}$ eggs) is of the same order of magnitude as that based on both legs ($3x10^{13}$ eggs). Two questions regarding this survey design are raised: is the second leg necessary, and is it relevant to combine the results of the two legs?

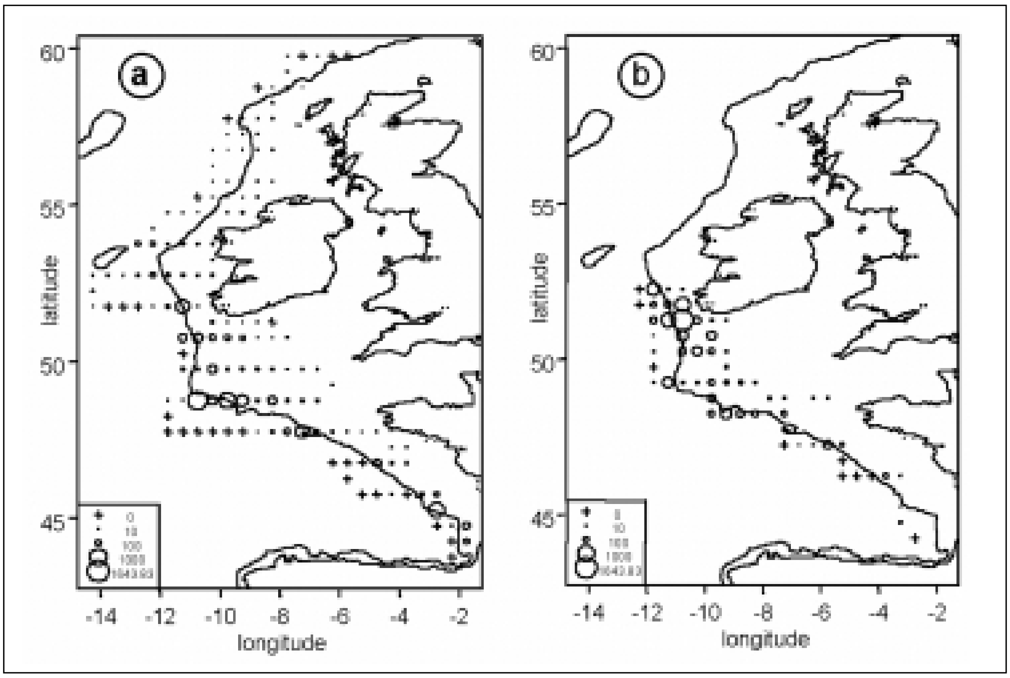

Fig. 1

A geostatistical model (covariogram) is used to analyse the egg spatial structures and to compute estimation variances. The covariograms (Fig. 2) show no difference when computed with either the first leg data or with all the data; both have the same large-scale structure, the same nugget effect, and the same proportion (around 50%) of the spatial structure occurring at distances smaller than the inter sample distance (25 nautical miles). The reduction in the coefficient of variation from 20% to 15.4% for the first leg data and all data respectively is then only due to the reduction of the grid mesh when using both legs (block size =

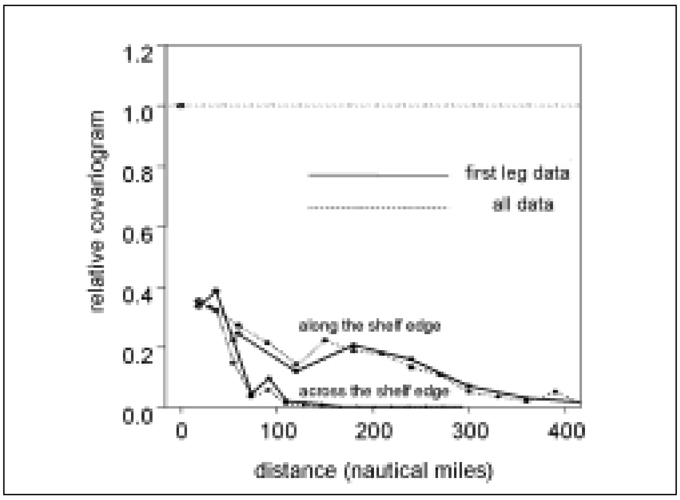

Fig. 2

0.5°x 0.5°) rather than the first leg alone (block size = 0.5° x 1°). Thus, the second leg provides no extra qualitative information compared to the first leg, but contributes to increasing the precision of the estimate in a statistical manner.
Nonetheless, two scenarios for the dynamics of the mackerel spawners are possible, and cannot be distinguished using this sole statistical analysis:

1. As assumed by the Working Group, spawning activity evolves slowly in time and the egg distribution is fairly stable during the entire cruise. In this case, the two legs can be merged and eggs appear to be concentrated in two small, high density patches.
2. The area of high egg concentration observed during the first leg has moved 2° northwards between the two legs. This assumes an equivalent shift of the spawners as the egg development lasts less than 2 weeks (the eggs found during the second leg are certainly different eggs to those observed during the first leg). This assumption could be compatible with the experimental covariograms obtained if the eggs are concentrated in one spot, with a radius of the order of magnitude of one inter-transect distance (half a degree).

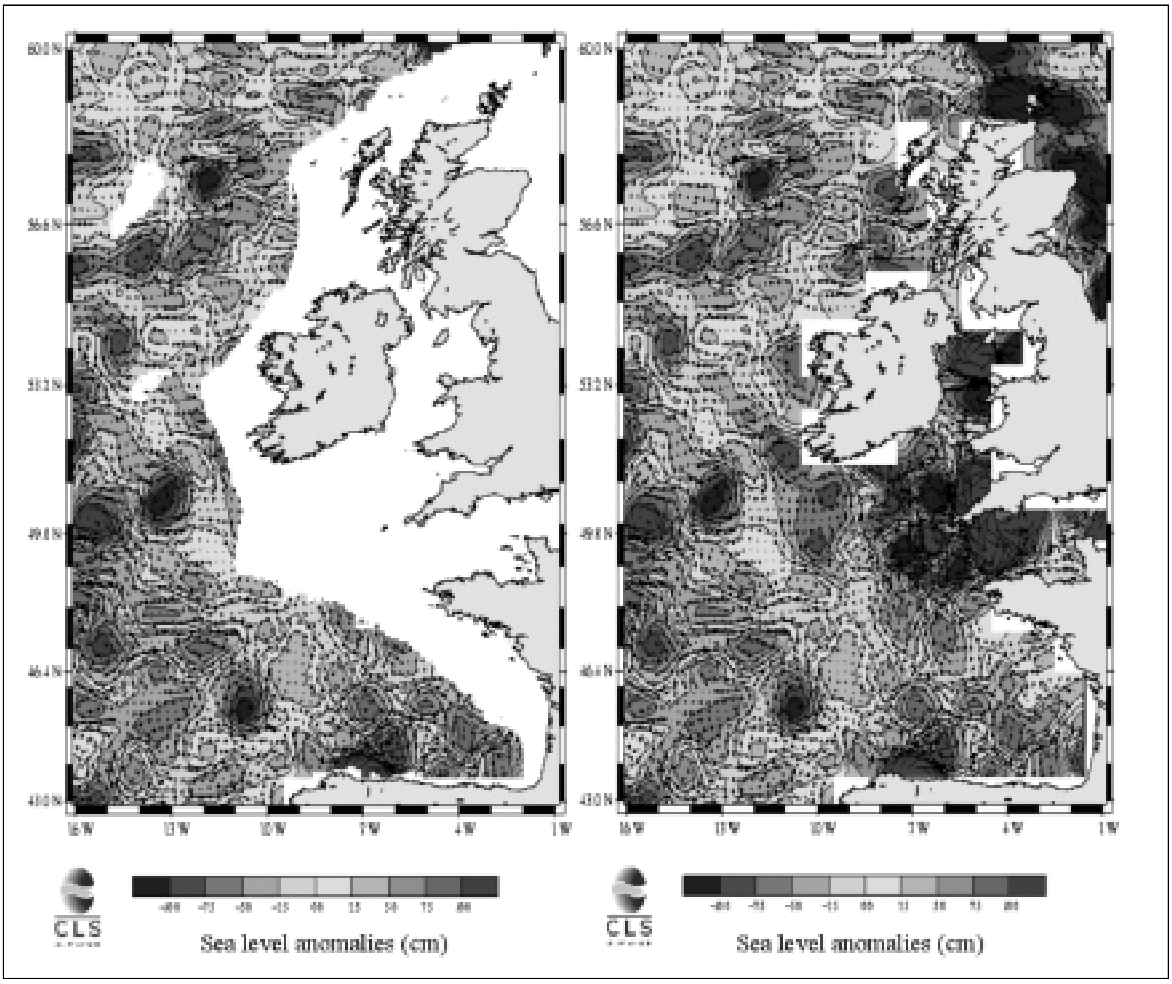

Fig. 3

The potential of altimetric data, *i.e.* measurements of sea levels anomalies (Fig. 3), is discussed with regards to the second alternative above. In particular, changes in altimetric sea conditions are examined as an external driving factor. However, no clear result emerges here.

Finally, a comparison of the covariograms obtained for each of the triennial surveys performed since 1986 shows that the nugget effect changes from year to year while the rest of the covariogram remains stable, that is the presence and/or the observation by accurate sampling of egg patches. This year to year fluctuation of the nugget effect, together with systematic low abundance in areas where a substantial number of samples are collected, supports the idea that the sampling pattern should be revised with particular attention to the inter-transect distance.

Figure Legends

Figure 1. Number of mackerel eggs during the first (a) and second (b) parts of the survey (Cantabrian Sea excluded). Crosses represent zero values and symbol sizes are proportional to the sample values.

Figure 2. Comparison of the covariograms obtained with data from the first leg only and using all data. Computations are made in a reference system conforming to the shelf edge and are expressed in 10-3 nm-2. Results concern the along- and across-shelf directions after normalisation by the value at the origin (i.e. for zero distance).

Figure 3. Example of altimetric maps (the week of 28th March 2001) with (left panel) or without (right panel) the shelf area masked. The tidal signal in shelf areas is such that altimetric measurements are considered invalid.

Summary of spatial distributions of small pelagic fish populations off Peru over the period 1983-2000

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IMARPE carries out one or more acoustic surveys per year targeting, among other species, anchovy, sardine, mackerel, and horse mackerel. From 1983 to 2000, 25 such surveys have been carried out along the coast of Peru, providing an important amount of data that require global and robust tools in order to be synthesised. The objectives of the study were to follow through time the respective positions and dispersions of the four species and their mutual overlapping.

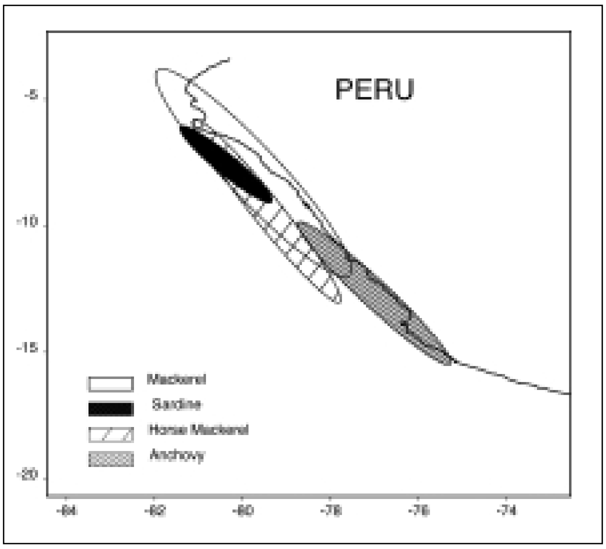

Fig. 1

As an histogram can be summarised by its mean and its variance, a spatial distribution can be summarised by its centre of gravity and its inertia. The centre of gravity represents the mean position of a population while the inertia globally quantifies its spatial dispersion. The inertia can be decomposed into two principal axes, representing the directions of largest and smallest spatial continuity (the ellipses shown in Fig. 1). The centres of gravity and the inertia can be used to compute an index of collocation (ranging between 0 and 1) that globally quantifies the overlapping between two populations (Bez and Rivoirard 2000; Table 1).

The main results of this study show that:

- For sardine, the inertia of the population increases when the abundance increases. This is not observed for the other species (Fig. 2);
- The centres of gravity of anchovy are generally 30 nautical miles east of the other species (*i.e.* closer to the coast; Fig. 3); and
- Over the period 1983-2000, sardine and horse mackerel regularly present high overlapping indices (average=0.90, CV=11%). In contrast, the average of the overlapping indices between anchovy and sardine is low (0.66). Despite this low average, the indices between these 2 species are the most variable (CV=38%); in 1992, anchovy and sardine had a very high index of collocation (0.98) but a very low one in 1994 (0.27).

The tools presented in this study enable a rapid, routine analysis of a large amount of data that will:

- Characterise the spatial distribution of each population; and
- Follow the evolution through time of the spatial dispersion of each population, and the overlapping between populations.

References

Bez, N. and J. Rivoirard. 2000. Indices of collocation between populations. In Checkley, D.M., Jr, Hunter, J.R., Motos, L. and C.D. van der Lingen. (eds.). Report of a workshop on the use of the Continuous Underway Fish Egg Sampler (CUFES) for mapping spawning habitats of pelagic fish. *GLOBEC Report* 14: 48-52.

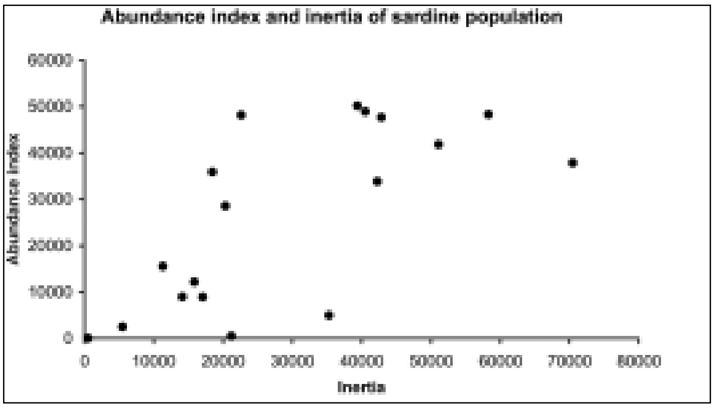

Fig. 2

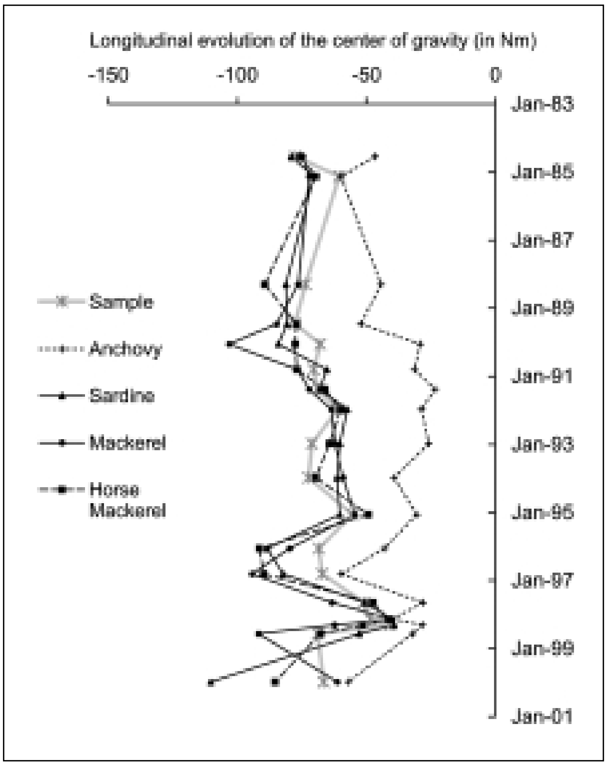

Fig. 3

Table 1. Global index of collocation for anchovy, horse mackerel, mackerel and sardine in April 1994.

	Anchovy	*Sardine*	*Mackerel*
Sardine	*0.27*		
Mackerel	*0.52*	*0.98*	
Horse mackerel	*0.66*	*0.81*	*0.93*

Figure Legends

Figure 1. Spatial distributions of anchovy, horse mackerel, mackerel and sardine off Peru in April 1994.

Figure 2. Abundance index versus inertia of the sardine population off Peru.

Figure 3. Distance (in degrees) from the coast of the centers of gravity of anchovy, horse mackerel, mackerel and sardine off Peru, 1983-2000.

ADVANCES IN RESEARCH ON THE SPATIAL DISTRIBUTION OF ANCHOVY AND SARDINE OFF THE PERUVIAN COAST

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Introduction

The climatic and oceanographic conditions off the Peruvian coast present a great spatio-temporal variability that can operate over short (seasonal), medium ("El Niño" – "La Niña") and long-term (cold period–warm period) timescales. Peruvian waters are characterized by cold water masses and important upwelling areas that permit the development of high abundances of species like anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax sagax*) that support the Peruvian pelagic fishery.

Methods and materials

Since 1950, IMARPE has collected statistics on landings of the pelagic resources and the distribution of catches from the Pelagic Fisheries Monitoring program. Biomass estimates and data on distribution patterns are collected during Pelagic Resources Hydroacoustic Surveys and information on anchovy behavior from the Fishery Logbook Project.

Results

Spatial distribution - During 2000 the main anchovy concentrations were located in upwelling areas, with the most important off Chimbote (9°S), Huacho–Chancay (11°S) and Pisco (13°S). The main sardine concentrations were located off Chimbote (9°S) and Paita (5°S). Anchovy shows a seasonal distribution pattern, being found close to the shore and near the surface in summer and extending further offshore and deeper in the water column during winter. During both summer and winter a latitudinal migration of schools is observed. However, this pattern changed during the occurrence of the "El Niño 1997/98" event. Initially the anchovy became concentrated within 10 nautical miles of the coast. The anchovy moved deeper in the water column (to depths of 30m on average) and simultaneously undertook a massive migration to the south. Sardine also concentrated inshore but to a lesser extent than anchovy, and also moved deeper in the water column (to 40m). The largest sardine concentrations were displaced to the central coast. With the normalization of environmental conditions, both species returned to the original pattern (Plate 6).

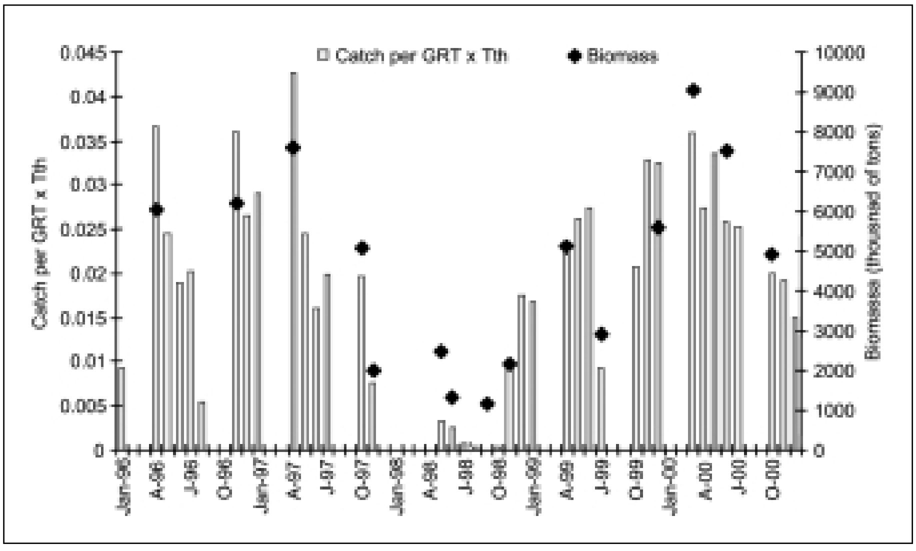

Fig. 1

Relative abundance – Over the period 1996-2000 relative abundance indices (CPUE) have been affected by factors influencing the catchability (strategy, management) and availability (environmental conditions) of anchovy. In 1996 the maximum CPUE values were obtained during fall and spring. During 1997 the maximum relative abundance value of the time series was obtained in Aril, and coincided with the beginning of "El Niño", as a result of the concentration of anchovy close to the shore and hence being more accessible to fleet. After this period and as a result of the fish moving deeper in the water column and migrating to the south, the relative abundance decreased to lower levels in August and remained low until the end of 1998. During 1999 a rapid increase in anchovy abundance was observed, with CPUE reaching the maximum value during the last trimester of the year and remaining high into 2000.

A second relative index of anchovy abundance, namely catch size (expressed as Tons/[Gross Registration Tonnage*Total trip hours]), showed the same trend described above (Fig. 1), and also showed a significant correlation with biomass estimates obtained from various survey cruises (r^2=0.823). Estimates of sardine relative abundance obtained from the same index (Tons/[GRT*Tth]) showed a progressive decrease in values from January 1996 to June 1998, that then recovered but not to the same levels as seen in past years. Low levels were constant during 2000.

School size index – The catch per set (or haul) was used as an index of anchovy school size. It shows a direct relationship with environmental conditions, being correlated to sea surface temperature anomalies. The largest school size (up to 120 tons) were observed during a period of negative SST anomalies reaching to -2°C. During periods of positive anomalies school size was reduced considerably, as was seen in 1997–1998 when anomalies reached +8°C and schools were only 20 tons in size (Fig. 2). For sardine, school size remained constant for the first half of 1997, but were reduced until May 1998 and then recovered until October 1999. After this period school size followed the same tendency as relative abundance and biomass, and decreased in a progressive manner to current low levels.

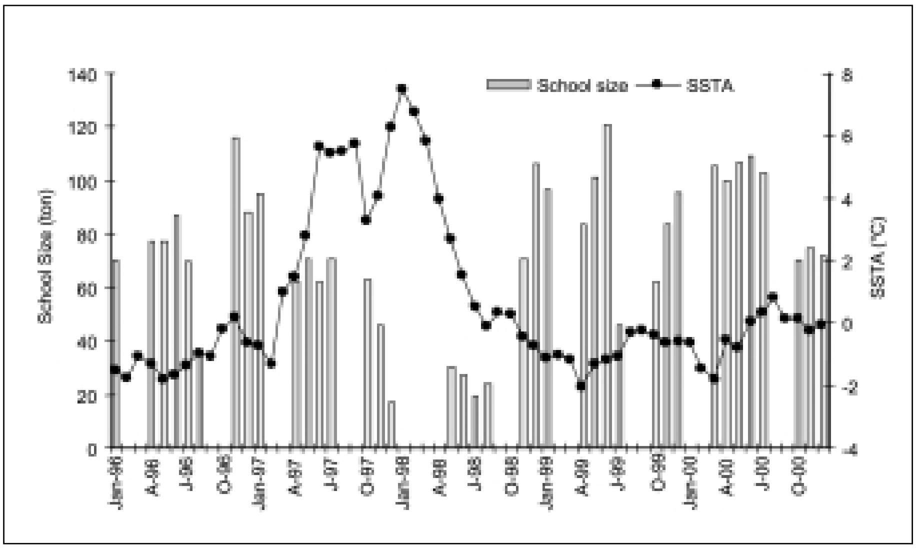

Fig. 2

Recruitment - During cold years such as 1996, 1999 and 2000 anchovy recruitment occurred in coastal areas related to upwelling areas. The modal progression by latitudinal degrees showed a south–north migratory tendency, indicating that the individuals were moving from south to north while they were growing, with the largest number of old individuals found between 4° and 5°S. Nevertheless, when environmental conditions were altered this pattern was reversed and showed a modal size progression in the opposite direction, indicating movement from north to south. Moreover recruitment areas were scarce and were restricted to the central region. The opposite case happened with sardine because the occurrence of "El Niño" expanded the recruitment areas and the magnitude of recruitment. During this period the longitudinally-expanded recruitment area was located off Chimbote (9°S), while in a normal year such as 1999 sardine recruitment occurred in a restricted area to the north of Chimbote.

Conclusions

The following conclusions can be drawn from this study.

- Under normal conditions the anchovy displacement pattern at the Peruvian coast is from south to north (Pisco, 13°S to Chicama, 7°S). This situation is changed by the effects of "El Niño", during which time migration is from north to south;

- The vertical distribution presents a seasonal pattern, with schools being deeper in winter and ascending to the surface at summer. During "El Niño" conditions the school depth increases;
- A significant relationship exists between acoustic biomass and relative anchovy abundance (Tons/[GRT*Tth]);
- Anchovy school size increases in cold conditions (SST anomalies from 0 to -2°C). Sardine school size increases in warm conditions; and
- Sardine recruitment is favoured during "El Niño" while anchovy recruitment is restricted to the southern shores. Despite low anchovy recruitment during "El Niño", the biomass of this species increased immediately after the event.

Figure Legends

Figure 1. Relative Abundance Index (Tons/[GRT*Tth]) for anchovy obtained from the Fishery Logbook Project and acoustically-estimated biomass obtained from hydroacoustic surveys from 1996 to 2000.

Figure 2. Anchovy school size obtained from the Fishery Logbook Project and Sea Surface Temperature Anomalies (off Chicama) from 1996 to 2000.

Alternate dominance in sardine and anchovy biomass in the Chilean central area: competition or ecosystem dependence?

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Introduction

Anchovy (*Engraulis rigens*) is distributed from the south of Peru to the central zone of Chile, while the common sardine (*Strangomera bentincki*) is only located in the south central zone. Both species share the area between latitudes 34°00'S and 40°00'S. The biological aspects of common sardine and anchovy are: (i) a short life span, (ii) rapid growth in length, with a seasonally oscillating growth rate; (iii) high natural mortality; (iv) adults feed mainly on phytoplankton; (v) oviparous, external fecundation with partitioned laying; and (vi) a seasonal fishery, with catches heavily dependent on yearly pulses of recruitment. The average annual biomass for both species is 1,072 million tons over the period 1991–1999, although the biomass decreased in years when the zone was influenced by the El Niño phenomenon (16% of the average in 1992 and 4% in 1997). The relative proportion of each species varied interannually.

Both common sardine and anchovy reproduce in winter and recruits appear at the end of the austral spring and beginning of summer. We studied the 2000 and 2001 recruitment of both species in December 1999 and January 2001. During these periods we performed acoustic surveys using a SIMRAD EK500 echo sounder and estimated recruit and adult biomass of each species. Oceanographic data (temperature, salinity, dissolved oxygen and chlorophyll *a)* were also collected along transects. We analysed the relationship between the biomass and distribution of the two species and the amount of precipitation measured using a pluviometer and the upwelling index calculated from wind values.

Species distributions

In December 1999 the common sardine was distributed as far as 25nm from the coast, and the anchovy was encountered until 30nm offshore, whilst in January 2001 the common sardine and anchovy presented a more costal distribution, only being found up to 15nm from the coast. In December 1999 50% of the common sardine and 52% of the anchovy biomass was distributed to a depth of 15m from the surface. In January 2001 70% of common sardine and 63% of anchovy was distributed to a depth of 15m. Thus, the resources presented a more near-surface distribution in 2001. In December 1999 58% of anchovy and 39% of common sardine were distributed inside the thermocline layer, whilst in January 2001 91% of anchovy and 95% of sardine were distributed below the thermocline upper limit.

