GLOBEC Norway Annual Science Meeting 2005

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Norway GLOBEC consists of the projects ECOBE, CLIMAR and ADAPT, funded by the Norwegian Research Council for the period 2003–2006. The objective of ECOBE is to understand and quantify the impacts of Arctic climate variability on trophic transfer and ecosystem structure of the Barents Sea in order to improve the prediction of growth and recruitment on the key fish species cod, haddock and herring. The project has a strong focus on process studies and development and applications on coupled biological-physical models. The principal objective of CLIMAR is to explore the coupling between climate fluctuations and the growth and migration patterns of the Norwegian spring-spawning herring in the Nordic Seas and particularly to investigate the impacts of climate change. Also this project has a strong focus on process studies and model development. ADAPT aims at quantifying the effects of the physical environment and population interaction for the evolutionary adaptation of the populations of *Calanus finmarchicus* and Norwegian spring-spawning herring in the Norwegian Sea.

There is a strong scientific interaction between the three projects. They have a common focus on the population dynamics of the key species *Calanus finmarchicus* and how climate fluctuations and climate change influence the target fish species. Hence, the Norway GLOBEC aims right at the center of objectives and methods of implementation of the North Atlantic GLOBEC regional programme.

Norway GLOBEC held their 2nd annual meeting 15–16 February 2005 at Marsteinen Hotel on the southwest coast of Bergen. 35 scientific presentations were made in addition to two theme discussions on coupling phytoplankton and zooplankton models and on coupling zooplankton and larval/pelagic juvenile fish models. Tore Johannessen gave an invited lecture on "Synergism – positive predator-prey relationship – evidence for an important ecological and evolutionary principle".

This year Norway GLOBEC was particularly interested in being evaluated on progress on model development, zooplankton dynamics, and the potential for applications in management of the fish stocks. Important feedback was given by the review panel which consisted of GLOBEC Chair, professor Cisco Werner, GLOBEC IPO Executive Director Manuel Barange and former Director of the Institute of Marine Research, Odd Nakken.

This issue of the GLOBEC Newsletter includes 17 abstracts from the GLOBEC Norway Annual Science Meeting, following the format established in the April 2004 Newsletter, which received the GLOBEC German project.

Participants at the GLOBEC Norway Annual Science Meeting, February 2005.

GLOBEC Focus 1 Working Group: Retrospective Analysis and Time Series Studies

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Objective

The objective of Focus 1 WG is the identification and understanding of the characteristic, natural modes of physical forcing and marine ecosystem variability over a range of temporal scales (interannual and longer), but also including spatial scales ranging from large marine ecosystems, to ocean basins, to global systems. Understanding these forcings and ecosystem responses across a wide range of nested temporal and spatial scales is crucial to linking the detailed site-specific studies of GLOBEC to population scale impacts. The approach is to develop and examine historical information on marine ecosystems from a variety of sources. The outputs will form a foundation for the structure and parameter estimates of ecosystem models (Focus 3), detailed process studies (Focus 2) and ultimately for GLOBEC Synthesis activities. Development of the Focus 1 activities requires close linkages with the other GLOBEC Foci and global change programmes such as PAGES (Past Global Changes) and CLIVAR (Climate Variability and Prediction Research Programme).

Members

Jürgen Alheit (chair, fisheries biology)
Andrew Bakun (physical oceanography)
Tim Baumgartner (paleoecology)
Ken Drinkwater (physical oceanography)
Benjamin Planque (zooplanktology)
Takashige Sugimoto (biological ceanography)

Former members

Ian Perry (former chair, fisheries oceanography)
Sergey Piontkovski (zooplanktology)
Neil Ward (climatology)

Achievements

To initiate co-operation with PAGES and CLIVAR, Focus 1 organised the GLOBEC/PAGES/CLIVAR Intersection planning workshop in 2000 in Sidney, Canada, with representatives of all three programmes. The objective was to develop broad communication and possible project collaboration among the IGBP programmes of GLOBEC and PAGES with the WCRP programme on Climate Variability (CLIVAR) (GLOBEC *et al.*, 2000). Follow-up activities were, *inter alia*, several PICES/CLIVAR Workshops during the Annual Meetings of PICES, e.g. the workshop on Scale Interactions of Climate and Marine Ecosystems in Honolulu, 2004. Patrick Lehodey presented a paper on Climate Variability, Fish and Fisheries was co-authored by a number of Focus 1 members at the International CLIVAR Science Conference in Baltimore 2004 (Lehodey *et al.*, in press). To initiate co-operation with PAGES, a SPACC/GLOBEC Workshop on Paleoceanography in Munich, Germany, 2001 brought together research teams carrying out high resolution analyses of sediment cores from different anoxic sites in order to compare and cross-calibrate methodologies and co-ordinate future co-operation and comparisons (Fig. 1). From this workshop resulted a publication in the PAGES Newsletter (Baumgartner *et al.*, 2004).

Focus 1 members co-convened a workshop with the IRI-IPRC on Pacific Climate and Fisheries in Hawaii, 2001. The objectives were to

1. identify alternative conceptual frameworks and ideas that may better support fruitful interdisciplinary collaborations,

2. to explore associated implications for innovative fisheries management approaches,

3. to consider potential applications of the comparative method as a means for effective multilateral research on climate/ecosystems/fisheries issues in the Pacific basin (Bakun and Broad, 2002).

An important outcome of this workshop was the initiation of the new GLOBEC Regional Programme on Climate Impacts on Oceanic Top Predators – CLIOTOP (CLIOTOP, 2005).

Focus 1 has a strong co-operation with the SPACC Theme 1: Long-term Changes in Ecosystems. Three meetings related to SPACC Theme 1 and GLOBEC Focus 1 were held over the last years.
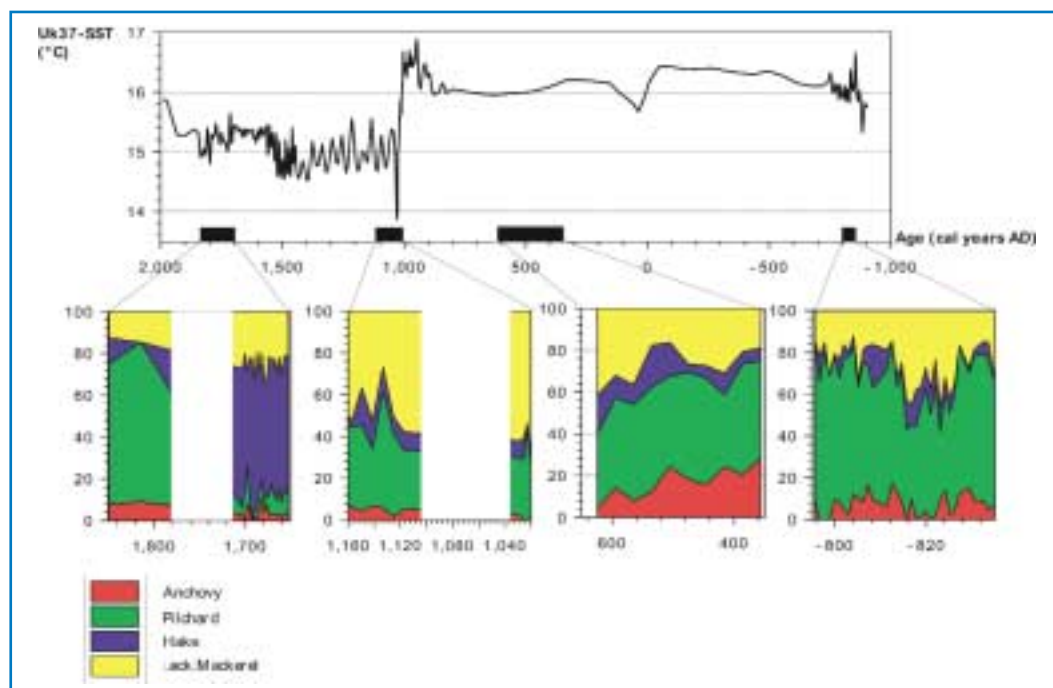
CONTENTS

Figure 1. SST as estimated from the alkenone undersaturation and relative abundance of fish scales from sardine, anchovy, hake and horse mackerel from a sediment core of the Benguela Current off Namibia (modified from Baumgartner et al. 2004).

1. Major Turning Points in the Structure and Functioning of the Benguela Ecosystem, Cape Town, South Africa 2001
2. The GLOBEC-SPACC/IAI workshop on Comparative Studies of Long-Term Variability of Small Pelagic Fishes in the Humboldt and California Current Ecosystems, Lima, Peru 2001
3. Long-term Dynamics of Small Pelagic Fishes and Zoo-plankton in Japanese Waters, Tokyo 2003 (Kawasaki, 2005)

Overviews of the outputs of these meetings were published in the April 2001, 2002 and 2003 issues of the GLOBEC Newsletter.

The Focus 1 Working Group also assembled an inventory of web sites which describe marine data observation programs, including sites which link to long-time series data sources. These web sites are organised geographically and linked to the map of ocean biogeographic provinces originally developed by Alan Longhurst – simply click on any of these provinces to obtain a linked-list of data sites available for that region (access through http://www.pml.ac.uk/globec/data/typology.htm).

Future Activities

The GLOBEC Focus 1 WG will continue its efforts on integration and synthesis activities. The main focus in 2005/06 will be to plan and organise a conference on Climate Variability and Exploited Marine Ecosystems. This conference will adapt the successful Dahlem Conference model. About 30 experts will start to prepare joint background papers one year before the conference which is planned for 2006. The product will be a special journal issue with the conference proceedings and the background papers. Emphasis will be on four subjects:

1. Large space-time scale variability in marine ecosystems – describing the patterns.
2. Sensitivity of fish populations to climatic variability and human exploitation – mechanisms creating the patterns.
3. Sensitivity of marine ecosystems to climatic variability and human exploitation – mechanisms creating the patterns.
4. Incorporating climate forcing into the advisory process for marine resource management – responding to the patterns.

Co-operation with the ICES Study Group on Regional Scale Ecology of Small Pelagics will continue, particularly in planning (i) a Theme Session for ICES Annual Science Conference 2006 on Large scale changes in the migration of small pelagic fish and the factors modulating such changes and (ii) a SPACC/ICES workshop on small pelagics in SW Europe with the idea of enhancing the comprehensive assemblage of different types of data (physics, plankton, landings, surveys, model outputs) at regional scale in a long-term perspective (20–50 years). Also, co-operation will continue with EPCOR (Eastern Pacific Consortium for Research on Global Change of IAI) and be initiated with ESSAS (the new GLOBEC Regional Programme on Ecosystem Studies of Sub-arctic Seas), the new SCOR WG on Zooplankton Time Series and the HMAP (History of Marine Animal Populations) initiative of the Census of Marine Life Programme.

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Kawasaki T. 2005. Differences in dynamics of the Far Eastern sardine subpopulations. GLOBEC International Newsletter 11(1): 4–6.

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. in press. Climate variability, fish and fisheries. Journal of Climate (Special issue of the CLIVAR conference, Baltimore USA June 2004).

