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Contents

Editorial

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Welcome to the October issue of the GLOBEC International Newsletter. This is a very exciting time in the GLOBEC International Project Office as we are planning for a number of large symposia in the coming months (Fig. 1) and following an election at the GLOBEC Scientific Steering Committee (SSC) meeting in Hiroshima, in May this year, it is with great pleasure that we welcome Dr R. Ian Perry (Fig. 2) as the incoming chair of the GLOBEC Steering Committee starting in January 2008. Ian will take over from Dr Cisco Werner, who after two terms as chair gets a well deserved break, although he will remain with GLOBEC as an ex-officio member of the SSC. Many thanks Cisco, and welcome Ian.

Ian was born and raised in Vancouver, Canada, and with living by the sea, he was always interested in marine biology. He obtained his BSc in Zoology and his PhD in Zoology and Oceanography with Dr Timothy Parsons at the University of British Columbia. Upon completion, he was offered a job as a Fisheries Oceanographer with Canada's Department of Fisheries and Oceans at the St. Andrews Biological Station in New Brunswick, Canada. There he worked in the Marine Fish Division, with half of the Division at St. Andrews and the other half at the Bedford Institute of Oceanography in

Figure 1. Forthcoming GLOBEC symposia a) Coping with global change in marine social-ecological systems, Rome, Italy, 8-11 July 2008 and b) Eastern boundary upwelling ecosystems: integrative and comparative approaches, Las Palmas, Gran Canaria, Spain, 2-6 June 2008. For further details see pages 12 and 51 of this newsletter.
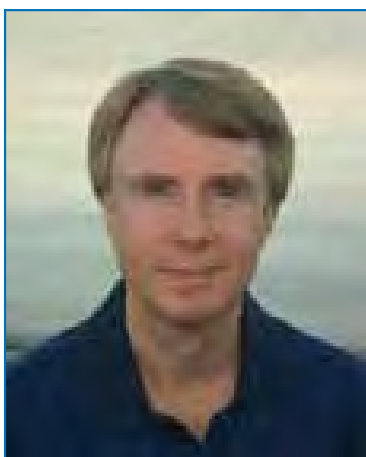
Figure 2. Dr R. Ian Perry the chair of the GLOBEC Scientific Steering Committee from January 2008.

Dartmouth, Nova Scotia. His responsibilities were to bridge the research gap between fisheries and oceanography in Atlantic Canada. He spent seven years in St. Andrews, working and building collaborative programmes between fisheries scientists and oceanographers, focusing on the Scotian Shelf, the Gulf of Maine, and Georges Bank. Work in these regions brought Ian into collaborative programmes with the US National Marine Fisheries Service and other scientists at Woods Hole, MA, which led to his involvement in the circulation and biological modelling studies funded in the first US GLOBEC programme, on Georges Bank.

Ian moved to the Pacific Biological Station (PBS), Nanaimo, BC, Canada, in 1991 to work in the newly formed Ocean Environment and Fisheries Section. This involved developing research programmes concerning environmental influences on fish distributions and recruitment in the Pacific region. At PBS, he conducts research on the environmental effects and food web interactions of larval, juvenile and adult stages of finfish and invertebrates, and research on the structure, function, and processes of fish production in marine ecosystems. He developed a framework to provide stock assessment advice for species about which little is known, and presently conducts the stock assessments for green sea urchins along the BC coast. Most recently, he has begun exploring ecosystem-based approaches to the study and management of marine systems in BC.

Ian's collaborative projects among fisheries scientists and oceanographers brought increasing involvement with international programs such as GLOBEC (Global Ocean Ecosystems Dynamics), both in the US and in Canada. He served on the Scientific Steering Committee for the Canada GLOBEC programme, and was a member of the Executive Committee of the PICES Climate Change and Carrying Capacity (CCCC) programme, being part of the team that drafted the CCCC Implementation Plan. Ian served as the first co-chair of the PICES MODEL Task Team. He was also the Vice-Chair of the IGBP/SCOR/IOC GLOBEC programme during its first six years, served as the first chair of its Focus 1 Working Group on retrospective analyses and time series studies, and presently serves as a co-chair of GLOBEC's Focus 4 on the human dimensions of marine ecosystem changes. He has been an official or ex-officio member of the GLOBEC SSC since its inception in 1996. In his spare time, Ian is a Regional Editor for Fisheries Oceanography, and has taught courses on fisheries oceanography at universities in Canada, Chile, and Portugal. He is looking forward to the opportunities and challenges of leading the IGBP/SCOR/IOC GLOBEC programme through its final years and into the transition with IMBER.
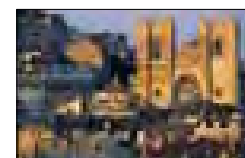
The 8th Larval Biology Symposium

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The next Larval Biology Symposium to be organised by IPIMAR, will take place 6-11 July 2008 in Lisbon, Portugal. This will be a great opportunity for the GLOBEC community to meet once more, since zooplankton research is a central focus of GLOBEC and this meeting.

The symposium programme aims to cover a wide range of research areas on zooplankton biology (Fig. 1). There will be five topic sessions (symposia) which were chosen to give a more comprehensive rather than a specialised approach. To whet your appetite the subjects of these five thematic symposia are:

Figure 1. Many aspects of zooplankton biology will be covered by the symposium.

- Larval behaviour, dispersal and mortality,
- Molecular and geochemical markers for assessing larval dispersal,
- Larval feeding strategies,
- Eggs, embryogenesis and early larval life, and
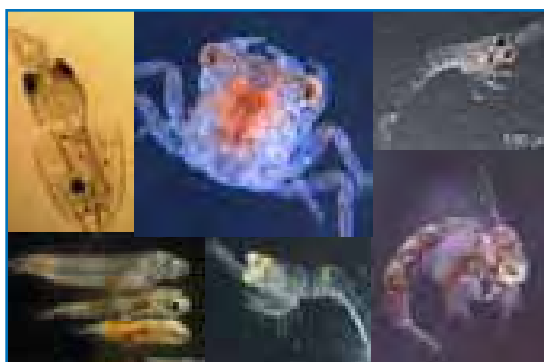- Ontogenetic strategies in extreme aquatic environments.

More information about the symposia and the meeting in general are available from the symposium website at http://ipimar-iniap.ipimar.pt/larval/index.html. The Symposium is endorsed by the Portuguese IGBP Committee under GLOBEC-Portugal.

Lisbon has a long history where the diversity of several cultures (Phoenician, romans, moorish, christian, etc.) mixed together to enrich the city, which was to become the capital of Portugal in the 13th century. Also, a reminder that good food is always a must in Portugal! We are also planning to have some fun (Fado - Portuguese folk music, excursions, beer,...). Life is short!!!

In particular, we would like to encourage the participation of students, as well as researchers from Europe and all over the world. So, come and enjoy! Recruitment will start soon!

The PICES/GLOBEC/ICES 4th International Zooplankton Production Symposium

Michael Dagg[1], Roger Harris[2], Shin-ichi Uye[3] and Luis Valdés[4]

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[3]Hiroshima University, Hiroshima, Japan
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Zooplankton play a key role in the pelagic food web by controlling phytoplankton production and shaping pelagic ecosystems. In addition, because of their critical role as a food source for larval and juvenile fish, the dynamics of zooplankton populations have a significant influence on recruitment to fish stocks.

In 1961, ICES convened the 1st Zooplankton Production Symposium in Charlottenlund, Denmark. ICES also played a lead role in the 2nd Zooplankton Production Symposium on "Zooplankton Production: Measurement and role in global ecosystem dynamics and biogeochemical cycles", held in Plymouth, UK, in 1994. The increasing importance of international programmes such as GLOBEC and the general concerns about global change and the changing role of zooplankton in ocean ecosystems were reflected in the development of this symposium.

This trend was further enhanced in the 3rd Zooplankton Production Symposium on "The role of zooplankton in global ecosystem dynamics: comparative studies from the world oceans", which was held in Gijón, Spain, in 2003. It was here that the symposium was co-sponsored by ICES, PICES and GLOBEC for the first time. The Gijón symposium attracted 333 participants from 38 countries from around the world.

The 4th International Zooplankton Production Symposium was held in Hiroshima, Japan, from 28 May to 1 June 2007. This symposium was the first of the series to be held outside Europe, and its focus was on "Human and climate forcing of zooplankton populations".

At the 1st zooplankton symposium only four themes were represented: "Methods at sea, Methods in the laboratory, Food and trophic relations, and Distribution". By the Plymouth meeting the number and variety of topics had increased to "Biomass and production measurements (New sampling and analysis techniques, Production and grazing methodology), Regional interactions of physics and population dynamics (Quantitative aspects of life history patterns, Population dynamics models and production), Food chain control (Grazing, flux and microzooplankton, Predation and gelatinous zooplankton), Spatial/temporal variability and prediction (Time-series and their significance, Large-scale physical/biological coupled models), and GLOBEC

Convenors of the 4th International Zooplankton Symposium. Left to right: Roger Harris, Mike Dagg, Shin-Ichi Uye and Luis Valdés.

International". This trend was further developed in Gijón with sessions on "Physical variability and zooplankton population dynamics, Role of zooplankton in biogeochemical cycles, Climate influences: What are long-term zooplankton datasets telling us? New approaches to zooplankton modelling, Progress in molecular biology, and Application of new technologies".

The 3rd symposium also saw a number of associated workshops on "Comparative life histories and life cycles of zooplankton populations within and between North Pacific and North Atlantic, Microzooplankton in the marine pelagial: recent advances from molecules to ecosystems, Gelatinous zooplankton and fish: predators, prey or nuisance, Meso- and bathy-pelagic zooplankton: current status and future aspects, and Climate variability, zooplankton abundance and distribution: comparative opportunities from the world's oceans".

The trend of the previous three zooplankton symposia was also towards an increasing number of participants and an ever expanding number of countries were represented. The Hiroshima symposium was certainly a notable landmark in this progression. Similarly, as noted above, new scientific themes have developed over the years, indicating the evolution of the field of zooplankton research. It has already been mentioned that the 1961 symposium had only four session themes. In the subsequent symposia, new emphasis on physical–biological interactions, climate change effects, time-series, molecular biology and modelling, as well as greater emphasis on zooplankton groups, such as microzooplankton and gelatinous zooplankton, are obvious evidence that our field continues to develop and innovate.

International co-sponsors of the Hiroshima symposium included: the North Pacific Marine Science Organization (PICES), the International Council for the Exploration of the Sea (ICES) and the Global Ocean Ecosystem Dynamics (GLOBEC) programme. Local sponsors were the Japanese Society of Fisheries Oceanography, the Plankton Society of Japan and Hiroshima University. Dr. Shin-ichi Uye, the Chairman of the Local Organising Committee, was very active in raising financial support for the meeting from many generous Japanese sources. In addition, SCOR (Scientific Committee on Oceanic Research) provided travel support to scientists from countries with "economies in transition".

Many Japanese students helped to prepare registration packs and with the registration desk.

Todd O'Brien and his COPEPOD poster.

PICES member countries recognise the importance of bringing marine scientists together to provide better understanding and predictive capability for the world's oceanic ecosystems. International meetings such as this symposium contribute greatly to these broad goals. This symposium not only provided a better knowledge of zooplankton production processes but also contributed to a deeper understanding of all marine ecosystems. Zooplanktologists from all around the world met to address issues important to marine science and society in this time of rapid and serious climate change. For this week-long symposium, 334 participants from 46 countries contributed 141 oral and 250 poster presentations. These demographics clearly indicate the international nature of zooplankton research.

On Monday 28 May there were three full-day workshops:

W1: Temporal and regional responses of zooplankton to global warming: phenology and poleward displacement. Convenor: Anthony Richardson (Australia) representing Wulf Greve (Germany) who was unable to attend;

W2: Zooplankton research in Asian countries: current status and future prospects. Convenors: Sun Song (PR China), Sanae Chiba (Japan) and Young-Shil Kang (Republic of Korea);

W3: Krill research: current status and its future. Convenors: So Kawaguchi (Australia) and William Peterson (USA).

On Tuesday 29 May, the symposium was officially opened with welcome addresses from the President of Hiroshima University, Dr Toshimasa Asahara, and the Chairman of the Local Organising Committee, Shin-ichi Uye. This was followed by brief presentations from symposium convenors representing ICES (Luis Valdés), PICES (Michael Dagg) and GLOBEC (Roger Harris).

The morning plenary session provided three excellent presentations on different aspects of the symposium theme:

• Impacts of ocean acidification on marine zooplankton: knowns and unknowns by Victoria Fabry;

• In hot water: zooplankton communities now and in the future by Anthony Richardson; and

• The role of microzooplankton in a changing ocean by Albert Calbet.

Parallel oral sessions followed in the afternoon and throughout the duration of the meeting. These were:

S1: Global comparisons of zooplankton time series. Convenors: David Mackas (Canada) and Luis Valdés (Spain).

S2: Importance of zooplankton in biogeochemical cycles. Convenors: Hiroaki Saito (Japan) and Deborah Steinberg (USA).

S3: The role of zooplankton in food webs: changes related to impacts of climate variability and human perturbation. Convenors: Hans Dam (USA) and Mike St. John (Germany).

S4: Mortality impacts on the ontogeny and productivity of zooplankton. Convenors: Mark Ohman (USA), Serge Poulet (France) and Anthony Verschoor (The Netherlands).

S5: Zooplankton functional groups in ecosystems. Convenors: Sanae Chiba (Japan) and Sun Song (PR China).

S6: Microbial loop vs classical short food chains: Implications for appraisal of food web efficiency and productivity. Convenor: Ulf Bamstedt (Sweden).

Joseph Torres, Bettina Meyer and Eileen Hofmann at the poster session.

The symposium banquet.

Tamara Shiganova and Chris Reid enjoying the local cuisine.

S7: Environmental and other constraints on zooplankton behaviour, life histories and demography. Convenors: Charles Miller (USA) and Atsushi Tsuda (Japan).

S8: Zooplankton biochemistry and physiology: practical and potential biotechnology applications. Convenors: Ann Bucklin (USA), Adrianna Ianora (Italy) and Kurt Tande (Norway).

S9: Advances in image technologies and the application of image analysis to count and identify plankton. Convenors: Cabell Davis (USA) and Xabier Irigoien (Spain).

S10: Analysis and synthesis: modelling zooplankton in aquatic ecosystems. Convenors: Daniel Grunbaum (USA) and Michio Kishi (Japan).

The large number of symposium participants required extensive time for poster viewing, so on both Tuesday and Wednesday there were official poster sessions of two hours each. Refreshments and snacks, combined with the many interesting posters, made these sessions a forum for terrific scientific discussions.

With such a range of topics and such a large number of contributions, it is difficult to single out highlights of the symposium. The standard throughout was very high and the level of interest and participation was great. Perhaps, looking to the future, the focus on topics such as the characterisation of zooplankton with novel approaches like bar-coding and image analysis, the increased emphasis on time-series analysis and large datasets, the range and activity of modelling approaches, emerging functional group concepts and concerted international efforts on particular groups or species (such as krill and *Calanus*), will come to be recognised as particular achievements of the Hiroshima symposium.

One emphasis of the symposium was the encouragement and recognition of young scientists. To highlight the importance of this issue, travel support for more than 40 early career scientists was provided from the symposium budget or directly by PICES and ICES. Many young scientists from Asian countries were also able to participate thanks to the special support arranged by Shin-ichi Uye. Awards for the two best posters by young scientists were presented during the closing ceremony.

The two best posters were:

• Yuichiro Nishibe (Japan) and T. Ikeda. Metabolism and elemental composition of four oncaeid copepods in the western subarctic Pacific.

• Jörn O. Schmidt (Germany), J. Renz and J. Dutz. Vertical distribution and diel vertical migration of the main copepod species in the Bornholm Basin (Baltic Sea).

On the afternoon of Thursday 31 May, everyone took a break from the formal sessions and participated in a symposium excursion to Miyajima Island, the location of the majestic Itsukushima Shrine, first built in 593, then rebuilt in 1168 on the same scale as seen today. The shrine was designated as a UNESCO World Heritage site in 1996. The evening's banquet dinner of fine Japanese foods brought the day to a close.

The closing ceremony was held after the sessions on Friday 1 June. Ceremonies began with a short speech by Teruaki Yoshida, a Japanese student presently pursuing his PhD in Malaysia (see box on page 6). If he is representative of the future, then we will have no worries about zooplankton research in the coming years. Poster awards, described above, were presented by Luis Valdés. Recipients received some nice prizes including encouragement, in the form of a waived registration fee, to attend the meeting on "Effects of climate change on the world's oceans" to be held in Gijón, in May 2008.

Roger Harris, Peter Wiebe and Skip McKinnell at the symposium banquet.

Closing scientific remarks were provided by Roger Harris, who gave a brief summary of the history of zooplankton research as represented by the three previous symposia, and then pointed to the future, reflecting on some of the key themes of the Hiroshima symposium. He concluded by projecting ahead to the next zooplankton symposium and anticipating significant advances in topics, such as automated/semi-automated characterisation of zooplankton spatial and temporal distribution on a global scale, coupling food web models from phytoplankton to fish, coupling between physical and biological models, and assessments and prediction of climate change on marine resources and marine ecosystems. He observed that society was starting to demand a predictive capability regarding marine ecosystems, and that this would be a major challenge for the community. With developing new technologies, carefully posed new questions and hypotheses, and with new people entering the field, future progress will be assured. The quality of presentations and the enthusiastic participation by early career stage scientists had been outstanding and he concluded that their contribution to the Hiroshima symposium provided real confidence for the future. Shin-ichi Uye then officially closed the symposium.

Two special publications will result from this symposium. Manuscripts based on papers and posters presented at the symposium will be considered for publication in a special issue of the ICES Journal of Marine Science. Publication is planned for the late summer of 2008, and approximately 35 to 40 papers are anticipated. All registered participants of the symposium will receive a copy of the special issue following publication. There will also be a special issue of Deep-Sea Research II on krill biology and ecology. This volume will be derived from papers and

PICES and GLOBEC secretariat: Julia Yazvenko, Dawn Ashby and Christina Chiu.

posters presented in the krill workshop (W3) and relevant papers and posters presented in the other sessions of the symposium.

The PICES staff (Alexander Bychkov, Skip McKinnell, Christina Chiu and Julia Yazvenko) contributed greatly to the smooth running of the symposium by their activity before and during the meeting. Additional assistance was provided by Dawn Ashby and Lotty Ireland from the GLOBEC office. Many Japanese students were of excellent assistance in running the registration desk and the audio-visual equipment used in all the sessions and workshops.

In summary, PICES, GLOBEC and ICES were privileged and pleased to have served as co-sponsors of the highly successful 4th International Zooplankton Production Symposium.

Teruaki Yoshida

I would like to thank Prof. Uye and the symposium organisers for giving me the opportunity to speak in front of so many distinguished zooplanktologists.

I am currently a PhD student at the University of Kebangsaan in Malaysia. Today, I am happy to have the opportunity to stand here in the presence of my mentor, Prof. Othman Haji Ross. Going back a few years, I met Prof. Othman for the first time at Soka University in Tokyo, where I was doing my Masters degree under the guidance of Prof. Toda, my other mentor. Both of them have a record of active collaborative research projects between Japan and Malaysia. Their collaborative efforts have borne fruit to 12 publications over the years, and there are more on the way. At that time, I had always wanted to go abroad to do a PhD, and I was happy when Prof. Othman kindly offered to take me under his wing. I have been working on zooplankton in Malaysia ever since.

As a participant from Malaysia, I had many fruitful discussions with scientists from all around the world, but I am especially happy to be able to meet participants from Asian countries as we exchanged opinions and formed mutual friendships as zooplanktologists from the same region. I found out that many of these countries faced similar challenges such as a lack of funding, expertise and facilities. Thus, I believe that it is important to form close networks with scientists for open exchanges and collaborative partnerships for major advances in the understanding of zooplankton.

40 years ago in Japan, nobody thought of studying plankton. Today, Japan has become a leading country in zooplankton research. Malaysia would like to aim for that. Although zooplankton studies are still at an early stage in Malaysia, I am taking this experience back and sharing it with fellow researchers and the next generation of students. I hope more Asian researchers will be able to participate in the next zooplankton symposium. Until we meet again. Thank you very much.

Zooplankton fauna of Ennore Creek, Tamilnadu, India

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The distribution of zooplankton in Ennore Creek was studied from July 2002 to March 2004. Three stations were sampled and 57 zooplankton species belonging to 35 genera from groups, Copepoda (21), Rotifera (11), Tintinnid (21), Cladocera (1) and Ostracoda (3) were identified. The most common genera were *Acartia*, *Oithona*, *Pseudodiaptomus*, *Tintinniopsis*, *Favella* and *Brachionus*. Copepod nauplii were more prominent during the post monsoon seasons. The abundance of copepods (12,000 ind l^{-1}) and rotifers (35,000 ind l^{-1}) peaked during the wet months (November, December and January) and the pre-monsoon month (August). The zooplankton abundance and richness were consistently high at the creek mouth and low in the upper regions of the creek. Shannon-Weaver diversity (H') of zooplankton was high (1.8-2.4) during December and January and low (1.3-2.1) during the remaining months and showed a negative correlation with the temperature in all the three stations.

Since ancient times, estuaries in India have been a focal point of human activity - for settlement, port and harbour development and for trade and commerce. The peninsular India, comprising Tamilnadu and Kerala, has been exposed to international trade since the sixth century BC through the ancient ports located at almost all the river mouths. An exhaustive account on 25 estuaries along the east and west coasts of India has been given by Qasim (2003) and eight of the estuaries on the east coast have been reported for their rich biodiversity resources. Typically, the most abundant groups of zooplankton occurring in temperate estuaries are Copepoda, Rotifera, Protozoa, Cladocera and the meroplanktonic stages of benthic invertebrates (Gaughan and Potter, 1995).

Ennore Creek (13.15°N; 80.15°E) is a part of the Buckingham canal system (Fig. 1) where a sand bar is formed continuously because the direction of the longshore currents is towards the mouth resulting in the partial closure of the creek's connection with the sea. Therefore, continuous dredging is carried out to keep the mouth fully open (Sridhar, 1982). Joseph (1989) has given an account of heavy metal contamination in fishes of Ennore Creek.

There have been few studies of Ennore Creek since 1990 and there lies a considerable gap in the literature pertaining to the ever-changing bio-resources of the creek. Therefore the present study was initiated to assess the current status and biodiversity of plankton in this creek. According to Froneman (2001), low freshwater flow and a relatively small catchment area can reduce the productivity of an estuary significantly and the Ennore Creek receives very little freshwater during the period from January to September.

Three stations from the Ennore Creek were identified for the present study. Station 1 close to the mouth region, station 2 near to the power plant coolant water outlet and station 3 was the highly eutrophic backwater region. Samples were collected from these stations from July 2002 to March 2004 on a monthly basis. Atmospheric and surface water temperatures were recorded at the site itself. Plankton samples were collected by filtering 100
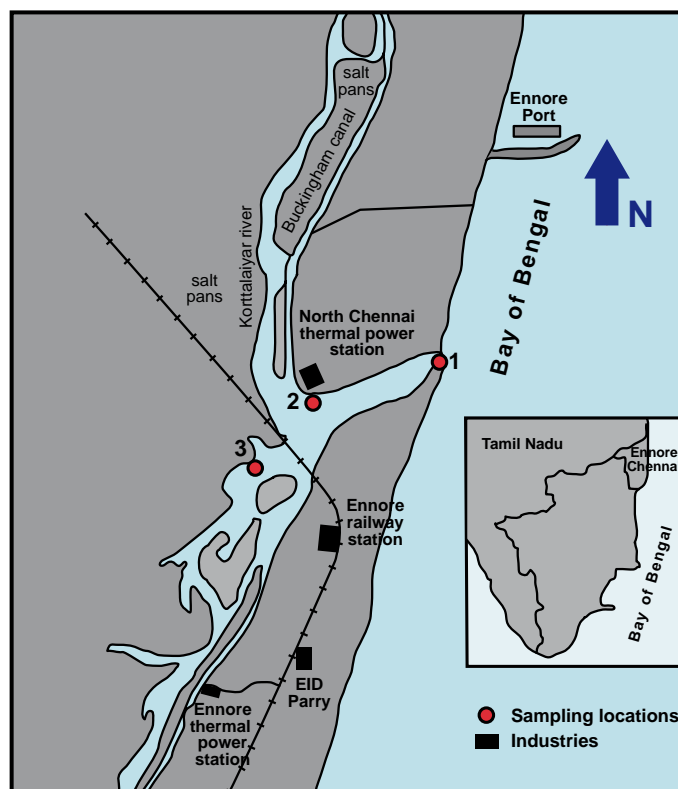

Figure 1. Map of study area indicating the sampling sites and industrial units.

litres of surface water through a 200 µm nylon mesh net. The plankton samples were preserved in 5% formaldehyde solution for further analysis (APHA, 1995). The plankton were identified under a light microscope up to the species level (Table 1) following standard identification keys (Edmondson, 1959; Kasthurirangan, 1963; Subrahmanian, 1964; Ranga Reddy and Radhakrishna, 1984; Battish, 1992). Enumeration of plankton was carried out using a Sedgwick–Rafter counting chamber. Pearson's correlation was carried out using the SPSS 10.0 package.

Station I was dominated by marine zooplankton species (Table 2) and the species composition was dominated by copepods (*Pseudodiaptomus* sp. and *Oithona* sp.). Station 2 was dominated by harpacticoid species like *Bryocamptus hiemalis* and *Euterpina acutifrons* during most of the seasons. The freshwater species, *Leydigia* sp. was recorded only from station 3 during the monsoon months (October to December). Calanoids were dominated by *Pseudodiaptomus annandalei* and the cyclopoid by *Oithona rigida*. *Brachionus* sp. and *Tintinnopsis* sp. were dominant during the post monsoon season (January to March). Station 2 had a higher surface water temperature (average 33.76°C) during the study compared to station 1 and 3 (29.97 and 30.17°C respectively). The same was the case with the diversity index (Table 3).

The Shannon-Weaver species diversity index (H') showed a negative correlation with the surface water temperature in all the three stations (-0.253 in station 1 and -0.404 in station 2). The
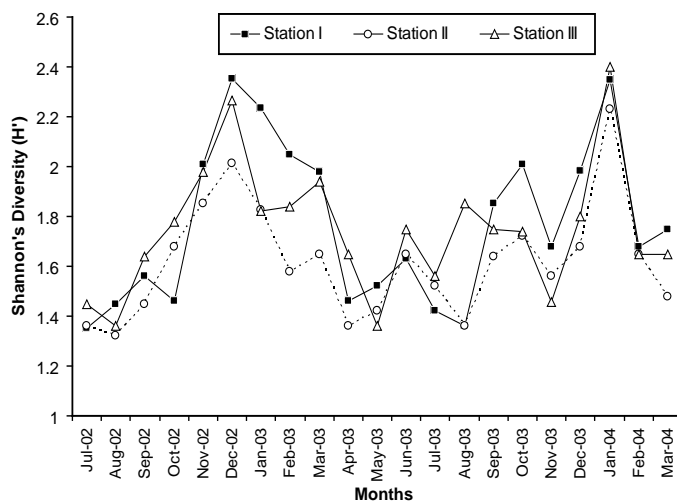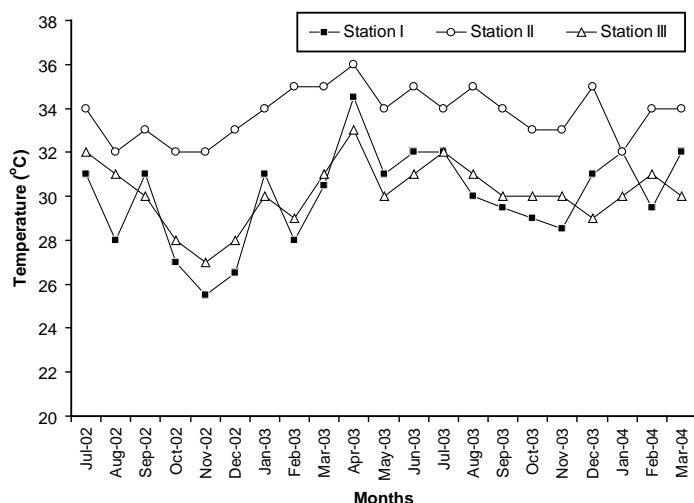
Figure 2. Monthly variation of temperature (°C) in 3 stations of Ennore creek.

Figure 3. Monthly variation of Shannon's (H') diversity index in 3 stations of Ennore creek.

Table 1. Zooplankton species recorded in Ennore Creek during July 2002 to March 2004

Calanoid	Rotifer
Acartia danae	Brachionus angularis
A. tonsa	B. bidentata
Calanus finmarchicus	B. calyciflores
Eodiaptomus sp.	B. caudatus
Nannocalanus minor	B. patulus
Neodiaptomus sp.	B. plicatilis
Paracalanus parvus	B. quadridentatus
Pseudodiaptomus annandalei	B. rubens
Temora turbinata	Filina longiseta
	Lepadella patella
Cyclopoid	Notholca acuminate
Cyclops bicolor	
C. crassicaudus	**Tintinnid**
Halicyclops normani	Condonolopsis orthoceros
Mesocyclops leuckartii	Eutintinnus tenius
Metis jousseaumei	Favella brevis
Microcyclops minutus	F. ehrenbergi
Oithona brevicornis	F. philippinensis
O. rigida	Leprotintinnus nordquisti
	L. simplex
Harpacticoida	Matacyclis jorgensenei
Attheyella alaskaensis	Tintinnidium incertum
Bryocamptus hiemalis	Tintinnidium primitivum
Euterpina sp.	Tintinnopsis bermudensis
Euterpina acutifrons	T. butschlii
	T. cylindrica
Ostracoda	T. directa
Candona faveolata	T. kofoidi
Cyclocypris ampla	T. lohmanni
Cypris subglobosa	T. mortensenei
	T. nucula
Cladocera	T. parvula
Leydigia sp.	T. tocantinensis
	T. urugueyensis

correlation of the diversity index at station 3 with the temperature (- 0.456) was significant at a 0.05 level of significance. Surface water temperature showed a significant difference between seasons (Fig. 2) with higher temperatures being recorded during the monsoon months (October to December). Station 2 showed an increased temperature during all the seasons, which may be attributed to the coolant water release from the thermal power plant. Figure 3 shows the monthly variation of zooplankton diversity in all three stations and lower values were observed at station 2. Increased species diversity was noticed during the months of December and January 2002 and November, December and January 2003. The higher diversity values coincide with the lower temperature and freshwater flow due to monsoonal runoff.

According to Linton and Warner (2003), stress is generally thought to induce both quantitative and qualitative changes in the structure and functioning of communities. Structural changes are usually assessed by analysing species diversity and/or composition. Functional changes include measures such as photosynthetic activity, growth rate and fecundity. In the present study the structure of the community, represented by species diversity and composition shows a strong seasonal and spatial difference. The major stress on zooplankton in the case of Ennore Creek may be the surface water temperature. The coolant water release from the nearby thermal power plant accounts for the rise in surface water temperature of Ennore Creek (Sivasamy, 1990). The presence of *Oithona* sp. during all the months of sampling and at all the stations of Ennore Creek confirms reports of Gallienne and Robins (2001), that *Oithona* sp. is probably the most abundant copepod in the world and it is a eurythermal, euryhaline and omnivorous species adapted to a wide range of habitats. *Acartia tonsa* is reported to be associated with higher temperatures in the Schelde estuary (Tackx *et al.*, 2004), which is also evident in our study.

Table 2 Number of species recorded in various groups in different sampling stations in Ennore creek

	No of species recorded		
	Station I	Station II	Station III
Calanoid	9	7	8
Cyclopoid	6	6	7
Harpacticoida	3	4	4
Ostracoda	2	2	2
Cladocera	-	-	1
Rotifer	7	9	11
Tintinnid	19	15	20
Total	**46**	**43**	**53**

Table 3 Mean and Standard deviations of temperature and Shannon-Weaver diversity index (H') at three stations of Ennore creek

Parameter	Stations	Mean	Standard deviation	N
Temperature	1	29.976	2.176	21
	2	33.762	1.179	21
	3	30.143	1.424	21
Shannon-Weaver diversity	1	1.7690	0.3229	21
	2	1.6189	0.2277	21
	3	1.7472	0.2609	21

References

APHA. 1995. Standard methods for the examination of water and wastewater (18th edition). American Public Health Association, Washington DC, USA.

Battish S.K. 1992. Freshwater zooplankton of India. Oxford and IBH Publishing Co. Ltd., New Delhi. India.

Edmondson W.T. 1959. Freshwater biology (second edition). John Wiley and Sons, New York, USA.

Froneman P.W. 2001. Seasonal changes in zooplankton biomass and grazing in a temperate estuary, South Africa. Estuarine, Coastal and Shelf Science 52: 543-553.

Gallienne C.P. and D.B. Robins. 2001. Is *Oithona* the most important copepod in the world's oceans? Journal of Plankton Research 23: 1421-1432.

Gaughan, D.J. and I.C. Potter. 1995. Composition, distribution and seasonal abundance of zooplankton in a shallow, seasonally closed estuary in temperate Australia. Estuarine, Coastal and Shelf Science 41: 117-135.

Joseph K.O. 1989. Heavy metal contamination of fish of the estuarine environment in Madras region. Proceedings of the National Academy of Sciences, India 59(B): 45-50.

Kasthurirangan C.R. 1963. A key for the identification of the more common planktonic copepods of Indian coastal waters. CSIR, New Delhi, India.

Linton D.M. and G.F. Warner. 2003. Biological indicators in the Caribbean coastal zone and their role in integrated coastal management. Ocean and Coastal Management 46: 261-276.

Qasim S.Z. 2003. Indian estuaries. Allied Publishers, New Delhi, India.

Ranga Reddy Y. and Y. Radhakrishna. 1984. The calanoid and cyclopoid fauna (crustacean, copepoda) of Lake Kollaru, South India. Hydrobiologia 119: 27-48.

Sivasamy S.N. 1990. Plankton in relation to coastal pollution of Ennore, Madras coast. Indian Journal of Marine Sciences 19: 115-119.

Sridhar M.K.C. 1982. A field study of estuarine pollution in Madras, India. Marine Pollution Bulletin 13(7): 233-236.

Subrahmanian K. 1964. Diatoms of Madras coast. Proceedings of the Indian Academy of Sciences 26(4): section B.

Tackx M.L.M., P.J.M. Hermanb, S. Gasparinic, X. Irigoien, R. Billionesa and M.H. Daro. 2003. Selective feeding of *Eurytemora affinis* (Copepoda, Calanoida) in temperate estuaries: model and field observations. Estuarine, Coastal and Shelf Science 56: 305-311.

Special issue of Journal of Plankton Research dedicated to a selection of papers presented during the 9th International Conference on Copepoda, Hammamet, Tunisia, 11-15 July 2005

In order to consider the most promising topics related to copepod (and more generally to ecosystem) research, the scientific programme of the 9th ICOC included four plenary sessions on the following topics: i) behaviour of copepods: role of small scale processes; ii) use of copepods as bioindicators; iii) role of copepods in climate change studies and iv) role of copepods in aquaculture. The 12 papers in this special issue of the Journal of Plankton Research (volume 29, supplement 1: Copepods) represent a diverse asset of presentations during these scientific sessions of the 9th ICOC.

Together these papers show the diversity of topics studied by copepodologists and the key role of copepods in ecosystem studies. Sophisticated techniques developed for the study of parasitic copepods can be applied to key planktonic copepods as well. Various studies showing the role of small-scale processes (behaviour, immunity and genetics) in copepod life cycle traits have not yet been incorporated into larger scale population or ecosystem models. One may hope that future conferences can enhance such new multidisciplinary studies based on copepods and other planktonic groups.

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Cover page of Journal of Plankton Research special issue. The cover image (by S. Souissi) is a Scanning Electron Microscopy image of an attached couple (male + female) of the estuarine copepod Eurytemora affinis (Copepoda: Calanoida) from the Seine estuary, France. A multidisciplinary research programme focusing on the life cycle strategies of E. affinis in the Seine estuary has been financed since 2001 by the Seine-Aval consortium (http://www.seine-aval.fr). This programme aims at developing new bioindicators of the ecosystem health in several temperate estuaries where the copepod E. affinis plays a key role in the food web. The Seine-Aval programme contributed to finance this special issue. The other sponsors are both co-convenors and co-sponsors of the 9th ICOC, National Taiwan Ocean University (Taiwan) and University of Sciences and Technologies of Lille (France).

SAHFOS PAGE

The synergistic effects of climate and eutrophication in the North Sea

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Phytoplankton are the primary producers of pelagic marine waters, the base of the marine food web, and an integral part of the ecosystem. Furthermore, plankton are closely coupled to environmental change, making them sensitive indicators of natural and anthropogenic ecosystem disturbance. As an area rich in resources, much of the North Sea is impacted by anthropogenic activities including fishing, shipping, and oil, gas, and aggregate extraction; eutrophication is also a priority issue in some areas. The combination of climatic and anthropogenic pressures has created difficulties in separating climate-induced changes in phytoplankton production from those caused by eutrophication.

Because of its proximity to land, the coastal North Sea is more heavily affected by anthropogenic nutrients than the open North Sea. To differentiate between changes in phytoplankton production caused by climate and those caused by eutrophication, two new quantitative phytoplankton datasets were created, one for the open (>125 nm from shore) and one for the coastal (<30 nm from shore) North Sea. These datasets were created based on the relationship between the Phytoplankton Colour Index (a semi-quantitative estimate of phytoplankton biomass obtained from the CPR) and quantitative remotely sensed SeaWiFS chlorophyll *a* (Chl *a*). The result was two new long-term (1948-2003) spatially comprehensive Chl *a* datasets, providing quantitative estimates of phytoplankton biomass in open and coastal North Sea waters (n >52,000). Spatially referenced climatic and nutrient data were also obtained and separately extracted for these regions.
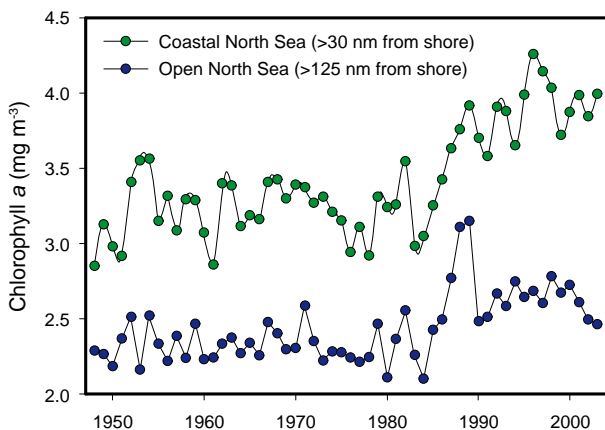
The new Chl *a* datasets reveal that the coastal North Sea is consistently richer in phytoplankton biomass than the open North Sea. During the 1980s, a significant increase in Chl *a* occurred in both open and coastal waters. This change was related to a climate-driven region-wide regime shift (Beaugrand, 2004; Fig. 1). Since the regime shift, Chl *a* has remained at a higher level in both open (13%) and coastal (21%) regions. In the coastal North Sea, chlorophyll continues to increase.
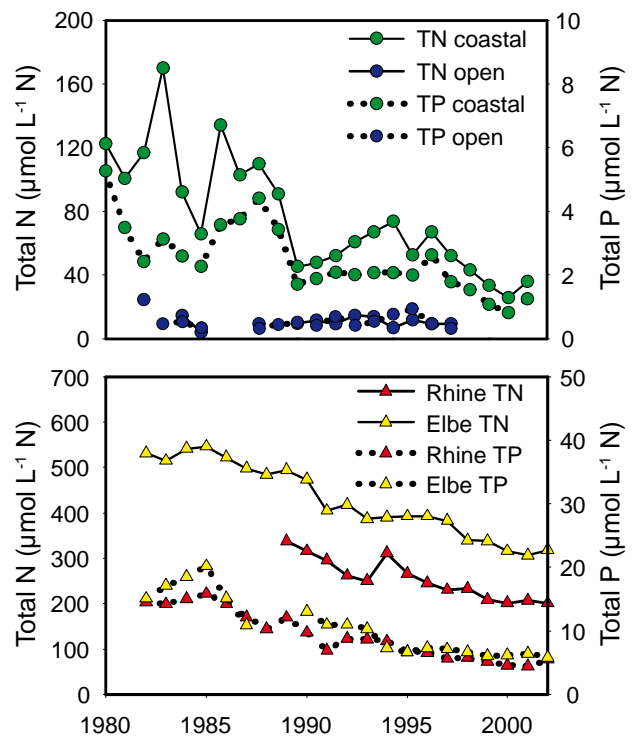

Figure 2. Annual total nitrogen (TN) and total phosphorus (TP) in the coastal North Sea and Elbe and Rhine rivers have decreased since the early 1980s.

Although phytoplankton biomass has increased since the regime shift, nutrient concentrations in the coastal North Sea and Elbe and Rhine rivers have decreased significantly as a result of policy measures and changes in agricultural practices (Fig. 2). Coastal Chl *a* is negatively correlated with coastal and riverine nutrients (Table 1); this is surprising, as traditionally increases in plankton production are triggered by increasing nutrients and are a symptom of eutrophication. The relationship between phytoplankton and nutrients therefore appears to be non-linear in coastal North Sea waters (i.e. a reduction in nutrient load does not lead to an equivalent reduction in phytoplankton biomass).

Figure 1. Time-series of the new Chl a datasets (annual means) for the period 1948-2003 in the coastal and open North Sea.

Table 1. Results of correlation analysis between Chl *a* and nutrient and climatic indicators. Significant (p<0.05) results are in italics.

	TN Coast	TP Coast	TN Open	TP Open	Elbe TN	Elbe TP	Rhine TN	Rhine TP	SST	Winter NAO	Atlantic Inflow	Winter Secchi
Coastal Chl *a*	*-0.65*	*-0.45*	-0.18	0.38	*-0.69*	*-0.84*	-0.36	*-0.77*	*0.42*	0.15	0.22	*0.63*
Open Chl *a*	-0.25	-0.08	-0.16	-0.09	-0.22	*-0.75*	0.36	-0.30	*0.32*	*0.28*	*0.36*	0.27

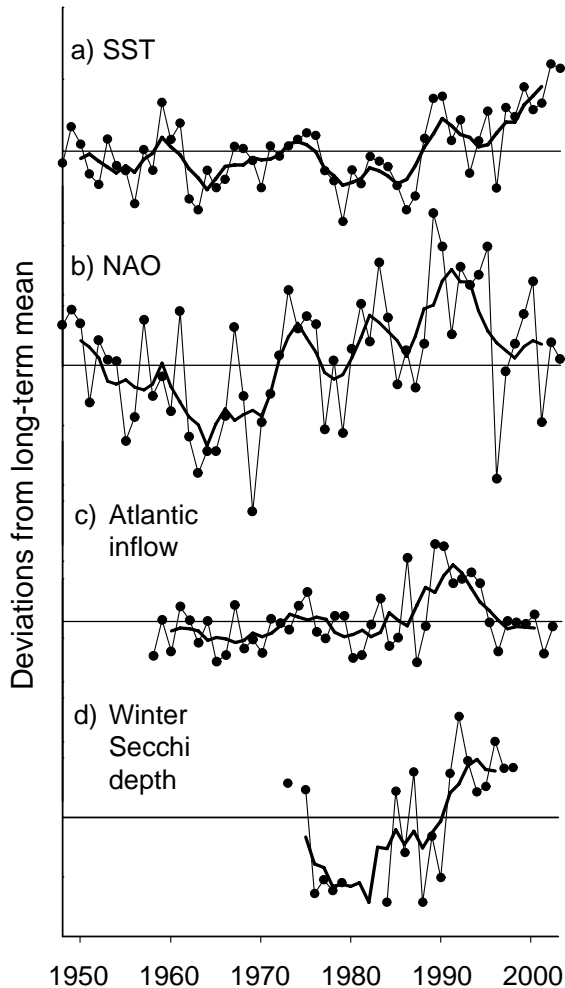

Figure 3. Changes in North Sea Chl a correspond to increased SST, a positive phase of the NAO, increased Atlantic inflow and increasing winter Secchi depth.

North Sea chlorophyll is not regulated solely by nutrients. The changes observed in Chl *a* are positively correlated with warming SST and a positive phase of the NAO. At the same time, inflow of clear water from the North Atlantic also increased, resulting in greater transparency of coastal North Sea waters (Fig. 3). The relationships between climate and Chl *a* differ in coastal and open areas (Table 1) with open chlorophyll regulated by Atlantic inflow, winter NAO and SST and coastal chlorophyll most influenced by SST and water transparency (measured by winter Secchi depth). This indicates that as North Sea waters become warmer and clearer, the phytoplankton growing season is extended and the normally light-limited coastal phytoplankton can utilise available nutrients more effectively.

It is therefore suggested that changes in large-scale climatological forcing have gradually eroded the resilience of the North Sea system until a critical threshold was reached in the mid-1980s. Since the regime shift, the North Sea has maintained a higher level of Chl *a* in both open and coastal waters. Additionally, although riverine and coastal nutrient concentrations are decreasing, coastal Chl *a* continues to rise. This suggests that, due to changes in climate, coastal North Sea waters are increasingly susceptible to nutrient fluxes, and stricter nutrient reduction measures are required in order to prevent further eutrophication in the coastal North Sea (McQuatters-Gollop *et al.*, 2007).

References

Beaugrand G. 2004. The North Sea regime shift: evidence, causes, mechanisms and consequences. Progress in Oceanography 60: 245-262.

McQuatters-Gollop A., D.E. Raitsos, M. Edwards, Y. Pradhan, L.D. Mee, S.J. Lavender and M.J. Attrill. 2007. A long-term chlorophyll data set reveals regime shift in North Sea phytoplankton biomass unconnected to nutrient trends. Limnology and Oceanography 52: 635-648.

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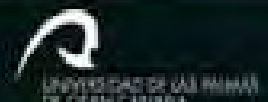
GLOBEC-related research activities in Spain

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The GLOBEC-Spain programme was launched after the first GLOBEC Spain symposium, held in El Puerto de Santa María, Cádiz in November 2001 (Echevarría *et al.*, 2002). This symposium was attended by 120 researchers with the assistance of invited speakers, Roger Harris (UK, then GLOBEC Chair), Cisco Werner (USA, present GLOBEC Chair) and Manuel Barange (UK, GLOBEC IPO Director). One of the outputs of the symposium was the proposal to form a GLOBEC Spain commission, coordinated by Dr Celia Marrasé (Instituto de Ciencias del Mar Barcelona, GLOBEC Scientific Steering Committee). The Commission has included representatives from the different geographical regions of the Spanish coastline, including the Canary Islands.

A second GLOBEC Spain symposium was held in March 2007, this time as a joint proposal from GLOBEC and IMBER. This symposium was hosted at the impressive "Ciudad de las Artes y las Ciencias" in Valencia (Fig. 1), with participation by more than 250 researchers. The three plenary conferences of the symposium were convened by Carlos Duarte, Manuel Barange and Julie Hall. The symposium had 8 scientific sessions (see Table 1), each with one invited speaker. Drs Jurgen Alheit and Miguel Santos, coordinators of GLOBEC in Germany and Portugal, were two of the invited speakers.

The scientific activities of GLOBEC Spain have been funded by national, regional or European agencies through individual projects (Ashby, 2004). In coming months the inventory of projects will be revised and updated, forming the core of the last phase of GLOBEC Spain. In addition, several GLOBEC-sponsored meetings of an international dimension have been organised in Spain in recent years, like the 3rd International symposium on zooplankton production, held in Gijón in 2003

Table 1. Sessions at the GLOBEC-IMBER Spain symposium held in Valencia (March 2007)

Session	Convenors	Invited speaker
Biodiversity, function and metabolism in the ocean	J. Gasol S. Agustí	C. Pedrós Alió
Trophic interactions	E. Saiz J.L. Acuña	A. Calbet
Retrospective analysis and time series studies	A. Bode A. Borja	J. Alheit
Physical-biological interactions in the ocean	C. Marrasé P. Sangrá	A.M.P. Santos
Effects of global change on species, ecosystems and biogeochemical cycles	X. Irigoien F. Echevarría	A. López-Urrutia
Transfer of matter and energy between oceanic interfaces	J. Arístegui X.A. Alvarez-Salgado	E.D. Barton
Role of ecosystems and ocean in climate regulation	E. Marañón A. F. Ríos	I. Cacho
Predictive capacity and modelling	A. Calafat F. Peters	J. Ruiz

Figure 1. Images from the 1st GLOBEC-IMBER Spain symposium, held in Valencia in March 2007. In the third image, Manuel Barange during the plenary conference in the "Mar Rojo" auditory, in front of the aquarium.
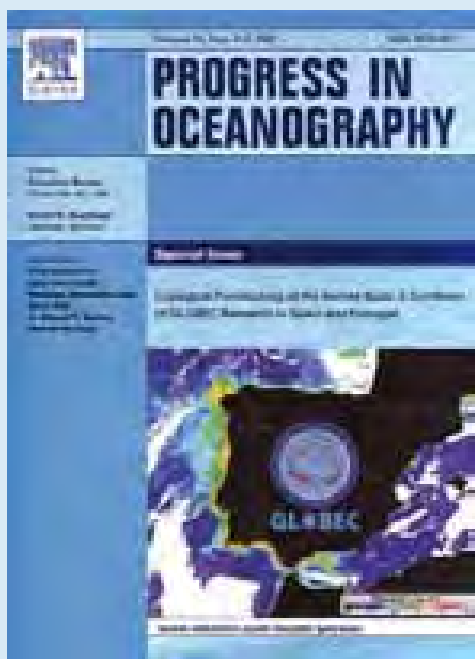
Figure 2. Cover of the special issue of Progress in Oceanography on "Ecological functioning of the Iberian seas: A synthesis of GLOBEC research in Spain and Portugal".

or the international workshop for image analysis of zooplankton (San Sebastián, 2005). Next year a couple of important GLOBEC events are being held in Spain: The "International symposium on the effects of climate change on the world's oceans", to be held in Gijón in May 2008 (see http://www.pices.int) and the international symposium on "Eastern boundary upwelling ecosystems" to be held in Las Palmas de Gran Canaria in June 2008 (see http://www.upwelling-symposium.org/).

Recently the journal Progress in Oceanography has dedicated a special issue to GLOBEC-related research activities in the Iberian Peninsula (Echevarría *et al.*, 2007), grouping a collection of 16 papers that represent a synthesis of GLOBEC research in Spain and Portugal (Fig. 2). This special section of the GLOBEC Newsletter on GLOBEC Spain is a synthesis of the information presented in this special issue. This section does not include papers from Portugal as there was a special section for GLOBEC Portugal in a previous issue of this Newsletter (Santos, 2006).

The seas around Spain show important heterogeneities: the western upwelling that extends from Galicia towards the Canary Islands, the oligotrophic Mediterranean waters to the east, the dynamic transition zone between Atlantic and Mediterranean waters to the south or the particular ecology of the Canary Islands. The satellite image in Figure 2 (a MODIS chlorophyll-*a* image of the seas around the Iberian Peninsula on 13 September 2005) is a good indicator of these heterogeneities, which are covered in the different contributions in this special section. I thank all the authors for their time and effort that make possible this overview. I am also very grateful to Elsevier for their kind permission to reproduce this information in the GLOBEC Newsletter.

References

Ashby D.M. (Ed.). 2004. Update of the Report on the GLOBEC National, Multinational and Regional Programme Activities, 2004. GLOBEC Special Contribution No. 7, 195pp.

Echevarría F., J.L. Acuña, S. Hernández-León, E. Saiz, A.M.P. Santos and M Barangé. (Eds.). 2007. Ecological functioning of the Iberian seas: A synthesis of GLOBEC research in Spain and Portugal. Progress in Oceanography 74(2-3): 95-422.

Echevarría F., C. Marrasé and L. Valdés. 2002. The first symposium GLOBEC-Spain. GLOBEC International Newsletter 8(1): 23-24.

Santos A.M.P. 2006. GLOBEC Portugal. GLOBEC International Newsletter 12(1): 7-31.

A decade of sampling in the Bay of Biscay: what are the zooplankton time series telling us?

