



# GLOBEC INTERNATIONAL NEWSLETTER

A CORE PROJECT OF THE  
INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME

<http://www.globec.org>

Vol.13, No.1

GLOBAL OCEAN ECOSYSTEM DYNAMICS

APRIL 2007

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## Editorial

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This extended issue of the GLOBEC International Newsletter welcomes special sections from the UK GLOBEC Marine Productivity programme (p.9) and the Southern Ocean GLOBEC regional programme (p.49).

Marine Productivity was a five year thematic programme funded by the UK Natural Environment Research Council which was completed in 2005. The main objective of the programme was to investigate the population dynamics of key zooplankton species with an emphasis on how physical factors influence their distribution, abundance and productivity.

The publication of a special section on Southern Ocean GLOBEC is particularly timely given that the International Polar Year (IPY; <http://www.ipy.org>) began in March 2007. GLOBEC has two regional programmes which contribute as lead programmes to IPY: ESSAS (Ecosystem Studies of Sub-Arctic Seas, see page 47 for latest activities) and ICED (Integrating Climate and Ecosystem Dynamics; see Figure 1 and page 33) which is a follow-up to Southern Ocean GLOBEC.

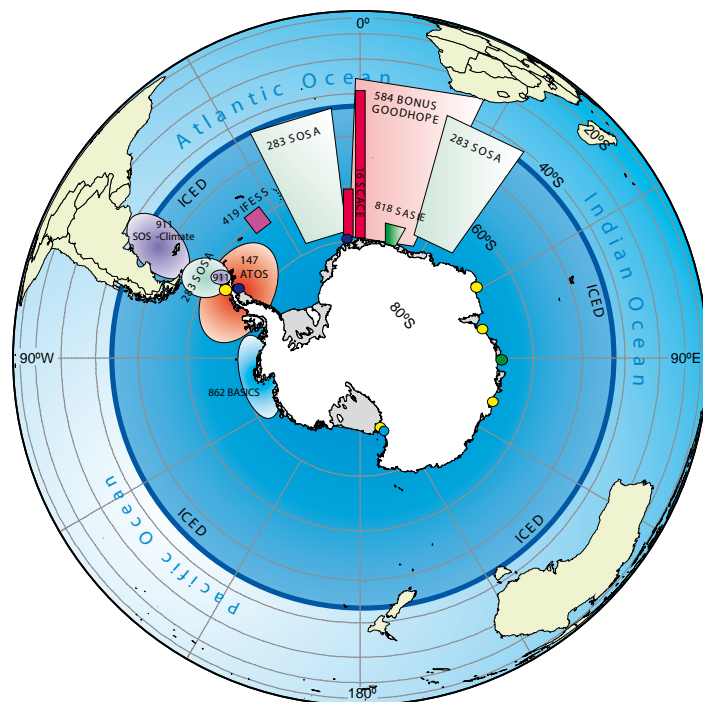


Figure 1. Map of proposed fieldwork location for projects co-ordinated by or linked to ICED-IPY.



## GLOBEC International synthesis book plans

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The GLOBEC International programme was set up as a 10 year research effort, due to complete its work by the end of 2009. However, this will not be the "end of the line" for all GLOBEC activities, as the structure of global science programmes are porous by design to allow for new discoveries and thinking by the community to develop beyond fixed deadlines. Several GLOBEC national and regional programmes will continue beyond December 2009, at least until their commitments to funding agencies have been fulfilled. In addition, it is likely that all the objectives of GLOBEC may not have been achieved by our deadline, and so new frameworks will be provided to facilitate this. For a more detailed account of the plans please see the Editorial of GLOBEC Newsletter 12(1). In a nutshell the IGBP and SCOR's goal is to see a "single integrated ocean project that includes the scientific activities of GLOBEC and IMBER by the end of 2009". GLOBEC and IMBER are actively working to implement this vision.

GLOBEC recently entered its synthesis phase, with the publication of an "Integration and Synthesis Blueprint" (available from <http://www.globec.org>) and a comprehensive programme of activities including symposia, workshops, special publications and books. One of the latter involves a GLOBEC-wide book which will be the culmination of the programme, and which will appear in the IGBP science book series published by Springer. The book is expected to be published in spring of 2009, coinciding with the final Open Science meeting of GLOBEC which is planned to be held in Paris, France.

The structure of the book has been debated and discussed by the members of the GLOBEC Steering Committee and the Regional Programme Chairs. Part of the work (incomplete at the time of

writing, but hopefully finished by the time you read it) involves the selection of co-authors for each chapter, to ensure that we properly reflect the breadth of the programme. In this article I would like to disclose the structure of the book and the lead authors for each chapter. Members of the GLOBEC community are welcome (in fact, encouraged) to contact lead authors if they would like their work to be considered in the book. However, this is unlikely to involve adding co-authors to what may already be a very large pool of generous contributors, but certainly it will ensure that key GLOBEC work is not omitted, particularly new findings that may be "hot off the press". After all, we are all human, and our ability to assimilate the full body of work in the literature is limited!

The book will be aimed at the academic marine science and management community, global change and sustainability scientists and managers and general ocean users. Whilst it will focus on GLOBEC contributions it will not exclude key findings from other programmes, so that the picture is complete.

Please note that the titles of the chapters are not yet finalised. The intention has been to provide titles which are clear with respect to the science they should encompass, but more creative titles will be drafted by the lead authors as the chapters develop. Finally, the lead authors and editors will have a drafting meeting in Dartington, UK, 2-4 July 2007, to ensure that there are no gaps in the book, that overlaps are reduced to a minimum and to ensure consistency of format and content. Completed chapters are expected early in 2008, to be followed by a strict review procedure. Soon, more detailed chapter structures, contents and full authorship will be made available through the GLOBEC website, so that you can get more information and follow up the process.

### Global Change and Marine Ecosystems

**Editors: Manuel Barange, John Field, Roger Harris, Eileen Hofmann, Ian Perry and Cisco Werner (alphabetical order)**

**CHAPTER 1: Introduction: The role of marine ecosystems in the Earth System (How are marine ecosystems connected to the Earth system?)**

Lead authors: Cisco Werner (USA)/Manuel Barange (UK)

**CHAPTER 2: Understanding marine ecosystems. I: observational methods (What are the GLOBEC methods of study?)**

Lead author: Roger Harris (UK)

**CHAPTER 3: Understanding marine ecosystems. II: modelling methodologies (What are the GLOBEC methods of study?)**

Lead author: Cisco Werner (USA)

**CHAPTER 4: Dynamics and structure of marine ecosystem (How do marine ecosystems work I?)**

Lead author: Coleen Moloney (South Africa)

**CHAPTER 5: Physical forcing of marine ecosystem dynamics at multiple scales (How do marine ecosystems work II?)**

Lead author: Brad deYoung (Canada)

**CHAPTER 6: Climate forcing on marine ecosystems (How do marine ecosystems work III?)**

Lead author: Ken Drinkwater (Norway)

**CHAPTER 7: Human impacts on marine ecosystems (How have humans impacted marine ecosystems?)**

Lead author: Keith Brander (Denmark)

**CHAPTER 8: Impacts of marine ecosystem change on human communities (How have marine ecosystem changes affected human societies?)**

Lead author: Ian Perry (Canada)

**CHAPTER 9: Predicting marine ecosystem responses to global changes (Can we predict how marine ecosystems will respond to future global change?)**

Lead author: Sin-ichi Ito (Japan)

**CHAPTER 10: Marine resources management in the face of change (How has GLOBEC influenced management?)**

Lead author: Manuel Barange (UK)

**CHAPTER 11: Perspectives on global change and marine ecosystems**

Lead author: Eileen Hofmann (USA)

## Climate and planktonic copepods in the Balearic Sea, Western Mediterranean

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The Balearic Sea is characterised by complex mesoscale features resulting from the interaction between the more saline and colder northern waters of the western Mediterranean and the southern, less saline and warmer water (Pinot *et al.*, 2002). This area, and particularly the Ibiza and Mallorca Channels, is the main passage of meridional exchanges of water masses in the western Mediterranean basin. Ecologically important, the Balearic waters encompass major spawning areas of pelagic fish, possibly due to an 'island stirring' effect (Mann and Lazier, 1991) which produces an increment of planktonic biomass around the islands as a result of disturbance of the oceanic flow. Hence, the Balearic Sea appears to be an ideal site to track the dynamics of meridional exchanges and mesoscale hydrographic variability in the western Mediterranean and their consequences on the structure of pelagic ecosystems.

Here we introduce novel results linking climate and the abundance of planktonic copepods in the Balearic Sea. These results were obtained in the framework of the long-term programme 'Time series of oceanographic observations in the Balearic Sea' funded by the Instituto Español de Oceanografía, which aims at identifying control factors of zooplankton abundance changes in the 0–75 m depth layer in the Balearic Sea and their potential relationship with large-scale atmospheric circulation. The novel insight is that planktonic copepods integrate over monthly scales the North Atlantic climate forcing in this region and therefore emerge as potential indicators of meridional water mass exchanges in the western Mediterranean (Fernandez de Puelles and Molinero, 2007).

The time series programme was established in 1994 with a biweekly survey in the southern shelf of Mallorca (39°28'59N; 2°25'63E). During the years 1994–2003, 346 plankton samples were collected by oblique hauls from a depth of 75 m to the surface. In addition, ancillary data, i.e. nutrient concentration and water temperatures, were recorded during plankton surveys. Details of the sampling methodology and analysis have been reported previously by Fernández de Puelles *et al.* (2004). Planktonic copepods comprised the majority of the zooplankton biomass (>54%) and their abundance may be indicative of zooplankton interannual changes.

The approach performed to depict the downscale pathway linking large scale climate and local phenomena was achieved by identifying the interrelations between large- and regional scale climate signals during the period 1950 to 2005 and their relationship with water temperature in the Balearic Sea. Details of statistical methods used are discussed in Molinero *et al.*, (2005). Regional meteorological parameters (extended area: 0–5°E, 38–41°N) from the Climate Diagnostics Center (NCEP/NCAR) reanalysis fields (Kalney *et al.*, 1996) were used to investigate mediating factors linking the North Atlantic climate and zooplankton variability. To assess the North Atlantic climate, a composite signal was achieved by truncating monthly time-series of climatic indices in the Northern Hemisphere that have an effect on the Western Mediterranean including the Northern Annular Mode (AO/NAO), the East Atlantic pattern (EA), the North Wall Gulf Stream Index (GSI), the East Atlantic Western Russian pattern (EA/WRUS) and the Northern Hemisphere Temperature (NHT).

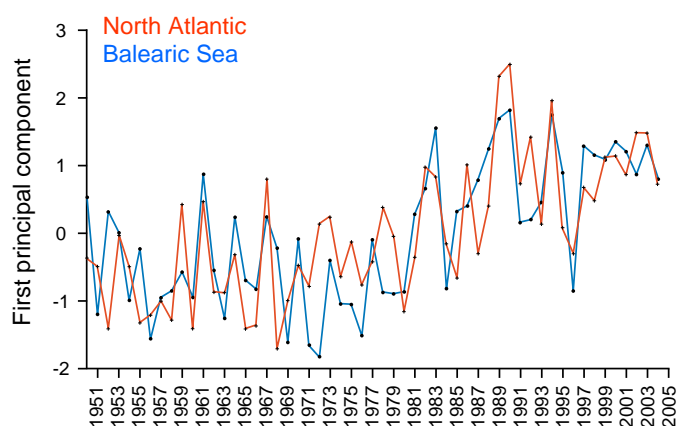


Figure 1. Interannual variability of the North Atlantic (red) and Balearic Sea (blue) climates over the 55 year period from 1950 to 2005. The signals are represented by the first principal components (PC1) of each data set. PC1 of North Atlantic climate represents 42% of the total variability, and PC1 of Balearic Sea climate represents 66% of the total variability. The Pearson correlation coefficient and the effective probability after correction for temporal autocorrelation are respectively  $r = 0.72$  and  $p < 0.001$ . Copyright (2007) American Geophysical Union.

The close link between the North Atlantic climate and the atmospheric variability in the Balearic Sea is shown in Figure 1. Canonical correlation analysis (CCA) reveals that such a relationship is noticeable over monthly scales ( $r = 0.63$ ;  $p < 0.001$ ). Interestingly, the same analysis shows that the influence of the North Atlantic climate is extended to subsurface water temperature, 75 m depth ( $r = 0.59$ ;  $p < 0.001$ ), which is a raw indicator of water mass variability at a local scale. The implication for the pelagic ecosystem appears evident in the relationship found between water temperature, nutrients and pelagic copepods (nutrients:  $r = -0.53$ ;  $p < 0.001$ ; copepods:  $r = -0.73$ ;  $p < 0.0001$ ). The analysis further shows that the critical time window where the forcing of the North Atlantic climate explains most of the copepod variability in the Balearic Sea during the winter months (December to March).

The cascade of links revealed by this investigation suggests that one of the factors favouring higher abundance of copepods during low North Atlantic climate anomalies is probably related to higher phytoplankton abundance because of the higher nutrient availability. Hence, the interactions emerging from these results indicate a close connection between the thermal features of the subsurface water masses in the Balearic Sea and the concentration of nitrates and the total abundance of copepods. This is clearly illustrated by considering water temperature records corresponding to the values of North Atlantic climate anomalies higher and lower than 1 standard deviation (Fig. 2a,b). High values of the North Atlantic climate anomalies (>1 standard deviation) have been suggested as discriminating thresholds for the atmospheric circulation in the northwestern Mediterranean region (Hurrell, 1995; Vignudelli *et al.*, 1999). Therefore, as shown by the link between nitrate concentration and the North Atlantic climate, these results point towards a bottom-up control on the

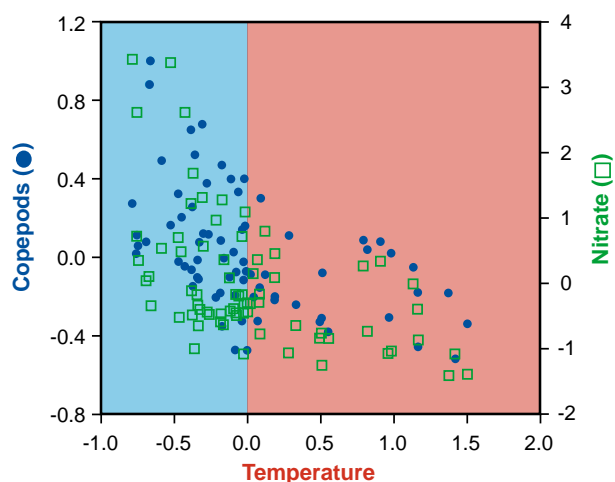


Figure 2. Dispersion diagram in the plane of anomalies (zero mean and unit variance) of temperature, nitrates and copepods. The Pearson correlation coefficient and the effective probability after correction for temporal autocorrelation are respectively  $r = -0.51$  and  $p < 0.001$  for temperature and nitrates; and  $r = -0.72$  and  $p < 0.001$  for temperature and copepods. Temperature data correspond to values observed during high anomalies ( $>1$  standard deviation) of the North Atlantic climate variability. Modified from Fernández de Puellas and Molinero (2007). Copyright (2007) American Geophysical Union.

abundance of copepods, likely promoted by the lower mixing and warm temperatures related to high North Atlantic climate anomalies, which would impair productivity locally and lead to less food availability for copepods. However, it is possible that during high NA anomalies (higher water temperatures) copepods undergo a higher predation pressure by gelatinous carnivores whose abundances substantially increase during warm periods in the western Mediterranean (Molinero *et al.*, 2005).

Because planktonic copepods support most of the food webs in the sea and constitute the main food source for pelagic fish, such as anchovy and sardine, it is ecologically plausible that the consequences of such climate forcing may affect patterns of spatial distribution of pelagic fish in the Balearic Sea since

they appear to be driven by mesoscale hydrodynamic features (Alemany *et al.*, 2006). Further analyses of the effects of changes in the hydrographic conditions on zooplankton trophic groups are presently underway within the oceanographic time series programme in the Balearic Sea.

**Acknowledgements**

The authors thank L. Vicente for help in zooplankton counting. We are indebted to the crew of the R/V Odón de Buén, captain A.P. Sanchez and technicians M. Serra and T. Salamanca. NCEP Reanalysis data were provided by the NOAA-CIRES ESRL/PSD Climate Diagnostics branch, Boulder, Colorado, USA, from their website at <http://www.cdc.noaa.gov/>. This is a contribution of the project Oceanographic Time Series in the Spanish coast carried out by the Centro Oceanográfico de Baleares.

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**Distribution of copepods in the Bay of Bengal**

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The Bay of Bengal is one of two northern embayments of the Indian Ocean, flanked by the Indian Peninsula and Sri Lanka in the west and the Andaman and Nicobar Islands and Myanmar in the East. There are many rivers that drain into the Bay of Bengal. The coastline is endowed with extensive areas of estuaries, brackish waters, lagoons, mangroves, coral reefs and seaweed beds. These coastal habitats are dynamic, rich in species and individuals with high productivity. Hence, they have a great ecological, social and economic significance for the region. These areas are important for the marine fisheries, serving as nurseries for many species of fish and shellfish (Bay of Bengal Programme, 1994). The coastline extends to about 5700 km on mainland and to 7500 km including two groups of islands. Major estuarine areas located along the Indian coastline extend to about 2.6 million hectares (Gauda and Panigrahy, 1999).

There have been many detailed studies on the distribution, abundance and composition of copepods from the Bay of Bengal since 1936

(Aiyar *et al.*, 1936; Aiyar, 1940; Ramamurthy, 1953; Pillai, 1971; Rangarajan and Marichamy, 1972; Vijayalakshmi and Venugopalan, 1973; Rao *et al.*, 1975; Elayaraja and Ramanibai, 2006; Mitra *et al.*, 1990; Mishra and Panigrahy, 1996; 1999; Indra, 1999; Eswari, 2002; Elayaraja, 2005). Most of these studies also provide an insight into the ecological aspects of the coastal habitats.

The aim of this article is to present the taxonomic diversity of copepods observed through various investigations in parts of the Bay of Bengal, carried out in the laboratory and using literature available from the last decade. Most of the copepod collections were from the coastal water bodies such as estuaries, backwaters and near shore waters from 1999 to 2006 (Fig. 1). Copepods were collected using plankton net with mesh sizes ranging from 50 µm to 250 µm and preserved in 4 to 5% buffered formaldehyde.

Indra (1999) reported the distribution and abundance of Copepoda from waters on the east coast of the Bay of Bengal



**Table 1. Copepod distribution in estuaries, backwaters and near-shore waters from the east coast of the Bay of Bengal, India**

1999	2002	2005	2006
<i>Diaptomus</i> sp. <i>Eucalanus</i> sp. <i>Epischura</i> sp. <i>Eurytemora</i> sp. <i>Oithona</i> sp. <i>Cyclops</i> sp. <i>Eucyclops</i> sp. <i>Halicyclops</i> sp. <i>Heterocyclops</i> sp. <i>Mesocyclops</i> sp. <i>Paracyclops</i> sp. <i>Bryocamptus</i> sp. <i>Mesochra</i> sp. <i>Paradactylopodia</i> sp. <i>Stenocaris</i> sp.	<i>Acartia major</i> <i>Acartia spinicauda</i> <i>Acrocalanus gracilis</i> <i>Bryocamptus heimalis</i> <i>Calanus finmarchicus</i> <i>Centropages dorsipinatus</i> <i>Clytemnestra scutellata</i> <i>Cyclops scutifer</i> <i>Diaptomus similis</i> <i>Diaptomus dorsalis</i> <i>Episura</i> sp. <i>Eucalanus subcrassus</i> <i>Eucyclops phaleratus</i> <i>Eurytemora affinis</i> <i>Halicyclops spinifer</i> <i>Mesocyclops meridius</i> <i>Metacyclops tredecimus</i> <i>Metacyclops subequalis</i> <i>Microcyclops</i> sp. <i>Microsetella gracilis</i> <i>Microsetella rosea</i> <i>Microsetella aculata</i> <i>Oithona nana</i> <i>Oithona brevicornis</i> <i>Oncaea conferta</i> <i>Paracalanus parvus</i> <i>Paracyclops parsinus</i> <i>Paracyclops longifurca</i> <i>Paracyclops vagus</i> <i>Parastenocaris</i> sp. <i>Phyllodiaptomus kieferi</i> <i>Pseudodiaptomus aurivilli</i> <i>Rhincalanus</i> sp. <i>Stenocaris minor</i> <i>Tropocyclops parcinus</i>	<i>Acartia danae</i> <i>Acartia tonsa</i> <i>Attheyella</i> sp. <i>Bryocamptus heimalis</i> <i>Calanus finmarchicus</i> <i>Calanus helgolandicus</i> <i>Centropages gracilis</i> <i>Corycaeus</i> sp. <i>Cyclops bicolor</i> <i>Cyclops crassicaudus</i> <i>Diacyclops</i> sp. <i>Eodiaptomus</i> sp. <i>Eucalanus elongatus</i> <i>Eucyclops</i> sp. <i>Eurytemora</i> sp. <i>Euterpina acutifrons</i> <i>Halicyclops normani</i> <i>Mesocyclops leukartii</i> <i>Mesocyclops</i> sp. <i>Metis jousseaumei</i> <i>Microcyclops miutus</i> <i>Nannocalanus minor</i> <i>Neodiaptomus</i> sp. <i>Oithona brevicornis</i> <i>Oithona similis</i> <i>Paracalanus parvus</i> <i>Pseudodiaptomus annandalei</i> <i>Pseudodiaptomus serricaudatus</i> <i>Temora turbinata</i>	<i>Acartia discaudata</i> <i>Acartia spinicaudata</i> <i>Acrocalanus gracilis</i> <i>Cletocamptus albuquerquensis</i> <i>Cletocamptus scutellata</i> <i>Enterpina acutifrons</i> <i>Euterpina acutifrons</i> <i>Halicyclops</i> sp. <i>Longipedia weberi</i> <i>Mesocyclops hyalinus</i> <i>Mesocyclops leukartii</i> <i>Metacalanus aurivilli</i> <i>Microcyclops minutus</i> <i>Nannocalanus</i> sp. <i>Oithona brevicornis</i> <i>Oithona linearis</i> <i>Oithona longispina</i> <i>Oithona plumifera</i> <i>Oithona rigida</i> <i>Oithona similis</i> <i>Oncaea venusta</i> <i>Onchocamptus benalensis</i> <i>Paracalanus parvus</i> <i>Pseudodiaptomus annandalei</i> <i>Pseudodiaptomus serricaudatus</i> <i>Scolecithrix danae</i> <i>Temora spinicaudata</i> <i>Tropocyclops</i> sp.

near Chennai. About 15 species were recorded from three main groups of Copepoda: Calanoida, Cyclopoida and Harpacticoida. A higher percentage composition of copepods was found in estuaries and backwaters rather than near-shore waters.

Eswari (2002) investigated the distribution of copepods from two estuaries (Adyar and Cooum) and backwaters (Ennore and Muttukadu) where great variation between habitats was observed. In total 36 species were recorded in this study. Elayaraja (2005) reported 29 species from ten estuaries (Pulicat, Ennore, Cooum, Adyar, Muttukadu, Edaiyur, Sadras, Uppanar, Vellar, Coleroon and Cauvery) off the coast of Tamil Nadu, and 28 species from Muttukadu Backwaters (Table. 1). Copepod nauplii and copepodites were also recorded and showed strong seasonal variation in their abundance.

The impact of the Asian tsunami during December 2004 on copepod occurrence was also recorded from estuaries (Adyar and Cooum), lagoon (Pulicat) and backwaters (Muttukadu), showing a marked variation in the pattern of species distribution and abundance in copepod distribution. Harpacticoid contribution was greater than Cyclopoida and Calanoida which was revealed by recent short term investigations (Bharathi Devi, 2005; Gem Alapat, 2005; Sujeevana Rao, 2005).

The spatial and seasonal variations in copepod distribution, might be due to the difference in the ecological conditions, feeding preferences of macrofauna and sampling methodology.

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## Laboratory observations of predation by *Labidocera* on copepod nauplii in Bahía de La Paz, Mexico

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Knowledge of copepod feeding habits is necessary for understanding marine ecosystem trophodynamics. The present study considers the relative impact of the carnivorous copepod *Labidocera* spp. on copepod nauplii concentration. Predatory planktonic copepods contribute significantly to the mortality of other planktonic animals and have an effect in regulating zooplankton community structure (Uye and Kayano, 1994). The predation rates of the copepods of the genus *Labidocera* have previously been studied by Lillelund and Lasker (1971) and Landry (1978) in the California Current. Studies on the abundance and distribution of the genus *Labidocera* has been reported by Hernández-Trujillo (1996; 1991) in Bahía Magdalena and the area surrounding the tip of the Baja California peninsula.

*Labidocera* is considered to be a mainly voracious omnivore, shifting from being primarily herbivorous in its juvenile phase and increasing its carnivorous diet in the adult phase (Mullin, 1979). The seasonal occurrence of total copepod abundance in Bahía de La Paz varies from 22% of relative abundance in spring to 46% in winter (Cruz-Hernández, 2006).

The relative proportion of animal food in copepod feeding habits has been considered in several studies but they rarely include estimations of predation rates of naturally co-occurring planktonic species (Conley *et al.*, 1985). Landry (1978) offered *Acartia* spp. nauplii to *L. trispinosa* and Conley *et al.*, (1985) fed *Pseudocalanus minutus* nauplii to *L. aestiva* (Anraku and Omori, 1963), and discussed the results with regard to mouthpart morphology.