Differences in dynamics of the Far Eastern sardine subpopulations

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Sardine populations (genus: Sardinops) distributed in areas distant from each other have shown long-term, interdecadal, synchronised fluctuations of high amplitudes (Kawasaki, 1983). During the last century, we have witnessed two global scale sardine regime shifts with abundance peaks in the 1930s and 1980s. However, close inspection of the dynamics of the different subpopulations involved reveals that they behaved differently during the two periods of high abundance.
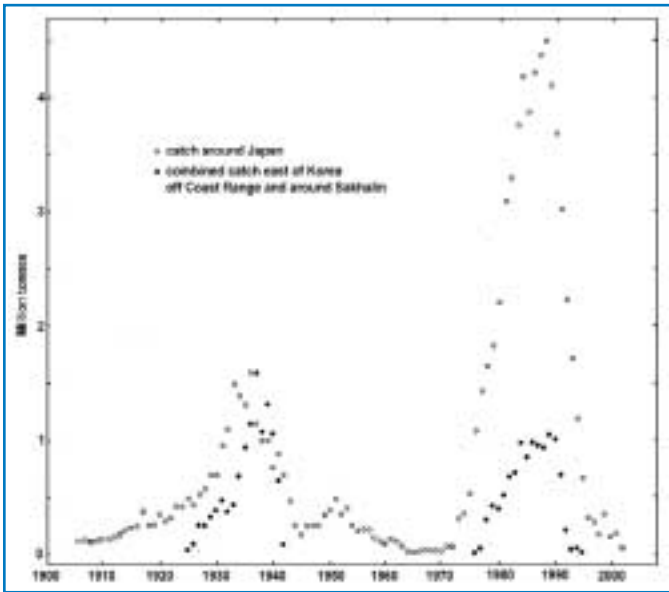

Figure 1. Timeseries of sardine landings in Japan and those on the continental coasts in the 20th century. Continental coasts include eastern Korean Peninsula, Coast Range and southern Sakhalin.
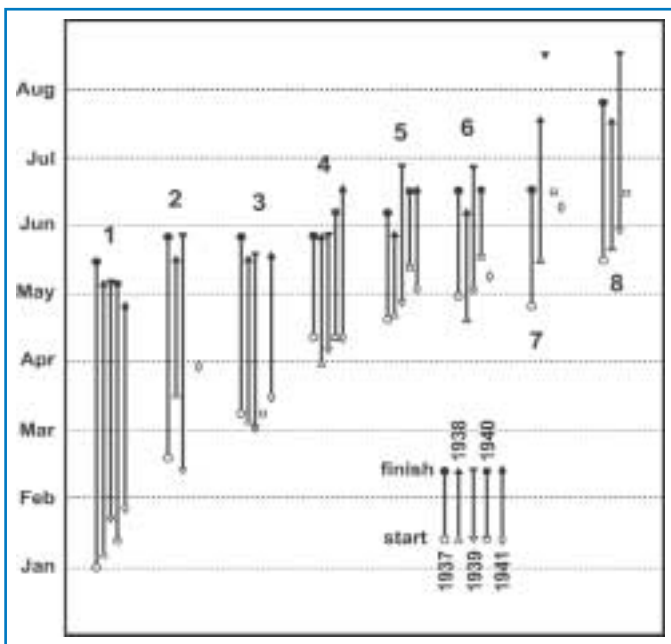

Figure 2. Northeastward shift of start and finish of drift-netting and gill-netting for the sardines along the Sea of Japan coasts of Honshu and Hokkaido from 1937 to 1941. Areas denoted by numerals 1-8 are shown in Figure 5. Adapted from Figure 3, Chapter 10.3, Matsushita 1991.

Thus, whereas catches of the Californian sardine were dominated in the 1930s by the subpopulation off the US coast of California, highest catches during the 1980s were reported from the subpopulation in the Gulf of California.

There are two subpopulations of the Far Eastern sardine in the temperate Northwest Pacific Ocean, the centre of which is in the waters around Japan. One is the Japan Sea Subpopulation (JSS) whose major area of distribution is the Japan Sea. The other is the Pacific Subpopulation (PS) that migrates mainly along the Pacific coasts of Japan. This article presents evidence that whereas in the last high abundance period in the 1980s catches from the PS by far surpassed those from the JSS, catches during the former high abundance period in the 1930s were dominated by the JSS.

A comparison between sardine landings recorded during the last century in Japan and those on the continent (including the entire area from the eastern Korean Peninsula, via Coast Range, to Sakhalin (Fig. 5)) demonstrates that landings on the continent were high in the 1930s and sometimes surpassed those in Japan (Fig. 1). However, during the 1980s, sardine landings in Japan were much higher than on the continent. The landings recorded on the continent were undoubtedly from the JSS. The important question is how to separate JSS and PS catches in the landing records in Japan.

High abundance period during the 1930s

During the 1930s, the sardine fishing season on the Japan Sea coast of Japan started usually in the near-shore waters of the westernmost area of Honshu as early as January, then moved northeastward along the Japan Sea coasts and finally ended off the west coasts of Hokkaido, where the fishing season usually started in late May and finished in late July (Fig. 2).

The majority of sardines arriving at the west end of the Tsugaru Strait passed through the Strait and after mid-June they were caught in abundance in Uchiura Bay which is located off southern Hokkaido (Fig. 3). Then, in mid-July, the sardines moved on to the waters east of Cape Erimo. Thereafter, in late August, they started to return to Uchiura Bay, where they

Table 1. Regional Breakdowns of sardine landings in Hokkaido

Region	Landings 1000 tonnes (%)			
	1937	1938	1984	1989
Okhotsk Sea coasts	23 (5.3)	– (0.1)	–	4 (0.4)
Soya Strait	5 (1.2)	1 (0.3)	–	–
Japan Sea coasts	57 (13.3)	34 (10.8)	–	–
Tsugaru Strait	33 (7.7)	34 (10.8)	–	–
Uchiura Bay	203 (47.2)	184 (58.2)	0	0
West of Cape Erimo	33 (7.7)	23 (7.3)	0	0
East of Cape Erimo	73 (17.0)	37 (11.7)	1103 (95.9)	879 (97.0)
Nemuro Strait	3 (0.7)	3 (0.9)	46 (4.0)	21 (2.3)
Total	430 (100.0)	316 (100.0)	1150 (100.0)	905 (100.0)

Source: 1937 and 1938: Matsushita 1991, 1984 and 1989: Yearbook of Fishery Products Circulation Statistics, Ministry of Agriculture, Forestry & Fisheries, Japanese Government, 1986 and 1991

Table 2. Comparison of lipid content and condition factor of the sardines between the JSS (the 1930s) and the PS (the 1980s) in Hokkaido waters

Region	Date of sampling	Average length (cm)	Average lipid (%)	Average condition
Uchiura Bay	2 Sep 1935	21.8	13.46	0.76
	3 Sep 1935	20.0	13.70	0.72
East of Cape Erimo	2 Sep 1982	19.0	22.52	1.03
	4 Sep 1983	20.5	19.84	0.78
	4 Sep 1986	23.6	22.55	0.85
	4 Sep 1988	22.0	22.73	0.78

stayed between mid-September and early December. Finally, they returned through Tsugaru Strait to the Sea of Japan between mid-November and mid-December. Some of the sardines arriving at the western end of Tsugaru Strait in mid-June, however, continued their northward migration to get to the northern tip of Hokkaido. After passing through Soya Strait, they reached the waters off the Sea of Okhotsk coast of Hokkaido from mid-July to late September (Figs. 3 and 5).

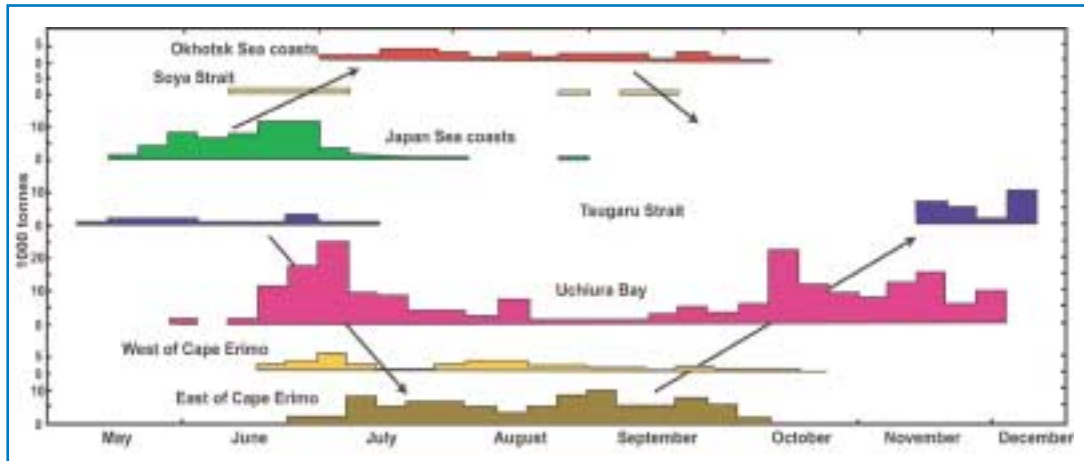Thus, almost all the sardine landings in Hokkaido in 1937 and 1938 must have come from the JSS (Fig. 5, Table 1). In 1937 and 1938, combined catches from the JSS must have been much higher than landings on the continental waters (Fig. 1) plus those in Hokkaido (1937, continent + Hokkaido = 2.01 million tonnes; 1938, continent + Hokkaido = 1.40 million tonnes), because landings on the Japan Sea coasts of Honshu, at western Kyushu and on the Pacific coasts of northeastern Honshu must be added as they also seem to have originated from the JSS. In contrast, catches from the PS must have been much lower than Japan total landings (Fig. 1) minus those in Hokkaido (1937, Japan - Hokkaido = 0.72 million tonnes; 1938, Japan - Hokkaido = 0.67 million tonnes). Consequently, it is concluded that in the high abundance period of the Far Eastern sardine in the 1930s, most of the sardine catches originated from the JSS and that this subpopulation was the dominating one.

Figure 3. Timeseries of weekly landings of the sardines at different areas around Hokkaido in 1937. Source: Matsushita, 1991.
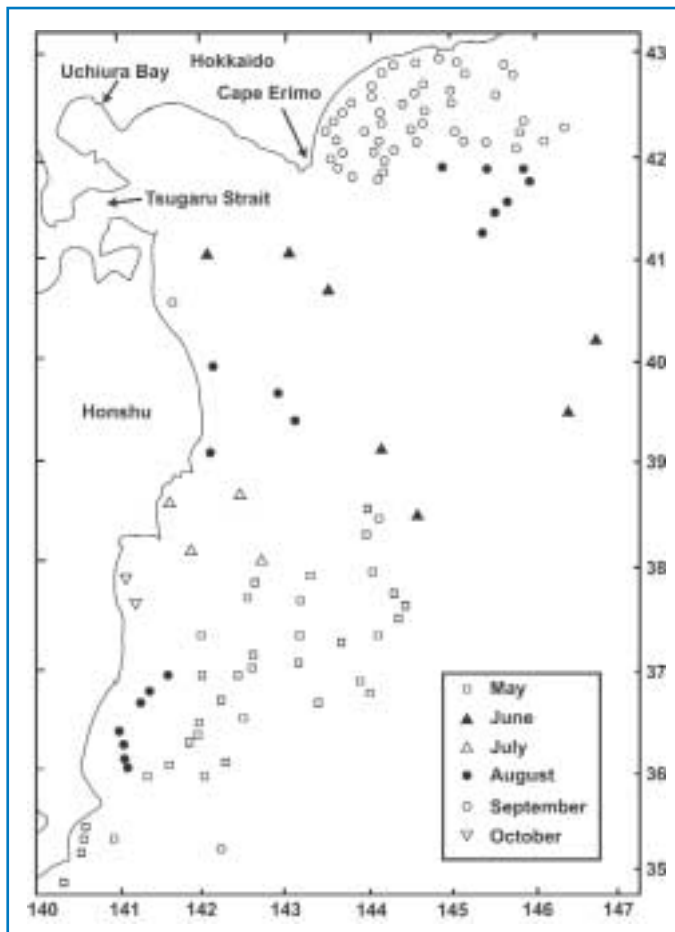