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The project "Studies on time series of oceanographic data" or RADIALES (Valdés *et al.*, 2002) was established as a pilot project by the Instituto Español de Oceanografía (IEO) in 1991. After more than a decade, the project has grown to encompass a network of 19 sampling stations in 5 different transects at the N and NW coast of Spain: Vigo, Coruña, Cudillero, Gijón and Santander beginning in 1987, 1988, 1993, 2001 and 1991, respectively (Fig. 1). At each location a coastal-ocean gradient is sampled monthly for hydrography, nutrients and planktonic communities following standard protocols (González- Pola *et al.*, 2005; Valdés *et al.*, 2005).

Since 1991 the project RADIALES has provided good hydrographical data for the southern Bay of Biscay. Using these time series, Cabanas *et al.* (2003) calculated a warming trend of 0.02-0.05°C yr^{-1} in surface layers over the shelf off Santander. In the oceanic waters off Santander this warming trend is currently detected in the intermediate waters from the mixed layer down to 1000 m depth (González-Pola *et al.*, 2005). The trend has an average annual rate of +0.032°C yr^{-1}, which is two to six times greater than is reported for the North Atlantic during the last half century). The warming trend in surface waters varies on a regional scale. This trend is upward in the Cantabrian Sea, but is less evident off Galicia. We also noted that maximum temperatures off Galicia, as a consequence of seasonal upwelling, do not reach the values observed in the Cantabrian Sea. Particularly evident over last 5 years is the increased amplitude of surface temperature
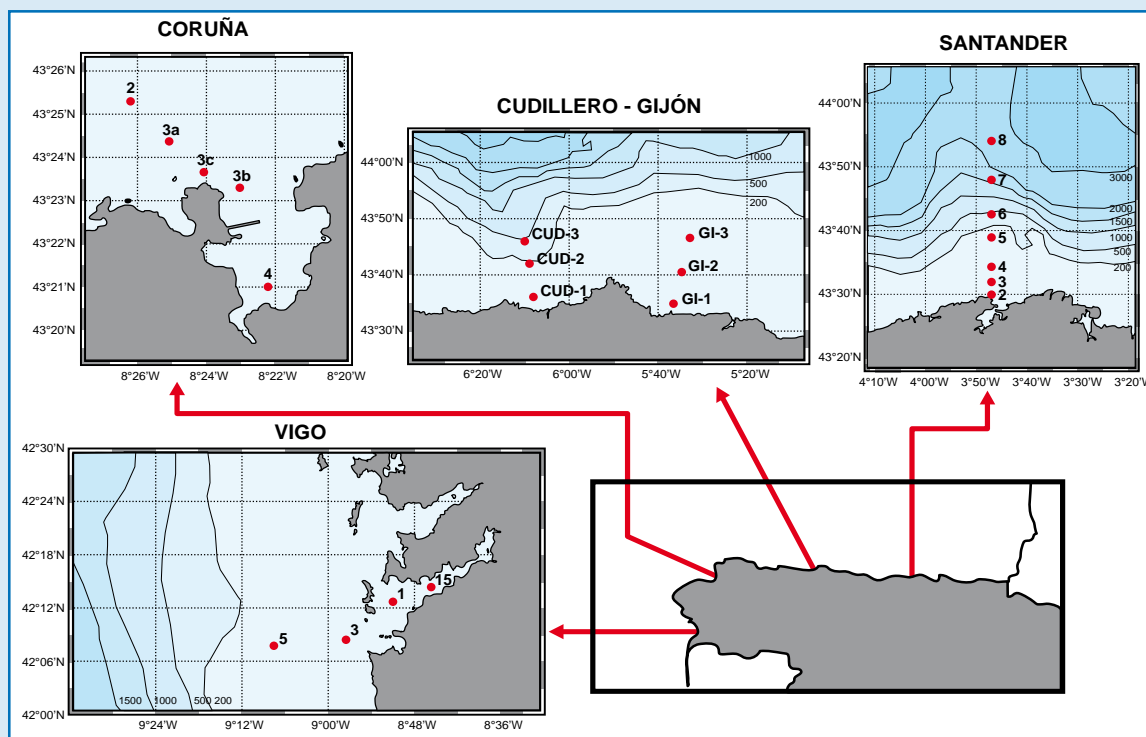
Figure 1. Location of sampling stations in N and NW Spain.

in the Cantabrian sea with warmer summers and colder winters. Upwelling is more intense west of Cape Peñas and Ortegal up to Finisterre, and acts as a mechanism generating spatial variability between the western and eastern zone of the Cantabrian Sea, and between the coastal mixed waters and the neighbouring oceanic stratified areas. Upwelling events are highly variable in intensity and frequency and show a significant year to year variability. Cabanas *et al*. (2003) showed that a notable shift in the winds has occurred during the last two decades, resulting in a reduction in the spring-summer upwelling off the northwestern Iberian Peninsula. Lavin *et al*. (1998) noted that the water column off Santander experienced a higher degree of stratification, which also remains stratified for a longer period of time. The same pattern is now observed for the other transects.

There were no clear inter-annual changes in the zooplankton biomass at any of the transects sampled (Fig. 2). There is, however, a strong regional gradient in the seasonal extension of the mesozooplankton biomass peak, driven by differences in water column stratification at each study site. In contrast to Cudillero and Santander, and in particular at the most oceanic station (St.6) where water column stratification is much stronger, the Vigo and Coruña transects are in an area where frequent upwelling events break up the water column during the summer months (Figs. 1 and 2). This seems to be correlated to the seasonal decrease in zooplankton abundance. Those locations where stratification is more intense have much lower zooplankton biomass during the stratified period; hence the peak in biomass is restricted to the spring period before the onset of surface warming.

The spatial distribution, seasonal dynamics and year-to-year variability of copepods can be combined to discriminate groups of species. There are five clusters observed in the Santander transect (Fig. 3). A first cluster of species predominate in the

coastal region during the late winter and spring. A second cluster consists of coastal and shelf species with a density maxima occurring later, during spring and summer. A third cluster is composed of shelf and oceanic species appearing in the spring, whereas the fourth cluster consists of species also appearing in spring but more restricted to oceanic conditions. Finally there is a cluster of summer-autumn species composed of *Temora stylifera*, *Onychocorycaeus ovalis* and *Sapphirina* spp. The former two species are characteristic of subtropical and Mediterranean areas, these species were more abundant during the last years of the time series when they also exhibited an extended seasonal persistence, from two months in the early 1990s to five months (summer and autumn) during the late 1990s. The case of *T. stylifera* is specially interesting as it was not recorded in the N-NW Iberian Peninsula before 1978. It was observed for first time in the Cantabrian sea by Alvarez-Marqués (1980) as a rare species always occurring at low densities. Over ensuing years several zooplankton studies recorded this species and it was pointed out as an example of change in the regional distribution of species due to global warming by Villate *et al*. (1997). This change in the presence of *T. stylifera* can be observed in the data from the transects off Vigo, Coruña and Santander (Valdés *et al*., 2007). At the stations where *T. stylifera* was most abundant, there is an increase in the abundance of this species from west to the east. In the Santander region, a definite increasing trend has been observed since the mid-1990s. The patterns of water column stratification are similar (Fig. 2), though with much weaker water column stratification in Vigo and Coruña than in Santander and with increased stratified conditions in Santander during recent years. We hypothesize that the observed seasonal, spatial and temporal patterns in occurrence of *T. stylifera* are related to those of water column stratification, which are reinforced by the warming trend.
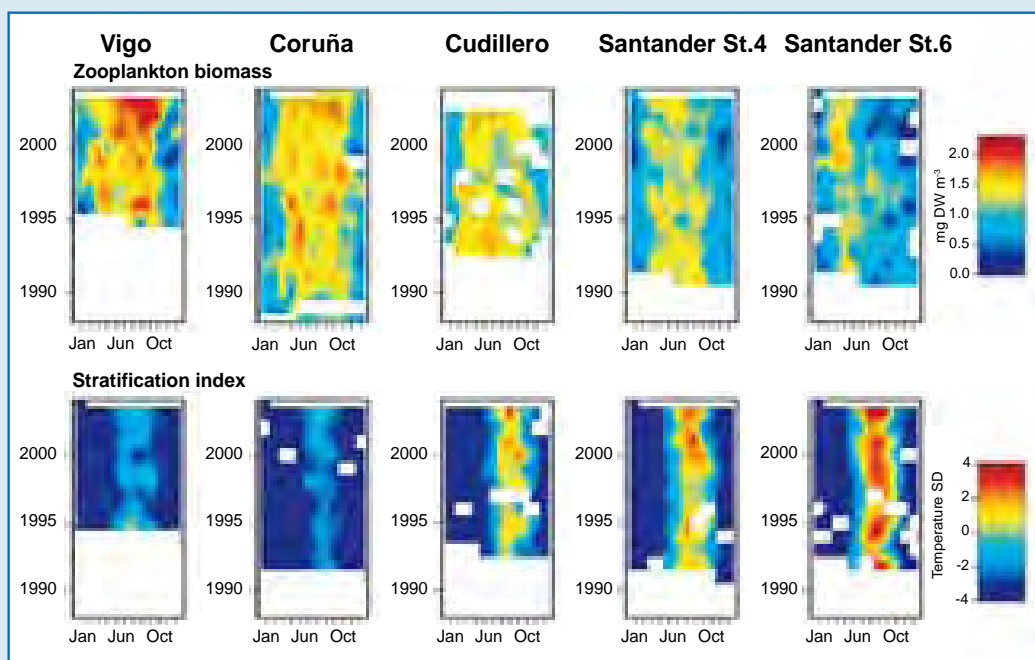
Figure 2. Zooplankton biomass (upper panels) and the stratification index (lower panels) for each of the shelf-break stations in each transect and for the most oceanic station off Santander.

Conclusions

Stratification plays a crucial role in structuring marine communities as it largely controls the fuelling of nutrients into the upper photic layers. Global change is predicted to increase the degree of stratification as well as the duration of the stratified period (Sarmiento *et al.*, 2004). As the stratification reaches deeper waters and the nutrient depletion in photic layers is extended in time, consequences are expected in seasonal and annual phytoplankton dynamics resulting in increased oligotrophy. This predicted change is already occurring and is observed in the increased stratification on the RADIALES transects (Figs. 1 and 2). Both, increase of stratification and decreases in upwelling intensity act together to reduce the growth of phytoplankton. We hypothesize that the whole region will be less productive in the future. These changes in the physical structure of the water column and in the functioning of lower trophic levels that drive ecosystem production, are likely to modify the structure, production and organisation of higher trophic levels through zooplankton to fish.

Long-term research programmes based on systematic observations have rendered significant results to earth sciences in general and to oceanography in particular. The Spanish IEO project RADIALES has allowed us to set statistically significant ranges for the variability of several environmental variables and biological communities. We have determined the rates and trends of warming due to climate change as well as describing some direct and indirect effects in the water column and effects on pelagic ecology. The project has contributed substantially to gaining a deeper knowledge of planktonic communities and species and to the production of baselines, climatologies and reference levels for the north Spanish coast. These allow accurate evaluations of the effects of environmental perturbations on the ecosystem, enabling forecasting of expected recovery times from perturbations and monitoring of the ecosystem for reversion to the previous stage. This multidisciplinary sampling programme is a good example on the importance of the basic research as an essential tool for a responsible management of natural resources.

References

Alvarez-Marqués F. 1980. Copépodos pelágicos de la costa asturiana: contribución al conocimiento de las especies de la zona de Gijón. Boletín Ciencias de la Naturaleza IDEA 25: 213-223.

Cabanas J.M., A. Lavín, M.J. García, C. González-Pola and E. Tel Pérez. 2003. Oceanographic variability in the northern shelf of the Iberian Peninsula, 1990-1999. ICES Marine Science Symposia 219: 71-79.

González-Pola C., A. Lavín and M. Vargas-Yáñez. 2005. Intense warming and salinity modification of intermediate water masses in the southeastern corner of the Bay of Biscay for the period 1992-2003. Journal of Geophysical Research 110: C05020.

Lavín A., L. Valdés, J. Gil and M. Moral. 1998. Seasonal and interannual variability in properties of surface water off Santander (Bay of Biscay) (1991-1995). Oceanologica Acta 21(2): 179-190.

Sarmiento J.L., R. Slater, R. Barber, L. Bopp, S.C. Doney, A.C. Hirst, J. Kleypas, R. Matear, U. Mikolajewicz, P. Monfray, V. Soldatov, S.A. Spall and R. Stouffer. 2004. Response of ocean ecosystems to climate warming. Global Biogeochemical Cycles 18(3): art. GB3003.

Valdés L., A. Lavín, M.L. Fernández de Puelles, M. Varela, R. Anadón, A. Miranda, J. Camiñas and J. Mas. 2002. Spanish Ocean Observation System. IEO Core Project: Studies on time series of oceanographic data. p.99-105. In: N.C. Fleming, S. Vallerga, N. Pinardi, H.W.A. Behrens, G. Manzella, D. Prandle and J.H. Stel. (Eds.). Operational oceanography: implementation at the European and regional scales. Elsevier Science, Amsterdam.

Valdés L., A. López-Urrutia, J. Cabal, M. Alvarez-Ossorio, A. Bode, A. Miranda, M. Cabanas, I. Huskin, R. Anadon, F. Alvarez-Marqués, M. Llope and N. Rodríguez. 2007. A decade of sampling in the Bay of Biscay: what are the zooplankton time series telling us? Progress in Oceanography 74: 98-114.

Valdés L., T. O'Brien and A. López-Urrutia. 2005. Zooplankton monitoring results in the ICES area, summary status report 2003/2004. ICES Cooperative Research Report 276: 34pp.

Villate F., M. Moral and V. Valencia. 1997. Mesozooplankton community indicates climate changes in a shelf area of the inner Bay of Biscay throughout 1988 to 1990. Journal of Plankton Research 19(11): 1617-1636.

Variability of the pelagic food web on the Iberian Atlantic: stable nitrogen isotope studies

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Two different types of food web are expected in the pelagic shelf ecosystem in the Atlantic margin of the Iberian Peninsula. During the upwelling season (from March to October), a metazoan food web based on new nutrients from the upwelling (as nitrate) is expected (Bode *et al*., 2003). On the other hand, the poleward flow during autumn and winter contains less nutrients than waters fertilised by the upwelling and displays low plankton biomass (Fernández *et al*., 1993). In this situation, a microbial food web based on the remineralisation of the organic matter would be expected. As light isotopes are preferentially mobilised in metabolic processes, plankton growing on nutrients remineralised *in situ* are expected to have a lower proportion of heavy isotopes than plankton growing on new nutrients originating from deep waters, such as those supplied by upwelling. Both oceanographic and trophic situations can be found during the transition from winter to spring (Calvo-Diaz *et al*., 2004).

Part of the GLOBEC-Spain programme, was to determine the trophic structure of the pelagic ecosystem on the Atlantic shelf of the Iberian Peninsula and its spatial and interannual variability. For this purpose, the natural abundance of nitrogen stable isotopes was measured in plankton and representative nektonic species. Plankton composition was mainly studied in size-fractionated samples, but the isotopic signatures of three copepod species, as representatives of primary consumers, were also considered. Several fish species were included as planktivorous consumers, with special attention to sardine (*Sardina pilchardus*), a key pelagic species (Carrera and Porteiro, 2003). Finally, top pelagic consumers were represented by the common dolphin (*Delphinus delphis*). The results presented herein are a synthesis of the main findings since 1998 (Bode *et al*., 2007).

Marine food webs are structured in terms of organism size (e.g. Jennings *et al*., 2002). In this regard, we found a significant linear relationship between trophic position (estimated from the natural abundance of stable nitrogen isotopes, δ^{15}N) and body size (in logarithmic size-classes) for the Iberian Atlantic (Fig. 1). This relationship, however, appears less constrained than those reported for other ecosystems. As a result, the ratio between the sizes of predators and prey is largely variable. Widespread omnivory and plankton consumption by relatively large predators are the likely causes. Trophic positions of plankton consumers vary in a narrow range of values, suggesting potential competition for food. Low nitrogen isotope enrichment between prey and consumers indicate nutrient limitation and recycling at the base of the food web. This suggests a bottom-up control of planktivorous fish and agrees with the described seasonal variability of nitrogen fluxes and heterogeneous distribution of upwelling zones within the studied shelf.
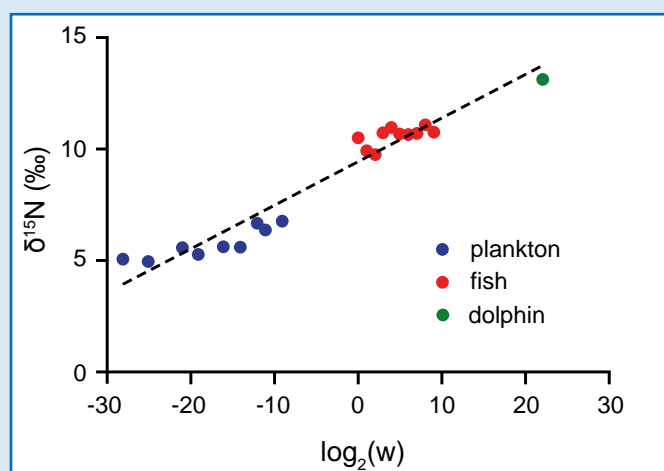
Figure 1. Overall relationship between mean δ^{15}N and individual weight (w) of pelagic organisms. The regression line is δ^{15}N = 9.386 + 0.194 $\log_2$(w) (r = 0.970, P < 0.0001, n = 20). Modified from Bode et al. (2007).
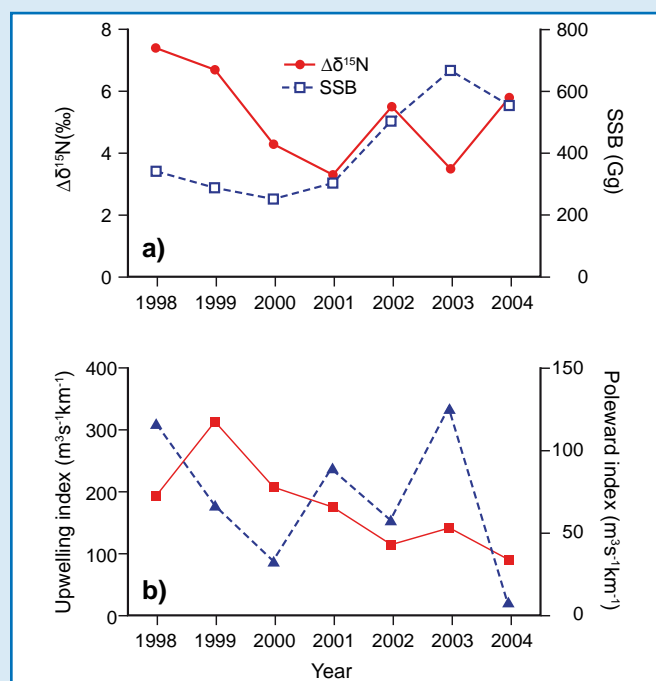
Figure 2. Annual variations of (a) mean difference between δ^{15}N (‰) of sardine and 200-500 µm plankton (δ^{15}N) (red symbols) compared to sardine spawning stock biomass (SSB, Gg = 10^3 tonnes, blue symbols) and (b) mean upwelling (red) and poleward (blue symbols) index values of the preceding year (m^3 s^{-1} km^{-1}). Modified from Bode et al. (2007).

The composition of nitrogen isotopes in the muscle of sardine integrates fish diet over seasonal periods and reflects the composition of plankton over large shelf areas. Differential isotopic signatures in high and low upwelling zones are consistent with low mobility of sardines during periods of low population size (Carrera and Porteiro, 2003), thus suggesting the use of isotopic abundance as a measure of the ability of sardines to exploit different areas (Bode et al., 2007). Interestingly, sardine and plankton $\delta^{15}N$ followed an inverse interannual pattern. Both variables should be positively correlated if nutrient inputs were dependent only of upwelling intensity, thus suggesting an interaction between upwelling and downwelling. The isotopic enrichment of sardines relative to plankton, however, showed a decrease between 1998 and 2000 followed by a general increase in recent years (Fig. 2a). This pattern was parallel to a marked increase in the size of the sardine population since 2000 and a decreasing trend in upwelling intensity (Fig. 2b). In contrast, the intensity of the poleward current first decreased before 2000 but showed alternative high and low values thereafter. The size of the sardine population was significantly correlated with upwelling but not with mean isotopic enrichment. Variability in the isotopic enrichment of sardines may be caused by mobility, change of diet or starvation. Large mobility of sardines can be expected in years when muscle $\delta^{15}N$ values are close to those of plankton, as in 2001 and 2003. The lack of a simple relationship between the main oceanographic events at a regional scale and the isotopic signature of plankton and sardine, however, calls for more studies to understand the role of mobility and nutrient enrichment in the isotopic composition.

References
Bode A., P. Carrera and S. Lens. 2003. The pelagic foodweb in the upwelling ecosystem of Galicia (NW Spain) during spring: natural abundance of stable carbon and nitrogen isotopes. ICES Journal of Marine Science 60: 11-22.

Bode A., M.T. Alvarez-Ossorio, M.E. Cunha, S. Garrido, J.B. Peleteiro, C. Porteiro, L. Valdés and M. Varela, M. 2007. Stable nitrogen isotope studies of the pelagic food web on the Atlantic shelf of the Iberian Peninsula. Progress in Oceanography 74: 115-131.

Calvo-Díaz A., X.A.G. Morán, E. Nogueira, A. Bode and M. Varela. 2004. Picoplankton community structure along the N and NW Iberian coastal transition zone in late winter-early spring. Journal of Plankton Research 28: 1069-1081.

Carrera P. and C. Porteiro. 2003. Stock dynamic of the Iberian sardine (Sardina pilchardus, W.) and its implication on the fishery off Galicia (NW Spain). Scientia Marina 67(Suppl. 1): 245-258.

Fernández E., J. Cabal, J.L. Acuña, A. Bode, A. Botas and C. García-Soto. 1993. Plankton distribution across a slope current-induced front in the southern Bay of Biscay. Journal of Plankton Research 15: 619-641.

Jennings S., J.K. Pinnegar, N.V.C. Polunin and K.J. Warr. 2002. Linking size-based and trophic analyses of benthic community structure. Marine Ecology Progress Series 226: 77-85

Could Bay of Biscay anchovy recruit through a spatial loophole?

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It is widely assumed that high food concentrations imply good recruitment of fish populations as they assure high growth rates. However, feeding does not only depend on food concentration; other factors include detecting and capturing prey and risk taken during the feeding process. When feeding, fish usually increase their visibility by moving to upper layers which increases their encounter rates with predators. Thus, there is a compromise between eating and being eaten. In fact, the advantage of high food concentrations might be that fish have to spend less time in risky places to get enough food. But also, areas with low food concentrations but few predators could also assure good growth rates because the fish could spend more time looking for food in areas with less risk. There has been little research, to date, on the effect on recruitment of the risk associated with feeding.

It has been observed in the Bay of Biscay that higher recruitment of anchovy occurs with climatic conditions that favour larvae drifting off the shelf (Borja et al., 1996). Anchovy juveniles are also regularly observed off the shelf whereas spawning occurs over the shelf, mainly in the river plumes. A conceptual model
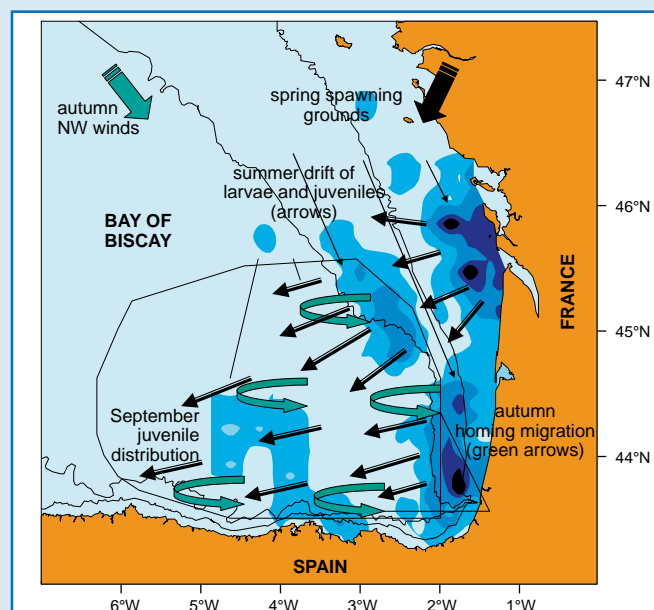

Figure 1. Scheme of the proposed spatial pattern of recruitment of the Bay of Biscay anchovy. Adapted from Uriarte et al. 2001.
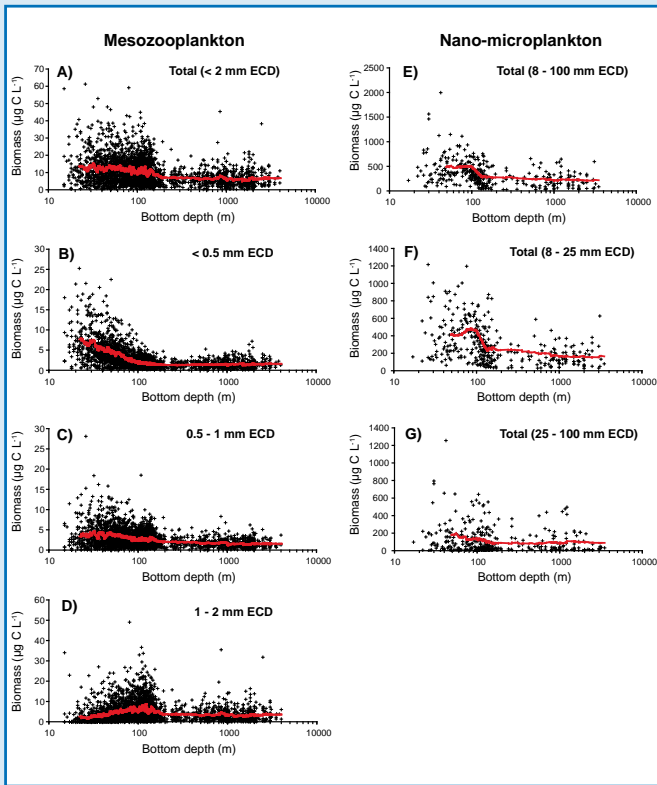
Figure 2. Nano-microplankton and mesozooplankton concentration (µg C l⁻¹) in the Bay of Biscay as a function of bottom depth.

Figure 4. The probability of survival (from 0.28 mg dw) to a given size (W_R = 0.1 g dw) for larval fish under combinations of daily food rations and relations between feeding and mortality rates. When feeding and mortality are correlated, survival to a given size is maximised at relatively low food intakes (grey line).

where recruitment could partially occur off the shelf has been proposed (Uriarte *et al.*, 2001; Fig 1). The distribution of the juveniles can be interpreted as advective losses of the population recruiting over the shelf but also as the population exploiting the off the shelf waters for recruitment through a loophole of lower predation (Bakun *et al.*, 2003). In our paper in the Progress Oceanography special issue on Ecological Functioning of the Iberian Seas: A synthesis of GLOBEC Research in Spain and Portugal (Irigoien *et al.*, 2007) this second hypothesis was tested through a review of the information available about different processes in the Bay of Biscay (anchovy distribution, size at age spatial differences, recruitment timing and spatial distribution and potential predators distribution). We also developed a model to explore recruitment success when predation risk is positively correlated with feeding opportunities.
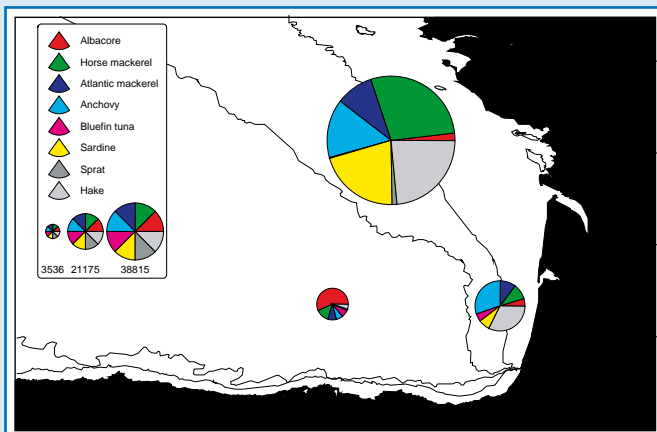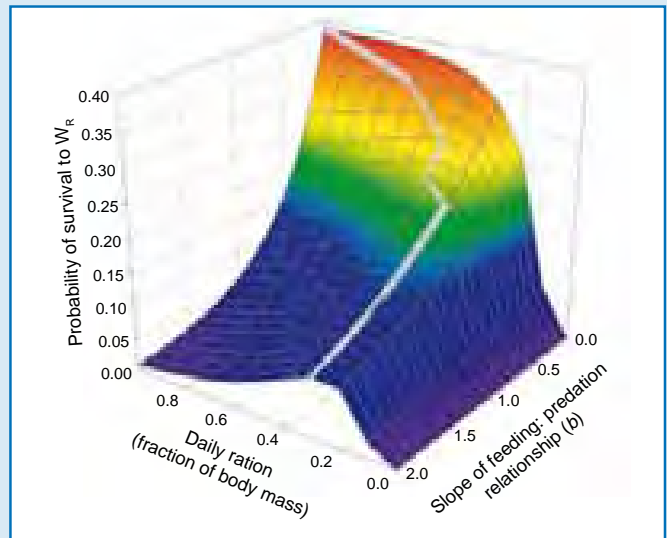
We observed that plankton concentration on the shelf is about two times that found off the shelf, but that difference decreases for larger micro- and mesozooplankton, the higher concentration of these being found at the shelfbreak (Fig. 2). Average circulation patterns during spawning and larval growth of anchovy in the Bay of Biscay (spring-summer) favour transport off the shelf and old larvae and small juveniles are found off the shelf according to the transport pattern. The off the shelf waters in the Bay of Biscay attract a trophic migration of albacore and bluefin tuna during summer suggesting that either there are enough larvae and juveniles of anchovy off the shelf so as to be profitable for tuna or that the waters off the shelf are rich enough to attract large predators. However, even considering tuna migration, the total number of potential predators for anchovy larvae and small juveniles remains much higher on the shelf than off the shelf (Fig. 3). The developed model confirms that, when there is a high risk associated with feeding activity, higher survival may be achieved at intermediate diets (Fig. 4). We conclude that the hypothesis of anchovy using off-shore (oceanic) waters as a spatial loophole for recruitment cannot be excluded.

References

Bakun A. and K. Broad. 2003. Environmental 'loopholes' and fish population dynamics: comparative pattern recognition with focus on *El Niño* effects in the Pacific. Fisheries Oceanography 12: 458-473.

Borja A., A. Uriarte, V. Valencia, L. Motos and A. Uriarte. 1996. Relationships between anchovy (*Engraulis encrasicolus* L.) recruitment and the environment in the Bay of Biscay. Scientia Marina 60(Suppl. 2): 179-192.

Irigoien X., Ø. Fiksen, U. Cotano, A. Uriarte, P. Alvarez, H. Arrizabalaga, G. Boyra, M. Santos, Y. Sagarminaga, P. Otheguy, E. Etxebeste, L. Zarauz, I. Artetxe and L. Motos. 2007 Could Biscay Bay anchovy recruit through a spatial loophole? Progress in Oceanography 74: 132-148.

Uriarte A., Y. Sagarminaga, C. Scalabrin, V. Valencia, P. Cermeño, E. De Miguel, J.A. Gómez Sánchez and M. Jiménez, 2001. Ecology of anchovy juveniles in the Bay of Biscay 4 months after peak spawning: do they form part of the plankton. ICES Council Meeting Documents CM/W:20.

Figure 3. Average (1973-2004) landings in tonnes per ICES area (VIIIa, VIIIb and VIIId). Source: ICES.

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Sardine spawning off the European Atlantic coast: characterisation of and spatio-temporal variability in spawning habitat

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The aim of this paper is to integrate data from all available and suitable ichthyoplankton surveys which sample sardine eggs in Atlantic European waters, and to analyse these data in order to draw a general picture of the main sardine spawning areas and their variability in time. The three main questions that were tested from the analysis of the data were; 1) are there discontinuities in the north-east Atlantic sardine spawning grounds that may support some degree of isolation between different sardine populations? 2) where are these discontinuities located and are they fixed over time? 3) is there any relation between the extension of spawning areas and the health of the Atlanto-Iberian stock?

Data on the occurrence of sardine (*Sardina pilchardus*) eggs from 42 national ichthyoplankton surveys along the European Atlantic coast were collated in order to describe the spawning habitat and spawning distribution of sardine in recent decades (1985-2005). The main sampling gear used in the different surveys varied from vertically towed ichthyoplankton nets like CalVET to different mouth diameter oblique towed Bongo nets. Analysis was carried out using a modified version of Single Parameter Quotient analysis (SPQ; van der Lingen *et al.*, 2005), and spatial models of egg abundance using Generalised Additive Models. Derived probabilities of egg presence were used as standard quantities to compare among years and to analyse the main spawning grounds, using average probability of egg presence across the time series.

Figure 1 shows the depth, temperature and distribution range of sardine eggs in the combined database. Sardine spawning off the Atlantic European coast is mainly restricted to the shelf area, with the main geographical range being between the Strait of Gibraltar (the southern limit of data available for this analysis) and the middle part of the Armorican Shelf (latitude around 47.5°N). Temperature at spawning locations was also restricted to a range between 12 and 17°C. Only one clear gap can be observed in the distribution from SPQ analysis; an area significantly devoid of eggs off the northern border between Portugal and Spain (Fig. 1).
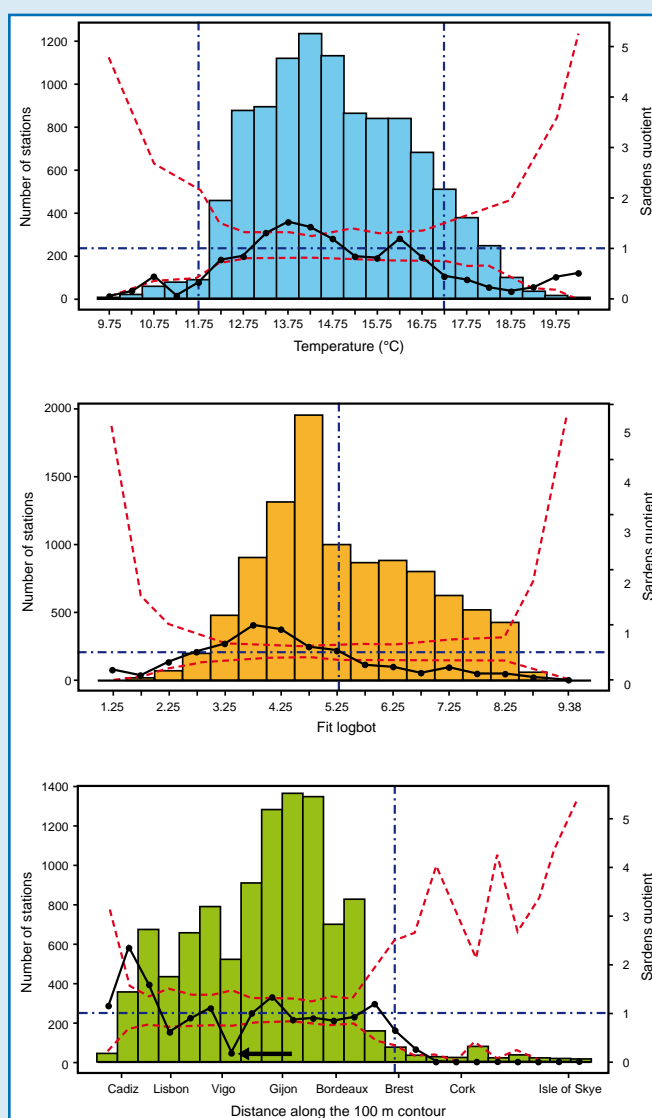
Figure 1. Spawning area characterisation in relation to temperature (top), logarithm of bottom depth (middle) and distance along the 100m depth contour line. Histograms represent the number of observations within each bin of the covariate, the continuous line represents the egg concentration quotient value. The horizontal dashed line represents the null hypothesis of evenly distributed eggs, and the thin dashed lines represent its upper and lower confidence intervals. Vertical dashed lines mark the limits of the significance of the null hypothesis. The arrow in the bottom panel shows the discontinuity in the spawning area.
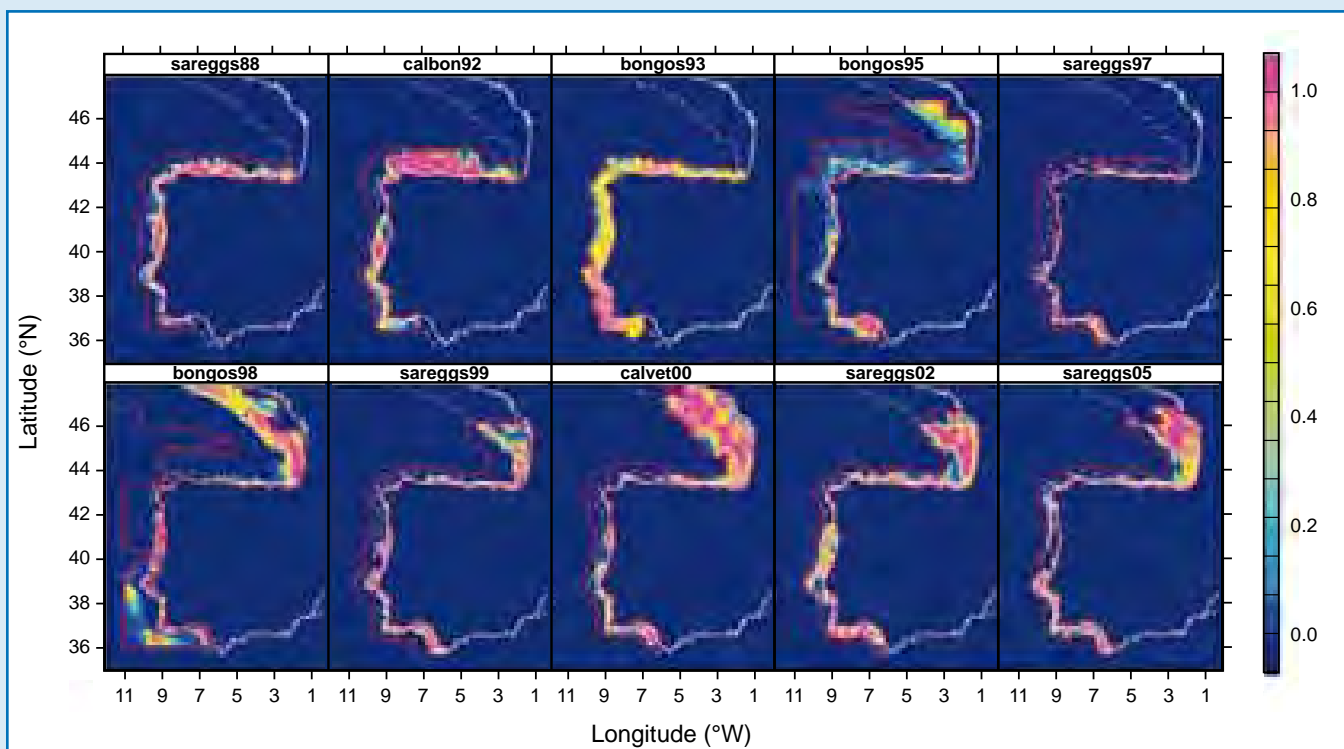
Figure 2. Derived probability of egg presence (from 0 to 1) from the egg concentration models. Colour scale on the right side of the figure. Red lines in the figure represent the sampled area for each year.

Figure 2 shows the spatial distribution of the probability of egg presence for the different years in the database for which a coherent Iberian coverage could be achieved by joining national surveys. Spatial distribution in this figure confirms the gap observed in Figure 1. Two more gaps were found when looking at the spatial distribution of spawning by year: i) a small secondary break at the Spanish-French border in the inner part of the Bay of Biscay and ii) another gap at the south west corner of the peninsula where there is a narrowing of the shelf width. These discontinuities were used to separate spawning grounds into four nuclei, used to describe changes in spawning distribution in the time series; south, west and north of the Iberian Peninsula, and the Armorican Shelf, off the southern French coast. The relative importance of each nucleus and the degree of separation between adjacent nuclei varies between years, with the exception of the permanent gap at the north west corner of the Iberian Peninsula, persistent throughout the time series. In the early years of the time series (especially in 1988 and 1992), spawning areas of all nuclei, except for the Armorican Shelf (not sampled in this period), are widely occupied, and only a reduced gap between the western and northern nuclei remains obvious. Subsequently in the time series (since 1995), spawning areas in the western and northern Iberian nuclei are reduced and confined to a narrow coastal strip (in the northern nucleus) or to restricted areas (in the western nucleus, see clear example in the 1995 and 2000 surveys, Fig. 2), with spawning not spreading throughout all the available habitat. The gaps between the southern and western, and the western and northern nuclei are more conspicuous in this period of the time series (1995-2005). Spawning areas over the Armorican Shelf are only sampled in this later period (1995-2005) and show two different situations: an early situation

in 1995 and 1999 in which spawning is patchy and some areas devoid of eggs within the shelf, and a later situation in 2000, 2002 and 2005 in which spawning spreads through much of the shelf.

Figure 3 compares the time series of the estimated sardine spawning biomass and the percentage of the shelf occupied with eggs, estimated for the years shown in Figure 2. The percentage of the shelf occupied by eggs is used as a measure of the percentage of the potential spawning area occupied in any given year. Year to year changes in the proportion of the potential spawning habitat in which spawning actually occurred, changed from around 60% before the mid-1990s to around 40% thereafter, and did not show any relationship with spawning stock biomass. Evolution of potential habitat occupation over the Armorican Shelf shows larger variability than that observed in the Iberian Peninsula, with percentages of occupation ranging from around 30% up to nearly 80% of the shelf in recent years (within the limitations of the relatively sparse data for this region).

The temperature range where spawning occurs, the restriction of spawning to the shelf area, and the wide distribution along European Atlantic waters, coincides with what is generally described in the literature (Furnestin and Furnestin, 1959; Stratoudakis *et al.*, 2004; Coombs *et al.*, 2005; Ibaibarriaga *et al.*, 2007). Nevertheless, the new analysis allow to i) detect the permanent gap in the north-west corner of the Iberian Peninsula, ii) analyse the evolution of the different spawning nuclei in time, and iii) obtain a standardised index of occupation of the potential spawning habitat, which could be compared to the time series of spawning biomass. The results obtained show different patterns of spawning off the Iberian Peninsula
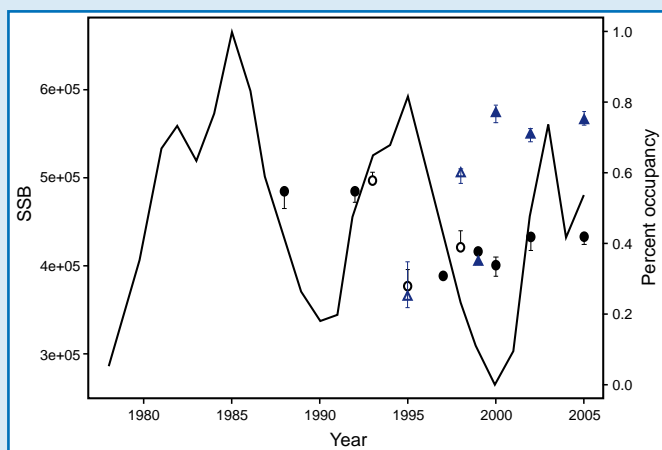
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Figure 3. Comparison between the time series of sardine SSB within the ICES stock unit (solid continuous line, scale on the left in tonnes), the percentage of shelf occupied by eggs within the same limits (circles, scale on the right), and the degree of shelf occupied with eggs in the Armorican Shelf (triangles, scale on the right). Solid symbols indicate "non-bongo" based surveys, while open symbols indicate bongo-based surveys.

for two different decades, with different spatial distributions of spawning areas, and different degrees of potential spawning habitat occupancy. Nevertheless the changes in spawning areas could not be related to changes in spawning biomass, and further information will be required to test different existing hypotheses on small pelagic stock size and spawning area relationships (e.g. Wyatt and Porteiro, 2002; Bakun and Broad, 2003; Carrera and Porteiro, 2003).

References

Bakun A. and K. Broad. 2003. Environmental 'loopholes' and fish population dynamics: comparative pattern recognition with focus on *El Niño* effects in the Pacific. Fisheries Oceanography 12(4-5): 458-473.

Carrera P. and C. Porteiro. 2003. Stock dynamic of Iberian sardine (*Sardina pilchardus*, W.) and its implication on the fishery off Galicia (NW Spain). Scientia Marina 67(Suppl. 1): 245-258.

Coombs S.H., N.C. Halliday, A.J. Southward and S.J. Hawkins. 2005. Distribution and abundance of sardine (*Sardina pilchardus*) eggs in the English Channel from Continuous Plankton Recorder sampling. Journal of the Marine Biological Association of the United Kingdom 85(5): 1243-1247.

Furnestin J. and M.L. Furnestin. 1959. La reproduction de la sardine et de l'anchois des côtes Atlantiques de Maroc (saisons et aires de ponte). Revue des Travaux de l'Institut des Peches Maritimes 23: 79-104.

Ibaibarriaga L., X. Irigoien, M. Santos, L. Motos, J. Fives, C. Franco, A. Lago de Lanzós, S. Acevedo, M. Bernal, N. Bez, G. Eltink, A. Farinha, C. Hammer, S. Iversen, S. Milligan and D. Reid. 2007. Egg and larvae distribution of seven fish species in the north-east Atlantic waters. Fisheries Oceanography 16(3): 284-293.

Stratoudakis Y., S.H. Coombs, N. Halliday, D. Conway, T. Smyth, G. Costas, C. Franco, A. Lago de Lanzós, M. Bernal, A. Silva, M.B. Santos, P. Alvarez and M. Santos. 2004. Sardine (*Sardina pilchardus*) spawning season in the North East Atlantic and relationships with sea surface temperature. ICES Council Meeting Papers CM 2004/Q:19.

van der Lingen C.D., L. Castro, L. Drapeau and D. Checkley, Jr. (Eds.). 2005. Report of a GLOBEC-SPACC Workshop on Characterizing and Comparing the Spawning Habitats of Small Pelagic Fish. GLOBEC Report 21: xii, 33pp.

Wyatt T. and C. Porteiro. 2002. Iberian sardine fisheries: trends and crises. p.321-338. In: K. Sherman and H.R. Skjoldal (Eds.). Large marine ecosystems of the North Atlantic: changing states and sustainability. Large Marine Ecosystems Series 10. Elsevier.

Anchovy in the Gulf of Cádiz: a case of BOTTOP control

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The anchovy (*Engraulis encrasicolus*) fishery in the Gulf of Cádiz (GoC) has shown manifest interannual fluctuations. Catches totally collapsed in 1995 and the fleet underwent a severe societal crisis. It was not then clear what was the origin of this collapse since changes in fishing effort where much lower than those of the landing size. Without an apparent source in the fleet activity, the environment, or the interaction of the fishing effort with the environment, must be the origin of the fluctuations.

Contrary to other fisheries (e.g. Cingolani *et al.*, 1996; Uriarte *et al.*, 1996), and probably due to the fishing effort exerted on the population, anchovy landings in the GoC are almost entirely comprised of year class one (ICES, 2004). This means that year one individuals very rarely live to become year two. It also implies that the stock cannot rely on adults to survive from one year to the next. The transfer of the population between years is then based on the year recruits and their capacity to survive

across the egg, larvae and juvenile stages. As evidenced by the work of García-Lafuente and Ruiz (2007) and synthesised in the following two paragraphs, the shelf at the north sector of the GoC offers an advantageous combination of oceanographic conditions for this survival.

The ebb and flood of the tide along the rivers that discharge into the GoC imprints thermal and biogeochemical signatures on nearby waters. SST images illustrate the presence of a pool of warm water that systematically appears near the Guadalquivir River mouth from April to October (Folkard *et al.*, 1997; Vargas *et al.*, 2003; Navarro and Ruiz, 2006). Nutrient concentrations in this pool are high (Ruiz *et al.*, 2006) and result in high chlorophyll values throughout the year (Fig. 1), including summer when mid-latitude oceans are under severe oligotrophic conditions (Longhurst, 1998). Contrasting with other more intermittent mechanisms of nutrient enrichment, such as wind-driven upwelling or other mesoscale features,
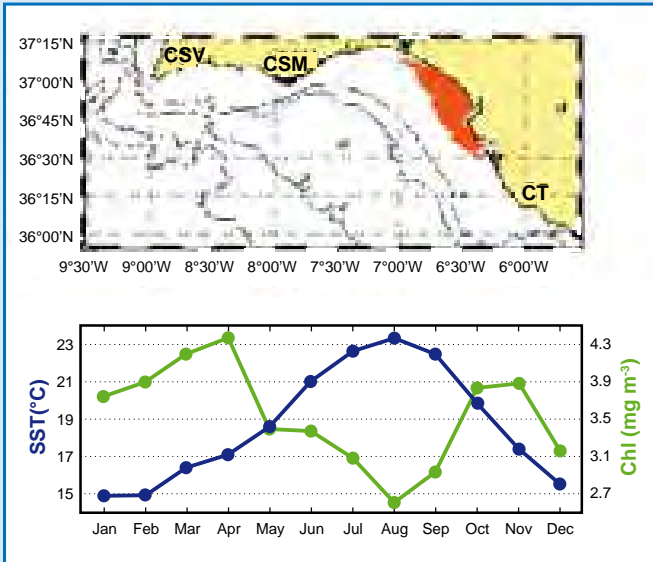
Figure 1. Monthly averages of sea surface temperature (SST, blue line) and sea surface chlorophyll (Chl, green line) obtained from AVHRR and SeaWiFS data according to the methods in Navarro and Ruiz (2006) for the shelf in the GoC near the Guadalquivir River mouth. The top figure depicts the geographical extent of this region as diagnosed by EOF analysis of SeaWiFS data by Navarro and Ruiz (2006). CSV, CSM and CT stand for Cape San Vicente, Cape Santa María and Cape Trafalgar respectively.
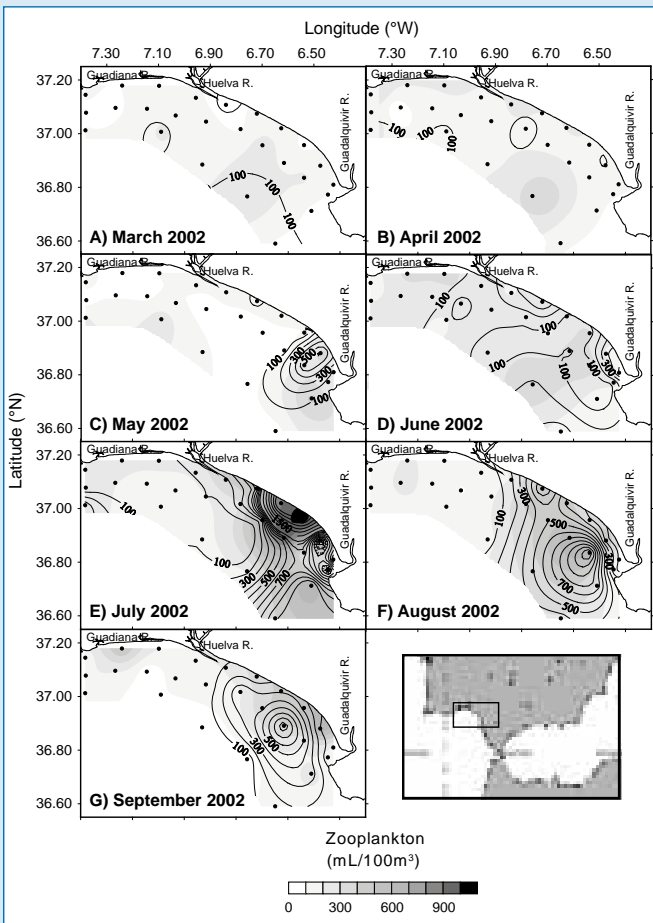

Figure 2. Anchovy larvae concentration (# larvae/100 m³, contour lines) and zooplankton biovolume (ml/100 m³) in the area near the Guadalquivir River mouth from March to September 2002. Data were obtained according to the methods in Ruiz et al. (2006). Dots show the location of the sampled stations. The insert of the lower right corner depicts the geographical extent of the sampled area. Figure modified from Ruiz et al. (2006).

tidally-driven fertilisation represents a continuous source of nutrients. The permanent nutrient input favours an efficient transfer of primary production towards higher trophic levels as illustrated by Figure 2. The figure shows increased zooplankton concentration near to the Guadalquivir mouth, where nutrients are injected into the sea. More zooplankton brings anchovy larvae, known to feed on copepods in this area (Baldó and Drake, 2002), to a higher concentration at this region of the shelf (Fig. 2).