In this study we estimated the feeding rates of *Labidocera* spp. in Bahía de La Paz under laboratory conditions using its natural prey, live copepod nauplii. These laboratory data were then combined with field data to estimate the predatory impact of *Labidocera* copepods on prey populations of the research site.

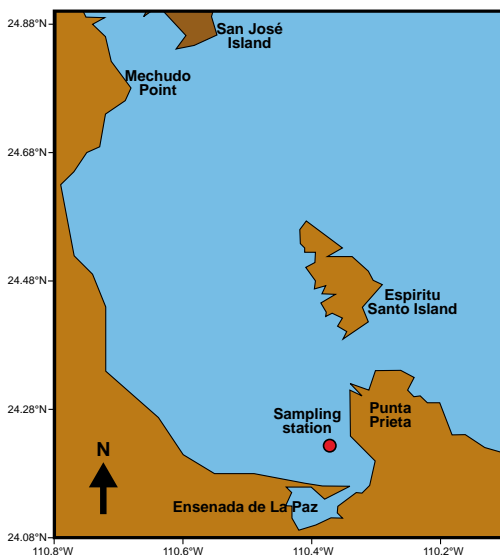


Figure 1. Study area, Bahía de La Paz, B.C.S. México

### Material and methods

Bahía de La Paz (Fig. 1) has an average depth, temperature, and salinity at 300 m, of 24.7°C, and 36 psu, respectively (Murillo, 1987; Cruz-Orozco *et al.*, 1990). It is also an important site for small pelagic fish spawning (Hinojosa, 2004), marine mammals (Flores-Ramírez *et al.*, 1996) and invertebrates (Gómez, 2003; Palomares *et al.*, 2003). The tidal regime is semidiurnal, and currents show maximum speeds in the San Lorenzo Channel and to the north of Partida Island (Obeso, 1986).

During spring 2003, a nine day time-series (21-29 April) of daily predation rates at a fixed station (24°14'N 110°19'W) was conducted (Fig. 1). Double surface zooplankton samples were collected from near the coast, between 08:00 and 10:00 am using a 500 µm mesh and a 54 µm mesh CalCOFI net. Horizontal hauls were made during daylight hours from 1 m depth to the surface. Seawater temperature was obtained using a Seabird CTD.

From the zooplankton samples (505 µm mesh) adult *L. acuta*; *L. acutifrons*; *L. detrunata*; *L. diandra*; *L. johnsonii* and *L. trispinosa* females were sorted live and held for six hours in filtered seawater without food. The prey, copepod nauplii, were sorted from the 54 µm mesh zooplankton samples and stored in petri dishes at 40, 60 and 80 ind l<sup>-1</sup>. Five females of *Labidocera* spp. were transferred to 1 l<sup>-1</sup> experimental jars filled with filtered seawater at sampling site temperature (22-23°C) to begin the experiment with two replicates per treatment. Jars were set in a temperature controlled container in the dark. After 24 hours the contents of the jars were poured over a 5 µm mesh sieve to recover copepods and nauplii. The non-ingested preys were counted. Nauplii were identified according to Kogal (1984) and their abundance was calculated following the Smith and Richardson (1979) procedure.

Experimental methods were designed taking into account previous studies made with other carnivorous copepods (Ambler and Frost, 1974; Landry, 1978; Mullin, 1979; Turner *et al.*, 1985, Hernández-Trujillo and Alvarez-Silva, 1999; Hooff and Bollens, 2004)

Predation rate ( $t_p$ ) was calculated as

$$t_{\text{predation}} = ((P_o - P_f) / (\text{No. predators})) / \text{time}$$

where:

$P_o$  = number of prey offered to the predators

$P_f$  = number of non-ingested prey

t = incubation time expressed in hours

The abundance of *Labidocera* spp. was obtained from 55 µm mesh daily zooplankton samples in order to be used in the calculation of the Potential Predatory Impact (PPI), according to Hooff and Bollens (2004). The abundances were combined with the daily predation rates to estimate PPI (percentage of prey population removed d<sup>-1</sup>) of *Labidocera* spp.

PPI = Predator Population Feeding Rate/Natural Prey Abundance

Correlations were calculated based on the raw data set, whilst one-way ANOVAs were based on transformed data. In general, a significance level of 5% was used.

**Results and discussion**

During the sampling period the salinity varied between 34.99 and 35.45 psu, with an average of 35.24 psu. The SST ranged from 22.3 to 22.9°C, and an average of 22.7°C. Both salinity and SST showed a similar variation pattern during the study period (Fig. 2).

Daily individual-based ingestion rates differed significantly ( $P < 0.05$ ) between the concentrations of prey offered (40 to 80 nauplii  $L^{-1}$ ). Copepod nauplii were ingested at a significantly lower rate when at a concentration of 40 prey  $L^{-1}$  than at 60 and 80 prey  $L^{-1}$ . The corresponding average predation rates were  $0.15 \pm 0.16$ ,  $0.20 \pm 0.02$  and  $0.27 \pm 0.04$  nauplii  $\cdot$  predator $^{-1} \cdot h^{-1}$  (Fig. 3).

Our daily survey revealed no significant difference ( $P > 0.05$ ) in predation rate of *Labidocera* spp. between days, despite the decrease of the rate (0.23 to 0.16 ind  $h^{-1}$ ) on 27 April (Fig. 4). The mean predation rate was 0.21 ind  $h^{-1}$ . The PPI of the predator on the copepod nauplii population showed that the most substantial impact was estimated at 25 April (0.064%), but this rate is unlikely to significantly impact the natural copepod nauplii abundance. In the remaining days, the prey population consumed per day was estimated between 0.005% and 0.0064% (Fig. 5). The mean PPI by *Labidocera* spp. over all the sample dates was 0.019% day $^{-1}$ . In comparison with other authors the PPI was about 200% smaller than previous estimations.

Feeding rates have been determined for a few pontellid copepod species as well as a few sites along the west coast of California and Washington (Table 1). In the present work we estimate an 81% higher predation rate than those estimated by Landry (1978) and our figures were about 170% smaller than Conley and Turner's (1985) figures. Lillelund and Lasker (1971) found that the predation rate was 63% smaller than that reported in the present work. Gao and Song (1992) carried out experiments with *L. euchaeta*, detecting predator rates ranging from 96.30% to 9.2% less than our own estimations. All of these surveys were made at sea water temperatures from 12.5 to 25°C, and our experiments were made between 22 and 23°C. Our data and previous reports (Table 1) demonstrate the temperature dependence of metabolic activity.

Estimates of Potential Predator Impact in the study area were notably smaller than others reported for carnivorous copepods, which suggest that the mortality of copepod nauplii population caused by *Labidocera* spp. could be marginal in Bahía de La Paz (Table 2).

The predation rate and potential predator impact which we have measured for *Labidocera* spp. is relatively small in comparison with the known capacity of this pontellid group species to affect the population sizes of copepod nauplii, especially in periods where large reproductive activity of *Labidocera* has been reported (Palomares *et al.*, 2003). Therefore the abundance of *Labidocera* could be greater and it would have a more

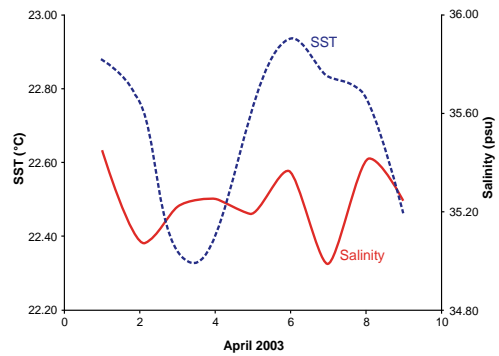


Figure 2. Daily variation of SST (°C) and salinity (psu).

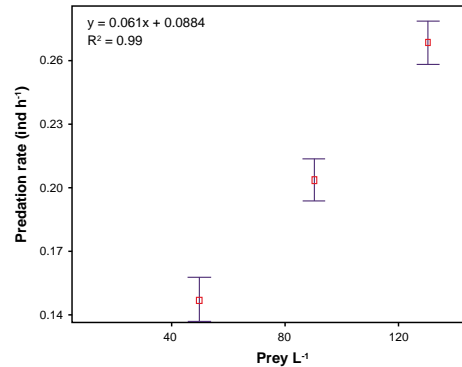


Figure 3. Predation rate of *Labidocera* spp. at different copepod nauplii abundance, error bars:  $\pm$  standard error.

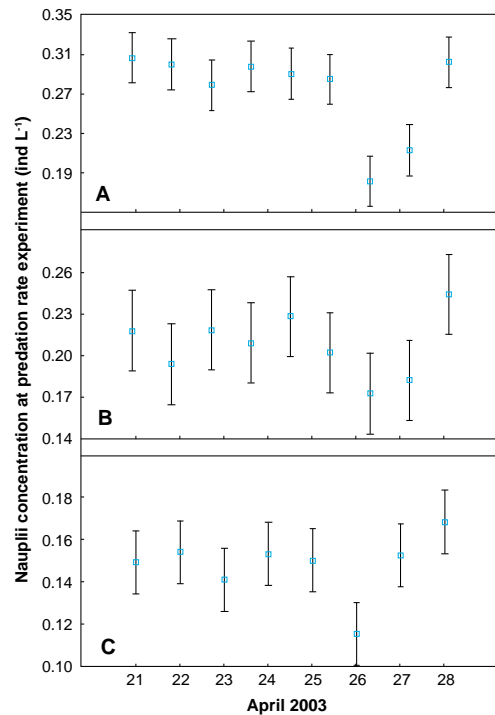


Figure 4. Daily predation rate at three prey densities, error bars:  $\pm$  standard error.

**Table 1. Copepod feeding rates**

Predator	Site	Reference	Prey offered	°C	Predation rate
<i>Labidocera trispinosa</i>	San Diego, CA	Lillelund and Lasker, 1971	Anchovy larvae	20	2 ind $d^{-1}$
<i>Tortanus discaudatus</i>	Puget Sound, WA	Ambler and Frost, 1974	<i>Calanus pacificus</i> nauplii	12.5	~23-32 ind $d^{-1}$
<i>Labidocera</i> spp.	La Jolla, CA	Landry, 1978	<i>Acartia</i> spp.	17.5-19	0.495 ind $d^{-1}$
<i>Labidocera aestiva</i>	Westport river estuary, MA	Conley and Turner, 1985	<i>Pseudocalanus minutus</i>	21-25	15 ind $d^{-1}$
<i>Tortanus discaudatus</i>	Friday Harbour, WA	Mullin, 1979	<i>Acartia clausi</i> nauplii	14-15	~0-25 ind $d^{-1}$
<i>Labidocera</i> spp.	Bahía de La Paz, Mexico	This study	Copepod nauplii	22-23	0.54 ind $d^{-1}$
<i>Labidocera euchaeta</i>	Xiamen harbour	Gao and Song, 1991	Fish larvae		0.2-5.9 ind $d^{-1}$

**Table 2. Potential Predator Impact**

Predator	Site	Reference	Prey offered	°C	PPI
<i>Euchaeta elongata</i> <i>Euphausia pacifica</i> <i>Sagitta elegans</i>	Dabob Bay	Ohman, 1986	<i>Pseudocalanus</i> sp.	15	3.5 d <sup>-1</sup> 1.0 d <sup>-1</sup> 0.5 d <sup>-1</sup>
<i>Tortanus</i> sp.	Fukuyama harbour, Japan	Uye and Kayano, 1994	<i>Oithona davisae</i>	20-25	2.0 d <sup>-1</sup>
<i>Euphausia superba</i>	South Georgia, Antarctic	Atkinson and Snýder, 1997	Small calanoids		1.6 d <sup>-1</sup>
<i>Tortanus dextrilobatus</i>	San Francisco estuary, CA	Hooff and Bollens, 2004	<i>Oithona davisae</i> <i>Acartia</i> sp. All copepoda	14	1.0 d <sup>-1</sup> 4.0 d <sup>-1</sup> 0.9 d <sup>-1</sup>
<i>Labidocera</i> spp.	Bahia de La Paz, México	This study	Copepod nauplii	22-23	0.019 d <sup>-1</sup>

intense predatory activity on both micro- and mesozooplankton populations and consequently show a greater potential predator impact.

It is clear that a nine day experiment does not give sufficient experimental and field data for a major discussion on these ecological issues, particularly when there is no previous data available for the study area. Consequently we are involved in further zooplankton food web research at Bahia de La Paz where more experimental studies are planned in order to understand the role of predation in controlling the growth of zooplankton, especially in estimating the effect on copepod recruitment because of their importance as a food resource for other planktonic invertebrates and fish larvae.

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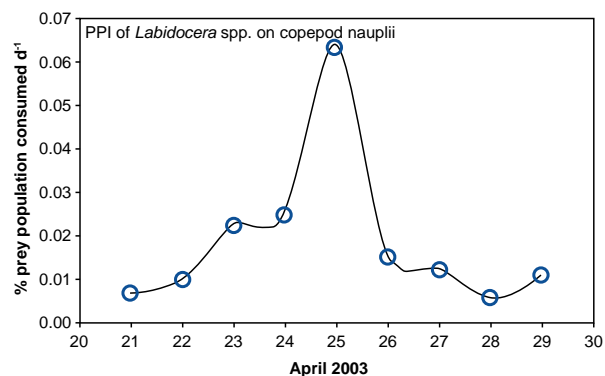


Figure 5. Daily predation rate Predation Potential Impact.

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**Acknowledgements**

Funding for this work was provided by the CGPI-IPN project #20040722. We thank the scientists and students of the project for help in the field and laboratory work. Thanks to Dr Ellis Glazier for editing the English language text.



## UK-MarProd study of *Calanus finmarchicus* dynamics in the Irminger Sea

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Working towards the vision of understanding the basin scale population structures and dynamics of key North Atlantic zooplankton species, the UK Marine Productivity programme (MarProd) undertook four multidisciplinary cruises in the Irminger Sea aboard the research vessel Discovery during 2001/2002 (D258, 8 November - 12 December 2001; D262, 25 April - 24 May 2002; D264, 28 July - 23 August 2002; D267, 15 November - 13 December 2002) (Fig. 1). The focus of the surveys was the connectivity between population dynamics of the euphausiids *Meganyctiphanes norvegica* and *Thysanoessa longicaudata*, the copepods *Oithona* spp. and *Calanus finmarchicus*, the physical oceanography and lower trophic levels in the region. The higher objective was to better understand the basin scale sensitivity of these species to climate change. The Irminger Sea was chosen as the geographical focus since other major gyre regions of the North Atlantic (Norwegian Sea, Iceland Basin,

Labrador Sea) had been extensively sampled in the preceding decade, whilst there had been little regional scale study of the zooplankton ecology in the Irminger Sea. Summarised here are our findings on the dynamics of *C. finmarchicus* (Fig. 2), which are shortly to be published in detail in the journal Progress in Oceanography (Heath *et al.*, in press).

Demographic data on *C. finmarchicus* in the Irminger Sea, other than from the Continuous Plankton Recorder (CPR) surveys, were scarce prior to our UK-MarProd study. The ICNAF-NORWESTLANT surveys in 1963 sampled the upper 100 m of the Labrador Sea and Irminger Sea between March and August but apart from these, there was no detailed demographic sampling until the studies of Gislason and co-workers in 1997 and thereafter (Gislason and Astthorson, 2000; Jonasdottir *et al.*, 2002; Gislason, 2003; 2005). These authors reported on the seasonal changes in *C. finmarchicus* demography, depth

distribution and egg production in the shelf and slope waters south and southwest of Iceland, and at two stations in the northern Irminger Basin (>2000 m water depth). Their data showed that stage C5 copepodites were abundant in the northern Irminger Sea at depths of 200-1800 m in Atlantic origin water of temperature of 3-6°C during November and December. Ascent to the surface commenced in March and continued through to early May. The studies provided indications of connections between the offshore stock of *C. finmarchicus* in the northern Irminger and Iceland Basins, and production on the Iceland shelf (Gislason *et al.*, 2000) but, due to the restricted spatial coverage, relatively little regarding the controls on population dynamics at the scale of the Irminger Sea basin.

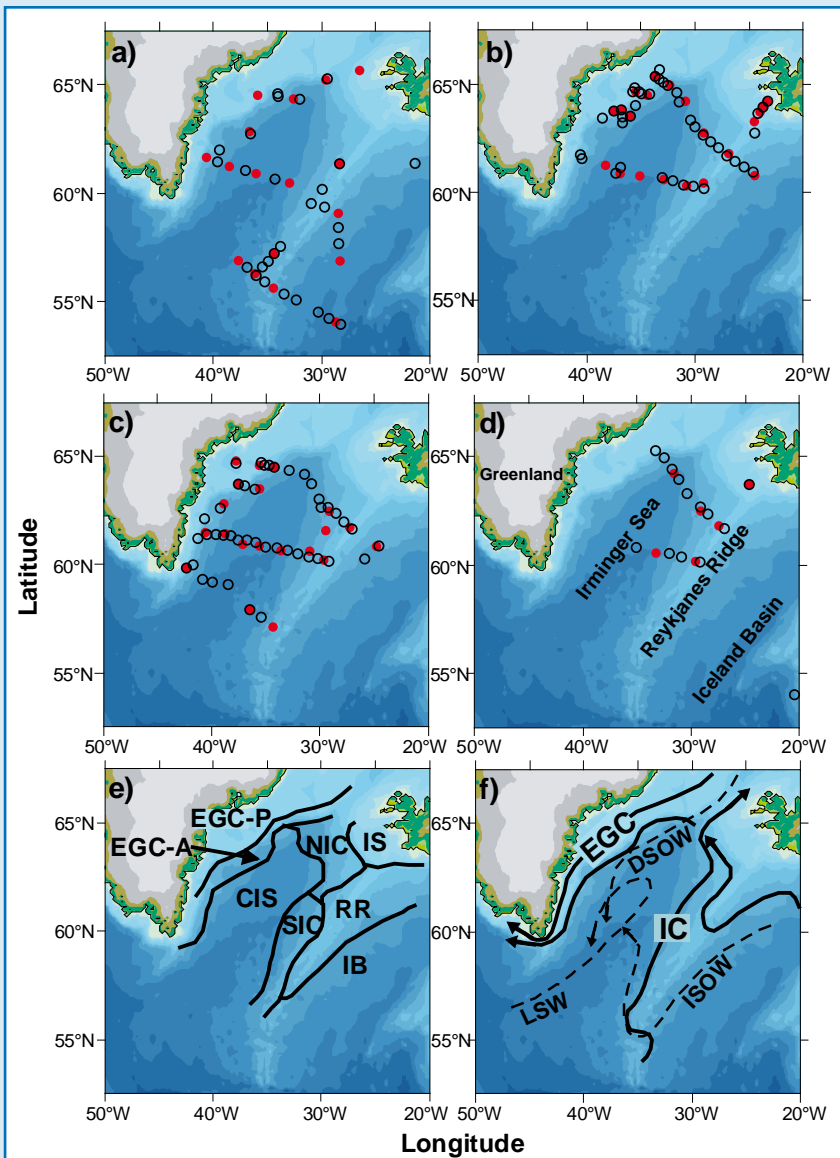


Figure 1. Sampling locations in the Irminger Sea during Discovery surveys a) D258, b) D262, c) D264 and d) D267. Solid red symbols indicate plankton and hydrographic sampling locations. Open symbols indicate sampling locations where only hydrographic measurements were carried out. e) Average boundaries of biophysical zones (according to Holliday *et al.*, 2006) to which the sampling stations in the 4 cruises were assigned (East Greenland Current-Polar (EGC-P), East Greenland Current-Atlantic (EGC-A), Central Irminger Sea (CIS), North Irminger Current (NIC), South Irminger Current (SIC) and Reykjanes Ridge (RR), plus the two additional zones Iceland Shelf (IS) and Iceland Basin (IB) which were only sparsely sampled. f) Schematic of the major currents and water masses in the region. Solid arrows indicate surface flows, dashed arrows indicate deep flows: East Greenland Current (EGC), Irminger Current (IC), Denmark Strait Overflow Water (DSOW), Iceland-Scotland Overflow Water (ISOW) and Labrador Sea Water (LSW).

\*Representing a consortium of researchers identified in the Heath *et al.* (in press) reference at the end of the article.



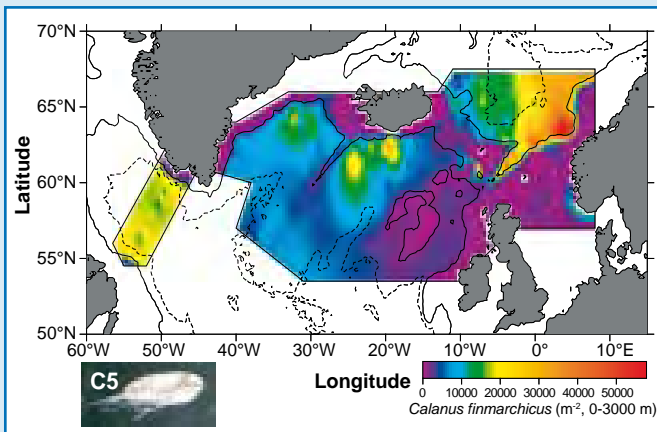


Figure 4. Water column integrated abundances ( $m^2$ ) of overwintering stages C4-C5 *Calanus finmarchicus* in November and December (Heath *et al.*, 2004). Composite image developed from data collected during the EU-ICOS and TASC projects in the northeastern Atlantic (1994-1999), MARPROD (2001-2002), and RV Hudson in the Labrador Sea (December 2001; E. Head).

in *C. finmarchicus* collected during the surveys, that the overwintering stock was in a diapause state in all regions except for some shallow distributed individuals (< 350 m) in the East Greenland Current.

We have no information from our surveys on the exact timing of ascent from overwintering depth in the Irminger Sea, but by late April-late May the majority of the surviving overwinter stock (G0) had developed to stage C6 females and males and migrated to the upper 50-100 m of the water column. G0 females were widespread in the Atlantic-origin surface waters of the region in spring. Females in the central Irminger Sea and Irminger Current had retained a lipid content only slightly less than that observed in the stock in the previous November/December, whilst those in the East Greenland Current were lipid-depleted. Per capita egg production in spring did not vary significantly across the region, but population egg production (G1) was highest in the Central Irminger Sea and Irminger Current. In contrast, recruitment of G1 nauplii and copepodites was highest around the fringes of the Irminger Sea, in the East Greenland Current and over the Reykjanes Ridge.

By late July-early August the G1 individuals were accumulating in C4 and C5 and were beginning to descend to overwintering depths. Descent timing was earlier in the east than in the west of the region, probably reflecting the warmer temperatures and consequent more rapid development. The greatest concentration of C5 in late summer was along the Greenland slope, below the boundary between the East Greenland Current and the Central Irminger Sea. However, approximately 7% of G1 developed to C6 rather than entering the overwintering stage, and were spawning in July/August especially along the East Greenland slope. The G2 offspring were present as early nauplii, but mortality rates of N3-N4 were higher than in spring and were probably the limiting factor for population development. It is likely that G2 made little contribution to the overwintering stock.

The predominant factors controlling the spatial pattern of recruitment and development appears to have been predation

mortality on eggs, partly by the G0 stock, and starvation mortality of first feeding nauplii. High mortality rates of naupliar stages 3 and 4 appeared to be linked to low chlorophyll a concentrations of less than  $0.6 \text{ mg m}^{-3}$  in the Central Irminger Sea. SeaWiFS images and our sampling showed that these conditions persisted throughout the year. Hence, the central basin was a persistently poor environment for *C. finmarchicus* recruitment. Carnivory made a contribution to the diet of G0 females in spring, and G1 C5s and C6s in the East Greenland Current in summer. Within the herbivorous component of the diet, non-diatoms were important in the East Greenland Current, and diatoms along the Reykjanes Ridge to the east.

We compared the stage abundance distributions during our surveys in 2002 with those collected during the NORWESTLANT surveys in 1963 and CPR surveys. We concluded that the spatial demography that we observed in 2001/02 appears to be representative of the region.

From these results, we developed a working hypothesis for the spatio-temporal population dynamics of the Irminger Sea. The elements of the hypothesis (Fig. 5) are that:

- Survivors of recruitment along the western margins of the Irminger Basin will probably be exported to the Labrador Sea in the surface circulation by the time they have developed to the entry stage for overwintering. Evidence for descent in this region is provided by sampling in December 2002 by the research vessel Hudson (E. Head pers. comm.; Heath *et al.*, 2004), concurrent with the November/December 2002 survey by Discovery. *C. finmarchicus* C4 and C5 copepodites were present at abundances of approximately  $18,000 \text{ m}^{-2}$  above the 2000 m isobath southwest of Greenland, distributed between 400 and 1500 m.
- Survivors of recruitment around the eastern and northern margins of the Irminger Basin will probably be distributed along the east Greenland slope by the time they have developed to the entry stage for overwintering. Evidence for descent in this region is provided by the Discovery July/August 2002 survey.
- Copepodites descending to overwintering depths along the eastern margin of the Irminger Sea (western face of the Reykjanes Ridge) are probably immigrants from spawning in the Iceland Basin.
- Direct descent is unlikely to be the main source of overwintering copepodites in the central Irminger Basin due to the poor recruitment in this area. Horizontal transport by sub-surface recirculation from the east Greenland slope, plus transport from the Irminger Sea in the LS Intermediate Water (Pickart *et al.*, 2003) is the more likely source.

If our hypothesis is correct, then the basis for a degree of spatial closure of the life-cycle of *C. finmarchicus* in the region would seem to exist. However, it is also clear that there must be extensive leakage to the Labrador Sea and input from the Iceland Basin. So, the Irminger Sea is unlikely to be a closed system with respect to population dynamics.