Figure 4. Aerial spotting of sardine schools over the waters east of Honshu and Hokkaido in 1984. Adapted from Figure 5.9, Matsushita 1991.
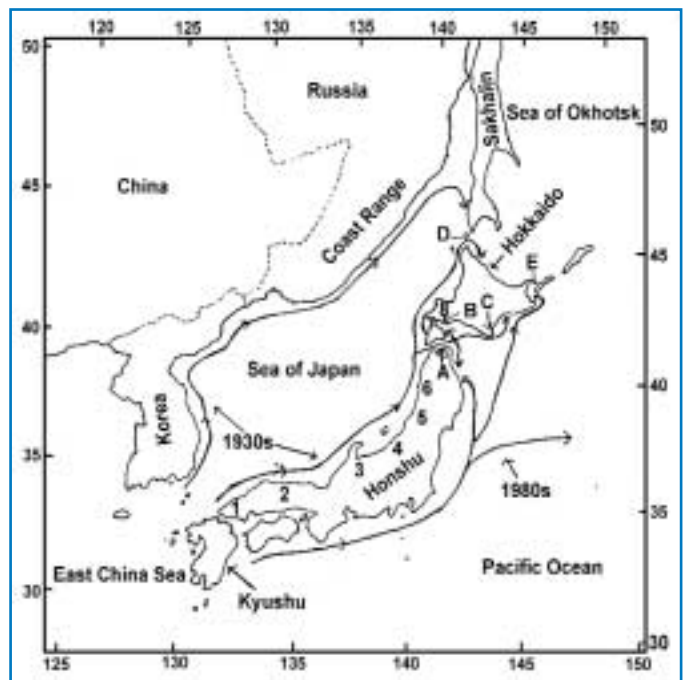

Figure 5. Schematic northward migratory routes of the sardine in the 1930s and 1980s. A: Tsugaru Strait B: Uchiura Bay C: Cape Erimo D: Soya Strait E: Nemuro Strait.

High abundance period during the 1980s

Records from spotter planes over the waters east of Honshu and Hokkaido in 1984 clearly show that, from May to August, sardine schools from the Pacific side of southern Japan migrated to the waters off the coasts of southeast Hokkaido (Fig. 4) where they were under intensive fishing pressure in September. Consequently, these sardines fished off Hokkaido did not come from the west, from the Sea of Japan, through Tsugaru Strait. The landing statistics of sardines in 1984 and 1989, the peak years during the last high abundance, demonstrate that the overwhelming majority of the sardine catches were landed at the areas east of Cape Erimo and that there were virtually no catches in the waters west of Cape Erimo and in Tsugaru Strait (Table 1). This is in striking contrast to the data in 1937 and 1938 (Table 1), suggesting that in the 1980s the fish schools off the southeastern coasts of Hokkaido stemmed exclusively from the PS. Consequently, during the 1980s, the PS was the dominating sardine subpopulation. The major migratory routes of the JSS in the 1930s and the PS in the 1980s are shown in Figure 5.

The two subpopulations were different in many aspects, especially in lipid content and condition factor. Fish data were selected that were similar in date of landing and fish size from the JSS in Uchiura Bay in the 1930s and also from the PS off southeastern Hokkaido area in the 1980s (Matsushita, 1991). The PS clearly exhibited higher lipid content and condition factor than the JSS (Table 2).

Noto and Yasuda (1999) assumed that both the dramatic biomass fluctuations of the Far Eastern sardine in the 1930s as well as those in the 1980s were caused by the PS. On this assumption, they emphasized close links between the mortality during the first year of life of the sardines and the sea surface temperature in the Kuroshio Extension area east of Japan (30–50°N and 145–180°E) where, they supposed, larval fish spawned off the Pacific coasts of southern Japan were transported and brought up. As demonstrated above, however, in the 1930s it was the JSS that exhibited high biomass fluctuations, not so much the PS and it follows that the assumption of Noto and Yasuda (1999) should be re-examined.

In conclusion, it seems that the regime shifts of the Far Eastern sardine do not happen in a stereotyped fashion. We need a broader-scale viewpoint to interpret regime shifts in the correct way.

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Focus 2 Working Group – Process Studies

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What is the purpose of the group? What is a process study?

The Focus 2 Working Group helps to facilitate international implementation of the research on process studies outlined in the GLOBEC Implementation Plan. The definition of "a process study" below illustrates the importance of such studies for GLOBEC and their particular relevance for models.

Process study

An organised, systematic investigation of a particular process designed to identify all of the state variables involved and to establish the relationships among them. Process studies yield numerical algorithms that connect the state variables and determine their rates of change; such algorithms are essential ingredients of Earth system models.

Clearly, the number of processes, interactions, and species within marine ecosystems is vast, so what are the processes that the group is tackling? Firstly, research on life histories and trophodynamics and their modelling in ecosystems. This research area includes zooplankton reproduction, growth and mortality rates, zooplankton trophodynamic strategies, zooplankton-fish interactions and the role of microzooplankton in food webs. Secondly, the identification and understanding of multiscale physical-biological interactions. These include

relations between ocean physics and basic biological processes of individual organisms, mesoscale biological-physical interactions and large-scale physical-biological interactions. The resources of the Working Group are limited, the issues to be tackled are varied and complex, so not all of these processes have been addressed yet. However, good progress has been achieved in a number of areas and this is illustrated in the next section. Finally in this article the importance process studies for the overall synthesis of GLOBEC research and the approaches taken by the Focus 2 Working Group in working towards integration and synthesis are outlined.

What are the achievements of the group so far?

The WG has a diverse membership representing both geographical regions and ecosystem types as well as relevant specialist expertise, for example with calanoid copepods, euphausiids, gelatinous zooplankton and microzooplankton.

The WG has held three meetings. The first full meeting was in Roscoff, France in September 2000, there was a smaller meeting at the 2nd Open Science Meeting in Qingdao October 2002, and last year in July 2004 a third full meeting was held at Salve Regina University, Rhode Island, USA. The Roscoff meeting set the foundations for the group's activities and began developing a series of review articles. A significant

example of such a published WG output is the review by Dalsgaard *et al.* (2003). The Qingdao meeting provided a particular opportunity for interaction and discussion with the Focus 3, Predictive and Modelling Capabilities, Working Group. Plans initiated at that meeting will provide the basis for future activities between the WGs as part of the GLOBEC integration and synthesis. The most recent meeting in Rhode Island had as its overall objective to summarise the key processes thought to affect the dynamics of target species and ecosystems in GLOBEC and GLOBEC type programs. The review work benefited from the database of GLOBEC publications maintained by the IPO as well as the recently published GLOBEC Special Contribution No. 7, *"Update of GLOBEC National, Multinational and Regional Programme Activities, 2004"*. The aim was also to identify gaps in process related knowledge critical for resolving the effects of global change, and through a comparison of research approaches and implementation strategies identify the strengths and weakness of individual programs so as to optimise future research initiatives. The work at the meeting centred on writing a review article on *"Feeding, growth, reproduction and mortality of copepods: a GLOBEC review"*. The strategy adopted was to consider what has been learned from GLOBEC research about these four processes for a subset of target species studied over a range of physical system types addressed in national and regional GLOBEC programmes. To make the problem tractable the initial effort has been mainly on *Calanus* species. Considering the California Current as an advection dominated shelf system the WG has considered *Calanus pacificus*, *C. marshallae* and *Euphausia pacifica*. Retention dominated shelf systems are exemplified by Georges Bank and the Yellow Sea where key species are *Calanus finmarchicus*, *C. sinicus* and species of *Pseudocalanus*. Processes for *Calanoides carinatus*, *Calanus agulhensis* and *C. marshallae* the Oregon and Benguela upwelling systems are being reviewed. The final system type, Open Ocean systems, Iceland, Irminger Sea, North East Atlantic is represented by *C. finmarchicus* and *C. helgolandicus*. The approach is to compare both between systems and between taxa, and this work is consistent with the wider GLOBEC integration and synthesis effort (see below). Processes are related to abiotic factors such as temperature, salinity, light, mixed layer depth, mixing regime, wind and nutrients, and to biotic factors, for example, chlorophyll, microplankton biomass, invertebrate and vertebrate predators. Particular characteristics of target species are types of spawner, types of eggs, diapause, number of generations, delayed development instead of diapause, vertical migration and feeding mode. This year the group will complete the copepod review article and submit it to a review journal for publication. We also plan to extend the approach to other groups specifically gelatinous zooplankton and euphausids and also to continue another initiative on small scale interactions between physics and zooplankton (turbulence, mixed layer dynamics, patchiness).

The concept of target species is important for the work of the group. To ensure that the group's work is most effectively linked with major national and regional programmes, the Focus 2 group tries to assimilate information on target species from these programmes. The group was represented at a US
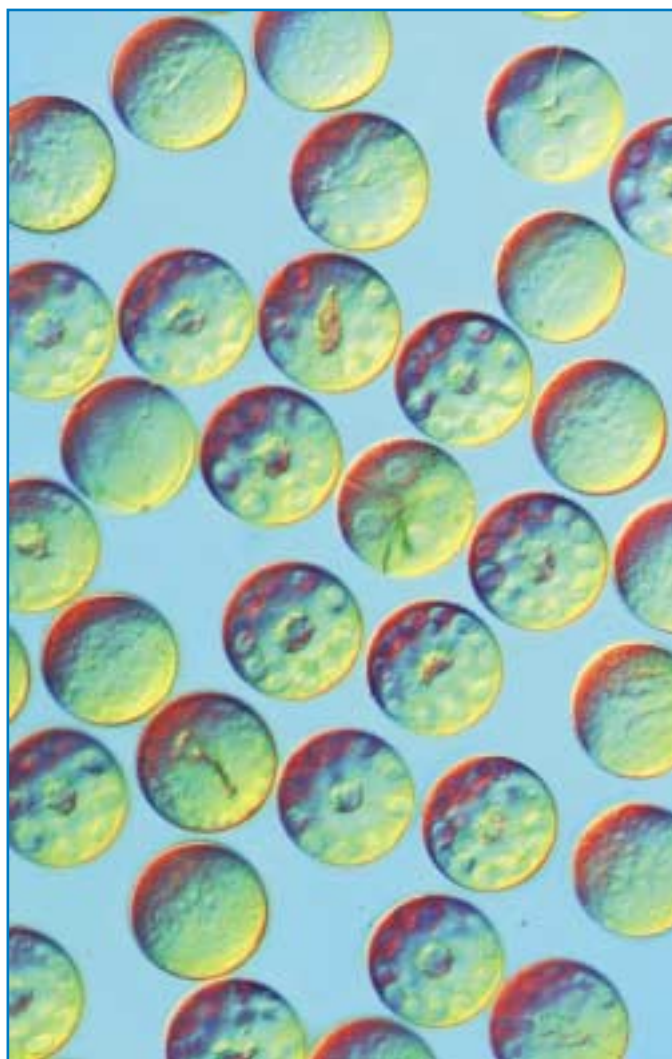
Figure 1. Eggs of the copepod Calanus finmarchicus, one of the GLOBEC target species. Egg production and mortality are among the processes being addressed by the Focus 2 Working Group.