In addition to suitable trophic and thermal conditions for the early survival of anchovy, summer circulation in the GoC favours the retention of planktonic stages at the shelf. The overall circulation scheme is presented in Figure 3 after García-Lafuente et al., (2006). The warm and productive waters described above are contained within the cyclonic cell formed by the slope eastward current (N1 in Fig. 3) and the coastal countercurrent (CCC in Fig. 3). This cyclonic cell recirculates waters within the shelf and is a key component preventing the export of anchovy eggs and larvae towards deep sea waters where survival is much less probable.

The combination of thermal, trophic and circulation environment described above allows the anchovy stock to jump between years through the survival of early stages. However, these stages are more vulnerable than adults to the unpredictability of the environment. Shelf fertilisation depends in a large extend on the rainfall and on the wind regime (Navarro and Ruiz, 2006). The increased latent heat flux during easterlies cools the water and hampers the spawning of anchovy (Ruiz et al., 2006). In addition, easterlies force important volumes of the CCC (Fig. 3) to proceed beyond Cape Santa María to the detriment of the cyclonic circulation (García-Lafuente et
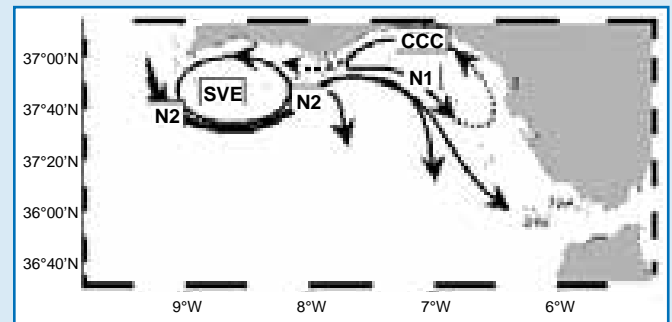
Figure 3. Sketch of the surface circulation in the Gulf of Cadiz proposed by García Lafuente et al. (2006). Core N2 is a branch of the longer-scale Portuguese-Canary eastern boundary current that veers eastward into the Gulf of Cadiz. It moves around a cyclonic eddy off cape San Vicente (SVE), which is a quasi permanent feature of the circulation in the Gulf associated with positive wind stress curl. Part of core N2 moves further east toward the Strait of Gibraltar to feed the Atlantic and the remainder veers southwards to re-join the Canary current or detach the shore as a filament off Cape Santa Maria. The eastern shelf is dominated by a cyclonic circulation bounded by core N1 (identified with the Huelva front) at the south and a warmer coastal counter current (CCC). The presence of Cape Santa Maria seems necessary to close the cyclonic cell by the west. Under easterlies, the coastal counter current bifurcates off Cape Santa María and a branch invades the western shelf (dashed arrow) making the SVE drift to the south. The spatial extension of SVE is exaggerated in the sketch (from García Lafuente and Ruiz, 2007).
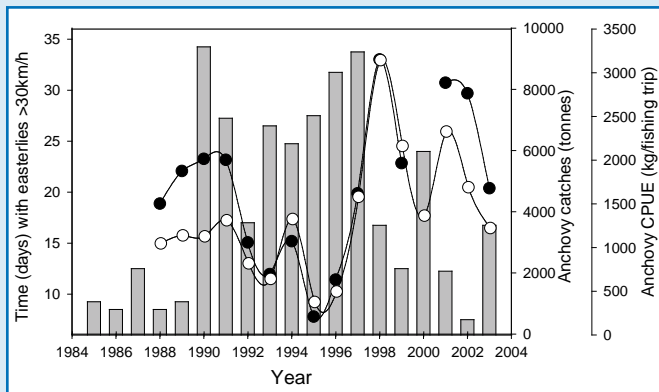
Figure 4. Anchovy catches (black circles) in the Gulf of Cádiz (ICES report for sub-division IXa south) and CPUE (white circles, kg/fishing trip) in Barbate single purpose pursue-seine fleet. Barbate is considered as a reference harbour for catches in the Gulf of Cádiz (ICES, 2004). Catch data for year 2000 are not included in the graph as catches were not representative due to social conflicts in the fleet. Bars represent the cumulated sum of days from March to September with easterlies stronger than 30 km/h in Cádiz. Figure modified from Ruiz et al. (2006).

al., 2006). Under this wind regime, shelf waters are exported westward outside the shelf (Relvas and Barton, 2002) with a subsequent advection of fish eggs and larvae (Catalán *et al.*, 2006). Consequently, years of low rain and strong easterlies do not guarantee the survival of early stages at the warm and productive pool described above. As Figure 4 shows, anchovy landings and capture per unit effort decline at these years since the environment hampers the transfer of the stock from one year to the next.

Landing crises at this fishery are then the result of a double bottom-up and top-down control. Together with natural mortality, fishing pressure exerts a severe control on the population from the top and prevents adults surviving beyond one year. Without adults, the population totally relies on recruits to persist between years. Owing to the vulnerability that early stages have to ocean processes, the stock is then totally controlled by meteorological fluctuations. During standard years these processes guarantee sufficient survival to sustain the stock. However, during adverse years (low rain and strong easterlies), the bottom control (low temperature, low primary production, advection, etc.) prevails and the stock collapses. As schematised in Figure 5, this severe control from the bottom is the result of a previous control (exerted by the fishery) from the top. Together they make the BOT-TOP control for the success/failure in yearly records of anchovy stock and landing at the Gulf of Cádiz.

References

Baldó F. and P. Drake. 2002. A multivariate approach to the feeding habits of small fishes in the Guadalquivir estuary. Journal of Fish Biology 61: 21-32.

Catalán I.A., J.P. Rubín, G. Navarro and L. Prieto. 2006. Larval fish distribution in two different hydrographic situations in the Gulf of Cádiz. Deep-Sea Research II 53(11–13): 1377–1390.

Cingolani N., G. Giannetti and E. Arneri. 1996. Anchovy fisheries in the Adriatic Sea. Scientia Marina 60(Suppl. 2): 269-277.
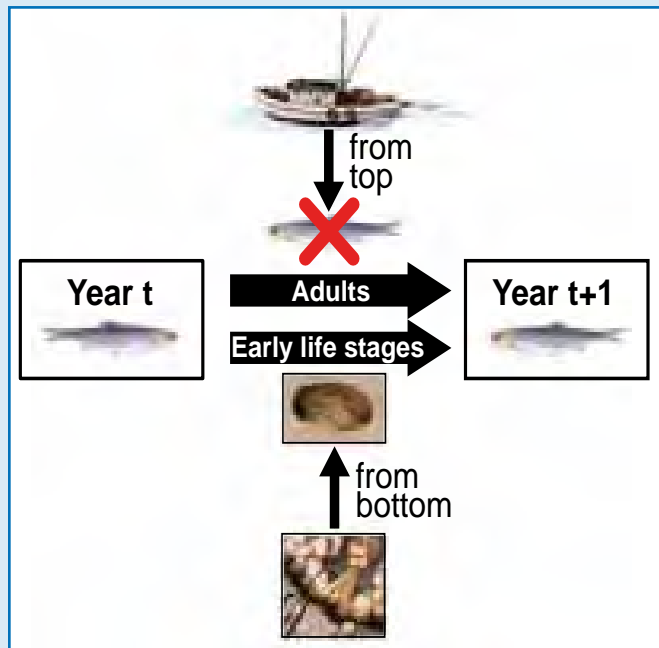
Figure 5. An schematic view of the BOTTOP control of the anchovy stock. Fishing pressure from the top prevents adults to survive beyond one year. The only path to transfer the population from year t to t+1 is through the survival of early stages. These are more vulnerable than adults to the environment. Consequently, the severe top-down control exerted by the fishery results in a severe bottom-up control exerted by the environment.

Folkard A.M., P.A. Davies, A.F.G. Fiuza and I. Ambar. 1997. Remotely sensed sea surface thermal patterns in the Gulf of Cadiz and the Strait of Gibraltar: Variability, correlations and relationships with the surface wind field. Journal of Geophysical Research 102C: 5669-5683.

García Lafuente J., J. Delgado, F. Criado Aldeanueva, M. Bruno, J. Del Río and J.M. Vargas. 2006. Water mass circulation on the continental shelf of the Gulf of Cadiz. Deep-Sea Research II 53: 1182-1197.

García-Lafuente J. and J. Ruiz. 2007. The Gulf of Cádiz pelagic ecosystem: A review. Progress in Oceanography 74: 228-251.

ICES. 2004. Report on the Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy. ICES Council Meeting Papers CM 2004/ACFM:08.

Longhurst A. 1998. Ecological geography of the sea. Academic Press. San Diego, California. 398pp.

Navarro G. and J. Ruiz. 2006. Spatial and temporal variability of phytoplankton in the Gulf of Cadiz through remote sensing images. Deep-Sea Research II 53: 1241-1260.

Relvas P. and E.D. Barton. 2002. Mesoscale patterns in the Cape Sao Vicente (Iberian Peninsula) upwelling region. Journal of Geophysical Research 107C(10): 3164, doi:10.1029/2000JC000456.

Ruiz J., E. García-Isarch, E. Huertas, L. Prieto, A. Juárez, J.L. Muñoz, A. Sánchez La-Madrid, S. Rodríguez, J.M. Naranjo and F. Baldó. 2006. Meteorological forcing and ocean dynamics controlling *Engraulis encrasicolus* early life stages and catches in the Gulf of Cadiz. . Deep-Sea Research II 53: 1363-1376.

Uriarte A., P. Prouzet and B. Villamor. 1996. Bay of Biscay and Ibero Atlantic anchovy populations and their fisheries. Scientia Marina 60(Suppl. 2): 237-255.

Vargas J.M., J. García Lafuente, J. Delgado and F. Criado. 2003. Seasonal and wind-induced variability of sea surface temperature patterns in the Gulf of Cádiz. Journal of Marine Systems 38: 205-219.

Mixing and biogeochemical effects induced by tides at the Strait of Gibraltar: a modelling study

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The negative hydrological budget of the Mediterranean Sea as a whole creates the well-known inverse estuarine circulation through the Strait of Gibraltar (Lacombe and Richez, 1982; Armi and Farmer, 1988; Hopkins, 1999) that leads to a natural tendency to oligotrophy in the Mediterranean basin. The strait plays a critical role in this hydrological budget and, along with the climatic conditions over the Mediterranean area, determines the size and structure of the exchanged flows (Bryden and Kinder, 1991; García Lafuente and Criado, 2001). The nutrient budget of the Mediterranean Sea depends on the water exchange through the Strait of Gibraltar, as well as on atmospheric and river inputs (Béthoux et al., 1998).

On average there is a superficial inflow of Atlantic waters and a deep outflow of Mediterranean waters. This mean exchange represents a net loss of biogeochemical elements from the Mediterranean basin. In such a context, a two-layer hydrodynamic model is used to estimate tidally induced mixing between the Mediterranean and Atlantic water layers and to simulate the effects of mixing processes on biogeochemical fluxes and the pelagic community of the area. A detailed description of the coupled model can be found in the full paper (Macías et al., 2007) published in the Progress Oceanography special issue on "Ecological functioning of the Iberian seas" (Echevarría et al., 2007).

The model was run for 13 months, in order to analyse the effect of annual modulations in tidal amplitude on mixing. Incorporation of a third intermediate layer leads to a significant improvement in the model results (Fig. 1), showing the necessity for a three layer circulation scheme when modelling biogeochemical processes in the Strait of Gibraltar.

Figure 2. Relationship between percentage of nutrient recirculation and tidal height.

According to the model, mixing over the Camarinal Sill causes an average of 16% of the out-flowing nutrients to be returned back to the Mediterranean. This fraction varies between 4 and 35 percent as a function of the tidal amplitude (Fig. 2).

Pelagic processes are modelled using a simple nutrient-phytoplankton-zooplankton (NPZ) model (Fig. 3). The intense physical mixing and advection in the channel is the main influence on plankton dynamics in the area, so the use of a more sophisticated biogeochemical model does not lead to significant changes in the results obtained. It is found that residence times within the channel are so short that phytoplankton communities cannot grow appreciably during
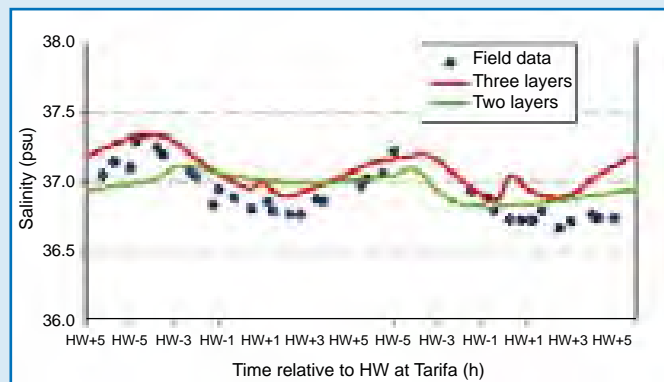
Figure 1. Measured (squares) and modelled upper layer salinity at the Eulerian station during 24 hours. Two (dot-dashed-line) and three (solid line) layer models.
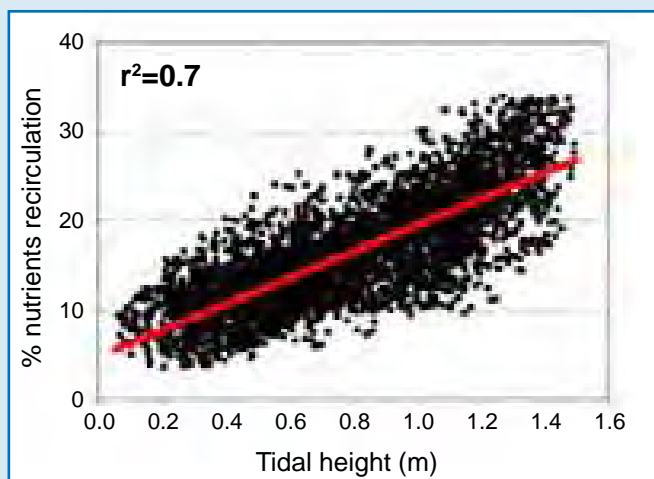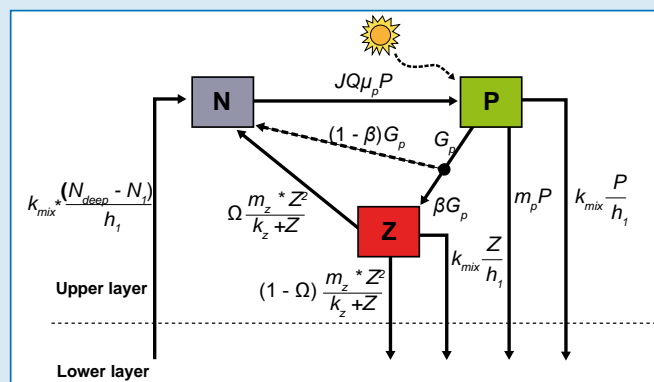
Figure 3. Conceptual diagram and equations of the NPZ model used. The arrows entering the lower layer in the diagram indicate losses from the modelled system.

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Figure 5. Measured and modelled phytoplankton concentration (mmol N/m³) in the upper layer along 24 hours at the Eulerian station.
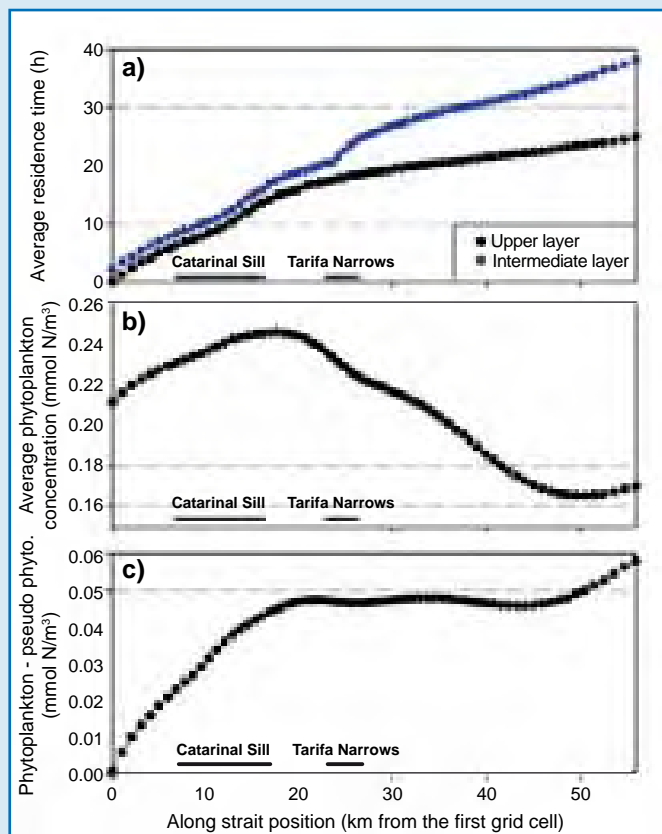
Figure 4. a) Residence time of phytoplankton at each position in the along strait section. b) Average concentration of phytoplankton in the upper layer for each position throughout the 13 month of simulation. c) Differences between phytoplankton and pseudo-phytoplankton at each position for the same period.

their transit (Fig. 4) and a negative relationship is found between phytoplankton concentration in the upper layer and tidal height (r^2=0.2; p<0.01). As a result, the phytoplankton concentration decreases progressively towards the eastern section of the channel (Fig. 4b). However, some field observations show high chlorophyll concentration in the eastern side of the strait (Minas *et al.*, 1991; Gómez *et al.*, 2001; Echevarría *et al.*, 2002). In order to assess the model predictions, the modelled phytoplankton concentration in the upper layer has been compared with the observations collected during the diel cycle carried out at one site in the eastern end of the strait (Fig. 5).

Although the model output shows similar behaviour, it has two important drawbacks. Firstly, it must be noticed that scales for modelled (left) and observed (right) concentrations in Figure 5 are different, so the observed concentration of phytoplankton is about double the concentration predicted by the model. Secondly, there is also a clear difference in the time when predicted and observed maxima appear, the maximum observed concentration coinciding with a minimum of predicted abundance and vice versa (correlation coefficient r^2= 0.3, p<0.01). Although the model predicts the spatial distribution of salinity reasonably well, is not able to predict phytoplankton abundance satisfactorily, a fact that stands independently of the complexity of the biogeochemical model.
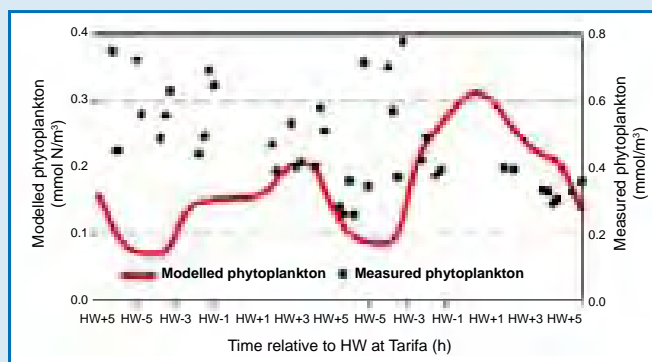
With the residence times predicted by the model, it is clear that the high levels of chlorophyll measured in the eastern section of the strait must be the result of something other than local growth. Another source of chlorophyll is necessary in order to explain the high concentration observed in the eastern section. In the western part of the strait, the currents in the surface layer reverse during part of the semidiurnal tidal cycle (Béthoux and Copin-Montégut, 1986; Candela *et al.*, 1990) while they hardly ever reverse east of the Tarifa Narrows (García Lafuente *et al.*, 2000), giving rise to intense divergences in the upper layer. The physical model reproduces this phenomenon and indicates that the divergence takes place between the Tarifa Narrows and the Camarinal Sill around high water.

Internal oscillations of the interface can partly account for the upper layer divergence (García Lafuente *et al.*, 2000) but some compensation by horizontal flow from both the north and south coastal areas cannot be disregarded. The input from the chlorophyll-rich coastal surface waters into the central channel would increase the chlorophyll concentration periodically by means of a mechanism not specified in our model.

An indirect proof for this is the recent result of a series of Longhurst-Hardy Plankton Recorder (LHPR) casts along the strait crossing over Camarinal Sill presented by Echevarría *et al.* at the 2005 ASLO Summer Meeting. A first leg carried out at HW-3 registered a low concentration of particles but a later leg around HW-1 found a high concentration of chlorophyll and plankton biomass over the sill. At this time, dilution should have reduced the chlorophyll concentration due to the strong mixing but it actually showed enhanced levels, thus suggesting horizontal advection from the north and south as one likely mechanism of chlorophyll supply.

This comparison of the model results with field data suggests that in order to obtain an accurate simulation of the plankton ecosystem dynamics in the strait, it is necessary to take into account the full horizontal flow, as recirculation and coast-channel interactions seem to be very important processes explaining the biological patterns in the area.

References

Armi L. and D. Farmer. 1988. The flow of Mediterranean water through the Strait of Gibraltar. Progress in Oceanography 21: 41-82.

Béthoux J.P. and G. Copin-Montégut. 1986. Biological fixation of atmospheric nitrogen in the Mediterranean Sea. Limnology and Oceanography 31(6): 1353-1358.

Béthoux J.P., P. Morin, C. Chaumery, O. Connan, B. Gentili and D. Ruiz-Pino. 1998. Nutrients in the Mediterranean Sea, mass balance and statistical analysis of concentrations with respect to environmental change. Marine Chemistry 63: 155-169.

Bryden H.L. and T.H. Kinder. 1991. Steady two-layer exchange through the Strait of Gibraltar. Deep-Sea Research 38: S445-S463.

Candela J. 1990. The barotrophic tide in the Strait of Gibraltar. p.457-475. In: L.J. Pratt (Ed.). The physical oceanography of sea straits. Kluwer Academic Publishing.

Echevarría, F., J.L. Acuña, S. Hernández León, E. Saiz, A.M.P. Santos and M. Barangé (Eds.). 2007. Ecological functioning of the Iberian seas: A synthesis of GLOBEC research in Spain and Portugal. Progress in Oceanography 74(2-3): 95-422.

Echevarria F., J. García-Lafuente, M. Bruno, G. Gorsky, M. Goutx, N. González, C.M. García, F. Gómez, J.M. Vargas, M. Picheral, L. Striby, M. Varela, J.J. Alonso, A. Reul, A. Cózar, L. Prieto, T. Sarhan, F. Plaza and F. Jiménez-Gómez. 2002. Physical-biological coupling in the Strait of Gibraltar. Deep-Sea Research II 49(19): 4115-4130.

García Lafuente J., J.M. Vargas, F. Plaza, T. Sarham, J. Candela and B. Basheck. 2000. Tide at the eastern section of the Strait of Gibraltar. Journal of Geophysical Research 105(C6): 14197-14213.

García Lafuente J. and F. Criado Aldeanueva. 2001. La climatología y la topografía del Estrecho de Gibraltar determinantes de las propiedades termohalinas del agua del Mar Mediterráneo. Física de la Tierra 13: 43-54.

Gómez F., G. Gorsky, L. Striby, J.M. Vargas, N. Gónzalez, M. Picheral, J. García-Lafuente, M. Varela and M. Goutx. 2001. Small-scale temporal variations in biogeochemical features in the Strait of Gibraltar, Mediterranean side-the role of NACW and the interface oscillation. Journal of Marine Systems 30: 207-220.

Hopkins T.S. 1999. The thermohaline forcing of the Gibraltar exchange. Journal of Marine Systems 20: 1-31.

Lacombe H. and C. Richez. 1982. The regime of the Strait of Gibraltar. p.13-73. In: J.C.J. Nihoul (Ed.). Hydrodynamics of semi-enclosed seas. Elsevier, Amsterdam.

Macías D., A.P. Martin, C.M. García, M. Bruno, J. García Lafuente, A. Izquierdo, A. Vázquez, A. Yool and F. Echevarría. 2007. Mixing and biogeochemical effects induced by tides on the Atlantic-Mediterranean flow in the Strait of Gibraltar. An analysis through a physical-biological coupled model. Progress in Oceanography 74(2-3): 252-272.

Minas H.J., B. Coste, P. Le Corre, M. Minas and P. Raimbault. 1991. Biological and geochemical signatures associated with the water circulation through the Strait of Gibraltar and in the western Alboran Sea. Journal of Geophysical Research 96(C5): 8755-8771.

Linkage between lower trophic levels and nutritional status of the sardine larvae in the northwest Alboran Sea (Mediterranean Sea)

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The productivity (as estimated in terms of chlorophyll *a* standing stock) and the taxonomic composition of the phytoplankton communities in the northwestern area of the Alboran Sea are subjected to intensive year-to-year changes and inter-decadal variability (Mercado *et al.*, 2005). From a trophodynamic viewpoint, these changes should propagate towards higher trophic levels since a strong bottom-up trophic linkage between phytoplankton, zooplankton and resident fishes has been demonstrated in some oceanic areas (e.g. in northeast Atlantic, Richardson and Schoeman 2004). Therefore, these changes could affect the feasibility of the Alboran Sea to be favourable spawning habitats for small pelagic fishes. Contrastingly, an improvement of the reproductive success of these species under conditions of reduced ocean productivity fuelled by environmental perturbations has been reported for different regions of the Pacific Ocean. According to Bakun and Broad (2003), these unexpected changes in the pelagic ecosystem are due to loopholes in the biological controls of early life stages by predators.

Within the frame of this theoretical context, the linkage between changes in phytoplankton communities and growth and nutritional status of *Sardina pilchardus* larvae has been recently examined in the northwestern area of the Alboran Sea (see the Progress Oceanography special issue on Ecological Functioning of the Iberian Seas: A synthesis of GLOBEC Research in Spain and Portugal; Mercado *et al.*, 2007). The study was based in the analysis of time series of multiple
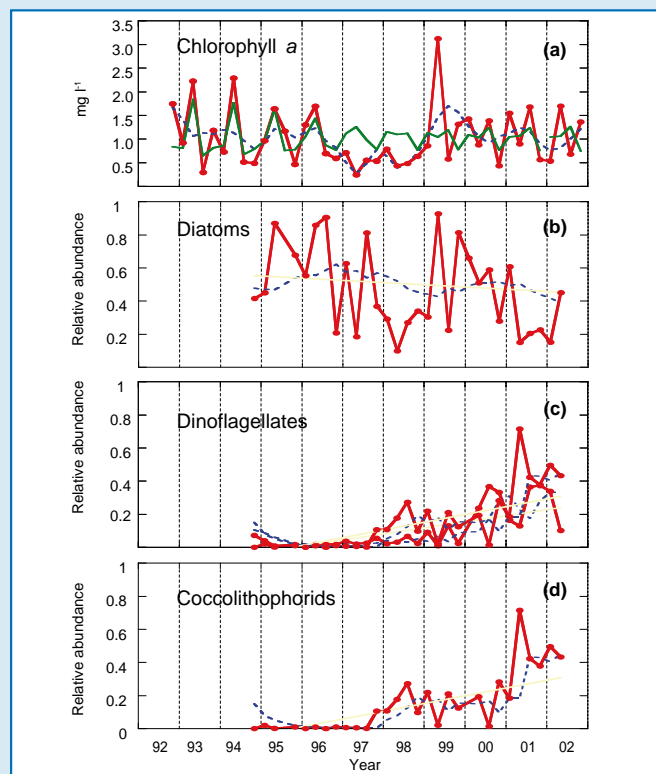
Figure 1. Raw data (red line) and trend component (discontinuous blue line) series of a) chlorophyll a, b) diatom, c) dinoflagellate and d) coccolithophorid relative abundances estimated from autumn 1994 to spring 2002. For chlorophyll a, the seasonal component is also shown (green line). The straight yellow solid line is the linear trend calculated by least square fit of the trend component time series (the Mann-Kendall statistics were significant at p < 0.05).
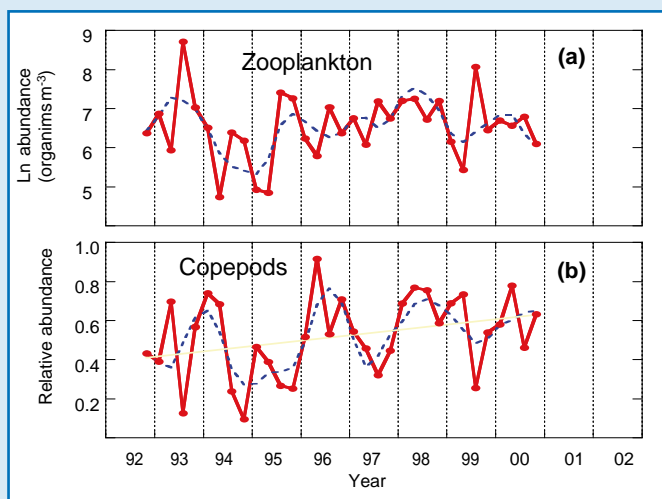
Figure 2. Raw data (red line) and trend component (discontinuous blue line) series of a) zooplankton and b) copepod abundances estimated from autumn 1994 to spring 2002. The straight solid yellow line is the linear trend calculated by least squares fit of the trend component time series (the Mann-Kendall statistics were significant at $p < 0.05$).

Figure 3. Average larval RNA content vs. daily otolith increments for sardine larvae spawned in winter (black spots) and spring (white spots) of 1997, 1998, 2000 and 2001.

environmental variables of quarterly data acquired from 1992 to 2002 within the frame of the monitoring project ECOMALAGA (Instituto Español de Oceanografía). On average, the study area was characterised by an annual nutrient peak in spring. Concordantly, chlorophyll *a* concentration and cell abundance of micro- plus nano-phytoplankton increased during this season (Table 1 and Fig. 1). In spite of these seasonal changes, the analysis of the taxonomic composition of the phytoplankton communities did not reveal a clear annual succession pattern. Contrastingly, peaks of zooplankton abundance were obtained in summer (Table 1 and Fig. 2) due to the increased presence of brachiopods with respect to copepods, which dominated from autumn to spring.

A seasonal change in the larval growth pattern was also detected, as on average, the larval growth at the onset of

Table 1. Seasonal means of different variables estimated from 1992 to 2002. The statistical significance of the differences among the means was determined by an ANOVA. For each file, the means with different superscripts were statistically significant at p < 0.05. The values are mean ± 1 standard deviation.

Variables	Autumn	Winter	Spring	Summer
Chl *a* (µg l^{-1})	0.85±0.21[a]	0.98±0.11[a]	1.51±0.81[b]	0.80±0.20[a]
Phytoplankton abundance (cell ml^{-1})	228±181[a]	211±136[a]	446±635[b]	234±186[a]
Diatoms (%)	44.6±21.3	39.9±18.6	50.6±34.5	50.1±31.2
Dinoflagellates (%)	12.8±15.5	8.9±11.36	6.9±8.1	16.2±16.2
Coccolithophorids (%)	14.3±13.9	13.1±17.1	19.5±25.8	15.4±17.7
Zooplankton abundance (ind. m[-3])	829±376[a]	809±389[a]	467±428[a]	1964±1854[b]
Copepoda (%)	47±19[a]	58±13[a,b]	68±17[b]	37±20[a]

the post-flexion phase (12 mm SL) and otolith growth were higher in spring. The greater somatic mass increase in spring was validated by the significant increase of RNA (Fig. 3), demonstrating a better nutritional status during this station which could be related to the higher phytoplankton abundance (note that zooplankton abundance was lower in spring). Accordingly, García *et al.* (2006) reported high carbohydrate content (i.e. higher phytoplankton food ration) of spring-spawned larvae in the Alboran Sea. In spite of this seasonal pattern, significant interannual changes were obtained in the phytoplankton and zooplankton communities (Figs. 1 and 2). Thus, the abundance of dinoflagellates and coccolithophorids relative to diatoms tended to increase from 1997 to 2002. In particular, 2001 was characterised by a shift of a diatom-dominated phytoplankton community to a non-siliceous algal dominated one, in which coccolithophorids and dinoflagellates become dominant. These inter-annual changes appeared to affect the growth of the winter-spawned *Sardina pilchardus* larvae as the higher growth rates in terms of somatic mass enhancement (using DNA as proxy) occurred in 2001 (Fig. 4).

The comparative analysis of the spring-spawned larvae showed that the lower growth rates corresponded to the larvae captured in the spring of 1997, when the annual peak of chlorophyll *a* was not detected. From this period onwards, the spring larval samples showed an increasing trend, attaining their maximum in 2001. This increase coincides with the initial sharp increase of coccolithophorids and dinoflagellates (Fig. 1), as well as the increase of copepods (Fig. 2). Therefore, the changes in abundance and taxonomic composition in the lower trophic levels adequately explained the observed variability in the nutritional status of the sardine larvae, and it can be concluded that the study area is a favourable spawning habitat for sardine even under changing environmental conditions.

Figure 4. Comparisons of the growth data series in terms of standard length (SL) and DNA increase (W: winter-spawned larvae; S: spring-spawned larvae). Vertical lines indicate one standard deviation.

References

Bakun A. and K. Broad. 2003. Environmental 'loopholes' and fish population dynamics: comparative pattern recognition with focus on *El Niño* effects in the Pacific. Fisheries Oceanography 12(4/5): 458-473.

García A., D. Cortés, T. Ramírez, C. Guisande, J. Quintanilla, F. Alemany, J.M. Rodríguez, J.P. Alvarez and A. Carpena. 2006. Field co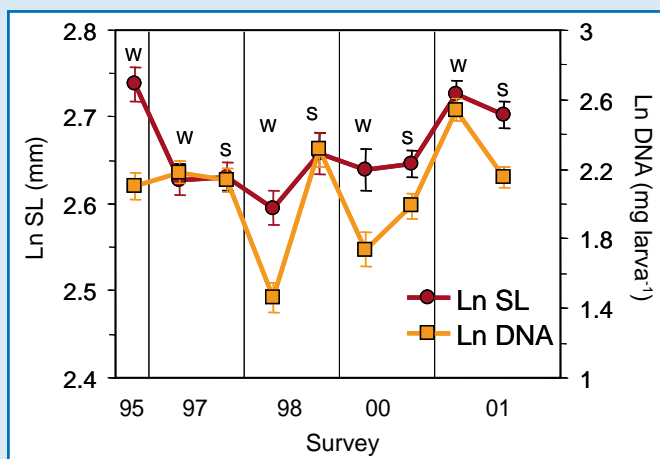mparison of sardine post-flexion larval growth and biochemical composition from three sites in the W. Mediterranean (Ebro River coast, Bays of Almeria and Malaga). Scientia Marina 70: 79-91.

Mercado J.M., D. Cortés, A. García and T. Ramírez. 2007. Seasonal and Inter-annual changes in the planktonic communities of the northwest Alboran Sea (Mediterranean Sea). Progress in Oceanography 74: 273-293.

Mercado J.M., T. Ramírez, D. Cortés, M. Sebastián and M. Vargas. 2005. Temporal changes of the phytoplankton communities in an upwelling area of the Alborán Sea. Scientia Marina 69(4): 451-465.

Richardson A.J. and D.S. Schoeman. 2004. Climate impact of plankton ecosystems in the Northeast Atlantic. Science 305: 1609-1612.

Zooplankton activity and physical-biological interactions in the Catalan Sea (western Mediterranean)

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The Catalan Sea is located in the northwestern area of the Mediterranean, occupying the stretch of water between the Balearic Islands and the northern Iberian Peninsula. It is a highly dynamic environment, characterised by mesoscale singularities related to the existence of density fronts at both sides of the basin, and the geostrophic associated circulation (Salat, 1996). From a biological point of view, the Mediterranean is considered to be an oligotrophic sea, with low nutrient concentrations, but relatively moderate levels of pelagic primary production (100-150 g C m^{-2} y^{-1}; Estrada, 1996).

Typically three phytoplankton blooms occur in the Catalan Sea: one in February-March after the high pressure period in January, the spring bloom in May-June, and finally the autumn bloom in September-October (Duarte *et al.*, 1999). Probably one of the most singular biological structures in the Mediterranean Sea is the presence of a deep chlorophyll maximum (DCM) at the base of the pycnocline during most of the stratification period. This covers most of the year, typically beginning in spring and ending around November/December as a result of both increased cell pigmentation and active cell growth (Estrada, 1996). The DCM covers, patchily, a large area of the NW Mediterranean basin, with chlorophyll maxima associated with the shelfbreak front in the northern side and with the divergence at the centre of the basin (Estrada *et al.*, 1993; Estrada, 1996).

In two papers which appeared in the recent issue of Progress in Oceanography on "Ecological Functioning of the Iberian Seas: A synthesis of GLOBEC Research in Spain and Portugal", we have reviewed the present knowledge on the trophodynamics

Figure 1. Large volume water bottles to take samples for zooplankton biomass.

and growth of zooplankton in the area, and on the effects of physical variability at different scales on zooplankton community and rate processes (Alcaraz *et al.*, 2007; Saiz *et al.*, 2007).

The spatial distribution of zooplankton biomass (Fig. 1) and metabolism (respiration, and excretion of ammonia and phosphorus) in the Catalan Sea appears closely related to the physical characteristics of the mentioned mesoscale hydrographic features. Similarly, their coefficients of variation strongly depend on the physical forcing. Throughout the year, the vertical distribution of zooplankton biomass at noon follows
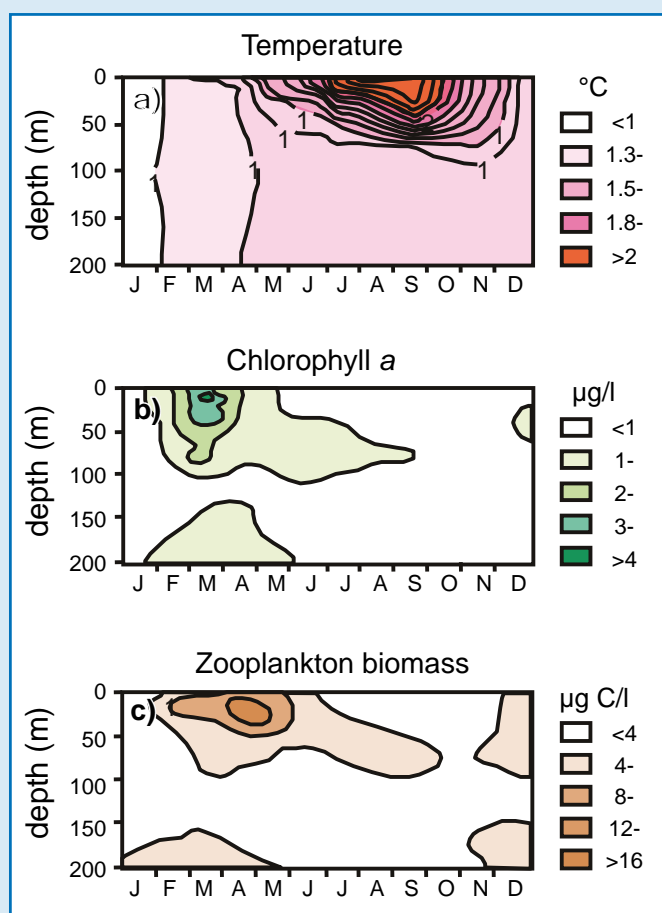
Figure 2. Vertical section (0-200 m depth) of the average annual cycle of A: Temperature, °C; B: Chlorophyll a, µg l⁻¹; C: Zooplankton biomass (µg C l⁻¹) in a station between Barcelona and the channel between Mallorca and Menorca islands. After the winter mixing the stability increases, with the development of a phytoplankton bloom at surface. With the summer stratification, it evolves into a deep phytoplankton layer (DPL) as a consequence of the summer thermal stratification and the nutrient exhaustion. Zooplankton follows a trend similar to phytoplankton, with a short time lag, and in summer develops a deep maximum, coinciding with the DCM.

The average specific respiratory carbon demand of zooplankton, normalised to 13°C, is 0.22 d⁻¹ (Calbet *et al*., 1996). The winter-spring values are slightly lower than the summer-autumn ones, although differences are not statistically significant. On average, during the summer and autumn months routine zooplankton metabolism requires from 20% to 63% of the carbon fixed by primary producers (Alcaraz, 1988).

The excretion values in summer and autumn are not statistically different from those in winter and spring, although the zooplankton C:N metabolic ratios (indicators either of the metabolic substrate or of the trophic nature of the organisms) are higher in winter. This suggests that the zooplankton metabolism is based on lipids or carbohydrates, or that the community is composed of a higher proportion of herbivores than in summertime, when the C:N metabolic ratios are lower. PO_4-P excretion rates are also similar for winter and summer periods. The specific NH_4-N excretion rates by zooplankton (0.097 d⁻¹) can provide for most of the nitrogen required by phytoplankton for primary production at coastal and frontal areas during summer (Alcaraz *et al*., 1994). The phosphorus excretion by zooplankton in surface layers during the night represents, during the summer period of thermal stratification, about 62% of the requirements for primary production.

Feeding of zooplankton in the Catalan Sea typically appears to be food limited, with average daily rations on a yearly basis in the order of 48% C d⁻¹ (Broglio *et al*., 2004; Atienza *et al*., 2006). Heterotrophic prey (ciliates) constitute a relevant fraction of their diet (ca. 31 and 46%, respectively, of the carbon and nitrogen intake), as an alternative to the scarce phytoplankton. In oligotrophic systems such as the Catalan Sea, ciliates (and likely other microheterotrophs as well) represent from the copepod point of view an additional large-sized nutritional resource in a diluted phytoplankton environment (Calbet and Saiz, 2005). In this regard the DCM must be viewed as an oasis for zooplankton feeding (Saiz and Alcaraz, 1990), accentuating the difference between a poor surface layer (0.2-0.3 µg chl l⁻¹) and relatively richer waters at depth (1-2 µg chl l⁻¹; Estrada, 1996). This effect is further enhanced by the fact that an important part of the ciliate community also locates at the DCM depth (Dolan and Marrasé, 1995).

From a structural point of view, the inclusion of ciliates and other microheterotrophs in the diet of zooplankton in the Catalan Sea constitutes an indirect link between copepods and the small primary producers and nanoheterotrophs of the microbial food web, too small to be preyed on efficiently by copepods. However, the strength of this coupling is uncertain because the trophic impact and control exerted by zooplankton on their prey populations are typically low on standing stocks. At certain times, nevertheless, predation by crustacean zooplankton could account for 30-50% of the phytoplankton and ciliate production in the area.

a pattern similar to that of chlorophyll. In summer, a significant proportion of the epipelagic zooplankton biomass is concentrated in a deep layer, coinciding with the DCM (Alcaraz, 1988).

Average zooplankton biomass (>200 µm mesh; Fig. 2) in the Catalan Sea is about 8 µgC l⁻¹ and 1.2 µgN l⁻¹, with winter-spring values slightly higher than summer-autumn ones. Zooplankton horizontal distribution follows a negative coast-offshore gradient, with minimum biomass values located in the front (Calbet *et al*., 2002). In general, the spatial distribution pattern in relation to the frontal structures is comparable to those observed in the Ligurian front (Boucher, 1984).

As expected from the control exerted by physical variability on the biological properties of plankton, the short-term variability (hours, days) of zooplankton biomass and individual size are significantly higher at the shelfbreak, where intermittent, non-periodic mechanical energy inputs like wind episodes induce higher instability.

Figure 3. Euphausiids frequent in the Catalan density front (from a drawing by M. Alcaraz). From top to bottom and left to right: Meganyctiphanes norvegica, Euphausia krohnii, Stylocheiron longicorne, Thysanoessa gregaria, and Nematoscelis megalops.

Regarding zooplankton production (Fig. 3), the available estimates of growth rates in the area are based on the egg production rate of copepods (Calbet *et al*., 1996; Saiz *et al*. 1999; Calbet *et al*., 2002). Although there are no systematic studies focused on seasonal patterns of copepod egg production in the Catalan Sea, the reported data show that egg production rates appear to be limited, especially in summer. The copepod egg production studies conducted concern the changes in productivity in relation with coastal-offshore gradients and the presence of the shelfbreak front in the Catalan Sea evidenced, similarly to what was mentioned above about zooplankton distribution, no support to an enhancement of copepod productivity at the front. Tentative estimates of copepod production in the Catalan Sea are in the order of 20-40 mg C m^{-2} d^{-1}. These values are comparable, given the assumptions taken and the differences in approaches, to previous secondary production estimates in the nearby Gulf of Lions and to available estimates for neritic and oceanic tropical waters. The zooplankton production estimated for the Catalan Sea would account for roughly 6-11% of the average primary production estimated for the western Mediterranean basin (300-400 mg C m^{-2} d^{-1}; Estrada, 1996).

References

Alcaraz M. 1988. Summer zooplankton metabolism and its relation to primary production in the Western Mediterranean. In: H.J. Minas and P. Nival (Eds.). Océanographie Pélagique Méditerranénne. Oceanologica Acta 9: 185-191.

Alcaraz M., A. Calbet, M. Estrada, C. Marrasé, E. Saiz and I. Trepat. 2007. Physical control of zooplankton communities in the Catalan Sea. Progress in Oceanography 74: 294-312.

Alcaraz M., E. Saiz and M. Estrada. 1994. Excretion of ammonia by zooplankton and its potential contribution to nitrogen requirements for primary production in the Catalan Sea (NW Mediterranean). Marine Biology 119: 69-76.

Atienza D., A. Calbet, E. Saiz, M. Alcaraz and I. Trepat. 2006. Trophic impact, metabolism, and biogeochemical role of the marine cladoceran *Penilia avirostris* and the co-dominant copepod *Oithona nana* in NW Mediterranean coastal waters. Marine Biology 150: 221-235.

Boucher M. 1984. Location of zooplankton populations in the Ligurian marine front; role of ontogenic migration. Deep-Sea Research 45: 133-173.

Broglio E., E. Saiz, A. Calbet, I. Trepat and M. Alcaraz. 2004. Trophic impact and prey selection by crustacean zooplankton on the microbial communities of an oligotrophic coastal area (NW Mediterranean Sea). Aquatic Microbial Ecology 35: 65-78.

Calbet A., M. Alcaraz, E. Saiz, M. Estrada and I. Trepat. 1996. Planktonic herbivorous food webs in the Catalan Sea (NW Mediterranean): temporal variability and comparison of indices of phyto-zooplankton coupling based on state variables and rate processes. Journal of Plankton Research 18: 2329-2347.

Calbet A. and E. Saiz. 2005. The ciliate-copepod link in marine ecosystems. Aquatic Microbial Ecology 38: 157-167.

Calbet A., E. Saiz and M. Alcaraz. 2002. Copepod egg production in the NW Mediterranean: effects of winter environmental conditions. Marine Ecology Progress Series 237: 173-184.

Dolan J.R. and C. Marrasé. 1995. Planktonic ciliate distribution relative to a deep chlorophyll maximum: Catalan Sea, N.W. Mediterranean, June 1993. Deep-Sea Research I 11/12: 1965-1987.

Duarte C.M., S. Agustí, H. Kennedy and D. Vaqué. 1999. The Mediterranean climate as a template for Mediterranean marine ecosystems: the example of the northeast Spanish littoral. Progress in Oceanography 44: 245-270.

Estrada M. 1996. Primary production in the northwestern Mediterranean. Scientia Marina 60 (Suppl. 2): 55-64.

Estrada M., C. Marrasé, M. Latasa, E. Berdalet, M. Delgado and T. Riera. 1993. Variability of deep chlorophyll maximum characteristics in the Northwestern Mediterranean. Marine Ecology Progress Series 92: 289-300.

Saiz E. and M. Alcaraz. 1990. Pigment gut contents of copepods and deep phytoplankton maximum in the Western Mediterranean. Journal of Plankton Research 12: 665-672.

Saiz E., A. Calbet, D. Atienza and M. Alcaraz. 2007. Feeding and production of zooplankton in the Catalan Sea (NW Mediterranean). Progress in Oceanography 74: 313-328.

Saiz E., A. Calbet, X. Irigoien and M. Alcaraz. 1999. Copepod egg production in the western Mediterranean: response to food availability in oligotrophic environments. Marine Ecology Progress Series 187: 179-189.

Salat J. 1996. Review of hydrographic environmental factors that may influence anchovy habitats in northwestern Mediterranean. Scientia Marina 60(Suppl. 2): 21-32.

Variability of zooplankton during the decade 1994-2003 in the Balearic Sea (western Mediterranean)

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During the period 1994-2003 a 10 day resolution time-series of sampling was done at a monitoring station in the Mallorca channel (Balearic Sea; Fig. 1). The main objective was to examine the temporal variation of zooplankton groups in relation to environmental variables and large scale climatic indexes, such as the winter NAO (details in Fernandez de Puelles *et al.*, 2007). The correlation found between copepod abundance and large scale climatic factors suggested that these act as the main driver of the zooplankton community. Therefore, the seasonal, and particularly the interannual variation observed in plankton patterns of the Balearic Sea seem to be highly modulated by large scale forcing and can be considered to be an ideal location to investigate the potential consequences of global climate change.

Temperature showed seasonal cycles with mixing during winter months and stratification from spring to autumn. The SST ranged from 13.5°C in March to 27.2°C in August, meanwhile at 75 m depth the range was 13°C to 16°C. Minimum temperatures were registered in 1996 and the maximum values (30°C) in 2003, followed by 1998 (Fig. 2). Interannual variability was found (mean=7.82°C; SD=2.91) and in consequence an increasing pattern was not observed during the study.

Although no clear seasonality was seen in salinity, the highest concentrations (>38 psu) were observed in winter and spring and the lowest (37 psu) in summer and autumn. Remarkable interannual variability was found with low saline years (1995 and 1998) and a period of high salinity after 1999 (Fig. 3; mean of 37.62 psu; SD=0.16). Contrary to temperature, an evident increase in salinity was observed during the analysed period.

Chlorophyll *a* data followed a seasonal cycle (mean=0.28 µg l^{-1}) in which maxima appear regularly in the upper water column early in the year and closer to the bottom in late spring and summer. Usually chlorophyll concentration was very low (<1.5 µg l^{-1}) with the highest values in spring (3.9 µg l^{-1} in 1999 and 2.5 µg l^{-1} in 2000-2001). Interannual variability was evident, with the highest concentration when intense cold winds and heavy storms favoured water mixing and the entrance of nutrient-rich northern waters into the Mallorca channel.

Figure 1. Location of the sampling station in the Mallorca channel (Balearic Sea; Western Mediterranean).
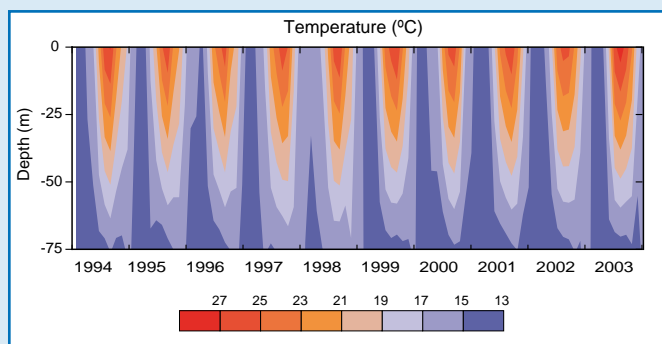
Figure 2. Interannual variability of temperature in the monitoring station at 75 m depth (°C).
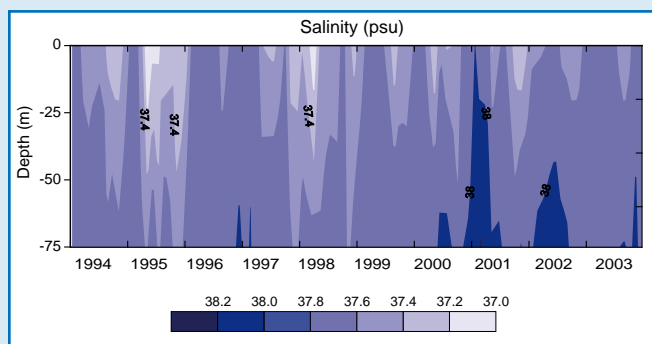

Figure 3. Interannual variability of salinity in the monitoring station at 75 m depth (psu).