## Understanding the role of *Calanus nauplii* in the ecosystem dynamics of the North Atlantic

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The copepod *Calanus finmarchicus* is a key species in North Atlantic ecosystems. As such it was a target species of the UK Marine Productivity programme as well as a number of other GLOBEC national and multinational programmes in this ocean basin. While adult and late stage *C. finmarchicus* are among the most studied marine copepods, relatively little is known about the ecology of the earlier developmental stages and in particular *Calanus* nauplii. To help fill this gap in knowledge we studied recruitment and mortality of *Calanus* eggs and nauplii (Fig. 1) both for *C. finmarchicus* in the Irminger Sea during the Marine Productivity cruises, and for the congeneric species, *C. helgolandicus*, a key species in European Shelf seas (Bonnet *et al.*, 2005) and one which could be studied intensively at a time-series station off Plymouth (UK) as well as in laboratory cultures.



Figure 1. *C. helgolandicus* eggs and nauplii in laboratory culture.

Our work aimed to disentangle, quantify and comprehend the processes controlling *Calanus* recruitment in order to contribute to the scientific debate over whether observed seasonal and interannual changes in Atlantic *Calanus* populations are predominantly physically or biologically mediated. We tackled a number of aspects of the biology and ecology of *Calanus* nauplii using data from the Irminger Sea cruises, the long term monitoring station L4 off Plymouth and from laboratory experiments. In this article we summarise three aspects of our work: the natural diet in relation to food limitation, cannibalism by late stage and adult *Calanus*, and predation and mortality on a seasonal basis.

Recent studies have shown that passage through the naupliar stages is a key event in the population dynamics of *C. finmarchicus*. As a step towards understanding if and how trophic interactions influence this event we investigated the feeding of *C. finmarchicus* nauplii IV –VI in the Irminger Sea during spring and summer in a series of shipboard incubation experiments (Irigoien *et al.*, 2003). Samples were analysed using conventional microscopic analysis of phytoplankton and microzooplankton. Generally, feeding efficiencies were highest on large cells, whereas small

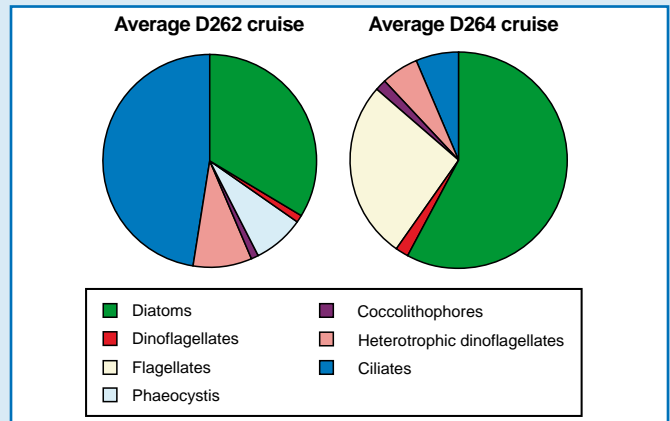


Figure 2. Examples of the composition of the diet of *Calanus finmarchicus* nauplii determined in incubation experiments during the Marine Productivity cruises in the Irminger Sea.

flagellates were ingested at very low rates. Among the larger cells, the diatoms *Chaetoceros pelagicus* and *Tropodineis* sp. and the ciliate *Strombidium* sp. were the main food sources (Fig. 2). A negative relationship between the percentage of diatoms in the food environment and the filtration rate on *Strombidium* sp. was observed. We therefore suggest that the combination of low feeding efficiency on small cells and the generally low concentrations of ciliates in oceanic waters explains why *C. finmarchicus* relies on phytoplankton blooms for recruitment from nauplius to the first copepodite stage.

Recent modelling studies have suggested that cannibalism on eggs and young nauplii are an important factor controlling the population dynamics of *Calanus*. In laboratory culture experiments we measured cannibalistic feeding rates on eggs and nauplii of *C. helgolandicus* (Fig. 3). Clearance rates were

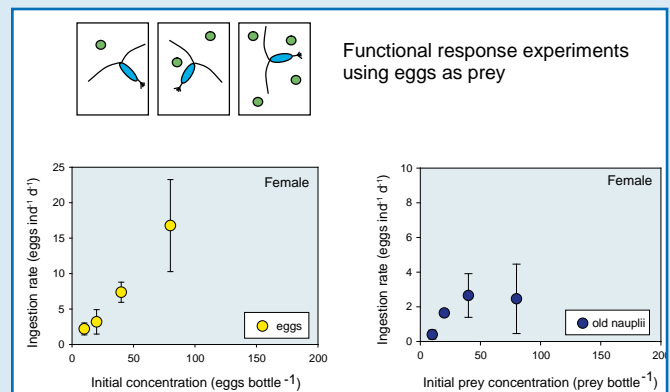


Figure 3. Experiments on *Calanus* cannibalism. Upper panels show schematic design of laboratory experiments where adult female *Calanus helgolandicus* were incubated with different concentrations of their eggs. Bottom panels show ingestion rates at different concentrations of eggs and nauplii as prey.



## Integrating conventional microscopy and molecular analysis to analyse the abundance and distribution of *Calanus* spp. in the North Atlantic

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Analysis of the demographic structure of *Calanus* species in the North Atlantic presents particular difficulties due to the overlapping spatial distributions of four main congeneric species (*Calanus finmarchicus*, *C. helgolandicus*, *C. glacialis* and *C. hyperboreus*). These species have similar morphologies making microscopic discrimination only possible between some of the species and only at late copepodite or adult stages. However, molecular techniques now offer the possibility of screening significant numbers of specimens and unambiguously identifying them to species, regardless of developmental stage. Unfortunately, the processing rate of specimens by molecular methods is still too low to offer a realistic alternative to microscopy for analysis of samples from large field surveys, especially where the requirement is for species and stage-resolved demographic data.

The main objective of the work was to use microscopic analysis of plankton samples to estimate the abundance of taxonomic groups, and to integrate this with molecular methods to enhance the species resolution. The need for this initiative arose from the key field studies of the main UK GLOBEC programme, Marine Productivity, which focused on plankton production and especially *C. finmarchicus* population dynamics, in the Irminger Sea. This is a mixing area for warm Atlantic water carried northwards by the Irminger Current, and cold polar water travelling south with the East Greenland Current. Hence, both *C. finmarchicus* and *C. glacialis* could be expected in the survey region, in varying proportions. In addition, the eastern part of the survey region encroached on the oceanic distribution range of *C. helgolandicus*. Hence, the precision of *Calanus* species discrimination was an important issue for the programme.

Sampling was carried out on four surveys on the RRS Discovery which were mainly centred on the Irminger Sea basin, the fringing east-Greenland shelf, the southwest Iceland shelf, and the northern end of the mid-Atlantic Ridge, referred to as the Reykjanes Ridge. Plankton were sampled with either the ARIES or OCEAN Sampler system which was designed to collect a sequential set of discrete depth plankton samples. *Calanus* individuals were enumerated by microscopic analysis, developmental stage C1–C6 from formalin preserved descent-leg ARIES nets (200 µm mesh net) and *Calanus* early moult stages N1–N3, N4–N6, C1, C2 and C3 from the fine mesh samples from OCEAN Sampler (95 µm mesh net). A partially automated molecular identification technique (Fig. 1; Lindeque *et al.*, 1999; 2006) was used to identify individual *Calanus*, at all developmental stages to species level according to the RFLP signature of its mitochondrial 16S rDNA. As it was only possible



Figure 1. Robotic workstation onboard RRS Discovery. Conventional microscopy has been merged with molecular analysis to analyse *Calanus* species composition in the North Atlantic during the large-scale surveys of the Marine Productivity programme.

to perform molecular analyses on specimens from a small subset of the samples collected during the surveys molecular data was aggregated over several stations to provide statistically robust estimates of species composition for each developmental stage. Stations were aggregated within a common homogeneous zone, defined for the Irminger Sea by Holliday *et al.* (2006).

A total of 458,923 specimens of *Calanus* stages N1–C6 were analysed from the four surveys to give an estimate of abundance. Molecular analyses were successfully carried out on a total of 5,368 individuals of stage N1–C6. Depth interval data (0–400m) from the spring survey was used as a case study for blending the stage abundance estimates from microscopy with the percentage species compositions determined by molecular analysis. The hypothesis that the proportional species composition was homogeneous for each stage within each zone was tested with a single factor ANOVA test and the results indicated no significant difference in species composition between stations in each zone. The zonal compositions derived from the molecular analysis were applied to the microscopically derived stage abundance of every sample falling within each zone. Figure 2 shows semi-synoptic maps of the stage abundance data apportioned into *C. finmarchicus* and *C. glacialis*. For a subset of the Aries nets, the prosome lengths of individual specimens of *Calanus* spp., stages C4–C6, were measured under a compound microscope. This allowed comparison between molecular and prosome length data as a method of discriminating between *C. finmarchicus* and *C. glacialis* in the Irminger Basin.





## Long-term limited dispersal in the North Atlantic copepod species *Calanus finmarchicus*

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One of the main predicted outcomes of climate change is a shift in the ranges of many temperate and cool-temperate species towards the poles as a consequence of increasing temperatures. The fate of taxa with limited dispersal capability may ultimately be extinction as the rate of climate change may exceed the ability of species to colonise suitable habitats (Thomas *et al.*, 2004). Habitat change may be particularly pronounced in marine ecosystems due to factors such as elevated sea levels, changes in pH due to an increase in atmospheric carbon dioxide and changes in circulation patterns. It was long believed that marine organisms were capable of particularly high levels of dispersal due to an ostensible lack of barriers to gene flow but an increasing number of studies have suggested much higher levels of population structuring than had previously been thought (Palumbi *et al.*, 1994).

The cool water marine copepod *Calanus finmarchicus* is the dominant contributor, in terms of biomass, to the mesozooplankton in the northern North Atlantic and also in the adjacent Norwegian Sea. The species is an important indicator organism as well as being a key component of the North Atlantic food chain and recent studies have demonstrated an apparent northward range shift due to increasing sea temperatures coupled with a 70% decrease in total biomass (Beaugrand *et al.*, 2002, 2003). Previous molecular studies have suggested some degree of genetic substructuring in *C. finmarchicus* populations (Bucklin *et al.*, 2000) but traditional genetic analyses cannot discriminate between the relative roles of historical and contemporary dispersal in shaping current-day patterns of genetic variation. Nested clade analysis of statistical parsimony networks, however, allows the analysis of coalescent events over a range of chronological levels (Templeton *et al.*, 1998).

In order to dissect the role of historical and contemporary processes in shaping the levels and patterns of gene flow in *C. finmarchicus*, we carried out a nested clade analysis on DNA sequence variation in the nuclear pseudogene copy of

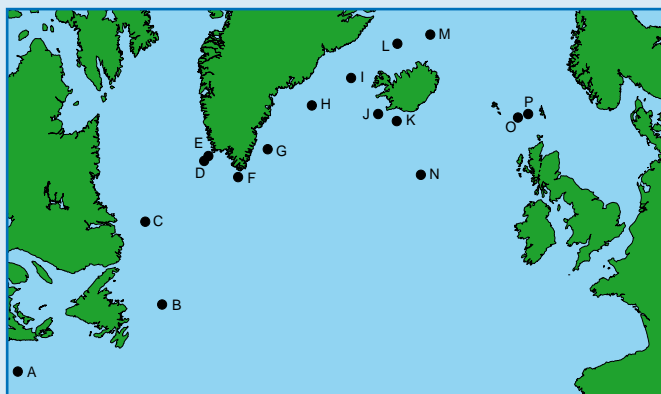


Figure 1. Sampling sites across range of *Calanus finmarchicus*: A) Nova Scotia; B) Flemish Cap; C) West Labrador Sea; D,E) East Labrador Sea; F) Cape Farewell; G,H) East Greenland Shelf; I) Denmark Strait; J,K) South Iceland; L) North Iceland; M) Icelandic Plateau; N) Iceland Basin; O,P) Faeroe/Shetland Channel.

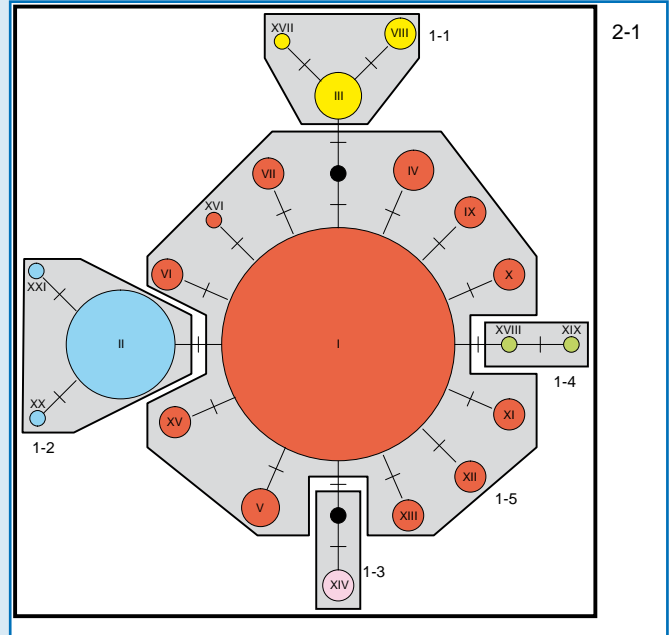


Figure 2. Nested clade diagram of 21 haplotypes revealed by sequencing of the nuclear pseudogene copy of the mitochondrial cytochrome oxidase gene. Circle sizes are approximately proportional to haplotype frequency.

the mitochondrial cytochrome oxidase gene in 96 individuals sampled from 16 sites (Fig. 1). A total of twenty one haplotypes were detected and the resulting network displayed a star-shaped structure characteristic of population expansion following the last glacial maximum (Fig. 2). Using mismatch distribution analysis of the sequences, the expansion time for the populations studied was estimated to be *ca.* 16,000 years before present which is coincident with postglacial expansion. An analysis of molecular variance (AMOVA) revealed a significant degree of differentiation between populations, with 10% of the total genetic variation existing as variation between populations as a consequence of limited gene flow. More importantly, the nested clade analysis showed that this pattern of restricted gene flow and isolation by distance was apparent across a range of chronological levels, suggesting that the postglacial demography of *C. finmarchicus* populations has always been characterised by restricted dispersal.

The findings of this study suggest that the potentially limited dispersal of *C. finmarchicus* reported previously may not be due exclusively to recent events. The perceived assumption of largely panmictic populations of marine organisms has been questioned recently and our evidence of long-term limitations to the dispersal ability of *C. finmarchicus* is consistent with this. Furthermore, our findings may also explain the link between the 70% reduction in biomass and the observed northward shift of the species' range (Beaugrand *et al.*, 2002; 2003) and highlight the potential problem where the rate of dispersal in a species is insufficient to accommodate climate change-induced shifts in the species' habitable range.







## An increase in snake pipefish (*Entelurus aequoreus*) in the northeast Atlantic: possible causes and effects

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Climate induced changes in the planktonic community have been reported in the North Atlantic in recent years (Beaugrand *et al.*, 2002), and similar responses have been seen at higher trophic levels such as fish (Brander *et al.*, 2003). Many of these responses have been identified by the use of the Continuous Plankton Recorder (CPR), and here we discuss recent results from the survey concerning pipefish, numbers of which have increased dramatically around the UK in recent years. This has also been reported in both the scientific and popular press, and anecdotally by many divers. Pipefish are easily recognised, being vermiform with a long slender 'snout' and an armoured outer layer, much like an elongated seahorse. This increase has raised many questions, why has it happened and what affects will it have on the ecosystem?

The Continuous Plankton Recorder Survey has sampled the North Atlantic extensively for over 70 years, routinely recording over 300 zooplankton and over 200 phytoplankton taxa. The CPR samples at a depth of 7-10 metres, and is towed behind merchant vessels on their regular monthly routes. One of the initial objectives of the CPR survey was to aid understanding of fish stock variability, and for the potential prediction of fish distribution using plankton abundance and distribution data for the North Sea and the north-eastern Atlantic. Fish eggs and larvae are recorded in the routine analysis of CPR plankton samples however with the exception of isolated studies fish larvae have not been specifically identified since the late 1970s/early 1980s, when reduced funding resulted in a change in research priorities. Fish larvae are among the largest organisms sampled by the CPR and due to their nature are often damaged during sampling, however they can be generally be assigned to genus, family or to more homogeneous groups. One type of larval fish that is easily identified, and is therefore routinely noted in the records, is the pipefish. They have a tough exterior, like other members of the Sygnathidae (such as seahorses), and this allows them to remain intact when they enter the CPR. The use of genetic techniques has identified the species as the snake pipefish, *Entelurus aequoreus*, the most oceanic member of the family.

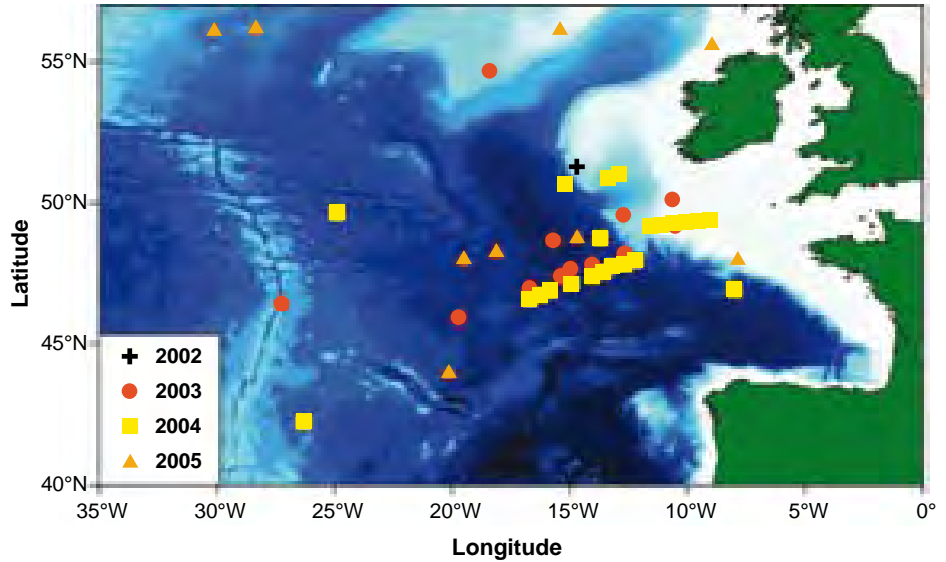


Figure 1. Pipefish records in the CPR survey.

Prior to 2002, pipefish were rarely recorded in the CPR survey. In 2002, unprecedented numbers of pipefish were recorded in the north east Atlantic, and this has continued up to the present day. They have been recorded as far west as the mid-Atlantic Ridge, and throughout their natural range from the Azores to Iceland (Fig. 1). The species has, so far, been generally absent from the North Sea in CPR samples (although for two successive years individuals have been recorded on the Shetland to Aberdeen route). CPRs from west of Ireland have returned with large adult specimens caught on outside protuberances (for example the shock absorber at the front of the mechanism), suggesting very high abundances in the area. Harris *et al.* (in press) report the increase in snake pipefish over a wide geographic area, from the southern North Sea northwards towards Spitsbergen and the Barents Sea.

The reason for the increase could be due to a rise in sea surface temperatures (SST), affecting the animal's physiology. Male *E. aequoreus* brood the eggs on their abdomen, where they are laid by the females in an incubation area. Whilst the eggs are in position, the males are unable to mate with the females, who are batch spawners. It is thought that *E. aequoreus* responds to a rise in temperature similarly to the related *Sygnathus typhle*, where an increase in sea temperature from 10 to 15°C can reduce egg incubation time by approximately 23 days. This would allow the males to breed more frequently (Kirby *et al.*, 2006). Another possible reason for the increase could be due to changes in the



plankton prey of the pipefish. These changes could be in abundance or distribution of prey species, both of which may have altered due to increased SST. For example, there has been a decrease in the abundance of *Calanus* around the UK (Edwards *et al.*, 2006), and a northward shift in calanoid copepods (Beaugrand *et al.*, 2002).

The effects of this increase in the species are as yet not fully understood, but it is already apparent that seabirds are feeding snake pipefish to their young, with disastrous results (Harris *et al.*, in press). The bony nature of the species has led to chicks choking, and the apparent poor nutritional content of snake pipefish has contributed to chicks in some colonies starving to death. Prior to 2004, snake pipefish had not been recorded in the diet of seabirds, but a shift to their inclusion may prove to have a detrimental effect on seabird colonies that are already under stress from the decline in sandeel populations.

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**Species diversity and biogeography of chaetognaths in the Indian Ocean**

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The link between biodiversity and biogeography leads to meaningful expressions of diversity patterns for zooplankton and this concept is examined for chaetognaths in the Indian Ocean. Chaetognaths form a significant part of the carnivore community of zooplankton. In the Indian Ocean the massive variability in the distribution of zooplankton can be explained using circulation patterns and well defined latitudinal subdivisions (Nair, 2006). This contribution is based on data from the extensive zooplankton collections of the International Indian Ocean Expedition (1960-1965) and later zooplankton collections made by National Institute of Oceanography from 1978.

Thirty one species of chaetognaths are recorded from the Indian Ocean (Nair, 2003) of which 20 are epipelagic, 7 mesopelagic and 4 bathypelagic (Table 1). *Sagitta enflata* and *S. decipiens* are the dominant species at the epipelagic and mesopelagic strata respectively. *Eukrohnia fowleri* dominated the bathypelagic realm of the northern Indian Ocean and is replaced by *E. hamata* in the subtropical waters. On the basis of spatial and bathymetric distributions the species recorded from the Indian Ocean can be grouped as in Table 1 (Nair, 1977, 1978; Pierrot-Bults and Nair, 1991).

**Horizontal distribution**

The Somali - Arabian coast is rich with regard to most species of chaetognaths and maximum species diversity is also confined mainly to this region (Nair, 1977). The effect of the monsoon regime is observed only in the northern part of the Indian Ocean, north of 10°S. All the epipelagic chaetognaths except *S. minima* have a higher abundance along the northeastern part of the Indian Ocean during the southwest monsoon when the circulation is from west to east. During the northeast monsoon, the flow is

**Table 1. Indian Ocean species of chaetognaths**

Group	Location	Species
la	Epipelagic: Atlantic, Indian and Pacific Oceans	<i>Krohnitta subtilis</i> <i>S. enflata</i> <i>Pterosagitta draco</i> <i>S. hexaptera</i> <i>Sagitta bipunctata</i> <i>S. minima</i>
lb	Epipelagic: Indian and Pacific Oceans	<i>K. pacifica</i> <i>S. pacifica</i> <i>S. bedoti</i> <i>S. pulchra</i> <i>S. ferox,</i> <i>S. regularis</i> <i>S. neglecta</i> <i>S. robusta</i> <i>S. oceania</i>
lc	Epipelagic: endemic to Indian waters	<i>S. bombayensis</i> <i>S. nairi</i> <i>S. madhupratapi</i>
ld	Epipelagic: typical cold water species	<i>S. tasmanica</i>
le	Epipelagic: typical Atlantic species	<i>S. serratodentata</i>
ll	Mesopelagic	<i>S. decipiens</i> <i>S. maxima</i> <i>S. gazellae</i> <i>S. planctonis</i> <i>S. lyra</i> <i>S. zetesios</i> <i>S. macrocephala</i>
lll	Bathypelagic and cosmopolitan	<i>Eukrohnia</i> <i>E. fowleri</i> <i>bathypelagica</i> <i>E. hamata</i>
IV	Bathypelagic and restricted to west coast of India	<i>E. minuta</i>

reversed and the relatively higher population in the eastern side begins to spread along the west coast of the Indian peninsula. This shifting of the population towards the west is more evident in the distribution of *S. bedoti*, *S. bipunctata*, *S. enflata*, *S. pacifica*, *S. regularis* and *S. robusta* (Nair, 1977).

The species composition indicates the predominance of tropical Indo-Pacific elements in the fauna. There is much interchange

of water between the Pacific and Indian Ocean through the Indonesian Archipelago and this helps to maintain a wide distribution of populations of warm water species, whilst the cold water species are found continuously between the two oceans via waters south of Australia.

The typical Indo-Pacific species seem to be carried sporadically along the coastal regions of East Africa and also into the Agulhas stream. Smaller numbers of Indo-Pacific species are being carried into the offshore regions of the Agulhas bank, but the species coming into the Atlantic with the Agulhas branch do not enter the Benguela waters. The west wind drift sustains a free interchange of cold water species between the Atlantic and Indian Oceans.

### Stratification

Maximum density of chaetognaths is confined to the upper 250 m, particularly the upper 125 m stratum (Nair, 1978). 2000 m -1000 m sustained the lowest number of chaetognaths and between the two depth intervals there was a progressive reduction in numerical abundance. Species diversity also gradually reduced from the epipelagic to the deeper zone and the maximum number of species was recorded between 250 m and 125 m depth, due to the mixing of mesopelagic and epipelagic species. In a similar way the 1000 m to 500 m stratum also sustained a relatively higher number of species due to the extension of bathypelagic species into the mesopelagic domain. In regions south of the subtropical convergence, the upper 200 m water column maintained lower numbers of species than the deeper strata.

The Indo-Pacific species, *Krohnitta pacifica*, *S. bedoti*, *S. neglecta*, *S. pulchra* and *S. robusta* were confined mainly to the region north of 10°S and were seldom found below 250 m. *Pterosagitta draco*, *K. subtilis*, *S. bipunctata*, *S. enflata*, *S. hexaptera*, *S. ferox*, *S. minima*, *S. pacifica* and *S. regularis* often extended below 250 m in regions north of 20°S. Even though *S. hexaptera*, *K. subtilis* and *S. minima* were reported to be epipelagic, they exhibited a different pattern of stratification. *S. hexaptera* is sparsely represented in the upper 125 m and becomes more abundant below 200 m in regions north of 10°S whereas towards the south part it is more common in the epipelagic stratum. A similar pattern was observed for *K. subtilis*, although it is more abundant in the epipelagic realm south of 22°S. *S. minima* became more abundant in the epipelagic realm south of the equator.