GLOBEC Georges Bank target species meeting held in January 2005 in Durham, NH. Cod and haddock larvae and the calanoid copepods *Pseudocalanus* spp. and *Calanus finmarchicus* are the target species of the Georges Bank programme. The meeting focussed on identifying research areas where GLOBEC results suggest new conceptual models of biological processes in the Georges Bank/Gulf of Maine region and developing a plan for testing these hypotheses. The discussions provided updates on population dynamics modelling, spatial distributions, and on egg production, growth, and mortality data. They identified important problem areas that need attention, identified what data must be shared between groups to further the understanding of the target species and compared patterns of variability in target species with one another and with other important species.

What future activities are planned in relation to synthesis?

At the our Salve Regina meeting the Working Group spent a lot of time considering the *GLOBEC International Integration and Synthesis Blueprint* and how future work on process studies might best contribute to the programme-wide effort. This international integration activity aims to draw together

Physical Processes	Target Species
Gulf of Alaska Buoyancy Flow Cross-Shelf Transport Downwelling Stratification	*Calanoid Copepods* *Euphausiids* *Pink Salmon*
Georges Bank Cross-Front Exchange Retention/Loss Stratification	*Calanoid Copepods* *Cod* *Haddock*
California Current Alongshore Transport Cross-Shelf Transport Retention Stratification Upwelling/downwelling	*Calanoid Copepods* *Chinook Salmon* *Coho Salmon* *Euphausiids*
Southern Ocean Retention Sea Ice Dynamics Stratification	*Euphausia superba*

Table 1. Schematic of the approach being adopted in the US GLOBEC programme to compare between physical processes and target taxa within the programme's four US regional studies. Focus 2 WG is working with a similar approach globally to foster comparative studies of processes in ecosystems and for target species.

observations and results from the various components of the GLOBEC programme and to integrate them in an effective manner in order to develop a global synthesis. The overall GLOBEC synthesis focuses on ecosystem comparisons, and will facilitate understanding of the functioning of marine ecosystems and their responses to physical forcing. We hope that the future work of the Focus 2 WG will contribute significantly to this challenging task.

Synthesis activities will involve comparisons of processes both within and among marine ecosystems, and comparisons of ecosystem responses to large-scale forcings. Understanding and prediction of the different responses by these "ecosystem-types" to large-scale forcing is a core objective of GLOBEC uniting small-scale, regional, and global scales. The Focus 2 WG will continue with its work to develop strategies for synthesis and integration to develop approaches for comparative analysis between the work carried out within national and regional programmes. Comparative studies include contrasts among related species with regions, among regions, and across system types and processes. The aim will be to:

● Compare across systems and system types with particular respect to physical forcing.

● Compare across taxa, particularly emphasizing GLOBEC target species.

● To use comparative methodology between taxa and system types to extract broader lessons from GLOBEC studies.

This approach, exemplified in the work of the group at their Rhode Island meeting, is very consistent with the approach being adopted in other integration and synthesis activities. For example the US GLOBEC programme is comparing between its four regional programmes each with its own characteristic physical processes and target species (Table 1). The colouring indicates common elements between the regional programmes.

Following the discussions at the Qingdao meeting there is a consensus to hold a joint meeting between the Focus 2 and 3 WGs (the definition of a process study at the beginning of this article clearly indicating the links between process studies and models). We plan to invite selected members of Focus 3 WG to our 2005 meeting with a view to developing a proposal for a major workshop on linkages between experimentation and modelling of biological pelagic process. Building bridges between the four Focus WGs is another way of building GLOBEC integration and synthesis.

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National Programmes

If you would like a special section in the GLOBEC International Newsletter
to highlight the GLOBEC research from your country please contact the
GLOBEC IPO (globec@pml.ac.uk) for further information.

Plankton Visual Analyser

G. Boyra (gboyra@pas.azti.es), X. Irigoien, A. Aristegieta and I. Arregi
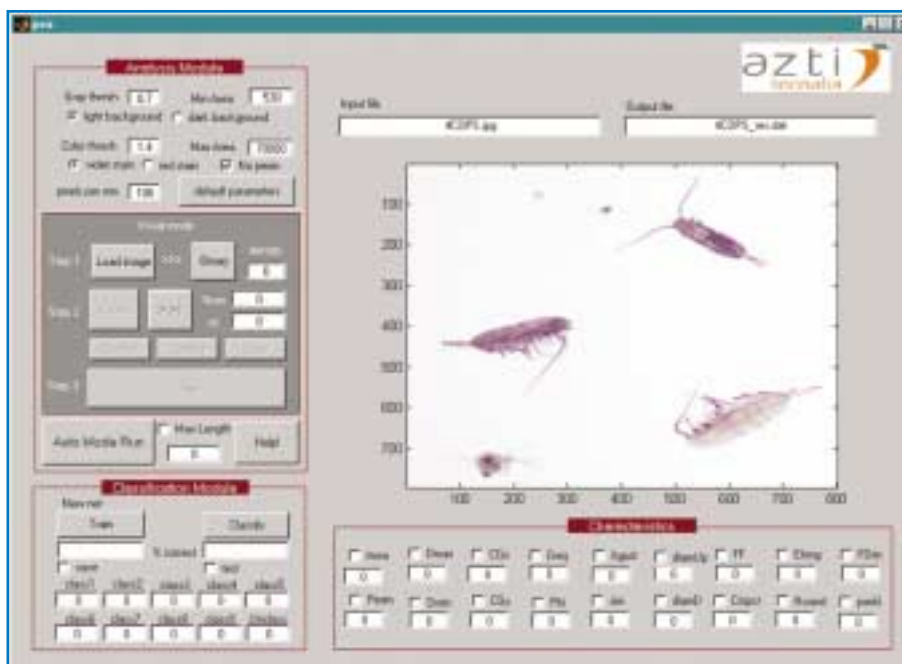AZTI, Pasaia, Spain

Figure 1. Graphic User Interface of the PVA, showing the analysis and classification modules (on the left side of the image), the measured characteristics of the plankton individuals (bottom-right) and the image of a zooplankton sample.

The analysis of plankton samples consumes large amounts of laboratory time. Therefore, a high percentage of the samples obtained year after year are not processed, because of the lack of time and money, and remain stored awaiting a solution.

In order to solve this problem it is necessary to achieve automatic processing of plankton samples. With this objective in mind, scientists from the Marine Research Division of AZTI have developed the Plankton Visual Analyser, or PVA. The PVA is free software devoted to the extensive processing (that is, counting, measuring and classification) of large samples of plankton. It uses digital images of the samples, previously taken by means of any imaging device (digital camera, scanner or any other) to analyse the organisms in the sample.

The PVA has a Graphic User Interface (GUI) for easy end user operation (Fig. 1). Behind the GUI, it combines techniques of Image Analysis and Pattern Recognition, allowing the user to configure and train the software to identify his own target species. The automatic analysis procedures involve three different operations with the plankton samples: counting, measurement of characteristics and classification (Fig. 2).

Counting

The PVA applies some grey level and colour thresholds to achieve the binarization of the original image. This way, it distinguishes the different individuals in each image, separates them from the background and counts the amount of individuals contained in the sample. The correct performance of the software in this phase depends strongly on the quality and contrast of the images obtained. Therefore, it is essential to develop a good image acquisition methodology, including staining the samples to improve the contrast.
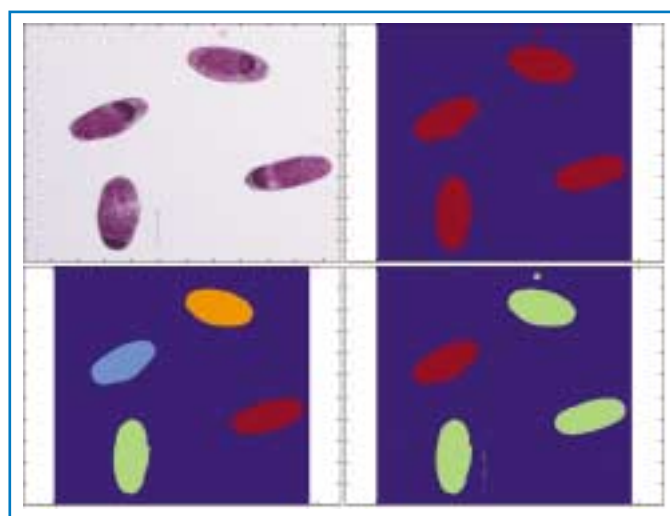
Figure 2. Successive transformations occurred on an image of a small sample of anchovy eggs, as is shown in the PVA screen, at different steps of application of the Image Analysis routines: Original image (top-left). Binary image, the ones in red and the zeros in blue (top-right). The image, once the counting procedure is completed, showing only the best candidates, each in a different colour (bottom-left). Aspect of the image screen at the time the characteristics of a selected individual are presented in the proper area, highlighting the selected individual from the rest of individuals of the samples (bottom-right).

Characteristics measurement

Once the organisms in the sample have been counted, the PVA measures a fixed series of characteristics for each sample. Up to now, the characteristics were limited to morphological attributes related to the contour of the binary images. Some of the characteristics obtained are primary, which are directly

measured on the image (e.g. area, perimeter, maximum diameter, minimum diameter, etc.). Other characteristics are secondary and are calculated by mathematical operations with the primary characteristics (among them we find roundness, fractal dimension, etc.).

Classification

Finally, the PVA identifies the organisms by means of a kernel-based classifier with a Gaussian density function. It requires the development of a set of prototypes classified by the user to serve as a reference for the automatic classification. In these phases, the PVA no longer works with images, but with tables of characteristics. The PVA classifies the images, achieving a percentage of success that will depend on the chosen characteristics. This value constitutes the classification capacity of PVA for each class.

Figure 4. Distribution of small zooplankton abundance (less or equal than 1 mm in maximum length, ind. m⁻³) found in the Bay of Biscay during the Bioman 2001 survey.

Applications and first results

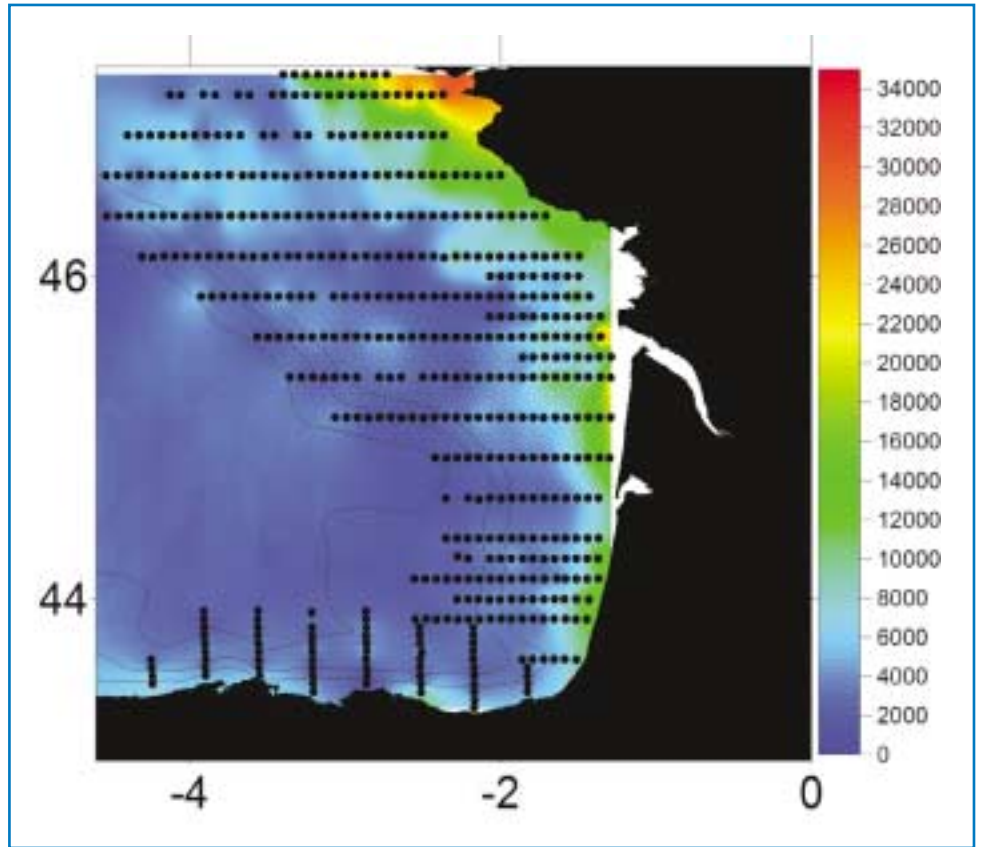AZTI has tested the PVA automatic counting capabilities by comparing the microscopic and PVA counting of mesozooplankton samples. In order to test whether the procedure is efficient in real conditions, we used different subsamples for microscopy and PVA. As can be seen in Figure 3, the results obtained by both methods were similar.