In the zooplankton community, the copepods were the most abundant group (56%), followed by the appendicularians (17%), cladocerans (10%) and meroplankton larvae (4%). Three peaks (March, May and September) were distinguished during the annual cycle and a clear coastal-offshore decreasing gradient. More than 80 copepod species were identified, of which 10 amounted to 62% of total abundance. *Clausocalanus* and *Oithona*, dominant in all oceans, were by far the most abundant genera in the area. *Paracalanus parvus*, *Ctenocalanus vanus*, *Centropages typicus*, *Acartia clausi* and *Temora stylifera* were also very abundant. All these species, including the less abundant *Calanus helgolandicus* and *Nannocalanus minor*, can collectively be considered as the main species to depict the copepod community, being good indicators of the areas hydrographic regime. It is important to note that the most abundant copepods previously mentioned are similar to those observed in other Mediterranean areas (Mazzocchi and Ribera d'Alcala, 1995; Christou, 1998). This suggests that, at least in recent decades, the environmental changes which have taken place in neritic waters of the Balearic Sea did not strongly affect the structure of the copepod community.

Interannual variability also emerged from the zooplankton abundance, particularly due to the group of copepods (Fig. 4). Highest abundance was registered during cool years (1996, 2000 and 2001) and the lowest values during the warm 1998. It is noteworthy that during early summer in 2000 and 2001 an increase of cladocerans was observed, mainly due to *Penilia avirostris*. Among this irregular pattern, seasonal cycles were always evident. A decrease of doliolids and chaetognaths was observed during the last years, that was not followed by copepods or appendicularians and siphonophores. In relation to that, significant but opposite correlations between hydrography and the main zooplankton abundance groups were found (p<0.05). This indicates the preference of the zooplankton groups for different properties of the water masses when they are prevalent in the area. Interannual variability was also found in the ichthyoplankton community (1994-1999) with the lowest abundance in 1998. During 1999, the high annual abundances were a result of sardine larvae, whereas the 1997 spring peak was attributable to mesopelagic species, just after the high zooplankton abundance of the previous year.

Overall, the low biomasses but moderate zooplankton abundances found in the Balearic Sea were comparable to oligotrophic areas of the eastern Mediterranean and were lower than other areas of the western Mediterranean. A general "poverty" is evident from the low concentrations of nutrients and plankton biomass; this could however, not always apply to the abundance of zooplankton (predominantly small organism size), whose seasonal distribution may vary irregularly in relation to changes in the water circulation of the Balearic Sea.

In the western Mediterranean, cold years tend to be more productive, partly because winter mixing may reach greater depths, and in part because the formation of deep water in the Gulf of Lions may occur over a larger area (Estrada *et al.*, 1985). This enhanced production gives rise to an increase in zooplankton production, as was observed in our data during the cool and saltier years. The increase during cool years, could be caused by a higher influence of northern Mediterranean waters, whose fertility is higher in relation to the rest of the basin. Contrary to this, the high influence of Atlantic waters clearly observed during 1998, and the lowest zooplankton abundance could have a clear response to warming, when the waters were stratified. Due to this variability no significant zooplankton or copepod trends were found during the 10 year time-series. It seems that the dominant physical factor governing zooplankton abundance is winter air temperature, a proxy for winter climatic conditions which influenced the water temperature by local mixing and by driving oceanic advection into the Mallorca channel. At smaller scales, the mesoscale hydrographic features, as fronts or eddies, resulting from the interaction between both surface water masses, condition the abundance and the structure of planktonic communities in the Balearic Sea.

Significant correlation was found between zooplankton, in particular copepods, and the winter NAO index during the studied period (r^2= 0.50; p<0.05). A negative NAO index (<1) seems to produce a strong effect in the northwestern Mediterranean, since it may bring cold air to Europe and moist air into the Mediterranean producing cooler winters (Vignudelly *et al.*, 1999). The lack of westerly winds in western Europe, would favour the input of winds and northern upper waters reaching the Balearic area and then, higher amounts of zooplankton, and particularly copepods, would be expected. On the other hand, a positive winter NAO does not exhibit such a clear relationship with zooplankton. The intensity and permanence of the westerly winds reaching the Iberian mainland during the positive NAO favoured higher input of Atlantic waters into the western Mediterranean with other consequences in the distribution of zooplankton. According
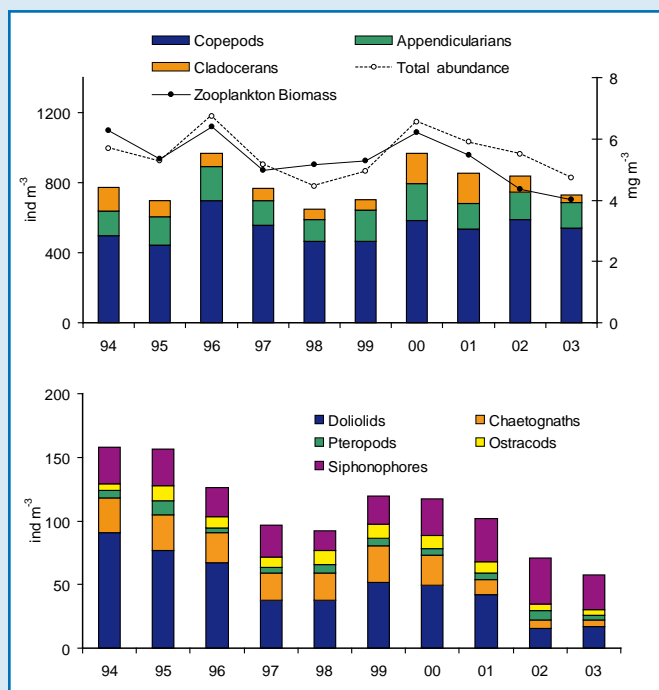
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Figure 4. Interannual variability of main zooplankton groups (annual values of biomass as mg m^-3 and abundance as ind m^-3).

to that, the Mallorca channel would be a sensitive area to study large scale effects in the western Mediterranean. The synchronous variation found between the abundance of zooplankton groups and the hydrological features in the Balearic Sea suggests strong linkages to mechanisms acting over large scales, likely related to atmospheric oscillations, as main drivers of the hydrodynamics at the scale of the western Mediterranean basin. Since temporal variability was observed during these 10 years of data, they seem not to be enough to draw final conclusions and, larger scale investigations should

be conducted, especially to further determine the relationship between atmospheric oscillations and western Mediterranean zooplankton. This may help us to improve our knowledge and better comprehend the zooplankton variability in the pelagic ecosystems of temperate latitudes. In order to assess ecological mechanisms through which planktonic functional groups respond to hydrographic regimes driven by climate, future work should focus on the identified indicator zooplankton species at different time-scales as in other areas of the North Atlantic (Fromentin and Planque, 1996). In turn, in response to a warming climate, this will improve our ability to forecast future changes in the abundance and distribution of the zooplankton community in the whole Mediterranean Sea.

References
Christou E.D. 1998. Interannual variability of copepods in a Mediterranean coastal area (Aegean Sea). Journal Marine Systems 15: 523-532.

Estrada M., F. Vives and M. Alcaraz. 1985. Life and production in the open sea. p.150-200. In: R. Margalef (Ed.). The western Mediterranean. Pergamon Press, London.

Fernandez de Puelles M.L., F. Alemany and J. Jansa. 2007. Zooplankton time-series in the Balearic Sea (western Mediterranean): Variability during the decade 1994-2003. Progress in Oceanography 74(2-3): 329-354.

Fromentin J.M. and B. Planque. 1996. *Calanus* and environment in the eastern north Atlantic. II. Influence of the north Atlantic oscillation on *C. finmarchicus* and *C. helgolandicus*. Marine Ecology Progress Series 134: 101-109.

Mazzocchi M.G. and M. Ribera d' Alcala. 1995. Recurrent patterns in zooplankton structure and succession in a variable coastal environment. ICES Journal Marine Science 52: 679-691.

Vignudelly S., G.P. Gasparini, M. Astraldi and M.E. Schiano. 1999. A possible influence of the North Atlantic Oscillation on the circulation of the Western Mediterranean. Geophysical Research Letters 26(5): 623-626.

Physical and biological processes controlling the distribution of fish larvae in the NW Mediterranean

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The Mediterranean is globally considered to be an oligotrophic sea. However, its complex coastline and bathymetry, added to a strong seasonality, lead to a high environmental diversity at both regional and local scales. Among these diverse environments there are certain places or seasons in which mechanisms that enhance fertility may occur. These mechanisms and related processes are especially relevant when they take place during the period of larval development. This study analyses how environmental conditions occurring in the NW Mediterranean at local and seasonal scales contribute to determining the temporal and spatial patterns of fish reproductive activity in the region. This includes a description of the main physical and biological processes responsible for productivity in relation to the temporal and spatial distribution patterns of fish larvae, as well as how these processes control the population dynamics of fish larvae in

the region. This coupling between environmental processes and fish reproductive success is a key factor for understanding the maintenance of fish populations in the Mediterranean Sea.

The structure of the bathymetry, bottom type, diversity of adult fish habitats, as well as mechanisms controlling the primary production in the region determine the location of spawning, whereas physical processes (e.g. shelf-slope density front and associated currents, continental water inflows, winter mixing, stratification of the water column) determine the final distribution patterns of fish eggs and larvae. High larval concentrations occur over the edge of the continental shelf in relation to the presence of the shelf-slope front associated to the Northern Current. However, this pattern is subject to considerable spatio-temporal variability, due to frontal mesoscale activity and mechanisms
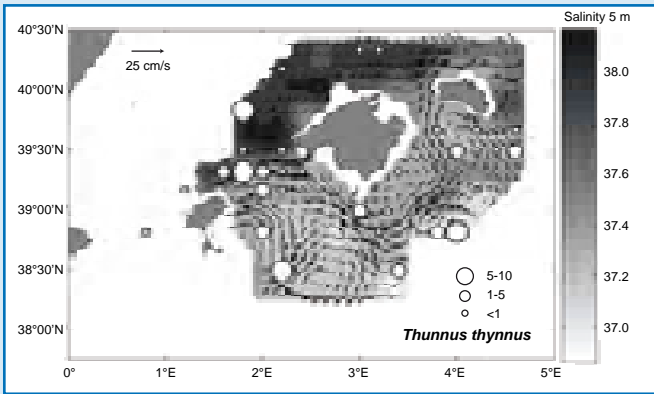
Figure 1. Distribution of Thunnus thynnus larvae off the Balearic archipelago. Larval fish abundance is expressed as number of individuals/100 m³. Salinities under 37.8 correspond to waters of recent Atlantic origin. Arrows represent geostrophic currents at 10 m depth.

Figure 3. Vertical distribution of Engraulis encrasicolus and Sardina pilchardus larvae by size class, during the stratified and mixed period respectively. Daytime (light shading), night time (dark shading).

of convergence/accumulation and divergence/dispersion are associated with the current's meandering flow pattern (Sabatés et al., 2004). Larvae of large pelagic migratory species are mainly located in topographically induced anticyclonic eddies in areas under the influence of recent Atlantic water, near the Balearic frontal system (García et al., 2004; Fig. 1). Adults of these large pelagic migratory species could reach the Balearic archipelago by accompanying the surface Atlantic water and spawning could take place in these water masses.

A pronounced seasonal variability regarding both the number of species and the number of fish larvae in the plankton can be observed throughout the year. The two dominant species, sardine and anchovy, have long reproductive periods with completely opposite seasonal cycles, autumn-winter and spring-summer respectively. The diversity of larval feeding patterns (Sabatés and Saiz, 2000; Fig. 2) as well as the succession of the reproductive activity of different fish species throughout the year might reduce inter- and intraspecific competition for food resources in this area.

During the winter, vertical mixing enhances productivity on continental shelves and maximum algal biomass and high primary productivity have been reported (Estrada et al., 1999). Nevertheless, only a few fish species reproduce: those fish

characteristic of relatively cold water, such as *Sardina pilchardus*, various species of Gadidae, Pleuronectidae and also some species of mesopelagic fish. Vertical vertical distribution of larval species that reproduce in this period is relatively wide (Fig. 3) due to the absence of vertical gradients, which involves a fairly uniform distribution of phytoplankton and microzooplankton in the upper layers. Moreover, there are no intense currents on the shelf and the circulation is usually anticyclonic, favouring larval retention in this zone. Most Mediterranean fish reproduce during the spring-summer stratified period, when the phytoplankton biomass values at the upper layers are lower than in winter. Thermocline development prevents vertical motion and nutrient supply to the surface is interrupted. Therefore, a deep chlorophyll maximum (DCM) can be found at the bottom of the photic zone. The development of the DCM and the high zooplankton biomass associated with it offers an important food source for fish larvae and high concentrations of larvae in advanced developmental states have been found close to the DCM (Olivar et al., 2001; Fig. 3). Additionally, during this period the inputs of continental waters are one of the fertilisation mechanisms of surface waters and some species, such as anchovy, take advantage of this situation. It is important to point out that during summer the cladocerans, which are very abundant in surface layers, make up a significant component in the diet of larvae of various fish species. In addition, during this period an important part of the larval fish diet comes directly from food items of protozoan origin. Calbet et al. (2002) suggested that during the summer, when densities of autotrophs are low, a significant part of the diet of zooplankton would be constituted by heterotrophs. Probably, in oligotrophic areas such as the Mediterranean this trophic link was of major importance resulting in a high efficiency of biomass and energy transfer from primary producers to higher trophic levels.

The variability in the spatio-temporal distribution patterns of larvae of different fish species can be explained by their coupling with the hydrodynamic processes and biological production associated with these. Fish species show reproductive strategies and larval fish behaviour that allow them to take advantage of the available resources throughout the seasonal cycle in an oligotrophic environment. These strategies, together with the high ecological efficiency of oligotrophic systems contribute to the relatively high yield of Mediterranean fisheries.
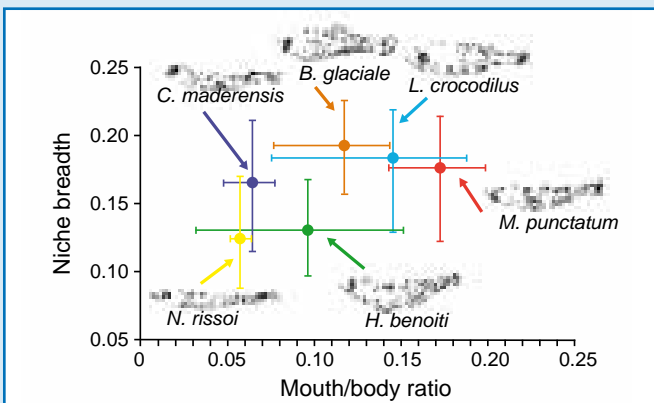

Figure 2. Relationship between mouth size: body size ratio and niche breadth (average of SD of log₁₀ prey for each mouth-size class) for six Myctophiform fish larvae (Benthosema glaciale, Ceratoscopelus maderensis, Hygophum benoiti, Lampanyctus crocodilus, Myctophum punctatum, Notolepis rissoi).
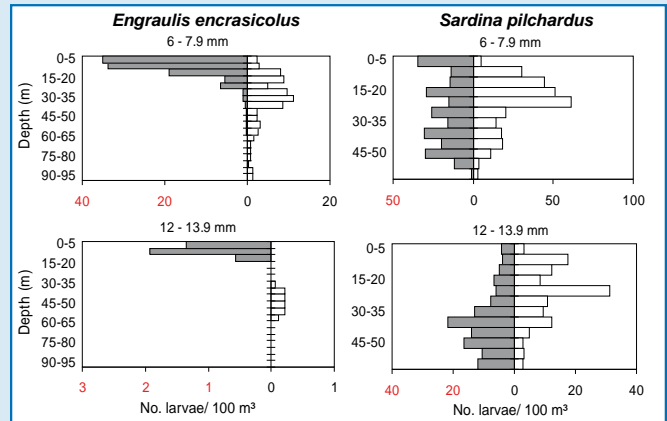
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References

Calbet A., E. Saiz and M. Alcaraz. 2002. Copepod egg production in the NW Mediterranean: Effects of winter environmental conditions. Marine Ecology Progress Series 237: 173-184.

Estrada M., R.A. Varela, J. Salat, A. Cruzado and E. Arias. 1999. Spatio-temporal variability of the winter phytoplankton distribution across the Catalan and North Balearic fronts (NW Mediterranean). Journal of Plankton Research 21: 1-20.

García A., F. Alemany, P. Velez-Belchí, J.L. López Jurado, D. Cortés, J.M. de la Serna, C. González Pola, J.M. Rodríguez, J. Jansá and T. Ramírez. 2004. Characterization of the bluefin tuna spawning habitat off the Balearic archipelago in relation to key hydrographic features and associated environmental conditions. Collective volume of scientific papers, International Commission for the Conservation of Atlantic Tunas 58(2): 535-549.

Olivar M.P., J. Salat and I. Palomera. 2001. Comparative study of spatial distribution patterns of the early stages of anchovy and pilchard in the NW Mediterranean Sea. Marine Ecology Progress Series 217: 111-120.

Sabatés A. and E. Saiz. 2000. Intra- and interspecific variability in prey size and niche breadth of mesopelagic fish larvae. Marine Ecology Progress Series 201: 261-271.

Sabatés A., J. Salat and M. Masó. 2004. Spatial heterogeneity of fish larvae across a meandering current in the northwestern Mediterranean. Deep-Sea Research I 51: 545-557.

Small pelagic fish in the NW Mediterranean Sea: an ecological review

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In the NW Mediterranean Sea, anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) are the most important small pelagic fish in terms of biomass and catch. Round sardinella (*Sardinella aurita*) and sprat (*Sprattus sprattus*) are also present in this region. A review of the information available on their biology and ecology has been done (Palomera *et al.*, 2007) to point out the gaps in current knowledge necessary to understand the dynamics of small pelagic fish in the region and to progress towards a precautionary and adaptive management. The commercial exploitation of small pelagics in the NW Mediterranean has been significant since the early 1940s. Although sardine makes up the largest share, anchovy reaches a higher price in the market and is thus more important and subject to heavier fishing pressure.

Data obtained from different studies in the NW Mediterranean allowed us to characterise the spawning habitats of sardine, anchovy and round sardinella by temperature and salinity. Egg abundance superimposed on T-S plots (Fig. 1) clearly defines the spawning habitats of the three species based on water mass characteristics. Anchovy eggs in the region are mainly found in warm waters, between 17 and 23°C, a temperature range that is located between that of the other two species. Moreover, anchovy is the only species that spawns in a wide salinity range, including waters of continental origin. Cold waters (12-14°C) are preferred by sardine to spawn, although spawning also occurs up to 19°C (Fig. 1). The opposing trend is shown by round sardinella, which may spawn at an SST higher than 23°C. The reproductive period of round sardinella in the NW Mediterranean stretches over the warmest period of the year, from July to October in accordance with its tropical origin.

According to their spawning periods, the increase in temperature and day length must trigger anchovy spawning, while the decrease in temperature and day length is the trigger in sardine. Nevertheless, the processes involved in the homogenisation of the water column and the considerable decrease in temperature

are much more variable than those leading to the increase and stratification of the water column. This implies that the processes to reach optimum spawning conditions for sardine are longer and more variable than for anchovy. Larval distribution is also related to major productivity mechanisms of the respective spawning seasons. In spite of the different thermal regimes that anchovy and sardine experience during the early larval stages, growth rates for the two species are within similar ranges (Fig. 2). Taking into account that metabolic rates should be lower in colder waters, this suggests that other factors like food quality or assimilation efficiency could have a more important role as a compensatory factor in sardine larval growth processes.
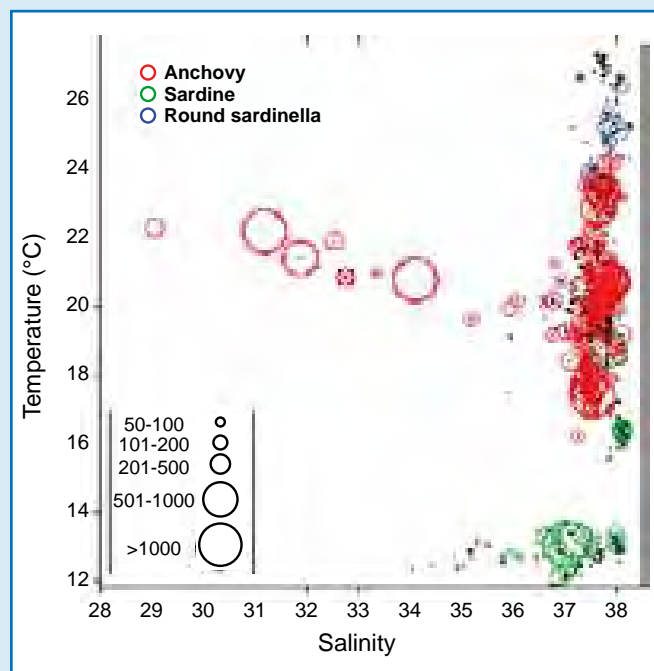

Figure 1. Surface temperature–salinity plots for anchovy, sardine and round sardinella eggs from surveys carried out in northwestern Mediterranean waters (only abundances >50 egg m⁻² are drawn).
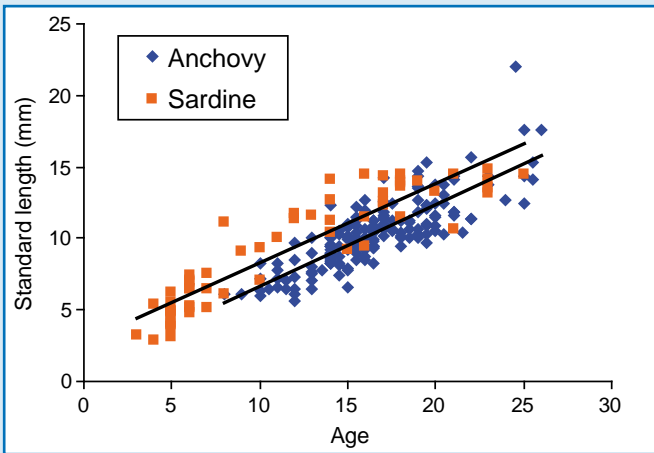
Figure 2. Age-length relationship of sardine (y = 0.5518x + 2.7806) and anchovy (y = 0.5588x + 1.1399) larvae sampled in February 1999 and June 2001, respectively

Because adults and larvae of sardine and anchovy feed on plankton, recruitment of these species in the highly variable NW Mediterranean will be determined by variations in environmental processes. An increase in planktonic production during the spawning period (e.g. by increasing nutrient availability mediated though river runoff or wind mixing) may affect these species rapidly. Linear transfer function models between landings and environmental variables during the spawning season of anchovy and sardine revealed the importance of Ebro River discharges for anchovy production, and of wind mixing for sardine production. Results indicated significant and positive correlation between spawning of anchovy and sardine with river flow and wind mixing, respectively (Lloret *et al.*, 2004). This is in agreement with the reproductive behaviour of both species. Spawning of anchovy is restricted to the surface

and larvae remain above the thermocline (Palomera, 1991). Thus, an increase in surface primary productivity in the enriched continental waters enhances production of zooplankton, the main food for anchovy larvae (Tudela *et al.*, 2002). The only source that may contribute to surface productivity is nutrient input from river outflow (Salat, 1996). Sardine spawns during autumn-winter, when the water column is vertically homogeneous and relatively cool. At that time, vertical mixing partly associated with wind regimes will affect the entire surface layer, carrying nutrients to the entire euphotic zone. Sardine larvae exhibit deeper vertical distribution than anchovy, with preferred levels above 50 m depth (Olivar *et al.*, 2001). Survival of sardine larvae is therefore closely related to vertical mixing and, consequently, to wind stress as a contributing mechanism.

Trophic behaviour studies of adult anchovy carried out during the spawning season in the Catalan Sea and the Gulf of Lions evidenced that this species feeds on small zooplankton, mostly copepods, and to a lesser extent on molluscs, cladocerans, other crustaceans and appendicularians (Tudela and Palomera, 1997; Plounevez and Champalbert, 2000). The main prey species for anchovy are *Centropages typicus*, *Temora stillifera*, *Microsetella rosea* and *Oncaea* spp. The daily ratio of food ingested by anchovy in the NW Mediterranean Sea was 4% of individual weight (34.1 cal g[-1]). In the Catalan Sea, the consumption of adult anchovy was estimated to represent as much as 20% of the total zooplankton production accessible to anchovy aggregations. These results evidence the important role of this species in channelling energy from the pelagic food webs to higher trophic levels. Because sardine is more abundant than anchovy in the NW Mediterranean, combined predation of both anchovy and sardine may account for consumption of a large proportion of zooplankton production in the region.
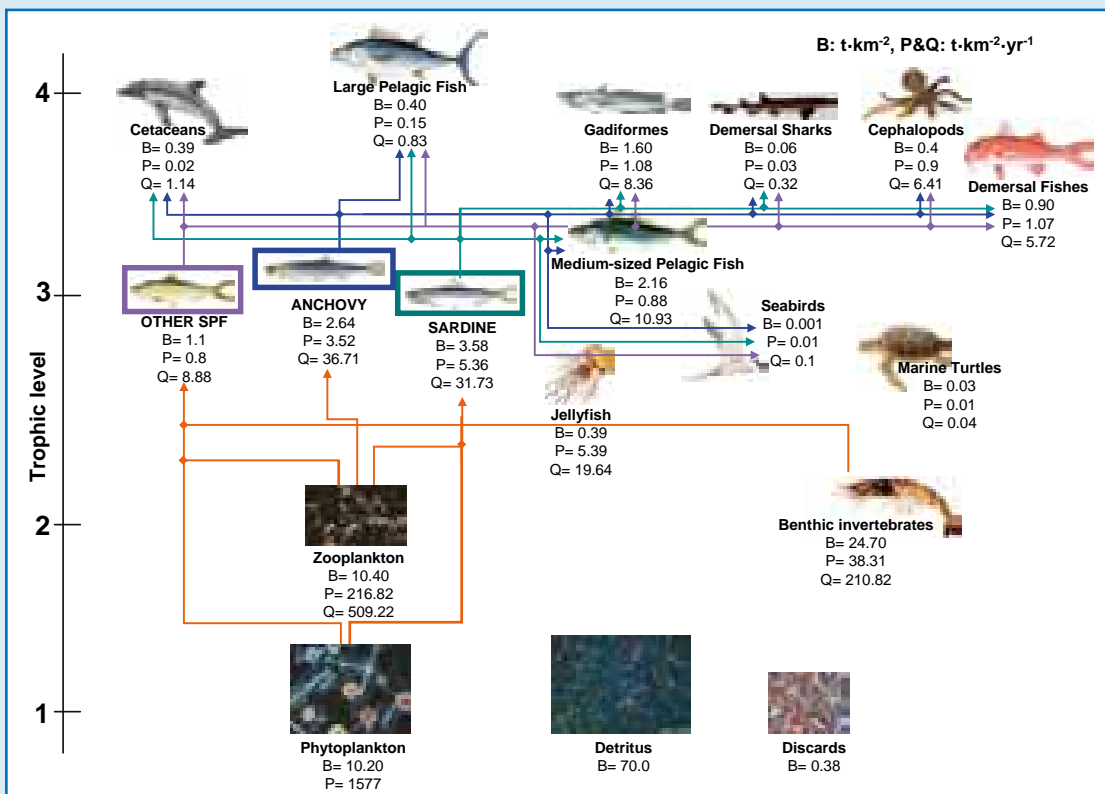

Figure 3. Schematic representation of the South Catalan Sea continental shelf food web, where the trophic role of small pelagic fish is highlighted.
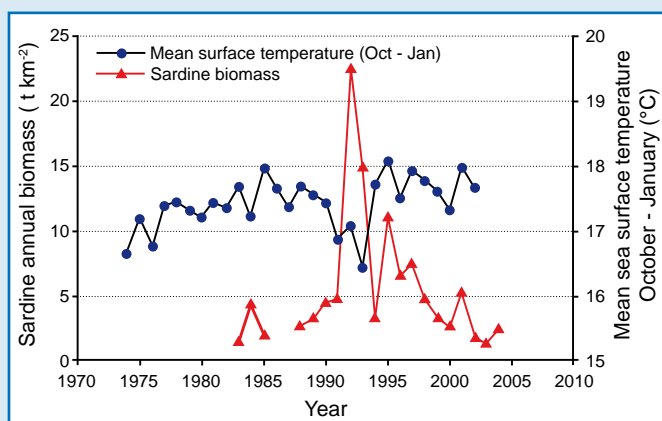
Figure 4. Time series of sardine biomass (t, km^{-2}) and yearly mean sea surface temperature (SST, ºC) during the spawning months in the South Catalan Sea area.

Modelling the exploited continental shelf and upper slope ecosystem associated with the Ebro River Delta (in the South Catalan Sea; Coll *et al.*, 2006) using the Ecopath with Ecosim software highlighted the role of small pelagic fish in the NW Mediterranean (Fig. 3). Analysis of the biomass, production, and consumption of production highlighted the importance of sardine and anchovy within the system: anchovy consumed 22% of system production, while sardine consumed 25%. Dynamics of biomass and catch related to anchovy and sardine were successfully reproduced over time, demonstrating a decrease in biomass and catches of anchovy and sardine in the ecosystem from the late 1970s to the present. In addition, the intense decrease in sardine biomass had a slight positive effect on anchovy, probably due to partial competition for trophic resources.

Sardine was identified to be involved in wasp-waist flow control situations (controlling both the prey and the predators), while anchovy and the other small pelagic fish group were identified as important bottom-up flow control groups (controlling predators). Dynamic modelling which enabled prediction of an environmental function related to the primary production dynamics. The environmental function decreased with time, while there was an increase in both temperature and NAO index related with warmer and drier time periods in the Mediterranean region. Because there is no evidence of a decrease in the primary production in the area, this environmental function is suggested to be related to sardine biomass dynamics, where there is a negative relation of sardine biomass in the South Catalan Sea area and the mean SST per year during the spawning months (Fig. 4).

Small pelagic fish have therefore been shown to be key mid-trophic levels in the NW Mediterranean Sea. Both internal features of the food web (e.g. flow control and trophic interactions) and external features (e.g. fishing activity and environmental factors) are significant drivers of small pelagic fish dynamics in the NW Mediterranean Sea over time.

References

Coll M., I. Palomera, S. Tudela and F. Sardà. 2006. Trophic flows, ecosystem structure and fishing impact in the South Catalan Sea, North Western Mediterranean, Journal of Marine Systems 59: 63-96.

Lloret J., I. Palomera, J. Salat and I. Solé. 2004. Impact of freshwater input and wind on landings of anchovy (E*ngraulis encrasicolus*) and sardine (*Sardina pilchardus*) in shelf waters surrounding the Ebre River delta (North Western Mediterranean), Fisheries Oceanography 13(2): 102-110.

Olivar M.P., J. Salat and I. Palomera. 2001. A comparative study of spatial distribution patterns of the early stages of anchovy and pilchard in the NW Mediterranean Sea. Marine Ecology Progress Series 217: 111-120.

Palomera I. 1991. Vertical distribution of eggs and larvae of *Engraulis encrasicolus* in stratified waters of the western Mediterranean, Marine Biology 111: 37-44.

Palomera I., M.P. Olivar, J. Salat, A. Sabatés, M. Coll, A. García and B. Morales-Nin. 2007. Small pelagic fish in the NW Mediterranean Sea: An ecological review. Progress in Oceanography 74(2-3): 377-396

Plounevez S. and G. Champalbert. 2000. Diet, feeding behaviour and trophic activity of the anchovy (*Engraulis encrasicolus* L.) in the Gulf of Lions (Mediterranean Sea), Oceanografica Acta 23(2): 175–192.

Salat J. 1996. Review of hydrographic environmental factors that may influence anchovy habitats in North Western Mediterranean. Scientia Marina 60(S2): 21-32.

Tudela S. and I. Palomera. 1997 Trophic ecology of European anchovy *Engraulis encrasicolus* in the Catalan Sea (northwest Mediterranean), Marine Ecology Progress Series 160: 121-134.

Tudela S., I. Palomera and G. Quilez. 2002. Feeding of anchovy *Engraulis encrasicolus* larvae in the northwest Mediterranean. Journal of Marine Biological Association UK 82: 349-350.

The coastal-ocean transition zone in the Canary Current system

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During the last decade, the institutions engaged in marine science in the Canary Islands have collaborated in the development of a science strategy related to GLOBEC. The objectives attained were 1) the retrospective analysis of zooplankton taxonomy, abundance and biomass data, 2) the development of new methods for the study of zooplankton growth and metabolism, 3) the study of the role of the deep scattering layers in the structure of the pelagic ecosystem in oceanic waters, 4) the mesoscale variability due to the effect of eddies shed by the Canary Islands and their effect in the accumulation of zooplankton and fish larvae, 5) the effect of upwelling filaments in the transport of zooplankton and fish larvae from the northwest African shelf to the islands, 6) the distribution and evaluation of fish biomass using acoustics around oceanic islands, and 7) the interplay between the physical variability and predation by the deep scattering layers and fish on the development of fish stocks in the area.

The Canary Current is the easternmost branch of the North Atlantic subtropical gyre flowing southward. The most important characteristic of the region is the presence of the large upwelling

area off the northwest African coast. High chlorophyll and primary production normally observed in coastal waters due to upwelling, decrease rapidly towards the ocean. Therefore, the sharp gradient from the permanently stratified waters of the subtropical gyre to the coastal upwelled waters makes this area of great oceanographic interest. Mesoscale phenomena are of importance in this region as besides upwelling filaments, the complex eddy system shed from the Canary Islands is unique in comparison with other similar systems such as the Humboldt, California and Benguela. The Canarian Archipelago extends over 600 km perpendicular to the general flow of the Canary Current. Therefore, the physical setting is quite different due to the mesoscale variability imposed by the islands (Barton and Arístegui, 2004).

Biological consequences of these perturbations are important for the upper trophic levels. Zooplankton and fish larvae drift with currents and are influenced by the eddy field. Zooplankton show low values of biomass in relation to cyclonic eddies due to the outward movement of the water and an accumulation around anticyclonic eddies due to the inward effect (Hernández-León *et al.*, 2001a). Ichtyoplankton surveys around the islands also show a tendency of larvae to concentrate in two stagnation points upstream and downstream of the island (Rodríguez *et al.*, 2001).

The coupling of production in the coastal area off northwest Africa with the oceanic zone through filaments and eddies topographically formed in the coast or shed by the islands promotes a continuous transport of organic matter towards the deep ocean. In the Canaries region, filaments are recurrent structures shed from the African upwelling, between Cape Juby and Cape Bojador. They transport upwelled waters rich in chlorophyll (Fig. 1; Pacheco and Hernández-Guerra, 1999), zooplankton (Hernández-León *et al.*, 2002) and fish larvae (Fig. 2; Rodríguez *et al.*, 1999).

The fish larvae community was poorly known in the Canaries and a special effort has been made during recent years to describe the taxonomical composition along the annual cycle.
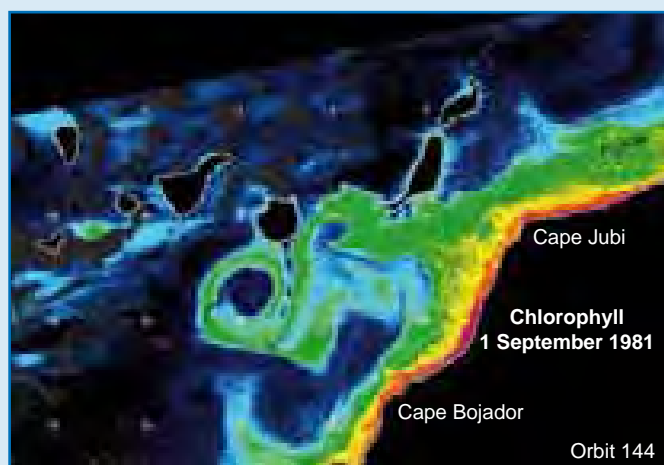
Figure 1. Remote sensing image of chlorophyll taken by the CZCS sensor showing an upwelling filament trapped by an anticyclonic eddy generated by the Gran Canaria Island. Chlorophyll in the figure increases from blue to red. From Pacheco and Hernández-Guerra (1999).
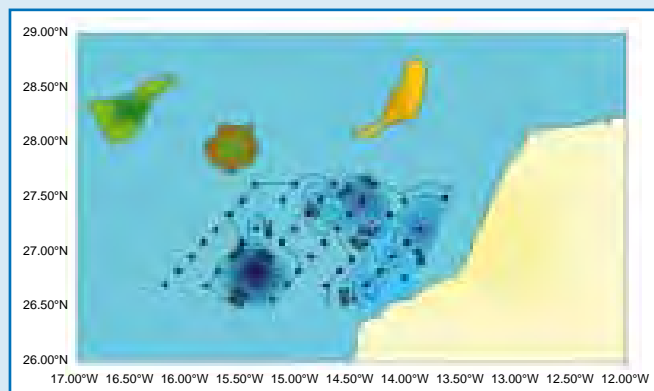
Figure 2. Abundance of Sardina pilchardus along an upwelling filament off northwest Africa. Redrawn from Rodríguez et al. (1999).

Of particular interest were the clupeiform larvae due to their important economical and ecological value. *Sardinella aurita* (round sardinella) were the most common species of this group in the last decade, in contrast to *Sardina pilchardus* (pilchard), which used to be so in the early 1990s. Concentration and retention processes are typical of upwelling filaments. These effects were observed for African neritic fish larvae (Rodríguez *et al.*, 2004). A quasi-permanent cyclonic eddy, located near the upwelling zone, represented a nursery area for some clupeiform larvae, enabling them to overcome the negative effect of the Ekman transport. Neritic fish larvae transported offshore in these filaments sometimes reach the eastern coasts of the Canary Islands, as shown by Bécognée *et al.* (2006). Some clupeiforms, such as the pilchard, round sardinella and European anchovy appeared to be good tracers of these structures. In particular, the case of the pilchard is of interest to study the long-term climate changes. As deduced by biometric studies, this species is not reproducing in the Canary Island waters. However, early stages are found in the ichtyoplankton samples around the islands. The presence of this larvae coinciding with the strike of upwelling filaments with the islands were confirmed in the study of different annual cycles, suggesting that this transport is a common dispersal process.

An important component of the pelagic fauna, unfortunately scarcely studied, are the organisms inhabiting the Deep Scattering Layers (DSLs). In the Canary Current this layer is enhanced due to the influence of the coastal upwelling and is located between 400 and 600 m depth almost permanently (Boden and Kampa, 1967). A portion of these organisms are interzonal diel vertical migrants. A high percentage of this fauna predate upon epizooplankton and the consequences of their migration to the upper layers of the ocean at night are now being understood. In the study of an annual cycle of epipelagic copepods around the Canary Islands, Hernández-León (1998) observed an important variability in their abundance. Curiously, a succession of peaks was found to coincide with the full moon. This variability showed a sharp similarity with the zooplankton lunar cycle described by Gliwicz (1986) in African lakes. Historical data review of zooplankton abundance (Hernández-León, 1998; Hernández-León *et al.*, 2001b) and later field studies (Hernández-León *et al.*, 2002, 2004) showed the presence of a lunar cycle in epizooplankton due the predatory pressure of

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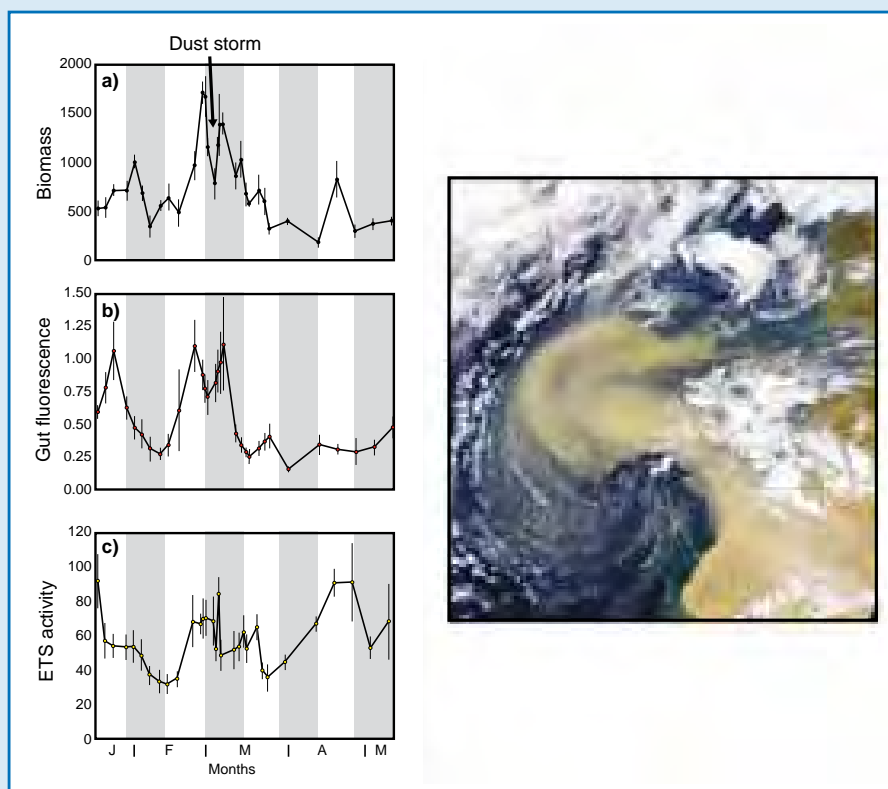
Figure 3. a) Total zooplankton biomass (mg dry weight·m⁻²) and b) average (± standard error) specific gut fluorescence (µg pigment·mg⁻¹ protein) and c) specific ETS activity (µlO₂·mg⁻¹ protein·h⁻¹). Note the increase in specific gut content and ETS activity before the increase in biomass. Shaded areas correspond to the periods from waning to crescent moon. Observe the increase in mesozooplankton biomass during the illuminated period of the moon cycle and the sharp decrease during the dark period.

The dust storm observed in the photograph (see information in http://visibleearth.nasa.gov/ cgi-bin/ viewrecord?22352) was generated on the date indicated by the arrow in Figure 1a. A sharp increase in chlorophyll (not shown) preceded the increase in mesozooplankton biomass and gut fluorescence coinciding with the dark phase of the moon. Redrawn from Hernández-León et al. (2004).

diel vertical migrants. These organisms do not reach the upper layers of the ocean during the full moon to avoid predation by oceanic fish allowing the zooplankton community to grow. In the annual cycle studied during 2001 (Bécognée et al., 2006), the abundance of Sardinella aurita larvae during the full moon was 38% of that found during the new moon, also suggesting a coupling with the lunar cycle observed in zooplankton.

Finally, the interplay between the physical frame, promoting the biological response and the effect of predation by diel vertical migrants seems of interest to disentangle the fate of carbon in this area. Vertical mixing during winter promotes a slight nutrient enrichment in the euphotic zone, which enhances phyto- and zooplankton growth (Fig. 3). Dust storms also promote large-scale fertilisation in the area. However, the increase in mesozooplankton biomass promoted by the dust storm is transported downward due to predation by diel vertical migrants in the shallower layers during the new moon, sequestering this carbon into the mesopelagic zone. Zooplankton and fish larvae transported by upwelling filaments are also influenced by migrants and the lunar cycle. The active flux promoted and the effect on fish larvae and fisheries deserves further research.

References

Barton E.D.and J. Arístegui. 2004. The Canary Islands coastal transition zone- upwelling, eddies and filaments. Progress in Oceanography 62: 67-69.

Bécognée P., C. Almeida, A. Barrera, A. Hernández-Guerra and S. Hernández-León. 2006. Annual cycle of clupeiform larvae around Gran Canaria Island, Canary Islands. Fisheries Oceanography 15: 293-300.

Boden B.P. and E.M. Kampa. 1967. The influence of natural light on the vertical migrations of an animal community in the sea. Symposia of the Zoological Society of London 19: 15-26.

Gliwicz Z.M. 1986. A lunar cycle in zooplankton. Ecology 67: 883-897.

Hernández-León S. 1998. Annual cycle of epiplanktonic copepods in Canary Island waters. Fisheries Oceanography 7: 252-257.

Hernández-León S., C. Almeida, P. Bécognée, L. Yebra and J. Arístegui. 2004. Zooplankton biomass and indices of grazing and metabolism during a Late Winter Bloom in subtropical waters. Marine Biology 145: 1191-1200.

Hernández-León S., C. Almeida, M. Gómez, S. Torres, I. Montero and A. Portillo-Hahnefeld. 2001a. Zooplankton biomass and indices of feeding and metabolism in island-generated eddies. Journal of Marine Systems 30: 51-66.

Hernández-León S., C. Almeida, A. Portillo-Hahnefeld, M. Gómez, J.M. Rodríguez and J. Arístegui. 2002. Zooplankton biomass and indices of feeding and metabolism in relation to a filament off the Northwest African Upwelling zone. Journal of Marine Research 60: 327-346.

Hernández-León S., C. Almeida, L. Yebra, J. Arístegui, M.L. Fernández de Puelles and J. García-Braun. 2001b. Zooplankton biomass in subtropical waters: Is there a lunar cycle? Scientia Marina 65: 59-64.

Pacheco M. and A. Hernández-Guerra. 1999. Seasonal variability of recurrent phytoplankton pigment patterns in the Canary Islands area. International Journal of Remote Sensing 20: 1405-1418.

Rodríguez J.M., E.D. Barton, L. Eve and S. Hernández-León. 2001. Mesozooplankton and ichtyoplankton distribution around Gran Canaria, an oceanic island in the NE Atlantic. Deep-Sea Research I 48: 2161-2183.

Rodríguez J.M., E.D. Barton, S. Hernández-León and J. Arístegui. 2004. Taxonomic composition and horizontal distribution of the fish larvae community in the Canaries-Coastal Transition Zone, in summer. Progress in Oceanography 62: 171-188.

Rodríguez J.M., S. Hernández-León and E.D. Barton. 1999. Mesoscale distribution of fish larvae in relation to an upwelling filament off Northwest Africa. Deep-Sea Research I 46: 1969-1984.

ICES/GLOBEC/EUR-OCEANS Workshop on the Integration of Environmental Information into Fisheries Management Strategies and Advice [WKEFA]

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Under the auspices of ICES, GLOBEC and EUR-OCEANS a workshop was hosted at the ICES headquarters in Copenhagen, Denmark, 18-22 June 2007, with the objective of identifying methodology to operationalise the use of environmental information for the improvement of fisheries management advice. This objective was to be carried out on the basis of a number of case studies for which consequences for medium term and short term influences in management could be discussed. The meeting was by invitation, co-chaired by John Simmonds (Marine Laboratory, Aberdeen, UK) and Manuel Barange (Plymouth Marine Laboratory, UK), and attended by 18 scientists.

The workshop was preceded by a small planning meeting in February 2007 to assemble a small set of illustrative case studies in which environmental factors can be shown to have had a significant impact on exploited fish population dynamics, so that these could be further developed at the main workshop. The case studies included: east and west Greenland cod, eastern Bering Sea flatfish, eastern Bering Sea pollock, North Sea cod, eastern Baltic cod, north-east Arctic cod, North Sea autumn spawning herring, California sardine, Baltic sprat, Bay of Biscay anchovy and north-east Atlantic sardine. We also used a set of management simulations of the South African pelagic fishery assuming alternate sinusoidal abundance cycles between sardine and anchovy, and theoretical simulations of management under conditions of regime shifts for different types of population and levels of exploitation (Fig. 1).

The main conclusions of the workshop are summarised below. While it has been long accepted that we are providing fisheries advice within the context of a varying environment, the workshop recognised that in the face of global environmental change we need to take into account not only stochastic variability but also trends and shifts in the environment as we develop scientific advice.

The workshop concluded that the effects of environmental change on fisheries management are better addressed by separating variability according to the time scale of the changes. Some aspects such as catastrophic events can only be dealt with though a willingness to remain aware and the collection of information, observing and accounting for unusual events causing migration, mortality or recruitment failure.

Some short term changes can be observed, estimated and brought into advice even where the complexity of the drivers is unknown. For example changes in growth and maturation can be brought directly into methods for estimating spawning stocks one or two years ahead and for estimating catch where TACs are required. Combining such information can improve the performance of management but only if the errors in the information are included appropriately. There are a number of
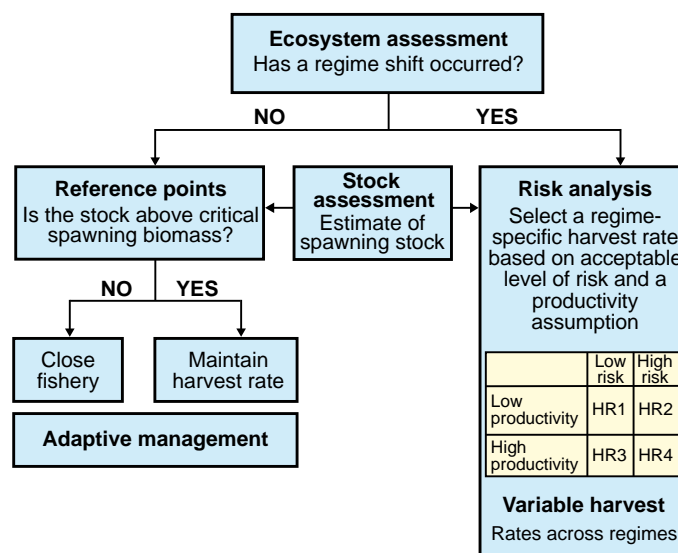
Figure 1. Conceptual decision-rule framework using existing science and management actions available to conduct ecosystem-based fisheries management which includes ecosystem monitoring or assessment for the detection of regime shifts and sets regime-specific harvest rates (HR). From King and McFarlane. 2006. A framework for incorporating climate regime shifts into the management of marine resources. Fisheries Management and Ecology 13: 93-102.

instances where environmental drivers have been clearly shown to explain variability in recruitment, but once in use some have shown problems. This indicates that testing the utility of indicators in management simulations must be a requirement before they are formally applied, including developing implementation frameworks that are informative and robust to errors.

As habitats change, spatial distributions of fish change, both horizontally and vertically. These changes can interact with surveys and fisheries, leading to the requirement to monitor and account for change in catchability in assessment tuning series.

Medium term change cannot be predicted in the same way as short term effects. The approach needs to follow two avenues. Where explicit relationships exist between stock and the environment the mean of stochastic projections can be modified accordingly. Such situations include average temperature dependence, species interactions and food availability for different exploited stocks. Where no explicit relationships exist or there is no basis for predicting environmental drivers into the future, advice should be based on scenario testing.

As a general recommendation the workshop concluded that in the light of climate change, rather than assuming that the mean of a given parameter derived from the (recent) past will best define future we should consider trends and attempt to estimate them. This calls for the development of a number of tools that evaluate estimates of current values and current trends in the

presence of noise in both measurement and environment. The workshop concluded with a number of specific recommendations for changes in:

- productivity regimes that require adapting management procedures or procedures robust to regimes,
- habitat influencing measurement and stock carrying capacity
- growth and maturation influencing short and medium term advice, and
- recruitment changes due to environmental influence in the short and medium term.

Recommendations also include the use of multi-species models primarily for hypothesis testing and testing management procedures. Finally the group recognised the need for longer term prediction and thus for developing climate scenarios for sensitive areas such as the Baltic Sea.

The report of the meeting is available through the ICES (http://www.ices.dk/reports/ACFM/2007/WKEFA/WKEFA_2007.pdf) and the EUR-OCEANS Knowledge Transfer websites (http://www.eur-oceans.eu/training_and_outreach/wp9/).

ICES Working Group on Zooplankton Ecology meet in Riga, Latvia

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Held from 26-29 March 2007, the meeting of the ICES Working Group on Zooplankton Ecology (WGZE) was the largest meeting so far of the group. The meeting, chaired by Astthor Gislason (Marine Research Institute, Reykjavik) was hosted in Riga, Latvia at the kind invitation of Solvita Strake from the Institute of Aquatic Ecology and was attended by 30 scientists representing 14 countries (Fig 1). This article provides a short summary of the discussions and outcomes. The full report of the WGZE meeting can be found at: http://www.ices.dk/iceswork/workinggroups.asp

Some highlights of the WGZE discussions included:

- In the North Atlantic, significant changes have occurred in the abundance, distribution, community structure and population dynamics of zooplankton and phytoplankton, mainly reflecting changes in regional climate, caused predominantly by the warming of air and sea surface.

- The changes in the zooplankton and phytoplankton communities which are at the bottom of the marine pelagic food web, affect higher trophic levels, as the synchrony between predator and prey (match-mismatch) plays an important role (bottom-up control of the marine pelagic environment) in the successful recruitment of top predators, such as fish and seabirds.