Latitudinal distribution and relationships with oceanographic parameters

In December 1999 common sardine was distributed in specific areas, being principally located close to river mouths and therefore showing a preference for low salinity waters. Common sardine were located in areas of low thermal (0-0.35 °C/nm) and salinity (0.1 psu/nm) gradients. Anchovy was mainly distributed in areas of low temperature, close to the upwelling areas, where thermal gradients were high. In January 2001 common sardine distribution was linked to low temperatures because of the influence of upwelling influence, but it was again encountered close to river mouths and in areas of low salinity. Anchovy was observed in low temperature areas, where upwelling-linked gradients were high. In 2001 anchovy was also encountered close to river mouths. In both years both species were encountered in areas with low chlorophyll concentrations.

Comparison of species distributions

A comparison of common sardine and anchovy distributions in December 1999 showed that each species occupied specific areas. In areas of high common sardine abundance, anchovy biomass was absent or very low, and *vice versa*. This is in contrast to the observations made in January 2001, when common sardine and anchovy were encountered in the same areas. In high anchovy density zones however, common sardine density was low. In December 1999 common sardine was present in 47% of ESDU, anchovy in 47% of ESDU, when both species together in 6% of ESDU (Fig. 1). In January 2001 common sardine was present in 48% of ESDU and anchovy in only 18% of ESDU, but both species were encountered together in 33% of ESDU.

This result indicates that the overlap in common sardine and anchovy distributions differ interannually. The question is whether these differences are due to environmental conditions or to trophic competition, since both species are at the same trophic level and consume similar prey and have the same predators. The environment where these clupeids are encountered is a thin coastal layer with high hydrodynamic variability. Hence coastal oceanographic conditions vary at small and medium scales.

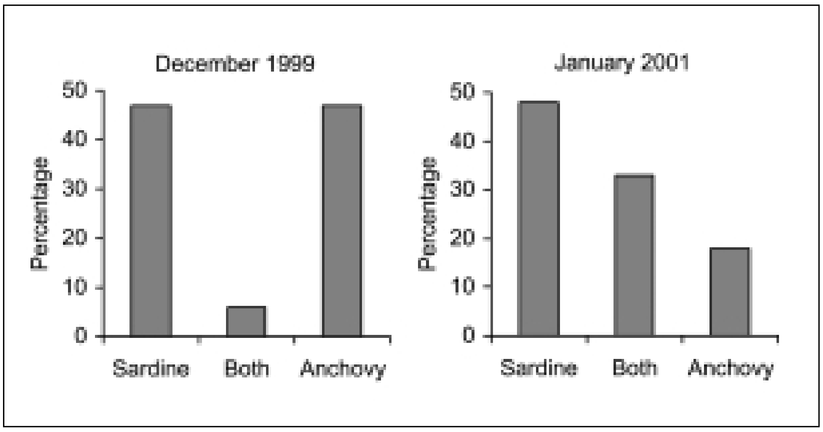

Fig. 1

Comparison of environmental conditions in 1999 and 2000

Analysis of rainfall data (sampled at 36°40'S) shows that 1999 was a very dry (10 inch) year arising from a La Niña influence, whilst in 2000 rainfall was high (52 inch). The influence of rainfall is higher close to the river mouths; thus when river flow and wind speed are low sardine and anchovy occupy different areas. In contrast, when river flow and the resultant plume increase due to high rainfall, the intrusion in coastal waters of desalinated water becomes more important and distribution of the two species is more homogeneous, with both present in the same areas. Analysis of wind speed during October (which corresponds to the beginning of the upwelling season) shows that the wind intensity was low in the spring of 1999, with a maximum later than the cruise period. In contrast, spring 2000 was characterised by higher wind speed intensity during the cruise.

Distribution patterns and the environment

Results show that both species present contagious aggregative patterns; the concentration index (the ratio between the number of sampling units representing fish and the total number of sampling units) in December 1999 is highest (26.3%) for anchovy in December 1999 but highest (43.5%) for common sardine in January 2001 (Table 1). The relationship with oceanographic conditions indicates that the distribution of common sardine is related to the amount of precipitation, whilst anchovy is located in upwelling areas, which depends on local wind conditions.

In addition to distributional differences between the two years, alternate dominance in abundance between these two species is apparent: in 1999 anchovy dominated with 60.3% of the total biomass while in 2000 sardine was dominant with 57.2% of the total biomass (Table 1). We propose the hypothesis that this alternate dominance is not due to any competition between the two species, which depend on different ecological enrichment systems, but rather on the meteorological condition favouring alternately one of these two systems.

Table 1: Covering indices (positive ESDU/total ESDU) and relative biomass (%) for anchovy and common sardine during acoustic surveys in December 1999 and January 2001.

Year	Covering Index (CI) (Positive ESDU/Total ESDU)	
	Anchovy	Common Sardine
2000 (Dec ‘99)	26,3	15,7
2001 (Jan ‘01)	30,5	43,5
	Biomass (%)	
	Anchovy	Common Sardine
2000 (Dec ‘99)	60.3	39.7
2001 (Jan ‘01)	42.8	57.2

Figure Legends

Figure 1. Percentage of elementary sampling distance units (ESDU) having a presence of common sardine, anchovy and both species in acoustics surveys.

INFLUENCE OF LATITUDE VARIATIONS IN SPAWNING HABITAT CHARACTERISTICS ON THE EARLY LIFE HISTORY TRAITS OF THE ANCHOVETA, *ENGRAULIS RINGENS*, OFF NORTHERN AND CENTRAL CHILE

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Introduction

The Peruvian anchoveta, *Engraulis ringens*, is distributed along the Humboldt Current from 4˚S through to 42˚S, a latitudinal range over which strong variations in environmental conditions occur. The effect of latitudinal changes in oceanographic conditions on early life history traits of the anchoveta, a species that constitutes one of the most important pelagic fisheries of the world, has, however, been traditionally ignored. Most of the studies throughout the species range have been carried out to determine egg and larval distributions, for adult stock assessment or as recruitment studies, primarily on the largest stocks.

Three major stocks are recognized along the Humboldt Current System; the largest stock off northern Peru, a medium-sized one off southern Peru–northern Chile, and a smaller stock off central Chile. In an attempt to determine how the early life stages of this species cope with the variations in environmental conditions along its latitudinal range, a series of studies were initiated in 1995 in the southern stock area (Castro *et al.* 2000, Castro and Hernandez 2000, Hernandez and Castro 2000). These studies have now been extended to the area of the medium-sized stock. In this study we report a) preliminary results on variations in some early life history characteristics of populations located at different latitudes along northern and central Chile, and b) we document latitudinal variations in environmental characteristics during the spawning season that correlate with the early life history traits under study. The early life history characteristics analyzed are: i) egg size, ii) larval hatch size, iii) yolk volume at hatch, and finally iv) larval growth rates. The approach has been to combine information and samples collected in the field with new results of egg and larval rearing experiments carried out under laboratory-controlled conditions.

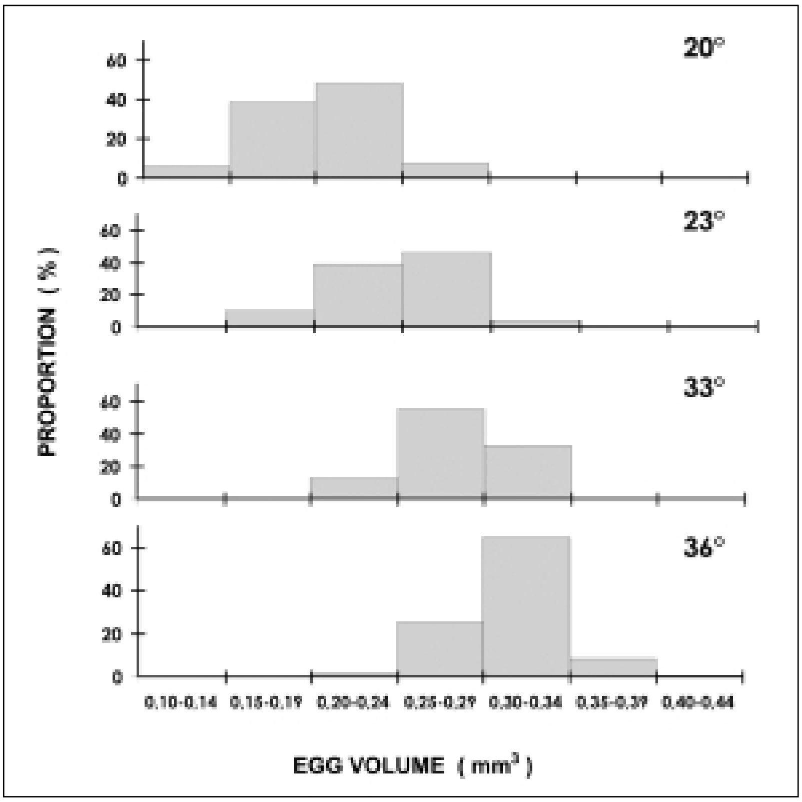
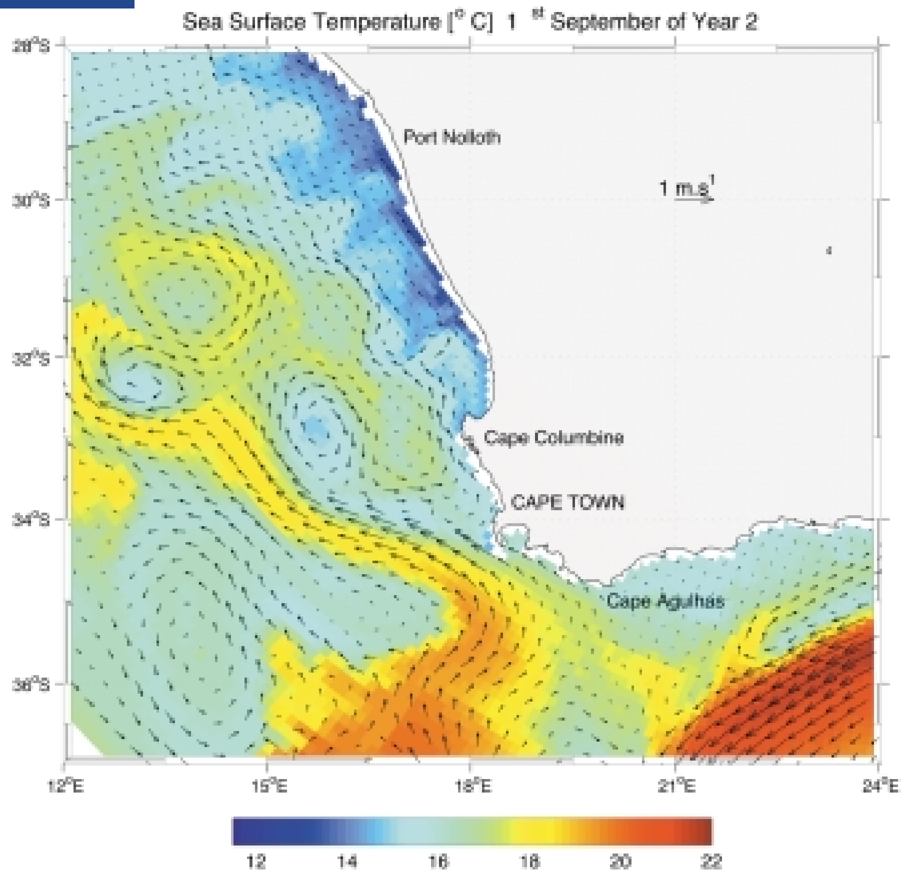


Fig. 1

Results

The analyses of egg size data based on ichthyoplankton samples collected during the peak spawning season (July – September) in 1996 show that

PLATE 1



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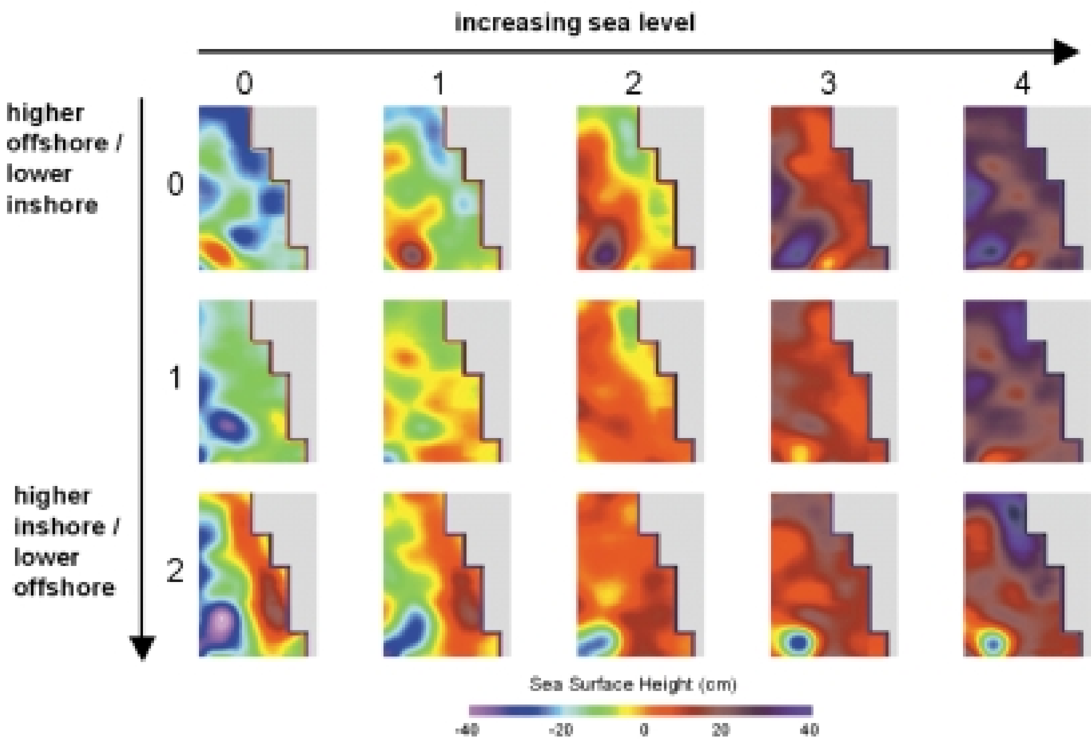

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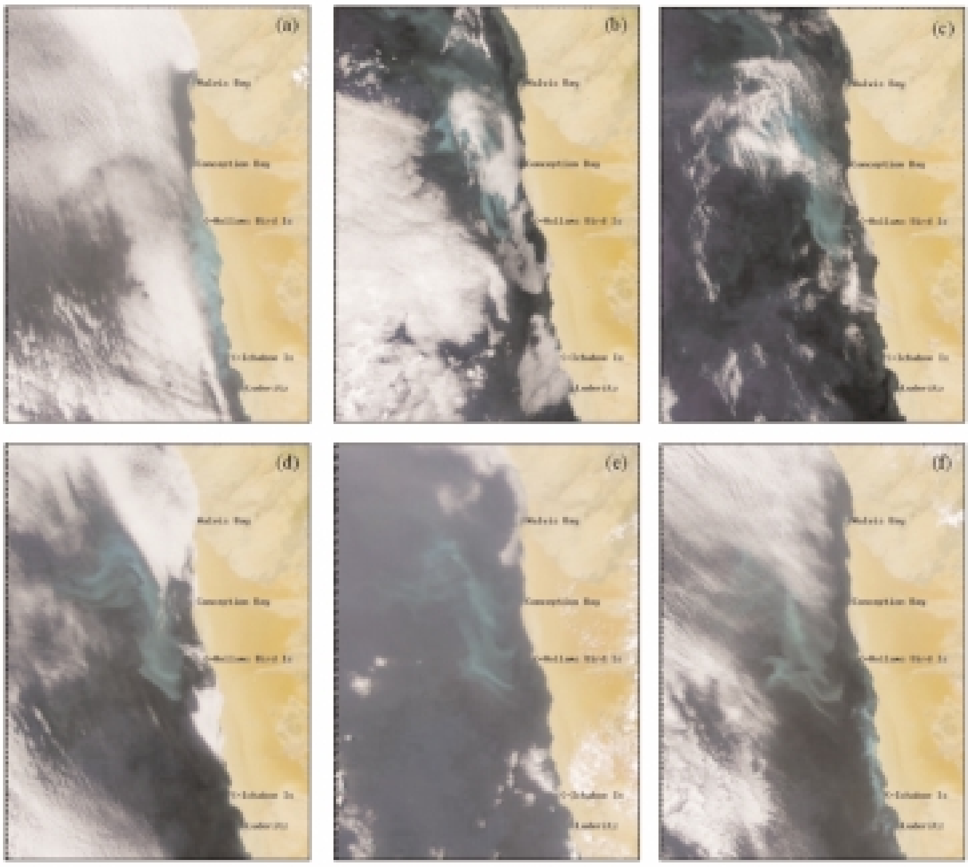

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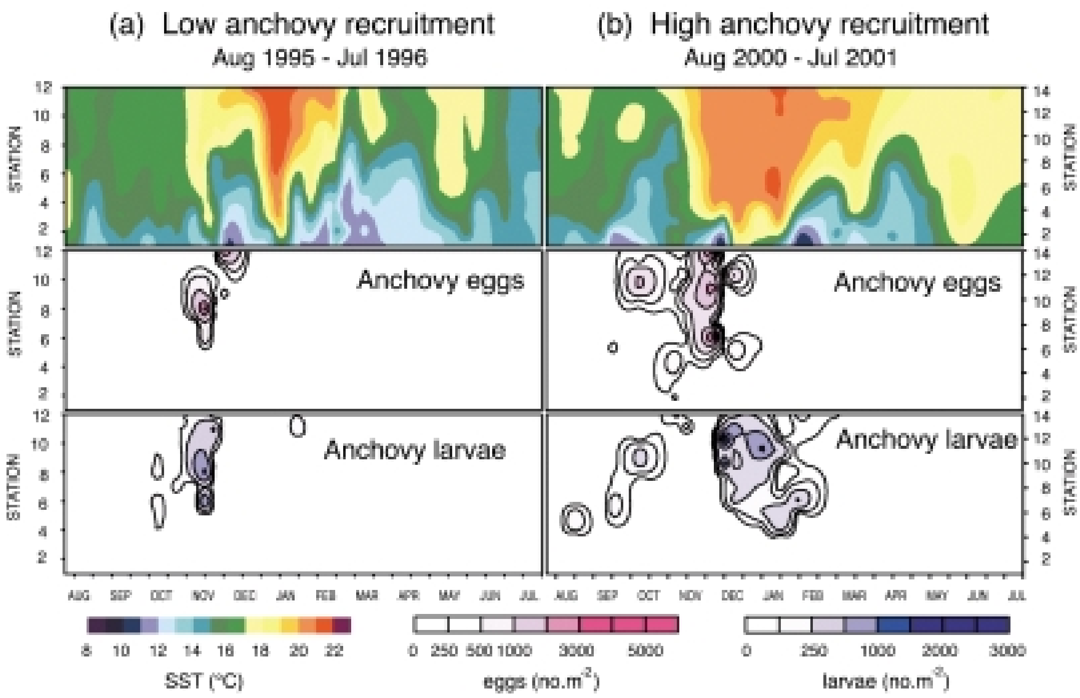

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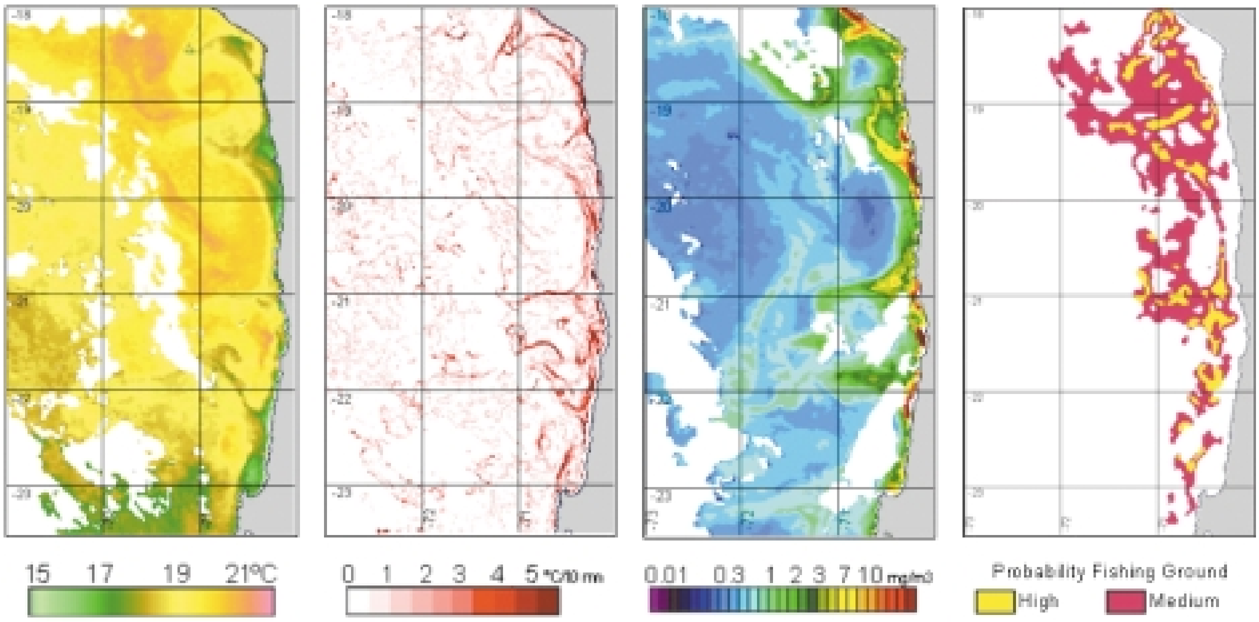

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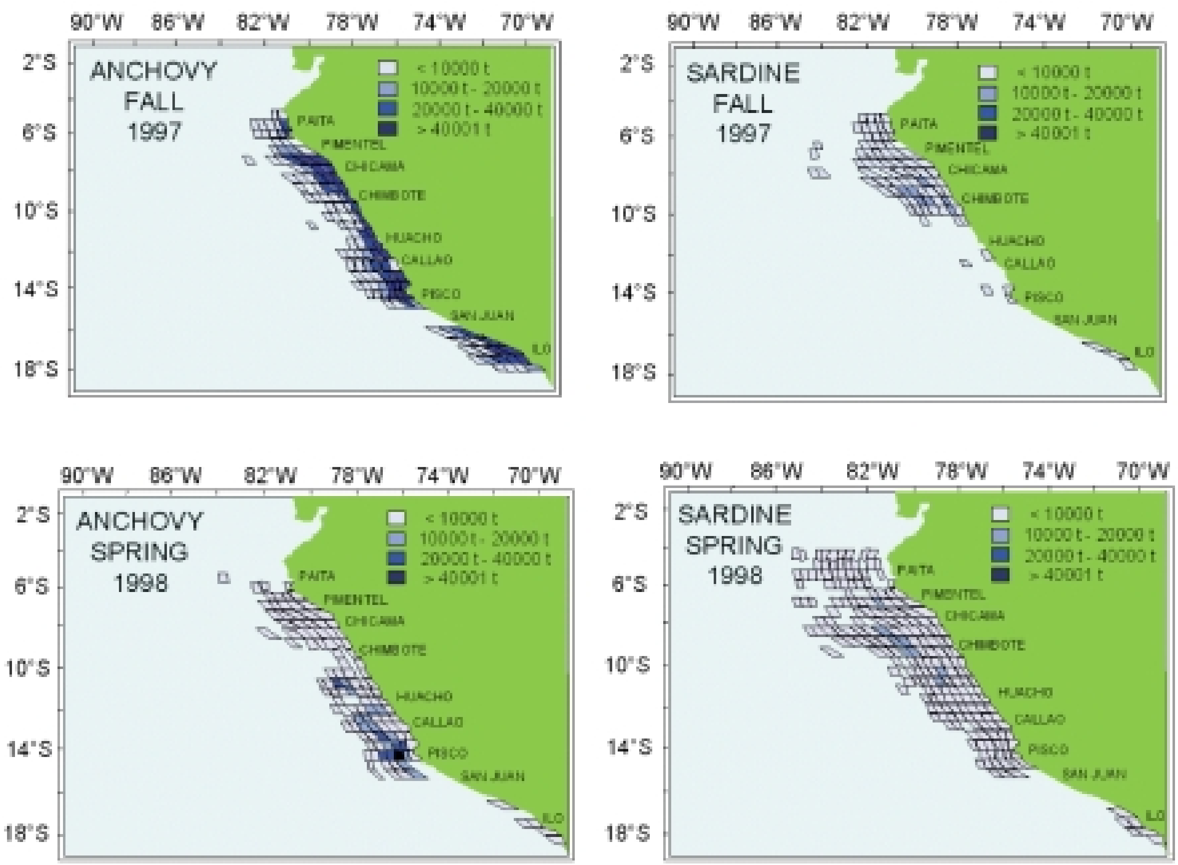