In addition, a first test of the analyser classification abilities was developed on a sample of around 500 planktonic individuals of

different species (anchovy and sardine eggs mixed with many other zooplankton species), which showed a correct egg identification capacity of about 94%. Nevertheless, for future versions of the software, new characteristics will be added in order to improve its efficiency and broaden the range of classifiable species.

AZTI is using the PVA in two main tasks. On the one hand, it is working on the extensive analysis of historical samples of zooplankton (Fig. 4) that were not analysed routinely. On the other hand, the PVA is also being used for quick counting, sizing and identification of fish eggs, a task that constitutes the base of the Daily Egg Production Method (Lasker, 1985), one of the main methods for estimating abundance of pelagic fisheries in the Bay of Biscay.

In conclusion, the PVA allows for an automatic analysis of plankton samples, offering a simple and fast way to process a large number of samples that otherwise would not be able to be processed. The PVA is free software that allows large amounts of samples to be processed at low costs. It can be downloaded from www.azti.es.
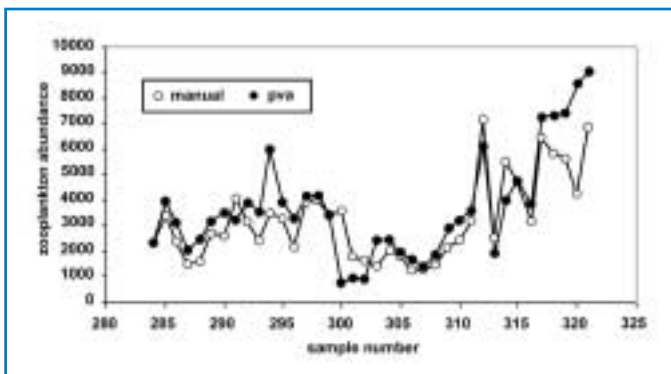
Figure 3. Comparison of zooplankton abundance obtained by both microscopic counting and PVA for 36 samples. The microscopic and automatic counting processes were applied over two different 6 ml sub-samples of each sample. Empty circles indicate the individuals counted using the microscope and the black filled circles are samples counted using PVA.

Reference

Lasker R. 1985. An egg production method for estimating spawning biomass of pelagic fish: application to northern anchovy (*Engraulis mordax*). US Department of Commerce NOAA Technical Report NMFS 36: 99pp.

The Odate Project: Phenological change in the Oyashio copepod communities for 1960–2002

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Impacts of decadal to multi-decadal scale climatic variation on marine ecosystems has been one of the hot study topics in recent years. As regional information has been accumulated, for example, in the eastern North Pacific and North Atlantic based on the long-term plankton monitoring efforts, the next step is to integrate such information to gain a basin to hemisphere scale picture. For this purpose, better understanding of climate-ecosystem link in the western North Pacific, as well as other less investigated regions, is indispensable.

The Odate Collection

An extensive, historical zooplankton collection exists in the western North Pacific. About 18,000 zooplankton samples taken in waters adjacent to Japan from the 1950s by several research institutes were assembled and each wet weight was measured at the Tohoku National Fisheries Research Institute by K. Odate, which is known as the Odate Collection (Odate, 1994). All samples were collected with a consistent method: 0–150 m vertical haul of a NORPAC net or a net with the equivalent specification (mesh size: 0.33 mm). Under financial support by the Japanese Ministry of the Environment, we kicked off the inter-institutional, long-term ecosystem change study, the Odate Project, in FY2003 based on the Odate Collection and additional samples collected after 1990.

The Odate Collection covers Oyashio (sub-arctic), Kuroshio (sub-tropical) and the transition region, and we first targeted the Oyashio region which is known for extensive spring blooms and high productivity. Samples taken in the Oyashio were extracted following the criteria of water temperature <5°C at 100 m deep. We found a decadal scale oscillation in total zooplankton biomass for 1953–2002, which was significantly correlated (R = −0.843) to wintertime PDO (http://tao.atmos.washington.edu/pdo/) (Fig. 1). Yet, as total biomass did not provide enough information about how climatic forcing affected the lower trophic level productivity, we conducted microscopic analysis on copepod species composition of the selected
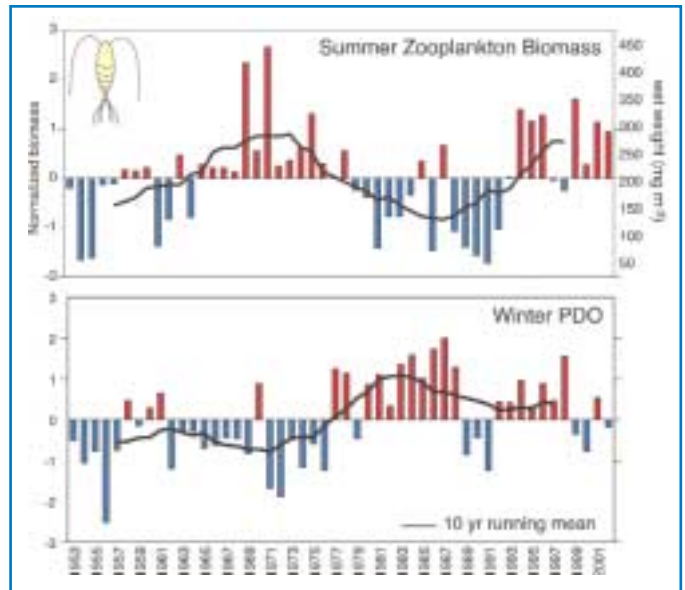
Figure 1. Time series of summertime total zooplankton wet weight (mg m⁻³) in the Oyashio (upper), and wintertime PDO (http://tao.atmos.washington.edu/pdo/)(lower) normalized for 1953–2002.
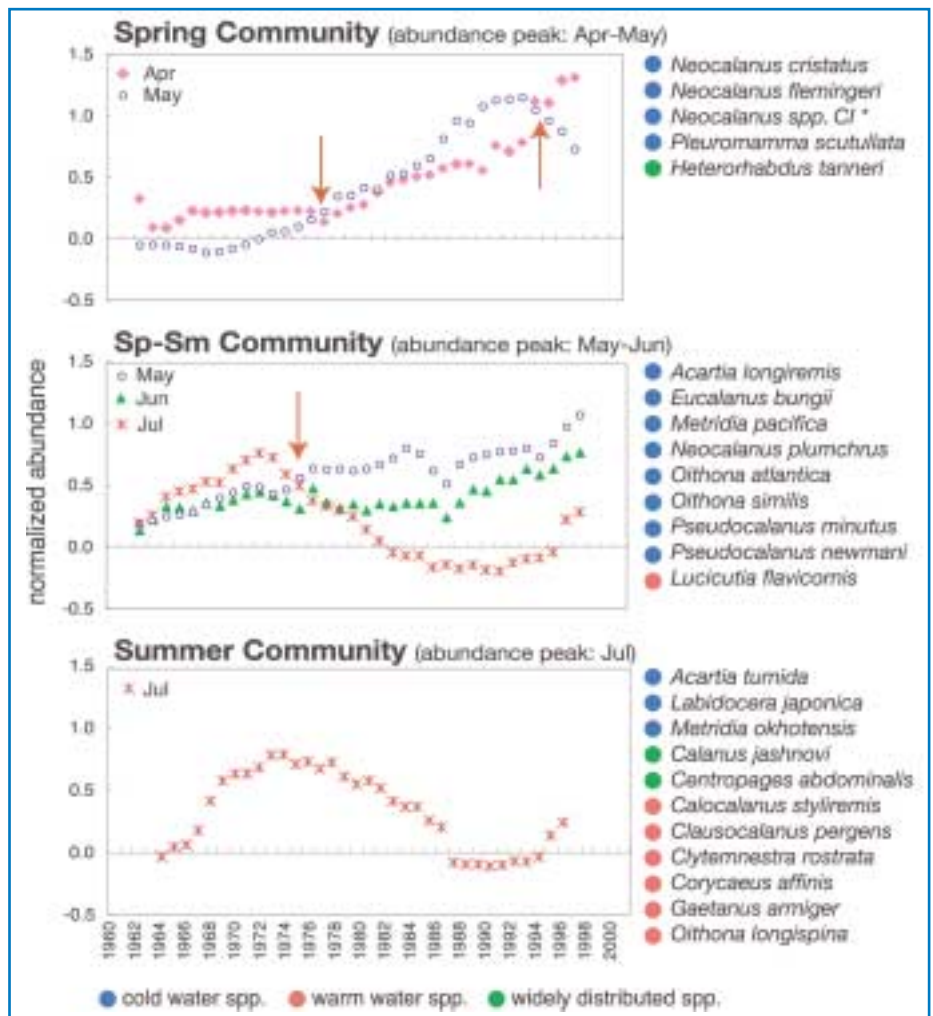

Figure 2. Time series of normalized abundance in the month(s) of peak occurrence of each seasonal copepod community (10 yr running mean) with the list of species for each group was on the left. Red arrow indicates shift of peak month.
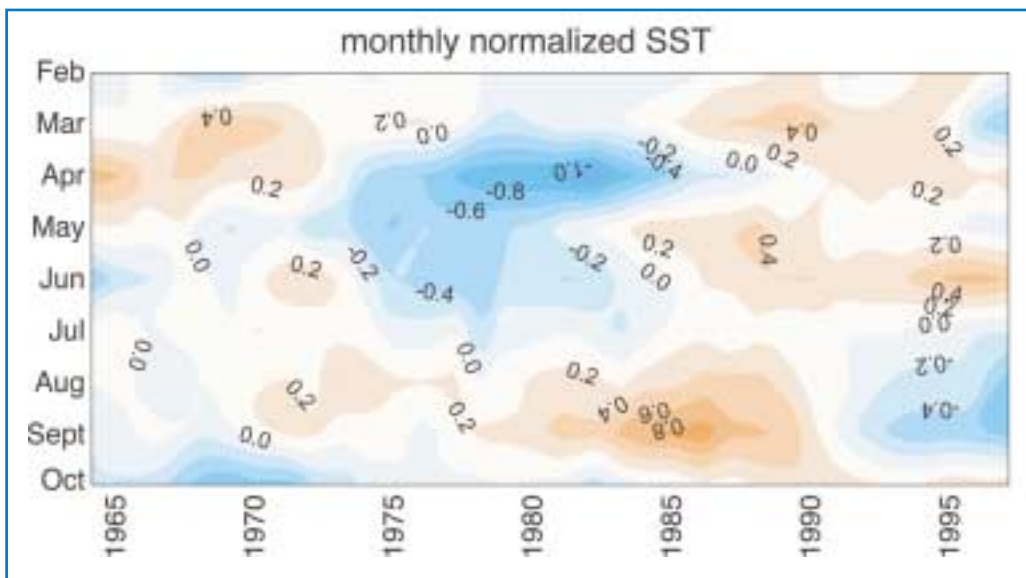
Figure 3. Ten year running mean of monthly SST (February–October) normalized for each month.