- The poor recruitment of several fish of commercial interest and the low seabird breeding productivity recorded in recent years in some regions are associated with changes in plankton biomass and in the seasonal timing of plankton.

In reviewing the ICES Annual Plankton Status Report (http://www.ices.dk/pubs/crr/crr281/CRR281.pdf) various plankton trends and changes were noted and important additions and improvements to the report are planned.

When considering phenological changes several examples were discussed (e.g. *Acartia* sp., *Temora longicornis*, *Pleurobrachia pileus*, echinoderm larvae in the North Sea). Phenology is already included in the ICES Annual Plankton Status Report and will be expanded.

The WGZE had been asked to assess and report on changes in the distribution, population abundance and condition of zooplankton in the OSPAR maritime area in relation to changes

Figure 1. Participants at the WGZE meeting in Riga.

in hydrodynamics and sea temperature. Considering the OSPAR Climate Request the following evidence was provided of changes in the plankton in relation to hydroclimatic changes:

- The NAO has been rising over the past 30 years, as have the surface water temperatures of the European continental shelf. This has caused changes in the planktonic compartment of the marine ecosystem affecting plankton production, biodiversity, species distribution which has had effects on fisheries production and other marine life (e.g. fish larvae and seabirds).

- In North Sea, the population of the previously dominant zooplankton species (the cold water *Calanus finmarchicus*) has decreased in biomass by 70%, between the 1960s and the post 1990s. Warm-water species have moved northwards to replace this species although their biomass is not as abundant.

- A shift in the distribution of many plankton and fish species by more than 10° latitude northward has been recorded in the OSPAR area over the past thirty years.

- The seasonal timing of phyto- and zooplankton production also altered in response to recent climate changes. This has consequences for plankton predator species, including fish,
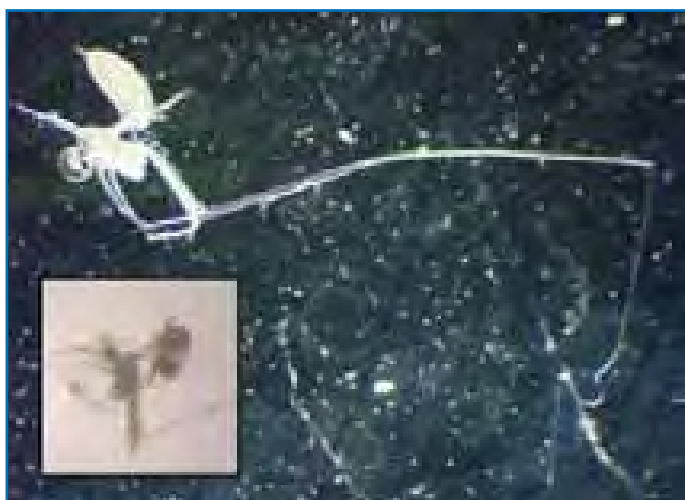
Figure 2. Cercopagis pengoi, an introduced species of cladoceran, which through its predatory activity has had a major impact on the plankton community structure in Baltic. Photographs courtesy of Arno Põllumäe and Julia Polunina (inset).

whose life cycles are timed in order to make use of seasonal production of particular prey species.

- In the North Sea and around the British Isles, considerable increase in phytoplankton biomass has been recorded since the mid-1980s.

- In the North Sea functional changes in the phytoplankton community have been recorded in recent decades, with an increase of dinoflagellates and a decrease of diatom abundance in response to warmer sea waters.

- In the North Sea, warmer conditions earlier in the year together with increased phytoplankton abundance since the late 1980s, have determined the significant increase of meroplankton, in particular echinoderm larvae of *Echinocardium cordatum*. This change in the food web structure, due to the competitive exclusion of the holozooplankton (i.e. permanent plankton species) by the meroplankton, may significantly diminish the transfer of energy towards top pelagic predators (e.g. fish) while increasing the same transfer towards the benthic component.

- Future warming is likely to alter the geographical distribution of primary and secondary pelagic production, affecting oxygen production, carbon sequestration and biogeochemical cycling. These changes may place additional stress on already-depleted fish stocks as well as have consequences for mammal and seabird populations.

Several examples of introduced species were noted from both sides of the North Atlantic, most notably *Mnemiopsis leydii* that has been observed in the Baltic Sea, the Kattegat and the North Sea, and has extended to waters off Bergen.

The WGZE encouraged microzooplankton to be included in time series monitoring within the ICES area.

Arrangements for the planning of the 'Joint WGZE/CIESM Workshop to compare Zooplankton Ecology and Methodologies between the Mediterranean and the North Atlantic (WKZEM)' (Co-

Zooplankton studies in the Baltic

During the Riga meeting a Baltic Sea Mini Session, which included the following presentations of the work of the regional research community.

Short overview of Baltic Sea activities
Piotr Margoński, Sea Fisheries Institute, Gdynia

National research programme climate change impact on the water environment of Latvia
Andris Andrushaitis, Institute of Aquatic Ecology, Riga

Baseline port surveys for invasive marine species in the north-eastern Baltic Sea
Solvita Strake, University of Latvia, Riga

Trying to find out more (about marine mesozooplankton).
Anda Ikauniece, Latvian Institute of Aquatic Ecology, Riga

Monitoring of zooplankton in the SE Baltic
Natalja Demereckiene, Latvian Fish Resource Agency

Zooplankton in the south-east Baltic
Julia Polunina, P.P. Shirshov Institute of Oceanology, Kaliningrad

Hydrological regimes instability and climate changes influence on zooplankton community of open parts of the Baltic Sea and the Gulf of Finland
Larisa Litvinchuk, Zoological Institute of the Russian Academy of Sciences, St Petersburg

Recent newcomers in zooplankton of Estonian coastal areas
Arno Põllumäe, Estonian Marine Institute, Tallin

Zooplankton monitoring as it is carried out by FIMR
Juha Flinkman, Finnish Institute of Marine Research, Helsinki

Sea Fisheries Institute zooplankton activities
Piotr Margoński, Sea Fisheries Institute, Gdynia

Chairs: A. Gislason, Iceland, and G. Gorsky, France), adopted by ICES in 2006, are progressing well. It was decided that the workshop be held in Heraklion, Crete, Greece in the second half of October 2008.

During the meeting a 'Baltic Sea Mini Session ' was held during which scientists from the region presented their research activities (see text box). A particular focus of these talks was the importance of introduced species in affecting the community structure and dynamics of the Baltic. An example cited was the predatory cladoceran, *Cercopagis pengoi* (Fig. 2), which was first found in the Gulf of Riga in 1992. The species is thought to be of Ponto-Caspian origin having been introduced as a result of the discharge of ballast water.

Climatic variability and the swordfish fishery in the eastern South Pacific Ocean: hypotheses and a conceptual model

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The conceptual model of the system inhabited by the swordfish assumes that the fish's life cycle includes the following different stages: a) larval, b) juvenile, and c) adult. The model also assumes that each phase of the life cycle is carried out in a different, geographically separated area: a) spawning zone (oceanic area around Isla de Pascua), b) rearing zone (part of the Cordillera de Nazca), and c) feeding zone (eastern South Pacific off Chile; 24-40°S).

The general hypothesis of the model indicates that environmental phenomena on diverse scales (interannual, seasonal, intraseasonal) that develop in the Pacific Ocean affect the basic biological processes of the swordfish in its different developmental stages and associated zones. Moreover, a series of hypotheses were formulated for the different temporal scales (interannual, seasonal, and intraseasonal).

For the interannual scale, the following hypotheses were formulated:

- The *El Niño* Southern Oscillation (ENSO) events that are manifested as positive (*El Niño*) or negative (*La Niña*) anomalies of the sea surface temperature (SST) in the Pacific Ocean affect:
  - i) the duration and spatial distribution of swordfish spawning in the oceanic area around Isla de Pascua.
  - ii) the spatial distribution, availability, and vulnerability of juvenile swordfish in the Cordillera de Nazca zone.
  - iii) the spatial distribution, availability, and vulnerability of adult swordfish in the feeding zone (the area where the fishery is located).
  - iv) the qualitative and quantitative composition and distribution of the biotic community of which the swordfish is part.
  - v) the spatial distribution, availability, and vulnerability of the swordfish; these have repercussions in regional and local economic-social fishery aspects such as employment, price, investment, and accumulated effort.

For the seasonal scale, the following hypotheses were formulated:

- The annual cycle of solar radiation that is manifested as changes in the distribution of the SST isotherms, the movement of the Pacific anticyclone, oceanic circulation, the location of the subtropical front, and the intensity of the upwelling season in the eastern South Pacific Ocean (ESP) affect:
  - i) the duration and spatial distribution of swordfish spawning in the oceanic area around Isla de Pascua.
  - ii) the spatial distribution, availability, and vulnerability of juvenile swordfish in the Cordillera de Nazca zone.

  - iii) the spatial distribution, availability, and vulnerability of adult swordfish in the feeding zone (the area where the fishery is located).
  - iv) the qualitative and quantitative composition and distribution of the biotic community of which the swordfish is part.
  - v) the spatial distribution, availability, and vulnerability of the swordfish and, therefore, its fishing yields; this, in turn, affects economic-social fishery aspects such as employment, price, investment, and accumulated effort.
- The fishing effort exercised by the foreign fleet affects the local relative abundance of juvenile swordfish in the Cordillera de Nazca zone.
- The fishing effort exercised by the Chilean fleet affects the local relative abundance of adult swordfish in the feeding zone (the area where the fishery is located).
- The geomorphology of the Pacific basin off Chile influences the migratory circuit of the swordfish and, therefore, its spatial distribution, availability, and vulnerability.

For the intraseasonal scale, the following hypotheses were formulated:

- Upwelling fronts and mesoscale structures such as vortices and filaments affect:
  - i) the spatial distribution, availability, and vulnerability of juvenile swordfish in the Cordillera de Nazca zone.
  - ii) the spatial distribution, availability, and vulnerability of adult swordfish in the feeding zone (the area where the fishery is located).
  - iii) the qualitative and quantitative composition and distribution of the biotic community of which the swordfish is part.
  - iv) the distribution of the swordfish fleet operation, which has local repercussions in the costs and prices of the resource.

The theoretical model of the ecosystem inhabited by the swordfish is presented as a diagram of spatial-temporal scales (Perry *et al.*, 2000; Perry and Ommer, 2003). This is a useful tool for conceptualising, integrating, and exploring the relationships of the elements mentioned in the previous section. Such models have been used, for example, to identify the physical processes (e.g. turbulence, tides, fronts) that could influence a variety of biological processes (e.g. feeding, vertical migration, etc.) of the fishery resources (Perry *et al.*, 2000). This type of interscale and interdisciplinary comparison presents productive analytical challenges, attempting to simultaneously understand specific behaviours and identify their underlying processes.

Considering the climatological-oceanographic information from the Pacific Ocean basin and the biological and ecological data on swordfish reported and available in the international literature, along with the environmental and bio-fishery information from

the Chilean swordfish fishery (Barría *et al.*, 2006; Vega *et al.*, 2005; Yáñez *et al.*, 2004, 2006), an integrated conceptual model was adapted to the different spatial-temporal phenomena that affect the marine environment in the Pacific Ocean and the ESP and the distribution and abundance of swordfish in the different stages of its life cycle (Fig. 1). The model considers the variability in swordfish vulnerability and catchability (q), which has been shown in several studies (Bigelow *et al.*, 1999; Podesta *et al.*, 1993; Sedberry and Loefer, 2001; Seki *et al.*, 2002, Yáñez *et al.*, 1996), to be associated with fluctuations in the environmental conditions (environmental forcing). The integrated conceptual scheme implies, for example, that variations in the catch rates (fishery plane) are influenced by physical variability (physical environment plane) through the biological responses of the species and the pelagic community, which occur on similar spatial-temporal scales. Likewise, it also implies that if the scale of these dynamics changes, the impact of the forcing could be reflected in human elements such as the economy, fisheries administration and employment.

Conceptually, swordfish catchability (q) can vary on different spatial-temporal scales. These variations can reflect changes occurring on similar temporal and spatial scales, both in the physical and biological realms. Understanding variations in catch rates as a response to variations in environmental conditions is an important component through which, as previously mentioned, stock evaluation models and fisheries administration can be improved. The proposed conceptual model shows, for example, how interannual fluctuations (associated with *El Niño* events) which are developed in the Pacific Ocean are also manifested on smaller scales in the ESP. Thus, these fluctuations affect the swordfish fishery off Chile (24-40°S and 70-120°W) through the seasonal annual cycle and the intraseasonal dynamics of mesoscale phenomena. In the biological plane, the effects of the physical environment in the Pacific Ocean affect the regional swordfish stock on an interannual scale, as do the seasonality of the swordfish migratory circuit in the ESP and local juvenile and adult feeding processes in the fishery zone. These fluctuations in the physical and biological environment, in turn, affect the fishery plane (human), generating variations in the resource catch rates and, on a larger scale, influencing prices and economic cycles.

Of the biological processes of the swordfish population in the region, reproduction contains a series of elements, variables, or proxies that can be used to reveal the resource's dynamics. Mortality is also important in all its forms, whether natural or due to fishing. Other associated elements include the processes of feeding, local movements, and large-scale movements such as annual migrations. The ecological processes refer mainly to competition within the pelagic community with other fish species that have similar trophic niches, and predation on swordfish, principally on its eggs, larvae, and juveniles, since the adults are considered to be top predators, only preyed on by humans through fishing.
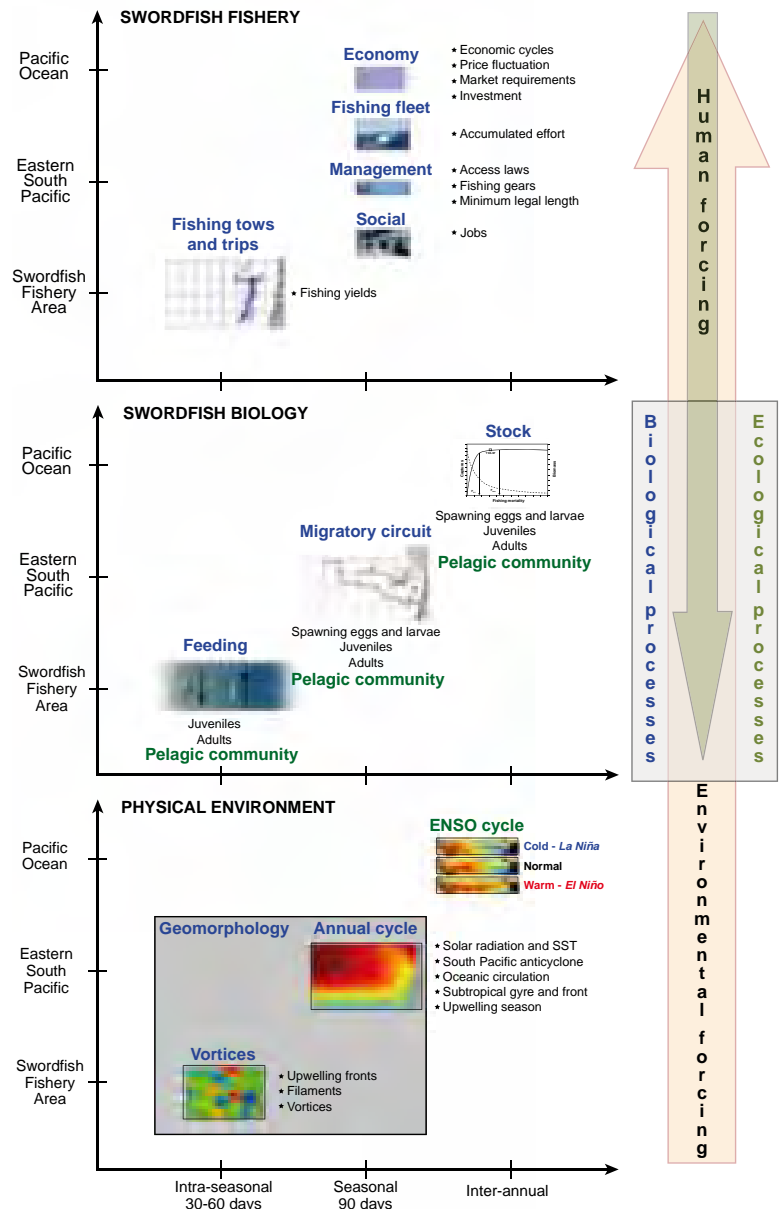
*Figure 1. Spatio-temporal (3*3) conceptual model in the physical marine environment, biological and human (fishery) layers; and the ecosystem processes and forcing inhabited by the swordfish.*

The effect of fluctuations in the physical environment on swordfish individuals, local populations, and regional stocks over distinct spatial-temporal scales is known as environmental forcing. The proposed model considers this to be exercised within the physical environment plane, acting first on the resource's biology and ecology and then affecting humans in the fishery plane through changes in the catch rates. Inversely, variations in the fishery plane such as changes in the intensity of the fishery, administration of the national and international resource, economic cycles, and others, affect or are propagated in the biological plane of the swordfish, causing responses on the regional stock level.

On an interannual scale, the changes generated by the ENSO cycle in the ESP are known to cause non-periodical anomalies in SST that can affect the position and intensity of the Pacific anticyclone, the subtropical gyre, the subtropical front (STF), and the western drift current. Such anomalies affect the intensity and duration of the season and upwelling as well as the formation of fronts, filaments, and vortices.

During *El Niño* events, the advection of warmer waters increases the temperature anomalies in the eastern Pacific. These are projected towards the ESP, displacing the subtropical gyre, the western drift current, and the STF southwards and towards the coast. Under these conditions and considering that swordfish spawning is associated with temperatures over 24°C, a direct positive effect is expected on the development of the swordfish larvae in the oceanic area around Isla de Pascua. Also during *El Niño* events, since swordfish are associated with the STF, the availability and vulnerability of adult specimens are expected to increase in the feeding zone as they come closer to the coast, favouring the fishing industry and improving catch rates. Increased catches could affect the regional market, generating lower prices due to the augmented swordfish supply.

During the cold years of the ENSO cycle, the physical conditions are inverted; temperatures drop and the subtropical gyre and STF are displaced to the north and further from the coast. Given these conditions, an inverse effect is expected to be observed in terms of swordfish spawning and larval development, and availability and vulnerability of the resource in the feeding zone should decrease since the resource moves away from the coast. This negatively affects fishery yields, especially for the small-scale fishery, which has less autonomy and lower efficiency. The decreased catches and, therefore, product supply on the local market are expected to generate increased sale prices.

The model considers the annual cycle or seasonal variability associated with three zones (reproduction, rearing, feeding). These areas have different abiotic and biotic conditions and are also associated with the migratory circuit and different developmental stages of the swordfish. The annual circulation and solar radiation cycles in the ESP affect the swordfish in terms of the duration and spatial distribution of their spawning as well as the spatial distribution, availability, and vulnerability of juveniles and adults in the distinct geographic distribution zones.

The feeding area is partially associated with the coastal upwelling zone, where cold waters increase productivity in the upper trophic levels, providing prey for top predators such as swordfish. The migratory cycle begins in March, when adult swordfish enter the feeding area via the southern boundary (38-42°S) in association with the STF. The adults remain in this zone until November, moving to the north and northeast as the annual season progresses. The abiotic conditions of this zone which are related to the presence of swordfish include a SST of 16 to 18°C and lower salinity (34.2-34.6‰) are associated with the gyre and STF. In this feeding area, the swordfish distribution is associated with greater productivity, as reflected by higher chlorophyll concentrations (0.12-0.2 mg m^{-3}) in the reproduction (oceanic) and rearing (Cordillera de Nazca) areas.

At the end of October, the swordfish begin to migrate to the west towards the reproduction area. The swordfish seek out warmer subtropical waters (SST over 24°C) that stimulate their reproductive process. This migration is carried out between November and March.

A third area, the so-called rearing zone, is populated mostly by juvenile swordfish. After spawning, the juveniles travel to this zone, which is theoretically more appropriate for their feeding and survival. The rearing area of the juveniles is partially located in the Cordillera de Nazca. The presence of swordfish in this area is associated with environmental conditions that differ from those found in the other areas.

The model presented herein relates the effects of mesoscale structures (e.g. vortices, upwelling fronts) with the spatial distribution, availability, and vulnerability of juvenile and adult swordfish in the rearing and feeding zones. The vortices that are generated in these zones are water transport mechanisms, lifting the water in the centre to create local upwelling. Such local oceanic upwelling is rich in nutrients, increasing biological production and resulting in the transport, accumulation, and production of biomass, being able to sustain local trophic levels in oceanic zones far offshore. The increased generation and frequency of vortices and upwelling fronts in the feeding zone heightens biological production, favouring the availability of food items for the swordfish. These conditions result in greater availability and vulnerability of adult swordfish in the feeding zone. A greater number of vortices also tends to have a positive effect on fishing tows and trips, generating higher fishing yields of adult specimens.

References

Barría P., M. Donoso, J. Azócar, F. Cerna, H. Miranda and V. Catasti. 2006. Programa Seguimiento del estado de situación de las principales pesquerías nacionales. Investigación Situación Pesquerías de Recursos Altamente Migratorios, 2005. Final Technical Report, IFOP - Subsecretaría de Pesca 140pp.

Bigelow K.A., C.H. Boggs and X. He. 1999. Environmental effects on swordfish and blue shark catch rates in the US North Pacific longline fishery. Fisheries Oceanography 8: 178-198.

Perry R.I., J.A. Boutillier and M.G.G. Foreman. 2000. Environmental influences on the availability of smooth pink shrimp, *Pandalus jordani*, to commercial fishing gear off Vancouver Island, Canada. Fisheries Oceanography 9: 50-61.

Perry R.I. and R.E. Ommer. 2003. Scale issues in marine ecosystems and human interactions. Fisheries Oceanography 12: 513-522.

Podestá G.P., J.A. Browder and J.J. Hoey. 1993. Exploring the association between swordfish catch rates and thermal fronts on US longline grounds in the western North Atlantic. Continental Shelf Research 13: 253-277.

Sedberry G.R. and J.K. Loefer. 2001. Satellite telemetry tracking of swordfish, *Xiphias gladius*, off the eastern United States. Marine Biology 139(2): 355-360.

Seki M.P., R. Lumpkin and P. Flament. 2002. Hawaii cyclonic eddies and blue marlin catches: The case study of the 1995 Hawaiian International Billfish Tournament. Journal of Oceanography 58: 739-745.

Vega R. and M. Cortés. 2005. Pesca de Investigación del pez espada en la zona de Isla de Pascua. Proyecto Monitoreo y análisis de las operaciones de pesca conjunta de pez espada CE/Chile. Informe de Crucero, IFOP - Subsecretaría de Pesca, 32pp.

Yáñez E., C. Silva, M.A. Barbieri and K. Nieto. 1996. Artisanal swordfish fishery and sea surface temperatures from NOAA satellites in central Chile. Investigaciones Marinas Valparaíso 24: 131-144.

Yáñez E., C. Silva, J. Marabolí, F. Gómez, N. Silva, E. Morales, A. Bertrand, J. Campalans, A. Gamonal, J. Chong, P. Rojas, B. Menares and J.I. Sepúlveda. 2004. Caracterización ecológica y pesquera de la Cordillera de Nazca como área de crianza del pez espada". Final Technical Report, FIP 2002-04 Project, Subsecretaría de Pesca, Chile. 388pp. http://www.fip.cl/prog_x_year/2002/2002-04.htm

Yáñez E., C. Silva, N. Silva, A. Ordenes, F. Leiva, P. Rojas, J. Chong, J. Campalans, S. Palma, G. Claramunt, C. Oyarzún, R. Meléndez and R. Vega. 2006. Caracterización ecológica y pesquera de Cordillera de Nazca como área de crianza del pez espada. Fase II. Final Technical Report, FIP 2004-34 Project, Subsecretaría de Pesca, Chile, 236pp. http://www.fip.cl/proyectos/2004/2004-34.htm

The challenge of change: managing for sustainability of oceanic top predator species

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CLIOTOP's Working Group 5 (WG5) hosted a multidisciplinary international workshop on 12-14 April 2007 at the Marine Science Institute at the University of California, Santa Barbara. The workshop focused on the management of oceanic top predator species in the context of climate variability and other sources of change and uncertainty.

WG5 (Socioeconomic aspects and management strategies) seeks to strengthen the scientific basis for managing human impacts on tuna, sharks, billfish and other oceanic top predator species by improving our understanding of the drivers and controls of harvesting and other relevant human activities. Oceanic top predators, such as tuna and billfish, have been intensively harvested in competitive fisheries, resulting in undesirable socioeconomic outcomes, fish stock declines, damage to by-catch species, and associated impacts on ocean ecosystems. The management of these highly-migratory species is complicated by the fact that migratory patterns, recruitment, prey availability, and other population dynamics are sensitive to imperfectly predictable climate variability and change. In addition, rapid technological and socioeconomic changes have fuelled the explosive growth of industrial fisheries targeting several oceanic top predator species.

International fisheries governance institutions, including Regional Fishery Management Organizations (RFMOs) have developed to ensure both sustainable management of these resources and an equitable international division of fishery benefits, but they face formidable challenges. There is a clear need to promote the development of a broadly-based research community capable of providing useful advice to these resource managers. There is also a particular need to encourage the productive engagement of social scientists in this collaborative effort. The workshop sought to fill that need by promoting cross-disciplinary communication and mutual understanding and by opening avenues for multidisciplinary research collaborations.

The workshop brought together four dozen academic researchers and resource managers from a wide variety of social and natural science disciplines. Through a mixture of presentations and

Figure 1. Participants in CLIOTOP WG 5 workshop on the challenge of change: managing for sustainability of oceanic top predator species.

discussion sessions, the participants explored how various types of expertise and methods of analysis could contribute to the design and implementation of more robust and sustainable management systems for these species. Participants included high-level current and former senior officials from four of the RFMOs responsible for tuna and billfish management, as well as representatives of the UN Food and Agriculture Organization and the US National Oceanographic and Atmospheric Administration Fisheries Office of International Affairs.

As a result of the workshop, several participants have formed interdisciplinary teams to develop proposals for research funding. In particular, interest in follow-up work is focused on the interplay between governance arrangements and innovations in fishery monitoring, market dynamics, and improved bio-economic modelling of harvesting activities. In addition, papers presented at the workshop will be incorporated in an edited book that will focus attention on the potential contributions of interdisciplinary research to management of these resources and to the design of effective governance arrangements.

The role of squid in open ocean ecosystems

GLOBAL OCEAN ECOSYSTEM DYNAMICS

GLOBEC Report No.24

THE ROLE OF SQUID IN OPEN OCEAN ECOSYSTEMS

Report of a GLOBEC-CLIOTOP/PFRP workshop, 16-17 November 2006, Honolulu, Hawaii, USA

Robert J. Olson and Jock W. Young (Eds.)

GLOBEC Report No. 24, "The role of squid in open ocean ecosystems. Report of a GLOBEC-CLIOTOP/PFRP workshop, 16-17 November 2006, Honolulu, Hawaii, USA" has now been published and is available from the GLOBEC website (http://www.globec.org/products/reports/report24.pdf) or as hard copy on request from the GLOBEC IPO (globec@pml.ac.uk).

The report documents a workshop that was held under the auspices of the CLIOTOP Working Group 3 (Trophic Pathways in Open Ocean Ecosystems) which is co-chaired by Robert Olson (IATTC) and Jock Young (CSIRO). The workshop was co-sponsored by GLOBEC, the Pelagic Fisheries Research Program (PFRP) of the University of Hawaii; the Inter-American Tropical Tuna Commission (IATTC); and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, and hosted by the PFRP. It aimed to summarise relevant information on pelagic squid and address how changing oceanographic conditions may affect squid's central role as prey and predator in open-ocean ecosystems.
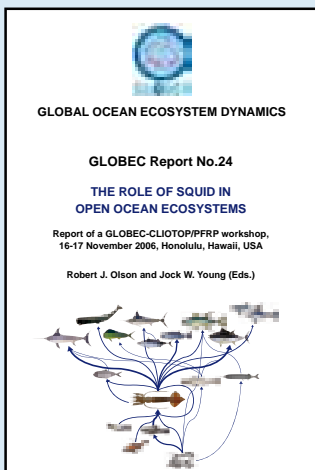
GLOBEC-ESSAS meets in Hakodate, Japan

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Professor Yasunori Sakurai hosted the second annual meeting of the GLOBEC regional programme Ecosystem Studies of Sub-Arctic Seas (ESSAS), in Hakodate, Japan, from 4 to 9 June 2007. The ESSAS Hakodate meeting was opened with a welcome address by the Vice Mayor of Hakodate, Toshiki Kudoh, followed by welcoming remarks by Professor Yasunori Sakurai and George Hunt. The sea-ice workshop, which was co-convened by Egil Sakshaug, Sei-ichi Satoh and John Bengtson, followed immediately. A total of 67 people attended the workshop, including a number of graduate students from the Hokkaido University Graduate School of Fisheries Sciences.

The first day of the workshop included 15 invited talks by scientists from France, Japan, Korea, Norway, and the USA on sea ice, physical oceanography, and ice-biota in sub-Arctic seas. Louis Legendre gave an

Attendees at the ESSAS Workshop, Hakodate, Japan, 4-7 June 2007.

introductory overview of the ecology of sea ice systems, and then there were talks on "monitoring and methodological progress", "physical characteristics", "phytoplankton and zooplankton", "fish" and "marine mammals and seabirds". An important benefit of the workshop was the opportunity to learn about recent results from Japanese research in the Bering Sea and the Sea of Okhotsk.

A common denominator for the workshop was to clarify the underlying mechanisms that regulate fluctuations in productivity and biomass at different trophic levels, especially the role of changes in seasonal sea ice cover brought about by climate fluctuations. Furthermore, the workshop discussed the possibility of writing review papers for refereed journals, with the expressed goal of distilling new knowledge by synthesising existing knowledge from different seas. To this end, the workshop split into two groups during the second day to discuss the possibility of writing two review papers, focusing on "Hotspots" and "Thresholds of change", respectively. Both groups emphasised identification of mechanisms that are crucial for improving models and relevant for modelling the biological impact of climate change in the Arctic.

The Hotspot group suggested a paper, *Mechanisms of hotspot generation in subarctic seas – relationship with sea ice*, with hotspots here defined as areas of high productivity and/or biomass. The rationale was that hotspots are spatially and numerically limited and therefore tractable to scientific study and to model and hypothesis testing. Moreover, hotspots are important to food webs in sub-Arctic sea ecosystems overall, including the resilience of fisheries and the success of species at higher trophic levels. Among the hotspots under debate were the Hudson Strait, the Kurile Islands, Unimak Pass, Shiretoko and the NOW Polynya, which offer examples of more or less different underlying mechanisms for high productivity and biomass. Also "hotbands" (greenbelts) were considered, such as those along the western shelf break of the Barents Sea north to Fram Strait, across the Bering Sea, the Sea of Okhotsk and the Greenland slope/shelf, and moving fronts such as those associated with the retreating ice edge, where the ice-edge bloom follows the retreating ice.

The thresholds for change group suggested a paper entitled *Non-linear biological responses to sea ice [climate] change in sub-Arctic seas*, to focus on how non-linear biological responses in sea ice ecosystems may be triggered by climate change when certain thresholds are exceeded. The group, moreover, suggested initiation of a threshold information database for the sub-Arctic seas. The topic of thresholds is important because there is a high probability of exceeding critically important biological thresholds in sub-Arctic marine ecosystems during the next fifty years.

The paper will define what the thresholds are and will also discuss how statistical and dynamical climate models can be applied to estimate the probabilities of future changes in the thresholds. Thresholds can be evident by a failure or switch in annual production, or in altered population status through several years (i.e. regime shift). Non-linear thresholds are, among many, the relationship between sea ice and black
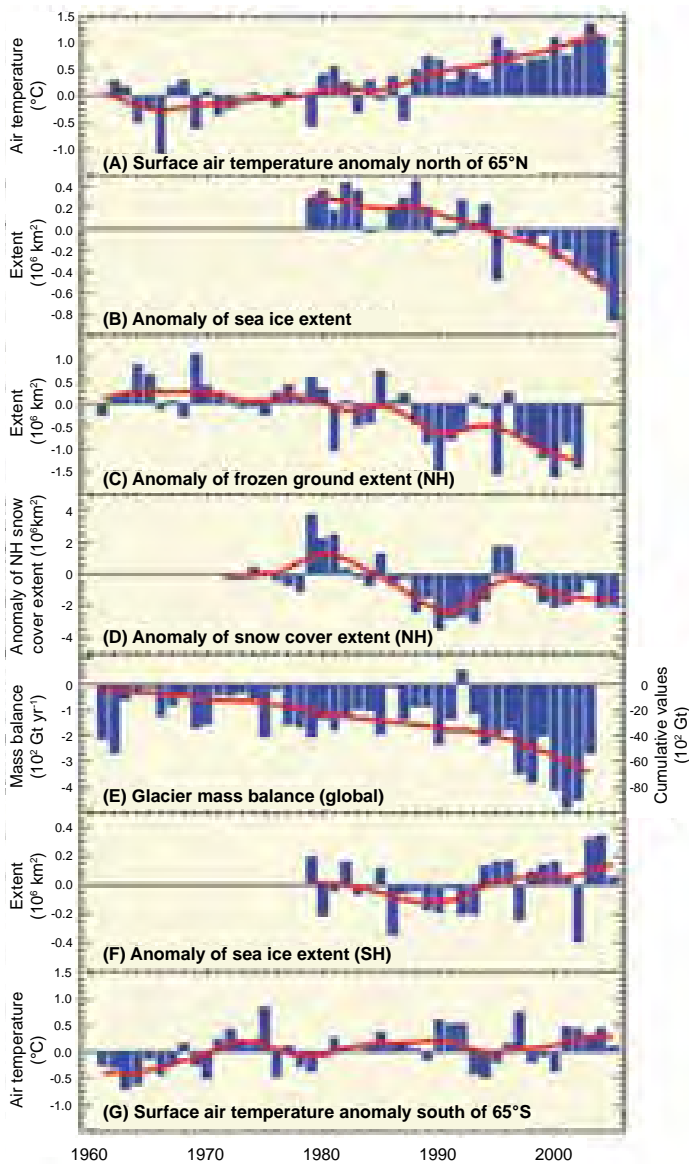
Figure 1. IPCC summary of recent variations in polar temperatures and cryospheric variables. Note, a change of more than 1 degree C temperature and 20% ice loss in the north, but no systematic changes in the south.

state of the art in high resolution physical models of the ESSAS regions, and charted a path forward for the WG during the next two years.

During the workshop, V. Kattsov, J. Walsh, T. Furevik (*in absentia*), and J. Overland reported on the AR4. The process had 450 lead authors, 130 countries contributed, and the report represented six years of work. The physical science basis was published in February 2007, while the direct results from the 22 climate models have been available for review over the last two years. A major AR4 conclusion is that most of the observed increase in global average temperature since the mid-20th century is very likely due to observed increase in anthropogenic green house gas concentrations. Observed changes in high latitude regions over the last 45 years are shown in Figure 1.

The AR4 forecast models appear to be much improved from the Third Assessment Report of six years ago in terms of spatial resolution, better ice parameterisation and ocean physics. Because of a lag effect, climate projections out to 2050 depend more on known CO_2 concentration increases than differences in economic or conservation scenarios. Thus, the largest uncertainties in future climate projections are from model to model differences. Models that are run several times with slightly different starting conditions (termed ensembles) seem to capture some of the natural variability in climate when the models are compared to 20th century data. Figure 2 shows that the models vary in terms of how much ice they produce relative to recent observations.

The first conclusion from the workshop was that, while there are still problems with the details of some of the variables, there is utility for ESSAS in the temperature, sea ice, and perhaps ocean stratification projections from a subset of the IPCC AR4 models. This conclusion was based on model improvements compared to previous reports, comparison with data, the large community involvement in AR4, and the modelling of key processes such as greenhouse warming and ice-albedo feedback. The second conclusion was that there are an number of outliers among the group of models compared to 20th century data, and that a carefully crafted set of rules for the selection of appropriate models would be helpful to constrain the uncertainty in future climate projections. There were several possibilities for selection approaches suggested to address this issue such as the use of a single indicator versus multivariate statistical fitting and seeking regional-specific output versus inter-regional consistency in output. Exploration of these rules and their statistical rigor is a challenge for the Working Group for the next year.

P. Budgell, H. Nakamura, and J. Zhang discussed high resolution modelling for the Barents Sea/North Atlantic, waters near Japan, and the Bering Sea. The Barents is a nested ROMS model at 4 km resolution. Hindcasts of ice variability are handled well by the model, given good meteorological forcing. The difficulty for downscaling the IPCC results to this model relates to the selection rules mentioned above, as most IPCC models over-predict the extent of cold temperatures. The models for Japanese waters predict an intensification of the Kuroshio with

guillemot nesting, certain species of fish and *Calanus* species, and the requirements of seals and polar bears for sea ice cover. A crucial question is how statistical and dynamic climate models can be applied to estimate the probabilities of future changes in thresholds.

On Wednesday, 6 June, the ESSAS Working Group 1 on Regional Climate Prediction (WGRCP) held a one-day workshop to provide quantitative estimates of the magnitude and uncertainty of future climate change, and the frequency distribution of the large natural variability known to influence the ESSAS marginal seas. A major resource for the development of these future climate scenarios is the recently available output from 22 state-of-the-art coupled atmosphere-ocean climate models which are part of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). The workshop provided background material on the IPCC AR4 process and results, investigated the
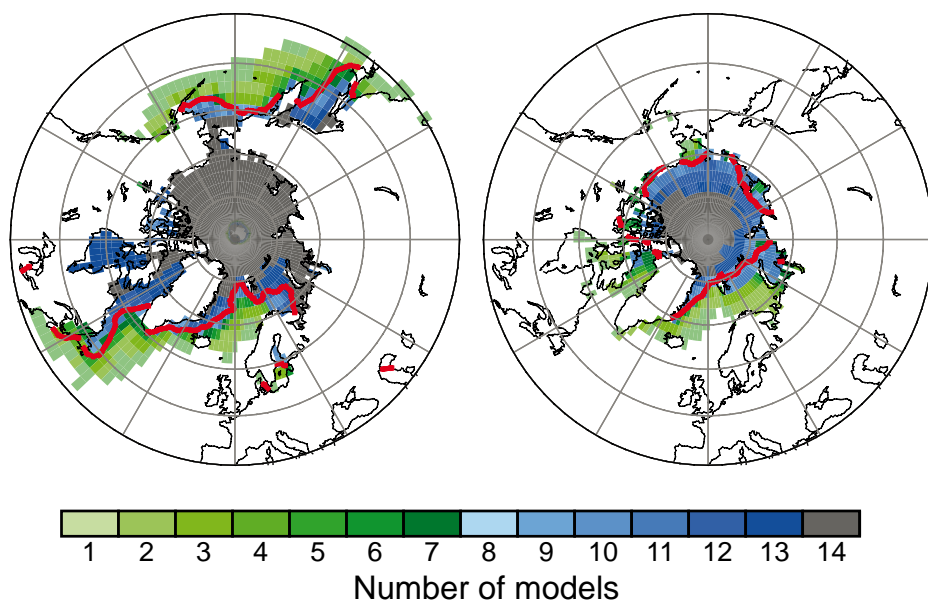
Figure 2. Sea ice in 17 IPCC AR4 models compared to recent data (red line) for March (left) and September (right). The colours indicate how many models have ice this far south. Note that about 5 of the models have too much ice in the Pacific and the western Atlantic in winter. The Barents Sea has a large percentage of models that have too much ice in both seasons.

purpose of the workshop was to develop a strategy for future work by WG3. Thus, the workshop reviewed recent efforts to model marine ecosystems and conduct comparisons of ecosystems using models of ecosystem function. During the plenary, four presentations were made. One concerned the status of the MENU (Marine Ecosystems of Norway and the US) programme, one covered possible collaborative opportunities with working groups 1 and 2, one discussed a JGOFS model comparison experiment, and the final presentation discussed some NEMURO applications, comparison of models from the NEMURO family of models, and the EUR-OCEANS model shopping tool web page (http://www.eur-oceans.eu/WP3.1/shopping_tool/index.php?mode=fromEuroceans). The remainder of the plenary covered topics such as the draft terms of reference, the possibility of preparing a proposal to create an IOC/SCOR working group on high latitude ecosystems, membership suggestions, and the preparation of an action plan.

global warming; realistic simulations require an eddy resolving model (0.1 x 0.1 degree). The Bering Sea model has a multi-category sea ice thickness, tides, and a POP ocean model. It is able to describe some of the basic features of sea ice advance and retreat, ocean circulation, and SST. These regional models are active areas of research, and the third conclusion of the workshop was that further work with these models should be encouraged and that planning of coupling (downscaling) of these models to the range of variability shown by the IPCC models should be explored.

M. Wang, G. Hunt and K. Drinkwater (*in absentia*), discussed the climatology of the ESSAS regions and how the physics may be coupled to the biology. In the example of cod in the Atlantic, climate shifts at the extreme southern and northern ranges show the most biological sensitivity. Thus, identifying particular climate thresholds for different species may be a more relevant approach than requiring overall high accuracy from the models. In the Pacific, it was pointed out that it is important for the modelling group to know from the biologists where, what months, what variable(s) and why (species and impact) potential ecosystem stress points may occur.

The priorities for the Climate Working Group are: 1) to pursue and evaluate a range of IPCC AR4 model selection rules for ESSAS regions, 2) to work with other Working Groups on matching potential biological impacts from climate change to the limits of credible projections from IPCC, and 3) to explore the general area of downscaling, particularly in the context of high resolution ocean models.

During the morning of 7 June, ESSAS Working Group 3 on Modelling Ecosystem Response convened a half-day workshop under the leadership of B. Megrey, S.-I. Iito and K. Rose. The

The final day and a half of the meeting was devoted to the ESSAS Science Steering Committee that evaluated the activities of ESSAS to date and formulated plans for the future. It was agreed to hold the next ESSAS Annual Meeting in Halifax, Nova Scotia, from 15 to 19 September 2008. This meeting will revisit the progress on the threshold and hotspot syntheses papers, and will focus attention on the various roles that advection plays in the sub-Arctic seas. Plans are underway to show off North Atlantic hospitality and local seafood specialities.

The Hakodate meeting was enlivened by a fine reception on the Monday evening and on the Tuesday evening by a visit to a hot spring spa followed by a traditional Japanese dinner that was greatly enjoyed by all. On Saturday, Professor Yasunori Sakurai guided a lucky group of participants to a fisherman's festival in a small fishing port where we were invited by the revellers to partake of numerous seafood delicacies barbequed on the docks of the village. Professor Sakurai then took us to visit a hot spring spa near Oonuma Lake National Park and after a refreshing soak, we walked some of the many footpaths around the lake.

The meeting participants greatly appreciated the generous hospitality of Professor Yasunori Sakurai and his colleagues at the Hokkaido University Graduate School of Fisheries Sciences. Support for the meeting was provided by the GLOBEC IPO, the city of Hakodate, Japan, the North Pacific Research Board, the NOAA Alaska Fisheries Science Center, and the North Pacific Marine Science Organization (PICES). The ESSAS SSC is grateful for this vital support of our scientific activities.

QUEST-FISH: Predicting the impacts and consequences of climate change on global fish production

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Quantifying and Understanding the Earth System

The UK Natural Environment Research Council (NERC) has funded a new 2.5 year research programme entitled "QUEST-Fish: Predicting the impacts and consequences of climate change on global fish production". QUEST-Fish is part of the UK QUEST programme (Quantifying and Understanding the Earth System (http://quest.bris.ac.uk/), and is a contribution to UK GLOBEC and to GLOBEC International Integration and Synthesis.

QUEST-Fish was put together in response to the increasing demand for information on the expected impact of global environmental change on the productivity of marine ecosystems, including fish and other higher trophic organisms (IPCC, 2007). Work conducted largely under the umbrella of GLOBEC has demonstrated that climate variability and change drives abundance fluctuations of fish populations at all scales and latitudes (Lehodey *et al.*, 2006), with particularly clear fluctuation patterns linked to warm and cold climate periods over decadal (Chavez *et al.*, 2003), multi-decadal (Ranvier and Fromentin, 2004) and multi-centennial (Baumgartner *et al.*, 1996) scales. Particularly evident are biological responses to reversals in climate indices, such as Pacific tuna in response to *El Niño*/*La Niña* (Lehodey *et al.*, 2003) or sub-Arctic cod stocks in response to the North Atlantic Oscillation (Ottersen *et al.*, 2004), among others.

Despite this volume of work the quantification of direct climate impacts on the production of fish resources at the global scale, and the risks and vulnerabilities of these impacts, has been hampered by:

a) difficulties of downscaling Global Climate Models to the scales of biological relevance,

b) lack of adequate global ecosystem models capable of capturing biological processes up to fish populations at the right scale and resolution,

c) uncertainties over future global aquatic net primary production (NPP), and the transfer of this production through the food chain and,

d) inadequate methodology to estimate human vulnerabilities to these changes at all scales.

In addition, fish populations are affected by multiple additional stressors related to exploitation practices, thus hampering the development of predictive models.

QUEST-Fish will address some of these challenges by focusing on investigating how climate change would affect the potential production for global fisheries resources in the future, compared to past and present scenarios, in the absence of exploitation. This approach removes uncertainties as to what exploitation regulations will be implemented in coming decades, and focuses on the added impacts that climate change is likely to cause, and on the subsequent additional risks and vulnerabilities to human societies.

QUEST-Fish: Exploring the past and future of fish production. Aquaculture pen at the Palace of the Popes, Avignon, France. Painting by M. Giovanetti, 1343.

The main objective of QUEST-Fish is to elucidate how climate change will affect the potential production for global fisheries resources in the future and to estimate the added vulnerability of these effects on national and regional economies in fishery-dependent areas and on specific elements of the fishery system at different scales.

The geographical unit of QUEST-Fish will be based on the Large Marine Ecosystem (LME) concept. QUEST-Fish will select a number of LME units, based on their contribution to global fish catches and their ecological and societal diversity and will compute potential fish production estimates for these areas, based on ecosystem considerations, for four fixed temporal scenarios: pre-industrial (1800), present (2005), and future (2050 and 2100). In order to estimate impacts and vulnerabilities for human societies of the production scenarios developed, figures for LMEs will be downscaled to national boundaries.

QUEST-Fish has four research modules:

1) **Climate change forcing scenarios and predictive planktonic ecosystem responses:** The aim of this module is to estimate primary (phytoplankton) and secondary (zooplankton) production in key coastal-ocean fisheries around the world under climate change scenarios provided by IPCC-AR4. Physical forcing scenarios will be based on GCOMS, a system for running multiple shelf seas model domains coupled to a global physics-ecosystem model (POLCOMS-ERSEM; Holt *et al.*, 2005), providing coverage of the coastal-ocean ecosystems around the world at a resolution of ~1/10° and including tides, stratification, river runoff, ocean-shelf exchange and upwelling. ERSEM will provide quantitative estimates of plankton production for Plankton Functional Types (PFT) for each system.

2) Development of fish biomass and production predictions: The goal of this module is to use plankton production estimates from Module 1 to estimate potential fish production, and to develop climate-forced models of fish biomass and production. Three complementary work streams will contribute to meeting this goal, including the development of new theory and models to allow prediction of fish biomass and production using metabolic scaling theory and dynamic size spectra models. These methods are based on metabolic scaling rules and knowledge of predator-prey interactions and energy transfer in size-based food webs supported by phytoplankton (Jennings and Mackinson, 2003; Jennings, 2005).

3) Impacts and consequences of global environmental change on the fishmeal-based global food markets: The main objective of this module is to develop scenarios to investigate the economic consequences of climate-driven changes for the global production of fishmeal. Fishmeal is a global commodity used in the animal feeds and aquaculture market. The majority of the species contributing to the fishmeal market are small pelagic fish with strong dependence to climate variability and change (e.g. Peruvian anchoveta). We will identify realistic scenarios of supply (production) and demand (market) for the fishmeal global markets, examine the impact of these scenarios on small pelagic fish stocks, fisheries and related markets through an integrated global bioeconomic model (Mullon and Freon, 2006) and examine the implications of substituting fishmeal in aquaculture (Kristofersson and Anderson 2006).

4) Future vulnerability of national economies and global fishmeal and food markets to effects of climate change and other drivers on fisheries: The main objective of this Module is to develop improved ways of assessing vulnerability of fisheries to future climate change (Allison *et al.*, 2005), in the context of other drivers of change: supply-demand changes, governance scenarios, macro-economic change (e.g. fuel price changes). Specific objectives are to use an Intergovernmental Panel on Climate Change (IPCC)-type risk exposure-sensitivity-adaptive capacity analysis to elucidate the pathways of potential climate impact on fish capture, aquaculture production and trade and consumption. We will develop a simple method of assessing climate change vulnerability and will analyse the vulnerability of fisheries to climate change at global, LMEs and national level.

QUEST-Fish is a partnership between the Plymouth Marine Laboratory (PML), the Universities of Plymouth (UoP), East Anglia (UEA) and Portsmouth (CEMARE), the Proudman Oceanographic Laboratory (POL) and the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), in collaboration with the WorldFish Centre (www.worldfishcenter.org). In order to liaise properly with other international efforts inside and outside GLOBEC, QUEST-Fish will appoint a group of selected international experts that will provide steering and networking with relevant work conducted elsewhere.

As a GLOBEC-affiliated project QUEST-Fish will report developments through this Newsletter. For more information please contact the Principal Investigator, Dr Manuel Barange, or follow links to our website through the GLOBEC International website (http://www.globec.org).

References

Allison E.H., W.N. Adger, M.-C. Badjeck, K. Brown, D. Conway, N.K. Dulvy, A. Halls, A. Perry and J.D. Reynolds. 2005. Effects of climate change on the sustainability of capture and enhancement fisheries important to the poor: analysis of the vulnerability and adaptability of fisherfolk living in poverty. Report number R4778J, Fisheries Management Science Programme, DfID, London, UK.

Baumgartner T., A. Soutar and W. Riedel. 1996. Natural time scales of variability in coastal pelagic fish populations of the California Current over the past 1500 years: Response to global climate change and biological interaction. In: California Sea Grant Report for 1992-1995, California Sea Grant College, La Jolla, 31-37.

Chavez F.P., J. Ryan, S.E. Lluch-Cota and M. Niquen C. 2003. From anchovies to sardines and back - multidecadal change in the Pacific Ocean. Science 299: 217-221.

Holt J.T., J.I. Allen, R. Proctor and F. Gilbert. 2005. Error quantification of a high-resolution coupled hydrodynamic–ecosystem coastal–ocean model: Part 1 model overview and assessment of the hydrodynamics. Journal of Marine Systems 57: 167-188.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: climate change impacts, adaptation and vulnerability. WGII summary for policy makers. 23p.

Jennings S. 2005. Size-based analyses of aquatic food webs. p.86-97. In: A. Belgrano, U.M. Scharler, J. Dunne and R.E. Ulanowicz (Eds.). Aquatic food webs: an ecosystem approach. Oxford University Press, Oxford, UK.

Jennings S. and S. Mackinson. 2003. Abundance–body mass relationships in size-structured food webs. Ecology Letters 6: 971-974.

Kristofersson D. and J.L. Anderson. 2006. Is there a relationship between fisheries and farming? Interdependence of fisheries, animal production and aquaculture. Marine Policy 30: 721-725.

Lehodey P., J. Alheit, M. Barange, T. Baumgartner, G. Beaugrand, K. Drinkwater, J.-M. Fromentin, S.R. Hare, G. Ottersen, R.I. Perry, C. Roy, C.D. van der Lingen and F. Werner. 2006. Climate variability, fish and fisheries. Journal of Climate 19: 5009-5030.

Lehodey P., F. Chai and J. Hampton 2003. Modelling climate-related variability of tuna populations from a coupled ocean-biogeochemical-populations dynamics model. Fisheries Oceanography 12(4-5): 483-494.

Mullon C. and P. Fréon. 2006. Prototype of an integrated model of the worldwide system of small pelagic fisheries. p.262-295. In: R. Hannesson, M. Barange and S.F. Herrick, Jr. (Eds.). Climate Change and the economics of the world's fisheries: examples of small pelagic stocks. Edward Elgar, Cheltenam, UK.

Ottersen G., J. Alheit, K. Drinkwater, K. Friedland, E. Hagen and N.C. Stenseth. 2004. The response of fish population to ocean climate fluctuations. p.73-94. In: N.C. Stenseth, G. Ottersen, J. Hurrell and A. Belgrano (Eds.). Marine ecosystems and climate variation: the North Atlantic. Oxford University Press, Oxford, UK.