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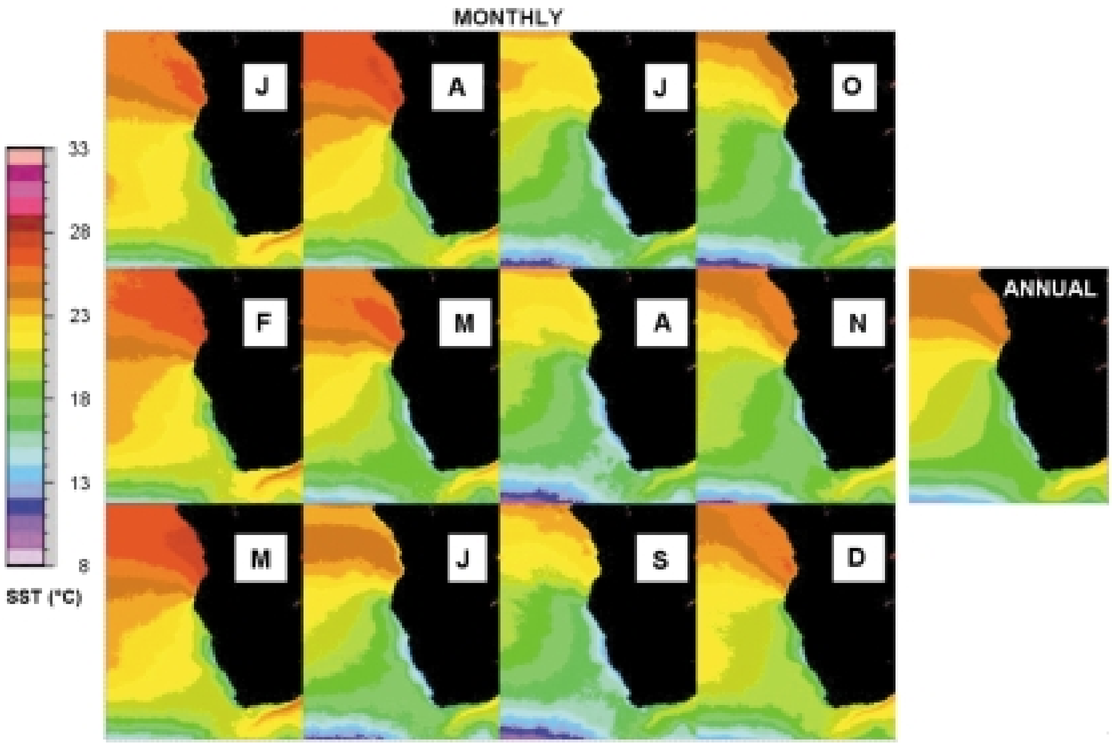
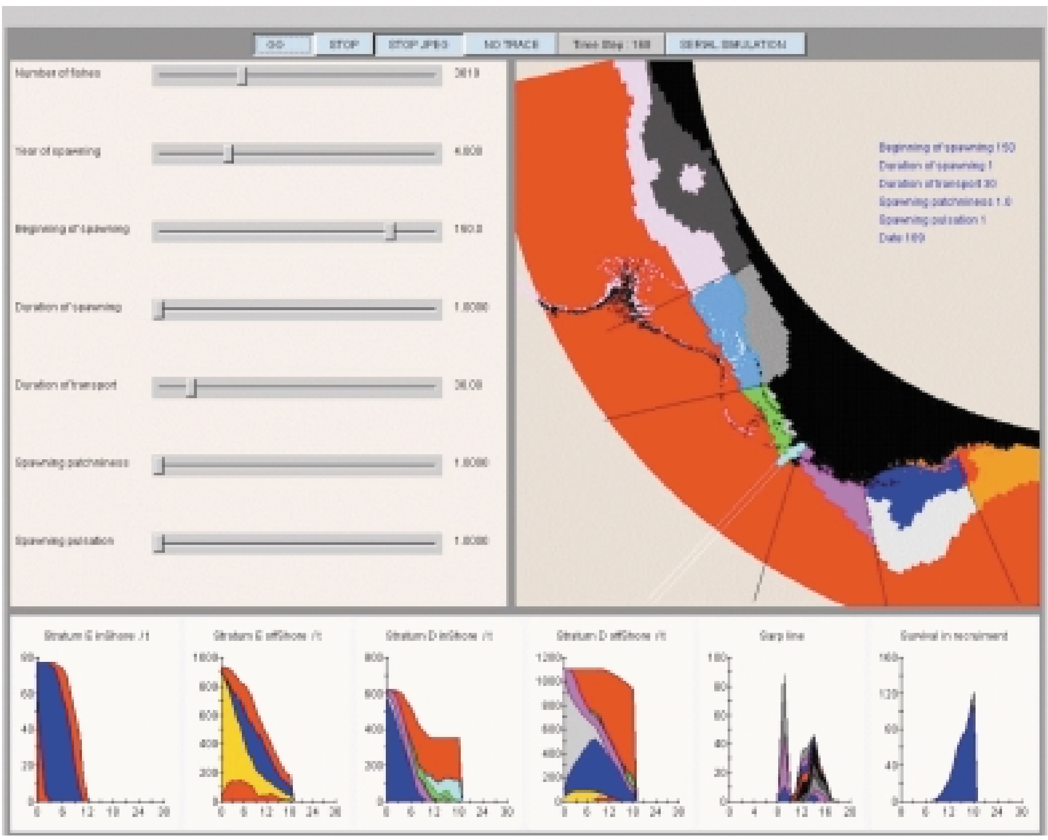


Plate 8



the mean anchoveta egg volume increase with latitude (Fig. 1). At the southern location considered in this study (Talcahuano, 36˚S), the mean egg volume was 55% larger than that of eggs from the northern location (Iquique, 20˚S).

From rearing experiments carried out on stage-III eggs collected from the wild during the peak spawning season at two localities (Antofagasta and Talcahuano) in the year 2000, we determined that larval size at hatching increased only slightly with latitude. Larvae at the southern location (Talcahuano, 2.81mm notochord length) were only 5% longer than those hatched from eggs collected at the northern experimental location (Antofagasta, 2.66mm notochord length), with both eggs and larvae reared at the same temperature (15˚C). Interestingly, the yolk volume of recently hatched larvae showed the greatest

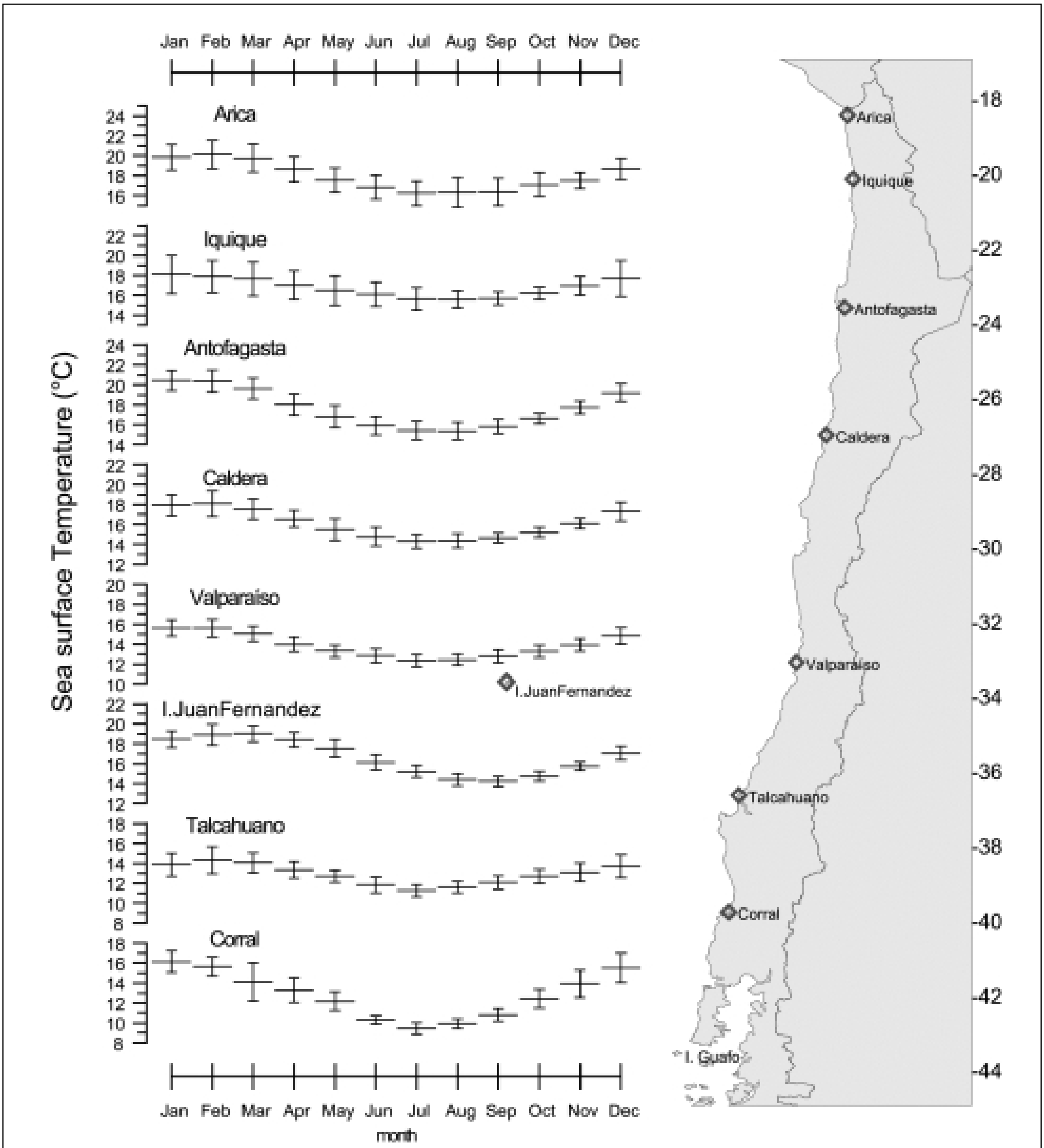


Fig. 2

variation between localities, with the volume of southern larvae (Talcahuano, 0.12mm^3) being on average twice that of recently hatched larvae from the northern location (Antofagasta, 0.05mm^3). As the number of recently hatched larvae measured is small (< 50 larvae) these results, although very remarkable, should be still be considered preliminary.

The growth rates determined for larvae reared in the laboratory under the same temperature and feeding conditions in Antofagasta and Talcahuano tended to increase with temperature. Growth rates were on average between 20 and 30% higher for larvae from the northern population (Antofagasta) at all temperatures considered (10, 12, 15 and 18˚C). Interestingly, at the lowest temperature utilized (10˚C), survival was very low in larvae from Antofagasta, in contrast to the situation that occurred in larvae from the Talcahuano population where survival was lowest at the highest temperature (18˚C).

Discussion

Our results show that egg size, larval length at hatch, and yolk sac volume of recently hatched larvae increase with latitude, and that instantaneous larval growth rates decrease with latitude. Concurrently, from our time series of environmental characteristics during the peak spawning season in winter we determined that the sea surface temperature decreases with latitude (*i.e.* about 4˚C difference between Antofagasta and Talcahuano, Fig. 2), wind induced turbulence increases with latitude, and offshore surface Ekman transport decreases with latitude (Fig. 3). A brief analysis of these results suggests they are in agreement with the expectations based on known temperature effects on physiological rates (Houde 1989) and on ecological factors related to the requirement for the retention of early life stages in nearshore environments (Bakun 1996). At lower latitudes the sea surface temperature is higher and the offshore surface Ekman transport is stronger, suggesting that larvae growing in such conditions should grow rapidly. Alternatively, anchovy larvae at higher latitudes are retained nearshore in winter (as the Ekman transport is negative) but are exposed to lower temperatures and to very strong turbulence that may not facilitate the first feeding of recently hatched larvae and subsequent rapid larval development.

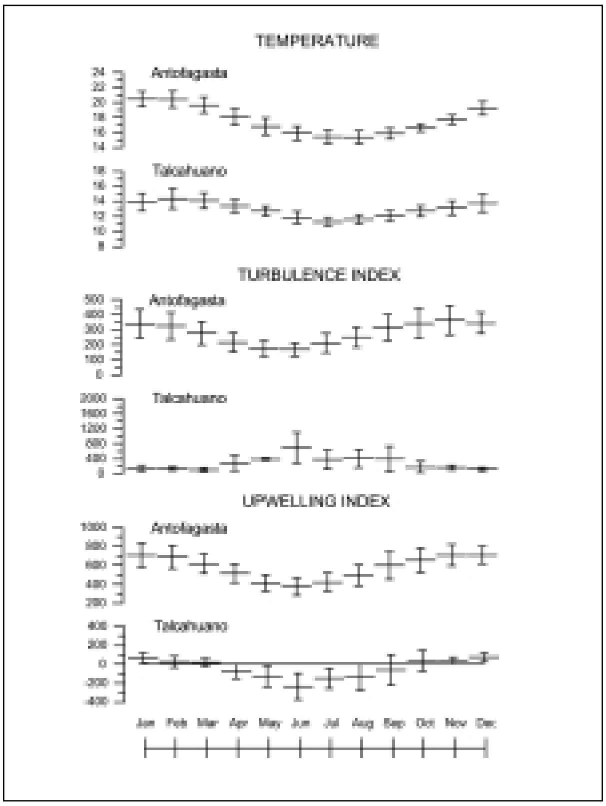


Fig. 3

Another important implication of this study results from the comparison of larval growth rates between populations located in northern and central Chile. Both populations showed plasticity in their larval growth rates; however, their tolerance to extreme lower and upper temperatures differed. This suggests that their capacity for growth is different (Conover 1990, Conover and Present 1990) and, therefore, that some selection might be taking place between these populations located at different latitudes.

Acknowledgements

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Figure Legends

Figure 1. *Engraulis ringens* egg volume distribution at different latitudes along the Chilean coast from field samples collected during the peak anchoveta spawning season.

Figure 2. Time series from 1970-1999 of sea surface temperature (˚C) measured at the tidal gauge stations along the Chilean coast.

Figure 3. Time series from 1970-1999 of sea surface temperature (˚C), turbulence index m^3/s^3) and upwelling index ($m^3/s/1000$) at Antofagasta (23˚S) and Talcahuano (36˚S).

TEMPORAL SHIFTS IN THE SPATIAL DISTRIBUTION OF ANCHOVY SPAWNERS AND THEIR EGGS IN THE SOUTHERN BENGUELA: IMPLICATIONS FOR RECRUITMENT

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Marine and Coastal Management, Cape Town, South Africa

Stock assessment surveys for anchovy (*Engraulis capensis*) and sardine (*Sardinops sagax*) have been conducted off South Africa since 1985. During the spawner biomass surveys carried out in early summer, data on the abundance and distribution of adults and their eggs is collected using hydroacoustics and CalVET net samples respectively. The Western Agulhas Bank (WAB) was previously considered to be the major spawning area of anchovy in the Southern Benguela (Shelton *et al.* 1993, Roel *et al.* 1994), selected by fish because of the efficiency of transport of eggs and larvae to the West Coast nursery grounds by the shelf-edge jet current (Hutchings *et al.* 1998). Over the period 1985-1989, over two-thirds of the anchovy biomass observed during November spawner surveys was located west of Cape Agulhas, primarily over the WAB (Fig. 1a). From 1990-1994, half of the anchovy biomass was found west of Cape Agulhas, and the other half east of Cape Agulhas, whilst in 1995 most of the anchovy biomass was again located over the WAB. In 1996 however, the anchovy population was at its lowest observed level (143 000 tons), and almost all (80%) of this biomass was located east of Cape Agulhas, principally over the outer shelf of the CAB and EAB. Since then this pattern has continued, with the bulk (>60%) of the anchovy population observed during spawner biomass surveys being found east of Cape Agulhas (Fig. 1a). This shift from the WAB to the Central and Eastern Agulhas Banks is also evident for anchovy eggs, although it occurred earlier (1989) than that observed for the spawners (Fig. 1b). From 1996 onwards, only 14-29% of the total egg abundance observed during November surveys was found west of Cape Agulhas. Hence the region east of Cape Agulhas appears to have replaced the WAB as the principal anchovy spawning area.

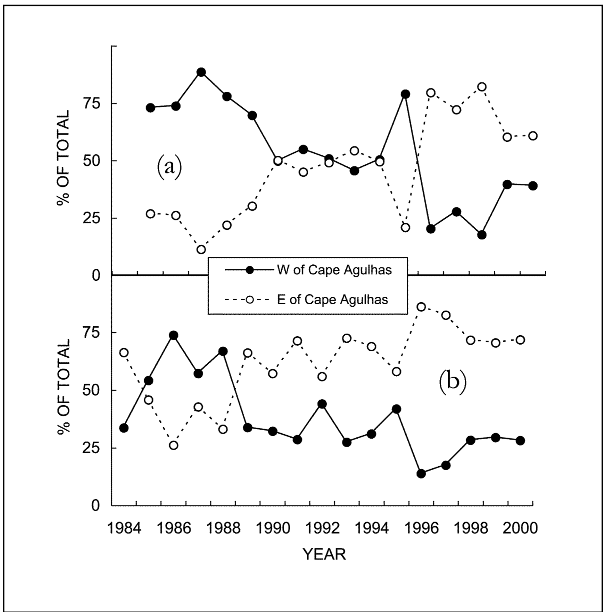

Fig. 1

Concomitant with the observed eastward shift in the principal anchovy spawning grounds has been a change in relative anchovy recruitment strength (recruitment biomass in year-n divided by spawner biomass in year$_{n-1}$). For the first 12 years of the time-series (1985-1996), relative anchovy recruitment was stable and low, with an average value of 0.34±0.25. From 1997-2001 however, relative anchovy recruitment became higher and more variable, having an average value of 1.21±1.12 (Fig. 2). Although the mean values of these two periods are not statistically significant at the 5% level, the data suggest either an increasing trend through time, or a "switch" from low and stable to high and variable relative recruitment. The close correspondence between the timing of the observed eastward shift in anchovy spawning and the increased relative recruitment strength suggest that the two may be linked.

Possible mechanisms for this linkage are explored in the presentation. Cury's (1994) "extended natal homing" reproductive strategy hypothesis is used to suggest why the CAB and EAB have remained the principal anchovy spawning grounds since 1996. Cury (1994) postulated that from one generation to the next, individuals avoid the experience of new reproductive environments by attempting to replicate the environmental conditions in which they were spawned. If this is the case, then newly-spawned anchovy memorize environmental cues characteristic of the CAB and EAB through teleonomic and irreversible

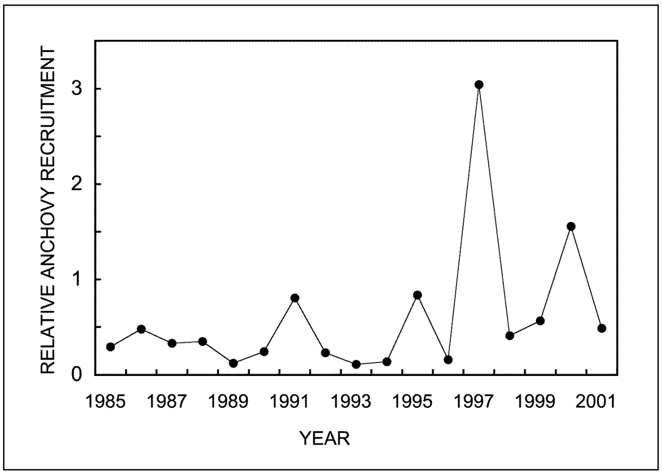

Fig. 2

imprinting, and attempt to return there themselves to spawn. That the CAB and EAB are now the major anchovy spawning grounds, and have remained so since the shift from the WAB was initiated in 1996, supports this hypothesis.

It is speculated that the increased relative recruitment resulting from this eastward shift may arise from the enhanced condition of spawners on the CAB and EAB compared to the WAB. The "parental condition" hypothesis suggests that spawners in good condition (*i.e.* having large lipid reserves) produce fewer, larger eggs than spawners in poor condition. Because of their large size and high lipid content, such eggs are likely to have a higher survival probability than those produced by poor condition parents. A positive effect of parental condition on subsequent recruitment success has been shown for Japanese sardine, where strong year classes developed from high-quality eggs that were relatively few in number (Morimoto 1996). Similarly, a positive relationship between recruitment success and the total lipid energy content of the parental stock has been shown for Barents Sea cod (Marshall *et al.* 1999). An east-west gradient in the condition of anchovy spawners over the Agulhas Banks appears plausible, given that the CAB and EAB have higher copepod biomass and hence provide a better food environment for anchovy than does the WAB (Hutchings *et al.* 1995, Hutchings and Field 1997). Estimates of the lipid content of anchovy during spawner biomass surveys made from visual assessments of mesenteric fat do show a spatial component, with anchovy over the CAB and EAB having slightly higher lipid levels than those over the WAB (Fig. 3). However, these results are preliminary and further work in this field is required, including more precise measures of fish condition.

Anchovy in the Southern Benguela have shown an eastward shift in the location of their principal spawning area, from the Western to the Central and Eastern Agulhas Banks. This shift was initiated in 1996 when anchovy spawner biomass was very low, and has persisted since then. The eastward shift appears to have resulted in increased recruitment success, which may be attributed to better feeding conditions and the resultant increased condition of fish east of Cape Agulhas relative to those to the west. Eggs and larvae produced by these good condition spawners are likely to have a higher survival probability when they arrive on the west coast nursery grounds than those produced by parents in poor condition.

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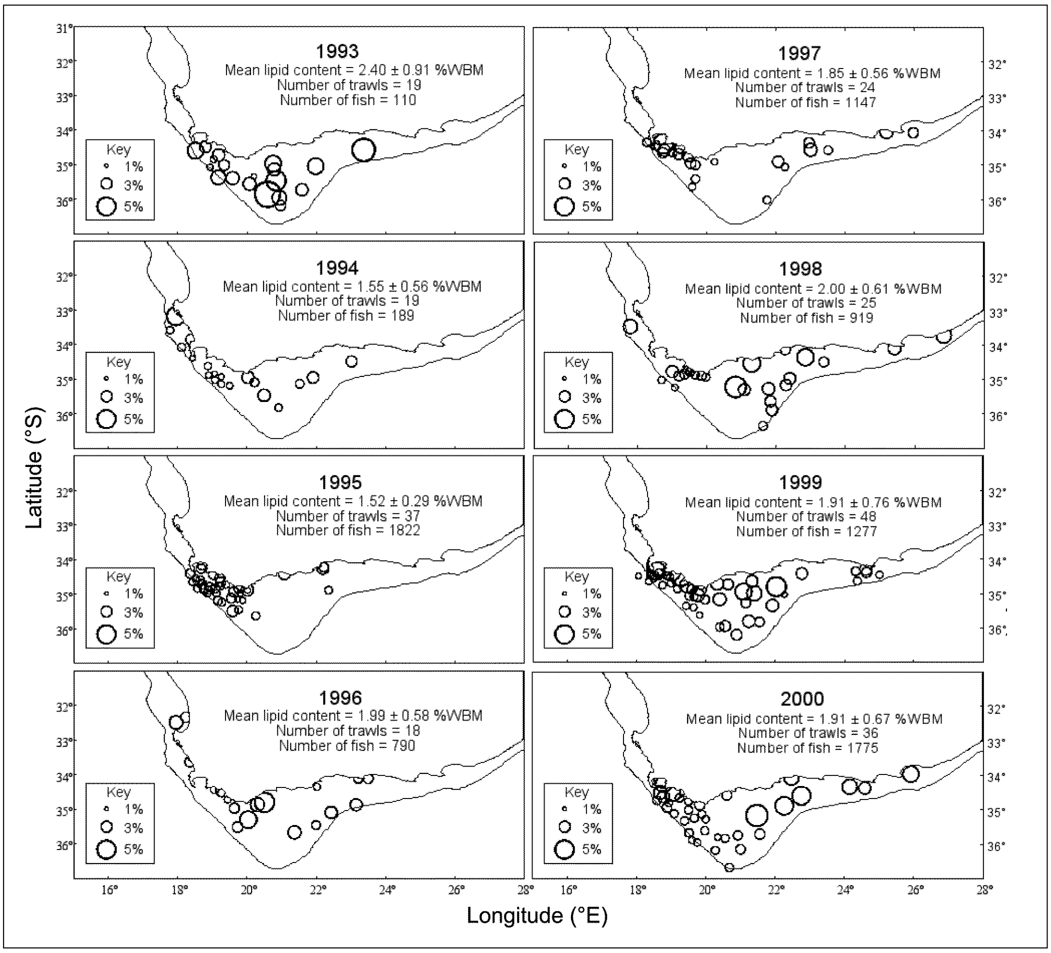

Fig. 3

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Figure Legends

Figure 1. Distribution of (a) anchovy spawners (% of total biomass) and (b) anchovy eggs (% of total abundance) west and east of Cape Agulhas during November spawner biomass surveys, 1984-2000.

Figure 2. Relative anchovy recruitment strength (recruitment biomass in year-n divided by spawner biomass in year_{n-1}) of anchovy in the Southern Benguela, 1985-2001.

Figure 3. Spatial distribution of anchovy condition, estimated as percentage lipid relative to wet body mass, during November spawner biomass surveys, 1993-2000.

THE UNUSUAL 1999-2000 SUMMER SEASON IN THE SOUTHERN BENGUELA: IMPLICATIONS FOR ANCHOVY RECRUITMENT

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Two unusual oceanographic events occurred during the 1999-2000 summer season off the West Coast of South Africa (Roy *et al.* 2001). The first was a strong and sustained warming that occurred in mid-December and lasted for two weeks. The second was an enhanced cooling that lasted from mid to late summer. Both events were the result of fluctuations in wind-induced upwelling. A period of moderate upwelling separated the two events.

The chronology and magnitude of these major oceanographic events affected the water mass over the continental shelf from Cape Point to Hondeklip Bay during the 1999-2000 upwelling season (Fig. 1). The warm event had a comparable magnitude along the Cape Peninsula and the West Coast, with Sea Surface Temperature (SST) anomalies reaching +2.0°C during the third week of December. The cold episode appeared to be more pronounced in the vicinity of Cape Columbine where the SST anomaly in early April reached -2.0°C. The time-series of alongshore wind and the cumulative divergence at Cape Columbine, illustrated the succession of events that triggered the fluctuations in upwelling off the West Coast (Fig. 2).

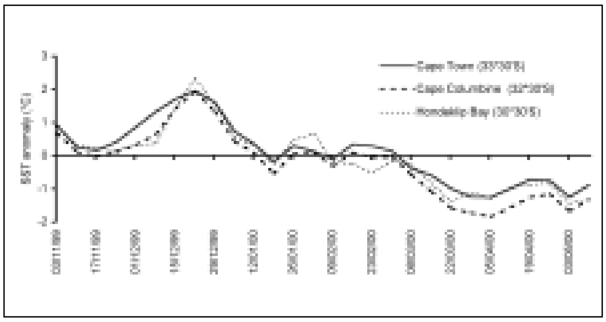

Fig. 1

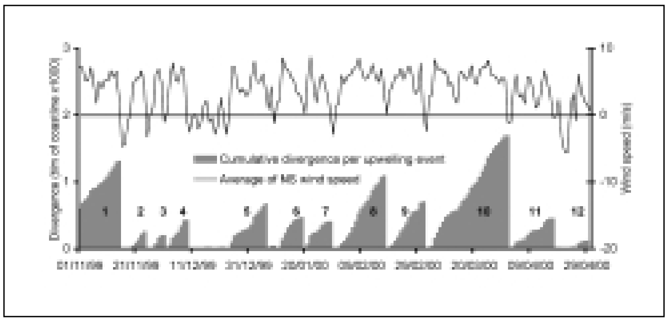

Fig. 2

Using SST data from ships of opportunity, the whole 1999-2000 upwelling season was placed within the long term climatic context by examining the averaged SST anomalies and SST standard deviation from November through to the following April for the last 30 years (Fig. 3). The 1999-2000 season appeared to be 0.58 °C cooler than the average conditions recorded over the last 30 years, with the 1999-2000 summer ranked as the third coolest summer over this period, and the seventh largest in terms of absolute amplitude of the anomaly. A different picture emerged from the SST standard deviation data, however. The SST standard deviation can be interpreted as an index of the variability in oceanographic conditions during the summer season. During the 1999-2000 summer, it reached 1.36°C, which was 50% higher than the previous maximum recorded during the 1993-1994 summer season (Fig. 3). This indicated that the succession of both extreme cold and warm events observed during the 1999-2000 summer was highly unusual and has not been recorded with such intensity during the past 30 years.