1527 samples. Copepods accounted for 70 to 90% of zooplankton biomass in the Oyashio, and are major food sources for commercially important fish species including Japanese sardine (*Sardinops melanostictus*). Here I introduce one of the first findings of our project.

Changes in Copepod Communities

Normalised year-month mean numerical abundance from March to September 1960–2002 was estimated for the major copepod species, so that variation of each species were equally weighted for comparison. These species were classified into four seasonal groups depending upon when the abundance reached its peak: Spring Community, Spring–Summer Community, Summer Community and Autumn Community (Fig. 2, note: information on the Autumn Community is not shown). There was a clear seasonal succession in species composition from the Spring Community which was dominated by cold-water species to the Autumn Community which was dominated by warm water species.

Abundance of the Spring Community gradually increased through the 40 years (Fig. 2). The Spring-Summer Community also showed an increasing trend in May and June but a decadal scale oscillation in July. The Summer Community also varied on a decadal scale with an offset of several years from the variation of the Spring-Summer Community. We found a shift of peak abundance month, both in the Spring and the Spring-Summer Communities roughly corresponding to the 1976/77 climate regime shift (Fig. 2). The peak abundance delayed one month from April to May in the Spring Community, while it became earlier from July to May in the Spring–Summer Community, resulting in overlap of the high productivity periods of the two communities after the late 1970s. Also, decline in July abundance in the Spring–Summer and Summer Communities resulted in the overall decrease in copepod summertime abundance during the 1980s. In the 1990s, while summertime abundance recovered to the level before the regime shift, the overlap in occurrence of the Spring and Spring–Summer community in May was still consistent.

Relatively fresh, cool water covered the surface Oyashio from winter to early summer during the decade from the mid 1970s (Fig. 3), reflecting enhancement of the western North Pacific sub-arctic gyre due to the Aleutian Low intensification. Springtime SST increase was large between February and April before the 1976/77 regime shift, while that between April and May was larger after the regime shift, suggesting that wintertime cooling after the mid 1970s delayed the timing of surface water stabilisation and subsequently that of the lower trophic level production. Interestingly, summertime condition was quite different from winter-spring condition, as the surface water was relatively warm in mid-summer during the cool winter years. SST increase between June and July was large before the 1988/89 regime shift, and its variation had a significant negative correlation to the Arctic Oscillation Index (AO, http://tao.atmos.washington.edu/ao/). It is reported that the Japanese region experiences a cold summer due to the strong Okhotsk High following the winter with negative AO (Ogi *et al.*, 2003), and vice versa. Summertime warming enhanced stratification, and subsequent nutrient limitation was likely to reduce summertime production of the Spring–Summer Community, which consisted of more or less herbivorous, cold water species, before 1988. In summary, wintertime cooling and summertime warming were considered to shorten the productive season of plankton communities from the late 1970s to the late 1980s.

The majority of the climate – ecosystem link studies have put emphasis on winter to spring processes. However, our study suggested that climatic forcing with a different decadal scale cycle worked in winter and summer to present seasonal/interannual variation of hydrographic conditions, and thus combination of such the wintertime and summertime processes determined the seasonal/interannual copepod productivity. This will be particularly important in the sub-arctic region where availability of light and nutrients is the limiting factor of primary production in winter and summer, respectively.

References

Odate K. 1994. Zooplankton biomass and its long-term variation in the western North Pacific Ocean. Bulletin of Tohoku Regional Fisheries Research Laboratory 56: 115–173.

Ogi M., Y. Tachibana and K. Yamazaki. 2003. Impact of the wintertime North Atlantic Oscillation (NAO) on the summertime atmospheric circulation. Geophysical Research Letters 30: 10.1029/2003GL01728

SAHFOS WinCPR Browser for North Sea Plankton

Anthony J. Richardson (anr@sahfos.ac.uk),
Darren Stevens, Philip C. Reid

Recent efforts have focused on making CPR data more available by developing software to allow users easier access and increased flexibility of data interrogation. One such product that has been developed is the SAHFOS WinCPR. This free software is available for download via the SAHFOS website (www.sahfos.org) from March 2005 and is available on CD. This product provides researchers with valuable graphical outputs that aid data interpretation and overcomes some of the problems of non-standard sampling due to the coverage of the shipping routes.

WinCPR is a gridded database browser of North Sea plankton containing data over a 50 year period (1948–1997) targeting not only the marine science community, but a wider audience including the general
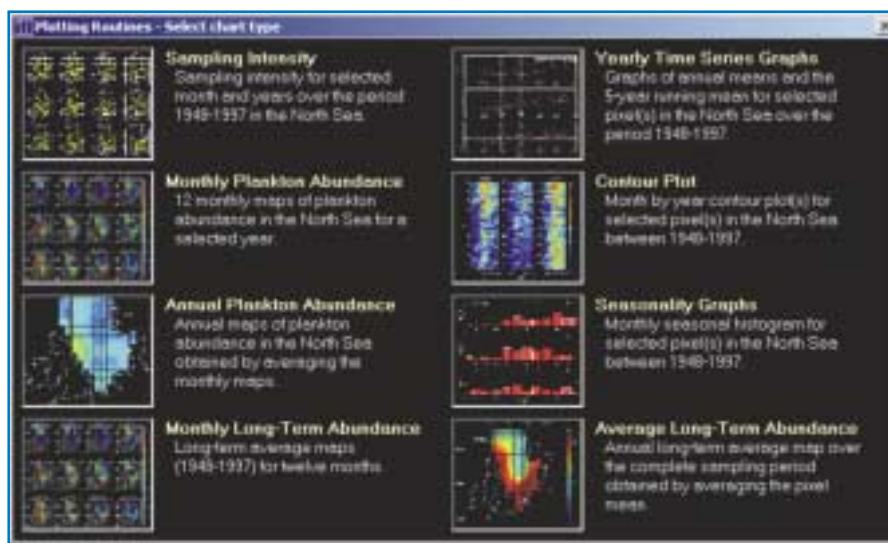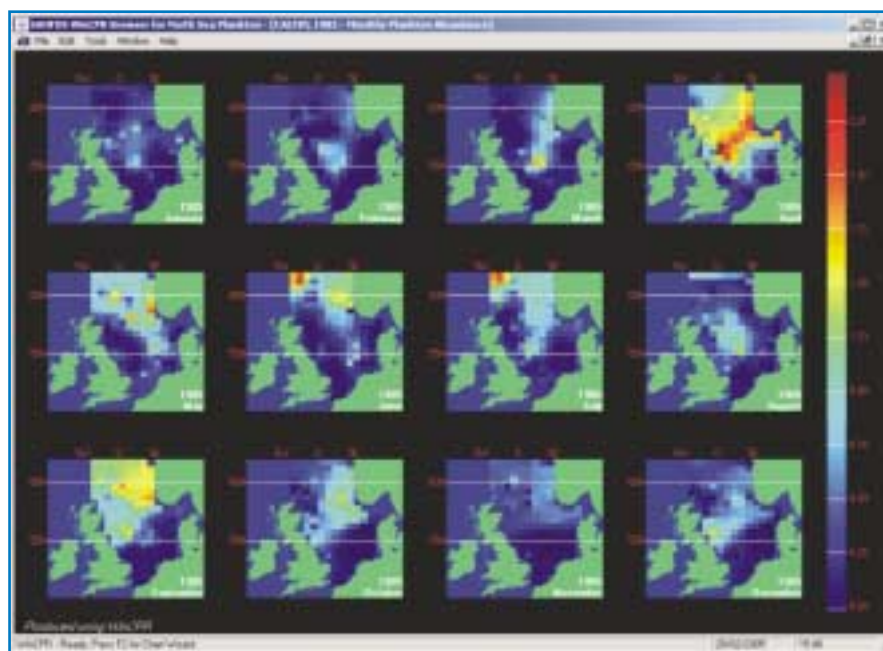

Figure 1. The interface of SAHFOS WinCPR v1.0.

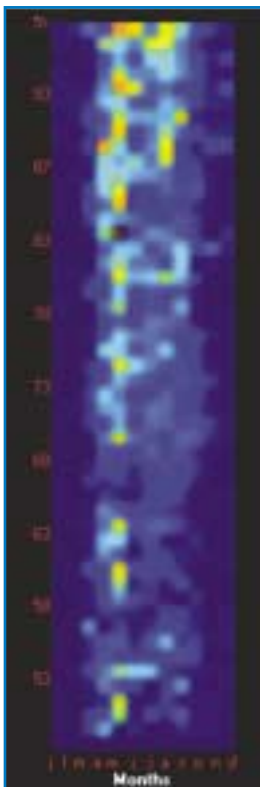Figure 2. Monthly spatial distribution of Calanus finmarchicus in 1985.

Figure 3. Contour map of the Phytoplankton Colour Index by year and by month.

public, and students from schools and universities (Vezzulli and Reid, 2003). Figure 1 shows the main interface for the software (Vezzulli *et al*, 2005). The user-friendly information and buttons on the opening page are visually appealing, clear, and allow the user to perform sophisticated analysis quickly. The grid consists of 172 pixels centred on 1° longitude by 0.5° latitude. A total of 110 plankton taxa as well as Phytoplankton Colour (an estimate of phytoplankton biomass) have been averaged for each month within a forty or fifty year time span (fifty years for zooplankton and Phytoplankton Colour 1948–1997, forty years for phytoplankton 1958–1997). To facilitate access in a user-friendly way, a range of eight plotting options are available for the presentation and visualisation of CPR data. These include distribution maps for each month (Fig. 2) or annually over the whole 50 years, graphs of abundance through time and seasonal cycles, and month by year contour plots for individual and groups of pixels (Fig. 3). The underlying gridded data can also be exported. This facility will be particularly useful for plankton ecologists investigating long-term change, as well as ecosystem modellers for model validation and initialisation. We welcome feedback on WinCPR, and ask that any papers or reports that stem from work with WinCPR or CPR data acknowledge SAHFOS. The more researchers actively use CPR data, the more secure the Survey will be in the future.

References

Vezzulli L and P.C. Reid. 2003. The CPR survey (1948–1997): a gridded database browser of plankton abundance in the North Sea. Progress in Oceanography 58(2–4): 327–336.

Vezzulli L, P.S. Dowland, P.C. Reid, N. Clarke and M. Papadaki. 2005. Gridded database browser of North Sea plankton: fifty years (1948–1997) of monthly plankton abundance from the Continuous Plankton Recorder (CPR) survey. Sir Alister Hardy Foundation for Ocean Science, Plymouth, UK. At URL: www.sahfos.org.

"Out of the Hands of Fishermen..."