Ravier C. and J.-M. Fromentin. 2004. Are the long-term fluctuations in Atlantic bluefin tuna (*Thunnus thynnus*) population related to environmental changes? Fisheries Oceanography 13(2): 145-160.

BASIN: Resolving the impact of climatic processes on ecosystems of the North Atlantic basin and shelf seas

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BASIN is an initiative to develop a joint EU North American research programme in the field of ocean ecosystems in support of the Global Earth Observation System of Systems (GEOSS) initiative. The first BASIN meeting took place in Iceland in March 2005 (see GLOBEC Report No.23). Four meetings are being held in 2007 to engage both the European and North American communities, explore coordinated funding mechanisms and to draft a BASIN Science Plan. The implementation of joint research programmes is at present a significant obstacle facing researchers in many research areas where a large-scale multi-national approach is now needed to tackle the key problems of the future (e.g. climate, ecosystem research). BASIN will seek to identify, with the aid of programme managers, appropriate and effective implementation mechanisms.

BASIN: A major internationally coordinated research programme working towards an understanding of impacts of climate variability on the marine ecosystems of the North Atlantic Basin

Why do we need a Basin scale approach?

One of the key issues facing the scientific community at present is to further our predictive understanding of the complex linkages between physics, chemistry, and biology and their importance for the functioning of marine ecosystems in order to understand, adapt to, and anticipate the effects of global change. Based on the importance of the North Atlantic basin for global climate and for exploited resources such as fisheries, it is timely and appropriate to conduct a review and develop a science plan focusing on the North Atlantic deep ocean and associated shelves and to examine:

- the effects of climatic processes on ecosystems and their feedbacks to climate,

- available observatories and time-series stations,

- status of basins-scale coupled physical/biological models, and

- existing infrastructure and data management.

Geographic domain: BASIN, as its name implies, focuses on the North Atlantic basin and associated shelf-seas. Throughout the development of BASIN it has been crucial to define the interests and needs of the programme and it has been agreed that the primary focus of BASIN should remain the sub-polar gyre system and associated shelf systems of the North Atlantic, whilst not neglecting important connections to the sub-tropical gyre.
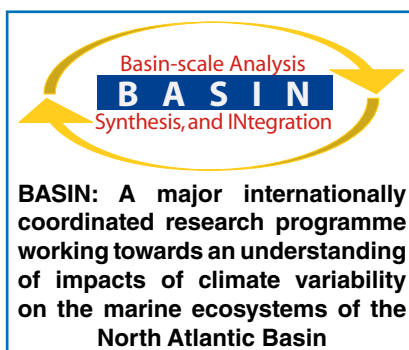
Aim: At present the aim of BASIN is to understand and simulate the impact of climate variability and change on key species of plankton and fish, as well as community structure as a whole, of the North Atlantic and to examine the consequences for the cycling of carbon and nutrients in the ocean and thereby contribute to ocean management.

Links to management: Useful and relevant results for management are essential to the success of the BASIN programme. BASIN has the potential to offer data, analysis and models that could be included in ecosystem management activities around the whole of the Atlantic basin in a fully integrated way. Explicit plans to coordinate the integration of basic science into management should be developed. One approach is for BASIN to form, from its inception, partnerships with the management agencies in North America and Europe (NOAA/NMFS, DFO, ICES, and DG FISH) to ensure that the science developed is relevant to needs of management.

Upcoming activities: BASIN is now moving into Phase 2 which seeks to identify an appropriate model for developing and funding a large scale international collaborative programme. The next BASIN workshop will be a meeting between the steering committee members and international funding and programme managers (US National Science Foundation; European Union and the Canadian National Science and Engineering Research Council) to discuss and develop a potential proposal and funding models. Thereafter a team of scientists from Europe and North America will collaborate to integrate the results of the science-based workshops with the input received from the programme managers and develop a Science Plan that presents a balanced research programme necessary to address the ambitious goals of BASIN.

For further information about BASIN see http://www.globec.org/structure/multinational/basin/basin.htm

Acknowledgements

23 - 26 June 2008, Plymouth, UK
Hosted by Plymouth Marine Laboratory

AMEMR 2008

Advances in Marine Ecosystem Modelling Research II
'Bridging the Gaps'

This International symposium is being convened as a forum for presentation and discussion of all aspects of model based marine ecosystem research, encompassing numerical, conceptual, mathematical and statistical approaches, focussing on understanding and predicting the marine ecosystem rather than the technical aspects. This is highly relevant to today's major challenges such as climate change, sustainable management of marine bio-resources and human impacts on the marine system.

The symposium will contribute to the next generation of model based exploration by providing scientists an opportunity to discuss and contrast recent advances, outstanding problems and future requirements.
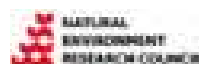
Programme:
enquiries@amemr.info

Registration:
admin@amemr.info

Timeline
* Call for abstracts: Sept 2007
* Abstract deadline: Jan 2008
* Programme announced:
  March 2008
* Registration from late 2007,
  closing in May 2008

www.amemr.info

The Southern Ocean Observing System (SOOS)

Mike Sparrow

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The importance of the Southern Ocean to the global climate system and the uniqueness of its ecosystems are well known. The region is remote and logistically difficult to access and thus is one of the least sampled regions on the planet. Design and implementation of an observing system that encompasses physical, biogeochemical and ecological processes is therefore a formidable challenge.

An initial Southern Ocean Observing System (SOOS) meeting was held in Hobart in July last year. This brought together on an opportunistic basis a group of oceanographers, biologists and engineers to examine the feasibility of establishing a SOOS and in particular to investigate the possibility of incorporating data collected by marine mammals and seabirds, building upon efforts made during the International Polar Year. With reference to observation systems in the other oceans of the world, the importance of sustainable and coordinated observations was emphasised. During this meeting the attendees:

- reviewed existing systems and technology,
- discussed oceanographic datasets collected by seals and seabirds,
- reviewed important biological questions,
- considered what species would be suitable for ongoing studies,
- assessed data handling and compatibility issues and considered protocols for integrating datasets,
- considered existing ocean datasets that would benefit from such data, and
- discussed outreach facilities to share the vision beyond the technical community.

A full meeting report can be obtained from the SOOS website on: http://www.clivar.org/organization/southern/expertgroup/SOOS.htm

A follow up meeting is being held in Bremen in October this year (see: http://www.clivar.org/organization/southern/expertgroup/SOOS_workshop.htm). The aim of this meeting is to more fully develop a SOOS plan. Around 35 attendees from a wide range of backgrounds will be attending.

The first day of the meeting will consist of a series of summary lectures and discussion about the SOOS structure. The second and third days will see attendees split into various groups to tackle different (though interconnected) aspects of any SOOS, for example i) physics, ii) ecosystems/biology, iii) biogeochemistry/carbon, iv) cryosphere and sea ice, and v) meteorology. The idea will be that these groups will articulate i) why sustained observations are needed and what science/policy questions they address ii) what mix of observations are required to address these questions, iii) what is presently done and possible, and finally iv) a vision for the future. At the end of the meeting we will aim to produce a well thought out discussion of the relative priorities of any observing system. After the meeting this will go out to the wider community for further discussion and modification. A near final draft document will be discussed at the SCAR/IASC Open Science Conference being held in St. Petersburg in July 2008.

Although there will be opportunities for groups and individuals to feed into the design of any SOOS after the Bremen meeting we welcome comments and feedback at any stage of the process. Please e-mail Mike Sparrow (mds68@cam.ac.uk) for further details.

Progress of the German GLOBEC project

Jürgen Alheit (Coordinator)

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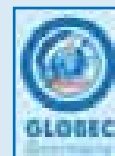
The German GLOBEC project (http://www.globec-germany.de) entitled "**Trophic Interactions between Zooplankton and Fish under the In**f **uence of Physical Processes**" aims for a better understanding of the trophodynamic interactions between zooplankton and fish under the influence of physical processes, in order to elucidate the principal mechanisms accounting for the high variability of copepod production and reproductive success of fishes. The results from the project will form the basis for strategic modelling of the recruitment success of

pelagic fishes in the Baltic and North Sea. The project is due to be completed by the end of 2007.

Progress reports have been presented in previous issues of the GLOBEC International Newsletter (10(2), April 2004 and 12(1), April 2006). The project is based on retrospective studies, laboratory experiments, field studies and modelling as demonstrated by the following collection of representative contributions. The results of the on-going project synthesis will be presented at an international symposium organised by the German GLOBEC project from 14-15 November 2007.

The GLOBEC-Germany database

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This paper outlines the structure and the operating mode of the project database GLOBAN (GLObec BAltic Sea–North Sea). GLOBEC Germany focuses on the trophic interactions between zooplankton and fish under the influence of physical processes. The implementation of GLOBEC Germany combines field studies, experimental investigations and models of recruitment success. In field studies two planktivorous clupeids, herring (*Clupea harengus*) and sprat (*Sprattus sprattus*), and the prevailing copepods *Pseudocalanus* sp., *Acartia* sp. and *Temora longicornis* were surveyed and the composition of trawls determined. Nutrient, oxygen and physical measurements complement the experimental database.

Sampling was done on a standardised station grid both in the North Sea and the Baltic Sea (Fig. 1). The same instrumentation was deployed on a predefined grid during each cruise. Frontal systems in the North Sea (tidal mixing front and river plume front) were first identified during each cruise and then sampled by transects.
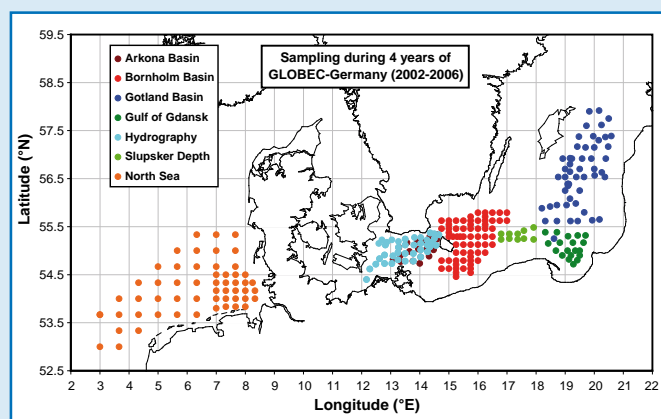
Figure 1. GLOBEC-Germany sampling locations, 2002-2006.

Database structure

A unique design has been set up for the GLOBEC Germany project database GLOBAN. GLOBAN is a relational database under MS Access 2000 and can be run as a stand alone version on PCs equipped with Access 2000 or later.

All data tables relate to the central or first level event table. Subordinate tables describe the instruments deployed on the second level. The third level contains the data. Each instrument deployment is connected to the corresponding data.

Data input

Besides data storage GLOBAN features an interface for data input and near real time data acquisition during the cruises. Thus no information is lost during subsequent data input thereby improving data quality. Input forms for metadata were designed for events and instruments respectively. Tables linked to the event table provide further information about the cruises. Six different input forms serve 28 different instruments.

Most of the tow data were entered into GLOBAN during the cruises using a combination of forms and subforms (e.g. catch composition, length, length classes, extraction of otolith, weight, maturity, gonads). Results from zooplankton counts and length measurements were pasted into the data tables in a tab-separated ASCII format. For key zooplankton species taxa were distinguished by growth stages (nauplia, CI-CIV, male and female adults).

Data content

Currently the GLOBAN database contains metadata of 50 cruises from the years 2002 to 2006. The Baltic Sea was surveyed during 34 cruises and the North Sea during 16 cruises for which 12,365 records with metadata, and 540,301 total data records were achieved. Table 1 shows the target area of the cruises and the number of records for each year.

Table 1. Target area of German GLOBEC cruises

Year	No. cruises	No. events	No. data records	Target area
2002	14	3666	221257	Baltic Sea
2003	12	2724	85705	9 Baltic Sea 2 North Sea
2004	11	3488	133297	3 Baltic Sea 8 North Sea
2005	12	2257	92714	6 Baltic Sea 6 North Sea
2006	3	333	7324	2 Baltic Sea

Table 2. Data records for German GLOBEC cruises

Gear	Total number of records with metadata	Records with processed data	No. of data records	
Bongo	2261	336	abundance: length: medusae:	16249 21668 607
Multinet	696	688	abundance:	72826
CTD	5145	3749	fluoroprobe: nutrients:	336724 215293 1159
Trawl	951	839	catch composition: length: stomach content: single fish: gonads:	4952 28337 41892 17496 10291

Table 2 shows how the total numbers of records are divided up into the single parameters. From the tows 28,337 records with length classes (mainly clupeids) and 17,496 single fish records with length, mass, maturity, liver mass and gonad mass (mainly cod) are available. Stomach samples were taken and analysed from a subsample of those records. For another subsample of sprat for which length measurements were made, the maturity of the gonads (10,291 records) was determined.

Data output

GLOBAN offers a set of queries for users who have just a very basic understanding of MS Access. Those queries allow access to all available data which may be exported from GLOBAN in file formats such as .txt, .csv, .asc, .html, .xls. More specified customised queries can either be developed with the help of

an MS Access assistant or using SQL (Serial Query Language) statements and VBA (Visual Basic for Applications). A complete station list for each cruise may be retrieved as a report in a "ready to print" format. The station positions are displayed in a map of the North Sea and Baltic Sea, respectively.

Accessing GLOBAN

GLOBAN will be available to download from the GLOBEC Germany homepage (http://www.globec-germany.de) after termination of the project, which presently is due to be in 2008.

Acknowledgement

We would like to bear tribute to Stefan Zabanski who started the work on the GLOBAN database and sadly passed away in 2005.

Differences in life history traits of congeneric copepod species

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Copepods of the genus *Pseudocalanus* play an important role in the trophic ecology of temperate and boreal pelagic ecosystems of the northern hemisphere (Corkett and McLaren, 1978). The genus comprises a suite of congeneric species that exhibit exceptional morphological and ecological similarity. Due to these similarities (Frost, 1989) studies of species-specific life history traits of congeners are difficult. Observations on other genera have revealed large differences in distribution patterns and vital rates and response to their physical and biological environment (*Temora* and *Centropages*: Halsband-Lenk *et al.*, 2004; *Calanus*: Conover, 1988). These differences are especially important when examining the amount of energy which is provided for higher trophic levels.

Despite their geographic proximity there are large differences in physical and biological conditions (temperature and salinity regime, seasonal timing of plankton blooms, phytoplankton and mesozooplankton composition) between the Baltic Sea and North Sea. Copepods of the *Pseudocalanus* group are important members of the mesozooplankton fauna in both ecosystems.
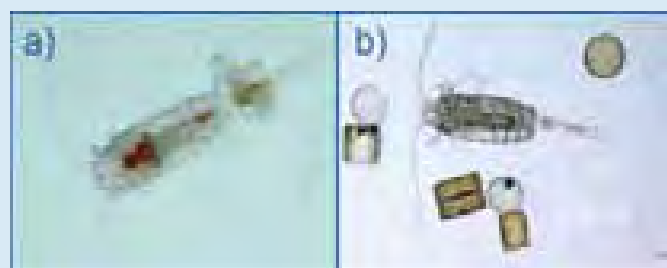
Figure 1. a) Pseudocalanus acuspes and b) P. elongatus

The life cycle and vital rates of *Pseudocalanus* spp. from the Bornholm Basin (central Baltic Sea) and the southern North Sea were determined on an almost monthly basis during two intensive field studies. Concurrently, samples for genetic identification of *Pseudocalanus* were taken in both areas.

In the Baltic Sea, with the exception of the occurrence of a small number of *P. elongatus* directly after an inflow of North Sea water, only *P. acuspes* was identified by genetic analyses (Fig. 1a). In the southern North Sea *P. elongatus* was found exclusively (Fig. 1b). The two species seem to be strictly separated, although there is often considerable exchange of

water masses. Apparently *P. elongatus* is not able to adapt to conditions and maintain a population in the central Baltic Sea, as no further individuals could be detected by genetic identification during the months following the inflow. Salinity tolerance could be one of the limiting factors, as *P. acuspes* in the central Baltic occurs over a much wider salinity range.
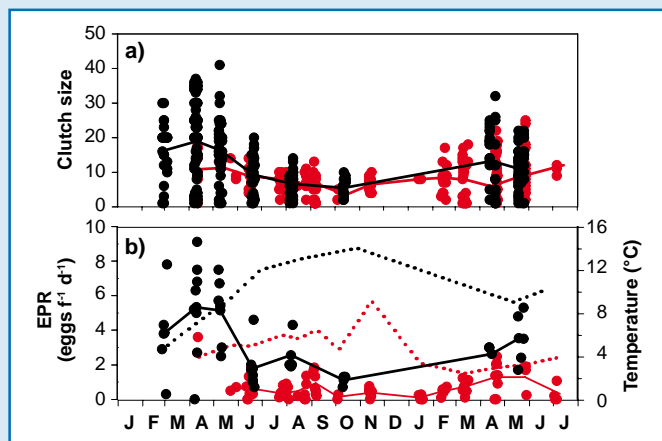
Figure 2. a) Clutch size and b) egg production rate (EPR) of P. acuspes from the central Baltic Sea (red) and P. elongatus from the southern North Sea (black); dots clutch size of single females and EPR at different stations; solid lines mean; dotted lines represent temperatures at weighted mean depths of females

Both species exhibit strong differences in reproduction and growth characteristics. The life cycle of *P. elongatus* in the southern North Sea is characterised by a reproduction peak during the phytoplankton bloom between March and May with egg production rates up to 9 eggs female^{-1} d^{-1} (Fig. 2). Moulting rates are highest in spring, resulting in stage durations well in the range of laboratory investigations at food saturation (Table 1). Four to five generations per year can be distinguished by differences in female size. In contrast, egg production rates of *P. acuspes* from the central Baltic Sea are only 1/3 as great, with a peak in April/May. Its moulting rates are extremely low, and the predicted stage durations are 3-5 times longer than those of the congener. A life cycle with only 1-2 annual generations and potential minor cohorts during summer reflects adaptation to life in high latitudes and characterises *P. acuspes* as an arctic relict species. Consequently, despite similar abundances of the congeners, secondary production of *P. acuspes* was approximately 9 times lower.

Table 1. Mean stage duration of copepodite stages of *P. elongatus* (North Sea) and *P. acuspes* (Baltic Sea)

| Month	T [°C]	Stage duration [days]				
		CI	CII	CIII	CIV	CV
P. elongatus (North Sea)						
Feb	5		4.6	5.6	5.0	7.6
Apr	7	1.9	2.4	2.9	3.5	6.0
Jun	12		2.0	5.1	3.6	6.1
Aug	13		2.5	4.3	2.4	8.0
P. acuspes (Baltic Sea)						
Apr	5	5.3	4.0			
May	3.5		16.0	14.3	22.0	
Jul	4			29.5	29.4	
	4	26.2	26.7	36.2		

Our genetic analyses confirm the observations by Frost (1989) and the genetic analyses by Bucklin *et al.* (2003), who identified *P. acuspes* in the Baltic Sea. The remarkable differences in the life cycles of both species point towards the importance of *in situ* measurements of vital rates especially when calculating secondary production and linking variability in recruitment of commercially important fish stocks with fluctuations in the abundance of these copepods. Recent Baltic Sea studies still use laboratory derived rate measurements of *P. elongatus* to explain life cycle characteristics or estimate production of *P. acuspes*.

References

Bucklin A., B.W. Frost, J. Bradford-Grieve, L.D. Allen and N.J. Copley. 2003. Molecular systematic and phylogenetic assessment of 34 calanoid copepod species of the Calanidae and Clausocalanidae. Marine Biology 142: 333-343.

Conover R.J. 1988. Comparative histories in the genera *Calanus* and *Neocalanus* in high latitudes of the northern hemisphere. Hydrobiologia 167/168: 127-142.

Corkett C.J. and I.A. McLaren. 1978. The biology of *Pseudocalanus*. Advances in Marine Biology 15: 1-231.

Frost B.W. 1989. A taxonomy of the marine calanoid copepod genus *Pseudocalanus*. Canadian Journal of Zoology 67: 525-551.

Halsband-Lenk C., F. Carlotti and W. Greve. 2004. Life-history strategies of calanoid congeners under two different climate regimes: a comparison. ICES Journal of Marine Science 61: 709-720.

Differences in life-cycle strategies and trophic niches of the copepods *Temora longicornis* and *Acartia longiremis* in the central Baltic Sea - a success story

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Owing to a climate-induced temperature increase and a salinity decrease during the last two decades, the pelagic system of the Baltic Sea experienced a drastic shift in community structure spanning almost all trophic levels (Möllmann *et al.* 2000; Wasmund and Uhlig, 2003). Both, *Acartia* spp. and *Temora longicornis* populations obviously benefited from higher temperatures, although *T. longicornis* exhibited a much

higher variability in biomass anomalies (Möllmann *et al.*, 2003). Apparently, different processes seem to be involved in the recruitment success of the respective species, potentially a consequence of their different geographical range. While *A. longiremis* is an arctic-neritic species, for which the central Baltic Sea is on the edge of its distribution, *T. longicornis* extends far southwards into warmer water regions. Therefore,

detailed knowledge on habitat-specific life-cycle strategies as well as trophic niches of both species is fundamental to evaluate physical versus trophic control mechanisms. To elucidate these aspects, trophic fatty acid markers in storage lipids of adult females of *A. longiremis* and *T. longicornis* as well as lipid content, stage composition and *in situ* egg production were studied in an extensive field programme covering the period from March 2002 to March 2003 on essentially a monthly basis within the GLOBEC-Germany programme.

Distinct trophic niches of both species are reflected in interspecific differences of their fatty acid composition (Fig. 1). *T. longicornis* shows a general tendency to feed herbivorously, with similar levels of diatom (16:1(n-7), 20:5(n-3)) and dinoflagellate markers (18:4(n-3), 22:6(n-3)). However, phytoplankton markers never reached the high levels known from other regions (Kattner *et al.*, 1981; Peters *et al.*, 2007). In contrast, high amounts of C-18 unsaturated fatty acids and extremely low values of 16:1(n-7) in *A. longiremis* emphasise that feeding on diatoms was strongly reduced. *Acartia* species are known to switch from a suspension to an ambush feeding mode in times of low food supply or in the presence of large dinoflagellates and especially ciliates (Jakobsen *et al.*, 2005). Thus, prevailing ratios between diatoms and mobile prey in the Baltic Sea apparently favour selective feeding on heterotrophic organisms or at least on non-diatom food items. Although the respective trophic niches are very distinct, both species are characterised by comparatively high 18:1(n-9) values, indicating a more heterotrophic food composition as compared to other habitats.

An alignment of seasonal changes in diet composition with life-cycle characteristics revealed a strong coupling of *T. longicornis* to primary production, with peak egg production corresponding to the spring and autumn bloom, as well as increase in diatom markers during times of high reproductive activities or intense lipid

accumulation (Fig. 2). Storage lipid levels in females began to rise in September, although energy was still mainly transferred into reproduction, as is evident from the second peak in egg production in October. Maximum lipid reserves were built up in November. The proportion of reproducing females declined from September (97%) to November (23%) (data not shown), whilst their body size increased. Hence, overwintering females most likely belonged to a new cohort with proceeding development but reduced reproduction in favour of lipid accumulation. Lipid reserves slowly decreased during winter, serving as an energy buffer against starvation and the build-up of gonads. Reproductive activity remained low until the onset of next year's spring bloom in March. Although resting eggs contribute significantly to the spring-population recruitment in other habitats (Lindley, 1990), no hatching of *T. longicornis* eggs from sediments was observed in the Baltic Sea so far (Madhupratap *et al.*, 1996). Apparently, next year's recruitment of *T. longicornis* depends substantially on mortality and reproductive success of the overwintering older copepodids and females, suggesting feeding conditions and thus trophic control as one key process in stock-size regulation.

In contrast to *T. longicornis*, *A. longiremis* females accumulated no lipid deposits for overwintering, although in high latitudinal habitats this species endures winter with increased levels of triacylglyerols and wax esters and premature gonads (Norrbin *et al.*, 1990). There is no evidence for another overwintering
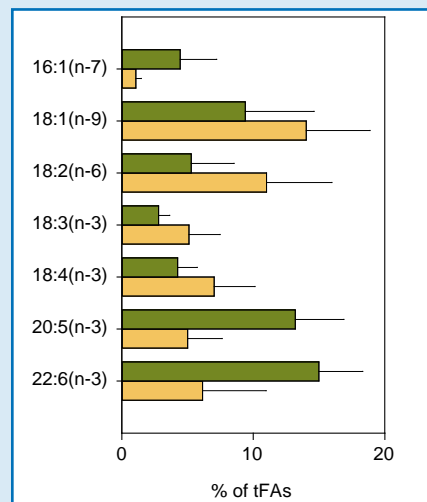
Figure 1. Annual means of marker fatty acids in the storage lipids of adult females of Temora longicornis (green) and Acartia longiremis (yellow) in percent of total fatty acids (tFAs); error bars = standard deviation.
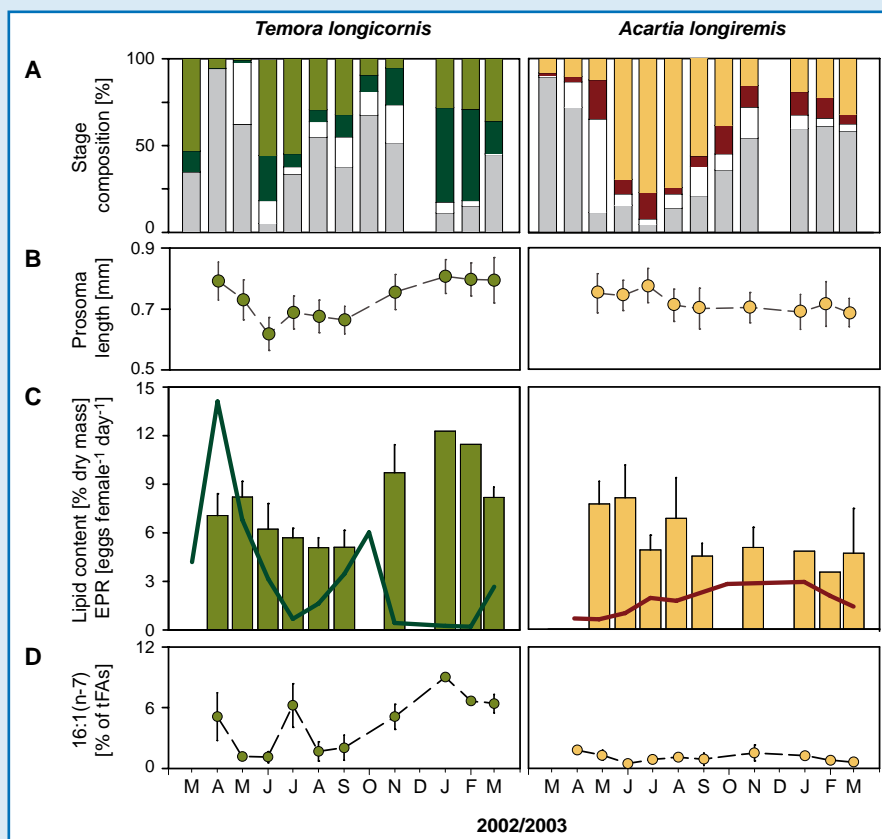
Figure 2. A. Stage composition (% of abundance) grouped by nauplii (grey), copepodite stages (C) I-III (white), CIV-V (dark green/red), CVI (light green/yellow); B. Prosoma length of females; C. Lipid content of females (columns) and daily egg production rates (EPR) (line); D. Relative amount of 16:1(n-7) on total fatty acids (tFAs) in storage lipids of females; error bars = standard deviation.

copepodite stage in the Baltic Sea, but high abundances of nauplii occurred during winter. Thus, energy was invested into reproduction rather than storage. However, both egg production and hatching success were poor from January to April 2003 (Dutz *et al.*, 2004) and sediment cores from the Bornholm Basin released large amounts of *Acartia* spp. nauplii after incubation under ambient temperature conditions (Dutz *et al.*, 2004). Thus, *A. longiremis* seems to extend its reproductive phase into the winter period, probably by using microzooplankton as an energy source and recruits at least partly the first generation of the following year from resting eggs. Therefore, the standing stock relies less on the survival of last year's females throughout winter, but on hatching success of eggs from the sediment, which is a temperature-dependent process. Thus, physical factors have a high potential to directly control the stock size of *A. longiremis*.

In conclusion, life-cycle strategies of both species in the central Baltic Sea differ from that in other habitats. Both species benefit from the environmental changes. Our results suggest that trophic effects play a more important role for the recruitment success of *T. longicornis*, leading to more variability in temperature-biomass correlations, while the population size of *A. longiremis* is potentially more directly influenced by physical factors.

References

Dutz J., V. Mohrholz, J. Peters, J. Renz and J. Alheit. 2004. A strong impact of winter temperature on spring recruitment of a key copepod species in the Bornholm Basin: potential linkages to climate variability. International GLOBEC Newsletter 10(1): 9-10.

Jakobsen H.H., E. Halvorsen, B.W. Hansen and A.W. Visser. 2005. Effect of prey motility and concentration on feeding in *Acartia tonsa* and *Temora longicornis*: the importance of feeding modes. Journal of Plankton Research 27: 775-785.

Kattner G., M. Krause and J. Trahms. 1981. Lipid composition of some typical North Sea copepods. Marine Ecology Progress Series 4: 69-74.

Lindley J.A.1990. Distribution of overwintering calanoid copepod eggs in sea-bed sediments around southern Britain. Marine Biology 104: 209-217.

Madhupratap M., S. Nehring and J. Lenz. 1996. Resting eggs of zooplankton (Copepoda and Cladocera) from the Kiel Bay and adjacent waters (southwestern Baltic). Marine Biology 125: 77-87.

Möllmann C., G. Kornilovs and L. Sidrevics. 2000. Long-term dynamics of main mesozooplankton species in the central Baltic Sea. Journal of Plankton Research 22: 2015-2038.

Möllmann C., F.W. Köster, G. Kornilovs and L. Sidrevics. 2003. Interannual variability in population dynamics of calanoid copepods in the central Baltic Sea. ICES Marine Science Symposia 219: 294-306.

Norrbin M.F., R.-E. Olsen and K.S. Tande. 1990. Seasonal variation in lipid class and fatty acid composition of two small copepods in Balsfjorden, northern Norway. Marine Biology 105: 205-211.

Peters J., J. Dutz and W. Hagen. 2007. Role of essential fatty acids on the reproductive success of the copepod *Temora longicornis* in the North Sea. Marine Ecology Progress Series 341: 153-163.

Wasmund N. and S. Uhlig. 2003. Phytoplankton trends in the Baltic Sea. ICES Journal of Marine Science 60: 177-186.

Stage resolved description of copepods in three dimensional ecosystem models

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In the framework of the GLOBEC Germany project we aimed at developing a consistent model description of copepods. The work started with resolving the life cycle of *Pseudocalanus*. Life cycles can be imagined as a 'propagation' along a mass axis, starting from eggs to adults. Since not every single detail must be resolved, it is obviously sufficient to group some stages into aggregated state variables. For example, the nauplii stages can be aggregated into a "one model" stage, which is characterised by the limits of the corresponding mass interval. In this way, the important function of nauplii as food for larvae (match-mismatch) can be accounted for. Similarly, we group the various copepodite stages into two aggregated model copepodite stages and an adult stage, where the reproduction occurs. This concept is sketched in Figure 1, which shows the different copepod model stages as intervals of the mass axis. For a detailed model description see Fennel (2001).

The development of such a model can start with a relatively simple box model. The box may reflect a rearing tank or an example grid cell of a full three-dimensional circulation model. The next step is embedding this model component into a 3D model environment of a circulation model with a biogeochemical component. The usual bulk-zooplankton variable in biogeochemical models can be replaced by our stage resolving copepod model. This approach allows an explicit resolution of temporal and spatial distributions of the different stages. First results, indicated the important role of the shallower part of the basins of the Baltic Sea (Fennel and
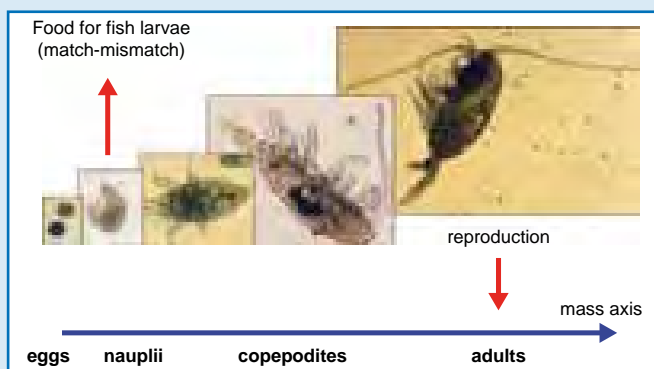
Figure 1. Sketch of copepod life cycle development of in the model (Pseudocalanus).

Neumann, 2003), in particular in the vicinity of river mouths where nutrient inputs from the rivers stimulate biological activity. However, it was also found that the vertical distribution patterns of the Baltic Sea copepods cannot sufficiently be captured with only a one stage resolving model.

For a refinement of the life cycle description we considered two different groups of copepods, *Pseudocalanus* and an aggregated group of 'others' comprising *Acartia* and *Temora*. In addition to pelagic reproduction, we also included resting eggs, which are lying on the sea bed and transported in a similar manner as easily erodible material. An implementation of behavioural aspects, in particular the vertical migration

due to ontogenetic patterns and in response to environmental or internal signals, is crucial for the differentiation of the two groups. This was achieved by an approach which quantifies the response to different external and internal stimuli, such as salinity, temperature, oxygen, starvation, avoidance etc. After weighting the relative importance of the stimuli, copepods react with a vertical migration. For example, lack of oxygen has a high weight and initiates an upward migration, even if the copepods move into lower salinity. A detailed description of this model component is given in Neumann and Fennel (2006). Examples of simulated copepod distributions for a run covering the years 1999 and 2000 are shown in Figure 2, and show different 'centres of mass' of the distribution of nauplii and adults for the two model groups. The adult *Pseudocalanus* prefer a habitat in the centre of the Bornholm Sea which is characterised by high salinity. The other group of copepods is more abundant in the southern Bornholm Sea where nutritional conditions are better. The patterns of nauplii abundance indicate the high reproduction potential at the southern coast and slope whilst the abundance of nauplii in the central basin is lower.

One important aspect of the use of a comprehensive model system with an elaborated biogeochemical model is the explicit simulation of oxygen dynamics. In particular, prediction of anoxia is an important issue for the assessment of reproduction of copepods and recruitment of fish.

In general, our model provides a three dimensional perspective of copepod reproduction and development in response to hydrographic events (e.g. major inflows). The interannual variation in the reproduction of *Pseudocalanus* depends strongly on the size of the reproductive volume, i.e. the volume of water with a salinity of more then 12 and oxygen concentration exceeding 1 ml/l (Schmidt *et al.*, 2003). An Empirical Orthogonal
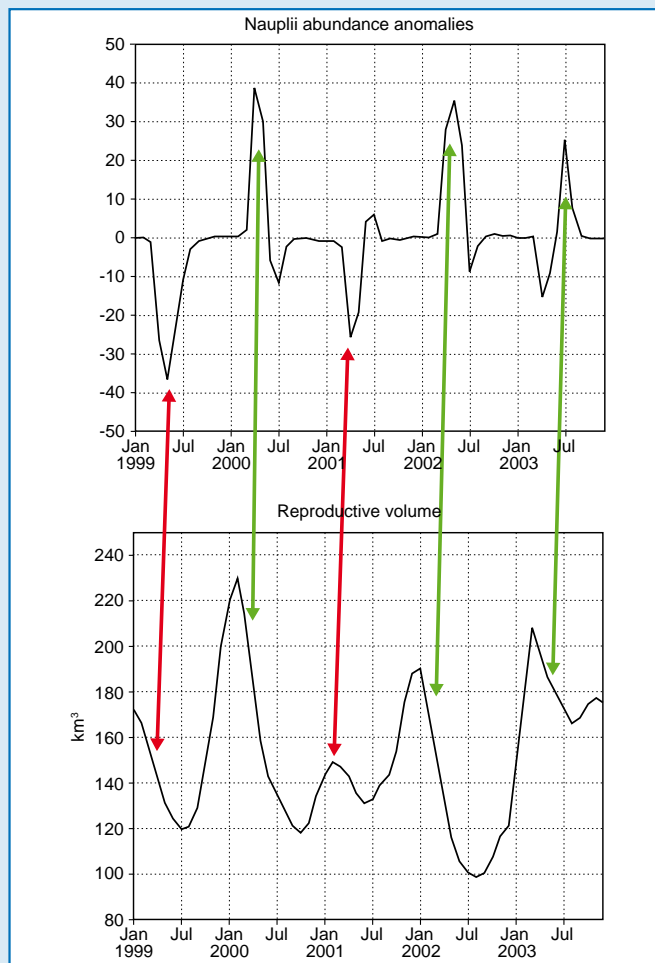
Figure 3. Time series of the principal component (first EOF mode) of the Pseudocalanus nauplii abundance anomalies (upper panel) and the temporal changes of the reproductive volume (lower panel). A higher reproduction is correlated with a higher reproductive volume (green arrows).

Function (EOF) analysis of the de-trended, normalised anomalies of simulated *Pseudocalanus* nauplii abundance revealed that the highest variability of reproduction occurs in the central Bornholm Sea. Time series of the first EOF mode together with time series of the reproductive volume are shown in Figure 3. The reproductive success of *Pseudocalanus* is correlated with the size of the reproductive volume, as indicated by the arrows. This underlines the influence of hydrographic conditions on *Pseudocalanus* reproduction and hence of the development of population density. Since *Pseudocalanus* is an important nutritional source for fish in the Baltic Sea, effects of hydrographic conditions on *Pseudocalanus* reproduction may propagate up the food web.

References

Fennel W. 2001. Modeling of copepods with links to circulation model. Journal of Plankton Research 23: 1217-1232.

Fennel W. and T. Neumann. 2003. Variability of copepods as seen in a coupled physical-biological model of the Baltic Sea. ICES Marine Science Symposia 219: 208-219.

Neumann T. and W. Fennel 2006. A method to represent vertical migration of zooplankton in 3D-eulerian models. Ocean Modelling 12: 188-204.

Schmidt J., C. Möllmann, A. Temming, J.-P. Herrmann, J. Floeter, A. Sell and M.A. St. John. 2003. Unusual water mass advection affected Central Baltic key species 2: *Pseudocalanus* and the winter inflow. GLOBEC International Newsletter 9(2): 28-29.
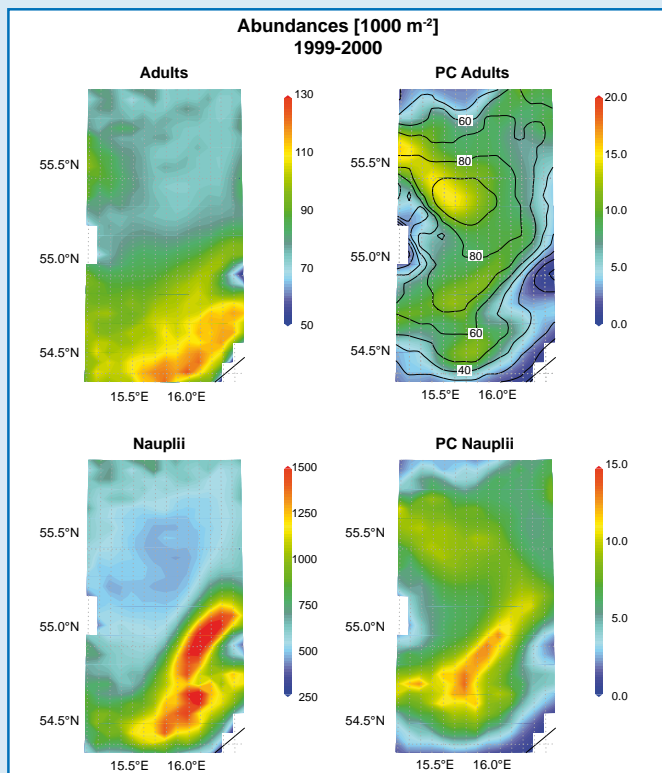
Figure 2. Average spatial patterns of Pseudocalanus (right column) and other copepods (left column) abundances of adults and nauplii in the Bornholm Basin. Isolines reflect the bathymetry.

Modelling competition between a structured population and rest zooplankton in the North Sea using the three-dimensional ecosystem model ECOHAM

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A three-dimensional ecosystem model was developed which includes competition between *Pseudocalanus elongatus* and the rest of the zooplankton community. The model describes the seasonal cycle of North Sea zooplankton based on bottom-up food control.

In the North Sea, nutrient and phytoplankton dynamics have been studied using several ecosystem models (Moll and Radach, 2003). Only some models included zooplankton development in detail and none of these included all the relevant processes. Therefore, an increasingly structured representation of the population is required. In GLOBEC-Germany the focus is placed on small copepods such as *Pseudocalanus elongatus* (Moll and Stegert, 2007).

The goal of this study was to resolve the most important features of zooplankton dynamics in terms of biomass distribution and population life cycle. The approach was to simulate one specific population in competition with the rest of the zooplankton embedded in a coupled hydrodynamical-ecological model providing food based on primary production.

The zooplankton formulation

The three-dimensional model ECOHAM3 (ECOsystem model, HAMburg, Version 3) consists of two components for coupled physical-biological modelling: hydrodynamics based on HAMSOM and ecosystem dynamics using biogeochemical cycles of carbon and nitrogen.

For implementation of stage-structured zooplankton we used the approach of population modelling by Fennel (2001), which at first was parameterised to environmental conditions of the North Sea (Stegert *et al.*, 2007) and tested within ECOHAM2 for a northern North Sea water column (Moll and Stegert, 2007) without competition. The zooplankton population consists of five stage groups for *Pseudocalanus elongatus* representing the stage-resolved abundance and the biomass in terms of nitrogen and carbon ($Pe_A(i)$, $Pe_N(i)$, $Pe_C(i)$, $i=1,5$). The sum of the five state variables $Pe(i)$ represents the total biomass of the population.

In ECOHAM3 we included the rest of the zooplankton community within one state variable, called "rest zooplankton" in terms of
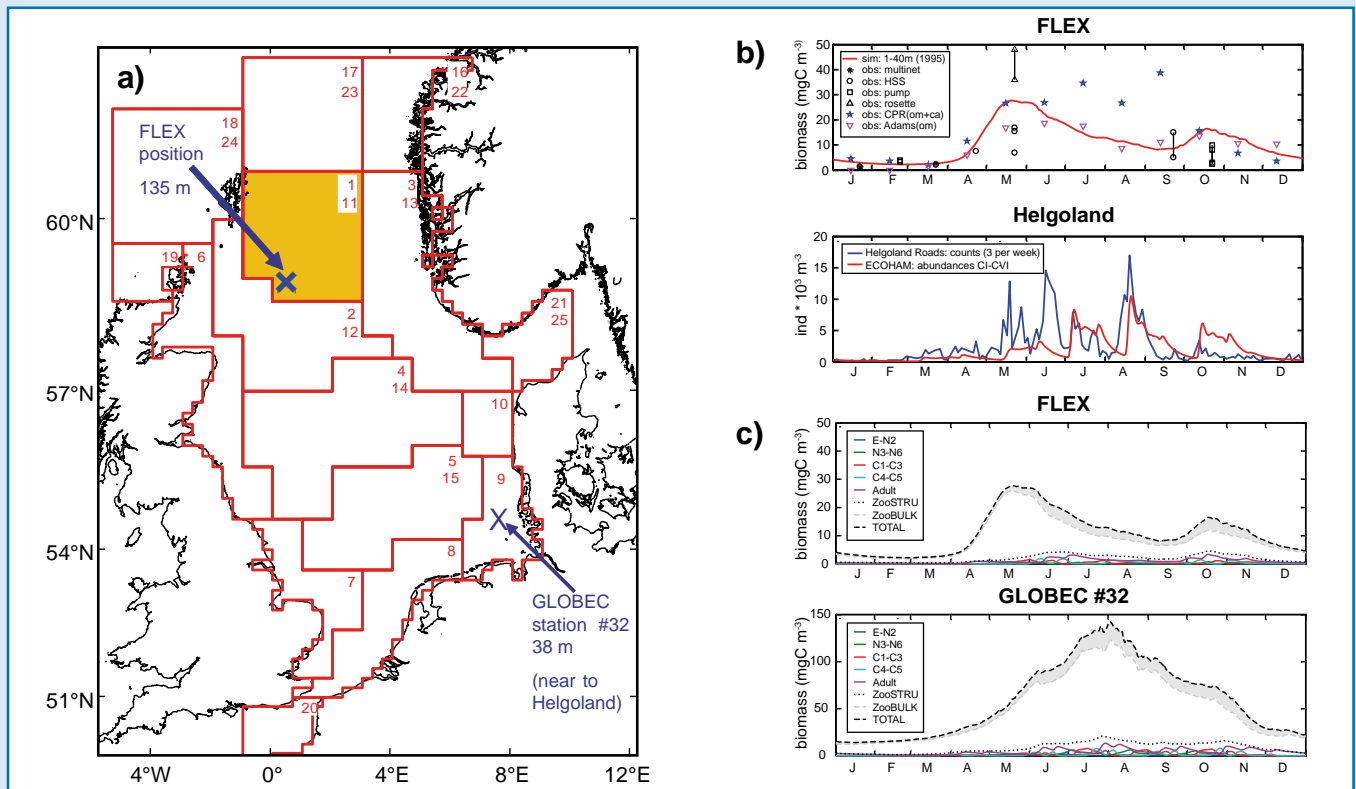
Figure 1. Simulated zooplankton biomass for 1995 for two sites: a) map of the North Sea with selected positions, b) validation of total biomass at FLEX using different gears, and validation of Pseudocalanus elongatus abundance of copepodites at Helgoland Reede, c) total zooplankton biomass (bold dashed line) as the sum of rest zooplankton (pale dashed line) and population with stage-structured biomass (dotted line); for better inspection as grey shaded area.

Figure 2. Simulated P. elongatus biomass in June 2004 and percentage of population versus total zooplankton biomass.

nitrogen and carbon biomass (Z_N, Z_C). Competition is formulated as a competition for food and tested for the annual cycle (Kreus, 2006). While the rest zooplankton is able to react forthwith on food resources the population takes longer development times due to the moulting process with weight- and temperature-dependent ingestion.

Application and results

The model has been applied for the years 1993-1996 for validation and 2003-2004 for investigation within the GLOBEC-Germany frame. Atmospheric forcing and boundary data determine hydrodynamic circulation fields which control the biogeochemical and biological variables. At first, the model was validated against data. Two North Sea positions were selected for analysis (Fig. 1; Kreus, 2006): one site in the northern North Sea (FLEX, 58°55'N, 0°30'E; 135 m) and another station in the southern North Sea (GLOBEC #32, 54°40'N, 7°00'E; 38 m). An additional station known as Helgoland Reede has a long tradition in plankton analysis. For these sites we present a short validation based on biomass and abundance.

In a first step we compared observed total biomass concentrations for the FLEX position, which exhibited a great variability due to different gears and different years (Fig. 1b). The simulated daily biomass concentration at the northern station fits within this variability for nearly all months. The comparison to Helgoland Reede data (as a second step) showed that the simulated abundance covered the observed feature of several generations and was below the amplitude of the measurements, which were observed three times each week.

This validation gives us confidence that the model system is able to reproduce the ratio of population biomass to total biomass (Fig. 1c). Until spring, structured zooplankton is not significant in total biomass. The contribution increases up to 20% during summer at FLEX and is less at GLOBEC station #32. For the southern North Sea *P. elongatus* biomass showed increased values compared to the FLEX site with peaks induced by the development of generations. Then, the additional three-

dimensional simulation for the GLOBEC-Germany cruise period in 2004 was performed and analysed for regional differences in the German Bight. Figure 2 illustrates the total and relative biomass of *P. elongatus* in the German Bight.

Population biomass remains low during winter and increases in spring/summer showing a gradient towards the central North Sea. For shallow southern areas the ratio increases due to higher food supply. Near coastal areas showed decreased ratios because of increased rest zooplankton.

The next steps are to analyse simulation results of population and bulk zooplankton in detail using extended observations from the North Sea (Krause *et al.*, 2003) and cruise data from 2004 to interpret regional differences. We expect characteristic differences of summer and autumn competition between stratified northern and tidally-mixed southern stations due to the food- and temperature-dependent ingestion parameterisation which results in different mean body weights of the population stages. A connection to larval fish modelling will be established by the deliverance of size-based zooplankton prey fields for 2004.

References

Fennel W. 2001. Modelling of copepods with links to circulation models. Journal of Plankton Research 23(11): 1217-1232.

Krause M., H. Fock, W. Greve and G. Winkler. 2003. North Sea zooplankton: a review. Senckenbergiana Maritima 33(1-2): 71-204.

Kreus M. 2006. Untersuchung der Generationszeiten von Zooplankton-Populationen in Abhängigkeit der physikalischen und biologischen Umweltbedingungen für verschiedene Nordseeregionen. Diploma Thesis, Universität Hamburg, 74 pp.

Moll A. and G. Radach. 2003. Review of three-dimensional ecological modelling related to the North Sea shelf system. Part 1: Models and their results. Progress in Oceanography 57(2): 175-217.

Moll A. and C. Stegert. 2007. Modelling *Pseudocalanus elongatus* population dynamics embedded in a water column ecosystem model for the northern North Sea. Journal of Marine Systems 64(1-4): 35-46.

Stegert C., M. Kreus, F. Carlotti and A. Moll. 2007. Parameterisation of a zooplankton population model for *Pseudocalanus elongatus* using stage duration laboratory experiments. Ecological Modelling 206(3-4): 214-234.

Predation control by hydrographic gradients

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In the Bornholm Basin, a central basin of the southern Baltic, pronounced hydrographic stratifications persist due to fresh water input and topography and a permanent halocline is found at 60 m depth. During summer a thermocline separates the warm surface water from the cooler winter water at 20-30 m, resulting in a three-storeyed water column (Fig. 1). Between March 2002 and May 2003 a total of 832 multinet samples were analysed for compositional differences of 23 zooplankton species by means of multivariate methods, weighted depth centroids and individual analyses of the vertical distribution. Clearly certain species and developmental stages are bound to distinct layers and partially migrate between them seasonally (Schulz *et al.*, 2007). As each layer is characterised by specific temperature/salinity combinations, they put different demands on the physiology and can therefore be conceived as habitats, determining the vertical distribution. A total of five different utilisation modes of the water column were identified (Schulz, 2006), which sort the zooplankton community into functional groups (Fig. 2). These functional groups should be used in models of prey fields to differentiate resources at the depth where predators linger. Also calculation of active selection indices requires knowledge of the spatio-temporal predator-prey overlap. Our results show that the use of unstratified hauls is critical.

The main consumers of the zooplankton in the Baltic Sea are planktivorous fish and scyphomedusae. Larval and young-of-year cod (*Gadus morhua* L.) remain mostly in the vicinity of the halocline and hence prey on taxa of Mode d and e. Larval and young sprat (*Sprattus sprattus* L.) concentrate in shallower layers (Makarchouk and Hinrichsen, 1998) and feed in spring on Modes b and c and after the formation of the thermocline on Modes a and b, e.g. on *Acartia* spp. This may explain why years with high *Acartia* spp. abundances are correlated with strong year classes of sprat (Dickmann, 2005).

Figure 2. The five different utilisation modes of zooplankton in relation to hydrographic parameters as revealed by multivariate and traditional approaches and their indicator species. a) Species which are only present when a warm surface layer is established and dwell mainly in this layer, like Bosmina coregoni maritima. b) All stages of Acartia bifilosa seasonally take advantage of the warm surface layer, but are also present prior to and after the formation of this seasonally appearing habitat. c) Acartia longiremis is a characteristic species that resides in the layer of the intermediate winter water between thermo- and halocline during summer. d) Only Fritillaria borealis utilised the complete water column except for the warm surface layer in summer. e) Characteristic species bound to the deep haline waters were identified to be Oithona similis and the C4-C6 stages of Pseudocalanus sp.

Figure 1. Schematic overview of the different hydrographic strata in the Baltic Sea.