There were indications of a direct response in plankton abundance to the alternation of weak and strong upwelling episodes (see Fig. 10 in Roy *et al.* 2001). The chlorophyll *a* concentration off the West Coast, derived from SeaWiFS ocean colour images, suggested that plankton abundance was low during the

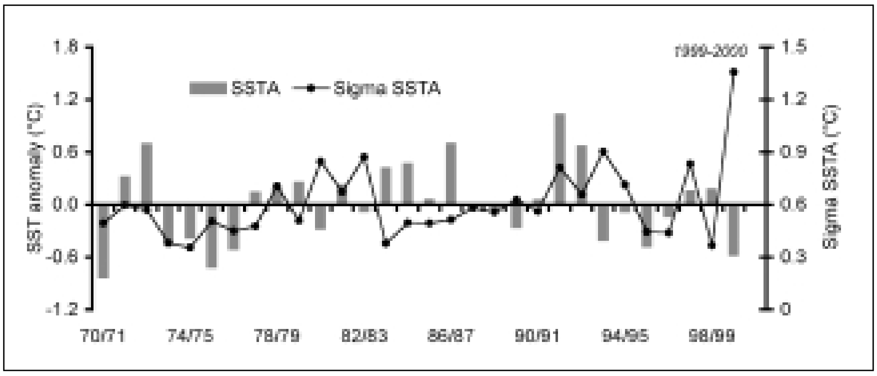

Fig. 3

relaxed upwelling episode in December 1999, and increased significantly later in the season.

One of the major ecological consequences of the unusual 1999-2000 upwelling season, might well be the record high level of anchovy recruitment observed in 2000 (the most successful anchovy recruitment recorded since the beginning of the time-series in 1985). Both wind and SST data indicated that, when averaged over the whole season, the 1999-2000 upwelling was greater than usual. Previous studies have suggested that there is a detrimental effect on anchovy recruitment during seasons of strong upwelling (Boyd *et al.* 1998). Surprisingly, the enhanced upwelling in 2000 appears to have favoured anchovy recruitment. By placing the timing of the warm and cold events in the context of anchovy reproductive strategy, it appears to be possible to reconcile previous findings with the exceptional recruitment recorded in 2000. In doing so, several facts need to be considered:

- Anchovy spawning peaks in late spring and early austral summer (October-December) on the Agulhas Bank. It is during the transport phase to the West Coast nursery ground that enhanced upwelling is thought to affect dispersal of eggs and larvae (Hutchings *et al.* 1998). In late summer and autumn (January-April), larvae and juveniles are located both on and offshore of the shelf along the West Coast.

- The collapse of the upwelling during the last two weeks of December 1999 might have drastically reduced the advective loss of eggs and larvae, and enhanced the number of larvae reaching the West Coast nursery area. Additionally, the elevated water temperatures recorded in December 1999 might have resulted in more rapid larval growth, which is likely to have reduced mortality rates.

- The moderate upwelling intensity that followed the December warm event may have favoured the development of an upwelling plume downwind of Cape Columbine. The associated eddy is thought to enhance transport and retention into the coastal environment (Penven *et al.* 2000).

- The following sustained episodes recorded later in the season probably resulted in increased primary and secondary production. Rather than being detrimental to the larvae, the upwelling regime recorded during the mid and late summer season might have enhanced food availability to the larvae population that previously reached the West Coast nursery during the December 1999 relaxed upwelling event. Enhanced food availability probably reduced mortality of anchovy post-larvae and young juveniles.

Considering the unusual characteristics of the 1999-2000 upwelling season, these observations suggest that, when investigating the linkage between anchovy recruitment and environmental factors, it might be more important to consider the temporal succession of events and their magnitude, than just the mean conditions over the whole season as has been done in previous studies. Further work is being conducted to determine if the succession of events during the 1999-2000 upwelling season represents the canonical pattern of environmental variability for maximizing anchovy recruitment (see Roy *et al.* this volume).

Acknowledgements
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Figure Legends

Figure 1. Weekly SST anomalies (°C) at three locations off the West Coast of South Africa from November 1999 to mid-May 2000 (source: OISST).

Figure 2. Daily time series of North-South wind speed ($m.s^{-1}$) at Cape Columbine from 1st November 1999 to 30th April 2000 (upper) and cumulative divergence ($t.m^{-1}$) per upwelling event (lower) for the same time period. The episode number is indicated for each major upwelling event. The calculation of cumulative divergence was performed on the October-June time-series. This explains why upwelling event number 1 does not start at 0 on 1st November 1999.

Figure 3. Seasonally averaged (November-April) time series of SST anomaly (SSTA) (°C) from 1970-1971 to 1999-2000 (column), and standard deviation of SST anomalies (Sigma-SSTA; °C; November-April) from 1970-1971 to 1999-2000 (line). Source: COADS dataset and Climate Diagnostics Centre.

An empirical model of anchovy recruitment variability in the southern Benguela

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From the mid-1980s to the late 1990s, anchovy recruitment variability in the Southern Benguela has been relatively moderate for a small pelagic fish population when compared with other regions. This changed in 2000, when a record high level of anchovy recruitment was observed, estimated in May/June 2000 as being four times higher than the previous historical record over the last 15 years. This exceptional recruitment was confirmed later in the season during the spawner biomass survey which showed an adult biomass of more than 2 times the previous highest level observed since the start of the time-series in 1984 (van der Lingen *et al.* 2001).

Environmental conditions recorded off South Africa's West Coast during the 1999-2000 summer season were highly unusual, being characterized by a pronounced warm event in mid-December 1999, followed by a moderate upwelling in January 2000 and an enhanced upwelling from mid to late summer 2000 (Roy *et al.* 2001a). The extreme oceanographic variability recorded during the 1999-2000 summer may have significantly contributed to the record high level of anchovy recruitment observed in 2000. It has been proposed that the succession, within a short period of time, of contrasting oceanographic events during that summer and their respective timing relative to the anchovy reproductive strategy might represent the canonical pattern of environmental conditions for anchovy recruitment success (Roy *et al.* 2001b, Barlow *et al.* this volume):

- Relaxed upwelling in December along the Cape Peninsula, following the November peak anchovy spawning, might limit offshore loss of eggs and larvae during the transport phase from the spawning to the nursery grounds;

- Moderate upwelling off the West Coast in January might have enhanced retention and provided food for the larvae; and

- Enhanced upwelling later in the season and the development of secondary production may have enhanced food availability for late larvae and early juveniles.

The validity of this assumption is tested using an empirical approach. Two environmental indices (Sea Surface Temperature anomalies) are used as surrogates for upwelling intensity off the Cape Peninsula in December and off the West Coast (Hondeklip Bay) in January. These indices were selected in order to describe the pattern of upwelling variability following the anchovy's peak spawning that occurs in November over the Agulhas Bank. SST anomalies off the Cape Peninsula during December are considered to represent the modification of the transport process from the spawning to the nursery grounds caused by variations in upwelling, whilst SST anomalies of the West coast in January represent the effect of upwelling once the larvae have arrived on the nursery grounds. These two environmental indices are individually related to anchovy recruitment strength estimated from winter hydroacoustic surveys (Barange *et al.* 1999) for the first two-thirds (1985-1994) of the anchovy recruitment strength time-series. Scatterplots show that anchovy recruitment increases as the SST anomaly off the Cape Peninsula in December (designated CT4) increases (Fig. 1), suggesting that weak upwelling promotes successful recruitment. A dome-shaped relationship between recruitment and SST anomaly (and hence upwelling intensity) off the West Coast in January (designated HB4) indicates that both weak and strong upwelling are detrimental to recruitment success whilst moderate upwelling promotes recruitment (Fig. 1).

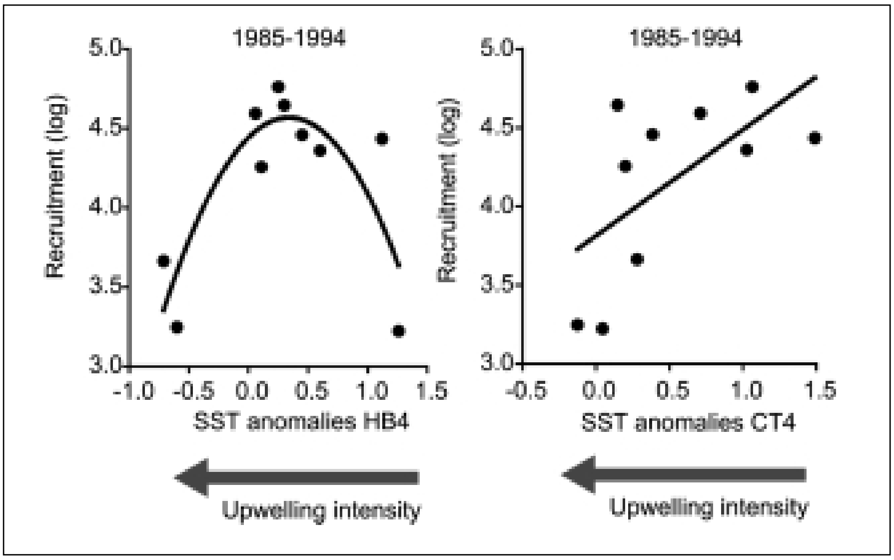

Fig. 1

These observed relationships are combined into an empirical model that is used to hindcast anchovy recruitment success for the remaining part (1995-2000) of the time-series. The empirical model suggests that weak upwelling off the Cape Peninsula in December followed by moderate upwelling off the West Coast region in January generally contribute to favour anchovy recruitment success over the whole time series. A reasonable fit between hindcast and observed recruitment strength is observed (Fig. 2), with 1998 and 2000 outlying points where the model underestimated subsequent recruitment. Further development of this empirical model using GAM is underway.

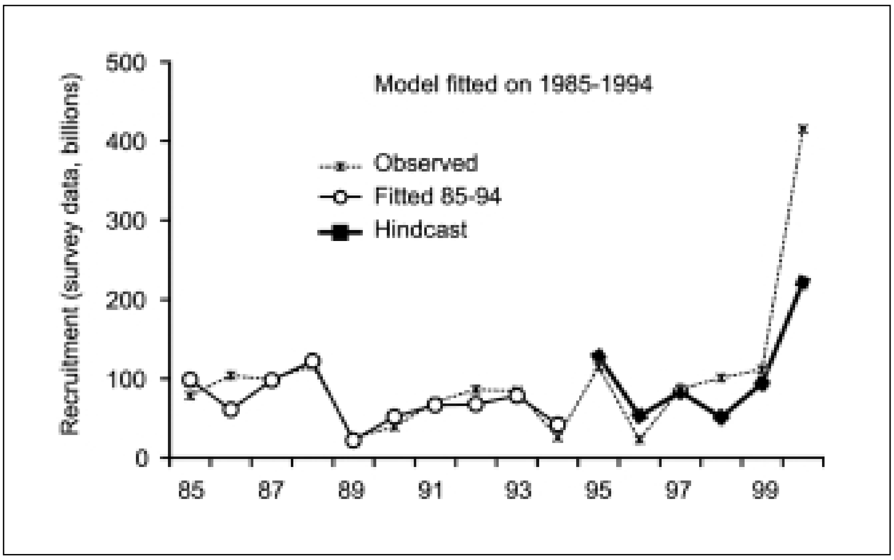

Fig. 2

Anchovy recruitment in 2001 was of the same order of magnitude as in 2000 (Coetzee *et al.* 2001); our model failed to predict this high anchovy recruitment. However, with an adult biomass well above the average level measured during the period over which the empirical model was calibrated, processes other than just environmental control of egg and larval survival may have become important as determinants of recruitment success.

Acknowledgements
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Figure Legends

Figure 1. Scatter plots of anchovy recruitment and SST anomalies in December off the Cape Peninsula (CT4; right panel) and anchovy recruitment and SST anomalies in January off the West Coast (HB4; left panel).

Figure 2. Observed and modelled anchovy recruitment time-series in the Southern Benguela.

BIOLOGICACL IMPACT OF AN ENVIRONMENTAL ANOMALY IN THE NORTHERN BENGUELA: 1994-1995

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The period 1994-1995 was marked in the Northern Benguela by large-scale and sustained environmental anomalies. Following negative anomalies in upwelling-favourable wind-stress, widespread anoxic conditions prevailed off the Namibian shelf 1994 and a large-amplitude Benguela-Niño event occurred during the first half of 1995. During the same period, commercial pelagic stocks like sardine, anchovy and horse-mackerel showed substantial declines, poor recruitment and changes in distribution, while the 1995 Cape hake cohort was the weakest on record. Although there is no direct information on the abundance of non-commercial epi- or meso-pelagic species of the Namibian shelf (particularly bearded goby and myctophids), the dramatic response of top predators (seabirds and fur seals) suggests that the entire food web has been altered during 1994-1995. Some of these changes have not shown signs of reversal seven years after the event.

Spatial structure of acoustic backscatter along the Angolan coast, with the focus on aggregations of sardinellas and their relation to the seasonal and interannual variability in environmental conditions

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Using integrated oceanographic and hydroacoustic datasets, we have studied associations between hydrographic regimes and patterns of acoustic backscatter from assemblages of small pelagic fish. The study was conducted in the region off Central Angola located between 10°45’S and 12°15’S and used data from four surveys conducted in March and August of 1996 and 1998. The surveys were selected to cover the extremities of seasonal and interannual cycles: winter and summer during a warm anomaly (1996), and also during an average year (1998). Environmental data analyzed included vertical profiles of temperature, salinity and oxygen from a CTD probe, and sea surface temperature at 1 nautical mile intervals along the survey track. Estimates of the acoustic abundance of sardinellas (*Sardinella aurita* and *S. maderensis*) were obtained from echo-integration and raw, ping-based data collected using a SIMRAD EK500 echosounder operating at a frequency of 38kHz and with spatial resolution of 9.4 m along the track and 0.2-1m in width. Customized software was written to manage the voluminous content of raw acoustic data files. All data were obtained from fish census surveys conducted aboard the *R/V Dr. F. Nansen* (FAO 2000).

Two distinct seasonal regimes dominated hydrographic conditions in the shelf region studied; the oceanic regime, which was observed during winter, and the brackish water regime which occurred during summer. The oceanic regime was manifested by waters of Tropical Atlantic origin present over the entire shelf, including the inshore region. Vertical sections shown in Figure 1a depict these conditions during March 1998. Offshore, the top 30m of the water column was occupied by Tropical Surface Water (TSW), with a subsurface layer of South Atlantic Central Water (SACW) below. Inshore, the TSW was replaced by SACW throughout the upper 90m of the water column. The upward-sloping isolines toward the coast and concomitant decrease in temperature, salinity and oxygen indicate a phase of an active upwelling (Fig. 1a). These conditions were unique for the 1998 case. During winter 1996 the SACW remained subsurface across the length of the shelf, while the resident coastal water, with temperatures and salinities lower than TSW, dominated the surface in the coastal region (this case is not shown in Fig. 1.)

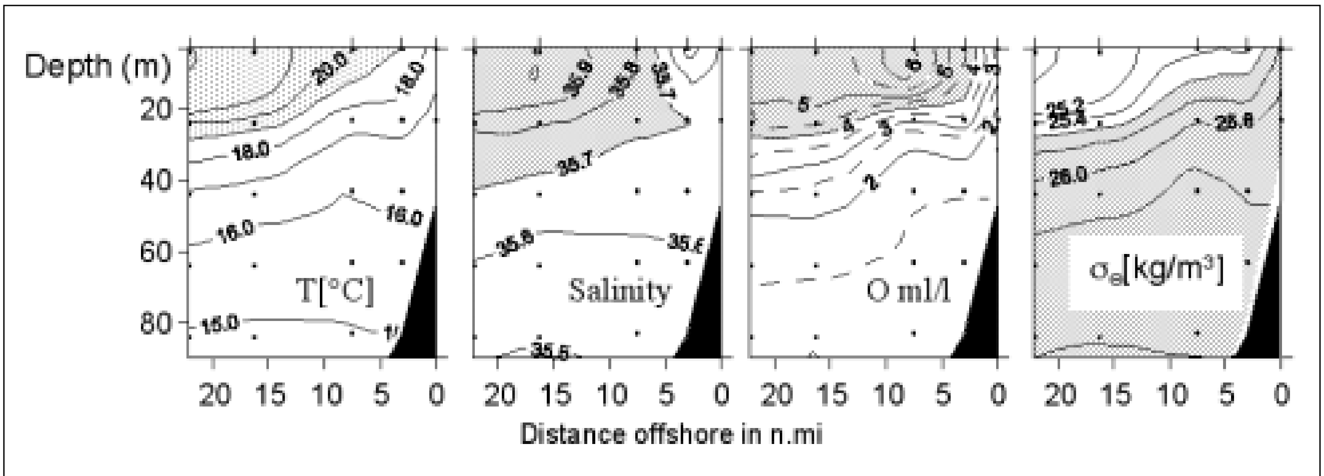

Fig. 1a

The brackish water regime was typical of summer surveys, and was manifested by periods of low-salinity surface water of terrestrial origin over the shelf. During 1996, the brackish surface layer dominated the entire shelf region, but was confined to the vicinity of the coast during 1998. Hydrographic sections from

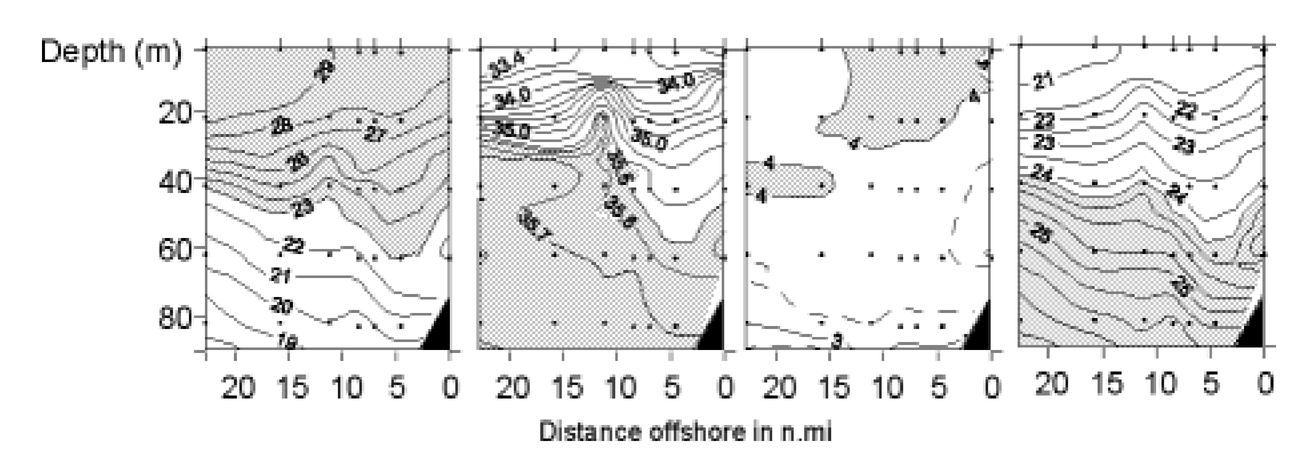

Fig. 1b

March 1996 are depicted in Figure 1b. Note the downwelling inshore, and a strong (compared to the winter) pycnocline. These physical conditions prevent the transport of nutrients to the euphotic zone, which causes a decrease in primary productivity and a consequent deterioration of grazing conditions for small pelagic fish. These unfavourable grazing conditions persisted during both survey periods in summer 1996 and in 1998.

In order to detect associations between hydrographic regimes and assemblages of small pelagic fish, we first analyzed the data using standard echo post-processing, performed onboard for abundance estimation (MacLennan and Simmons, 1992). Distributions of acoustic density attributed to sardinellas were mapped and overlaid with SST data. The results for all of the four surveys are depicted in Figure 2. In the case of winter 1998, the association is evident (Fig. 2d): schools of sardinellas are clearly seen in the inshore region, coinciding with upwelling SACW with a SST of <19°C. For the remaining surveys (Figs. 2a-c), no association was observed. Moreover, there is no pattern in the fish distribution itself. Geostatistical analysis (FAO 2000) has demonstrated that in the case of the sardinella stocks off Angola, the lack of structure in echointegrator-derived data is commonplace. These species tend to occur in small assemblages, which do not display clear patterns in the data regularized on intervals of 1 or 5 nautical miles typically used during echo-integration. The upwelling-induced association between hydrographic regimes and sardinella assemblages seen in winter 1998 represents an exception due to environmental forcing.

A spatial distribution that does not display patterns is not very useful for feature localization and for making associations with other distributions. The sardinella distributions, such as those presented in Figures 2a-c, have a limited value to studies on the links between the fish and the environment. An alternative search for such associations was thus applied, based on the analysis of raw, ping-based echosounder data. The task was pursued by splitting echogram data from a survey into segments in such a way that each segment consisted of a straight section of the survey track. Typically, 20 such sections were obtained for a survey. For each section, images representing the distribution of backscatter strength across the shelf were derived and displayed according to the same scale. Individual pings were integrated with respect to depth and were displayed on top of the backscatter images. Once the images for all sections were derived, a visual classification of patterns was performed in respect of the following features:

- Number of schools in the survey area;
- Their location within the survey area;
- Shapes and scales of schools;
- Contingency of patterns between adjacent sections;
- Time of the day differences in the observed patterns;
- Contingency of patterns on non-adjacent sections representing the same phase of daylight;
- Levels of background scatter; and
- Manifestation of hydrographic influences: layers, fronts and internal waves

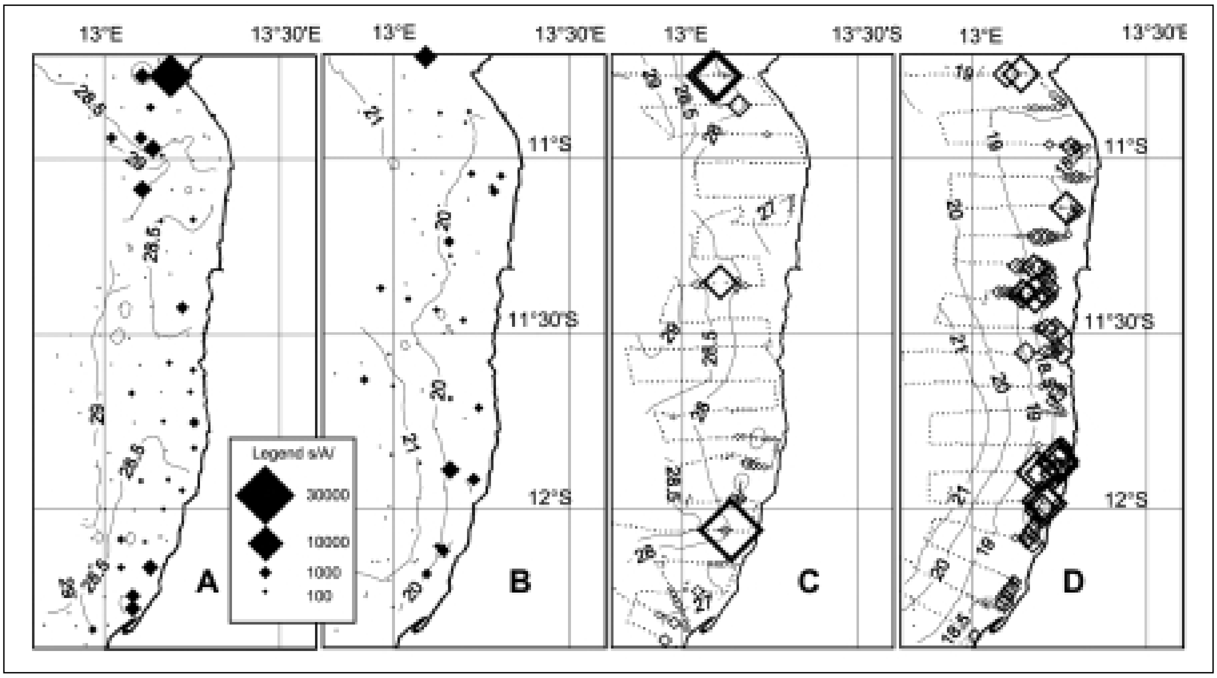

Fig. 2

Preliminary results from this analysis are encouraging. Patterns and seasonal cycles were clearly visible with respect to pelagic schools and to background scatter. By way of example, a short description of the general features of the backscattering conditions observed in the region of 10 nautical miles nearest to the coast during March 1996, March 1998 and August 1998 (Fig. 3) is given below. In March 1996 (Fig. 3a) brackish water covered the entire shelf. Pelagic schools were absent in the nearshore region, but traces from solitary fish were commonplace. In March 1998 (Fig. 3b) the brackish water was confined to the inshore areas, and there was no upwelling signature. Very few pelagic schools were found, but those that were seen were very large, with nearly 90% of the biomass occurring in three schools, the horizontal extent of which along the survey track was <0.2 nautical mile. No clear relationship between day-night schooling patterns was observed. In August 1998 (Fig. 3c) the oceanic water regime was observed, with upwelling conditions inshore. Schools were seen on all sections, occupying the region in the depth range between 30 and 45m. More schools, and larger schools were observed during daytime than at night, when part of the stock disperses and migrate offshore, where they are seen in the region of thermocline.

The status achieved so far has not yet reached a level of quantitative analysis. Algorithms for automated identification of patterns and for scale analysis need to be incorporated. Methods based on wavelet analysis (Foufoula and Kumar 1994) have been already developed, tested and are ready for inclusion in the analysis.