Among the mesopelagic species, *S. decipiens* was the dominant species with a maximum abundance between 1000 m and 250 m. The maximum abundance of *S. maximus* is usually found at the 1000 m - 500 m stratum north of the equator, and south of the equator in the 500 m - 250 m stratum. South of the subtropical convergence zone it is encountered in samples from 250 m to 125 m hauls. The same pattern has been exhibited by *S. macrocephala*. *S. lyra* is mesopelagic up to 30°S and is found in the surface layers of 125 m - 0 m.

*E. fowleri* is the dominant bathypelagic species in regions north of 20°S and south of 20°S whereas *E. hamata* dominates the bathypelagic realm in the tropical zone. South of 28°S *E. hamata* has been observed in 500 m - 250 m hauls and beyond 34°S the population has started spreading towards the 250 m -125 m stratum. *E. bathypelagic* is less abundant north of 25°S where

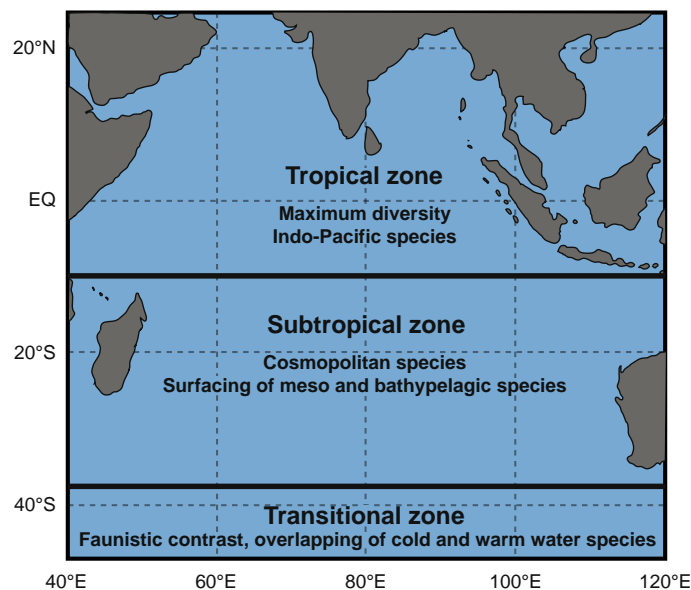


Figure 1. Biogeographic provinces for chaetognath species.

it is found in the 2000 m -1000 m stratum and south of 25°S it becomes more abundant entering the 1000 m - 500 m stratum.

The striking feature observed at the subtropical convergence is the absence of epipelagic species excluding the *serratodentata* group (*S. serratodentata* and *S. tasmanica*). Incidence of mesopelagic species in the epipelagic and bathypelagic species in the mesopelagic strata are characteristics of this zone.

The trend in the biodiversity of chaetognaths in the Indian Ocean shows three well defined biogeographic provinces (Fig. 1). The hydrochemical front at 10°S and the subtropical convergence towards 40°S delineate the chaetognath fauna into 3 biogeographical provinces. The tropical zone north of 10°S is defined as the zone of the monsoon gyre (Wyrtki, 1973) which sustains typical Indo-Pacific species, and is unique in maintaining the species in their respective bathymetric levels. The subtropical region south of 10°S extending to 38°S is dominated by cosmopolitan species of temperate and warm waters. At this zone the mesopelagic and bathypelagic species start penetrating into the strata just above the levels which they are expected to occupy. Maximum faunistic contrast was noticed at the subtropical convergence or the transitional zone where the species of southern cold water and subtropical waters overlap.

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## Effects of global changes on aquatic ecosystems in Western Europe: role of planktonic communities

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Long-term changes in aquatic ecosystems, linked to anthropogenic and/or natural forcing, have been hotly debated within the context of climatic change. Such studies have been possible by the existence of long-term monitoring programmes (i.e. CPR, CalCOFI, CIPEL), whose results have encouraged the exponential increase of publications on these topics observed in recent decades. Retrospective analyses have highlighted long-term trends, abrupt changes of the abundance of plankton and different correlations between ecosystem attributes (i.e. diversity, productivity, trophic level) and meteorological parameters. These findings result in different hypotheses explaining the relationship between global change and the functioning of aquatic systems.

Although retrospective analysis has been a crucial and necessary step in investigating long-term changes of climatic, physical, chemical and biological factors, generalisation of these conclusions from one or more long-term monitored sites to unexplored areas remains a delicate task. Hence, an immediate challenge faced by oceanographers, marine and freshwater ecologists and climate scientists are inter-site and inter-ecosystem comparisons. The pertinence and utility of such an approach allowing the identification of global synchronies in marine zooplankton population has been addressed by Perry *et al.* (2004).

Since 2003, efforts have been made to achieve inter-site, inter-ecosystem comparisons within the French national project APR

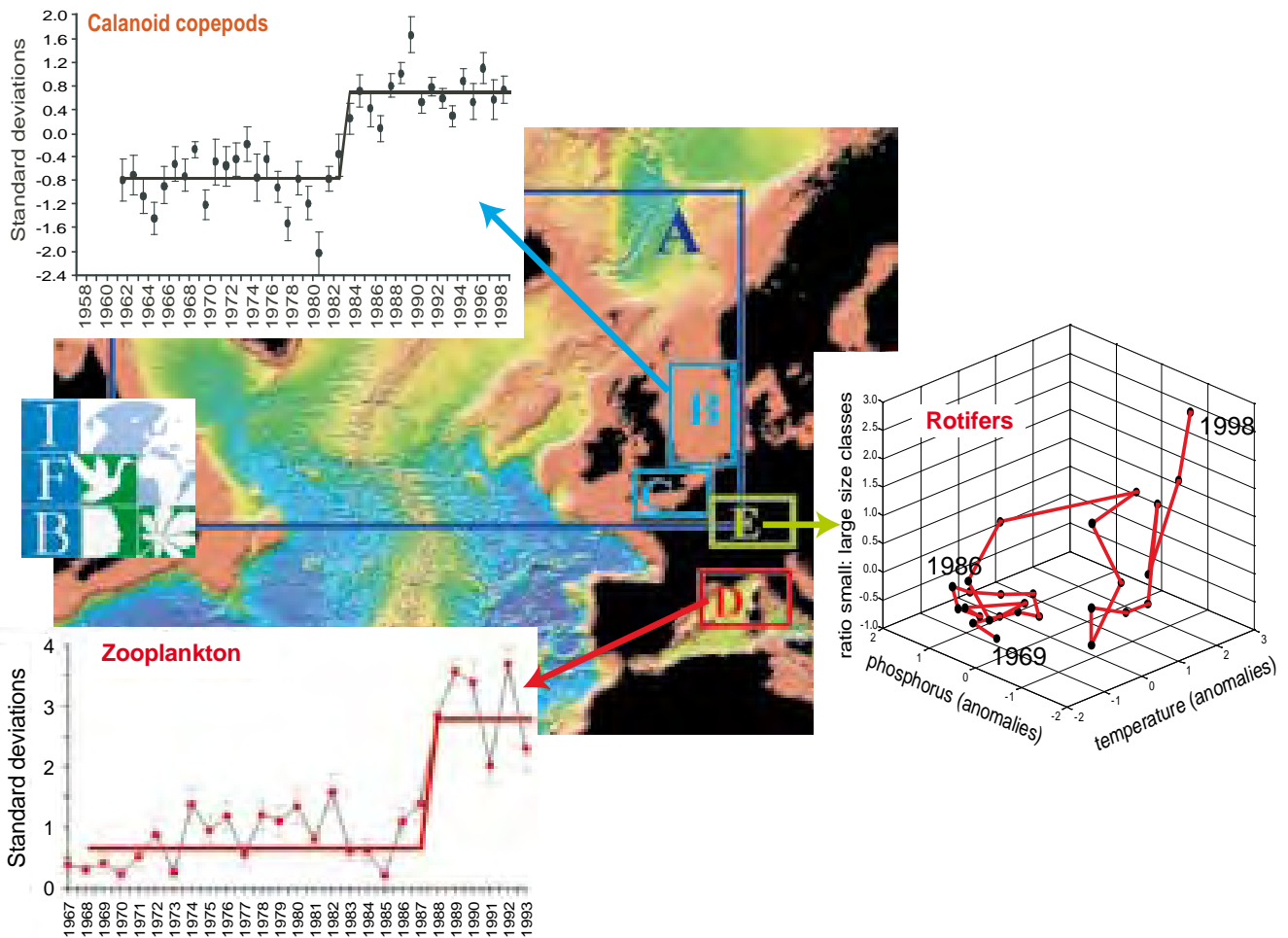


Figure 1. Geographical domain and ecosystems studied in the IFB-GICC project: A) North Atlantic, B) North Sea, C) English Channel, D) north-western Mediterranean Sea and E) sub-alpine lakes. The abrupt changes in the targeted pelagic ecosystems were observed in the middle-late 1980s and they are illustrated by calanoid copepods in the North Sea (top: modified from Beaugrand and Ibanez, 2004), zooplankton in the Ligurian Sea (bottom: modified from Molinero *et al.*, in press) and rotifers in Lake Geneva (right: modified from Molinero *et al.*, 2006).

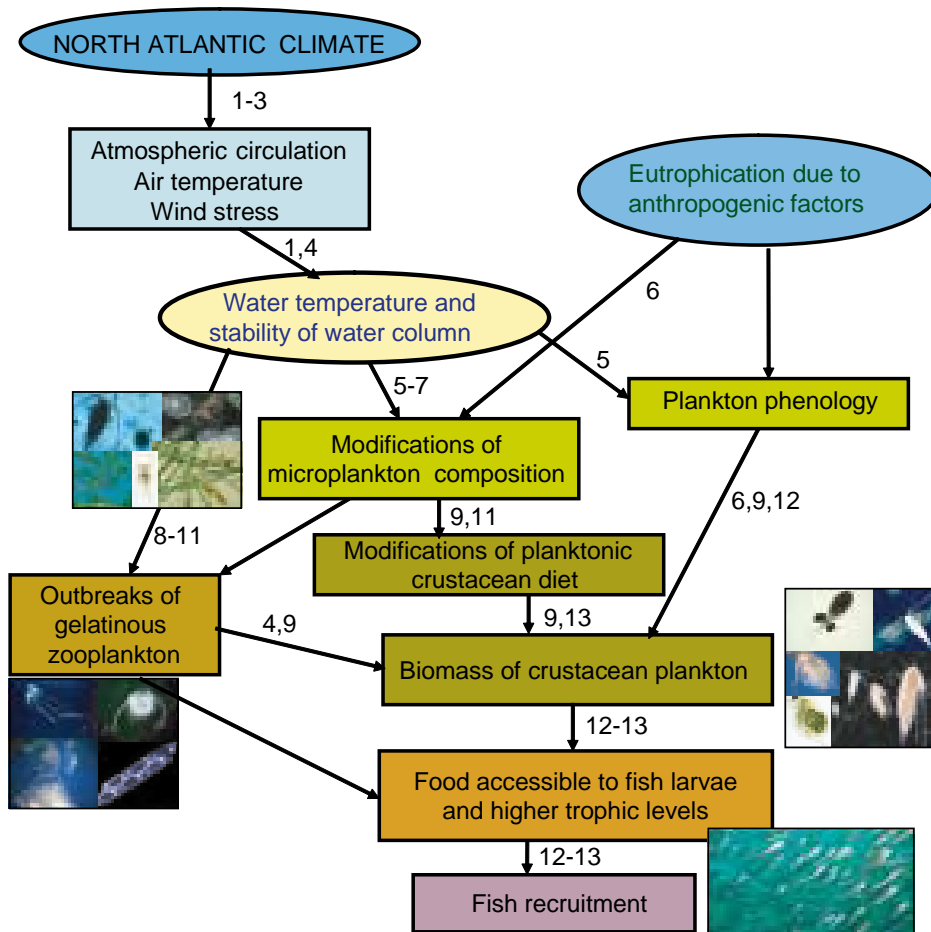


Figure 2. Schematic representation of the effects of the North Atlantic climate on aquatic ecosystems in Western Europe. The figure shows a cascade of interactions principally linked to climate. Climate forcing may interfere and reinforce other effects linked to anthropogenic factors (e.g. overexploitation, eutrophication). The numbers corresponded to the following references used to illustrate the mechanisms drawn (arrows): 1. Hurrell, 1995; 2. Trigo *et al.*, 2000; 3. Rixen *et al.*, 2005; 4. Molinero *et al.*, 2005a; 5. Anneville *et al.*, 2002; 6. Molinero *et al.*, 2006; 7. Straille *et al.*, 2003; 8. Buecher 1999; 9. Molinero *et al.*, 2005b; 10. Licandro *et al.*, 2006; 11. Molinero *et al.*, in press; 12. Beaugrand *et al.*, 2003; 13. Anneville *et al.*, submitted.

2003 No.15D; (<http://medias.obs-mip.fr/gicc/interface/projet.php?15D>) jointly funded by the French Institute of Biodiversity (IFB; [http://ezpub.cirad.fr/index.php/ifb\\_en](http://ezpub.cirad.fr/index.php/ifb_en)) and the French research programme 'Management and Impacts of Climate Change' (GICC; <http://medias.obs-mip.fr/gicc/interface/english.php>). Briefly, the central goals were: 1) to identify the mechanisms responsible in order to improve models on plankton population variability and their implications for the sustainability of marine and freshwater systems and 2) to investigate whether large-scale synchronies in plankton response to climate variability have occurred at the European scale. The targeted aquatic systems, as well as the long-term changes in different zooplankton groups are shown in Figure 1. By using the same methodology, the signature of the Atlantic climate on the selected marine and freshwater ecosystems appears evident.

The North Atlantic Ocean is the largest oceanic water mass associated with Europe. In this area atmospheric dynamics are driven by different interrelated phenomena, e.g. Northern Annular Mode (North Atlantic Oscillation/Arctic Oscillation), East Atlantic pattern, Gulf Stream, East Atlantic Western Russian pattern, which affect the local climate of other European Seas and lakes and, subsequently, their ecosystem functioning. Data obtained from large-scale climate phenomena can be truncated to obtain a general pattern of the North Atlantic climate sector. Such an approach was used to investigate climate – plankton interactions in the NW Mediterranean (Molinero *et al.*, 2005a), as well as in the largest body of freshwater in Western Europe, Lake Geneva (Molinero *et al.*, 2006). Figure 1 clearly shows that the variability

of plankton in different ecosystems shifted during the middle to late 1980s.

In Figure 2 we propose an empirical model whereby the North Atlantic climate forcing modified the long-term dynamics of Western European aquatic ecosystems. Water temperature and the stability of the water column seem to be the appropriate mediator between global climate change and the plankton dynamics in each aquatic ecosystem. Even if the sensitivity of all planktonic groups to climate change was shown in our project (Fig. 2) the intensity of their response and their phenology would have been different. Moreover anthropogenic forcing, such as bottom up control due to eutrophication (Anneville *et al.*, 2004) or top-down control due to overfishing, has affected the long-term dynamics of these aquatic ecosystems.

By including inter-site, inter-ecosystem comparisons the approach used allows a better understanding of marine and freshwater biodiversity responses to global change scenarios. Our initiative has now been extended to include estuarine ecosystems at a larger spatial scale. The present phase of the project will include further experimental work aiming at identifying responses of some key zooplankton species (e.g. estuarine copepods) to temperature changes. The experimental approach is necessary in order to build and validate individual-based models which can be used to explore the mechanisms at both individual and population scales before building appropriate ecosystem models.



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**Book review: Leonid B. Klyashtorin and Alexey A. Lyubushin. 2005. Cyclic climate changes and fish productivity**

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Leonid B. Klyashtorin and Alexey A. Lyubushin. 2005. *Cyclic climate changes and fish productivity*. VNIRO Publishing, 235pp ISBN 5-85382-212-8 [In Russian].

It is known that populations of commercially valuable fish species of the Atlantic and Pacific Ocean undergo long-term oscillations, many of which seem to be synchronised. Over the past decade, global synchrony in fish populations (anchovy and sardine, for instance) and climate change has been, and still remains in the focus of numerous investigators who use climatic indices and statistical procedures to prove or disprove this event. The book of Leonid Klyashtorin and Alexey Lyubushin complements the efforts in this field and summarises one of the approaches used by the Russian scientists.

The authors have chosen the Atmospheric Circulation Index (ACI) which was proposed and used by the Russian school of meteorologists and climatologists. This index characterises the dominant direction of air mass transport in the Atlantic-

Eurasian region (from 80°N to 30°N latitude and 45°W to 75°E longitude). According to Klyashtorin and Lyubushin, ACI is less variable and in closer correlation with the long-term fluctuations of the main commercial stocks.

The authors of the book have analysed long-term fluctuations of the North-East Atlantic herring, Norwegian herring, Arcto-Norwegian cod, Alaska Pollock, Pacific salmon, Japanese sardine, Japanese anchovy, Peruvian anchovy and zooplankton biomass in appropriate regions along with some other parameters with regard to the ACI.

Spectral analysis of the time series of catch statistics, global air surface temperature anomaly, and ACI, along with some other physical parameters estimated from direct observations, showed a 55 to 65 year periodicity. These correlations were used as a basis for a stochastic model intended to forecast the long-term fluctuations of catches of the major commercial species for up to 30 years ahead.

The book would have benefited from more extended analysis and discussion of possible mechanisms linking the long-term dynamics of fish populations with the ACI.

Hopefully, the authors will undertake efforts to make their work available to a broad English speaking community.

## Planktonic biomass and water masses in the shelf and oceanic areas off northeast Brazil

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The Atlantic circulation off northeast Brazil is dominated by the Equatorial Current System formed by the North Brazil Current and the Brazil Current, which results in two distinct oceanographic environments. The boundary between these two environments corresponds to the area where the South Equatorial current bifurcates around Cape Calcanhar. The North Brazil Current follows at a mean velocity of  $75 \text{ cm s}^{-1}$ , with superficial temperatures between  $28$  and  $30^\circ\text{C}$ , and superficial salinity between  $35.0$  and  $37.0$  psu (Medeiros *et al.*, 1999). The Brazil Current flows to the south at a mean velocity of  $10$  to  $15 \text{ cm s}^{-1}$  with mean superficial temperature of  $26^\circ\text{C}$  and salinity greater than  $35$  psu (Tchernia, 1980).

The study area shows typical characteristics of tropical regions, with high salinity and temperature, low thermal oscillation and oligotrophic water. Oceanic regions within tropical zones are usually considered oligotrophic due to a minimal vertical flow of nutrients and subsequent low biological productivity (Longhurst and Pauly, 1987). Such characteristics may be explained by the existence of a warm surface layer above a colder and denser sub-surface layer, which creates a permanent thermocline. This tends to inhibit the upward flow nutrient rich deeper layers, restricting primary production in surface waters (Travassos *et al.*, 1999).

Whilst the majority of tropical regions are characterised by minimal vertical circulation, in some areas mixing is promoted by localised mechanisms such as the divergence of currents, wind stress tension and the interaction between oceanic currents and submarine relief (Rogers, 1994; Roden, 1987; Petit *et al.*, 1989). In the Atlantic Ocean off northeastern Brazil, there are three areas where submarine relief and local currents may facilitate the hydrological process. These include the Saint Paul's Rocks, the Fernando de Noronha Chain and the North Brazilian Chain. The objective of this study was to evaluate the temporal and spatial distribution of the planktonic biomass and to relate the oceanographic conditions to rainfall in the shelf and oceanic areas of the Brazilian Northeast during the REVIZEE Project (Brazilian Environmental Federal Agency). Samples were collected by the Antares oceanographic vessel during the dry period (January - March 1997) and rainy period (May - July 1998) from 142 oceanographic stations (Fig. 1). The water masses were characterised by temperature ( $^\circ\text{C}$ ) and salinity (psu). Water samples for determination of primary biomass (chlorophyll *a*) at the surface (5 m) were obtained using a fluorescence sonde. Macrozooplankton samples for the determination of the secondary biomass (organic weight) were collected through oblique hauls by Bongo nets with a 50 cm diameter mouth and a 300  $\mu\text{m}$  mesh.

Water temperature ranged from  $26.2$  to  $29.4^\circ\text{C}$  (mean =  $28.9^\circ\text{C}$ ) during the dry period and from  $25.8$  to  $28.6^\circ\text{C}$  (mean =  $27.1^\circ\text{C}$ ) during the rainy period. Salinity ranged from  $34.8$  to  $37.2$  psu (mean =  $36.2$  psu) during the dry period and between  $34.5$  and  $37.4$  psu (mean =  $36.4$  psu) during the rainy period. There were significant differences in temperature (unpaired *t* test with Welch correction,  $p < 0.01$ ) and salinity ( $p < 0.0001$ ) between the two periods analysed. The values of salinity and temperature registered in all



Figure 1. Map of the study area showing the location of sampling station.

the periods, indicated the presence of Superficial Equatorial Water (SEW), which had a salinity  $>35$  psu and temperature  $>26^\circ\text{C}$ , and Coastal Water (CW) with salinity around  $35$  psu. The lowest primary biomass (Fig. 2) was found in the dry period with values between  $0.07$  and  $4.1 \mu\text{g l}^{-1}$ . The highest values were observed in the rainy period where values ranged between  $0.1$  and  $5.1 \mu\text{g l}^{-1}$ . The dry weight (Fig. 3) presented lower values during the rainy period, oscillating between  $0.02$  and  $3.2 \text{ g}/100 \text{ m}^3$  whereas most of the high values ( $0.03$  to  $11 \text{ g}/100 \text{ m}^3$ ) were found during the dry period. The chlorophyll *a* and organic weight was significantly different between periods ( $p < 0.0001$ ).

It was observed that the highest values of primary and secondary biomass were located at the northern sector under the influence of the North Brazil Current. In the shelf area the highest values of primary biomass were registered at the north and south slope and may be attributed to shelf break upwelling. In the oceanic area the highest values of primary and secondary biomass were registered in the areas adjacent to the North Brazilian Chain, the Fernando de Noronha Chain and Saint Paul's Archipelago probably due to topographic upwelling offshore. An important source of nutrients in superficial oceanic areas is the vertical transport of deep nutrient-rich water (Eppley and Weiler, 1979). The temporal increase of phytoplankton biomass in tropical oligotrophic waters was also registered in the Sargasso Sea (Menzel and Ryther, 1961), Arabian Sea (Rhyter and Menzel, 1965), East Pacific Ocean (Owen and Zeitschel, 1970) and the Northeast Pacific Ocean (Thomas, 1966). A slight elevation of biomass concentration was also observed at a station along the 200 and 1000 m isobaths northeast of Brazil by Ekau *et al.* (1999). It is assumed that these higher concentrations were due to weak upwelling caused by the effects of the South Atlantic Central Water along the shelf slope and topographical features (Medeiros *et al.*, 1999). In the Brazilian Northeast temporal variations in spatial distribution of planktonic biomass could be attributed to local meteorological conditions, continental water discharge, circulation patterns, upwelling and reproductive strategies of phytoplankton and zooplankton.

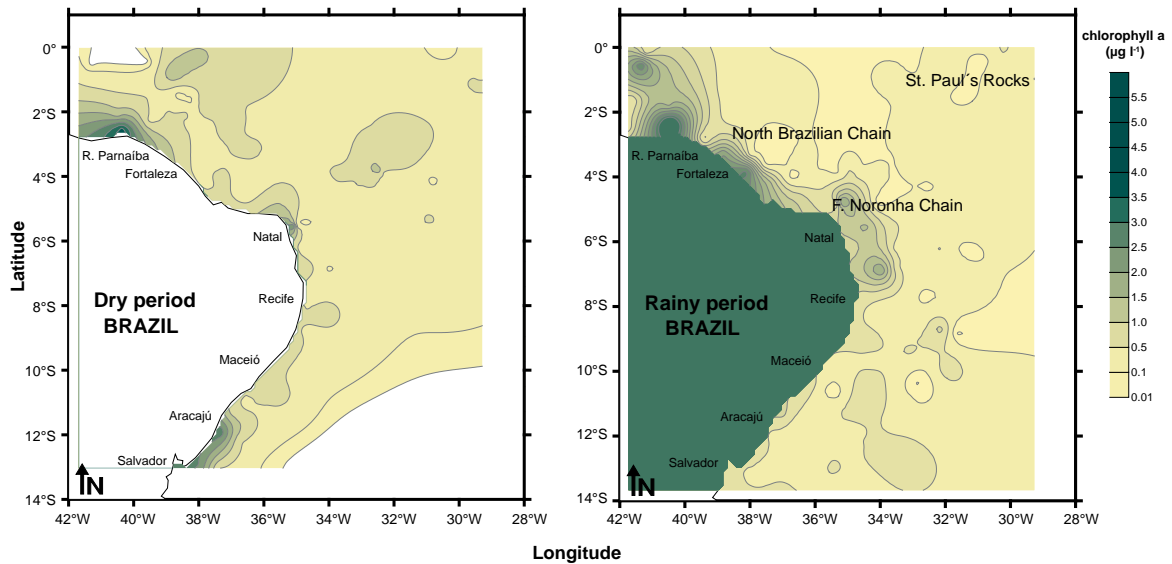


Figure 2. Temporal and spatial distribution of chlorophyll a ( $\mu\text{g l}^{-1}$ ) off northeast Brazil.