Between July and September the medusa *Aurelia aurita* mainly inhabits the layer above the thermocline and feeds mainly on the cladoceran *Bosmina coregoni maritima* (Mode a). The less abundant *Cyanea capillata* prefers the intermediate water layer and the halocline (Mode c). The appearance patterns of scyphomedusae showed a seasonal and vertical mismatch with the eggs and larvae of fish and thus prevents them from predation and competition (Barz and Hirche, 2005).

References

Barz K. and H.J. Hirche. 2005. Seasonal development of Scyphozoan medusae and the predatory impact of *Aurelia aurita* on the zooplankton community in the Bornholm Basin (Central Baltic Sea). Marine Biology 147(2): 465-476.

Dickmann M. 2005. Feeding ecology of sprat (*Sprattus sprattus* L.) and sardine (*Sardina pilchardus* W.) larvae in the Baltic Sea and North Sea. PhD thesis, University of Rostock, Germany, 95pp.

Makarchouk A. and H.-H. Hinrichsen. 1998. The vertical distribution of ichtyoplankton in relation to the hydrographic conditions in the Eastern Baltic. ICES Council Meeting Papers CM 1998/R:11.

Schulz J. 2006. Spatial and temporal distribution patterns of zooplankton in the central Baltic Sea and methods to detect them. PhD thesis, University of Bremen, http://nbn-resolving.de/urn:nbn:de:gbv:46-diss000106605.

Schulz J., C. Möllmann and H.-J. Hirche. 2007. Vertical zonation of the zooplankton community in the Central Baltic Sea in relation to hydrographic stratification as revealed by multivariate discriminant function and canonical analysis. Journal of Marine Systems 67(1-2): 47-58.

Environmental factors influencing larval sprat *Sprattus sprattus* feeding in the Baltic Sea

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It is generally known that the year-class strength of fish populations is determined by factors acting on the early life-history stages (e.g. Gulland, 1965; Myers and Cadigan, 1993). Several hypotheses suggest a causal link between feeding success, larval survival rates and the subsequent recruitment strength of the year class (Hjort, 1914; Cushing, 1990). However, it has become increasingly obvious that the spatio-temporal variability of factors other than prey abundance, such as turbulence and temperature, have the potential to alter feeding success (MacKenzie *et al.*, 1990, 1994; Lough and Mountain, 1996; MacKenzie and Kiørboe, 2000). Thus, larval feeding success seems to be determined by a wide range of potentially interacting environmental factors.

Information about Baltic sprat larval feeding behaviour in terms of quantitative gut content analysis is available (e.g. Voss *et al.*, 2003; Dickmann *et al.*, in press). These studies focused, however, on seasonal prey spectra, gut fullness, and predator-prey size relationships. Although prey abundance was found to be somehow linked to larval survival success (Voss *et al.*, 2006), an analysis identifying the functional relationship and relative importance of other environmental factors is missing. The purpose of the present analysis was to define the key factors for larval sprat feeding success in the Baltic Sea and to challenge the null-hypothesis that larval feeding success is predominantly determined by the density of potential prey organisms.

An expansion of Generalized Additive Models (GAMs) was adopted that allows the inclusion of interaction terms in a non-parametric regression model (Porter *et al.*, 2005). Sprat larvae were collected over a period of three months covering the main spawning season in 2002 (May-July), thereby sampling over a wide range of environmental conditions.

The following biological and physical environmental variables were determined for each larval sampling time and position and subsequently used as independent variables to explain larval feeding success: water depth, ambient temperature, wind speed (a proxy of small scale turbulent dissipation rates; Oakey and Elliot, 1982), feeding time (the number of hours from sunrise to larval collection), prey abundance, cloudiness (ratio of cloud cover as an approximation of light levels) and larval size.
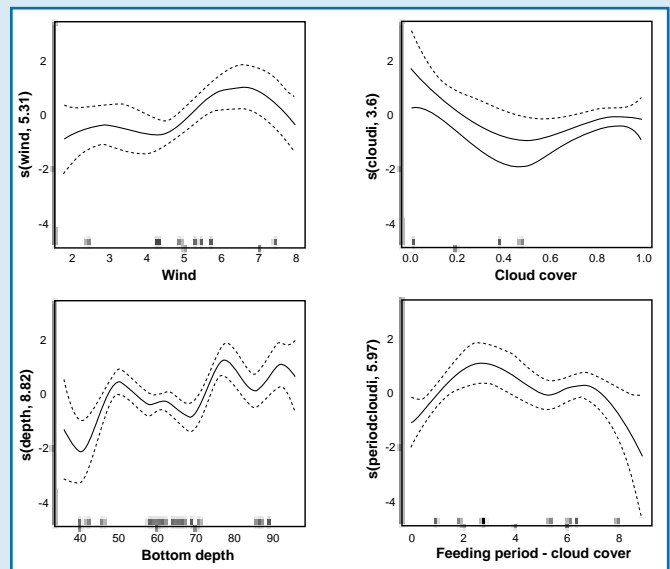

Figure 1. Partial effects of environmental factors in the second Generalized Additive Model (GAM) explaining sprat larval feeding success with the additional help of interaction terms. The solid lines represent the estimated smooth function and the dashed lines the corresponding 95% confidence limits. The rug plots along the x-axis show the values of the covariates for each smooth and the number in each y-axis caption is the effective degrees of freedom of each term. From left to right and from top to bottom: natural logarithm of wind forcing (ln(windspeed³)), ratio of cloud cover, bottom depth (m) and feeding period-cloudiness interaction (h).
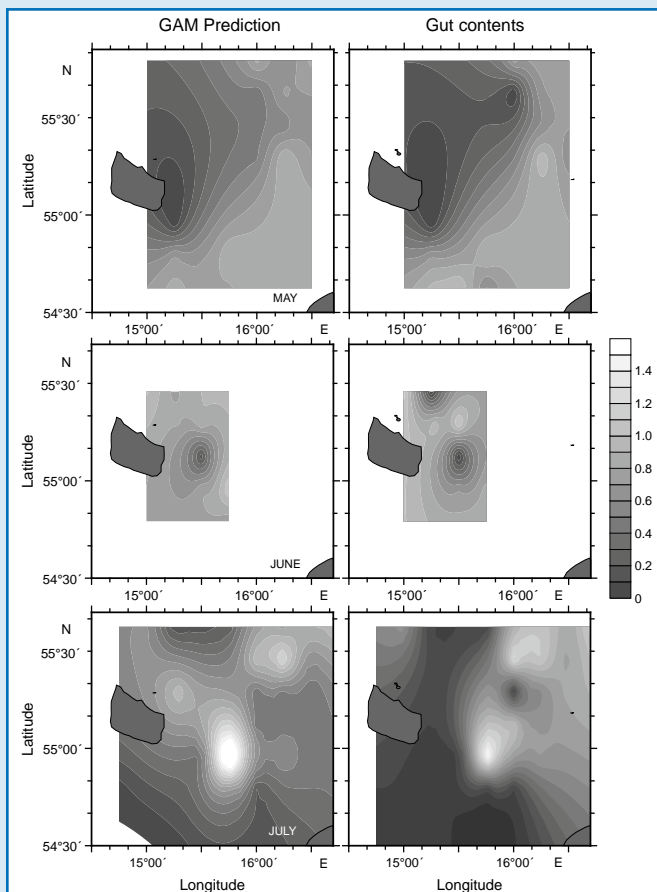
Figure 2. Predicted (left panels) versus observed (right panels) larval feeding success (NPG) in May (top), June (middle) and July (bottom). Predictions are based on the second Generalized Additive Model (GAM) explaining sprat larval feeding success with the additional help of interaction terms.

As dependent variable *larval feeding success* (NPG) was defined: from each larval sampling station 3 to 55 larvae of 7.5 mm to less than 12.5 mm length were analysed and the mean number of prey in the gut (NPG) per station calculated. As the dependent variable NPG was not normally distributed, a fourth-root data transformation was applied. Afterwards no significant deviation from the normal distribution occurred ($p<0.05$).

In the first step, all environmental factors were initially included as covariates in an additive GAM model. The Generalised Cross Validation (GCV; Wood, 2000) was used as the criterion for model selection: all combinations of covariates were tested, potentially excluding non-significant ($p>0.05$) covariates and minimising the GCV. All analyses were conducted using the R-software (version 2.2.0, http://www.r-project.org), specifically the package "mgcv".

After the key environmental variables affecting larval feeding success were identified, it was tested whether the inclusion of interaction terms of these key variables increased the percentages of the explained variance. All possible two-way second order interactions between the key covariates were separately included in non-additive GAMs.

The final modelling step led to the identification of 1 ($p < 0.05$) out of 15 significant interactions terms. Only the inclusion of the feeding period-cloudiness interaction resulted in a better model fit. The final non-additive model included a) wind forcing ($\ln(\text{windspeed}^3)$), b) ratio of cloud cover, c) bottom depth, prey abundance (as factor variable) and, d) feeding period-cloudiness interaction as significant variables. The final model showed an explained variance of 79.4% and a minimised GCV score of 1.9699. The directions of the effect of the environmental factors were changing over the investigated ranges of measurements (Fig. 1). An increase in prey abundance had a strong positive effect on NPG. The partial effect plot for wind speed showed again a positive effect for moderate conditions (6 to 13 m s^{-1}). An increase in cloud coverage generally decreased NPG, however, showing some non-linearity. Depth had a positive effect in two areas: at higher water depth (> 70m) and around 50 m depth. When using the final non-additive model to predict NPG surfaces at sampling time, a high degree of similarity to observed NPG values became obvious (Fig. 2). However, spatial coverage was not always sufficient to extrapolate to the whole basin area.

Our study demonstrated that the feeding success of sprat larvae in the Baltic Sea is controlled by a number of simultaneously acting key environmental factors.

References

Cushing D.H. 1990. Plankton production and year-class strength in fish populations: An update of the match/mismatch hypothesis. Advances in Marine Biology 26: 249-294.

Dickmann M., C. Möllmann and R. Voss, R. in press. Feeding ecology of central Baltic sprat *Sprattus sprattus* larvae in relation to zooplankton dynamics: implications for survival. Marine Ecology Progress Series.

Gulland J.A. 1965. Manual of methods for fish stock assessment. Part I fish populations analysis. FAO Fisheries Technical Paper 40: 1-68.

Hjort J. 1914. Fluctuations in the great fisheries of Northern Europe viewed in the light of biological research. Rapports et Proces-verbaux des Reunions. Conseil International pour l'Exploration de la Mer 160: 1-228.

Lough R.G. and R.D. Mountain. 1996. Effect of small-scale turbulence on feeding rates of larval cod and haddock in stratified waters on Georges Bank. Deep-Sea Research II 43: 1745-1772.

MacKenzie B.R. and T. Kiørboe. 2000. Larval fish feeding and turbulence: A case for the downside. Limnolology and Oceanography 45(1): 1-10.

MacKenzie B.R., W.C. Leggett and R.H. Peters. 1990. Estimating larval fish ingestion rates: can laboratory derived values be reliably extrapolated to the wild? Marine Ecology Progress Series 67: 209-225.

MacKenzie B.R., T.J. Miller, S. Cyr and W.C. Legett. 1994. Evidence for a dome-shaped relationship between turbulence and larval fish ingestion rates. Limnology and Oceanography 39: 1790-1799.

Myers R.A. and N.G. Cadigan. 1993. Is juvenile natural mortality in marine demersal fish variable? Canadian Journal of Fisheries and Aquatic Sciences 50: 1591-1598.

Oakey N.S. and J.A. Elliot. 1982. Dissipation within the surface mixed layer. Journal of Physical Oceanography 12: 171-185.

Porter S.M., L. Ciannelli, N. Hillgruber, K.M. Bailey, K.S. Chan, M.F. Canino and L.J. Haldorson. 2005. Environmental factors influencing larval walleye pollock *Theragra chalcogramma* feeding in Alaskan waters. Marine Ecology Progress Series 302: 207-217.

Voss R., C. Clemmesen, H. Baumann, H.-H. Hinrichsen. 2006. Baltic sprat larvae: Coupling food availability, larval condition and survival. Marine Ecology Progress Series 308: 243-254.

Wood S.J.R. 2000. Modelling and smoothing parameter estimation with multiple quadratic penalties. Journal of the Royal Statistical Society Series B 62: 413-428.

Shift in larval fish diets related to phytoplankton blooms revealed by stable isotope analysis

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Larval stages of many fish species generally select larger prey items as they grow (Voss *et al*., 2003), which is attributed to the maximisation of energy gain per prey capture effort (Pearre, 1986). Consequently, under good feeding conditions trophic niche width of growing larvae should remain constant (Pearre, 1986), whereas under poor feeding conditions niche width should increase to compensate for the lack of prey with the optimal ratio of time spent searching/handling to gain energy (Werner and Hall, 1974).

The trophic position of an organism in its environment is reflected by its chemical and biochemical composition. One measure for the trophic position is the ratio between the heavy stable nitrogen isotope ^{15}N to the light isotope ^{14}N. Nitrogen isotopes can be used as a trophic tracer (Peterson and Fry, 1987; Fry, 1988), as the stable isotope signatures of a consumer generally reflects the isotopic composition of their diets plus a relatively predictable enrichment in heavier isotopes (DeNiro and Epstein, 1981; Post, 2002). Hence, based on the predictions above, we can expect a gradual upwards shift in δ^{15}N (and hence in trophic position) of larval fish with increasing body length in the case of constant niche widths and good feeding conditions. Under poor feeding conditions, however, we predict a decrease in mean δ^{15}N coupled with an increase in variance as a result of broader niche widths.

Isotopic signals were studied in an extensive field campaign carried out in spring 2004 to elucidate the feeding ecology of larval lesser sandeel (*Ammodytes marinus*) and dab (*Limanda limanda*). Daily ichthyoplankton samplings and two seston samples per week were taken at the Helgoland Roads Station (54°11.18' N and 07°54.00' E, German Bight, southern North Sea). Larval fish were analysed for length and isotopic composition, and seston was analysed for isotopic composition. Additionally, diatom carbon concentrations were derived from the Helgoland Roads long term monitoring programme (Wiltshire and Manly, 2004).

Primary production was characterised by constantly low diatom carbon concentrations and a rapid development of a diatom bloom in the middle of April (Fig. 1). This diatom bloom coincided with a drastic decrease in larval fish prey abundance (Fig. 1; for further details see Malzahn *et al*., 2007). The seston δ^{15}N signature constantly increased until the onset of the diatom bloom and decreased coinciding with the phytoplankton bloom (Fig. 1). This pattern can be interpreted as an increasing proportion of heterotrophic organisms relative to the autotroph proportion contributing to the microplankton community, which is reversed at the moment of the onset of the phytoplankton bloom. The same pattern of an increase in δ^{15}N in the pre-diatom bloom situation and a decrease during the bloom was observed in both species of larval fish, with the remarkable difference that the decrease in δ^{15}N was more pronounced than it was in the seston signatures (Fig. 1). This reduction of the δ^{15}N signature of larval fish in late spring is a clear evidence for a downwards shift in trophic level of larval fish, implying that the larvae substituted a shortage in zooplankton prey during the diatom bloom
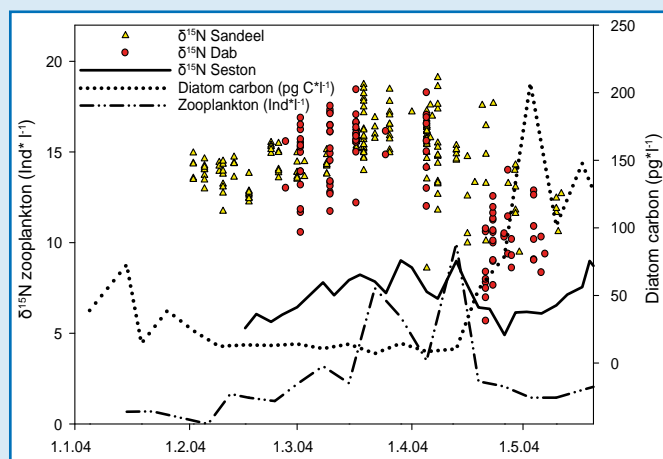

Figure 1. δ^{15}N signature of larval dab (Limanda limanda), sandeel (Ammodytes marinus), seston, diatom carbon concentrations as well as zooplankton abundance in spring 2004 at the Helgoland Roads station.
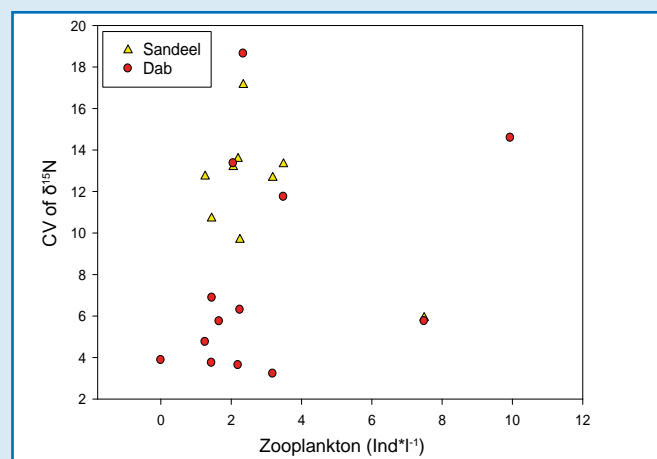

Figure 2. Coefficient of variation (CV) of the δ^{15}N signal of larval dab and larval sandeel on a weekly basis versus zooplankton densities.
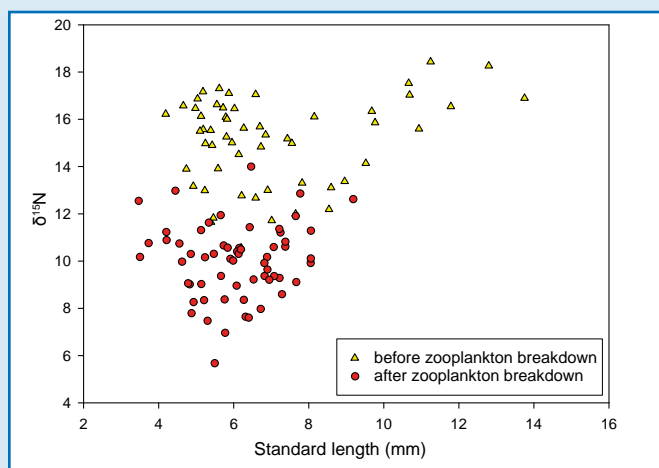
Figure 3. $\delta^{15}N$ signatures of larval dab (Limanda limanda) caught in spring 2004 at the Helgoland Roads station plotted against larval size. The dataset is divided into pre-phytoplankton bloom (before zooplankton breakdown) and phytoplankton bloom (after zooplankton breakdown).
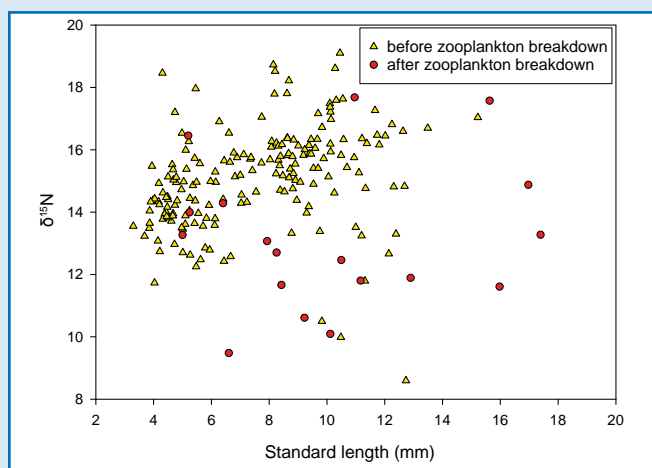

Figure 4. $\delta^{15}N$ signatures of larval sandeel (Ammodytes marinus) caught in spring 2004 at the Helgoland Roads station plotted against larval size. The dataset is divided into pre-phytoplankton bloom (before zooplankton breakdown) and phytoplankton bloom (after zooplankton breakdown).

with organisms of lower trophic levels. The alternative food sources were presumably small microzooplankton as well as some phytoplankton species, as indicated by the fact that the difference between the seston $\delta^{15}N$ signal and that of the larval fish decreased. Linear regression analysis revealed that the variability of the $\delta^{15}N$ of larval fish, expressed as the coefficient of variation (CV=standard deviation/mean*100) of the $\delta^{15}N$ signature on a weekly basis, did not significantly vary with prey availability (Fig. 2).

As we did not investigate a specific cohort of larval fish but rather the full suite of size classes caught with the plankton gear, it can be ruled out that the shift was caused by feeding habits of different larval size-classes alone (Figs. 3 and 4). In fact, all size classes in the catches showed a downward shift in their trophic position after the breakdown of the zooplankton densities. As shown by Malzahn *et al.* (2007), low RNA:DNA ratios indicate reduced nutritional conditions in larger larval fish during times of reduced zooplankton availability. As this was not the case for smaller larvae, it can be concluded that small larvae were sufficiently nourished by microzooplankton and phytoplankton.

Prior studies on cod (Kane, 1984), dab, flounder and sole (Last, 1978) as well as American sandeel (Monteleone and Peterson, 1986) showed that the smallest larval fish can feed on phytoplankton. However, all these studies reported a rapid shift to zooplanktivory with increasing size. In this study, we showed that, depending on the availability of prey, large shifts in the diet of larval fish can be observed and that even larger individuals can be obliged to feed on algae and microzooplankton. The lack of well-conditioned larger larvae feeding on phytoplankton reported by Malzahn *et al.* (2007) suggests that although larger larvae are able to find alternative food sources, food items such as microzooplankton and phytoplankton do not support proper growth of larger individuals.

References

DeNiro M.J. and S. Epstein. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. Geochemical Journal 45(3): 341-352.

Fry B. 1988. Food web structure on Georges Bank northwestern Atlantic Ocean from stable carbon nitrogen and sulfur isotopic compositions. Limnology and Oceanography 33(5): 1182-1190.

Kane J. 1984. The feeding habits of co-occurring cod and haddock larvae from Georges Bank. Marine Ecology Progress Series 16(1-2): 9-20.

Last J.M. 1978. The food of four species of pleuronectiform larvae in the eastern English Channel and southern North Sea. Marine Biology 45(4): 359-368.

Malzahn A.M., M. Boersma, K.H. Wiltshire, C. Clemmesen and S. Laakmann. 2007. Comparative nutritional condition of larval dab and lesser sandeel in a highly variable environment. Marine Ecology Progress Series 334: 205-212.

Monteleone D.M. and W.T. Peterson. 1986. Feeding ecology of American sand lance *Ammodytes americanus* larvae from Long Island Sound. Marine Ecology Progress Series 30(2-3): 133-143.

Pearre S., Jr. 1986. Ratio-based trophic niche breadths of fish, the Sheldon spectrum, and size-efficiency hypothesis. Marine Ecology Progress Series 27(3): 299-314.

Peterson B. and B. Fry. 1987. Stable isotopes in ecosystem studies. Annual Review of Ecology and Systematics 18: 293-320.

Post D.M. 2002. Using stable isotopes to estimate trophic position: models, methods, and assumptions. Ecology 83(3): 703-718.

Voss R., F.W. Köster and M. Dickmann. 2003. Comparing the feeding habits of co-occurring sprat (*Sprattus sprattus*) and cod (*Gadus morhua*) larvae in the Bornholm Basin, Baltic Sea. Fisheries Research 63(1): 97-111.

Werner E.E. and D.J. Hall. 1974. Optimal foraging and the size selection of prey by the bluegill sunfish (*Lepomis macrochirus*). Ecology 55: 1024-1054.

Wiltshire K.H. and B.F.J. Manly. 2004. The warming trend at Helgoland Roads, North Sea: phytoplankton response. Helgoland Marine Research 58(4): 269-273.

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Variability in growth rates of larval fish at frontal stations in the southern North Sea: is the "mean" all that matters?

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In the GLOBEC Germany programme we are currently employing an Individual-Based Model (IBM) that can be coupled to different 3D hydrodynamic models to understand how physical and biological factors interact to influence the vital rates (survival, feeding and growth) of eggs and/or larvae of key clupeid species in the Baltic and North Sea. In the German Bight (southern North Sea), the IBM was used to gain spatially-explicit estimates of growth and survival of clupeid larvae in April, May and June 2004 by combining hydrodynamic model estimates (temperature, water currents) and *in situ* data for zooplankton preferred as prey by larval fish.

Prey data were based upon monthly station grid surveys of the abundance and size distribution of key calanoid copepods (*Pseudocalanus*, *Temora*, *Acartia* spp.). The IBM predicted that most areas of the inner German Bight were favourable environments for growth and survival of sprat (*Sprattus sprattus*) larvae (Kühn *et al.*, submitted). Mean growth rates predicted by the IBM for larval sprat were similar to those obtained by previous field studies employing otolith microstructure analysis on this species (e.g. for reviews see Huwer, 2004; Dänhardt *et al.*, 2007).

During 2003, process-oriented cruises were conducted along transects bisecting tidal mixing and river plume fronts in an attempt to understand how these hydrographic features influenced the trophodynamic structure of the German Bight (Fig. 1, insert). During a cruise in June 2003, growth rates of field-caught larval sprat and European sardine (*Sardina pilchardus*) were determined from measurements of otolith microstructure (Huwer, 2004) as well as calculated based upon concentrations of nucleic acids (Holtappels, 2004).

Mean dry mass-specific growth rates at all stations were between ~20 and 30% d^{-1} and, interestingly both otolith-based and nucleic acid-based techniques indicated that growth estimates were highly variable among individual larvae captured at the same station (Fig. 1a). The variance among growth rates declined with increasing larval size (Fig. 1b) but was unrelated to station (i.e. all stations had similar amounts of inter-individual variability in growth rates).

We used the coupled 3D hydrodynamic IBM to investigate the potential sources of within-station variability in clupeid growth rates. First, we assessed whether growth rate differences among
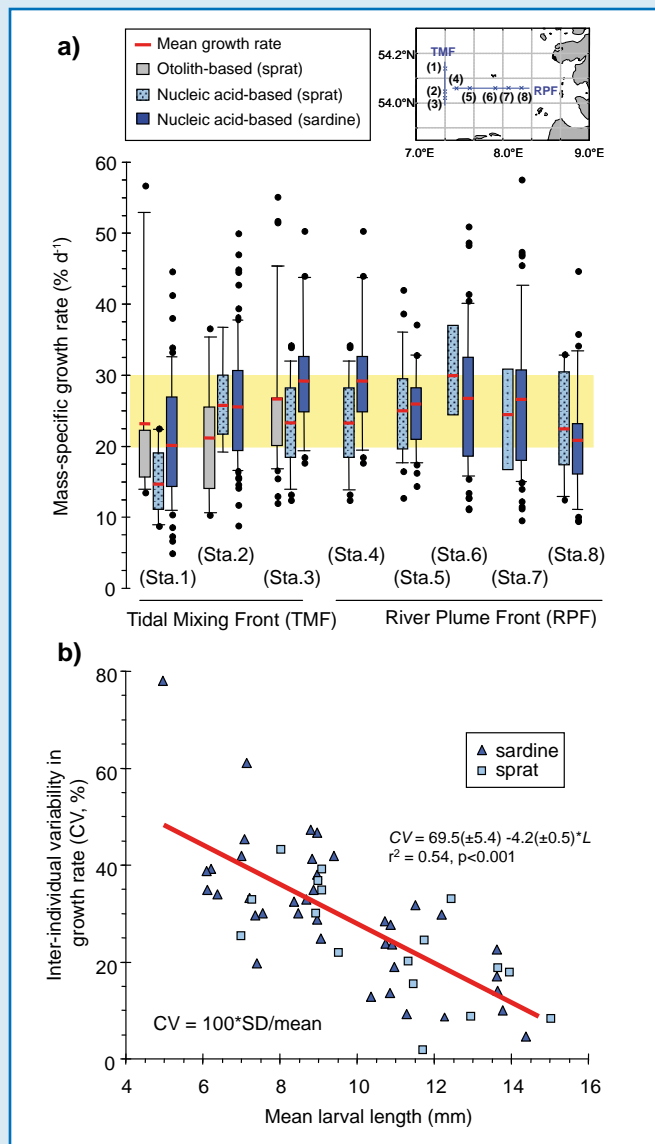

Figure 1. Insert: Map showing the location of tidal mixing front (TMF) and river plume front (RPF) transects and sampling stations in the German Bight. Panel A) Mass-specific growth rates (SGR, % d^{-1}) at each of nine stations along TMF and RPF transects. The bar and whisker plots denote the 10th, 25th, 75th and 90th percentiles, points were outliers. Otolith-based growth rates (mm d^{-1}) were converted to SGR using standard published mass-length relationships for larval sprat. The yellow area outlines the range in mean values calculated for most stations. Panel B) Inter-individual variability in growth rates (coefficient of variation, CV, %) versus larval standard length (mm). Each point is the CV for a group of larvae captured at the same station within a 2.5 mm size bin.
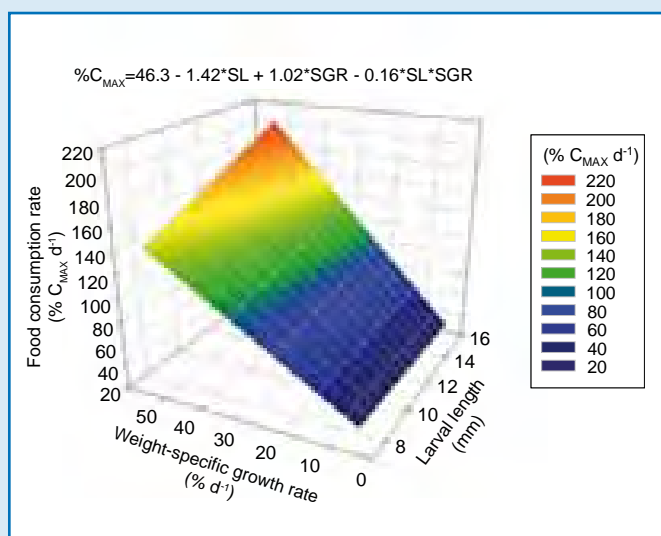
$$\%C_{MAX}=46.3 - 1.42*SL + 1.02*SGR - 0.16*SL*SGR$$

Figure 2. Example of model-based estimates of recent (7 day) feeding rates (%C_{MAX}) versus growth rate (SGR, %) and larval standard length (mm) at a specific frontal station. C_{MAX} was calculated based upon mean larval growth rates using a balanced bioenergetics approach. Hence, individual larvae may feed at rates that are higher or lower than "C_{MAX}".
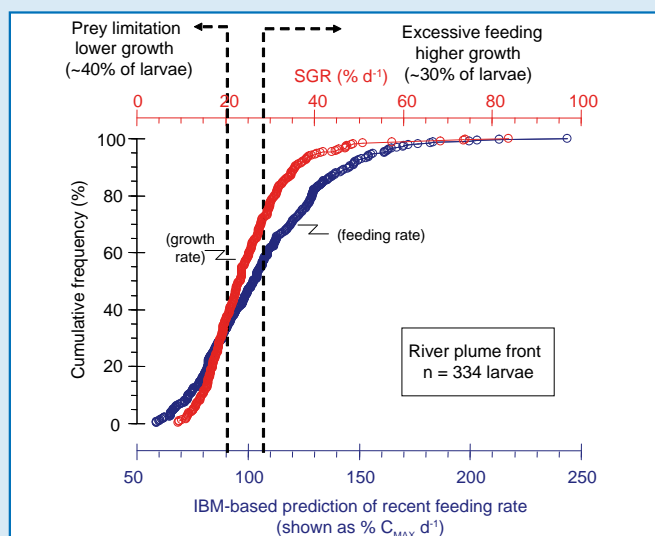

Figure 3. Cumulative frequency of observed (in situ) growth rates and model-based estimates of relative feeding rate of 334 individual larvae captured at stations along a river plume front in the German Bight (southern North Sea). Mean growth rates were between 20 and 30% for all stations.

larvae could be due to differences in depth and temperature-histories along drift trajectories. To do this, we back-calculated the position of larvae 7 days prior to capture in each of three depth levels (0-5, 5-10 and 10-15 m) and ran the foraging and growth subroutines assuming that larvae were able to feed at their size- and temperature-specific "maximum" rate (C_{MAX}). The latter assumption was made because detailed prey field data were unavailable. Results of these simulations indicated that differences in growth estimates of larvae in the three depth layers were relatively small (mean 2% among layers at a station) and that temperature alone could not account for the observed intra-station variability in larval fish growth rates.

Next, we performed a series of 7 day IBM simulations using larvae of different sizes (7.5, 10.0, 12.5 and 15.0 mm SL) that were constrained to feed at different rates (40, 60, 80, 100, 120 and 140% C_{MAX}). Due to the unique temperature history experienced by larvae at each station, 7 day simulations were conducted for larvae at each of the six stations along the river plume front. Model output was used to develop equations yielding estimates of feeding rates based upon in situ growth rate (SGR), and larval length (SL) at each station (for example, see Fig. 2). Two- to five-fold differences in rates of food consumption by larvae at the same station were required to fuel the observed in situ growth differences (Fig. 3). Based on these results, we speculate that each net sample contained a mixture of larvae that originated from an amalgam of micro-habitats that provided markedly different feeding conditions (e.g. prey concentrations and encounter rates) for individual larvae. Although intrinsic differences in larval performance (i.e. differences in growth efficiency or growth physiology of larvae feeding at the same prey concentration) may also have contributed to growth differences.

In the wild and at the level of the individual, most fish larvae are unlikely to experience "mean" prey fields calculated from net hauls. This is undoubtedly the case in regions where prey aggregate due to either physical features (e.g. frontal convergence zones) and/or behavioural attributes (e.g. turbulence avoidance). Whether this prey patchiness should be included within models of larval fish foraging and growth will depend upon the spatio-temporal scale of the processes being investigated (see Peck and Daewel, in press). Although average prey conditions may be sufficient on longer time scales (weeks to months), using models to explore the causes and consequences of daily variability in larval fish vital rates will require more highly spatially-resolved prey fields (e.g. measured using optical devices such as the video plankton recorder) that more adequately reflect the environment experienced by an individual larva.

References

Dänhardt A., M.A. Peck, C. Clemmesen and A. Temming. 2007. Depth-dependent nutritional condition of sprat *Sprattus sprattus* larvae in the central Bornholm Basin, Baltic Sea. Marine Ecology Progress Series 341: 217-228.

Holtappels M. 2004. Nutritional condition of sprat and sardine larvae in the frontal systems of the German Bight. Diplomarbeit, Universität Rostock, Institut für Ostseeforschung Warnemünde.

Huwer B. 2004 Larval growth of *Sardina pilchardus* and *Sprattus sprattus* in relation to frontal systems in the German Bight. Diplomarbeit, Christian-Albrechts-Universität, Kiel.

Kühn W., M.A. Peck, H.-H. Hinrichsen, U. Daewel, A. Moll , T. Pohlmann, C. Stegert and S. Tamm. submitted. Spatial and temporal changes in the habitat suitability of the German Bight (southern North Sea) for larval sprat: An IBM approach using size-structured prey fields. Journal of Marine Systems.

Peck M.A. and U. Daewel. in press. Physiologically based limits to food consumption, and individual-based modeling of foraging and growth of larval fishes. Marine Ecology Progress Series.

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Spatial and temporal variability of Baltic larval sprat otolith growth: a modelling study combining abiotic and biotic environmental variables

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Sprat, *Sprattus sprattus* L., spawn in the Baltic deep basins at strongly varying environmental conditions with feeding success, growth and survival during the larval and juvenile stages regarded as major bottlenecks. Otolith increment widths of Baltic larval sprat were used to describe daily resolved growth rates (e.g. Baumann *et al.*, 2006; Voss *et al.*, 2006). Otolith increment width is assumed to represent a measure of individual daily growth rates in terms of larval length, as well as larval weight. This manuscript presents a new methodology utilising Generalised Additive Models (GAMs) to identify key environmental factors determining otolith growth rates of larvae.

Extensive horizontal resolving plankton sampling was conducted in the Bornholm Basin during three cruises in spring and early summer 2002 (Fig. 1). A hydrodynamic model (Lehmann, 1995) has been utilised to simulate Baltic sprat larval drift for different sampling periods during the spawning season. Larvae were inserted into simulated flow fields at their position of catch and their drift was back calculated until the day of first feeding (Hinrichsen *et al.*, 1997) as obtained by otolith microstructure analysis (Fig. 2).

Besides otolith increment width information representing larval growth, biological and physical environmental variables were determined for each estimated individual larva position and subsequently used for the GAM-analyses as independent input variables to explain otolith growth. For a daily integrated view of the ambient environmental variables the larvae experienced, daily averaged temperatures (Fig. 2) as well as bottom depths were assigned to the corresponding larval increment width.
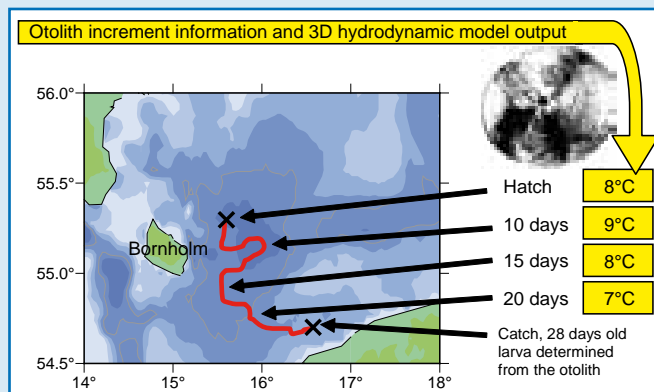
Figure 2. Schematic of backward drift calculation from catch to hatch of an individual sprat larva in the Bornholm Basin. Along the drift trajectory experienced temperatures of the larva were added to the corresponding otolith informations.

From a highly temporally and spatially resolved meteorological database, daily averaged cubed wind speeds were used as a proxy of small scale turbulent dissipation rates. Prey field data were taken from zooplankton samples and spatially and temporally interpolated onto a fine model grid. Furthermore, the ratio of cloud cover, as an approximation of light levels at the sea surface, was determined on this spatial and temporal explicit scale. Finally, age of a larva as well as year-day representing a measure of day-length were selected to be used as independent input variables.

The results indicate that sprat larval growth is not only influenced by the density of potential prey organisms as a single factor, but that a number of simultaneously acting environmental factors control larval growth. The final model explained more than 80% of the variance of otolith growth with larval age showing the strongest positive significant impact on otolith growth. Secondly, otolith growth was based on the statistically significant ambient environmental factors temperature, bottom depth, accumulated prey densities of C1 to adult copepod stages, as well as cubed wind speed as proxy for small scale turbulence (Fig. 3). Generally, consumption rates were positively correlated with temperature with an optimum effect at a temperature of 15°C. Water depths between 60 and 80 m have been identified to be most beneficial for larval growth, a zone which is characterised where the permanent halocline interacts with bottom topography. Larval feeding success was only significantly correlated with prey abundances up to values of 25 individuals per litre, while a significant positive impact of small scale turbulence on larval growth was only observed for wind energy values representing wind speeds of between 8 and 10 m s^{-1}. Cloud coverage as well as year-day were identified as non-significant environmental variables. Furthermore, the GAM analyses revealed that otolith growth was not significantly controlled by the interaction of key environmental variables.
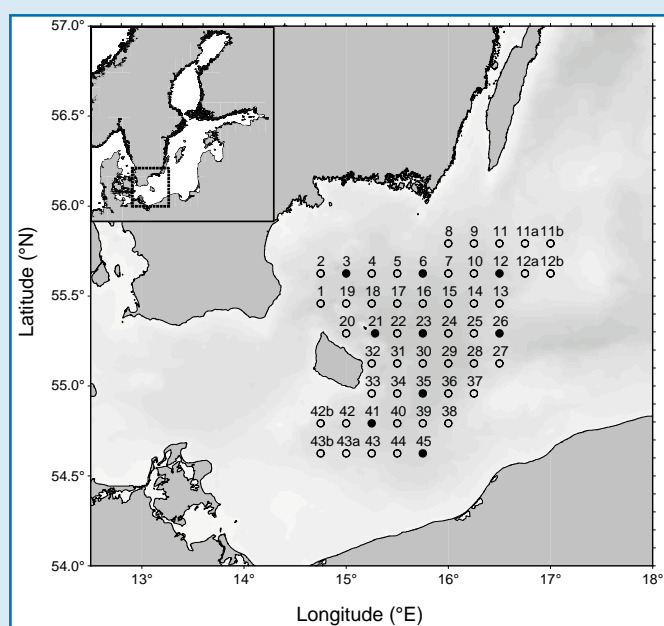

Figure 1. Sprat spawning ground and station grid during the spawning season in the Bornholm Basin 2002. Prey abundance data were available at nine stations (black dots).
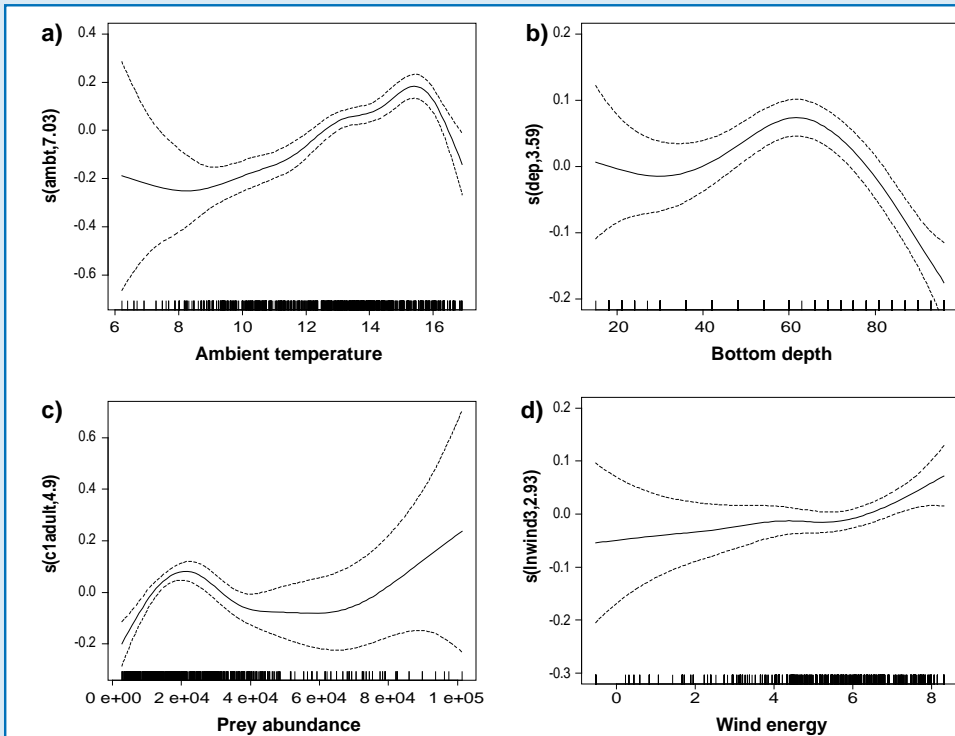
Figure 3. Partial effects of environmental variables in the Generalized Additive Model (GAM) explaining larval sprat otolith growth. The solid lines represent the estimated smooth function and the dashed line the 95% confidence limits. The rug plots along the x-axis show the values of the covariates for each smooth and the number in each y-axis caption is the effective degree of freedom of each term with a) ambient temperature, b) bottom depth, c) prey abundance (C1 to adult), and d) wind energy.

References

Baumann H., H.-H. Hinrichsen, R. Voss, D. Stepputtis, W. Grygiel, L.W. Clausen and A. Temming. 2006. Linking growth-to environmental histories in central Baltic young of the year sprat, *Sprattus sprattus*: an approach based on otolith microstructure analysis and hydrodynamic modeling. Fisheries Oceanography 15: 465-476.

Hinrichsen H.H., A. Lehmann, M.A. St. John and B. Brügge. 1997. Modelling the cod larvae drift in the Bornholm Basin in summer 1994. Continental Shelf Research 17: 1765-1784.

Lehmann A. 1995. A three-dimensional baroclinic eddy-resolving model of the Baltic Sea. Tellus 47(A): 1013-1031.

Voss R., C. Clemmesen, H. Baumann and H.-H. Hinrichsen. 2006. Baltic sprat larvae: Coupling food availability, larval condition and survival. Marine Ecology Progress Series 308: 243-254.

Gaining robust estimates of predatory impacts by zooplanktivorous fish in the Baltic Sea

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The trophic structure and functioning of the Baltic Sea is impacted heavily by both bottom-up and top-down processes. The latter are particularly important due to the dramatic increase in the abundance of the clupeid predator sprat (*Sprattus sprattus*) observed during the mid 1990s (ICES, 2007). During the GLOBEC-Germany project, we successfully maintained field-caught sprat in the laboratory and measured parameters required to build robust models depicting seasonal growth and feeding. Our laboratory trials have focused on quantifying both rates of energy loss (due to standard, active and feeding metabolic costs) and rates of gut evacuation, to better assess rates of feeding by field fish and the potential for top-down control of key zooplankton species (Möllmann *et al.*, 2004). Although previous bioenergetics-based estimates of clupeid predatory impact (feeding rates) in the Baltic were based upon parameters "borrowed" from other, often unrelated species (e.g. see Arrhenius and Hansson, 1994), our new laboratory data will make this largely unnecessary.

To estimate rates of metabolism in sprat, we performed a series of laboratory trials measuring oxygen consumption rates of

groups of fish via intermittent flow respirometry (Fig. 1a). Trials were conducted at different temperatures (9.5-20.8°C) using between 12 and 25 fish that were free-swimming within a 103 l circular tank (Fig. 1c). Measuring periods lasted 15-20 minutes and were followed by a 5 minute refreshing period when oxygen saturated water from the surrounding tank was pumped into the chamber to refresh the oxygen concentration (Fig. 1b, d). Specific information about the experimental protocol and data analyses are provided by Herrmann and Enders (2000). Concomitant measurements of swimming activity (via computer-image analysis) were made during oxygen consumption measurements (Fig. 1c) which allowed us to estimate rates of standard (RS), feeding (RSDA), and active (RA) metabolism. Distinguishing among different activities and their costs is especially important when attempting to model the metabolic costs of active (schooling), pelagic zooplanktivores such as sprat.

A prerequisite gaining estimates of feeding by field fish is to quantify the effects of temperature, body size, and meal size on rates of gut evacuation (e.g. Van der Lingen, 1998). To do
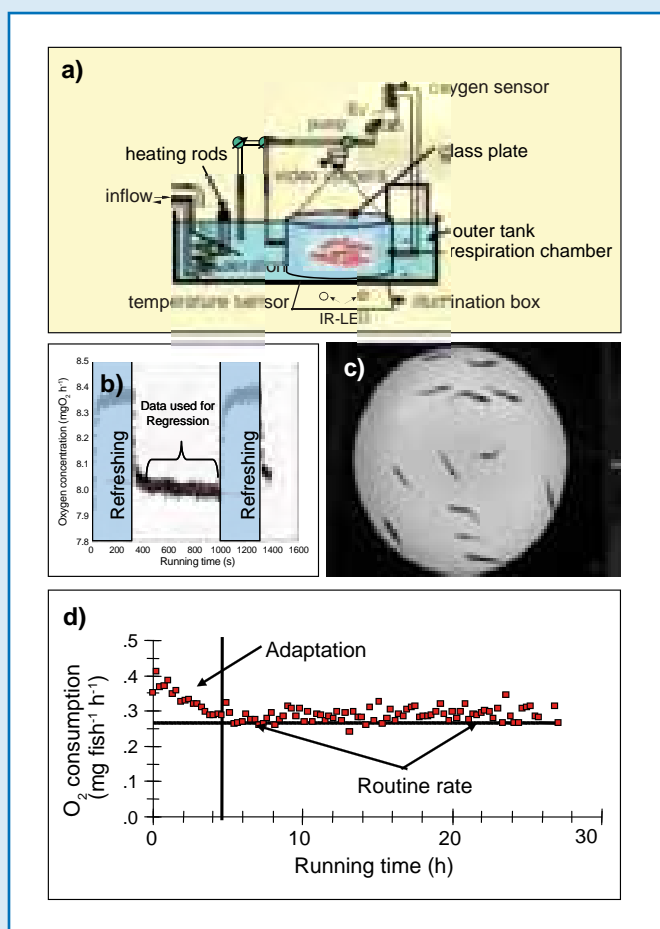
Figure 1. a) Schematic of the intermittent-flow respirometer used to measure respiration rates of groups of sprat (Sprattus sprattus). b) Example of the time course of O_2 concentration within the intermittent-flow respirometer. c) Example of image recording for activity analysis. d) Example of the time course of O_2 consumption of a group of sprat.
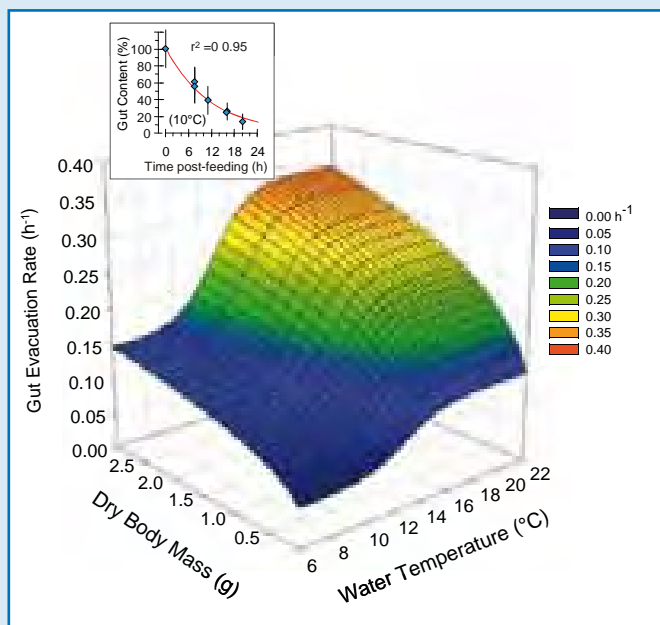

Figure 2. Predicted gut evacuation rate constant (h^{-1}) at different body sizes (dry mass, g) and water temperatures (°C) for sprat (Sprattus sprattus). The model was based upon the results of 14 gut evacuation trials (see text).

this, the rate of loss of food from sprat guts was measured in 14 experiments using different mean fish sizes (0.2 to 1.0 g dry mass) and a wide range in temperatures (7.5 to 21.5°C). Evacuation rates were determined for free-schooling fish that were fed live zooplankton (*Artemia* sp. nauplii) in replicate ~150 l tanks (Bernreuther *et al.*, submitted). Results indicated an exponential evacuation of *Artemia* nauplii with time at each temperature (Fig. 2, insert) and an evacuation rate that increased with increasing temperature and fish size (Fig. 2). The evacuation rate increased most rapidly with increasing temperature between 7.5 and 16°C (Q_{10} of 2.6). At temperatures warmer than 16°C, the rate of increase in gut evacuation declined and gut evacuation reached a plateau at about 19°C. Gross growth efficiency (or the scope for growth) of this species might be expected to decline between 19 and 21°C, a range in temperatures where rates of gastric emptying do not increase but metabolic costs (RS) continue to exponentially rise.

Laboratory data on metabolic rates, growth efficiency (not discussed here) and gut evacuation rates will be combined with *in situ* gut content and growth data (by age class) collected during an extensive field sampling campaign that included 20 cruises in the Bornholm Basin and adjacent Baltic Sea areas from March 2002 to November 2006 (e.g. Herrmann *et al.*, 2006). We now have two independent methods to assess the potential for top-down control, 1) size- and temperature-specific gut contents and gut evacuation rates, and 2) a bioenergetics model predicting feeding rates required to fuel *in situ* growth rates over a number of years with different climatic forcing patterns.

Based upon our laboratory gut evacuation trials, it is clear that gut contents after *ad libitum* feeding can be as much as 8.9% of sprat body mass. This is in stark contrast to the values of mean gut content weight observed for field fish that rarely exceed 0.5% (Fig. 3). Moreover, the maximum gut contents of individuals rarely approached 1.5% of body mass. This indicates that the Bornholm Basin may actually represent a rather unfavourable environment for feeding and growth and that at least sprat are forced by the hydrographic conditions to stay in this area for the extended spawning periods. Only in this deep area do sprat find the high salinities required for successful egg development.