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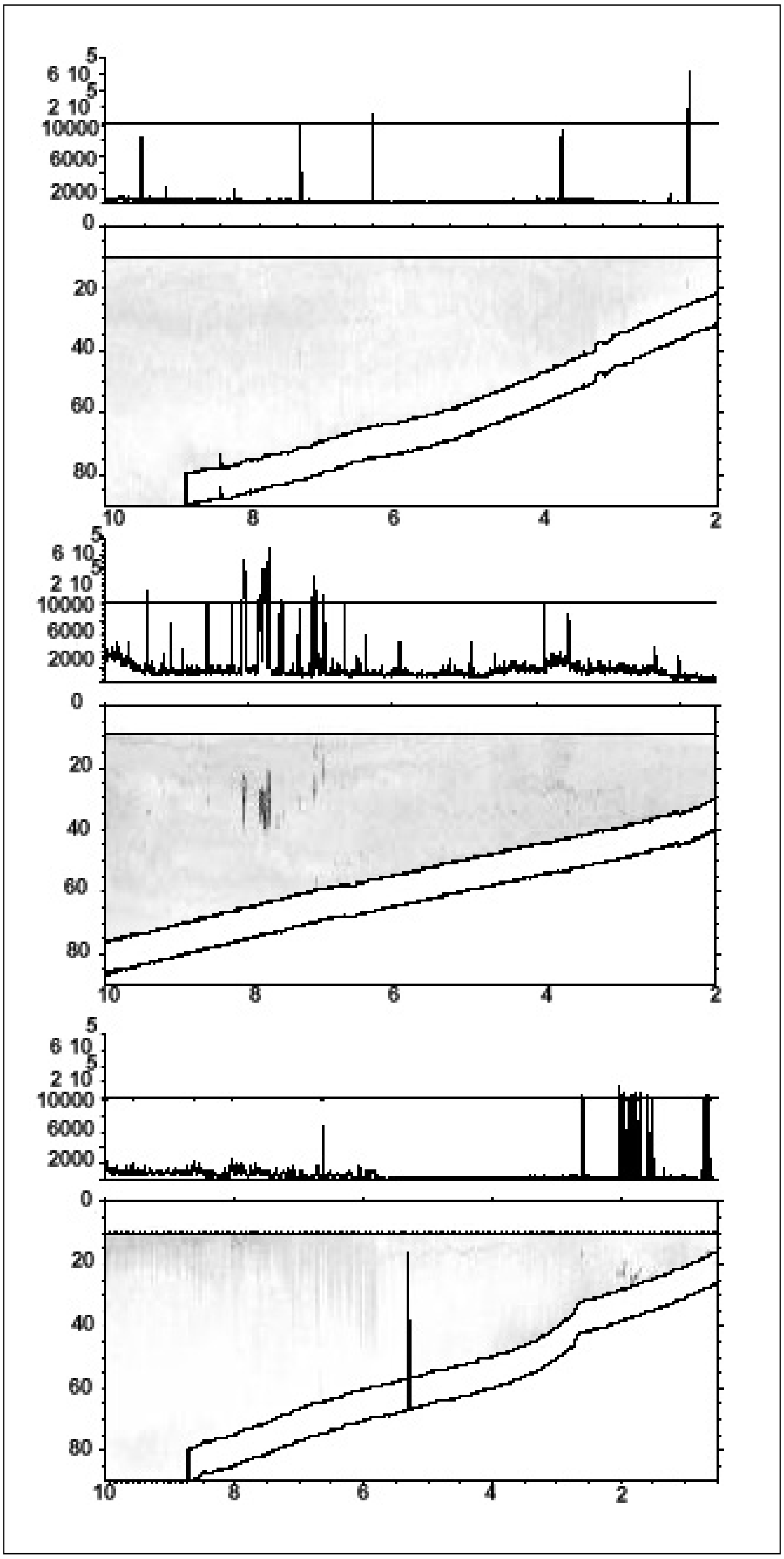

Fig. 3

Figure Legends

Figure 1. Distribution of temperature, salinity, oxygen and potential density across the Lobito section during (a) 24th March 1996 (12°09'S 13°10'E – 12°21'S 13°29'E) and (b) 4th August 1998 (12°07'S 13°05'E – 12°22'S 13°31'E).

Figure 2. Distribution of acoustic abundance of sardinella overlaid on top of SST distribution maps during four surveys conducted aboard *R/V Dr. F. Nansen*. A: 09.02 – 30.03 1996, B: 20.08 - 04.09 1996, C: 03.03 – 26.03 1998, D: 29.07-19.08 1998.

Figure 3. Sound backscattering conditions observed along the innermost (10 nautical miles) sections of acoustic transects, in (a) March 1996, (b) March 1998, and (c) August 1998. Each figure consists of two graphs. The bottom image represents a pelagic echogram of the topmost 90m of the water column, with depth displayed along the vertical axis and distance offshore along the horizontal axis. The graph above displays the s_A-values integrated for each image column separately. The scale on the upper graphs is broken into two, separately scaled areas; the lower area displays ping-based s_A-values $<10^4$, and the upper area s_A-values above this threshold.

BIOLOGY AND SEASONAL CHANGES IN THE DISTRIBUTION AND SPATIAL AGGREGATION CHARACTERISTICS OF CLUPEIDAE (*SARDINELLA AURITA AND S. MADERENSIS*) IN ANGOLAN WATERS

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The distributions of two congeneric, sympatric species of Clupeidae (*Sardinella aurita* and *S. maderensis*) over the Angolan shelf were studied using hydroacoustic and length frequency data collected during research trawl surveys carried out by the *R/V Dr. Fridtjof Nansen* in summer and winter over the period 1985-1999. The data were used to characterize the distributions of the two species in relation to region, season, time of day and bottom depth.

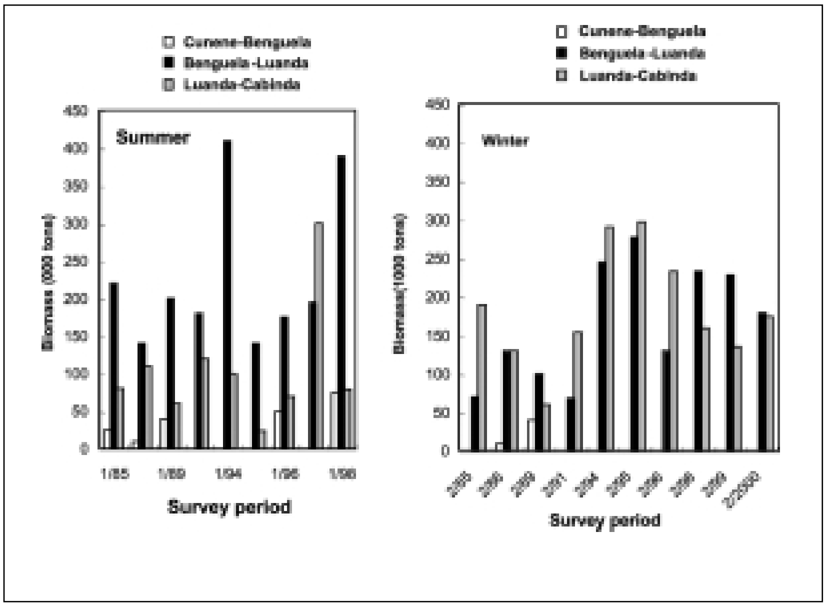

Fig. 1

Although *S. maderensis* was the most abundant species throughout the sampling area (except at the shallowest, rough-bottom sites) seasonal changes were observed for both species, with higher biomass estimates being recorded in the northern region during winter and in the central-southern region during summer (Fig. 1). During the warm season there is a southward displacement of adults as far as Baia dos Tigres for round sardinella (*S. aurita*) and to Lobito-Benguela for flat sardinella (*S. maderensis*). Northward displacement of both species occurs during winter, which is also the main upwelling season.

Length frequency distributions indicated the presence of both pre-adults and adults of each species during surveys. For both species the size distributions of catches indicated clear differences between seasons (Fig. 2). Significant differences in mean fish length according to bottom depth were apparent for *S. maderensis* only (Fig. 3). The structural heterogeneity of the Angolan continental shelf gave rise to a distribution characterised by patches; *S. aurita* had a clear preference for areas characterized by a wide shelf whereas *S. maderensis* was more abundant and frequent in coastal areas.

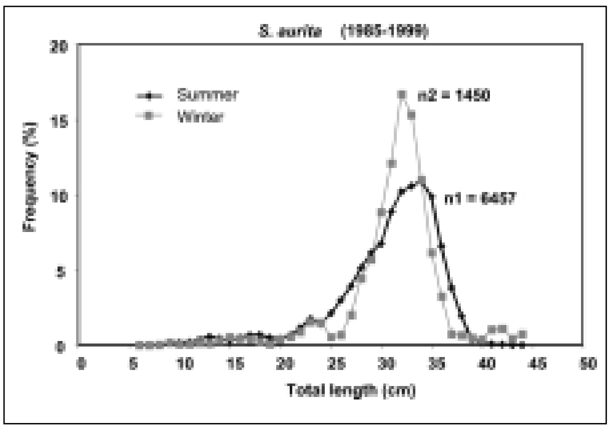

Fig. 2a

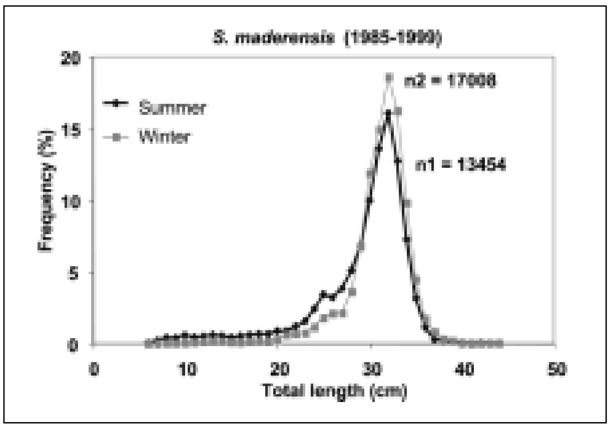

Fig. 2b

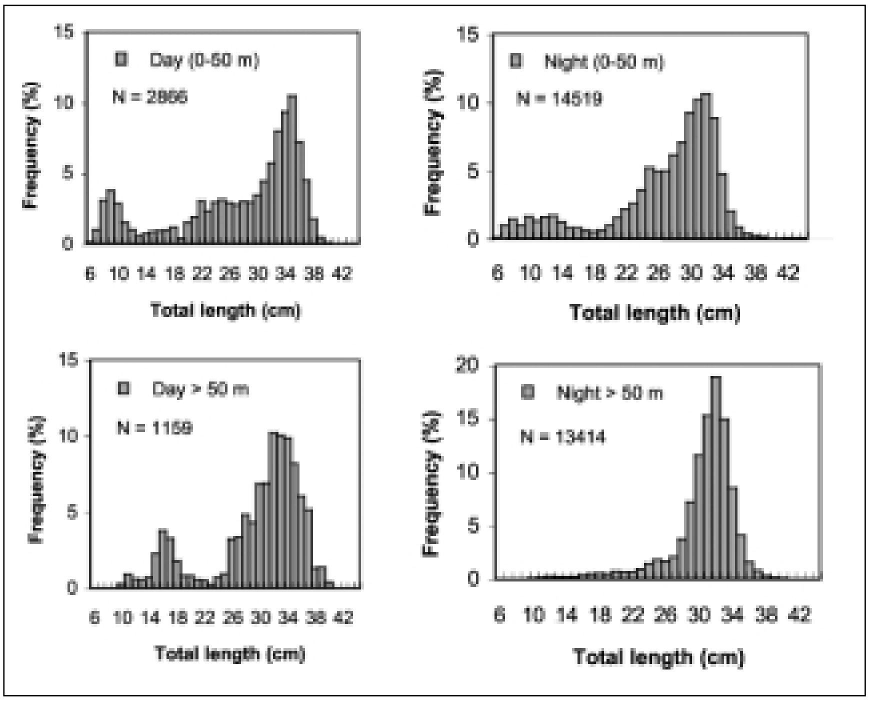

Fig. 3

Figure Legends

Figure 1. Acoustic estimates of the biomass of both *Sardinella* species combined in Angolan waters during the summer and winter. Each column represents the biomass estimate per region; Cunene-Benguela is in the south, Benguela-Luanda is central, and Luanda-Cabinda is in the north.

Figure 2: Length frequency distributions in summer and winter of (a) *S. aurita* and (b) *S. maderensis* collected during surveys conducted by the *RV Dr Fridtjof Nansen*, 1985-1999.

Figure 3. Length frequency distributions of *S. maderensis* for day and night catches made in two depth strata (0-50m and >50m) during surveys conducted by the *RV Dr Fridtjof Nansen*, 1985-1999.

Spatial and temporal variability in the diet of a top predator in the Northern Benguela

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The Cape fur seal (*Arctocephalus pusillus pusillus*) is an abundant and widespread top predator in the Benguela system. This species seems to be an opportunistic predator feeding on a wide range of meso- and epi-pelagic organisms. Historically, in the Northern Benguela, fur seals were important predators of commercial small pelagics, particularly sardine (*Sardinops sagax* [formerly *ocellatus*]) and anchovy (*Engraulis capensis*). Since the collapse of these commercial stocks, the fur seal's main prey changed to bearded goby (*Sufflogobius bibarbatus*), lanternfish (*Myctophidae*), juvenile horse mackerel (*Trachurus capensis*) and juvenile Cape hake (*Merluccius capensis*).

The main oceanographic features relevant to the distribution and migration of pelagic species in the Northern Benguela are the Angola Front and the Lüderitz upwelling cell. The Angola Front, the northern limit of the Benguela system, constitutes a feeding area for small pelagics that migrate between it and their spawning areas situated to the south, particularly between 19° and 24°S. The Lüderitz upwelling cell, the main upwelling center in the system, is situated between 26°S and 27°S in an area of maximum equatorward wind-stress. This area is thought to act as an environmental barrier to the migration of small pelagics. To the south, the area off the Orange River mouth constitutes the northernmost limit of distribution of small pelagics (particularly anchovy) of the Southern Benguela stocks.

Since 1993/1994 we have been monitoring changes in the diet of the Cape fur seal through scat-analysis at four different colonies spanning about six degrees of latitude between Cape Cross (21°47'S) and Van Reenen Bay (27°23'S). For this preliminary analysis, only the teleost portion of the diet is considered and the monthly relative contribution by number of the different prey categories analyzed. Prey species were

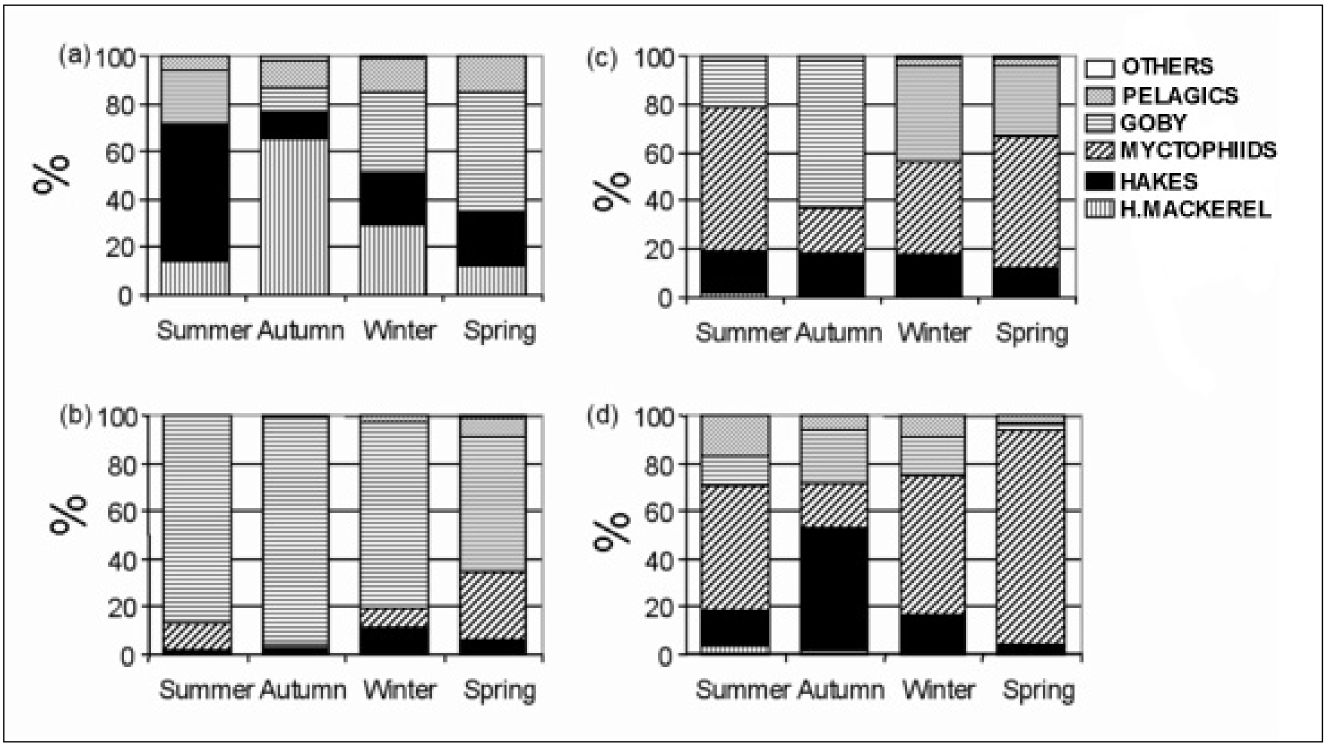

Fig. 1

identified from otoliths in the scats and quantified, using experimentally-derived, species-specific correction factors to account for differential otolith digestion rates. Due to their low contribution to the diet, sardine, anchovy and round herring *(Etrumeus whiteheadi*) were grouped together in the category "commercial pelagics".

Overall, during the period of study, there were clear differences in the seal diet composition between colonies (Table 1). Juvenile horse mackerel was numerically dominant at Cape Cross (32.6%) while rare at the other sites (2.1% or less). Bearded goby dominated at Spencer Bay (79.1%) and was the second most represented prey at both Cape Cross and Atlas Bay (28.9% and 38.7%, respectively). Myctophids were dominant at the two southern sites (Atlas Bay and Van Reenen Bay). Commercial pelagics were poorly represented in the diet at all sites, with a clear minimum in the Lüderitz area.

Figure 1 illustrates the seasonal differences in diet composition for the 4 sites. At Cape Cross, juvenile hake dominated in summer (November to January), juvenile horse mackerel in autumn and bearded goby in spring. Although never abundant, commercial pelagics reached a minimum in summer. This pattern agrees well with the seasonality in the purse-seine fishery catches targeting pelagics and juvenile horse mackerel, when the bulk of the catches in this area are made during autumn and winter. At Spencer Bay, goby dominated during all seasons. At the Lüderitz upwelling cell (Atlas Bay), there is a seasonal shift in the dominant prey, from goby in autumn to myctophids in spring and summer (the main upwelling season). Similarly, at Van Reenen Bay the contribution of myctophids to the diet reached a minimum in autumn, while commercial pelagics peaked in summer.

The inter-annual variability in the diet composition is best illustrated by juvenile Cape hake which is fairly abundant and for which some information is available from surveys. Seals feed on hake mostly in the 8 to 22 cm length range. These pre-recruits are in their pelagic phase, disappearing from the seal diet when they reach 23-24cm length, as they become demersal. Hence, only one hake cohort is available to the seals at a time. Hake recruits are first available to surveys at 24-25 cm length at 2.5 years of age. Hake recruitment strength in Namibia is highly variable and, since 1990, the survey estimates averaged around two billion fish (with a range of 0.33-5.14 billion fish). The contribution of hake in the seal diet at Atlas Bay is given in Figure 2, together with the survey estimates of the same cohorts. The strong correlation between the two data sets ($p<0.005$, $r^2=0.84$ for seven successive year classes) suggests that most of the inter-annual variability of juvenile hake contribution to the diet is dependent on the prey variability in stock size.

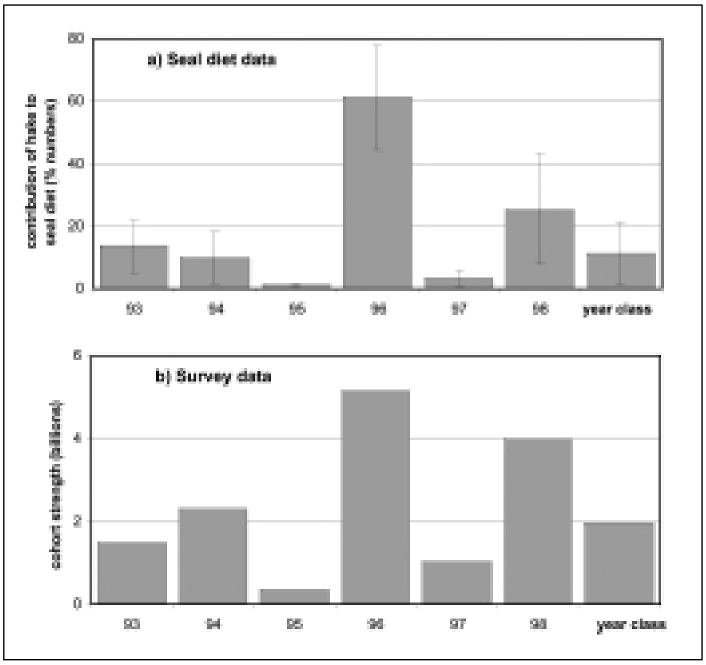

Fig. 2

In conclusion, fur seal diet variability in time and space seems to accurately reflect changes in the pelagic fish communities in the Northern Benguela. It could be used as a relatively inexpensive complement to traditional survey methods to track changes in the ecosystem.

Table 1: Composition of the teleost portion of seal diet (percentage in numbers) at 4 colonies along the Namibian coast (1993-2001). The number of months sampled and the total number of otoliths retrieved are also given; bold typeface indicates the dominant teleost species.

	Cape Cross	Atlas Bay	Spencer Bay	Van Reenen Bay
Latitude	24°47'S	25°44'S	26°50'S	27°23'S
# of months sampled	66	22	83	32
# of otoliths (000s)	266.1	55.9	458.1	80.3
Horse mackerel	**32.6**	0.4	0.6	2.1
Cape hake	25.6	5.7	16.5	21.2
Myctophidae	0.1	11.3	**41.2**	**52.0**
Bearded goby	28.8	**79.1**	38.7	15.1
Commercial pelagics	12.3	2.9	2.6	9.3
Other	0.6	0.6	0.4	0.3

Figure Legends

Figure 1: Seasonal composition of the teleost portion of the seal diet at 4 colonies along the Namibian coast; a) Cape Cross, b) Spencer Bay, c) Atlas Bay, and d) Van Reenen Bay.

Figure 2: a) Yearly average (+ Sd) of the juvenile Cape hake contribution to the seal diet (percentage in number) at Atlas Bay, and b) estimated Cape Hake year class strength (1993 to 1999) from trawl surveys on the Namibian shelf.

DISTRIBUTION OF SARDINE, *SARDINA PILCHARDUS* (WALB.) EGGS AND LARVAE ALONG THE SOUTH MOROCCAN ATLANTIC COAST (21-26°N)

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Introduction

The sardine is a commercially important fish in Morocco that occurs in high abundance along the margin of the Moroccan Atlantic coast. Its distribution area extends from Cape Blanc (21°N) to Cape Spartel; (35°45'N) with three stocks recognized (Belvèze 1984): the northern stock between El Jadida and Cape Spartel, the central stock from Laayoune to Cape Cantin (Safi) and the southern stock between Cape Blanc and Cape Boujdor. This paper concerns investigations of the spawning grounds and nursery areas of sardine in the southern stock between 21° and 26°N. The exploitation of this stock began in 1968 as a secondary catch to that of mackerel, *Scomber japonicus*, and horse mackerel, *Trachurus trachurus* (Belvèze 1984).

Materials and methods

Sampling for sardine eggs and larvae was carried out along the Moroccan Atlantic coast using the ship the *R/V Russian AtlantNIRO*. The sampling grid was composed of transects spaced 30 nautical miles apart and each comprising 3 to 5 stations. The temporal distribution of sardine eggs and larvae was studied over 1994 and 1995, during winter (January-February) and in summer (July-August). Sampling was carried out using a double Bongo net (20cm diameter) equipped with a flowmeter, hauled obliquely from a maximum of 100m depth to the surface at a speed of approximately two knots. The two nets had different mesh-sizes; that used for ichtyoplankton had a 417µm-mesh whilst the second (168µm) was used for zooplankton. Both nets were assembled on a framework, and each net had a cylindrical part in front of the filtration cone. Samples were preserved immediately after collection in a 5% borax-buffered formalin solution in filtered seawater.

Results

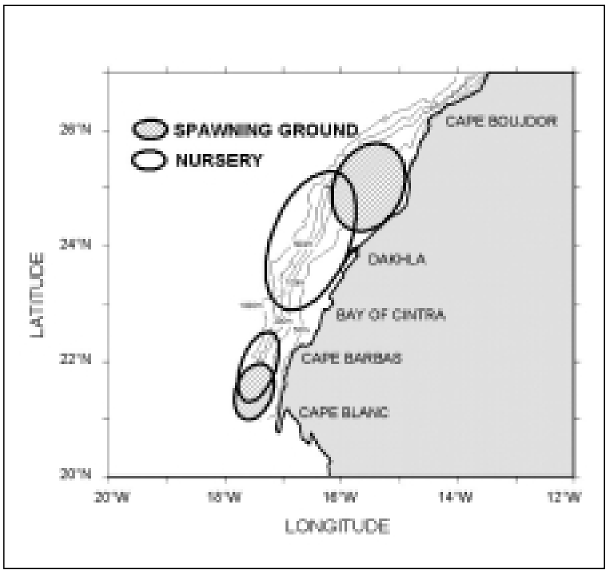

Fig. 1

The distribution of sardine eggs showed two zones of presence during winter 1994; the first was between Cape Boujdor and Dakhla and the second was off Cape Blanc. During the winter 1995, one zone was from Cape Boujdor to Cintra Bay, and a second zone was located near Cape Barbas (Fig. 1). During summer the egg distribution area was less extensive than in winter, and was localized between Cape Boujdor and Dakhla in 1994 and narrower in 1995. The area of maximum egg abundance was located north of Dakhla (24°N), with densities of 10-100 eggs/10m^2 during both winter and summer 1994, >1000 eggs/10m^2 during winter 1995, and from 100-1000 eggs/10m^2 during summer 1995. During winter 1994, a spawning ground was located in the south between Cape Barbas and Cape Blanc, with concentrations of 100-1000 eggs/10m^2.

The distribution of larvae from Cape Boujdor to Cape Blanc showed some variability from one season to another compared with that of the egg distributions, and the situation in 1994 differed from that in 1995. Larval distribution was wider than that of eggs, and covered the entire coastal region (Cape Boujdor-Cape Blanc) with higher concentrations occurring during the winter and summer of 1994. Maximum densities of larvae (>100 larvae/10m^2) were localized at the same place as the eggs between Cape Boujdor and Dakhla, and between Cape Barbas and Cape Blanc. During winter 1995, the sardine larvae were located between Cape Boujdor and Cintra Bay, with the highest concentrations (100-1000 larvae/10m^2) in the neighborhood of Dakhla. During summer 1995, the highest larval densities (100-1000 larvae/10m^2) were in the Dakhla-Cape Barbas region.

Discussion and conclusion

The distribution of eggs and larvae of pelagic fish is generally under the influence of oceanographic conditions (temperature, current, wind, availability of food *etc.*) that affect the geographical distribution of adults at the moment of reproduction. The distribution of the densities of sardine eggs and larvae reveals that winter is the main spawning season, with maximum egg abundance located North of Dakhla. Sardine larvae occur along the coast from Cape Blanc to Cape Boujdor with maximum densities between 23° and 25°N.