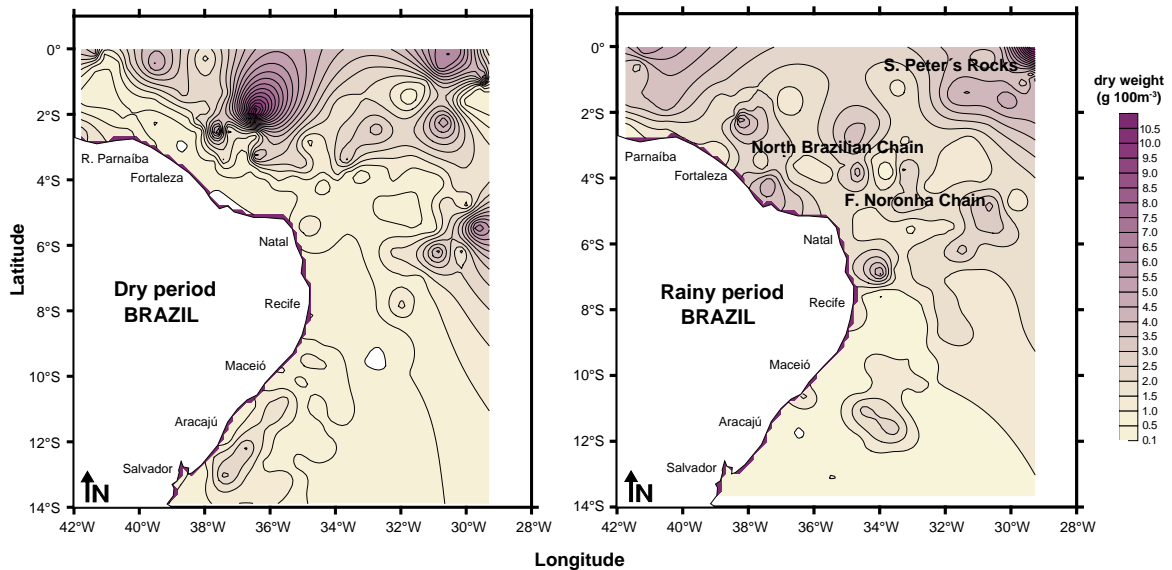


Figure 3. Temporal and spatial distribution of dry weight ( $\text{g } 100 \text{ m}^{-3}$ ) off northeast Brazil.

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## The BIOTROPH project. BIological resources in Antarctic polynyas: TROPHodynamics of planktonic and sympagic communities

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The evaluation of biological resources and their possible exploitation has hitherto been performed by studying the collected stocks and analysing life cycles of target species. This approach is essentially conservative and does not consider the different rates of prey population replenishment that support the available resources in areas of different potential production and different transfer rates within food webs. There are a wealth of reports on the structure and function of the pelagic realm in Antarctic ice-free waters. In contrast, there are relatively few reports concerning the differences in terms of production, consumption, degradation and carbon export in coastal areas characterised by different environmental features, and the impact of such differences on biological resources is still poorly understood.

Along with frontal areas, marginal ice zones, coastal areas and areas surrounding islands, areas of polynya are generally characterised by high levels of biological production; from the very onset of the austral spring huge phytoplankton blooms are observed that support an extremely rich pelagic biomass. Most of these areas of high productivity occur in the western Ross Sea which is considered one of the most productive areas of the Southern Ocean.

This research project conducted by researchers from Italian Universities (Ancona, Genoa, Messina and Naples) and research institutions (National Research Council of Trieste and Zoological Station A. Dohrn of Naples) put forward a funding proposal to the Italian National Antarctic Research Programme focusing on the evaluation of biological production in Antarctic coastal areas. Two different coastal sites, Terra Nova Bay and Woods Bay (Fig. 1), will be described in terms of structure, function and efficiency of trophic webs within the sympagic and pelagic compartments. To this end, a comparative analysis will be performed on production, consumption, degradation and carbon export processes on appropriate spatial and temporal scales.

Two polynyas are located in the Ross Sea, one of them in Terra Nova Bay, where marginal ice zones persist for several months along Victoria Land. Several studies on the distribution and production of planktonic communities in the Ross Sea have reported high biological production occurring from spring to early summer, both offshore and in coastal areas (Saggiomo *et al.*, 2000). In particular, in the south-western coastal area successive algal blooms have been observed from early spring until autumn, both in the sympagic and in the pelagic realm (Mangoni *et al.*, 2004). The information collected to date indicates Terra Nova Bay as the northern limit of

this high production area where microalgal blooms may exceed > 250 mg chlorophyll *a* m<sup>-2</sup> in the sympagic as well as in the pelagic compartments (Guglielmo *et al.*, 2000). Terra Nova Bay is also the northern-most area of specific features characterising the sea-ice along Victoria Land. In austral spring Terra Nova Bay is characterised by a thick layer of platelet ice that has a considerable impact on the sympagic primary production and the considerable accumulation of eggs of some pelagic fish species within the platelet-ice is an important feature (Guglielmo *et al.*, in press). North of Terra Nova Bay, from the adjacent Woods Bay, the coastal area is characterised by prolonged pack-ice coverage, the absence of platelet-ice and by low biological production.



Figure 1. Location of the two study areas: Terra Nova Bay and Woods Bay (Victoria Land, Ross Sea).

The main aim of the present proposal is to define the structure and function of the trophic webs in two coastal areas characterised by different physical and biological dynamics. The description of the structure and processes will allow for an estimate of the carrying capacity of the two systems and the available biological resources.

This aim will be achieved by means of: a) an estimate of the sympagic and pelagic stocks of the different compartments (from nutrients to micronecton) and of the benthic stocks (from prokaryotes to macrofauna);

b) the study of the dynamics of dissolved inorganic and organic nutrients in sea ice and in the water column, also in relation to the abundance and the structural and functional diversity of the bacterial and microalgal assemblages; c) an evaluation of the limiting factors (light, nutrients, trace elements) on primary production processes; d) an estimate, through field studies and laboratory experiments, of the transfer efficiency of the different fractions of particulate organic carbon (biopolymeric and bioavailable) to grazers (within the pack ice and in the water column), to the microbial loop (in pack ice, water column and in the sediments) and to the benthic realm by measuring the vertical fluxes.

The results of these studies are expected to provide a solid basis for a better understanding of primary production processes and carbon export in the coastal areas of the Ross Sea. They will also allow for an evaluation of the amount of resources regarding potential future utilisation.

The two study areas are characterised by different environmental settings such as the presence/absence of a polynya and a platelet ice layer and differences in the periods of pack ice coverage. Our previous observations have shown differences in the microbial

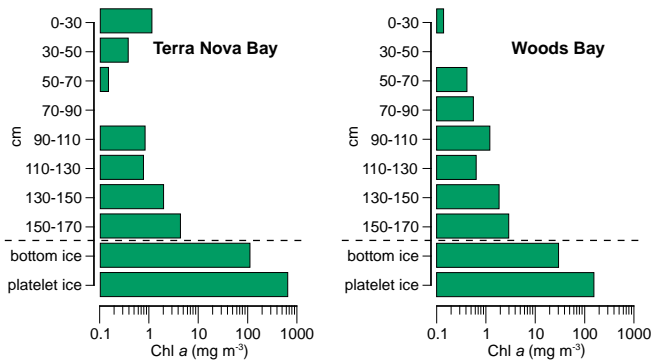


Figure 2. Microalgal biomass (Chl a) in ice cores from Terra Nova Bay (left panel) and Woods Bay (right panel).



Figure 3. Field operations of our ice-camp in Terra Nova Bay.

assemblages characterising the two areas. Notably higher sympagic biomass and microalgal diversity occur in Terra Nova Bay as compared to Woods Bay (Fig. 2). The field work (Fig. 3) will be carried out in two phases (ice cover and ice-free waters) between October and the end of February. During the first phase (October-December), chemical and biological analyses will be performed on ice core samples, platelet ice (if present) and water samples from below the ice sheet (down to 200 m) on at least three occasions. Sampling will be performed along coastal-to-offshore transects of at least three stations each, the outer-most being located close to the ice margin.

Sea ice and water samples will be collected for the determination of physical (temperature, salinity, irradiance), chemical (inorganic and organic nutrients; concentration and biochemical composition of particulate and dissolved organic carbon POC, DOC) and biological (bacterial abundance, biomass and diversity) parameters. Samples will also be analysed for microalgal assemblages (abundance, biomass, size and pigment spectra and species composition) and biomass and abundance of nano- micro- and meso-zooplankton and of the micro-nekton. Further, to evaluate the production, consumption, degradation and export of organic carbon the following processes will be studied throughout both sampling periods as well as in controlled experimental conditions: primary production, bacterial production and total community respiration, extracellular enzymatic activities, zooplankton and micronekton respiration. Biochemical and biological analyses will also be performed on material collected from sediment traps as well as on sediment samples.

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Photoacclimation is an important process that allows sympagic and pelagic production to occur in extreme light conditions (Lazzara *et al.*, 2007). To this end, micro- and mesocosm experiments will be set up to evaluate microbial response to environmental conditions such as different incident PAR, UV radiation as well as to the availability of macro- and micronutrients (e.g. iron) of the two major algal classes (diatoms and prymnesiophyceans) in terms of photosynthetic capacity and efficiency. These experiments will also attempt to determine the rates of consumption of dissolved and particulate organic carbon and nitrogen by the heterotrophic bacterial community in order to estimate the transfer efficiency of biopolymeric and bio-available particulate carbon towards higher trophic levels, and to evaluate the relationship between bacterial abundance, diversity and activity.

The results of the field work and of the experiments will allow for the reconstruction of the structure, dynamics and transfer efficiency of organic carbon produced at the lower trophic levels of the ecosystems which is channelled, also through the microbial food web, to the higher trophic levels and in particular to some key species (krill) and to the larvae of various fish species (*Pleuragramma antarcticum*). We will thus attempt to describe the trophic dynamics of two coastal sites, characterised by different levels of primary production, which may be considered representative of most of the Antarctic coastal areas.

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## New analyses of juvenile sprat growth and temporal origin in the German Bight (North Sea)

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The relatively shallow and highly productive German Bight in the south-eastern North Sea is recognised as an important retention (Bartsch and Knust, 1994) and nursery area for the larval and juvenile stages of many commercial fish species. The pre-recruit stages of sprat *Sprattus sprattus*, an ecologically and economically important clupeid, are particularly abundant in this area at most times of the year, which has made the species a preferred candidate for many larval growth and recruitment studies. In

the late 1980s and early 1990s, investigations conducted within the framework of the Sardine-Anchovy-Recruitment-Programme (SARP) compiled important information on seasonal and inter-annual spawning variability and larval abundance (e.g. Alheit *et al.*, 1987) and tested, for example, the hypothesis that larval growth is promoted in the vicinity of tidal or river plume fronts (e.g. Munk, 1993; Valenzuela and Vargas, 2002). Other approaches focused on the juvenile stage of sprat, using otolith microstructure analysis to deduce the temporal origin of individuals and whether certain periods of the year are more conducive to larval survival than others (Alshut, 1988).

More than a decade later, the German GLOBEC project has followed up on these previous investigations with a new 3 year programme of multi-disciplinary field research in the German Bight. In a recent GLOBEC study, the growth histories and temporal origins of sprat juveniles sampled during three consecutive cruises in August, September and October 2004 were studied by means of otolith microstructure analysis. A high month-to-month variability in sprat length distributions was encountered in the catches (Fig. 1), showing a continuous decline of the proportion of adult sprat (defined as > 90 mm TL) in the area, while the mean size of juveniles increased first from 71.1 mm TL in August to 76.4 mm TL in September, but decreased to 74.8 mm TL in October again. The majority of sprat juveniles, particularly in August and September 2004, were substantially larger than those caught during previous investigations, which may point to considerable interannual differences in the production and survival of sprat offspring from the German Bight and its adjacent spawning grounds. Uncertainties with regard to differences in gear selectivity and sampling locations, however, are known constraints to such comparisons across studies and decades.

Backcalculated days of first increment formation (dif), a proxy for hatch day, indicated that the majority of sprat juveniles in 2004 originated from the spring months of April and May (Fig. 1). Although from one survey to the next, later born juveniles appeared in the sampled population, whilst the earliest born conspecifics continuously disappeared (Fig. 1). However, the main

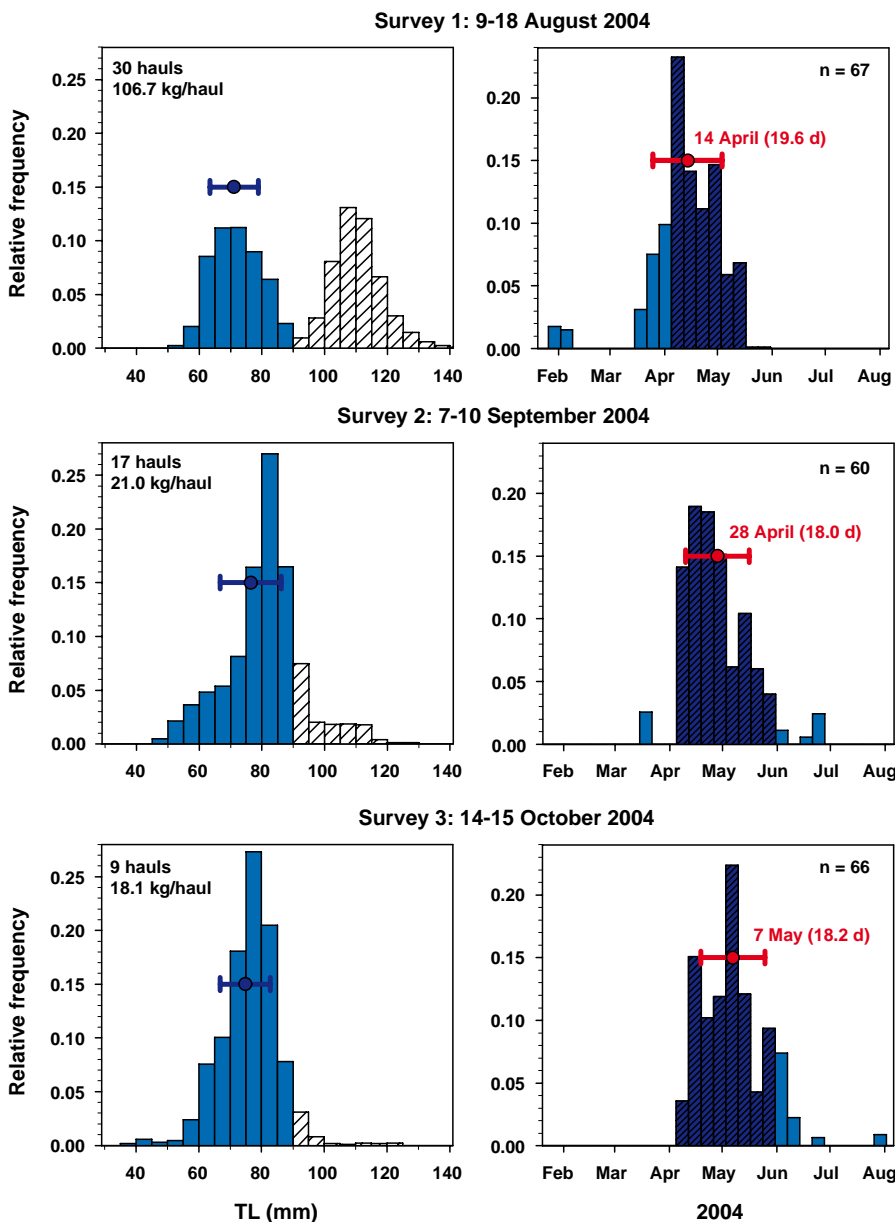


Figure 1. Left panels: Relative length frequency distributions of juvenile sprat (blue bars) sampled during 3 consecutive surveys 2004 in the German Bight (North Sea) with mean  $\pm$  SD of total length (horizontal error bars). Hatched bars depict relative frequencies of sprat > 9 cm TL, which were assumed to be  $\geq$  1 year of age and not analysed. Number of hauls and mean CPUE are also given. Right panels: Relative frequencies of the day of first increment formation (dif). Hatched, dark blue bars indicate the period when distributions from all 3 surveys overlapped. Number of analysed otoliths per survey and mean  $\pm$  SD dif (horizontal error bars) are also given.



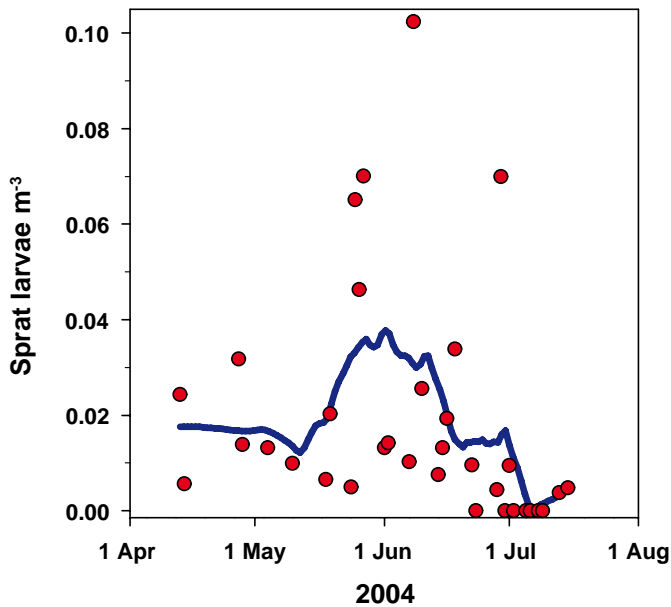
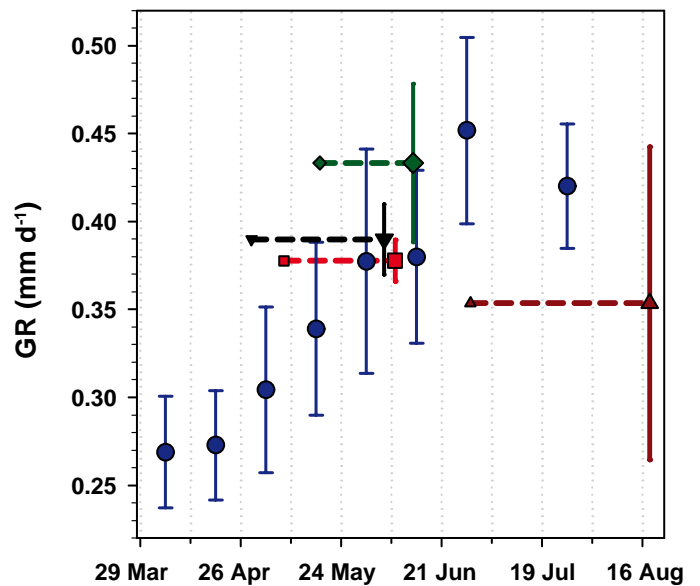


Figure 2. Seasonal abundance of small sprat larvae at the monitoring station 'Helgoland Roads' (54°11.18'N and 07°54' E), surveyed 3-5 times per week in 2004. Double oblique hauls were carried out using a CalCOFI ring trawl equipped with 500 µm mesh nets. A local smoothing function was used to estimate the seasonal trend in larval sprat abundance (Loess, SigmaPlot 10.0®).

spawning season in the German Bight generally commences later, typically at the end of May (Munk, 1993), which is consistent with seasonal monitoring data obtained for 2004 at Helgoland Roads (Fig. 2). Thus, many sprat juveniles encountered in late summer and autumn of 2004 in the German Bight may have been produced outside the study area, and either drifted and/or actively migrated subsequently into it (Alshut, 1988).

Otolith-based length and growth backcalculations suggested a second pattern in the seasonal dynamics of juvenile sprat in the German Bight. When backcalculated to a common date just prior to the beginning of the first survey (8 August), individuals present in the area in October were substantially smaller than those present in September, which in turn were smaller than those present in August. Similarly, a comparison of relative, i.e. 'age-independent' otolith growth rates clearly showed that sprat juveniles remaining in the area in October were those that grew slowest on average between the end of July and September 2004. In other words, the largest and fastest growing sprat juveniles seemed to have progressively disappeared from the study area, either as a consequence of selective migration and/or selective mortality. The latter would challenge a paradigm in larval fish ecology, being that larger and faster growing individuals generally have higher survival probabilities (Leggett and Deblois, 1994). Interestingly, however, average growth rates for sprat larvae in the German Bight – as compiled from the literature – were found to be consistently as high or even higher than backcalculated larval growth rates of juveniles with similar temporal origins (Fig. 3). To eliminate some of the many sources of uncertainty inherent to such comparisons (e.g. different methods to estimate growth rates from otoliths), further analyses are currently being carried out with sprat larvae sampled during 2004 in the German Bight.



- Juveniles 2004 (this study)
- Larvae 1989 (Valenzuela and Vargas, 2002)
- ▲ Larvae 1989 (Munk, 1993)
- ▼ Larvae 1990 (Re and Goncalves, 1993)
- ◆ Larvae 2003 (Huwert, unpublished data)

Figure 3. Published growth rates for sprat larvae from the German Bight compared to backcalculated larval growth rates of sprat juveniles sampled in 2004 (blue circles). Standard length growth rates (GR) were averaged ( $\pm$ SD) over the initial 50 days after first increment formation and for individuals with similar temporal origin (14 days intervals). Published larval growth rates are based on age-standard length relationships, error bars depict the range of reported growth rates. Dashed lines correspond to the encountered age range in each of the studies.

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## ICES/GLOBEC workshop on long-term variability of SW Europe

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Figure 1. ICES/GLOBEC workshop participants.

Over the last decade, there have been many efforts to analyse decadal-scale long-term time series in relation to marine ecosystems, particularly in the North Pacific and the North Atlantic. The goal was to better understand links between climate variability and marine ecosystems in light of anticipated global climate changes. The results demonstrate that climate variability can impact heavily on marine ecosystems and reorganise food chains up to fish populations and other top predators. The Small Pelagics and Climate Change (SPACC) programme has been very active in this field of research. In 1997, SPACC held a joint meeting with SCOR Working Group 98 on World-wide Large-scale Fluctuations of Sardine and Anchovy Populations (Schwartzlose *et al.*, 1999) in La Jolla. It was then decided to continue these studies by a series of regional workshops.

Previous meetings focused on the Benguela Current in 2001 (e.g. Cury and Shannon, 2004), the Humboldt Current in 2002 (e.g. Alheit and Niquen, 2004) and Japanese waters in 2003. The former ICES Study Group on Regional Ecology of Small Pelagics, now a permanent ICES Working Group (WGRESP), recommended at its annual meeting in 2005 to complete this series of workshops with a meeting focusing on waters surrounding the Iberian peninsula. To fulfil this goal, the joint ICES/GLOBEC Workshop on Long-term Variability of SW Europe (WKLTVSWE) was held from 13-16 February 2007 at the Portuguese fisheries institute, IPIMAR, and was co-sponsored by EUR-OCEANS (Fig. 1). The workshop was convened by Maria de Fatima Borges (Portugal), Alicia Lavin (Spain), Andrés Uriarte (Spain) and Jürgen Alheit (Germany) and was attended by 16 scientists from Portugal, Spain, Morocco and Germany.

The terms of reference were:

- to rescue, collate and jointly analyse decadal-scale, long-term time series of physical, chemical and biological data from ecosystems surrounding the Iberian peninsula with a focus on long-term changes of small pelagic fish;
- to identify possible links to climate variability;

- to look for possible teleconnection patterns with European and other marine ecosystems.

15 oral contributions were presented, focusing on the impact of climate variability on European marine ecosystems, particularly those of the Iberian shelf, and long-term time series of climatic, hydrographical and biological variables from waters surrounding the Iberian peninsula. Subsequently, data series were analysed in small groups using various methods for statistical time series analysis. Preliminary results show significant trends in climatic,

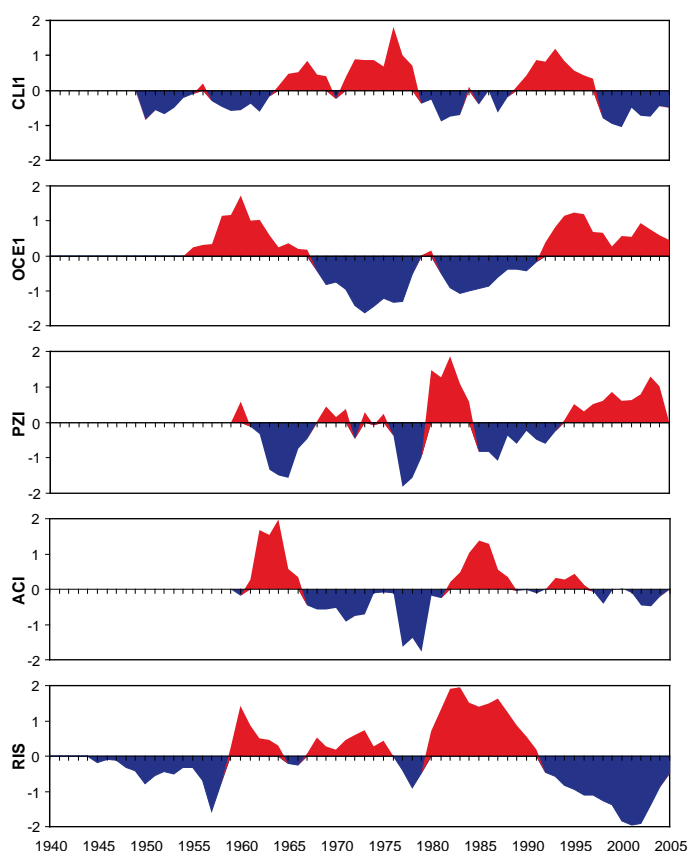


Figure 2. Succession of positive (red) and negative (blue) anomalies in selected indices representative of climate, oceanography and ecosystem structure in the NW Iberian and Bay of Biscay region. The dashed line indicates a marked shift in the sequence or in the periodicity or amplitude of the anomalies. CLI1 is the leading mode extracted from a principal component analysis of climatic indices for the North Atlantic and represents mostly the influence of NAO and subtropical forcing. Similarly, OCE1 is the first component of oceanographic variables indicating the stability of the upper water column in the N Atlantic. Three biological indices were representative of overall plankton structure, zooplankton composition and dominance of sardine versus anchovy, respectively. PZI is an index of relative proportions between phytoplankton and zooplankton computed from Continuous Plankton Recorder (CPR) data in the region. ACI represents the relative dominance of small copepods (*Acartia*) over large copepods (*Calanus*) and was also computed from CPR data. RIS represents an index equivalent to the relative indicator series (Lluch-Cota *et al.*, 1997) and expresses the succession of periods of relative dominance of sardine or anchovy in the region. All indices were computed from detrended, normalised and standardised variables.

oceanographic and ecosystem variables related to global warming at regional and subregional scales. Once the trends were removed, quasi-decadal-scale oscillations of positive and negative anomalies were apparent (Fig. 2). Marked shifts in the period, amplitude and phasing of anomalies are observed in most variables after the late 1970s. Such shifts may be related to the dramatic changes in community dynamics of most European shelf seas in association with the NAO index. The results of the analysis at the regional scale are consistent with the hypothesis of bottom-up control of the pelagic ecosystem through the climate effects on the physical dynamics of surface waters and subsequent effects on plankton and fish. Direct effects of climatic (e.g. winds) and oceanographic factors (e.g. upwelling) on planktivorous fish (e.g. larval dispersal) seem to be complemented by trophodynamic settings (e.g. plankton composition). These conclusions apply both to the whole NW Iberia and Bay of Biscay region and to subregions. In this way, the climate influence is exemplified in the Northwest of Iberia by the effect of increasing north winds during the winter in the dynamics of sardine.