By Gary D. Sharp[1], Menakhem Ben-Yami and J. 'Russ' McGoodwin
[1]Center for Climate/Ocean Resources Study, Salinas, CA, USA

A fully illustrated, full color volume that will provide readers from high school to professional levels with an account of the development of ocean fisheries. Starting from early hominid hunter-gatherers, then ocean-going island and continent colonizers, onward into the Age of Exploration, when resource exploitation became nationalised, and the expansion onto the high seas began in earnest. In the recent two to three centuries, humans have changed the structures and support systems for all the world's aquatic resources, with devastating consequences to riparian, estuarine, and coastal fishing cultures. Ecological relationships and human roles within these are carefully illustrated to show their interdependencies.

The ultimate message is that humans must restructure their fisheries management around the idea that they are not the sole beneficiaries, nor the major consumers in the world ecosystem. Sustainability will be defined and reclaimed only by their rehabilitation of the hydrologic functions along with the full width and breadth of ecological functioning, or we will lose the battle.

The book's layout has been designed around the presentation of colour photos, illustrations and maps in landscape mode, so as not to collapse the materials into unrecognizable formats. This softback, large-type edition was envisioned to serve a wide range of ages and reading needs, providing information for vested readers interested in the diversity and breadth of fisheries issues around the world. Examples of fisheries from every continent, and many island regions in all the oceans are the main source of historical insights. A few black-and-white images amongst the colour images provide the rustic feel necessary for readers to get the true sense of the primitive state of most of the world's fisheries. An additional reference section is provided to highlight other readings that expand our text.

This is a book for and about people; people whose lives are being challenged for all the wrong reasons. Meanwhile those folks confortably ensconced on the high inland watersheds are moving down into the coastal and floodplain environments, and their industries and activities continue to degrade natural habitats, and to remove options for sustainability. All this as natural climate change continues and other 'events' leave their marks. It is not fishermen who have 'extincted' their options, but an ever-growing denial by the larger and more reluctant shorebound cultures who pretend that 'stability' is possible, particularly that of aquatic ecosystems, despite Nature's historical patterns and surprises.

Out of Fishermen's Hands provides the insights into the how and why of the chaos that is rampant in today's fisheries, as well as providing a doorway to the next chapters on solutions, soon to follow.

Introductory materials, table of contents and example information can be downloaded from http://sharpgary.org/Fishermens HandsBrief_Order.pdf and information on how to order copies of the book (price US$15 plus US$5 postage and packing from http://sharpgary.org/FishermensHandsBrief _Order.pdf.

Abstracts from the GLOBEC Norway 2005 annual meeting

As introduced by Svein Sundby on page 1 of this Newsletter, the following abstracts provide preliminary results of the GLOBEC Norway projects ECOBE, CLIMAR and ADAPT. All GLOBEC National Programmes are encouraged to use the Newsletter to expose their research in this manner. Contact the Editors for further information.
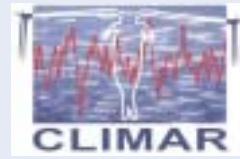
General aspects of the southern Barents Sea circulation

Lars Asplin, Randi Ingvaldsen, Harald Loeng and Roald Sætre
Institute of Marine Research, Bergen, Norway

Based on historical current measurements from more than 70 locations and numerous drifting satellite-tracked buoys in the period 1970–1996, some general features of the circulation in the southern Barents Sea are summarised. Results of a three-dimensional numerical ocean model for the period September 1997–July 1999 gives further information of the current system of the area.

The main findings were:

1. The mean current speed is generally low in the Barents Sea (<0.05 m/s)
2. There exist well defined regions of one-layer (barotropic) and multi-layer (baroclinic) flow
3. The eastward flow of Atlantic water have a seasonal latitudinal variation.

The current observations from all sources indicate that on average (and the averages are based on periods from several days up to months) only moderate current speeds occur. In the upper 100m depths 55% of the current speeds were less than 0.05m/s and only 15% were above 0.1m/s. In the water depths below 100m the speeds were lower, with 72% less than 0.05m/s and 6% above 0.1m/s.

At current moorings where recordings from several vertical levels were obtained, direction differences in the vertical could be found. This indicates whether the flow is mainly barotropic or if it is mainly baroclinic. The findings were that the flow is mainly baroclinic close to the coast in the southern part and on shallow banks in the middle and northern parts of the area (Fig. 1). In the regions where the Atlantic water inflow takes place, the flow is mainly barotropic.

To assess the flow of Atlantic water eastwards into the Barents Sea from the western border, numerous passive drifting particles were seeded into the currents from the numerical model results. The particles clearly follow a more northerly track on the mean when released during summer than during winter (Fig. 2), spending a year to cover the distance of the track. The current pattern will have impact on transport both of zooplankton and fish larvae.
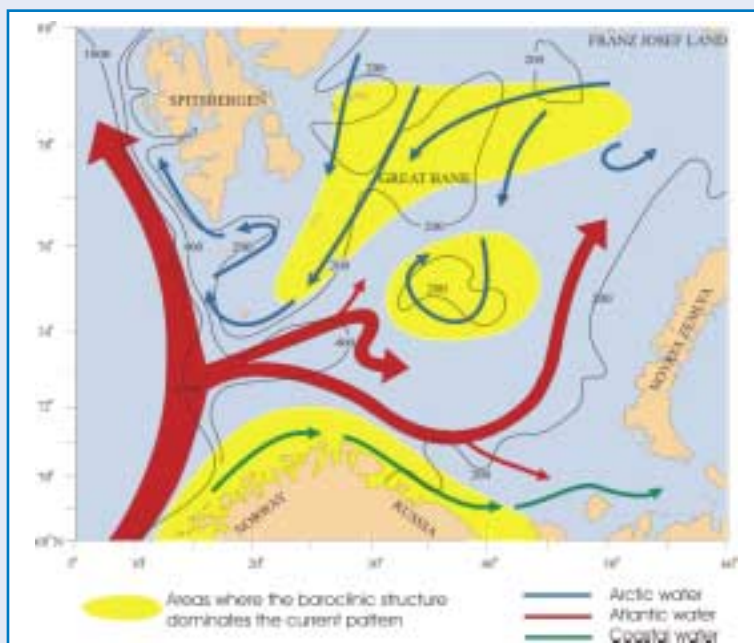
Figure 1. The general circulation of the Barents Sea with the areas of mainly barotropic and baroclinic flow.

Figure 2. Seasonal variability of mean trajectories for a large number of particles advected eastwards in the Barents Sea based on currents from a numerical model simulation. The particles flow at 100m depth basically in the Atlantic inflowing water. Three release positions for particles were used, all along the transect from Norway to Bear Island.

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Feeding migration and diet of Norwegian spring spawning herring in relation to the seasonal cycle of *Calanus finmarchicus* in the Norwegian Sea

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Institute of Marine Research, Bergen, Norway

The aim of this study is twofold: 1) to examine the importance of *Calanus finmarchicus* in the diet of herring (*Clupea harengus*) throughout their feeding migration in the Norwegian Sea, and 2) to study the timing of herring migration in relation to the life cycle of *Calanus finmarchicus*. The feeding ecology and distribution of herring were studied during cruises in 1995 – from the start of the feeding migration at the spawning grounds off the coast of Norway, to the main feeding area in the Atlantic and Arctic waters of the Norwegian Sea (Fig. 1). The feeding and migration have been related to differences in the seasonal cycle of production of *Calanus finmarchicus* in the different water masses obtained from acoustic mapping, stomach samples and zooplankton samples collected during the cruises.

Herring feed selectively on adults and older copepodite stages of *Calanus finmarchicus* (Fig. 2). The timing of the development of the Calanus population varies between water masses and herring also inhabit different water masses during their feeding season, which seems to be related to the occurrence of older developmental stages of *C. finmarchicus*.

In the beginning of the season, herring mainly feed on the overwintering population (G0) of *Calanus finmarchicus*, which concentrates towards the surface to feed and spawn during the phytoplankton spring bloom. They then switch to feed on the new generation (G1) when it has reached older copepodite stages. This switch may however not be so successful for older herring, which is in the northeastern part of the Norwegian Sea at the end of their feeding migration. The reason may be that this corresponds in time (July and August) with the descent to overwintering depths of the older stages of the G1 generation of *Calanus finmarchicus*. Simultaneously, a large part of the G1 generation has not yet reached the older stages that herring prefer to feed upon. This may explain the lower average stomach contents, more empty stomachs and a diet consisting of a wider variety of prey organisms compared with earlier in the feeding season (Dalpadado *et al.*, 2000).

References

Dalpadado P., B. Ellertsen, W. Melle and A. Dommasnes. 2000. Food and feeding condition of Norwegian spring spawning herring (Clupea harengus) through its feeding migration. ICES Journal of Marine Science, 57, 843–857.
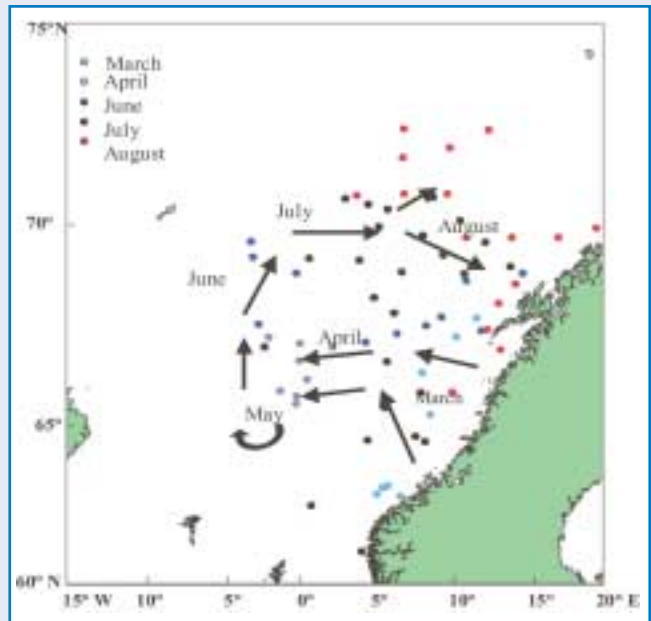
Figure 1. The feeding migration of Norwegian spring spawning herring in the Norwegian Sea from March to August 1995.
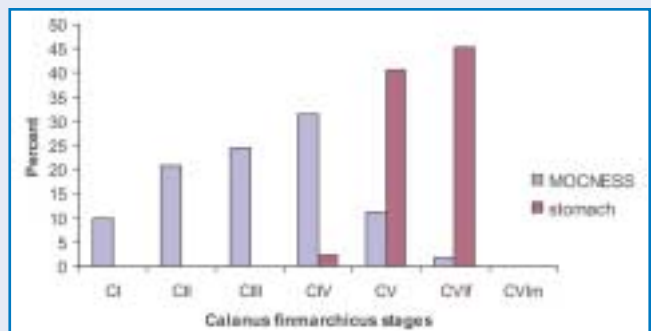
Figure 2. An example of selective feeding on adult and older copepodite stages of Calanus finmarchicus from trawl station 351, July 1995.

Prey-specific gastric evacuation of Norwegian spring spawning herring (*Clupea harengus*)

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The knowledge about the emptying rate of herring is minimal because very few earlier studies of this subject have been performed on herring or with small crustacea as the main prey. Gastric evacuation rates have earlier mainly been measured based on laboratory experiments. The aim of the present study is to obtain information of gastric evacuation rates when the herring are feeding in their natural environment.