These results agree with those of Conand (1975) who previously identified a sardine nursery area in the neighborhood of Dakhla. This area is characterized by a large, flat and relatively shallow continental shelf. These characteristics decrease the effects of dispersion towards the deep ocean, and this zone could constitute a favourable place for the retention and development of larvae (Roy 1991, Ettahiri 1996). Vertical movements of turbulence and westward drift in this area are reduced by the wide continental shelf (Roy 1991). This result is also similar to the conclusions of Marchal (1991) on the reproduction sites of other pelagic species along the West African coast; eggs and larvae remain mainly within the area of continental shelf because of the topography of the area. The same phenomenon was demonstrated for the Sidi Ifni-Cape Juby zone, which constitutes the spawning ground and the area of maximum abundance of larvae of the central sardine stock (Ettahiri 1996, 1997).

Blaxter and Hunter (1982) suggest that pelagic fish spawns in areas of substantial biological production to ensure adequate juvenile feeding. An area with such characteristics that acts as the spawning ground and nursery at the same time, and provides retention and concentration, fulfills Bakun's (1996) three conditions for the success of larval development: namely enrichment, concentration, and retention of the larvae in a favourable habitat.

Another important point is the existence of a shift in the location of the maximum densities of the larvae compared to eggs, especially during summer. This shift could result from drift of the larvae as they develop. Drift results from the surface currents that are directed from north to south (Mittestaedt 1991), as well as from active movements of the larvae, probably in relation to the search for adequate food. During the spawning season, the period of maximum egg production varies from year to year according to temperature, salinity, primary production and zooplankton. In the period of this study it is likely that the observations made in winter 1994 correspond to the end of the spawning season whilst those of winter 1995 correspond to the peak of the spawning season.

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Figure Legends

Figure 1. Spawning grounds and nursery areas of sardine, and bathymetric map of the Atlantic Moroccan south coast.

CHANGES IN THE DISTRIBUTION OF COASTAL PELAGIC RESOURCES OFF PORTUGAL: OBSERVATIONS AND WORKING HYPOTHESES

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Survey data collected in the past two decades off Portugal are currently being reviewed to identify changes in the distribution and abundance of small pelagic fishes. For example, data from 15 ichthyoplankton surveys were recently analysed (Stratoudakis *et al.* submitted) to describe the distribution of sardine eggs and larvae off Portugal during 1985-2000. Binomial models fitted to presence/absence data from three DEPM surveys show that the area of egg cover off Portugal significantly decreased from 11800 km^2 in 1988 to 7000 km2 in 1997 and 7400 km^2 in 1999. Standardised data from all surveys show a decline in the mean probability of egg presence within the Portuguese continental shelf from the mid-1980s to late 1990s. This decline is due to a marked reduction in the egg abundance in the northern Portugal spawning ground (Fig. 1), partly compensated by moderate increases in the southwestern and southern Portugal spawning grounds. Similar regional patterns are observed in the mean probability of larvae presence over time, but the reduction in the north is less marked than for the eggs (this comparison ignores the presence of sardine larvae beyond the continental shelf in the 1980s). Comparable changes are observed in Portuguese sardine catches and the acoustically estimated distribution area of sardine. Recent preliminary analysis of trawl data from acoustic surveys (1982-2000) has shown decadal differences in the depth distribution of sardine (being caught in deeper waters during the 1980s) and in the area of distribution of other pelagic species (*e.g.* bogue and chub mackerel were caught in a wider area and more frequently during the 1990s). This northern expansion of species with a more subtropical distribution (bogue and chub mackerel) could be explained by the increase in temperature observed over the last decades in the eastern North Atlantic (Brander *et al.* 2001).

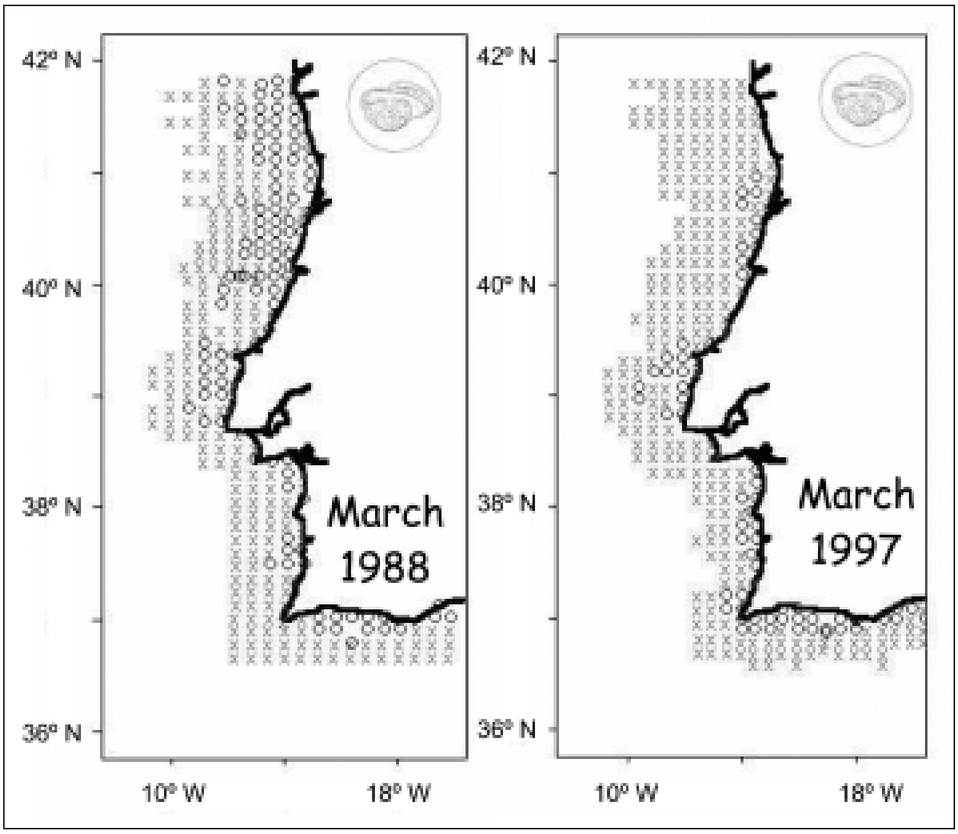

Fig. 1

Although the reasons for the observed changes are not clearly understood, they seem to be climate driven. Borges *et al.* (submitted) found an highly significant correlation between NAO and the winter northerly winds, and a significant correlation between wind conditions and the catch of sardine one year later. The long-term changes in alongshore winds off Portugal during the last decades related to NAO conditions lead to variations in the patterns of upwelling in the region, and are related to decadal - scale

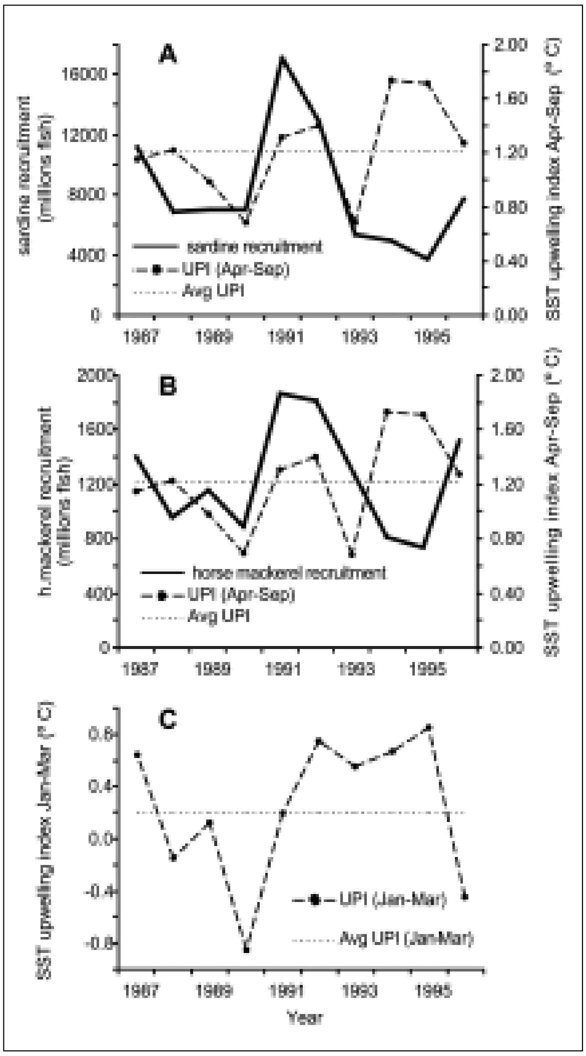

Fig. 2

fluctuations in the annual catch of sardine. Santos *et al.* (2001). have shown that the variability of upwelling patterns is a crucial factor in the recruitment dynamics of small pelagic fish species. Intense and frequent upwelling events during the spawning season (winter) have a negative impact on the recruitment of these species in the Portuguese west coast, limiting its success even if beneficial upwelling conditions occur later during the summer upwelling (feeding) season (Fig. 2). These findings led to the hypothesis that observed changes in the distribution and abundance of pelagic resources off Portugal are related to the increase of upwelling events, reported in the last decades, during the spawning season.

In order to test that hypothesis the SURVIVAL Project (PRAXIS/P/CTE/11282/1998) is conducting process-oriented studies, including *in situ* and remotely sensed observations of physical and biological parameters, as well as modelling activities using the Regional Ocean Modelling System (ROMS) and an Individual-Based Model (IBM). The project aims to study the impact of the physical processes (mainly upwelling events during the spawning season) on the dispersal and survival of small pelagic fish (mainly sardine) eggs and larvae (Santos and Borges 2000).

The results of the SURVIVAL cruise in February 2000 revealed that a coastal upwelling event occurred during almost the entire survey with the exception of the last few days. The event is clearly observed in satellite-derived sea surface temperature (SST) distributions, meteorological data (wind and sea level pressure data), and in current meter records. Sardine larvae and eggs were more abundant over the shelf break (Fig. 3), in contrast to what is known from previous ichthyoplankton surveys conducted by IPIMAR in the last decades, in which larvae were mainly found in the middle-shelf region (at a bottom depth ~100 m). It was also found that the mean length of larvae caught during the cruise increased meridionaly, from the southernmost to the northernmost cruise stations. These results constitute evidence of the impact of winter upwelling events and the poleward slope current on the distribution of larvae and eggs off western Iberia, and the implications of these factors on egg and larval survival are being further investigated. Finally, the preliminary ROMS-IBM simulations were in accordance with these field results, which reinforce the interest for future applications of these modelling techniques in the Western Iberian Upwelling Ecosystem.

Acknowledgements
This work was partially funded by the Portuguese Science Foundation under the projects PELAGICOS, SURVIVAL (PRAXIS/P/CTE/11282/98) and PO-SPACC (PRAXIS/P/CTE/11281/98). The IBM work is carried out in collaboration with the IDYLE Project (IRD-UCT-MCM). The SURVIVAL and PO-SPACC are GLOBEC-affiliated projects.

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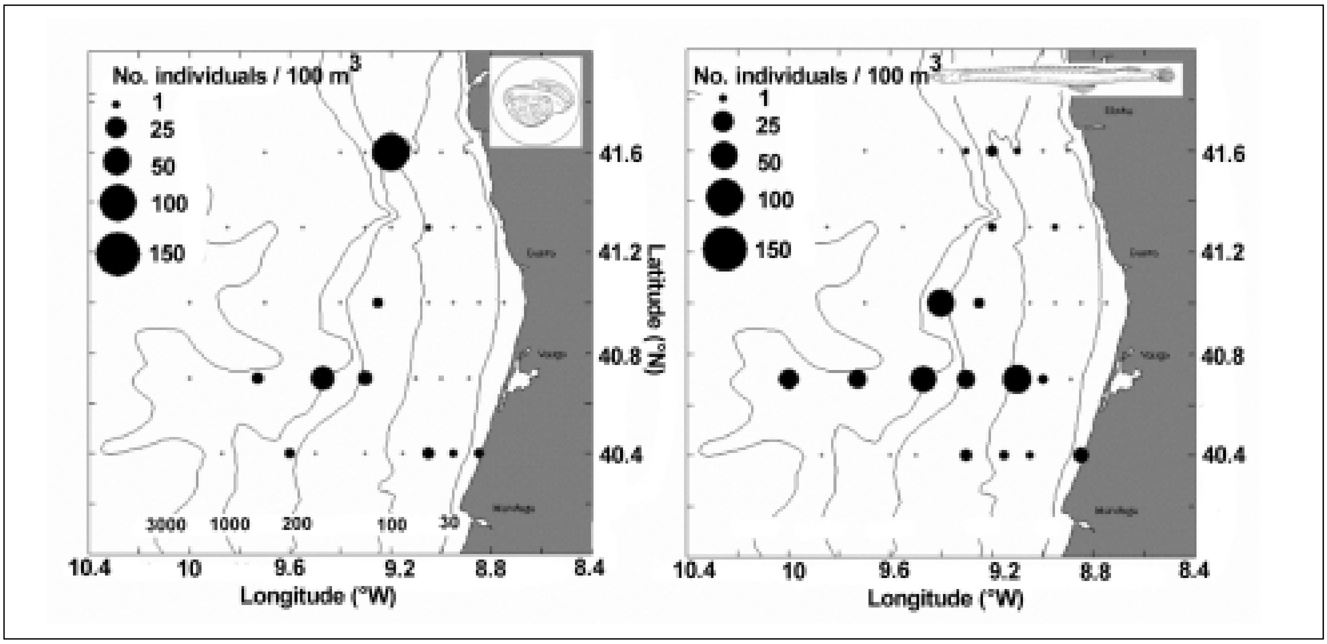

Fig. 3

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Figure Legends

Figure 1. Changes in sardine egg distribution off Portugal. The maps show the location of sampled stations for two DEPM egg surveys conducted by IPIMAR in March 1988 and 1997. Circles refer to stations where sardine eggs were found (adapted from Stratoudakis *et al.* submitted).

Figure 2: Annual upwelling indices (UPI) produced from satellite-derived SST anomalies between coastal and offshore areas (larger positive values indicate more intense upwelling conditions), and sardine (*Sardina pilchardus*) and horse mackerel (*Trachurus trachurus*) recruitment at age group-0 for the period 1987-1996: (a) UPI for the typical upwelling season of the west coast of Portugal (April-September) and sardine recruitment; (b) UPI during the typical upwelling season (April-September) and horse mackerel recruitment; and (c) UPI during winter (January-March), the spawning season of these fish species. The long-term mean of the upwelling index series is indicated by the horizontal dotted line (adapted from Santos *et al.* 2001).

Figure 3: Sardine egg (a) and larvae (b) distribution and abundance during the SURVIVAL cruise, 16-20 February 2000.

SPATIAL DYNAMICS OF SMALL PELAGIC FISH POPULATIONS IN THE CALIFORNIA CURRENT SYSTEM ON SEASONAL AND INTERANNUAL SCALES

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A recent large-scale, long-term analysis of the California Current system (Rodríguez-Sánchez *et al.* 2001) suggests that when the sardine (*Sardinops caeruleus*) population size increased during warming conditions (1930s), the bulk of its biomass and the center of its distribution were in the northern part of their reported distribution. During cooling conditions (mid 1940s to 1950s) the population size was decreasing and the center of distribution and bulk of abundance shifted from north to south, part of the population entering the Gulf of California during the cold 1960s. This population movement gave rise to a new fishery inside the Gulf of California. When the sardine population size decreased during the end of the cool conditions, the bulk of its biomass and the center of its distribution were mostly confined to the southwestern coast of Baja California and the Gulf of California.

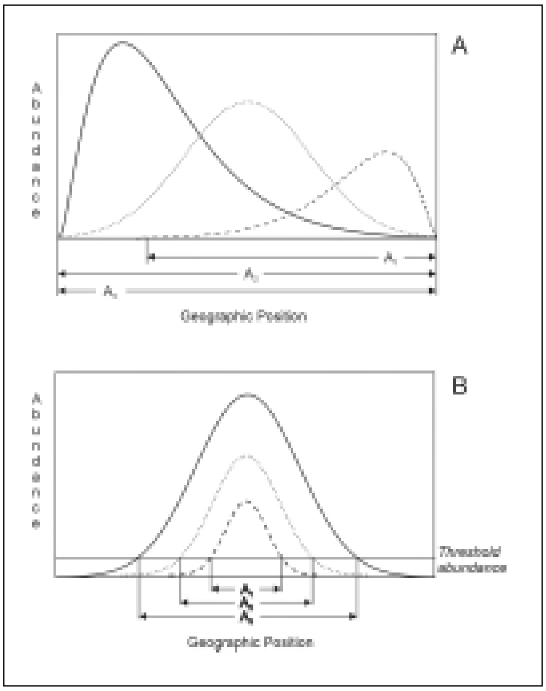

Fig. 1

An update of that analysis is presented here. Our results suggest that after the 1976-1977 regime shift, the sardine population was increasing during warming conditions and its center of distribution and the bulk of its abundance shifted from south to north. The reappearance of sardines in the north of the California Current ecosystem is a result of this large-scale long-term population movement. This spatial process described for *S. caeruleus* on a regime-scale basis (Fig. 1a) is different from that of homogeneous spread resulting from a simple expansion-contraction (Fig. 1b).

During the warming period of the 1930s, decadal averages of yearly SST anomalies were well coupled to the latitudinal distribution of sardine abundance. During the regime shift from high to low temperatures in the 1940s, the decline in sardine abundance in the northern areas was the first sign of ocean-climate and population interactions, with less apparent changes in the south. During the cool 1950s to 1960s, the relationship between sardine abundance and decadal SST anomalies is less clear. After the end of the cold regime in the 1970s, during which the sardine population was confined mostly to the coast of Baja California (the refuge area), a new warming period began, and again the latitudinal distribution of sardine abundance related well to decadal averages of yearly SST anomalies. During this last warming period, the increase in sardine abundance in the southern areas was the first sign of ocean-climate and population interactions, with less apparent changes in the north.

It has been suggested that ocean temperatures are a simple proxy for the more complicated and poorly understood suite of oceanographic variables that influence biological populations. The regime-scale analysis described here agrees with this, because an empirical relation is evident only at the beginning and at the end of the sardine population movement, whereas no relationship is apparent when the sardine distribution is shifting. Therefore, sardine distribution seems to be important when tracking responses to regime shifts of temperatures, but not along the sustained regimes. In other words, sardine abundance regimes are not those of the warm or cool periods, but those of warming or cooling periods.

Sardine population changes are related to environmental variability, while a spatial pattern of anchovy (*Engraulis mordax*) abundance alongshore is seen if it is assumed that sardine abundance is deleterious for anchovy. Anchovies colonized areas and increased in abundance where the sardine population level was low or absent. Thus, concerning the long-term and large-scale, neither sardine nor anchovy populations conform to the simple expansion-contraction model of range changes with population increase-decrease. This has important implications regarding our previous perceptions of marine population dynamics and stock assessment.

If ocean temperatures do not satisfactorily explain the interannual variability of pelagic fish populations, which other oceanographic processes or variables could better explain fish population abundance changes in space and time? We present a view of seasonal geographical dynamics of northern anchovy and California sardine populations along the California and Baja California coasts and their interannual variability in distribution, relative abundance and movements as a function of environmental variability during the last warming period. Our emphasis is on the young stages of *S. caeruleus* and *E. mordax*, and we use the live-bait catch records of these species from tuna bait-boats along the coast. Data are grouped in 1°x1° squares on a monthly basis for the 1980-1997 period.

Because small pelagic fish are particularly sensitive to ocean-climate variability, interannual variability in their seasonal patterns of distribution suggests that fronts appear to be the oceanographic processes in the California Current system that define the aggregation and forage habitat for young pelagic fish. Hence fronts will have a significant influence on the distribution and recruitment of anchovies and sardines.

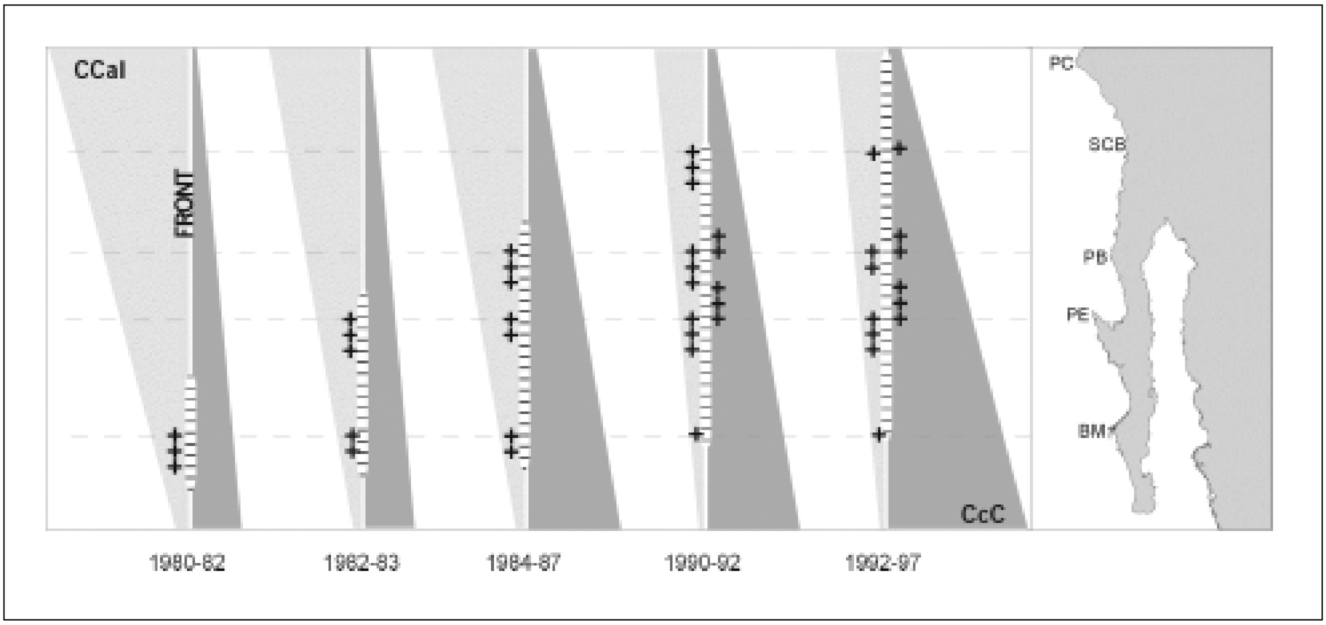

Fig. 2

We suggest that the central population of *E. mordax* is related to the Ensenada front, a geographically fixed feature. The southern population is related to a geographically dynamic front, where the equatorward California Current and the North Equatorial Current converge along the southern part of the Baja California peninsula. During ENSO conditions the predominance of warmer water masses weaken these oceanographic fronts, and upwelling caused by bathymetric or coastal shape characteristics become important oceanographic processes as refuge areas.

We further propose that the *S. caeruleus* population is related to a geographically dynamic front, where the equatorward California Current and the inshore California Countercurrent converge parallel to the shore off California and Baja California. As a result of the seasonal changes in advection of those currents, there is a section along the front with favourable conditions for the feeding of young sardines. The interannual variation of the seasonal patterns in sardine distribution and abundance suggests that the latitudinal position of population levels along the front change. Recruitment is increased where the latitudinal position coincides with optimal conditions for feeding, and diminishes where it coincides with sub-optimal conditions. Our results suggest a progressive interannual increase of northward advection of California Countercurrent after the 1976-1977 regime shift to warming conditions, while the southward advection of California Current weakened (Fig. 2).

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Figure Legends

Figure 1. Simplified diagram illustrating the differences between an homogeneous spread resulting from the simple expansion-contraction model of range changes with population abundance increase-decrease, and the spatial process described here for the *Sardinops caeruleus* population in the California Current System. A) A non-stationary dynamic model proposed for sardine on regime scale. Fish population changes its location within ocean habitat in an evolving progression over multi-decadal time scale. B) Expansion-contraction model, with the implicit assumption of geographically stationary population, usually underlying conventional analyses of long data series. In both models A_1 represents the refuge area occupied when the population size is at low level, A_2 is that when the population size is growing or diminishing, and A_3 is the largest extension occupied when the population size is at high level.

Figure 2. Schematic representation of interannual variation in space and time of the recruitment of *Sardinops caeruleus* in the California Current System for the period 1980-1997. Using five representative average-years within the period, the figure shows how northward advection by the inshore California Countercurrent (CcC) could increase progressively while the California Current (CCal) weakens. The resulting characteristics along the front changed (qualitatively and/or quantitatively), as well as the latitudinal position of the population levels. The section along the oceanographic front with conditions for the feeding of young sardine is indicated by short horizontal lines. Recruitment increases (+++) where optimal conditions are found and diminishes (++) or is low (+) where the characteristics of the front are sub-optimal. During the period 1980-1987 favourable conditions are reached when the seasonal advection of the California Countercurrent increased. In the last two average-years, favourable conditions are reached when the seasonal advection of the California Countercurrent is both increasing and when it is diminishing.

BENEFIT'S SPACC-RELATED RESEARCH IN THE BENGUELA

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The Benguela Environment Fisheries Interaction and Training (BENEFIT) Programme is a young partnership between Angola, Namibia and South Africa, devoted to the sustainable management of the living resources of the Benguela Current system. The Programme was formally launched in April 1997, and the Secretariat located in Swakopmund, Namibia in late March 1998. Funding for research activities was not received until mid-1999. Since then, the Programme has gone from strength to strength, building upon a firm desire of the partner countries to co-operate. The joint, transparent process by which research and training activities are planned and conducted has led to trust, progress and confidence in the partnership. Furthermore, as an SADC project, BENEFIT has attempted to facilitate training and technology transfer to other coastal states within the region.

BENEFIT's budget now approaches N$14 million per annum, including the incorporation of the premier Norwegian *RV. Dr. Fridtjof Nansen* into research and training activities. BENEFIT's two major donors are Norway and Germany; however, contributions are also received from France, Iceland, Japan, FAO, World Bank, and the African Development Bank, with the UK contributing indirectly through SADC. Funding of N$4-5 million annually in cash and in-kind contributions is also received from the partner countries.