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**Circumpolar ecosystems – launch of the ICED website**

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The Integrating Climate and Ecosystem Dynamics (ICED) programme was launched to develop a co-ordinated, multidisciplinary and circumpolar approach in studying the underlying processes driving Southern Ocean ecosystem responses to climate and anthropogenic forcings (Murphy *et al.*, 2006). Understanding these processes is essential to provide a sound basis for the sustainable management of the living resources of this globally important ocean. On a greater scale, there is an increasing focus on the requirement for predictions of the impacts and feedbacks of Southern Ocean ecosystems as part of the wider Earth System.

ICED has been developed with support from IMBER and GLOBEC. ICED will lead and co-ordinate international research in partnership with the Southern Ocean System of the European Network of Excellence for Ocean Ecosystems Analysis (EUR-OCEANS) and the International Polar Year (IPY) consortia ICED-IPY.

The ICED programme has launched a new website which is available from <http://www.antarctica.ac.uk/Resources/BSD/ICED/>

The website will be the focus of communication for ICED news and activities. The interactive ICED-IPY fieldwork map on the homepage (Fig. 1.) has been created as a starting point on which to build useful visual representations of some of the fieldwork in the Southern Ocean, to help encourage communication and co-operation. We aim to develop further versions in the near future to encompass more of the work going on in the Southern Ocean.

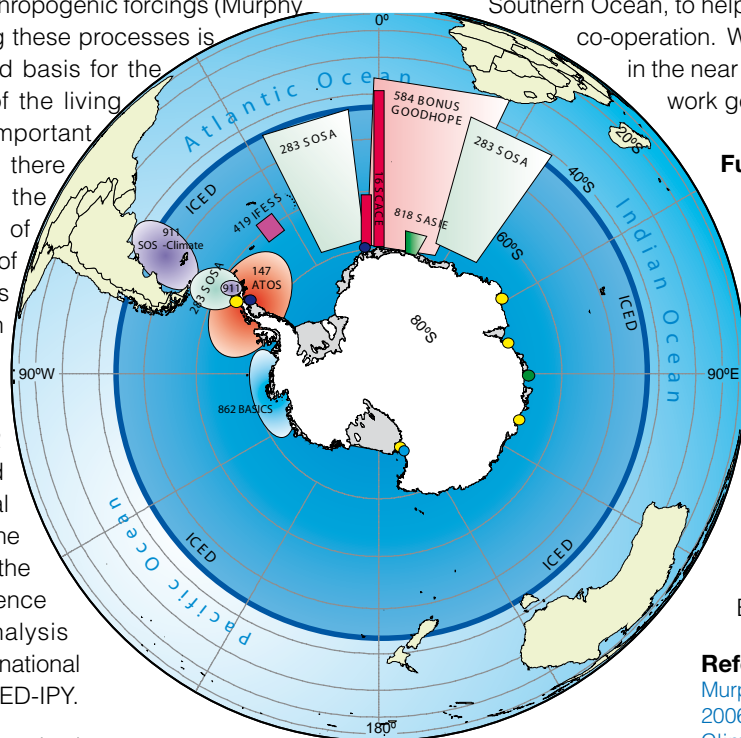


Figure 1. Map of proposed fieldwork locations for projects co-ordinated by or linked to ICED-IPY.

**Further information**

For further information about ICED, or to contribute to the website, please contact Rachel Cavanagh at the address below:

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## The China GLOBEC/IMBER programme implementation in 2006

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The China GLOBEC/IMBER programme “Key Processes and Sustainable Mechanisms of Ecosystem Food Production in the Coastal Seas of China” was launched in January 2006 with a duration of 5 years. The programme is sponsored by the Ministry of Science and Technology, PR China under the “National Key Basic Research Programme”, also known as the “973 Programme”. It is referred to by Chinese scientists as the China GLOBEC III Programme or the first combined GLOBEC/IMBER National Programme, China GLOBEC/IMBER I.

The core research is aimed at the interactions between marine biogeochemical cycles and key processes in the entire food web of coastal marine ecosystems. Synthesis research will cover the whole food web extending from the lowest to the highest trophic level, leading to an ultimate focus on food production. 68 scientists and about 100 postgraduate students from 6 major research institutions and universities are involved in the programme. The GLOBEC/IMBER programme will address the following issues:

- the supporting role of the main biogeochemical processes in food production;
- key physical processes of biogenic element cycles;
- primary production coupling with the main biogeochemical processes; and
- food production processes of biological functional groups together with their sustainable models.

The programme is operating over two phases (2 years and then a further 3 years) with a budget of 2.2 million USD in the first two years. The emphasis of China GLOBEC/IMBER I in the first 2 year period (2006-2007) is on first-hand field data collection. Six special field survey themes are designed to facilitate integrated multidisciplinary research. The themes are as follows:

**Theme 1:** Bloom processes of phytoplankton, with emphasis on the development of the bloom and its contribution to food production of the ecosystem.

**Theme 2:** The relationship between zooplankton and higher trophic level living resources, including the determination of key species and major functional groups at various trophic levels and their trophodynamic interactions in the food web. A typical ecological region of Yellow Sea Cold Water Mass (YSCWM) in the Yellow Sea has been selected as the main survey area. Two types of survey were designed under this theme, they include theme 2.1, a holistic survey covering the entire Southern Yellow Sea, and theme 2.2 which is dedicated to a zooplankton study with two transects intersecting the YSCWM where seasonal variations of the main zooplankton functional groups and their relationship to the physical environment will be observed.

**Theme 3:** Nutrient supply processes to the East China Sea Shelf, with an emphasis on the hydrodynamic processes of nutrient supply from the Kuroshio Current and the Taiwan Warm Current.

**Theme 4:** Nutrient supply processes in the coastal spawning ground in the East China Sea, including those due to land sources and to upwelling.

**Theme 5:** Mechanisms of the formation and harmfulness of coastal hypoxia off the Changjiang estuary, including the development of hypoxia off the Changjiang estuary, with an emphasis on the role of nutrient over-enrichment on the formation of hypoxia and its negative effect on the structure and function of the coastal ecosystem.

**Theme 6:** Biogeochemical cycles and ecological carrying capacity in typical mariculture areas, including shellfish/algae polyculture and sea-pen fish culture areas. This survey will be carried out in Sanggouwan Bay in the north and Xiangshangang Bay in the south.

During 2006, a total of 140 days of sea-going observations were carried out onboard the R/V Bei Dou. They included two cruises for theme 2.1 and two cruises for theme 2.2 in the Yellow Sea, one cruise for theme 3 in the East China Sea shelf, and three cruises for theme 5 in the Changjiang estuary and adjacent waters. In addition, three cruises totalling 66 days of observation were carried out in the typical shellfish/algae polyculture area in the Sanggou Bay in the Yellow Sea for theme 6.

All of the fieldwork for theme 5 was completed during 2006. Hypoxia and its relationship with food-web dynamics becomes an important topic as nutrient over-enrichment from land-based pollution of coastal/marine waters is resulting in “dead zones” within large marine ecosystems, which is one of the priority global concerns now. Among the Chinese IMBER/GLOBEC surveys, three cruises took place to examine the development of coastal hypoxia off the Changjiang estuary in June, August and October 2006, each with ship-time of 15 days. The aim of this work was to contribute towards the understanding of one of the scientific issues raised by the programme: “biogeochemistry in food-web dynamics”.

In June 2006, low dissolved oxygen (DO) waters were found in the southern part of the Zhoushan Islands with levels of DO of approximately 4 mg/l in near-bottom waters, although the overall coastal area off the Changjiang estuary had no incidences of hypoxia. In August, low DO waters were found in the northern part of the Changjiang estuary with DO in near-bottom waters as low as 1-2 mg/l which was accompanied by stratification in the water column. In October the DO profile showed an increase in concentration from surface to near-bottom waters together with strong vertical mixing.



The coastal waters affected by the Changjiang effluent plumes are eutrophic in character and show reduced concentrations of nutrients, particularly nitrate and silicate with an increase in salinity. However, in near-bottom water, concentrations of phosphate and nitrite show a reverse relationship with DO. Ammonia can also have higher levels in DO depleted waters, suggesting that hypoxia off the Changjiang estuary accelerates the regeneration of nutrients and hence changes the nutrient species ratio within the water column. Hence it can be expected that changes in nutrient regimes related to the development of hypoxia cause a change in the food web through competition for nutrients among phytoplanktonic species.

The distribution of photosynthetic pigments shows eutrophication with values of chlorophyll a up to 5-10 µg/l in surface waters. As

shown by Fuco pigment distribution, diatoms are dominant in phytoplanktonic biomass in most of stations off the Changjiang estuary, while dinoflagellates, shown by Perid, occupy stations further offshore. It was found that in the period of coastal hypoxia off the Changjiang estuary, when the chlorophyll a is higher than 4 µg/l, the near-bottom water DO becomes <3 mg/l, i.e. the higher the pigment concentration in surface waters, the lower the DO in near-bottom waters.

The field-data collection will continue to be the main task of studies in 2007. However, data analysis and synthesis research will be another important task during the second year of China GLOBEC/IMBER I. Several seminars for each of the survey themes will be held to facilitate integrated multidisciplinary studies, and to lay the foundation for future synthesis research.

## Sustainable aquaculture study in Sang Gou Bay, China

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Sang Gou Bay, located at the eastern end of the Shan Dong peninsula, China, is an important aquaculture base along the Yellow Sea coast, with a mean depth of 7-8 m. Supported by the China GLOBEC III programme, sustainable healthy aquaculture is studied to provide more seafood. Two field observations have taken place during April-May 2006 and July 2006, in order to investigate the effects of shellfish and algae aquatics on the hydrology and resuspended sediments/regenerated nutrient materials under different hydrodynamic conditions. There are five stations in this area, as shown in Figure 1, including northern Xun Shan (122°33'E, 37°08'N), southern Chu Dao (122°32'E, 37°03'N), Inner (122°29'E, 37°06'N), Outer (122°33'E, 37°06'N) and Centre (122°31'E, 37°06'N) of the bay.

At stations Xun Shan and Chu Dao, water level data were collected by an Aanderra water level gauge from 17 April - 17 May and 20 June - 20 July. A SonTek 1.5MHz Mini ADCP/Nortek 2MHz ADCP was mounted looking downward to measure velocity profiles at the Xun Shan and Chu Dao sites during each deployment (28 April-7 May and 13-20 July). However, at station Chu Dao in July, an RDI 1200kHz Workhorse Sentinel ADCP was mounted on a platform looking upward from the seabed, and a LISST-100 and an OBS were also mounted on the platform to measure the time series of the size and concentration of suspended particulate matter, turbidity and chlorophyll.

At the Inner and Outer stations, a chain was deployed to measure currents on the surface and bottom layers using two Alec velocimeters. An RBR 420 CTD was used to measure salinity and temperature in the median layer during the spring/neap period (25 hours) of each field observation. Unfortunately, data was not collected during the July observation at the Inner station due to a technical problem.



Figure 1. Aquaculture study sites in Sang Gou Bay, China.

At the Centre station, a platform was located above the seabed to collect near-seabed current and turbidity profiles near the bottom by an RBR Turbidity (XR 620), a LISST-100 and a NorTek 6M ADV for the spring period (25 hours) in May. At the same time, an RDI 1200kHz Workhorse Sentinel ADCP was mounted on the ship (downlooking) to measure the current profiles. Seawater was sampled from three layers (surface, median and bottom). All the data from the study are currently being analysed.

Prof. Jilan Su, from the Chinese Academy of Sciences and Prof. Qisheng Tang (Chinese Academy of Engineering) visited the observation stations personally to supervise the staff during the first cruise.

## Observations of the turbulent dissipation rate in the Yellow Sea

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As the first combined China GLOBEC/IMBER national project, “Key Processes and Mechanisms of Sustainable Food Production of Marine Ecosystem in China” was launched last year, the China-GLOBEC reached its third phase of development. One goal of this project is to understand the physical forcing of biogenic element cycles. Of the different types of physical forcing, turbulent mixing is thought to be of particular significance because of its profound effect in modulating the structure and function of the marine ecosystem (Kjørboe, 1993). Turbulent mixing controls primary production by determining phytoplankton’s access to light and nutrients and influences zooplankton and fish in many direct and indirect ways. As part of the new China-GLOBEC project, profiling measurements of the turbulent dissipation rate ( $\epsilon$ ) were conducted at two mooring stations in the Yellow Sea in order to understand mixing and its effects on the ecosystem.

The Yellow Sea is thought to be one of the principal regions of the global ocean with strong tidal dissipation (e.g. Liu and Wei, 2007). During the stratified season, which is usually from late spring to early autumn, hydrological features of the Yellow Sea are characterised by a strong thermocline, tidal front and the Yellow Sea Cold Water Mass (YSCWM). We made the first profiling measurements of  $\epsilon$  in the Yellow Sea in order to study the characteristics and mechanisms of turbulence and mixing throughout the water column, especially in the pycnocline and the tidal bottom boundary layer (TBBL). The profiling measurements of  $\epsilon$  were conducted using a free-fall microstructure profiler MSS-60, developed by Sea and Sun Technology GmbH (Germany), at two mooring stations S1 (35.01°N, 123.00°E, 73m depth) and S2 (35.00°N, 121.50°E, 38m depth) in late September 2006 (Fig. 1). At each station, 3 casts, separated by 4-5 minutes (S1) or 2-3 minutes (S2), of MSS-60 were taken every hour within two tidal cycles (25 hours). At station S2, an upward-looking 600 kHz RDI ADCP was

also moored on the seabed to take measurements of current velocity throughout the water column.

Large values for  $\epsilon$  were found near the surface, near the bottom, and around the thermocline at the deeper site S1 (Fig. 2). Strong dissipations (and hence production) near the surface are produced by wind forcing, and the near bottom dissipations are a result of bottom shear stress due to bottom friction from tidal currents.

A distinct TBBL with strong dissipation and mixing, which extended to ~13 metres above the bottom, was revealed in the time series of vertical structures of  $\epsilon$  and the vertical eddy diffusivity  $K$ . Both  $\epsilon$  and  $K$  in the TBBL exhibited a strong quarter-diurnal variation (regular semi-diurnal M2 tidal current dominated), with an evident phase lag with the height from the bottom. The strong dissipations around the thermocline were situated below the maximum temperature (density) gradient, where the water was less stratified, with a vertical thickness of ~8 metres. The subsurface chlorophyll maximum was always located within this enhanced dissipation region (not shown). Shear instability and internal wave breaking are speculated to be responsible for the enhanced dissipations around the thermocline.

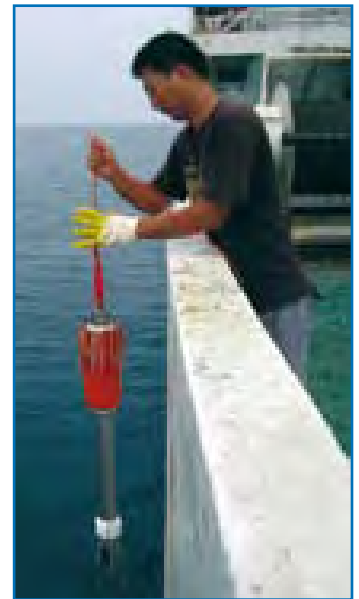


Figure 1. Zhiyu Liu operating the microstructure profiler MSS-60 on board the R/V Beidou in the Yellow Sea.

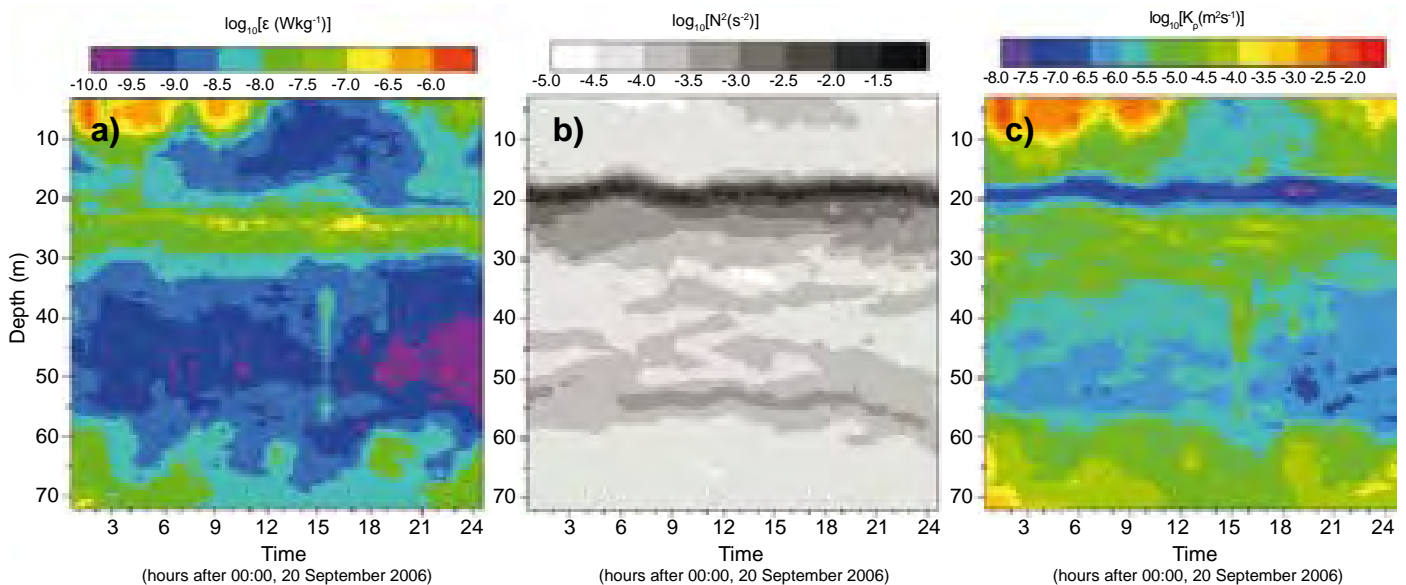


Figure 2. Time series of vertical water column structure between 00:00 20 September and 01:00 21 September 2006 at site S1. (a) Turbulent dissipation rate  $\epsilon$ ; (b) Buoyancy frequency squared  $N^2$ ; (c) Vertical eddy diffusivity  $K$ .

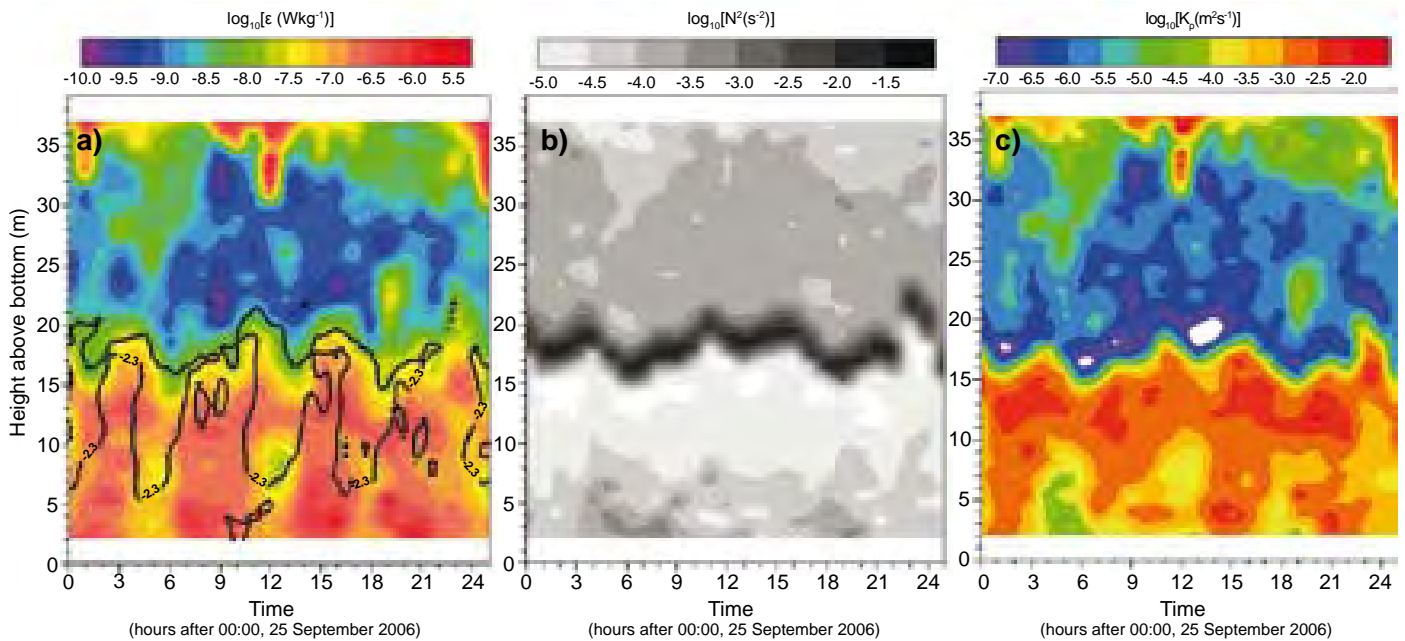


Figure 3 Time series of vertical water column structure between 00:00 25 September and 01:00 26 September 2006 at site S2. (a) Turbulent dissipation rate  $\epsilon$  (coloured) and shear squared (lines); (b) Buoyancy frequency squared  $N^2$ ; (c) Vertical eddy diffusivity  $K$ .

The weakest mixing ( $K \sim 10^{-7} \text{m}^2 \text{s}^{-1}$ ) was within the sharp thermocline due to high stratification ( $N^2 = (1-3) \times 10^{-2} \text{s}^{-2}$ ). Interestingly, both  $\epsilon$  and  $K$  are very weak ( $\epsilon = (0.1-1) \times 10^{-9} \text{Wkg}^{-1}$ ,  $K = (0.3-1) \times 10^{-6} \text{m}^2 \text{s}^{-1}$ ) in the water column between the TBBL and the thermocline base, indicating that the diapycnal transfer of nutrients from the nutrient-rich TBBL to the well-lit upper layer may not be primarily prohibited by the strong thermocline but by the lower less-stratified water above the TBBL. At the shallow site S2 (Fig. 3), the  $\sim 15 \text{ m}$  thick TBBL extended to the base of the thermocline, which meant that water below the thermocline exhibited strong tidally-induced dissipation and mixing.

The lowest values of dissipation and the weakest mixing were found in the water between the near-surface and the thermocline, where the water was weakly-stratified and the shear was very

small. A transition, across the thermocline, from strong (lower water) to weak (upper water) for the dissipation and mixing was very distinct, and the sharp thermocline acted as a barrier prohibiting the diapycnal transfer of nutrients. This was further illustrated by the permanent coincidence of the location of subsurface chlorophyll maximum and the thermocline base, given that the euphotic layer depth was below the thermocline (Wang, personal communication).

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**First call for an International Symposium on Eastern Boundary Upwelling Ecosystems: integrative and comparative approaches**

**Convenors: Pierre Fréon, Manuel Barange and Javier Aristegui**  
**Main sponsors: GLOBEC, EUR-OCEANS, IRD, IMBER and SOLAS**  
**Date: 2-6 June 2008**  
**Location: Las Palmas de Gran Canaria, Canary Islands (Spain)**  
**Website: [www.upwelling-symposium.org](http://www.upwelling-symposium.org)**

The symposium will consider most aspects of the dynamics, structure and functioning of the four major eastern boundary upwelling ecosystems linked to the Benguela, California, Canary (African Canary and Iberian Peninsula) and Humboldt Current systems. These aspects include climate and ocean dynamics, climate change, physics of the ocean and atmosphere, biogeochemistry, ecosystem production, ecology (including behavioural ecology), food-web structure and dynamics, trophic interactions, fisheries assessment and management.