Our GLOBEC-Germany sampling efforts were designed to provide detailed information regarding the interdependence of recruitment success, hydrography and copepod production in the Bornholm Basin, the main spawning area for sprat in the south-western Baltic. Clearly, sprat is a migratory species that spends periods outside of the deep Baltic basins. Future synthesis phase research efforts will apply a bioenergetics model coupled to secondary production estimates from an ecosystem (NPZD) model to examine differences in the potential feeding and growth of sprat among offshore (basins) and nearshore (coastal) areas.
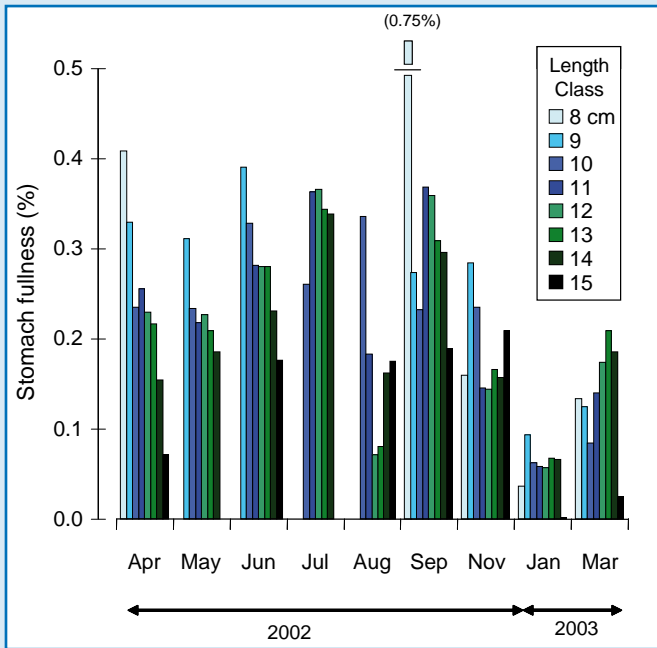
Figure 3. Seasonal development of the stomach fullness (% wet body mass) of sprat by length class (cm) in the Baltic Sea, Bornholm Basin from April 2002 to March 2003.

References

Arrhenius F. and S. Hansson. 1994. *In situ* consumption by young-of-the-year Baltic Sea herring *Clupea harengus*: a test of predictions from a bioenergetics model. Marine Ecology Progress Series 110: 145-149.

Bernreuther M., J.-P. Herrmann and A. Temming. submitted. The influence of temperature and body weight on the gastric evacuation in sprat (*Sprattus sprattus*, L.). Journal Fish Biology.

Herrmann J.-P. and E.C. Enders. 2000. Effect of body size on the standard metabolism of horse mackerel. Journal of Fish Biology 57: 746-760

Herrmann J.-P., M.A. Peck, M. Bernreuther, M. Fladda and A. Temming. 2006. Seasonality in morphometrics and energy allocation suggest food limitation with increasing size in Baltic sprat in the Bornholm Basin. GLOBEC International Newsletter12(1): 81-82.

ICES. 2007. Report of the Baltic Fisheries Assessment Working Group (WGBFAS). ICES Council Meeting Papers CM 2007/ACFM:15.

Möllmann C., A. Temming, H.-J. Hirche, D. Stepputtis, M. Bernreuther and F.W. Köster. 2004. Fish predation control of key copepod species in the Bornholm Basin. ICES Council Meeting Papers CM 2004/L:28

Van der Lingen C.D. 1998. Gastric evacuation, feeding periodicity and daily ration of sardine *Sardinops sagax* in the Southern Benguela upwelling ecosystem. South African Journal of Marine Science 19: 305-316.

Comparing recruitment processes in Baltic sprat 2002 vs. 2003 – predation

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Baltic sprat spawning stock biomass is only a poor predictor of recruitment (Köster *et al.*, 2003; MacKenzie and Köster, 2004). Major bottlenecks in the Baltic sprat life cycle are the egg, larval and early juvenile stage (Köster and Möllmann, 2000; Voss *et al.*, 2006). Process-oriented investigations are challenged by the long spawning time (March to August; Elwertowski, 1960; Grimm and Herra, 1984) and the corresponding need to appropriately monitor egg and larval survival in relation to important environmental conditions, e.g. predator abundance and distribution. In the highly stratified and dynamic Baltic Sea, the relative importance of processes might vary not only during ontogeny but also from year-to-year or even seasonally, so that survivors might emerge from temporally and spatially distinct 'windows of survival'.

Within GLOBEC-Germany we conducted a temporally highly resolved study in sprat spawning area of the Bornholm Basin to quantify egg survival, as one of the important agents of mortality-egg predation (Köster and Möllmann, 2000). During 22 cruises we recorded sprat egg abundance and distribution on a standard 52 station grid, covering two fundamentally contrasting years. Whilst 2002 represented a stagnation situation after several years without major Baltic inflows and hence detrimental deepwater conditions, sprat spawning in 2003 occurred in a post-inflow situation with improved

hydrographic conditions. Survival during the egg stage was calculated based on field-based production estimates of the youngest vs. oldest egg stages, using temperature-dependent developmental rates (Petereit *et al.*, submitted). Vertical distribution of sprat eggs was recorded on a monthly basis using regular Multinet tows. To quantify the predation effect on egg survival, monthly estimates of predator abundance (adult herring and sprat) and their vertical distribution were calculated based on hydroacoustic measurements, allowing the calculation of an overlap index to sprat eggs (Horn, 1966). By combining predator stock sizes and applying stomach content data in a model of gastric evacuation (Bernreuther, 2007), we were able to calculate egg consumption and hence an egg consumption to abundance ratio.

Our results show overall egg survival being much lower in 2002 compared to 2003 (Fig. 1). In 2002, maximum values of ~50% survival occurred only very early and very late in the season, being separated by periods of low, sometimes even without, egg survival. In 2003 we observed egg survival rates of up to 80% during the second part of the year. The vertical overlap between predator and prey was much higher in peak spawning time (spring) 2002 compared to 2003. This resulted in an almost four times higher consumption to abundance ratio in 2002 (2002: 0.8; 2003: 0.2), indicating a much stronger
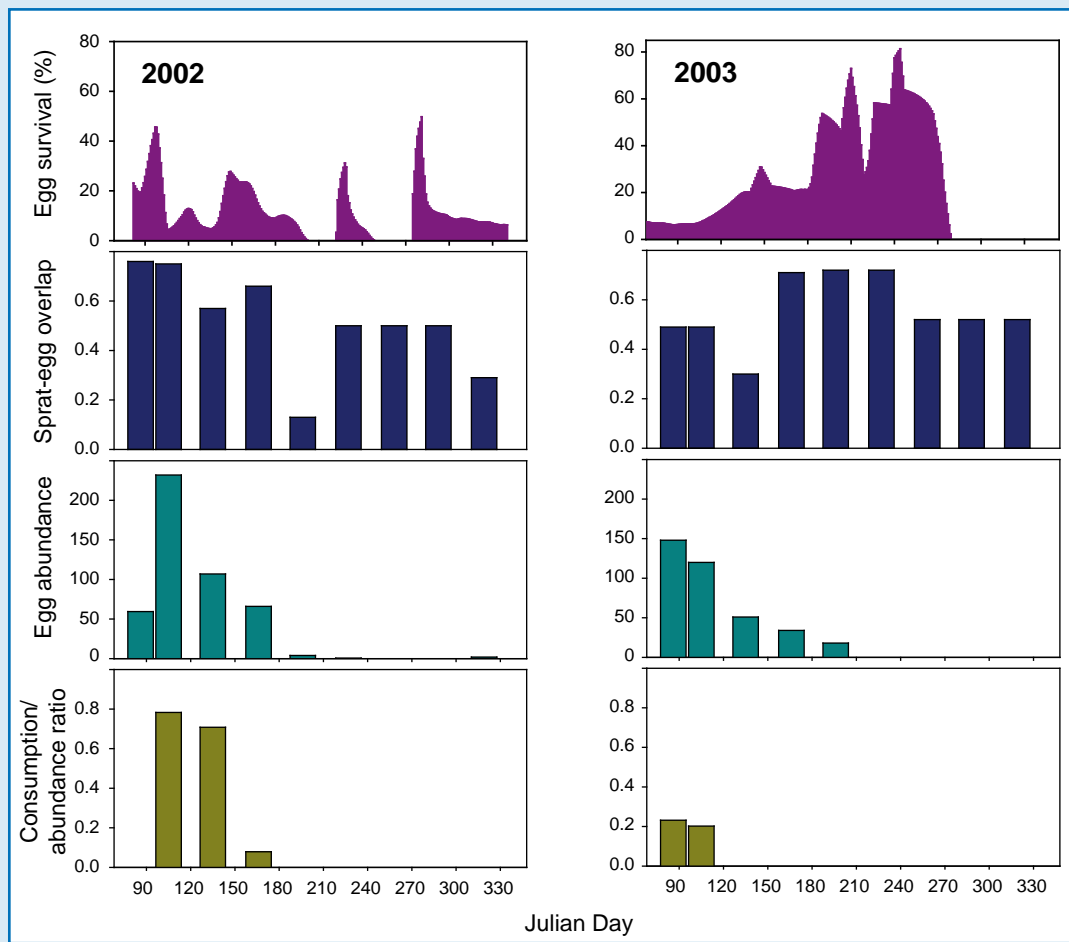
Figure 1. Sprat egg survival in the Bornholm Basin in a) 2002 vs. b) 2003. Top to bottom: egg survival based on field observations, predator-prey overlap, seasonal egg abundance and consumption to abundance ratio.

predation effect in the stagnation scenario. In absolute terms egg abundance was higher in 2002, but the observed lower egg survival due to predation will have contributed to a lower recruitment success in 2002 as observed by the regular stock assessment (ICES, 2007).

We conclude that in Baltic sprat, egg predation has the potential to significantly influence recruitment success, a process mediated by hydrographic conditions and eventually climate variability. Egg predation thus adds to processes acting in the larval phase (e.g. temperature conditions, transport, prey availability) together determining temporal and spatial recruitment variability (e.g. Baumann *et al.*, 2006; Dickmann *et al.*, 2007).

Our results show that the unique datasets derived within GLOBEC-Germany have resulted in a comprehensive understanding of sprat recruitment processes, of which predation control is an important aspect.

References

Baumann H., H.-H. Hinrichsen, C. Möllmann, F.W. Köster, A.M. Malzahn and A. Temming. 2006. Recruitment variability in Baltic Sea sprat (*Sprattus sprattus*) is tightly coupled to temperature and transport patterns affecting the larval and early juvenile stages. Canadian Journal of Fisheries and Aquatic Sciences 63: 2191-2201.

Bernreuther M. 2007. Investigations on the feeding ecology of Baltic Sea herring (*Clupea harengus* L.) and sprat (*Sprattus sprattus* L.). PhD thesis, University of Hamburg, 184pp.

Dickmann M., C. Möllmann and R. Voss. 2007. Feeding ecology of central Baltic sprat (*Sprattus sprattus* L.) larvae in relation to zooplankton dynamics - implications for survival. Marine Ecology Progress Series 342: 277-289.

Elwertowski J.1960. Biologische Grundlagen der Sprottenfischerei in der östlichen und mittleren Ostsee. Fischerei Forschung 3(4): 1-19.

Grimm S.K. and T. Herra. 1984. Spawning cycles of southern Baltic fishes based on surveys of eggs and larvae. ICES Council Meeting Papers CM 1984/J:30.

Horn H.S. 1966. Measurement of 'overlap' in comparative ecological studies. American Naturalist 100: 419-424.

ICES 2007. Report of the Baltic Fisheries Assessment Working Group. ICES Council Meeting Papers CM 2007, ACFM:15.

Köster F.W., H.-H. Hinrichsen, D. Schnack, M.A. St John, B.R. MacKenzie, J. Tomkiewicz, C. Möllmann, G. Kraus, M. Plikshs, A. Makarchouk and E. Aro. 2003. Recruitment of Baltic cod and sprat stocks: Identification of critical life stages and incorporation of environmental variability into stock-recruitment relationships. Scientia Marina 67(1):129-154.

Köster F.W. and C. Möllmann, C., 2000. Egg cannibalism in Baltic sprat *Sprattus sprattus*. Marine Ecology Progress Series 196: 269–277.

MacKenzie B.R. and F.W. Köster. 2004. Fish production and climate: sprat in the Baltic Sea. Ecology 85(3): 784-794.

Petereit C., H. Haslob, G. Kraus and C. Clemmesen. submitted. The effect of temperature on the development of Baltic and North Sea sprat early life history. Marine Biology.

Voss R., C. Clemmesen, H. Baumann and H.-H. Hinrichsen. 2006. Baltic sprat larvae: Coupling food availability, larval condition and survival. Marine Ecology Progress Series 308: 243-254.

Climate drives anchovies and sardines into North Sea

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Based on results of the International Bottom Trawl Survey of ICES, Beare *et al.* (2004) showed that abundance of the only sporadically occurring anchovies (*Engraulis encrasicolus*) and sardines (*Sardina pilchardus*) in the North Sea had increased suddenly after 1995. As these trawl surveys were carried out in the first and third quarter, outside of the spawning season of both species, it was not clear whether anchovies and sardines were only temporarily visiting the North Sea during some parts of the year or whether they would stay there for the entire year and spawn. The cruises of the German GLOBEC project from 2003-2005 clearly demonstrated that anchovies and sardines are now regularly spawning in the German Bight of the North Sea. All life stages of both species were found in the German Bight: eggs, larvae, juveniles and adults. Females with hydrated eggs which indicate imminent spawning within the next 12 hours were encountered. The recent, probably still increasing invasion of anchovies and sardines into the North Sea raises two highly interesting questions:

- What drives the move of anchovies and sardines into the North Sea?
- How can three small pelagic clupeiform species (anchovy, sardine and sprat) with very similar life histories (Hunter and Alheit, 1995) co-exist in the same area?

Studies of reproductive biology revealed that their spawning strategies differ and that they have partitioned their spawning habitats in space and time. Anchovy, a more southern, estuarine species spawned in very shallow areas, partly in the Wadden Sea, which are under the influence of freshwater outflow and characterised by high temperatures and lower salinity (Fig. 1). Sprat (*S. sprattus*), in contrast, spawns further offshore, in deeper waters which are cooler and more saline. Sardine takes up an intermediate position. Depth resolving vertical plankton tows with a Multinet demonstrated an even finer partitioning of the spawning habitat. In a tidal mixing front system in the
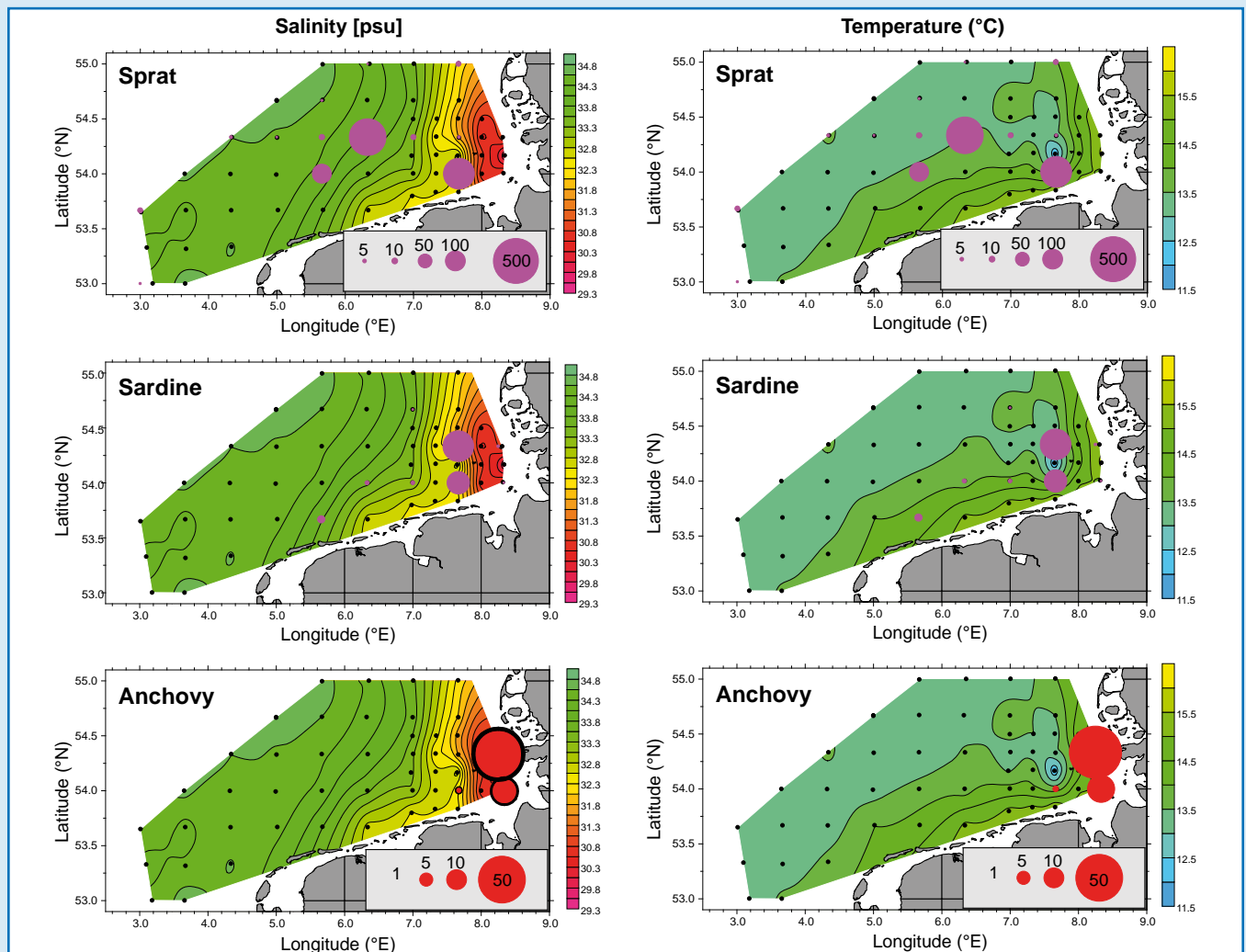

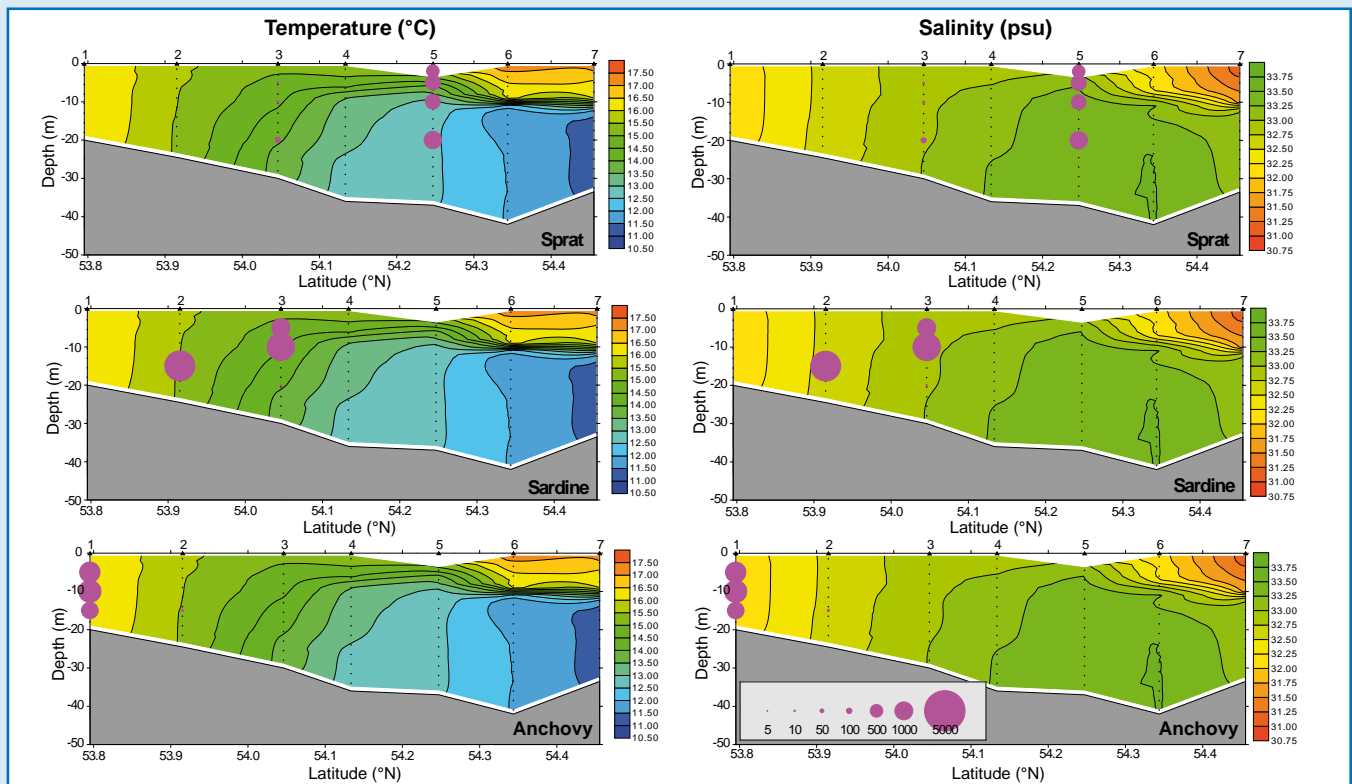*Figure 1. Horizontal egg distribution in the German Bight, North Sea, June 2004.*

Figure 2. Vertical egg distribution in tidal mixing front system in the German Bight, North Sea, July 2005.

German Bight, anchovy chose the shallow well mixed area of the frontal system, whereas sardines laid their eggs mainly in the front itself and sprat spawned in the stratified frontal area (Fig. 2). Because of its lower spawning temperature threshold, sprat, which dwells permanently in the German Bight, starts spawning already in March/April and continues until July with a peak in May/June. Sardine and anchovy begin to spawn later in the year, in June and July.

There have been previous periods of relatively high abundance and spawning of anchovies and sardines in the German Bight as reported by Aurich (1950, 1953), e.g. in a publication titled "Can we expect an anchovy fishery in the North Sea in 1950?". Egg distribution patterns as recorded from 1948-1952 (Fig. 3) are strikingly similar to recent observations (Fig. 2). Anchovy eggs were found close to the coast in warmer and less salty waters, whereas sardine occurred further offshore in colder and more saline environments.

Aurich (1953) related the settlement of anchovies and sardines in the German Bight to climate variability and retrospective studies confirm his hypothesis. Apparently, anchovies and sardines occurred in larger quantities in the German Bight during periods of elevated water temperatures as recorded from the early 1930s to about 1960 and, again, since the early 1990s. Interestingly, these periods of anchovy and sardine invasions into the North Sea correspond very well to the positive periods of the Atlantic Multidecadal Oscillation (AMO), a climatic index of North Atlantic surface water temperatures (Kerr, 2005). Hence, natural climate variability and, recently, elevated sea temperatures due to global warming, drive anchovies and sardines into the North Sea.
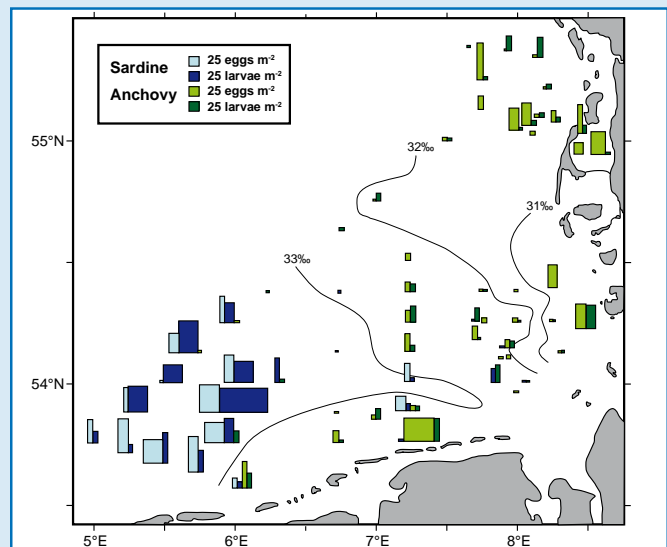

Figure 3. Horizontal egg and larval distribution in German Bight, North Sea, June 1951 (redrawn after Aurich, 1953).

References

Aurich H.J. 1950. Besteht für 1950 Aussicht auf eine Sardellenfischerei in der Nordsee? Fischereiwelt 2: 26-28.

Aurich H.J. 1953. Verbreitung und Laichverhältnisse von Sardelle und Sardine in der südöstlichen Nordsee und ihre Veränderungen als Folge der Klimaänderung. Helgoländer wissenschaftliche Meeresuntersuchungen 4: 175-204.

Beare D., F. Burns, E. Jones, K. Peach, E. Portilla, T. Greig, E. McKenzie and D. Reid. 2004. An increase in the abundance of anchovies and sardines in the north-western North Sea since 1995. Global Change Biology 10: 1209-1213.

Hunter J.R. and J. Alheit. 1995. International GLOBEC Small Pelagic Fishes and Climate Change Programme. GLOBEC Report 8: 72 pp.

Kerr R.A. 2005. Atlantic climate pacemaker for millenia past, decades hence? Science 309: 41-43.

Study of the physical effects on the seasonal hypoxia adjacent to the Changjiang Estuary

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Hypoxia refers to an oxygen deficiency, typically in bottom waters, which can cause physiological stress and, occasionally, death to aquatic organisms. Much attention has been paid to hypoxia because of its negative effect on the marine ecosystem, including degradation of habitat, altered migration patterns and decreased fishery production.

Changjiang, the third largest runoff in the world, empties into the East China Sea from Shanghai, the fastest developing area of China. With the increasing nutrient loads from the river, a severe hypoxic zone adjacent to the Changjiang estuary was found up to about 2×10^4 km^2 in size (Wei *et al.*, in press). The China GLOBEC/IMBER programme "Key Processes and Sustainable Mechanisms of Ecosystem Food Production in the Coastal Ocean of China" (2006CB400600) was launched in January 2006 with a duration of 5 years. The mechanism of the hypoxia adjacent to the Changjiang estuary is one of the key elements of this programme.

From 3 to 8 September 2006, *in situ* observations were conducted at an anchor site P11 (122°56'E, 30°49'N), about 100 km southeast of the Changjiang estuary (Fig. 1), in order to ascertain how the physical processes such as stratification, vertical turbulent mixing and horizontal advection contribute to the variation of hypoxia. The survey was interrupted by a storm which induced very strong winds and lasted for two days from 5 to 6 September with a typical wind speed of 14m s^{-1} in the direction of the north-east. Field data were obtained from 09:00 3 September to 10:00 4 September (before the storm) and from 11:00 7 September to 12:00 8 September (after the storm).

One cast of a multi-parameter water quality sound YSI-6600 was taken every two hours at a falling speed of about 0.1m s^{-1} to obtain vertical profiles of temperature, conductivity, dissolved oxygen (DO) concentration, chlorophyll *a* concentration and turbidity.
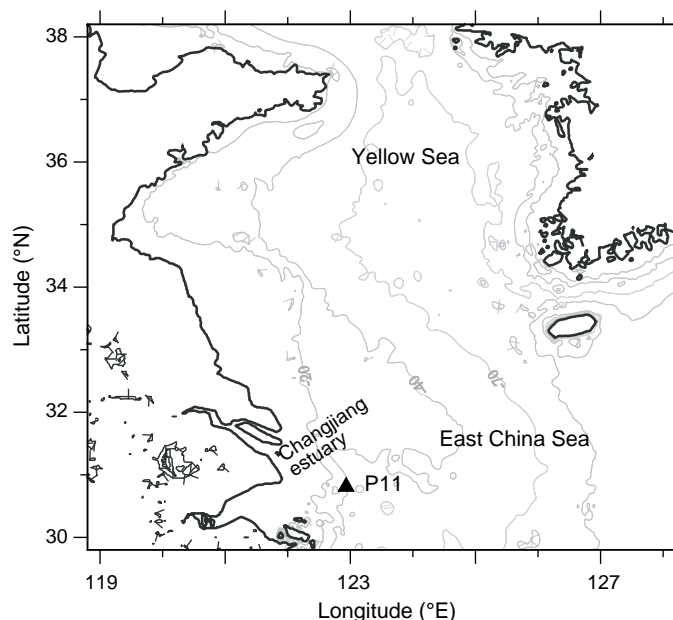

Figure 1. The anchor site P11 adjacent to the Changjiang estuary.

Three casts, separated by two to three minutes, of a microstructure profiler MSS-60 were taken every hour at a falling speed of about 0.6m s^{-1} to obtain vertical profiles of temperature microstructure, conductivity, and small-scale shear from the sea surface down to the bottom. Turbulent dissipation rate and eddy diffusivity can be obtained from these measurements (Liu *et al.*, submitted). Another YSI-6600 and a Nortek 6 MHz ADV were mounted at a frame 0.5 m above the seafloor. The mounted YSI-6600 recorded temperature, conductivity, pressure and DO concentration every 10 minutes during the first sampling period but was adjusted to every minute after the storm. The ADV worked in burst mode, with 256 records
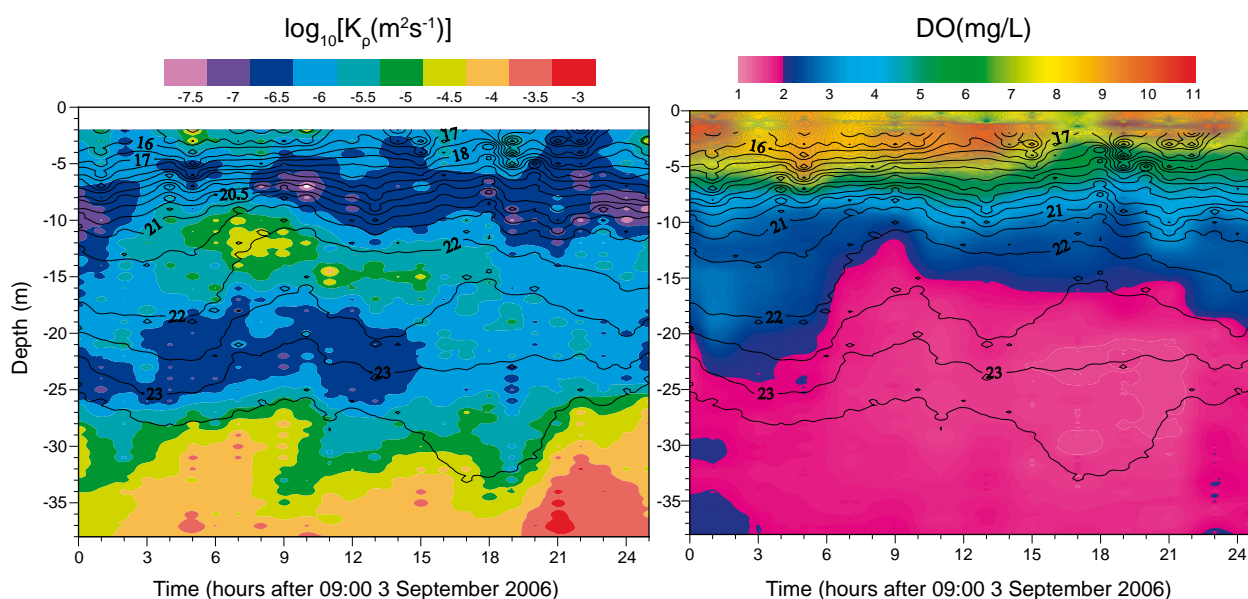

Figure 2. Time series of vertical profile between 09:00 3 September and 10:00 4 September 2006. a) Vertical eddy diffusivity Kρ (coloured) and potential density (lines); b) Dissolved oxygen (coloured) and potential density (lines).
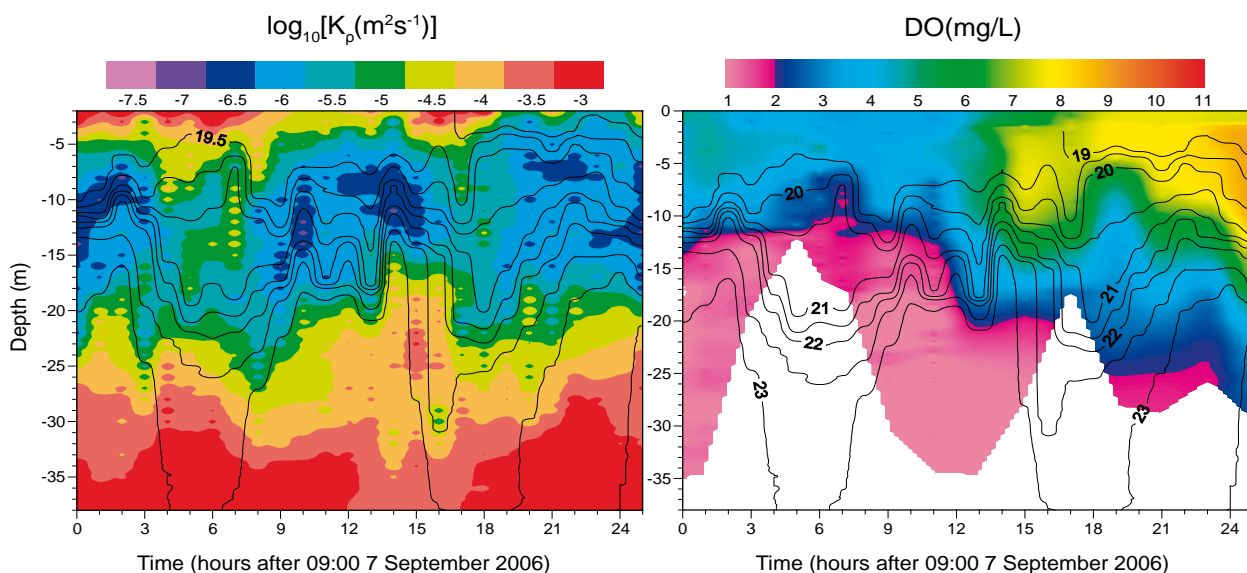
Figure 3. Time series of vertical profile between 11:00 7 September and 12:00 8 September 2006. a) Vertical eddy diffusivity Kρ (coloured) and potential density (lines); b) Dissolved oxygen (coloured) and potential density (lines). Blank in b) was because of the lack of data since the strong current made the instruments float horizontally.

every 15 minutes to obtain 4096 samples of three components of velocity vector at a frequency of 16 Hz. An Auto-Meteorological-Station was utilised to collect meteorological data.

The effect of the physical processes on hypoxia were explored using the field data. Stratification, which inhibits the vertical mixing of the water column, was found to be an important factor in forming and maintaining hypoxia. As shown in Figure 2a, there were two weak-mixing bands coinciding with the pycnocline, the upper one between 5 and 10 m depth and the lower one between 16 and 26 m depth. A hypoxic water column (DO <2mg l^{-1}) as thick as 20 m existed below the lower weak-mixing band (Fig. 2b). After the storm, the pycnocline was pushed down and became weaker (Fig. 3a). The DO concentration was almost homogenous above the pycnocline, whilst the water column below the pycnocline still remained hypoxic (Fig. 3b). The hypoxic water was even thicker after the storm. Unexpectedly, the DO concentration near the bottom was found to be even lower after the storm (Fig. 4). Water mass advection by rotated tidal currents was speculated to be responsible for the strengthening of bottom hypoxia.
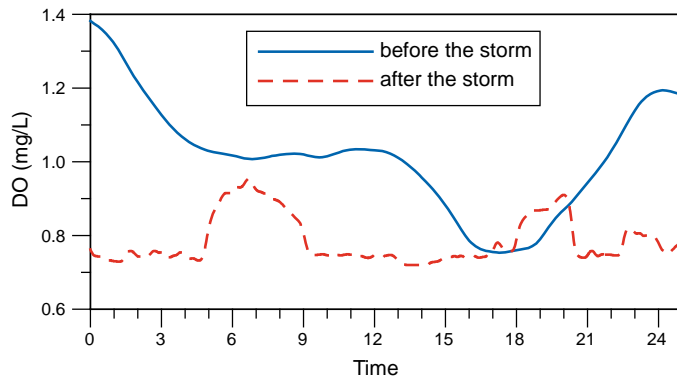

Figure 4. DO concentration near the bottom.

References

Liu Z.Y., H. Wei, I. Lozovatsky and H.J.S. Fernando. submitted. Observations of the turbulent dissipation rate in the Yellow Sea, Journal of Marine Systems.

Wei H., Y.C. He, Q.J. Li, Z.Y. Liu and H.T. Wang. in press. Seasonal hypoxia adjacent to the Changjiang Estuary. Journal of Marine Systems.

Linking herring

26-29 August 2008, Galway, Ireland

Convenors: **Maurice Clarke**

 Mark Dickey-Collas

 Aril Slotte

Sponsors: **ICES, GLOBEC and PICES**

http://www.linkingherring.com

Theme sessions

Counting herring: qualitative and quantitative estimation of herring and its application. John Simmonds (UK)

Advances in herring biology: Audrey Geffen (Norway)

Population integrity: the rigidity of stocks and the drivers of migration - David Secor (USA)

Variable production: particularly the role of reproduction, recruitment and life history strategies. Nils Christian Stenseth (Norway)

Herring in the middle: the trophic and ecological interactions and impacts of herring. Andrew Bakun (USA)

Managing change: management and exploitation of herring in a dynamic environment, within the context of long term change. Martin Pastoors (The Netherlands)

Japanese scientists receive prestigious awards:
Michio Kishi and Yoshioki Oozeki

The JOS Prize, the Prize of the Oceanographic Society of Japan, has been awarded to Michio Kishi. The JOS Prize is the highest prize in oceanography in Japan and is awarded to a member of the Society who has made outstanding contributions to the progress of oceanography. Last year Kishi-san was also awarded the Uda Prize from the Japan Society of Fisheries Oceanography and is the first scientist to have been awarded both prizes. His contribution on marine ecosystem modelling, education and outreach activity were evaluated for the prize including his contribution to the development of the NEMURO and NEMURO. FISH models.

Oozeki-san celebrating with GLOBEC colleagues. Outstanding Riesling wines courtesy of Jürgen Alheit.

Kishi-san, recipient of the JOS prize.

Yoshioki Oozeki has also been awarded the Uda Prize from the Japan Society of Fisheries Oceanography. Commemorating the late Professor Michitaka Uda, the Uda Prize is awarded to a member of the Society who has shown outstanding leadership of a research group or contributed notably to the education of oceanographers and the general public. Oozeki-san's study on pelagic larvae and his contribution to the saury version of the NEMURO.FISH model were evaluated.

The third Japan-China-Korea joint GLOBEC symposium
Hakodate, Hokkaido, Japan
13-15 December 2007

Japan, China and Korea are active participants in GLOBEC studies of the northwest Pacific, one of the highest fish production areas in the world. Marginal seas in the region, such as the Yellow Sea, the East China Sea and the Japan/East Sea, are very important to the ocean ecosystem studies. All three countries have very active national GLOBEC research programmes. The national committees of these three countries held the first China-Japan-Korea joint GLOBEC symposium at Ansan, Korea in December 2002 and the second symposium in Hangzhou, China in November 2004. The symposia provided a forum for exchanging new information and discussing research findings.

After the success of the first two symposia, the national committees decided to hold the third China-Japan-Korea joint symposium in Hakodate, Hokkaido, Japan on 13-15 December 2007. The central theme of the symposium will be the relationship between environmental variation and ecosystem responses in the northwest Pacific region. In this symposium, we will discuss how to integrate GLOBEC and IMBER after 2009.

The symposium is open to all scientists interested in GLOBEC research and both oral and poster presentations are welcomed. It is hoped that the symposium will forge future cooperation and collaboration among scientists from the three countries.

The following topics will be covered by the symposium:

- ecosystem structure and environmental factors,
- food web trophodynamics and marine biodiversity,
- physical-biological processes and models,
- climate change and regime shifts,
- bottom-up and top-down control of marine ecosystems, and
- ecosystem-based and adaptive management of fish stocks and fisheries.

Abstracts should be submitted to Dr Yoko Iwata (iwayou@fish.hokudai.ac.jp) no later than 30 October 2007 indicating whether the contribution is intended as an oral or poster presentation. A registration form and further details can be obtained from: www.globec.org/structure/national/japan/JCK_3rd_symp_dec07.pdf

NEMURO special issue of Ecological Modelling

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Kishi-san delivering the NEMURO special issue of Ecological Modelling to the Mayor of Nemuro.

The NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography) model is a result of work by the PICES Model Task Team. It was named NEMURO to acknowledge the gracious hosting by the Japanese city of Nemuro of several of the Task Team's initial meetings. The Model Task Team is a part of the GLOBEC Regional Programme PICES Climate Change and Carrying Capacity (CCCC), and was formed to encourage, facilitate and coordinate modelling activities within its member nations.

The first workshop was held in 1996 in Nemuro where standardising models and model approaches were discussed. At a 1998 workshop the participants concluded that: i) existing North Pacific models that included different state variables and mathematical formulations might be difficult to compare, and ii) regional comparison protocols were necessary. This resulted in the first "model build-up" workshop which was held in January 2000, again in Nemuro, where the participants reached a consensus on the structure of a prototype lower trophic level ecosystem model for the North Pacific Ocean.

The model was further expanded at a 2002 workshop in Nemuro where a higher trophic level bioenergetic model of fishes was linked to NEMURO. The new model was named NEMURO.FISH (NEMURO For Including Saury and Herring).

The Model Task Team agreed in 2002 to extend NEMURO.FISH to include population dynamics and Lagrangian formulations together with a feedback system connecting the fish model to the lower trophic model. Two follow-up meetings were held in 2003 in Yokohama to develop a dynamically coupled model that included prey-predator relationships between the lower trophic ecosystem and fishes, and to build a Lagrangian model to explicitly consider fish migration and fish population dynamics. These models were applied to two target fish species, Pacific herring and Pacific saury. A special issue of *Ecological Modelling*, dedicated to Dan Ware, was published in 2007. The articles are listed next.

Papers from the special issue on NEMURO and NEMURO. FISH - modeling of North Pacific marine ecosystems
Kishi M.J., B.A. Megrey, S.-I. Ito and F.E. Werner (Eds.)
Ecological Modelling 202(1-2), 2007.

Batchelder H.P. and M. Kashiwai. Ecosystem modeling with NEMURO within the PICES Climate Change and Carrying Capacity program.

Fujii M., Y. Yamanaka, Y. Nojiri, M.J. Kishi and F. Chai. Comparison of seasonal characteristics in biogeochemistry among the subarctic North Pacific stations described with a NEMURO-based marine ecosystem model.

Hashioka T. and Y. Yamanaka. Seasonal and regional variations of phytoplankton groups by top-down and bottom-up controls obtained by a 3D ecosystem model.

Hashioka T. and Y. Yamanaka. Ecosystem change in the western North Pacific associated with global warming using 3D-NEMURO.

Ito S.-I., B.A. Megrey, M.J. Kishi, D. Mukai, Y. Kurita, Y. Ueno and Y. Yamanaka. On the interannual variability of the growth of Pacific saury (*Cololabis saira*): a simple 3-box model using NEMURO-FISH.

Kishi M.J., M. Kashiwai, D.M. Ware, B.A. Megrey, D.L. Eslinger, F.E. Werner, M. Noguchi-Aita, T. Azumaya, M. Fujii, S. Hashimoto, D. Huang, H. Iizumi, Y. Ishida, S. Kang, G.A. Kantakov, H.-C. Kim, K. Komatsu, V.V. Navrotsky, S.L. Smith, K. Tadokoro, A. Tsuda, O. Yamamura, Y. Yamanaka, K. Yokouchi, N. Yoshie, J. Zhang, Y.I. Zuenko and V.I. Zvalinksy. NEMURO - a lower trophic level model for the North Pacific marine ecosystem.

Komatsu K., Y. Matsukawa, K. Nakata, T. Ichikawa and K. Sasaki. Effects of advective processes on planktonic distributions in the Kuroshio region using a 3-D lower trophic model and a data assimilative OGCM.

Megrey B.A., K.A. Rose, R.A. Klumb, D.E. Hay, F.E. Werner, D.L. Eslinger and S.L. Smith. A bioenergetics-based population dynamics model of Pacific herring (*Clupea harengus pallasi*) coupled to a lower trophic level nutrient-phytoplankton-zooplankton model: description, calibration, and sensitivity analysis.

Megrey B.A., K.A. Rose, S.-I. Ito, D.E. Hay, F.E. Werner, Y. Yamanaka and M. Noguchi-Aita. North Pacific basin-scale differences in lower and higher trophic level marine ecosystem responses to climate impacts using a nutrient-phytoplankton-zooplankton model coupled to a fish bioenergetics model.

Mukai D., M.J. Kishi, S.-I. Ito and Y. Kurita. The importance of spawning season on the growth of Pacific saury: a model-based study using NEMURO.FISH.

Noguchi-Aita M., Y. Yamanaka and M.J. Kishi. Interdecadal variation of the lower trophic ecosystem in the northern Pacific between 1948 and 2002 in a 3D implementation of the NEMURO model.

Rose K.A., F.E. Werner, B.A. Megrey, M. Noguchi-Aita, Y. Yamanaka, D.E. Hay, J.F. Schweigert and M.B. Foster. Simulated herring growth responses in the Northeastern Pacific to historic temperature and zooplankton conditions generated by the 3-dimensional NEMURO nutrient-phytoplankton-zooplankton model.

Rose K.A., B.A. Megrey, F.E. Werner and D.M. Ware. Calibration of the NEMURO nutrient-phytoplankton-zooplankton food web model to a coastal ecosystem: evaluation of an automated calibration approach.

Wainwright T.C., L.R. Feinberg, R.C. Hooff and W.T. Peterson. A comparison of two lower trophic models for the California Current System.

Werner F.E., S.-I. Ito, B.A. Megrey and M.J. Kishi. Synthesis of the NEMURO model studies and future directions of marine ecosystem modeling.

Yoshie N., Y. Yamanaka, K.A. Rose, D.L. Eslinger, D.M. Ware and M.J. Kishi. Parameter sensitivity study of the NEMURO lower trophic level marine ecosystem model.

Zuenko Y.I. Application of a lower trophic level model to a coastal sea ecosystem.

The Ocean Biogeographic Information System (OBIS)

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The Ocean Biogeographic Information System (OBIS; Fig. 1; http://www.iobis.org) is the information component of the Census of Marine Life (CoML, http://www.coml.org). It is an evolving strategic alliance of people and organisations sharing a vision to make marine biogeographic data, from all over the world, freely available over the internet. It is not a project or programme, and is not limited to data from CoML-related projects. Any organisation, consortium, project or individual may contribute to OBIS. OBIS provides, on an 'open access' basis through the World Wide Web:

- taxonomically and geographically resolved data on marine life and the ocean environment;
- interoperability with similar databases;
- software tools for data exploration and analysis.

Figure 1. Screen shot of the OBIS opening page.

OBIS is the most authoritative web-based provider of global geo-referenced information on marine species. In addition to gathering and maintaining marine species-level and habitat-level databases, it provides a variety of spatial query tools for visualising geographical relationships among species, and between species and their environment. OBIS is growing rapidly to become the national, regional, and international infrastructure for information on marine species and their distribution and abundance, and is also playing a central research role in ocean biodiversity informatics.
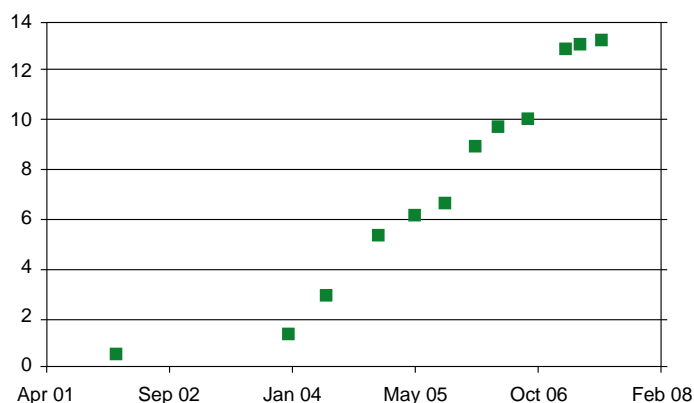

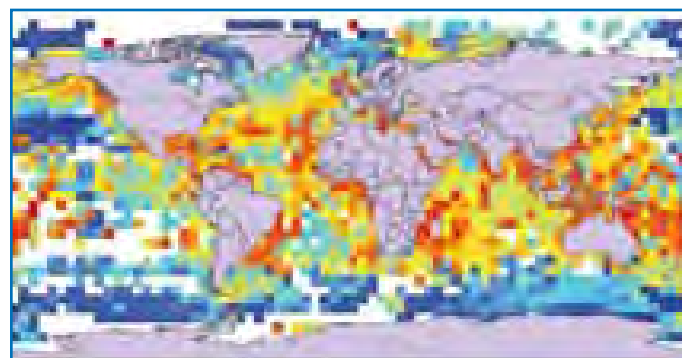Figure 2. Acquisition of records in OBIS through time.

Figure 3. Expected number of species in a random sample of 50 records.

Data acquisition into OBIS is on-going, and the number of records available in OBIS has been increasing linearly over the last four years (Fig. 2). The number of records in OBIS is now approaching 14 million, making it possible to perform the first global all-taxon analyses. Previously, such analyses were confined to a particular region, or to a particular set of taxa. The map shown as Figure 3 shows the expected number of species in a random sample of 50 records (ES(50)) from 5x5 degree squares. Blank squares are those ones for which less than 50 records are available.

There are still obvious gaps in the data cover, and we are eager to work together with as many potential providers as possible. We are aware that there are many datasets collected and managed by GLOBEC scientists. Please consider publishing your biogeographical datasets though OBIS.

OBIS is a true distributed system, facilitating access to biogeographical data from many different sources. The data users gain by having a one-stop shop for biogeographical data. The data providers gain, by increased visibility of their data, and the potential for collaborative ventures and extra use of the data.

CALENDAR

8-9 October 2007: IMBER and GLOBEC Executive Committee meetings, Brest, France.

8-12 October 2007: Second international symposium on tagging and tracking marine fish with electronic devices, San Sebastián, Spain.

26 October - 4 November 2007: PICES XVI Annual Meeting, Victoria, Canada.

19-21 November 2007: BENEFIT-BCLME synthesis symposium, Swakopmund, Namibia.

20-21 November 2007: EUR-OCEANS National Steering Committee meeting, Palma de Mallorca, Spain.

20-23 November 2007: ICES symposium: Environmental indicators - utility in meeting regulatory needs, London, UK.

27-30 November 2007: 6th European Conference on Ecological Modelling (ECEM'07). Challenges for ecological modelling in a changing world: global changes, sustainability and ecosystem based management, Trieste, Italy.

2 December 2007: CLIOTOP SSC meeting, La Paz, Mexico.

3-7 December 2007: 1st CLIOTOP Symposium, La Paz, Mexico.

13-15 December 2007: 3rd Japan-China-Korea joint GLOBEC symposium, Hokkaido, Japan.

7-8 February 2008: Living with climate change: are there limits to adaptation? Royal Geographical Society, London, UK.

2-7 March 2008: 2008 Ocean Science Meeting with special SO GLOBEC and ESSAS sessions, Orlando, Florida, USA.

17-19 March 2008: QUEST Annual Science meeting, UK.

2-4 April 2008: Food security and environmental change: linking science, development and policy for adaptation, Oxford, UK.

3 April 2008: Marine plankton: from cells to ecosystems. A celebration of the scientific career of Professor Patrick M Holligan, Plymouth, UK.

5-6 May 2008: GLOBEC SSC meeting, Cape Town, South Africa.

7-9 May 2008: IGBP Congress, Cape Town, South Africa.

10 May 2008: IGBP SC meeting, Cape Town, South Africa.

19-23 May 2008: ICES, PICES and IOC symposium: Effects of climate change on the world's oceans, Gijón, Spain.

2-6 June 2008: GLOBEC, IMBER, SOLAS and EUR-OCEANS symposium: Dynamics of eastern boundary upwelling ecosystems: Integrative and comparative approaches, Las Palmas de Gran Canaria, Spain.

23-26 June 2008: Advances in Marine Ecosystem Modelling Research II symposium (AMEMR II) "Bridging the gaps", Plymouth, UK.

8-11 July 2008: GLOBEC, FAO and EUR-OCEANS symposium: Coping with global change in marine social-ecological systems, Rome, Italy.

26-29 August 2008: ICES, GLOBEC and PICES symposium: Herring: linking biology, ecology and status of populations in the context of changing environments, Galway, Ireland.

GLOBEC INTERNATIONAL

GLOBAL CHANGE

A CORE PROJECT OF THE **IGBP** INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME
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