BENEFIT's research agenda has three primary foci: (1) fisheries resources, (2) natural environmental variability, and (3) resource:environment linkages. In BENEFIT's young history, most resource research has concerned commercial fisheries; however, there are exceptions. Examples of SPACC-related resource research projects and their duration are itemized below:

- Ageing of sardine and horse mackerel (1999-current);
- Retrospective analysis of commercial data on horse mackerel (1999-2001);
- Analysis of errors in acoustic surveys of pelagic species (2000 Workshop);
- Analysis of errors in acoustic surveys of sardines, sardinella and anchovy (2002);
- Identification of horse mackerel acoustic targets and analysis of survey errors (2001-2002);
- Improvement in survey design of pelagic species (2000-2002);
- Vertical migration patterns of horse mackerel (2001-2002);
- Recruitment studies of pelagic species (1999-2002);
- Biology and ecology of pelagic gobies (2001-2002);
- Retrospective studies on the spawning habitats of sardine and anchovy in the Northern Benguela (2002);
- Interaction of Cape fur seal with commercial fishing (2001-2002);
- ECOPATH and ECOSIM modelling of the Benguela (1999-2001); and
- Pelagic Stock Assessment Workshop in FY 2001.

This research agenda has been complemented by a number of environmental initiatives, including:

- Implementation of effective ADCP data collection and management for oceanographic and fisheries research in the SE Atlantic;
- Continuity and mesoscale patterns of circulation in the Benguela upwelling System (drifters);
- Environmental monitoring with ship-based transects;
- An integrated inshore environmental monitoring system for the Benguela Region;
- Monitoring and process studies of hydrographic and biological variables in the Northern Benguela upwelling system;
- Ground-truthing of remotely sensed ocean colour;

- Application of remote sensing in the Benguela ecosystem;
- Hydrogen sulphide studies; and
- Capacity development related to the Namibe Oceanographic and Fisheries Research Laboratory.

All the above activities have direct or indirect implications to GLOBEC-SPACC, and many are directed toward understanding resource:environment linkages.

BENEFIT's Management Action Committee (MAC) met in Cape Town on 28th-29th August 2001 to consider the future scope of BENEFIT. The outcome of this meeting will in time be considered as one of BENEFIT's fundamental milestones. At stake was the role BENEFIT might play in participating in the BCLME Programme. As agreed upon in the BCLME Project Document, "*…BENEFIT, will serve as the science "arm" of the BCLME project, consistent with the scope of BENEFIT." (Paragraph 57). The role of BENEFIT is further accentuated in Paragraph 65: "...BENEFIT will assume a direct responsibility in the execution of a number of program activities specified in scientific, technological, and training elements of the project, and resources will be provided to BENEFIT for this purpose. BENEFIT is already functioning as an independent scientific entity that provides ongoing transboundary scientific advice to the three countries with regard to BCLME. The project will strengthen the capacity of BENEFIT to continue to build upon this advisory function.*"

Independent of these considerations regarding the BCLME, MAC reaffirmed that BENEFIT's scope to develop the enhanced scientific capacity required for the optimal and sustainable utilization of the living resources of the Benguela ecosystem (Science Plan, p. 48) should not be altered. MAC furthermore re-emphasized the research commitment of the Programme toward all living resources, not just commercial species, that contribute to the structure and functioning of the system. Particularly mentioned, the following topics therefore fall within the remit of the Programme:

- Non-target species/by-catch;
- Inshore fauna and flora;
- Seabirds;
- Marine mammals;
- Ecological studies (vs. stock separation);
- Mariculture;
- Post-harvest technology, including quality control and clean technology;
- Effect of fishing activities on the ecosystem; and
- Effect of climate change on living marine resources.

With these objectives in mind, and taking into consideration BENEFIT's pending affiliation with the BCLME, MAC agreed that BENEFIT's geographic boundaries should be extended northward from about 14˚S latitude, near Namibe, Angola and the seasonal location of the Angola/Benguela Front, to about 5˚S latitude, near Cabinda, Angola. This expanded mandate means that BENEFIT's programmatic activities will include in future the sub-tropical and tropical systems along the Angolan coast to just north of the Congo River. In this context, the regional role of BENEFIT and its affiliation with GLOBEC-SPACC and other international bodies/institutions has the potential to be significantly increased, dependent upon the availability of funding and human resources to launch initiatives within this expanded geographic realm.

SPACC-RELATED RESEARCH IN THE HUMBOLDT CURRENT

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Introduction

The Humboldt ecosystem is one of main upwelling areas of the world's oceans, distinguished from the other upwelling systems by a considerable concentration of pelagic fish resources. These populations of small pelagic fish are the target of intense fishing activity, but are also preyed upon by birds, mammals and bigger pelagic fish. Small pelagic species of commercial value include horse mackerel (*Trachurus murphyi*), anchovy (*Engraulis ringens*), sardine (*Sardinops sagax*) and to a lessor extent mackerel (*Scomber japonicus*). The most abundant fish is anchovy, exploitation of which is almost exclusively dedicated to the production of fish meal and oil. The low price per unit mass of this species is compensated for by their high abundance; however, that high abundance has been endangered in 1972 and 1982 due to a notable decrease of the anchovy stocks.

On both occasions, intense fishing activity was accompanied by the occurrence of strong El Niño events. During these periods subtropical and equatorial waters that are scarce in food prevail, and natural mortality in the whole pelagic ecosystem is increased due to food limitation. This results in reduced rates of spawning and recruitment success of small pelagic species. This, together with the fact that research effort was previously focussed on analyzing data that was collected from the fishing fleet, rendered administration and management of fishing activities difficult and provided incomplete and limited data for scientific analysis.

The marine fishery in the Humboldt Ecosystem

The fishery for small pelagics in the Southeast Pacific began in the middle of 1950s. In 1966 the Peruvian Marine Institute (IMARPE) founded the EUREKA Programme to collect data for the study and management of this fishery, with special emphasis being given to monitoring the abundance of pelagic fish using the fleet itself. By this time networks to monitor the volume and composition of pelagic landings existed in Peru as well as in Chile, with daily measurements of population size structure collected and organs such as otholiths, gonads and stomachs retained for age, growth, fecundity and trophic ecology studies. Models of population dynamics such as VPA were initiated for the estimation of population abundance and total allowable catches.

After the 1972 El Niño, IMARPE, together with support from the FAO and NORAD, founded the CREA Programme (Latin American Electroacoustic Center). This programme was conducted between 1975 and 1980, and had as its aim the development of hydroacoustic assessment technologies directed at marine species in general and small pelagics specifically. During this period the fishery for horse mackerel and mackerel off Peru was initiated, with catches being made primarily by Polish, Soviet and Cuban fishing vessels. This was in contrast to Chile which at that time had a flourishing horse mackerel fishery that used local vessels. During the 1980s a survey programme named RASTRILLO was implemented off Chile; this was similar to the Peruvian EUREKA programme and the fishing fleet used for determination of the distribution and relative abundance of important pelagic species. By the end of 1980s Chile and Peru had adopted acoustic methodology as the main tool for direct assessment under the standards formulated by ICES, and both countries now possess a modern research fleet.

The warm event represented by the El Niño event of 1997-98 meant the end of a cycle of horse mackerel abundance. Additionally, the 1990s witnessed a northward movement of the population of sardine that had replaced anchovy in the ecosystem after 1982, from the Peruvian-Chilean border towards the north of Peru and the Galapagos Islands. After the El Niño event of 1997-98 the situation regarding horse mackerel and mackerel stocks is still uncertain, in spite of a slowly increasing horse mackerel abundance in the center and southern regions off Peru. This is in contrast to the anchovy population's quick recovery in the same period.

These large-scale fluctuations in the abundance of the main pelagic resources of the Humboldt ecosystem resulted in the development of an agreement between IMARPE and IFOP (Chilean Institute for the Development of Fisheries) at the beginning of the 1990s. This agreement primarily involved scientific co-operation in the form of workshops for the exchange and analysis of annually collected information concerning the main stocks. In Peru, IMARPE co-operates with universities to conduct research and recommend management decisions for the fishery on small pelagics, whilst IFOP and private companies and universities carry out investigation on these species in Chile.

The Humboldt Area, the GLOBEC-SPACC Programme and other initiatives

The Southeast Pacific countries (Colombia, Ecuador, Peru and Chile) share the exploitation of transzonal and highly migratory species. Although the main stocks of small pelagics are predominantly shared by Chile and Peru, shared demersal fisheries that focus on common species (e.g. hake *Merlucius gayii*) also exist. However, in spite of the existence of the CPPS (Permanent Commission of the South Pacific) that groups these countries, there is no co-operative programme to develop direct assessments of species of common interest.

The topics of common interest for these countries are not limited to small pelagics, but also to coastal resources, aquaculture, the environment and fishery management and administration. With the exception of the IFOP-IMARPE agreement, CPPS countries have not been able to articulate an initiative of regional research on marine species, although some proposals regarding this are being developed. Three of these are highlighted here: the ACTIVE Research Unit, the GLOBEC-SPACC Programme, and the ISPPA Project.

ACTIVE (Study of the Individual and Collective Behaviour of the Stocks under Exploitation and their Effect on the Catchability) is a Research Unit created by IRD (French Institute for Research and Development) that includes the participation of IFOP, IMARPE, UCV and other marine laboratories from France and Scotland. Emphasis of this investigation is placed on pelagic resources (primarily anchovy and horse mackerel) with acoustics used as the main research tool. Within this research unit a special study will be developed to assess the aggregative behavior of anchovy and horse mackerel using the 3D acoustic techniques newly created by the AVITIS Project.

Scientists from Peru and Chile are participating in research and meetings organized by the GLOBEC-SPACC Programme in spite of the lack of National GLOBEC Committees in these countries. In both cases scientists are adopting the pertinent actions to formalize the participation of their marine research institutes in GLOBEC initiatives. In addition, the idea of creating a new program affiliated to GLOBEC and dedicated to the development of comparative studies between the Benguela and Humboldt ecosystems is endorsed by both Chile and Peru, and several common aspects between both ecosystems have been established. It is considered to be of high scientific interest to develop an approach that makes provision for more consistent research related to probable teleconnections in the dynamics of oceanic processes (with emphasis on upwelling and the alternation of warm and cold events) and the main marine species.

ISPPA (Research on Small Pelagics and the Enviroment) is a research proposal that will be presented to the Census of Marine Life. The central aspect of this investigation is to use the fishing fleets for the collection of data for scientific use, with new-generation echo sounders or modified commercial echo sounders being used to calibrate and store the signals emitted and received by the fishing fleet. These will be analyzed by specialists to obtain a series of snapshots on the distribution and abundance of small pelagics, as was done previously during the EUREKA and RASTRILLO programmes. These snapshots can be directly compared with fishing yield, and the spatial distribution of the whole fishing fleet will be monitored by satellite, an aspect that is already available in Peru and will soon be available in Chile. In addition, ISPPA will incorporate the use of a LIDAR-like tool for quick surveying of pelagic resources, especially in shallow water areas. Also within the frame of Peru-Chile agreements a Large Marine Ecosystem Program for the Humboldt Area has been approved and is currently under construction through GEF.

A variety of methods for the study of population dynamics (*e.g.* CPUE, CLIMPROD, VPA, MPA, the Egg Production Method and Swept Area Method for demersal studies) are already widely used in both Chile and Peru, as are GIS and remote sensing. The use of numeric models intended to explain the dynamics of the ecosystem has not been extensively developed in these countries, although some advances are being achieved within the framework of the NAYLAMP Project (the Yearly El Niño and the Anomalies Measured in the Pacific Ocean) off Peru. A few achievements have been made from the point of view of modeling the distribution and abundance of small pelagics and their relation with environmental variables, although consistency has to be provided through the use of geostatistics and other techniques such as IBM. Future co-operation with scientists from the Benguela region in this respect would be an important objective for scientists from the Humboldt region, and should constitute a valuable contribution to the objectives of GLOBEC-SPACC.

Environmental conditions and fluctuations in distribution in small pelagic fish stocks (ENVIFISH) 1998 - 2001

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Introduction
ENVIFISH was a three-year, European Union-funded project with three African partners (Angola, Namibia and South Africa) and five European partners (Italy, Germany, UK, Portugal and Norway), designed to study the environmental conditions and fluctuations in pelagic fish stocks in the Benguela and Angola current systems. The following institutions were involved: Joint Research Centre, Italy; Instituto Investigaciones Pesquera, Angola; National Marine Information and Research Centre, Namibia; Marine and Coastal Management and the University of Cape Town, South Africa; Institute for Baltic Sea Research, Germany; Institute for Marine Research, Norway; Centre for Coastal and Marine Sciences, United Kingdom, and the Instituto de Investigação das Pescas e do Mar, Portugal. Dr Andy Bakun represented the interests of the FAO in the project.

Objectives
The main objective of the ENVIFISH project was to develop appropriate methodologies for improving the sustainable management of small pelagic fish, based on the identification and quantification of key environmental conditions that influence fluctuations in their recruitment and distribution in the Benguela and Angolan systems. More specific objectives of ENVIFISH were:

- To develop a consistent and quality-controlled database of satellite, oceanographic and fisheries data, together with tools for analysing the data;
- To identify and quantify the key environmental features associated with, and possibly causing, the significant variability observed in the abundance of small pelagic fish stocks in the last 15 years;
- To evaluate the impact of key environmental features, such as areas of spawning and recruitment habitat, as well as processes such as concentration, enrichment and retention, on recruitment success;
- To relate environmental conditions to the spatial distribution of small pelagic fish stocks; and
- To develop adequate training and capacity building to allow these scientific findings to be transferred to management and decision-making bodies in the African countries.

Approach
In ENVIFISH a retrospective analysis of fisheries, satellite, oceanographic and meteorological data covering the last 15 years was carried out. The data can be categorised as:

- SST and ocean colour satellite data;
- Meteorological data from models and observations;
- Oceanographic data from international data banks, research cruises, ships of opportunity and coastal stations;
- Fisheries data relating to catch and effort;
- Acoustic survey data of fish distribution and biomass of adults and recruits; and
- Larvae and egg surveys, and spawner biomass estimates from application of the egg production method.

Legacy of ENVIFISH
As a result of the project, an excellent data base of reanalyzed, NOAA weekly SST composites at a resolution of 4.5km and encompassing the region from the equator to 40°S and 2°W-30°E for the period

1982-2000 is now available to the marine science community (see Plate 7). A significant result of the project was the introduction of artificial neural network Kohonen self-organising map (SOM) analysis, which has been applied to a variety of data sets including SST, vertical chlorophyll profiles, altimeter derived sea level, and QuikScat winds. In this method, preprocessing of the data involved converting each ENVIFISH image into a single row vector, with cloud coded as missing data and the land removed. Data were then converted to ASCII format for the SOM software (Som_pak, http://www.cis.hut.fi/research). Examples of the SOM analysis appear elsewhere in this volume (see abstracts by Hardman-Mountford *et al.* and Silulwane *et al.* this volume) as do a number of the other main results arising from the ENVIFISH project.

Training of students

A number of students have obtained postgraduate training through the ENVIFISH project: Messers Ashley Naidoo and Carlos Villacastin at the PhD level; Ms Nonkqubela Silulwane, Ms Shona Young and Messers Quilanda Fidel, Nkosi Luyeye and Augustino Duarte at the MSc level; and Ms Maya Pfaff and Mr Beau Tjizoo at the BSc(Hons) level. A strength of the project was the opportunity to employ Drs Anthony Richardson (at UCT in South Africa), Nick Mountford-Hardman (at CCMS in the UK), and Georgi Daskalov (at NATMIRC in Namibia) as post -doctoral fellows.

Conclusions and recommendations

The ENVIFISH project has been very successful in providing useful datasets on environmental parameters in the Benguela Current region. There has not been sufficient time to fully utilise the data, and it is expected that they will be further analysed in the future. The program was also successful in introducing a rather novel tool (the SOM) to the analysis of SST and other data. A further success of the program was the excellent training that a number of students gained through participation in the project, principally from the new, young post-doctoral researchers. The international connections developed by the African partners will prove useful in the years to come. There were a few difficulties experienced during the project, most of which related to working at a distance. It was also thought that the project was rather ambitious in its attempt to cover all the goals in three years. It is hoped that it will be possible to continue extending the SST time series for 2001 and beyond, and to ensure that databases at JRC remain available to researchers in the region. A poster of the monthly series will be produced at JRC.

Acknowledgements

Funding for this research came from the European Union research project ENVIFISH (contract # IC18-CT98-0329).

RELATING THE DISTRIBUTION OF SOUTH AFRICAN PELAGIC FISH SPECIES TO ENVIRONMENTAL VARIABLES USING A NOVEL QUANTITATIVE APPROACH

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The distribution of large pelagic fish (tuna and sword-fish) generally shows a positive relationship between abundance and sea surface temperature (SST) fronts. In the case of small pelagic clupeoids the situation is not so clear, with some studies on the distribution of Californian anchovy and South African sardine showing no relationship to SST, whilst those on North Sea herring and Chilean anchovy and sardine distributions finding concentration at fronts. These investigations, however, all used a correlative approach, which suffers from the problem of covariance between SST and other environmental variables not included in the analysis. This problem can be alleviated by constructing models that include a suite of pertinent environmental variables, so that the effect of each variable in the model is independent of the others.

We report here on recent research using an 11-year time series of satellite-derived SST images and commercial catch records of South African anchovy (*Engraulis capensis*), sardine (*Sardinops sagax*) and round herring (*Etrumeus whiteheadi*). The index of fish distribution used in the models was "catch-per-set" (the tonnage of fish caught in a single haul). Research conducted in other purse seine fisheries (*eg.* West Africa) has demonstrated a relationship between mean catch per set and population size. We extrapolate this idea by assuming that similar relationships also exist at intermediate spatial scales and hence that catch per set and reflects local abundance. The initial set of predictors consisted of 20 variables, including seven temporal and spatial variables, four variables related to the fishing boat's characteristics, four related to solar and lunar ephemera, and five SST-related variables. This number was empirically reduced to a set consisting of year, month, time of day, latitude, water column depth, length of boat, moon phase, moon angle, sea surface temperature (SST), an index of frontal intensity (standard deviation of SST), and an index of SST warming or cooling (temperature difference between successive SST images). Model building was a two-step process. First, we built generalized additive models (GAMs) for each species to identify relationships between distribution and environmental variables. From the functional forms suggested by the GAM analysis, we developed predictive equations by constructing general linear models (GLMs). GLM is a rigorous approach supported by considerable statistical theory that combines ANOVA (categorical) and regression (continuous) variables to yield a predictive equation. GAMs do not produce predictive equations but are particularly adept at identifying non-linear relationships between variables.

The process is demonstrated in Figures 1 and 2. The GAM model, for example, showed that the variable 'time' had little effect on sardine catches (Fig. 1) and was thus not included in the GLM model (Fig. 2) for this species. Also, note that the GAM model suggested that variable 'latitude' should be implemented as a linear relationship and that 'length' (the size of the fishing boat) is best represented as a quadratic function. In the final GLM models the environmental variables accounted for 42.5%, 25.2% and 39.8% of the variance in distribution (catch-per-set) of anchovy, sardine and round herring respectively.

We further found that the relative importance of the individual environmental predictors varied considerably amongst the three species. The influences of the SST variables were not very strong (Fig. 3) but indicated larger catches of sardine in warm water and in cool water for anchovy and round herring. We also show that the influence of the SST standard deviation is generally very low, at least at the spatial and temporal scales used in this study (one week and 15 kilometers respectively). We suggest that a model

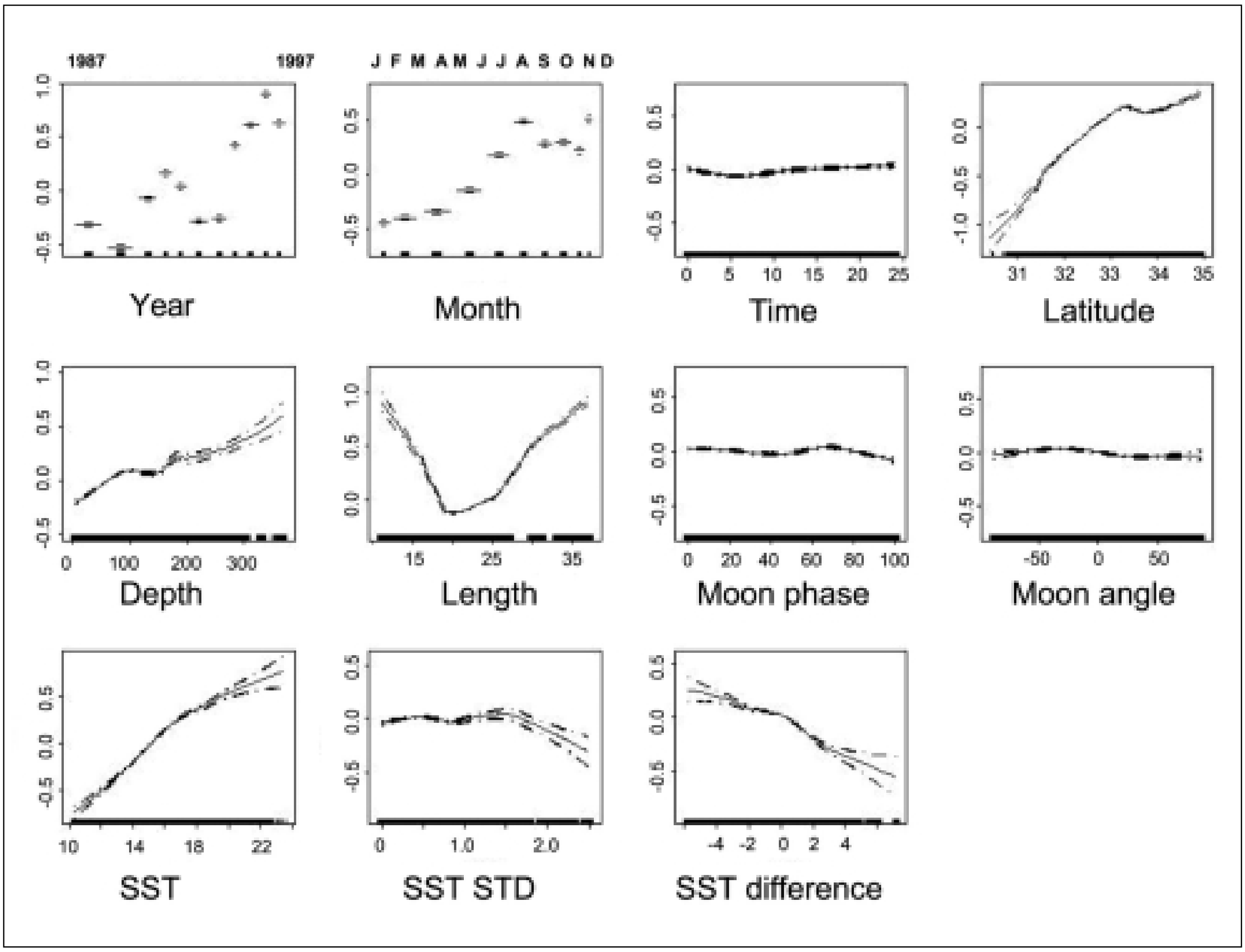
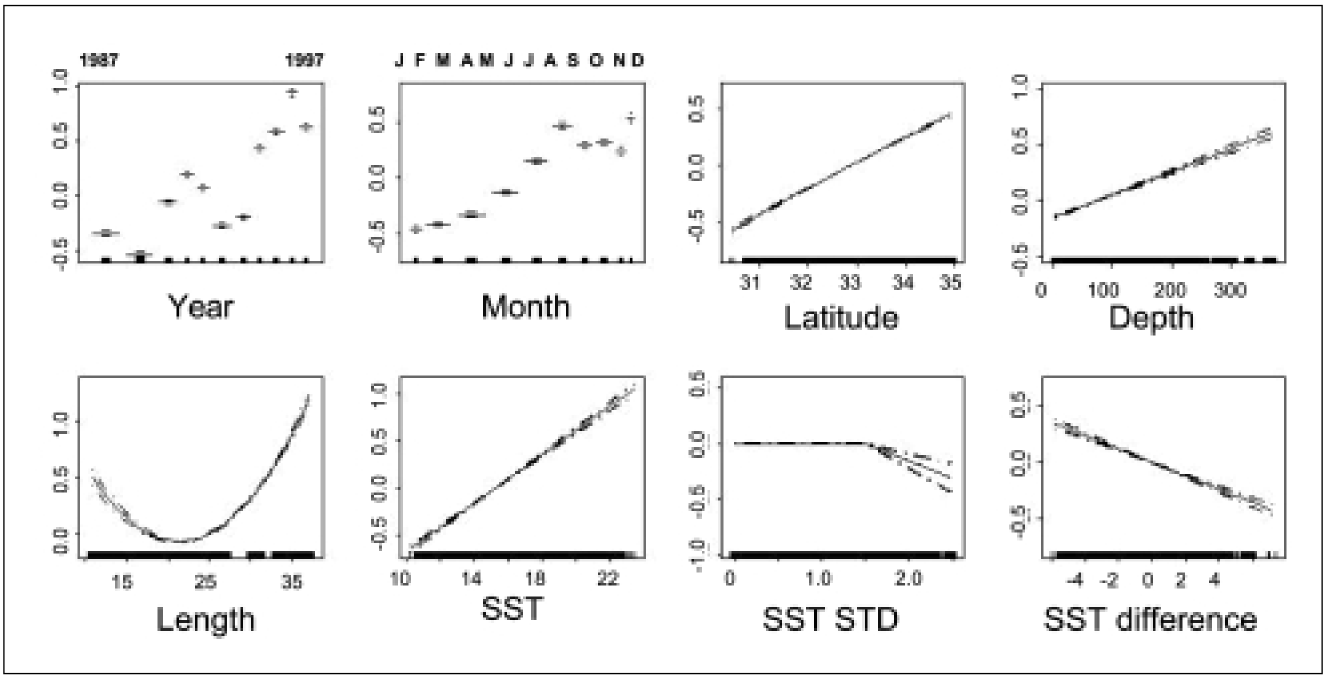

1987
1997
Year
J F M A M J J A S O N D
Month
Time
Latitude
Depth
Length
Moon phase
Moon angle
SST
SST STD
SST difference

Fig. 1


1987
1997
Year
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Month
Latitude
Depth
Length
SST
SST STD
SST difference

Fig. 2

building approach using GAMs and GLMs can be applied fruitfully to studies relating fish catches to environmental variables but it is also clear that to fully understand factors influencing pelagic fish catches, information on enrichment processes, species interaction and the fishing strategy of skippers need to be considered. It is further evident that the variable "catch-per-set", used by us to quantify fish distribution is very dependent on non-environmental variables (such as boat size) and also on fishing strategy. It would therefore be very desirable to find a more appropriate distribution index, or to construct a sub-set of the data in a manner that would eliminate such known problems.