Contributions addressing retrospective analysis and modelling integrative approaches, coupling at least two ecosystem compartments and studies dealing with management issues, particularly ecosystem based management, are encouraged. Experimental studies are also welcome. Papers including socio-economic aspects are favoured although those focusing exclusively on social and/or economic sciences will not be considered. All temporal and spatial scales are to be considered, as well as processes cutting across several scales. Priority will be given to comparative approaches between eastern boundary ecosystems and to integrated end-to-end studies of whole ecosystems. The deadline for abstract submission will be 1 January 2008 and early registration 15 February 2008.

## Regional project on assessment of productivity with regards to the carrying capacity of the Guinea Current Large Marine Ecosystem for living marine resources

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The Guinea Current Large Marine Ecosystem (GCLME) is one of 64 large marine ecosystems (LMEs) of the world, extending from Guinea Bissau in the north to Gabon in the south. The GCLME is considered to be a highly productive ecosystem, primarily due to a seasonal coastal upwelling off Cote d'Ivoire to Benin. An approximate 40% of the regions' 300 million people live in the coastal areas and depend on fishery resources as their major source of animal protein. However, this resource is currently under threat of over-exploitation, and thus, poses great food security within the region. In order to address this issue, countries bordering the GCLME have embarked upon a region-wide project aimed at "combating living resource depletion and coastal area degradation in the GCLME through ecosystem-based actions". The project is financed partly by the Global Environment Facility and participating countries over the period 2004 to 2009 (<http://www.gclme.org/>).

In accordance with the LME modular concept (Sherman, 1993), productivity is being assessed by one of three regional projects. The current project is an expanded activity of an earlier pilot project which involved Cote d'Ivoire, Ghana, Togo, Benin, Nigeria and Cameroon. During the pilot-phase, Continuous Plankton Recorders (CPRs) were, for the first time, towed within the upwelling region (i.e. Gulf of Guinea). Monthly plankton samples, over the period 1995 to 1999, were collected by ships of opportunity from Cape Palmas in Cote d'Ivoire to Doula in Cameroon (Fig. 1). These tows were coordinated by the Sir Alister Hardy Foundation for Ocean Science in Plymouth, United Kingdom. The results from the surveys represent the first ever consistent monitoring programme on a regional scale for plankton and, therefore, serve as the baseline for similar activities in the future.

The oceanographic regime of the Gulf of Guinea is characterised by a minor and major upwelling, alternating with hydrographic stratification, typically between Côte d'Ivoire and Ghana (Longhurst, 1962; Bakun, 1978). The oceanographic seasons play a key role in the plankton community structure (Houghton and

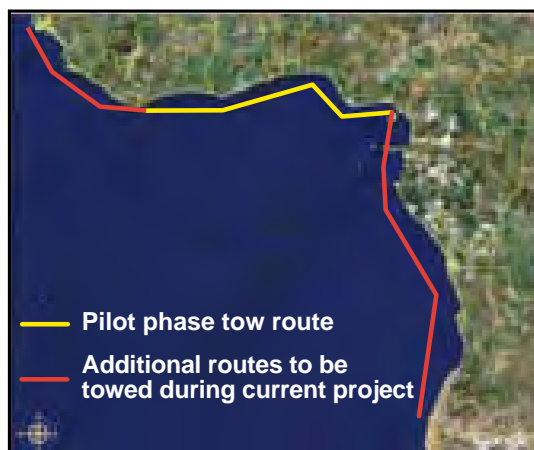


Figure 1. Continuous Plankton Recorder (CPR) routes towed during the pilot phase project (yellow lines). Additional tow routes (red lines) have been included to cover the entire GCLME, including the coastal areas of Angola.

Mensah, 1978), and in the case of zooplankton, the distribution during the major upwelling is driven mostly by changes in water temperature. It has been found, for example, that *Calanoides carinatus*, the dominant copepod only appears in the coastal waters during the major upwelling when temperature falls below 25°C (Bainbridge, 1972). Results from the CPR survey during the pilot phase indicated a different zooplankton community structure for the upwelling region (i.e. Ghana and Cote d'Ivoire; Fig. 2).

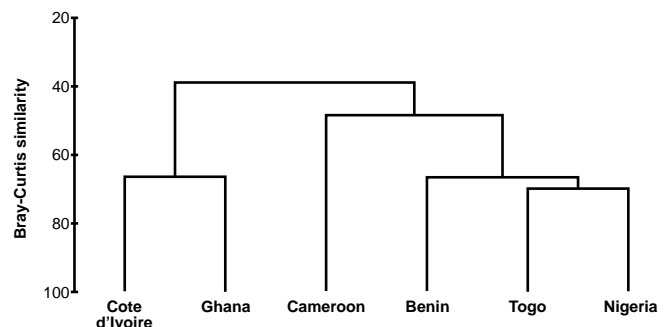


Figure 2. Hierarchical cluster analysis of spatial distribution zooplankton in the Gulf of Guinea using Bray-Curtis similarity on samples collected with Continuous Plankton Recorders in 1997.

The GCLME Project has set up a regional centre of excellence for productivity and biodiversity studies in the Department of Oceanography and Fisheries at the University of Ghana. The centre is expected to co-ordinate the implementation of all productivity surveys on a regional scale, and to develop standardised methodologies for field and laboratory activities. A regional Working Group on Productivity and Biodiversity has been set up with representatives from each of the 16 participating countries.

To complement the CPR tows within the region, annual plankton surveys are being undertaken with the Norwegian vessel RV Fridtjof Nansen, as well as analysis of satellite imagery to investigate primary productivity patterns. Efforts are underway to establish a harmful algal bloom regional reporting network for early warning, detection and prediction of blooms, particularly when the presence of potentially harmful algal species was identified in the CPR samples (Wiafe, 2002).

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## An end to end approach in modelling Mediterranean pelagic ecosystems: can the Naples approach be a proof of feasibility?

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The Mediterranean and Black Seas embrace a diversity of habitats which resemble a wide spectrum of the world's ocean habitats. Their prevailing oligotrophy (which may become extreme in the Levantine basin) is contrasted by the mesotrophic areas of convective deep mixing in the Gulf of Lion or the estuarine-like Northern Adriatic Sea, reaching the other extreme of anoxic conditions in the Black Sea.

*A priori*, this diversity does not seem to be the best arena in which to reach a consensus among experimentalists and modellers, but that is exactly what was achieved at the EUR-OCEANS M2EM (Mediterranean Marine Ecosystem Modelling) workshop (Fig. 1). More than thirty modellers and experimentalists with experience in the Mediterranean and the Black Sea met in the Zoological Station of Naples for three days. The latter gave their

views on processes and interactions that they felt were crucial in ecosystem functioning whereas the former provided their vision on what is feasible, to date, to achieve from the modelling side. No tight schedule was programmed and elements were discussed in a very flexible environment, with time apportioned according to the debate established for each topic.

From the start of the workshop, it was evident that it would be impossible to create a single, generic model capable of answering all the questions from end to end of the ecosystem and at all temporal and spatial scales. Instead, the group worked on the idea of embedding future advances into a flexible structure which resolved acceptably on specific processes and scales. One point was that the high diversity of the Mediterranean Sea makes the use of key species as 'bricks' for lower trophic levels inoperative. Therefore, the functional type approach, which is basically an ensemble average of schematic trophic behaviours, was taken as a good approximation of the response of the biota to habitat diversity up to the level of mesozooplankton.

The current representation of mesozooplankton in biogeochemical models was considered to be over simplistic and not precise enough to simulate the transfer towards higher trophic levels. In the interplay between eating and being eaten, mesozooplankton relocate photosynthesized carbon into exploitable fish biomass. The size of food is a basic constraint for any predator and a key variable to resolve in this interplay. Increasing mesozooplankton

resolution, even before resolving individual response, can be based on the constraints imposed by the size spectrum of the mesozooplankton and their prey. In addition, biological traits and tightly linked food preferences need to be taken into account. This led to five mesozooplankton functional groups being proposed as a balance between the simplification and complexity of the Mediterranean food webs.



Figure 1. Naples workshop participants.

Copepods were considered as omnivorous filter feeders, similar to Euphausiids but with significant vertical migration, while Appendicularians were classified as filter feeders of small particles, and gelatinous carnivorous zooplankton (chaetognaths and macro-gelatinous plankton such as medusae or ctenophores) predated on fish larvae and zooplankton. Gelatinous filter feeders (salps and doliolids) filtering particles

between 1  $\mu\text{m}$  and 1 mm were also considered. Similar groups were considered for the Black Sea except that salps and doliolids can be ignored. Even though both experimentalists and modellers felt at ease with the choice, they were also aware of the difficulties in constructing equations for the groups defined. In particular, parameterising the size of the gelatinous carnivorous zooplankton is not straightforward because of the inherent presence of tentacles. Also, the gelatinous filter feeders have very patchy and sporadic dynamics. This may reflect strong nonlinearities which are difficult to simulate, but models can help to clarify their role in the ecosystem (e.g. Andersen and Nival, 1988).

Although the development of mathematical homomorphisms for each functional type involves manifest difficulties, the use of new technological tools can make this task easier. Zooscan<sup>®</sup>, SIPPER<sup>®</sup> and other computer vision techniques applied to plankton are now complementing the picture of a devoted scientist attached to a binocular device. Their automatism is able to simultaneously provide size and some taxonomic sorting at processing speeds not envisaged in the past. Together with the exponential growth of computing power and automatism the information output from these new technologies will continue to increase in the future. Therefore, size resolved spatial and temporal patterns of mesozooplankton groups will become more readily available, thus enabling the validation of models which constrain them.

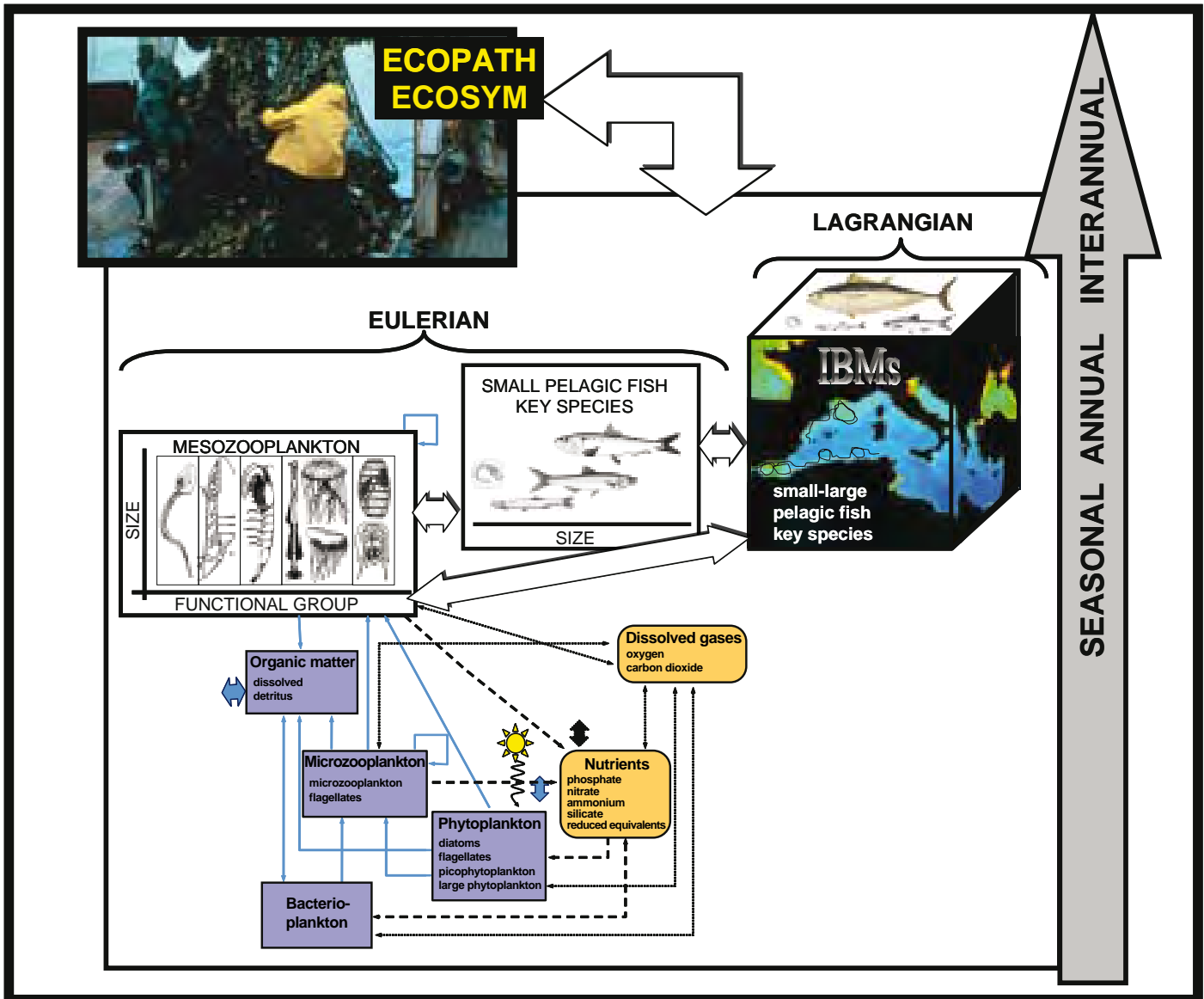


Figure 2. Schematic of the end to end met-modelling approach.

Fish mobility, behaviour and life cycles can impose temporal and spatial scales overriding those of advection and diffusion. In these cases, the Eulerian frame necessary to embed functional groups needs to be reconsidered for a model to be able to encompass the governing scales. To simulate ecosystem dynamics realistically at this level of complexity the life trajectory of individuals needs to be taken into account. This can be achieved using Lagrangian models based on these trajectories, the Individual Base Models (IBMs). In the workshop, small pelagic fish were considered as the border between Eulerian and Lagrangian approaches. An additional box can be included for them in an Eulerian frame or be modelled with IBMs. Rather than functional groups, key species were envisaged as the adequate focus at this level. Although IBMs can introduce biological elements not feasible in Eulerian schemes, they must be linked to the lower trophic dynamics simulated by Eulerian frames. The food allowing recruitment of exploitable species has its ultimate origin at these levels. This link must also be implemented to other frames like ECOPATH/ECOSIM in order to model top predators based on long term balances and network theory.

The conclusions from the Naples workshop provide a roadmap for future work and act as a guide for Mediterranean and Black Sea modellers to locate their inputs. The overall configuration is outlined in Figure 2 which depicts a meta-model already being adopted by new initiatives such as SESAME (Southern European Seas: Assessing and Modelling Ecosystem changes), a European Integrated Project of the Sixth Framework Programme. SESAME will develop equations for mesozooplankton and IBMs for targeted species as well as the connections between the different frames. SESAME aims to analyse past and future changes in the Mediterranean and Black Seas using models and will become an ideal testbed to check the implementation of this flexible frame in the heterogeneous oceanographic conditions present in the southern European Seas.

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## Ecosystem indicators and an Integrated Conceptual Model in the south-east Pacific

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The Chile-Peru eastern boundary ecosystem is one of the most productive systems on the planet. This richness is mainly due to coastal upwelling induced by winds blowing predominantly towards the equator and by the advection of nutrient rich water towards the south pole. In this ecosystem *El Niño* events correspond to those of most importance in the interannual variability. Nevertheless, after the 1972-73 *El Niño* a regime shift was observed which was associated with a clear decrease in the anchovy fishery after the mid-1980s. However, from the mid-1970s a remarkable increase of sardine landings and a smaller increase in jack mackerel and horse mackerel landings was observed. A second regime shift was observed after 1985 which was associated mainly with anchovy recovery and sardine decrease.

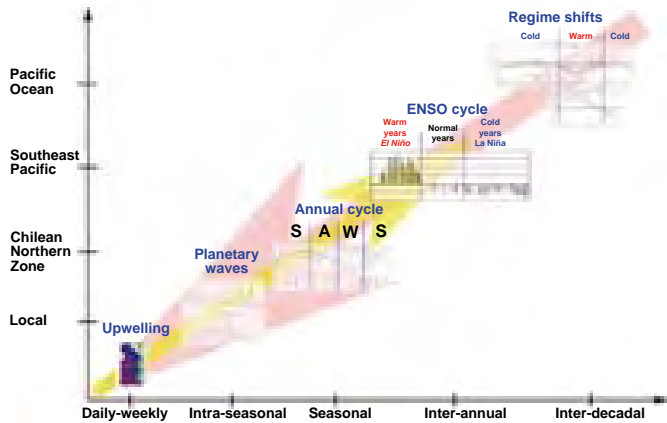


Figure 1. Conceptual model of local and large-scale phenomena affecting northern Chile and its main fishing resources. The arrows show the direction and magnitude of the phenomena influence.

We have developed an integrated conceptual model of local and large scale phenomena which affect the marine environment and the distribution and abundance of the main pelagic resources of northern Chile (Fig. 1). The model shows the effects of interdecadal (linked to the regime shifts) and interannual (linked to *El Niño* events) fluctuations. These fluctuations are developed in the equatorial Pacific Ocean, the southeastern Pacific Ocean and the northern area of Chile, affecting equatorial wave dynamics (Hormazábal *et al.*, 2002; Montecinos and Pizarro, 2005), annual cycles, coastal upwelling and pelagic fisheries (Yáñez *et al.*, 2001; 2005).

The model describes the three different periods (cold-warm-cold) observed in the interdecadal fluctuation associated with two regime shifts (Fig. 2). The first regime shift (mid-1970s) may have started after the 1972-1973 *El Niño* event; the second one occurred close to the 1990s but may have begun in the mid-1980s. The available data on environmental, biological and fishery fluctuations of this interdecadal period are used to characterise the three aforementioned periods. In a biological context, the interdecadal fluctuations play an important role in the sequence of alternating anchovy-sardine-anchovy regimes.

	a) 1950-1975	b) 1975-1989	c) 1990-2002
<b>Southern Oscillation Index</b>	↑	↓	↗
<b>Air temperature</b>	↓	↑	→
<b>Sea surface temperature</b>	↓	↑	↘
<b>Mean sea level</b>	↘	↑	↘
<b>Turbulence index</b>	→	↑	↘
<b>Ekman transport</b>	→	↑	↘
<b>Thermocline depth</b>	↑	↓	↗
<b>Anchovy biomass</b>		↓	↑
<b>Sardine biomass</b>		↑	↓
<b>Anchovy recruitment</b>		↓	↑
<b>Sardine recruitment</b>		↑	↓
<b>Anchovy landings</b>	↑	↓	↑
<b>Sardine landings</b>	↓	↑	↓
<b>Anchovy fishing effort</b>	↑	↓	↑
<b>Sardine fishing effort</b>	↑	↑	↓
<b>Sardine catch per unit effort</b>		↑	↓

Figure 2. Environmental, biological and fishery characteristics of three periods inferred from the temporal interdecadal analysis. The direction of the arrows denotes whether the variables are high (↑), low (↓), increasing (↗), decreasing (↘) or equal (→).

The period 1950-1975 is shown as favourable for anchovy fisheries due to high fishing efforts and landings between the 1960s and 1970s. The period was characterised by positive values of the Southern Oscillation Index and a comparatively cold environment (observed in air and sea surface temperatures) as well as a decrease in mean sea level, moderate winds (observed in Ekman Transport and the Turbulence Index) and a shallow thermocline depth (Fig. 2a). A second period (1976-1989) was favourable for the sardine fishery due to high fishing efforts and landings of sardine. However, anchovy landings were also important during 1986. During this period, the Southern Oscillation Index trends to decrease, and the air and sea surface temperatures were comparatively warmer, the mean sea level higher and the thermocline deeper. Moreover, local winds increased and consequently Ekman Transport and the Turbulence Index did as well (Fig. 2b). A third period (1990-2002) was once again favourable for anchovy fisheries due to high biomass levels, recruitment, fishing efforts and landings although the sardine fisheries did not see the same trends (Fig. 2c). Although air temperature remained constant the Southern Oscillation Index tended to recover positive values, mainly at the end of the period (except 1988-1989). The general characteristics of the period correspond to a cold environment, showing local variables (sea surface temperature, mean sea level, Ekman Transport and Turbulence Index) that clearly tend to decrease.

	<i>El Niño</i> phase	Normal/ cold phase
<b>Southern Oscillation Index</b>	↓	↑
<b>Niño 1-2</b>	↑	↓
<b>Niño 3-4</b>	↑	↓
<b>Air temperature</b>	↑	↓
<b>Sea surface temperature</b>	↑	↓
<b>Mean sea level</b>	↑	↓
<b>Thermocline depth</b>	↓	↑
<b>Acoustic abundance</b>	↓	↑
<b>Number of eggs</b>	↓	↑
<b>Distance from coast</b>	↓	↑
<b>Anchovy landings</b>	↓	↑
<b>Anchovy fishing effort</b>	↓	↑

Figure 3. Environmental, biological and fishery characteristics during *El Niño* events and normal-cold periods.

The interannual fluctuations were due to *El Niño* events, which usually cause “warming-up” in a relatively cold environment (Fig. 3). During *El Niño* events the Southern Oscillation Index tends to decrease and the temperature at the equator (*Niño* 1-2 and *Niño* 3-4) and the study area is high. There is also an increase in mean sea level and the thermocline is deeper (Fig. 3a). In these circumstances, anchovy abundance calculated using acoustics shows a decrease (at least during 1997). This also applies to egg availability and coastal distance and thus an increase in the dispersion and vertical distribution is observed. At the same time, there is a clear decrease in anchovy fishing efforts and landings. During the normal-cold years the observed conditions are completely inverted (Fig. 3b). Thus, the Southern Oscillation Index strengthens but temperatures at the equator (*Niño* 1-2 and *Niño* 3-4) and the study area decrease. A similar trend is observed with mean sea level although the thermocline depth becomes shallower. Under these conditions, particularly during long-term cold periods (before 1976 and after 1990), increases are observed in anchovy biomass, egg availability, coastal distance, fishing effort and landings. However, anchovy vulnerability will also increase due to the thermocline moving towards the surface.

*El Niño* events are amplified once they develop during long-term warm periods (1976-1990) which is reflected in sea surface temperature, mean sea level and air temperature indices observed during the 1982-1983 event. However, the high values showed by these variables during the great 1997-1998 *El Niño* must not be ignored. *El Niño* events may increase anchovy mortality during the first stages due to food quality changes related to less effective coastal upwelling. Furthermore, they may also reduce anchovy vulnerability because of changes in the horizontal and vertical distribution. These effects are reflected in the remarkable catch decreases during these events. In fact, biannual Rossby waves and coastal trapped waves with intraseasonal periods might influence the deepening of isotherms, mean sea level rise and anchovy vulnerability during *El Niño* events. Normally, higher anchovy densities are observed at an average depth of 15 m, with a vertical excursion not exceeding 50 m.

We conclude that fluctuations in different spatial and temporal scales relate local to decadal events, and local events to the Pacific Ocean. This vision stresses the necessity to consider ecosystem management of fisheries and, therefore, a research programme investigating climate mechanisms and anthropogenic environmental impacts. Precise biological and oceanographic information must be incorporated, ensuring long term data collection in three dimensional space, in order to be able to carry out an analysis of the processes involved and the development of monitoring and data management systems.

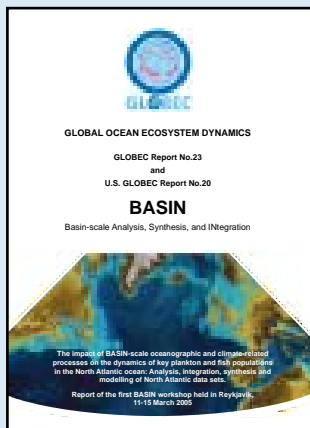
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**Basin-scale Analysis, Synthesis, and INtegration (BASIN) report**

The report of the first BASIN workshop which was held in Reykjavik, 11-15 March 2005 is now available as a part of the GLOBEC Report Series (GLOBEC Report No.23/US GLOBEC Report No.20).

The report considers the impact of BASIN-scale oceanographic and climate-related processes on the dynamics of key plankton and fish populations in the North Atlantic Ocean by the analysis, integration, synthesis and modelling of North Atlantic datasets.

The report is available to download from the GLOBEC webpages (<http://www.globec.org/products/reports/report23.pdf>) or please contact the GLOBEC IPO ([globec@pml.ac.uk](mailto:globec@pml.ac.uk)) if you would like to be sent a copy of the report.



## Workshop report: The ecological role of squid in pelagic ecosystems University of Hawaii, Honolulu, 16-17 November 2006

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CLIOTOP Working Group 3 (Trophic Pathways in Open Ocean Ecosystems) organised a workshop to examine the ecological role of squid in pelagic ecosystems. The workshop was designed to bring current and past workers in the field together to discuss the state of knowledge and to prioritise research objectives, particularly those relevant to understanding the effects of climate change on the distribution and ecology of squid populations. The workshop was held at the University of Hawaii on 16 and 17 November 2006, and was sponsored by GLOBEC and the Pelagic Fisheries Research Program (University of Hawaii).

### Background

The central aim of CLIOTOP is to identify, characterise, and model the key processes involved in the dynamics of oceanic pelagic ecosystems leading to top predators such as the tunas and billfishes. To do this we need to develop an understanding of the components of the pelagic ecosystem that lead to these top predators, and how changes in the pelagic environment will affect what we consider to be the status quo. The traditional pelagic food web model on which much of our understanding of ecosystem interactions is based is a conceptual pyramid with large pelagic fishes at the top preying on increasingly complex groups of organisms and supported by primary production at the base. In the middle of this web lies the squid community, itself composed of a vast array of species that inhabit all water masses from the surface to the deep water.

Several factors, including the ability of squid to avoid capture, their complex taxonomy and the lack of fisheries for them, have limited our understanding of their role in the pelagic ecosystem. We do know, however, that they are a central component of many pelagic ecosystems and can act as both prey and predator. Their short life spans (usually no more than a year), voracious appetites and rapid growth rates and their ability to withstand a range of environmental conditions suggest that they could play a role as indicators of ecosystem change in the world's oceans. For example, the recent rapid expansion of the Humboldt squid, *Dosidicus gigas*, off South and Central America may be an indicator of changed conditions in the eastern Pacific Ocean. Whether the expansion of this species is the result of climate forcing remains to be identified. However, understanding the ecology of this and other important squid species will be invaluable in understanding wider changes in the pelagic environment.

The increased awareness of the role of squid in pelagic ecosystems has facilitated a number of studies in the world's oceans that specifically address the ecological role of squid in pelagic systems. These studies have been greatly facilitated by new technologies such as archival tagging, analytical methods such as stable-isotope and fatty-acid analyses and developments in ecosystem modelling techniques. It seemed timely therefore to stock take on what is known and where the future directions in research lie for this diverse group.

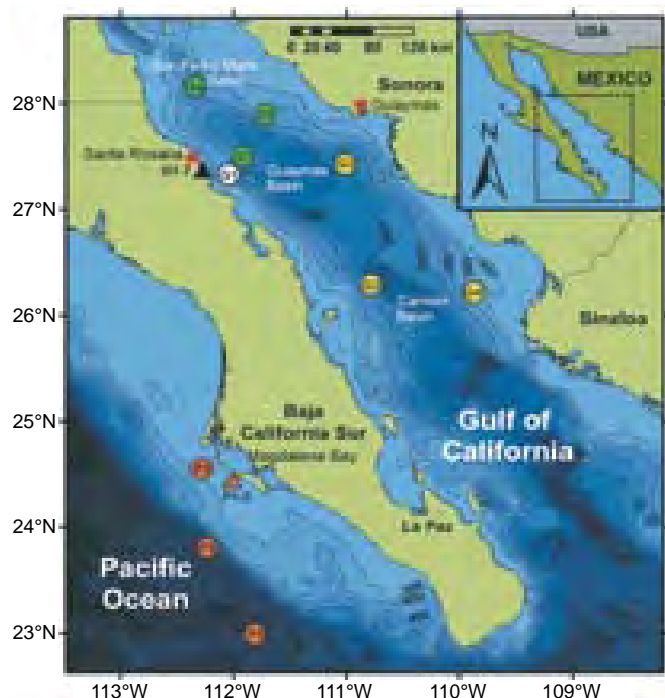


Figure 1. Satellite archival track of *Dosidicus gigas*. (Black triangle off Santa Rosalia marks deployment site for PSAT's G1-G7 (Wildlife Computer PAT 3.0); pop-up locations are given by yellow (October 2004) and green (November 2005) circles. Other tags deployed off Magdalena Bay in June 2005 (P1-P3) are denoted by a red triangle and individual red circles). Figure courtesy of William Gilly and drafted by Ashley Booth.

### The workshop

Oral presentations (and five posters) were given by twenty one squid researchers from ten countries, who attended with financial and logistical support from GLOBEC-CLIOTOP and the Pelagic Fisheries Research Program (University of Hawaii).

The focus of the workshop was:

- to consider the role of squid in pelagic ecosystems that support tunas and other upper-level predators;
- to consider how climate change might impact squid populations and the ecosystem;
- to consider the recent range expansions of *Dosidicus gigas* in the Pacific Ocean, especially in terms of its effects on the ecosystems; and
- to identify research needs for large pelagic squid to meet the goals of GLOBEC CLIOTOP and to identify potential research proposals.

The workshop was divided into four themes - biology and ecology, trophic links, climate impacts, and modelling. A final session led by the moderators from each theme reviewed the outcomes from each theme and highlighted potential future research objectives. A summary of these themes will be published electronically in the March 2007 PFRP newsletter and a brief account is given below.

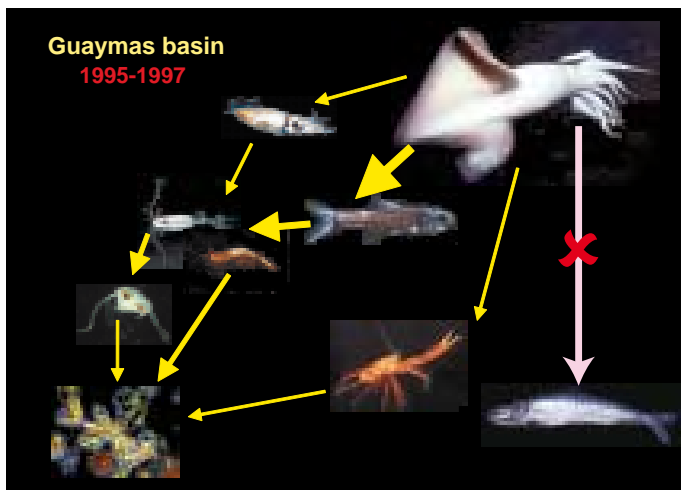


Figure 2. Prey of *Dosidicus gigas* in the Gulf of California. Figure courtesy of Unai Markaida.

The first theme concentrated on the biology and ecology of the Humboldt squid, which as previously mentioned, has become a dominant component of the eastern Pacific pelagic food web. The species is now the target of the world's largest cephalopod fishery. Discussion centred on the potential reasons for the apparent range expansion, including its tolerance to low oxygen environments, and its tolerance to wide temperature and salinity ranges. To understand the reasons for this seemingly rapid change several studies employing state of the art technologies have begun. For example, satellite archival tagging has shown that this squid migrates over a wide geographic range (Fig. 1). The vertical distribution data collected as part of these studies showed that this species migrates to depths below 400 m, well below the oxygen minimum, possibly out of the range of a number of its predators. The second session, climate impacts, presented fishery and limited fishery-independent surveys, which showed links between the distribution and abundance of *Dosidicus gigas* and other ommastrephid species and *El Niño/La Niña* oscillations. One longer-term study in the northern Pacific Ocean showed a link between the northward extension of less productive tropical water and weaker cohorts of *Ommastrephes bartramii*, a common oceanic species.

**The meeting brought a body of international squid biologists together with vertebrate-focused biologists, fisheries scientists and conservationists. A large part of the discussion focused on one species of squid in particular, *Dosidicus gigas*, the Humboldt or jumbo squid. Furthering our understanding of this species and its interaction with the pelagic and mesopelagic ecosystems in the eastern Pacific Ocean was deemed to be of critical importance. An informal consensus was reached that an international research effort was immediately needed to advance our knowledge of this species and its impacts on the highly productive ecosystems within its range, including the California and Peru Currents and the Costa Rica Dome.**

**In conjunction with discussions with several participants after the meeting, I agreed to investigate mechanisms of support and to begin organising an international group of potential participants. I propose to approach the problem by dividing the range of *Dosidicus gigas* into six biogeographic regions, each with a responsible co-ordinating investigator and other participants.**

**William Gilly (GLOBEC-funded participant)**

*I am thankful to GLOBEC for providing me with the opportunity to attend the workshop on the role of squid in pelagic marine ecosystems at Hawaii in November 2006. I had a great time participating in the joint workshop in which scientists from both squid and non-squid disciplines took part. I found the discussion on various topics related to the role of squid in pelagic marine ecosystem very interesting. I also learnt about the gap between the contributions presently being made by the squid scientists to GLOBEC-CLITOP objectives and the expectations of the non-squid scientists working towards the same objectives. I believe the joint workshop helped the scientists from both groups to understand the each others perspectives and will help to identify research subjects to narrow this gap in near future.*

*I also realised the importance of international collaborations for the holistic understanding of the pelagic ecosystem. For example, my institute has been collecting hundreds of stomach content samples annually from southern bluefin tuna, whose main food is pelagic squid, but those precious samples have only been used for preliminary analysis and then been abandoned due to lack of expertise in Japan. We should devise collaboration mechanisms between international groups for effective use of such samples.*

**Taro Ichii (GLOBEC-funded participant)**

The second day began with the trophic links theme, which again emphasised the central position of squid in a number of pelagic food webs in the Pacific and Atlantic Oceans. However, it soon became obvious that relatively few trophic studies were available on squid from the high seas, particularly in the Indian Ocean. Another limitation identified was the lack of time series studies from which evidence of climate change could be deduced. There was a recurring theme on the importance of detailed taxonomy of prey species to understand potentially subtle shifts in understanding these food webs. For example, data were presented for *D. gigas* from the Gulf of California showing the importance of lanternfishes in their diet, and not sardines as previously thought (Fig. 2). Fatty acid analyses were presented as a useful tool in efforts to separate potential prey items in the mostly digested remains with which squid trophic ecologists are usually presented. The final session dealt with models examining the role of squid in oceanic and coastal ecosystems. One study estimated that up to 30% of the fishery landings and market values from large marine ecosystems in the world's oceans pass through the cephalopod biomass pool (i.e. species that prey on cephalopods or cephalopods themselves).

The workshop ended with perspectives from contributors on a number of research areas. Linking tagging studies with the Census of Marine Life initiative, development of biochemical techniques to elucidate trophic structure, and laboratory studies to anticipate the effects of potential changes in the physics and chemistry of the world's oceans were some of the topics discussed. Gaps in knowledge included the lack of time series data and the lack of studies generally in the Indian Ocean. A full report of the workshop with extended abstracts will appear in a separate volume of the GLOBEC Report Series.

## Towards a new CLIOTOP project: the Mid-trophic Automatic Acoustic Sampler (MAAS)

Olivier Maury

IRD, Centre de Recherches Halieutiques, Sète, France (maury@ird.fr)

Despite their wide distribution, huge abundance and major influence on top predators, the mid-trophic level organisms (the meso-zooplanktonic and micro-nektonic prey of top predators) are still one of the lesser known components of pelagic ecosystems. To address this, the CLIOTOP Steering Committee decided during its last meeting in April 2006 to promote the development and large scale deployment of automatic acoustic recorders to provide the scientific community with a near real-time global scale monitoring of these organisms.

Following this recommendation, a CLIOTOP workshop "Designing an ocean Mid-trophic Automatic Acoustic Sampler (MAAS)" was organised at the Centre de Recherches Halieutiques in Sète, France, 15-18 January 2007 (the report of the workshop is available at <http://www.globec.org/structure/regional/cliotop/publications.htm>).

The general goal of the meeting was to "set up a new project to develop a novel tool for large scale monitoring of mid-trophic level prey organisms, their horizontal and vertical size-resolved distribution and abundance in the open ocean pelagic environment".

Sixteen scientists from a wide range of backgrounds attended the meeting and contributed, with their enthusiasm and their abilities, to its success. In conclusion to the workshop, the group proposed the official creation of a CLIOTOP-MAAS Working Group in charge of implementing the project.

### The Sète workshop

The MAAS project will be conducted in two phases. The first phase of the project corresponds to the development of a generic MAAS prototype and the second phase will be devoted to its large scale deployment in the three oceans. The Sète workshop aimed at identifying the technical and organisational requirements needed to address phase 1 of the MAAS project.

After the presentation of the objectives of the MAAS project in the CLIOTOP framework and the state-of-the-art of existing acoustic technologies and other related projects, the working group identified the potential technical limitations and discussed the details of the specifications required for the development of the MAAS.

During discussions following the presentations by the participants, the most critical technical aspects of the MAAS development were discussed with acoustic sounder manufacturers. The group decided that, depending upon the platform used for its deployment, the MAAS should enable two levels of technological sophistication: a high level adapted to large platforms such as fixed moorings, vessels or AUV and a low level adapted to autonomous drifters. As a first step, priority was given to the development of a drifter carrying simple multi-frequency acoustic equipment (at least two frequencies should be used to be able to discriminate taxonomic groups in the observations) associated



Figure 1. Some of the CLIOTOP-MAAS meeting participants: standing from left to right Nereus (the fish), Stratis Georgakarakos (IMB, Greece), Olivier Maury (IRD, France), Lars Nonboe Endersen (SIMRAD, Norway), David Demer (NOAA, USA), Rudy Kloser (CSIRO, Australia), Erwan Josse (IRD, France), Laurent Dagorn (IRD, France), Christophe Corbières (Simrad, France) Nils Olav Handegard (IMR, Norway). Squated: Patrick Lehodey (CLS, France), François Gerlotto (IRD, France), Hiroki Yasuma (Hokkaido University, Japan), Meng Zhou (UMB, USA).

with a data pre-processing software and a satellite transmission system. The use of simple and easily deployed drifting floats is indeed the easiest solution for covering large regions such as ocean basins. Furthermore, to be able to release a large number of such drifting floats in the three oceans (the target is at least one to two thousand permanently drifting buoys), each buoy has to be cheap and as simple as possible. This is required in order to achieve good geographic coverage of the observations at a reasonable cost.

The MAAS will be designed to enable detailed acoustic observations (i.e. using several frequencies) to be made up to 100-150 m. However, keeping in mind that most of the oceanic biomass is distributed in the first 1000 m of the oceans, the maximum depth of the MAAS observations should be at least 800 m, but with a lower resolution (using a single frequency). The use of additional sensors such as LOPC (Laser Optical Plankton Counter) has also been discussed and would be possible should there be complementary funds available. It would provide users with important additional data such as the size distribution of zooplankton at the surface.

A general proposal synopsis for a two year project addressing phase 1 was defined during the workshop. It will aim to organise the work around an appropriate selection of partners including private companies (acoustic and buoy manufacturers) and to set up bilateral agreements between the companies and the MAAS consortium. Phase 2 of the project will be planned during phase 1 implementation and launched once phase 1 is successfully completed.



**The MAAS in the CLIOTOP framework**

Acoustic observations are essential for obtaining information about the distribution of mid-trophic level organisms, their dynamics, ecology and behaviour. Those organisms constitute the bulk of the food of top predators and therefore they are essential in understanding their ecology. In CLIOTOP, both WG3 (trophodynamics) and WG4 (synthesis and modelling) explicitly identified hydro-acoustic studies of mid-trophic organisms as a key tool for their investigations.

In the framework of the CLIOTOP Working Group 4, two spatially-explicit basin-scale ecosystem models (APECOSM and SEAPODYM) are developed and run at a global scale. Presently, these models represent several groups of mid-trophic level organisms on the basis of their vertical distribution. Data assimilation techniques are used to estimate the parameters of the models and to improve their parameterisations through quantitative comparisons of outputs to fishery and tagging data. However, very few observations of mid-trophic level organisms currently exist so that the corresponding components of the models cannot be properly formulated, constrained and evaluated. The data produced by the MAAS (horizontal and vertical distribution of the biomass per taxonomic group, size distribution) would therefore be extremely useful in improving and

validating ecosystem models. This would require appropriate observation models specific to the acoustic data collected by the MAAS to be developed and coupled to the existing ecosystem models.

**Conclusions**

The MAAS project is challenging but the rewards could be far reaching. The 3D data that would be produced by a large scale MAAS network would indeed be of considerable interest to the whole marine science community and it can be reasonably expected that they would have the same kind of impact on marine ecology that satellite derived estimates of primary production had on biogeochemistry. The science involved in their analysis would undoubtedly be fascinating and the insights gained would add substantially to our understanding and predictive capabilities of the ecology of oceanic ecosystems.

Given the mid to long term perspective needed to implement the two phases of the MAAS project, the group decided to submit an official request to the CLIOTOP Steering Committee asking for the official creation of a CLIOTOP-MAAS Working Group responsible for the implementation of the project. This request will be discussed during the next meeting of the CLIOTOP SC in May in Shimizu, Japan.

**Joint IMBER/LOICZ Continental Margins Open Science Conference**

Shanghai, 17-21 September 2007

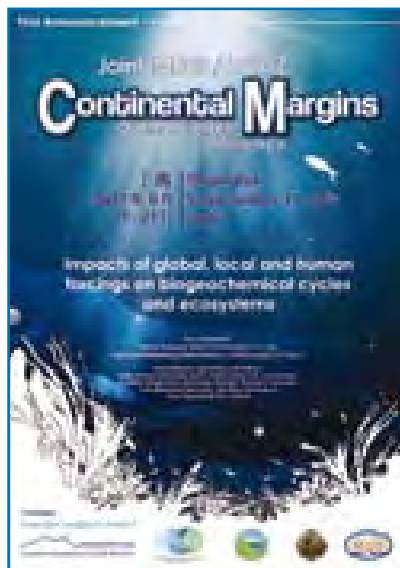
Coastal zones play a key role in earth system functioning, by contributing significantly to the life support systems of most societies. The coastal system is experiencing global and natural pressure, such as atmospheric and open ocean-shelf exchange, which are also modified by local and human forcings.

The larger scale forcings include proximity to large river plumes, physiography of the continental shelf, and human forcings that modify atmospheric deposition across broad shelf areas. These global, local, and human pressures interactively impact on biogeochemical cycles and the marine food webs and have direct consequences for society.

Progress has been made in understanding the changes in earth system processes that affect the coastal zone, and the role of coastal systems in global change. However, research is still required to develop a comprehensive understanding and accurate predictive capacity for coastal systems responses to anthropogenic drivers and environmental pressures. This knowledge will contribute to improve our capacity to predict the effects on earth system and human society, and also our ability to guide management and decision makers.

IMBER (<http://www.imber.info/>) and LOICZ (<http://www.loicz.org/>) are holding a joint conference to develop collaborative research activities on biogeochemical cycles and ecosystems in the continental margins. The geographic focus of the conference is

the mid to outer continental shelves, shelf breaks and upper slopes and exchanges across the coastal ocean and oceanic transition. The conference, while building on biogeochemical advances from international programs such as JGOFS and LOICZ I, aims to take the next steps in:



- linking the biogeochemical cycles of the coastal and open oceans,
- linking organisms, including higher organisms, to biogeochemical processes,
- moving past the present-day status and incorporating response/prediction to the global and local changes,
- exploring the function and possible future changes of the continental shelf pump and the climate related biogeochemistry of continental margins, and
- assessing the variability and sustainability of the continental margin ecosystems.

IMBER and LOICZ are jointly organising this Continental Margins Conference to provide a discussion platform for highlighting the most

recent advances in the field and try to identify emerging directions and future research challenges. The conference is open to all students and scientists involved in biogeochemical cycles and ecosystems in the continental margins.

Further information is available at <https://www.confmanager.com/main.cfm?cid=792>. The abstract submission deadline is 15 May 2007.



## ESSAS to meet in Hakodate, Japan 4-8 June 2007 for workshops and planning of future activities

George Hunt

University of Washington, Seattle, USA (glhunt@uci.edu)

Prof. Yasunori Sakurai of the Faculty of Fisheries, Hokkaido University, a member the GLOBEC SSC, has invited the GLOBEC Regional Program, Ecosystem Studies of Sub-Arctic Seas (ESSAS) to hold its 2007 annual meeting in Hakodate, Japan. In addition to the meeting of the ESSAS Science Steering Committee (SSC) on 8 June, ESSAS will hold a two-day workshop on 4-5 June on "The role of seasonal sea ice cover in marine ecosystems", and a one day workshop on 6 June on "Evaluation of Future ESSAS Climate Scenarios". These workshops will be followed on 7 June by a discussion of approaches to the use of models to compare the effects of climate change on the sub-arctic seas.

The co-convenors for the workshop on the role of sea ice are Professor Egil Sakshaug, Professor Sei-ichi Saitoh and Dr John Bengtson. The workshop on the role of sea ice will focus on what will happen to the amount, timing and fate of primary production as the temporal and spatial extent of ice cover, as well as its thickness, decreases in response to warming. The workshop will examine the mechanisms whereby sea ice influences these and other aspects of the marine environments of the sub-arctic seas. These topics address questions that will be the focus of new regional programmes in both the Atlantic and Pacific regions of interest to ESSAS. Although the focus of this workshop will

be sub-arctic marine ecosystems, there will be presentations on Antarctic systems where there has been extensive work on understanding the determinants of production and its fate in the Southern Ocean marginal ice zones.

Convened by Dr Jim Overland, the objective of the workshop on predicting future climate scenarios for the sub-arctic seas is to develop realistic scenarios of the effects of global warming on the climates of the sub-arctic seas. The eventual goal will be to create down-scaled climate and physical oceanographic scenarios for each of the various sub-arctic regions. These are important steps in providing the ESSAS Working Groups on Modelling Ecosystem Response and Biophysical Coupling with realistic inputs for modelling and for the development of an understanding of future impacts of climate change on the sustainability of fisheries in these regions.

The discussion on modelling approaches will be led by the newly-formed ESSAS Working Group on Modelling Ecosystem Response. This group, led by Bern Megrey, Shin-ichi Ito and Kenny Rose will have close ties with other groups of modellers working in the sub-arctic seas.

Although space is limited, those wishing to participate in these workshops should contact George Hunt (glhunt@uci.edu).



**second international symposium on the**

## Tagging And Tracking Of Marine Fish With Electronic Devices

<http://unh.edu/taggingsymposium/>

**October 8 - 11, 2007, San Sebastian, Spain**





The Second International Symposium on Tagging and Tracking Marine Fish with Electronic Devices, will be held on 8-11 October 2007 at the Palacio de Miramar, in Donostia, San Sebastian, Spain. The meeting will focus on the use of electronic devices to track movements and behaviours of marine fishes - present and future challenges and perspectives.

This symposium will provide an opportunity for scientists working in the marine environment to review the state of the art of electronic tagging and tracking, to examine the type and quality of information currently obtained and to identify future research challenges and tag developments. The symposium will make an important contribution in solving scientific questions motivating CLIOTOP Working Group 2 on Physiology, Behaviour and Distribution.

This symposium will appeal to:

- Biologists currently using or considering the use of electronic tagging and tracking devices.
- Assessment scientists and fishery managers interested in improving stock assessment estimates through the inclusion of behaviour.
- Fishery managers interested in creating more effective regulations.
- Engineers interested in developing and marketing new devices.
- Physical oceanographers interested in the possibility of using large marine animals as autonomous environmental samplers.

**Organising Committee**

- Haritz Arrizabalaga, Spain
- Nuno Fragoso, USA
- Molly Lutcavage, USA
- John Sibert, USA

**Scientific Committee**

- Alistair Hobday, Australia
- Bruce Mate, USA
- Jennifer Nielson, USA
- Ron O'dor, USA



## Background

The relationship between species and their environment is a central focus of ecological research. The concepts of habitat and ecological niche have led to the development of a number of modelling approaches aiming at describing the relationship between species' responses (presence-absence, abundance, richness, biomass,...) to one or more environmental gradients (depth, soil types, temperature, ...).

Predictive geographical modelling can be used for ecological research, to assess the impact of accelerated use of ocean resources and environmental changes, to improve faunistic atlases or to set up conservation priorities. In marine research, the importance of habitat modelling tools is growing in response to an increasing demand in spatial management issues (e.g. Marine Protected Areas, impact of climate change on biogeographical distributions).

The recent rapid increase in modelling concepts, statistical techniques and associated computer tools makes it a difficult task to select and rigorously apply habitat modelling techniques that are best suited to particular ecological or management questions.

The summer school will provide training to students and young researchers in the field of habitat modelling. The course will cover current habitat concepts, habitat models and tools for habitat modelling. It will provide the students the ability to develop and construct habitat models that are best suited to their research needs.

## Programme

The course will cover the following topics:

**Theoretical background of the niche and habitat concepts, continuum concept and neutral theory;**

**Specificities of habitat modelling in marine systems;**

**Numerical methods for modelling habitats (e.g. GLM, GAM, MARS, Boosted Regression, Quantile regressions, Quotient analysis, ...);**

**Practical tools and software for habitat identification, modelling and mapping;**

**The use of Geographical Information Systems for habitat mapping;**

**Quantifying uncertainties in habitat models;**

**Optimisation of MPA design using habitat models.**

The training course will include about 50% of practical work, mainly dedicated to the application of habitat identification and modelling techniques using statistical and GIS software. A number of case studies from a variety of marine systems and ecological questions will serve as a practical support to the lectures.

English will be the working language of the summer school.

A detailed schedule of lectures and practical sessions will soon be provided.

### Habitat Modelling of Marine Populations



**Venue: IPIMAR, Lisbon, Portugal**

**Date: 2-13 July 2007**

**Application deadline: 30 April 2007**

### Organisation

*This is a EUR-OCEANS summer school organised within the WP6 (Ecosystem Approach to Marine Resources) group by Benjamin Planque and Sandrine Vaz.*

### Lecturers

**Grégory Beaugrand** (CNRS, France), **Jan Geert Hiddink** (University of Wales, Bangor, UK), **Philippe Koubbi** (Université du Littoral Côte d'Opale, France), **John Leathwick** (NIWA, New Zealand), **Anthony Lehmann** (Université de Genève, Switzerland), **Olivier Le Pape** (Agrocampus Rennes, France), **Benjamin Planque** (Ifremer, France), **Jonathan Ready** (INCOFISH, Swedish Museum of Natural History, Sweden), **Sandrine Vaz** (Ifremer, France).

### Venue

*The summer school will be hosted by the Instituto de Investigação das Pescas e do Mar (IPIMAR) in Lisbon, Portugal from 2<sup>nd</sup> to 13<sup>th</sup> July 2007.*

### Contact & application

*The application deadline is 30 April 2007. Please refer to the website for application details. Applicants should have sufficient background knowledge in statistics (linear and non-linear regression models) and spatial data analysis. Habitat modelling should be of particular relevance to their research. Limited travel and subsistence funds are available for students. Contact: **Benjamin Planque**. [benjamin.planque@ifremer.fr](mailto:benjamin.planque@ifremer.fr)*