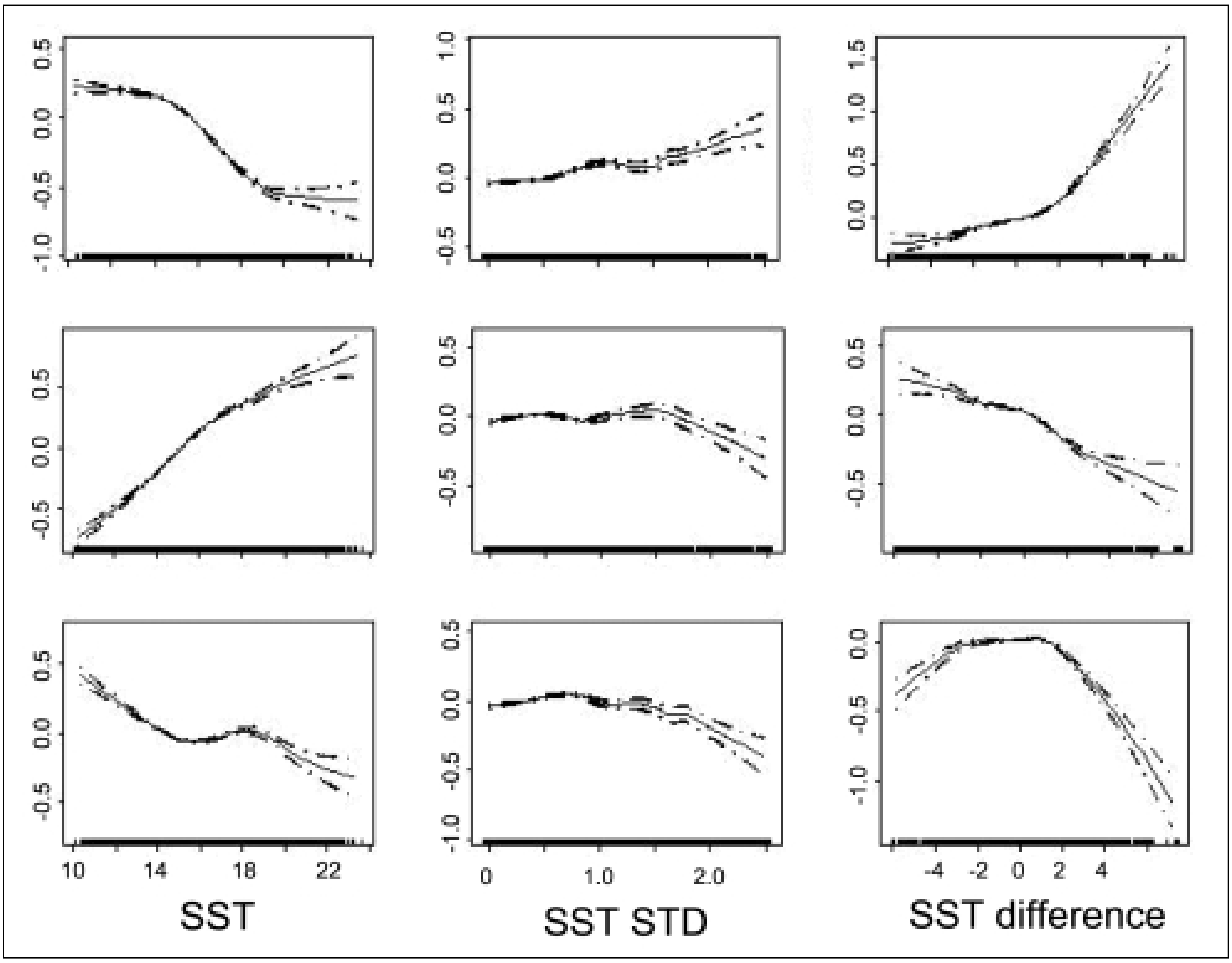

Fig. 3

Figure Legends

Figure 1. Sardine distribution ("catch-per-set") as a function of 11 predictors as obtained from a GAM model.

Figure 2. The functional forms of sardine distribution ("catch-per-set") versus eight predictors as deduced from Figure 1 for implementation in the GLM model.

Figure 3. Anchovy, sardine and round herring distribution as a function of SST variables after the effects of other variables have been removed by the GAM model.

INTERACTIONS AND SPATIAL DYNAMICS OF RENEWABLE RESOURCES IN UPWELLING ECOSYSTEMS: THE IDYLE PROGRAMME IN THE BENGUELA

Pierre Fréon[1], John Field[2], Frank Shillington[3], Carl Van der Lingen[4], and the whole IDYLE team

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Objectives of the programme

The scientific focus of the IDYLE programme is to understand how the adaptive strategies of the different species of fish and their dynamics are structured by the presence of inshore upwelling and the resulting ecosystem patterns. We focus on mesoscale dynamics of the environment, reproductive strategies, spatial strategies (macroscale) and on pelagic fish aggregation patterns, as well as on trophic strategies within the framework of ecosystem dynamics. Knowledge of these adaptive strategies is naturally applicable to the sustained development and viability of fisheries in upwelling regions.

The programme is based and developed in the Benguela upwelling ecosystem, where important knowledge has been accumulated. Generic tools are designed or adapted in order to allow the rapid transfer of methodology and results to other areas. IDYLE is a follow-up to the VIBES (VIability of exploited pelagic fish resources in the Benguela Ecosystems in relation to the environment and Spatial aspects, 1997-2000) project, which was primarily directed towards coastal pelagic resources and their management. Training will constitute a major aspect of this programme at both bilateral (France/RSA) and regional scales.

IDYLE is a collaborative programme between IRD (Institut de Recherche pour le Développement), MCM (Marine and Coastal Management Branch; Department of Environmental Affairs and Tourism), UCT (University of Cape-Town) and other universities/institutes in the region (Table 1). IDYLE is funded by these institutions and additional French funding, and is closely associated with the Benguela Ecology Programme (BEP-V) and affiliated to the BENEFIT regional programme.

Activities

The multidisciplinary focus of IDYLE will result in the implementation of different models that provide dynamic representations of an ecosystem. These will permit a better understanding of the impacts of: (1) the spatial structuring of the environment on the dynamics of populations; (2) interspecific relationships within the ecosystem; and (3) spatio-temporal structuring on the management of exploited resources. The IDYLE programme is subdivided into five scientific projects:

- 3D-Hydrodynamic modelling of the physical processes related to the transportation and the retention of eggs and larvae;
- IBM modelling of the coupling between the recruitment processes and the dynamics of the environment (in collaboration with the GEODES programme);
- Ecosystem modelling of the spatio-temporal dynamics of populations and the definition of ecosystem indices;
- A GIS approach to interactions in an exploited pelagic ecosystem (Fig. 1); and
- Retrospective analysis of the relationship between recruitment and spatial dynamics and other biological and environmental parameters.

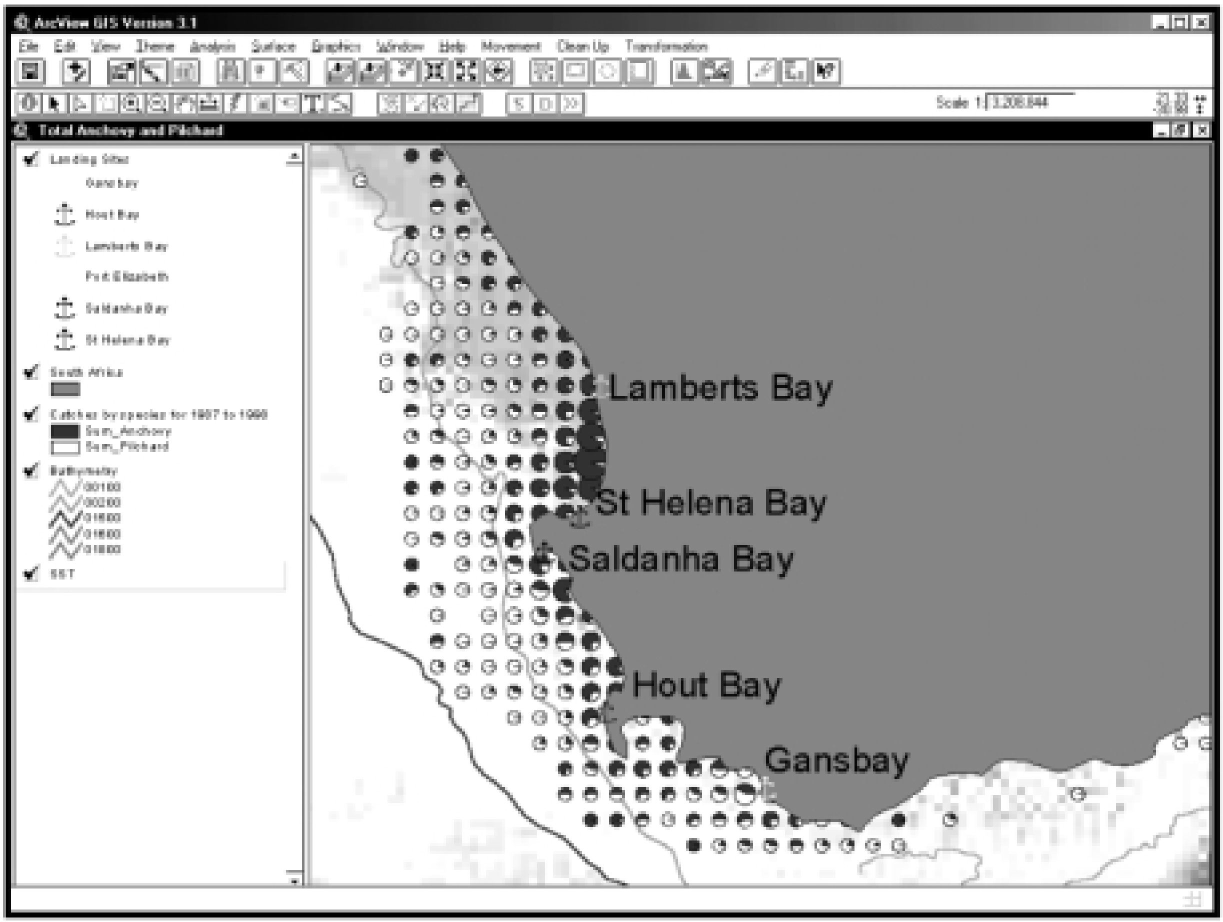

Fig. 1

Expected results

Improvement in Knowledge - the programme will improve understanding of the dynamic functioning of coastal upwelling ecosystems in view of their management. More specifically, it will contribute to identifying the causative roles of fisheries and the environment in relation to the large changes in abundance and spatial distribution of major fish species observed during past decades. We believe that results from this research will enable us to answer some important questions relating to the influence of the various strategies developed by the dominant species on ecosystem structure. The strategic choices in terms of pelagic fisheries management (quotas, control of fishing effort, marine reserves, ecosystem approach) in this kind of environment will benefit from the results of this study.

Products - the following products should be available at the end of the programme:

- a high-resolution 3D hydrodynamic model of the Benguela, implemented from the ROM code and easily transposable to other ecosystems;
- a generic IBM model of the dynamics of early life history stages in relation to the environment;
- a generic IBM model of specific interactions;
- the definition of new ecosystem and environmental indices;
- a CD-ROM on available environmental data (COADS, series of processed remote sensing images);
- software for quantifying upwelling and retention indices using satellite data;
- a South African fisheries GIS, easily transposable to other ecosystems;
- an atlas of pelagic fisheries off South Africa;

- a CD-ROM of a bibliographical database of publications (including grey literature) on the Benguela, linked to documents primarily held at MCM (Cape Town), NatMIRC (Swakopmund) and the Centre for Mediterranean and Tropical Fisheries Research in Sète; and
- publications in the primary literature.

Training - the IDYLE programme has four components:

- On-the-job training - French scientists work in close co-operation with students from the Benguela region. South African scientists co-supervise French students, and small working-groups will ensure regular interaction between the different participants and students;
- Intense training sessions - at least twice a year short training sessions on marine ecology and statistics will be organized in co-operation with partners (targeting scientists and students);
- Student exchanges - exchanges of students have been implemented between South Africa and France or other countries in order to exchange methodological advances;
- Implication of young scientists in national and international Working Groups - IDYLE is involved in several scientific groups (GLOBEC/SPACC, PNEC, SCOR-IOC WG 119) and promotes the involvement of young South African scientists in these research associations;
- In order to strengthen regional participation in the different research and training activities of the IDYLE programme, IDYLE is fostering specific actions and means to build links with research institutions and universities from Namibia and Angola.

Co-ordination and duration
The IDYLE programme started at the beginning of 2001 and will continue until the end of 2004. Co-ordinators of the Programme are listed in Table 2; at the end of 2003 all French scientists will be back in France. For more information access: http://sea.uct.ac.za/marine/idyle/.

Figure Legends
Figure 1. ArcView GIS output showing anchovy and pilchard (= sardine) catches by area over the period 1987-1998.

Table 1. Countries, institutes and number of scientific staff (in brackets) participating in the IDYLE Programme.

Country (Scientific staff)		Institute (Scientific saff)	
South Africa	(13)	MCM	(8)
		UCT	(4)
		OceanSpace	(1)
France	(9)	IRD	(9)
Namibia	(1)	MFMR	(1)
TOTAL	(23)		(23)

Table 2. Co-ordinators of the IDYLE programme.

Name	Title	Discipline	Institute
Pierre Fréon (programme director)	Dr	Ecology, fish behaviour	IRD
John Field	Prof	Ecology	UCT
Frank Shillington	Prof	Physical oceanography	UCT
Carl van der Lingen	Dr	Fisheries Biology	MCM

Individual based modelling (IBM) of the early stages of anchovy in the Southern Benguela system

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[4] Marine and Coastal Management, Cape Town, South Africa
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[6] UCT Zoology Department, Cape Town, South Africa

Introduction

Individual based modelling (IBM) is *"a bottom up approach that is focused in the parts (i.e. individuals) of a system (i.e. population) and then tries to understand how the system's properties emerge from the interaction among the parts"* (Grimm 1996). The resulting model is neither descriptive nor predictive, but rather an exploratory model. In this case the IBM is intended to represent, at an individual level, the main processes involved in the population dynamics of anchovy (*Engraulis capensis*) in the Southern Benguela. The implications of the spatial distinction between the Agulhas Bank spawning and West Coast nursery areas exhibited by anchovy are explored. This approach attempts to make explicit the underlying dynamics of conceptual models arising from previous work on the subject (Hutchings *et al.* 1992, Bakun 1996).

An emphasis is put on methodology, and involves an experimental, step-by-step procedure in which the processes of spawning, transport, growth, feeding, cannibalism and swimming are examined sequentially (Fig. 1). The approach is collective, and includes several scientists from UCT and MCM who try to follow the "Keep it Simple, Stupid" (KISS) principle. The IBM is designed to explain and reproduce a set of "testing patterns", defined as part of a pattern orientated approach (POA).

Implementation

The IBM is coupled with a hydrodynamic model of the region known as PLUME (see Roy *et al.* this volume). This model provides a virtual environment giving an exhaustive and coherent representation of the 3D dynamics, including such features as upwelling, eddies, and filaments. This virtual environment is enough to represent processes, but is insufficient to provide validated conclusions (Penven 2000).

Several individual IBM experimental simulations have been conducted to date and are detailed below.

Transport - hypotheses about the main factors impacting on transport success from the spawning grounds to the nursery area were examined. Spatial and temporal variations in spawning affected recruitment success, whereas parameters such as spawning patchiness and spawning frequency each month were less important (Plate 8).

Transport and buoyancy - hypotheses concerning the impact of variability in horizontal and vertical distributions of anchovy eggs arising from differential buoyancy were tested. Whether changes in buoyancy generated a significant variation in the horizontal distribution of eggs, and whether positive egg buoyancy reduced recruitment success because of offshore advection were examined. Results suggest that there is an optimal egg density ($1.025 g.cm^3$) that promotes the highest recruitment success in all experiments, leading

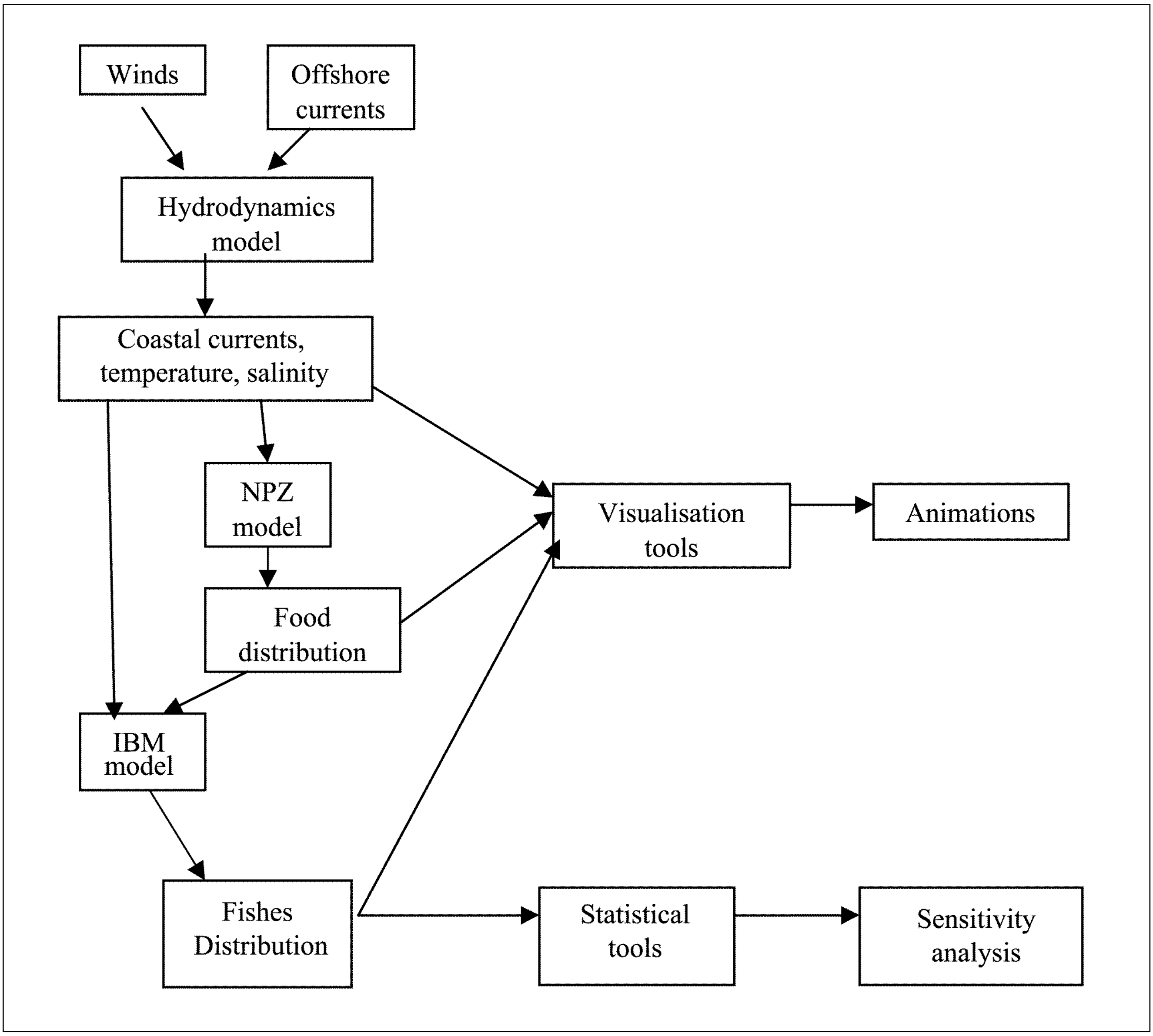

Fig. 1

to hypotheses of a trade-off between buoyancy properties and the efficiency of transport through the jet current (Parada *et al.* submitted.).

Growth - the effect of temperature on the mortality and growth of early stages of anchovy was examined. This IBM is based on a Gompertz equation which expresses the length of anchovy at each stage. The model relates independent variables (year, area, season of spawning, and feeding probability) to dependent variables (number of dead eggs and larvae due to temperature, and number of larvae at a feeding stage reaching the nursery area). Simulations show a trade-off between transport, temperature and feeding probability. If transport is too fast, eggs or young larvae arrive at the nursery area but cannot survive in the cold water. If transport is too slow, development occurs rapidly in the jet current, which may lead to food limitation (Table 1; Parada *et al.* in prep.).

Fronts and food availability - this preliminary experiment studies concentration processes, food availability and success in feeding through definition of the horizontal (SST gradient) and vertical (bottom of the thermocline) dimensions of fronts. The underlying hypothesis is that fronts are concentration areas where larvae can feed successfully.

Food **–** the aim of this preliminary experiment is to reproduce the highly variable distribution in space and time of food in the Benguela ecosystem. It represents the dynamics of nutrients, phytoplankton and zooplankton. Nutrients, i.e. masses of enriched water, are continuously released at 200-300m depth, and carried to the surface during upwelling events. Phytoplankton patches are advected by currents, and consume nutrients and reproduce according to satiation. Zooplankton colonies are also advected by currents and consume phytoplankton patches and reproduce according to satiation.

Evolutionary model of spawning - this evolutionary approach tries to express how patterns at the population level emerge from constraints at the individual level through a Darwinian selection process (Mullon *et al.* submitted). According to an initial set of selective constraints (concerning advection, temperature, and recruitment areas), a population of 10,000 individuals with random spawning behaviour is created. Over a simulation of 60 generations, individuals that have fulfilled these constraints are allowed to reproduce, creating new individuals with the same spawning behaviour as their parents. Examples of selective constraints are (1) to avoid offshore advection, (2) to avoid offshore advection and reach the nursery area, and (3) to avoid offshore advection and cool waters (14 °C).

This model may be considered as a genetic solver, which establishes a relationship between a set of constraints and population dynamics (including variability in spawning area and recruitment). Going further, one may consider that it represents some evolutionary features of the species, that the reproductive spawning strategy reflects the past environment. *"By its behaviour - its genetically determined use of habitats and resources - an animal largely defines the selective pressures to which it is subject"* (Lewontin 1983). It appears that studying spawning patterns is a relevant way to identify environmental factors important for recruitment studies. An important issue could be relating changing spawning patterns (see van der Lingen *et al.* this volume) and recruitment strength.

Next steps

New IBM experiments examining transport, buoyancy, growth and feeding and using the output of a more realistic PLUME model and a dynamic map of favourable spawning areas are planned for 2002, as is a new experiment to test the "Parental Condition" hypothesis. We also wish to improve the genericity of the tools, approach and the concept by applying them to other pelagic systems.

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Figure Legends

Figure 1. Flow-chart of an IBM model.

Table 1. Output of a sensitivity analysis examining the effect of various parameters (spawning area, model year, spawning date, and feeding probability) on anchovy recruitment success (significant parameters and interactions are shown in bold).

	DF	SS	MS	F	p	Explained variance
Intercept	1	3.78 E+08	3.78 E+08	7543.8	0	
AREA	**2**	**4.83 E+08**	**2.41 E+08**	**4816.6**	**0**	**65.8**
YEAR	4	17520065	4380016	87.4	0	2.4
DATE	6	41076224	6846037	136.6	0	5.6
FEED_PRO	4	718.2	179.6	0.0	1	0.0
AREA*YEAR	**8**	**39765476**	**4970685**	**99.2**	**0**	**5.4**
AREA*DATE	**12**	**42026995**	**3502250**	**69.9**	**0**	**5.7**
YEAR*DATE	**24**	**37520954**	**1563373**	**31.2**	**0**	**5.1**
AREA*FEED_PRO	8	7575.7	947.0	0.0	1	0.0
YEAR*FEED_PRO	16	6337.6	396.1	0.0	1	0.0
DATE*FEED_PRO	24	7630.3	317.9	0.0	1	0.0
Error	**1466**	**73466268**	**50113.4**			**10.0**
Total	1574	7.34 E+08				

DISCUSSION SUMMARY: THE FUTURE OF COLLABORATIVE WORK WITHIN SPACC WITH SPECIAL FOCUS ON BENGUELA-HUMBOLDT CO-OPERATION

As evidenced from the presentations made at the meeting, research in both the Benguela and Humboldt ecosystems is strong and has resulted in considerable improvements in knowledge of their respective dynamics. Researchers in both systems have encountered similar scientific problems and similar approaches have been used in attempts to solve these problems. Such similarities mean that there is a clear and unique potential for the development of comparative studies between the two regions within the framework of GLOBEC/SPACC. However, whilst comparative analyses of the two ecosystems is considered useful, such comparisons need to be based on a scientific framework that should aim to answer specific scientific questions.

One question suggested by meeting participants include was “Why is the Humboldt so much more productive than the Benguela?” Given that primary production and zooplankton biomass in these two systems are of a similar magnitude, it could be expected that the abundance of pelagic fish species and the landings made by pelagic fisheries would also be similar. Yet fish yield in the Humboldt is substantially greater than in the Benguela, indicating much higher biomass levels. Hutchings (1992) proposed that this difference was due to closer coupling between primary and secondary production and fish production in the Humboldt compared to the Benguela. The reduced transfer efficiency in the Benguela, particularly the Southern Benguela off South Africa, was attributed to the spatial separation between the spawning and nursery grounds of the dominant small pelagic species, and the consequent necessity for fish to migrate away from the productive west coast, against a food gradient, to the less productive Southwest and Southern coasts (the Agulhas Bank) where spawning occurred. Avoiding spawning on the West Coast was considered a mechanism to avoid offshore advective loss due to the prevailing southeasterly winds that occur over the summer reproductive season. In contrast, the spawning and nursery grounds in the Humboldt are less spatially discrete, with differences between the two tending to be in an offshore direction as opposed to an alongshore direction as is the case in the Southern Benguela. In the Northern Benguela off Namibia, the spawning and nursery grounds are less spatially discrete, and differences between the two also occur in an offshore direction.

Although detailed discussion concerning an over-arching scientific framework and specific questions under which collaboration would develop was lacking, the need for such was well received. Participants also felt that in addition to operating within the framework of a specific scientific question, collaboration between researchers in the Benguela and Humboldt should also aim to strengthen capacity building in areas where it is most needed, and encourage the sharing of expertise in relevant areas. Furthermore, such south-to-south collaboration between regions consisting of developing countries is likely to provide a useful model for other developing countries with substantial marine resources. Once a scientific framework and specific questions to be addressed have been agreed upon, an attempt should be made to match the knowledge and specific expertise of individual researchers from the two systems, since it is they who will form the “building blocks” of a successful collaborative venture. Areas of common research and expertise evident at the Spatial Approaches meeting include the use of satellite remote sensing techniques to monitor the ecosystem, studies on early life history stages (eggs and larvae) and characterization of spawning habitat, the use of hydroacoustics in estimating biomass and monitoring changes in the distribution of pelagic fish stocks, and comparative studies of various life history traits (including trophodynamics and reproduction) of small pelagic species. There is also a strong interest in sharing expertise and training between the two regions with regard to modeling physical and biological aspects of the two ecosystems and developing an ecosystem approach to fisheries.

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