Gastric evacuation field experiments were performed on Norwegian spring spawning herring (*Clupea harengus*) based on three catches obtained by purse-seining in Arctic/Atlantic water masses in the Norwegian Sea between
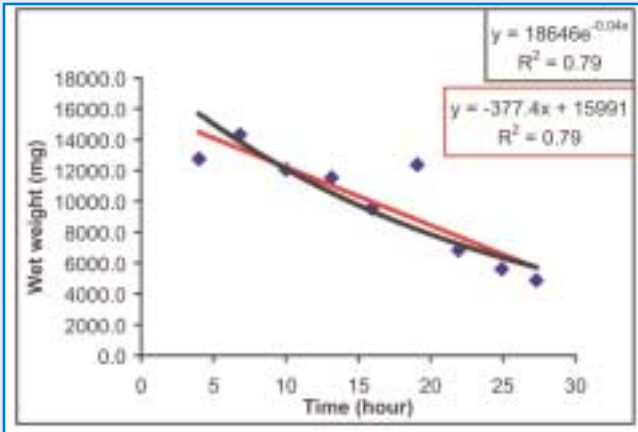
Figure 1. Gastric evacuation of the total stomach contents at station 2. Both an exponential and linear evacuation gave a good description of the data and had a high explanation value. Notice the high stomach content in the first sub-samples.

1 and 4 June 2002. After capture the herring were kept in the seine for about 24 hours, and during that time usually more than 20 individuals were sampled from the catch at time intervals of approximately three hours and frozen. The herring sub-samples were taken with gillnet stretched out in the seine. Sea surface temperature was noted at the ships sensors at the time of sampling. In the laboratory a total of 303 herring stomachs were analysed. The stomach contents were identified to the lowest taxonomic group, dried and weighed, and used to calculate the prey-specific evacuation rates.

Copepods were the main prey of herring in all three stations, amounting to 92–97% of the diet. *Calanus hyperboreus* constituted a large part of the diet owing to the strong influence of Arctic water at the sampling stations, while *Calanus finmarchicus* constituted a smaller part. Also krill and amphipods were found in the stomachs, but usually in small amounts.

Based on earlier studies we could expect an exponential evacuation of all the different prey types. In the present study however, a linear evacuation also gave a good description of the data from the total stomach contents (Fig. 1) and from the copepods (Fig. 2). Based on the time to 90% stomach evacuation at station 2, the estimated consumption of copepods per day was 9.8 and 7.0g wet weight according to the linear and the exponential model respectively. It is difficult to draw conclusions from the krill and amphipods because of their minor contribution to the diet.
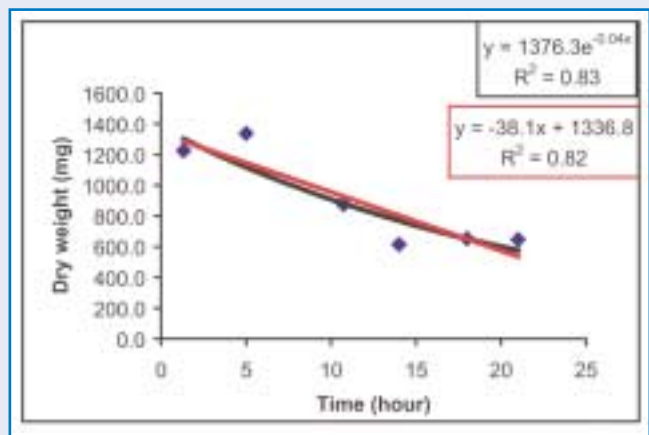
Figure 2. Gastric evacuation of copepods in the diet of herring from station 3. The copepods consisted almost entirely of Calanus hyperboreus and C. finmarchicus.

ROMS Model for the North Atlantic and Arctic Oceans

W. Paul Budgell, Institute of Marine Research and Bjerknes Centre for Climate Research, Bergen, Norway

The ROMS (Regional Ocean Modelling System) (http://marine.rutgers.edu/po/index.php?model=roms) model coupled to a dynamic-thermodynamic sea ice model has been used to conduct a simulation of ocean and ice conditions in the North Atlantic and Arctic Oceans for the period 1980–2004. The model horizontal resolution is 20 km in the Arctic Ocean and Nordic Seas and 30 km in the western North Atlantic. The vertical discretization consists of 30 vertical levels in a stretched sigma (S) coordinate system that provides higher resolution in the surface mixed layer. The forcing fields used in the simulation were daily mean surface heat and momentum fluxes from the NCAR/NCEP Reanalysis data set. Sample results from the simulation from January 1, 1994 for sea surface temperature (SST) and ice concentration are shown in Figures 1 and 2 respectively. The SST image shows that, although the model is not eddy-resolving, the simulation produces Gulf Stream separation at the correct
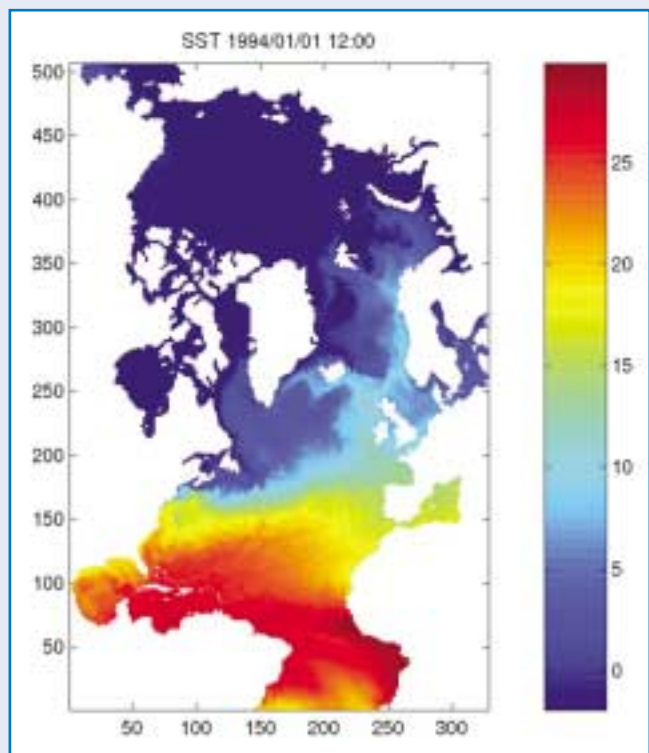
Figure 1. Simulated sea surface temperature for January 1, 1994.

location (Cape Hatteras, 35°(N). The Iceland-Faeroes front is clearly visible, as is the bifurcation of the Norwegian-Atlantic Current into the West Spitzbergen Current and the Barents Sea Inflow. The ice distribution shown in Figure 2 is representative of observed January conditions.

The model results are archived as 3-day mean fields for the period of the simulation. The archived data set is currently being used to provide the circulation and hydrographic fields for off-line ecosystem (NPZ) simulations and individual-based model (IBM) simulations of zooplankton and fish larvae distributions.

Work has now begun to carry out a hindcast for the full period of the NCEP/NCAR Reanalysis, 1948–2004. The archived model results will be made available to the GLOBEC community to aid studies of the impact of decadal-scale and climatic variations in abiotic forcing on the marine ecosystem.
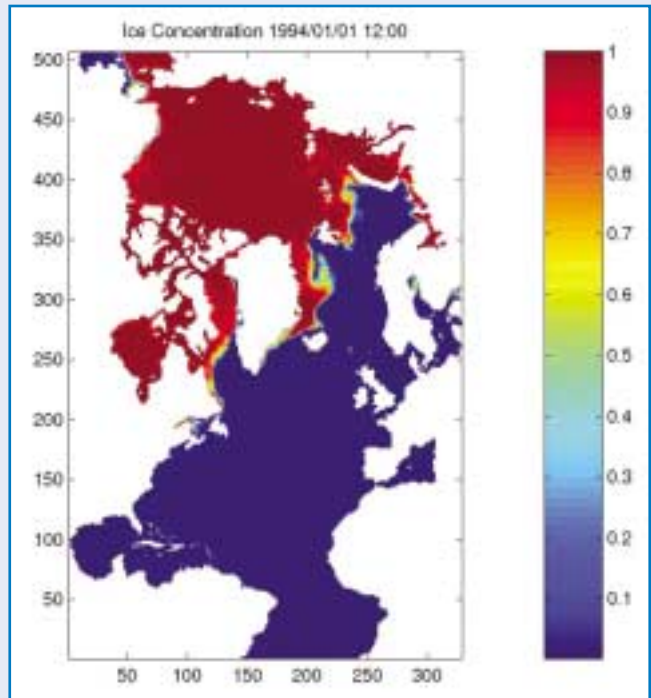
Figure 2. Simulated sea ice concentration for January 1, 1994.

Multiple predators in the pelagic: modelling behavioural cascades

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The behaviour of predators is rarely considered in models of predator-prey interactions, nor is it common to include multiple predators in models of animal behaviour. We introduce a model of optimal diel vertical migration in zooplankton prey facing predation from two functionally different predators, fish and other zooplankton. Zooplankton predators are themselves subject to predation from larger zooplankton, and all zooplankton face the classical trade-off between increasing growth rate and predation risk from fish towards the surface. Prey are most vulnerable to zooplankton predators at small sizes, but become more visible to fish as they grow. However, by habitat selection, prey continuously manage their exposure to different sources of risk. We analyse situations with cascading behavioural interactions of size-structured predator-prey interactions in the pelagic. In particular, we explore how vertical gradients in growth rates and relative abundance of fish and zooplankton predators affect optimal distribution patterns, growth and mortality schedules. A major model prediction is that prey susceptibility to one functional predator type depends on the abundance of the other predator. Higher abundance of zooplankton predators lead to risk enhancement from fish, minor increases in predation rate from zooplankton and unchanged prey growth rates. Increasing abundance of fish does not alter the risk from zooplankton predators, but reduce growth and development rates. Such asymmetric emergent effects may be common when prey and predators share the same spatial refuge from a common top predator.

Full article in press for Journal of Animal Ecology.
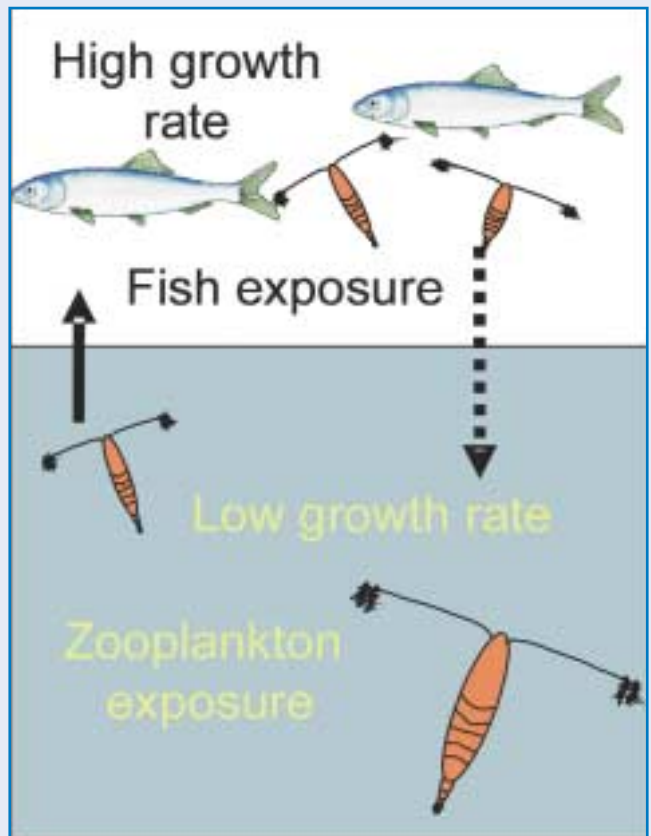
Figure 1. Size-structured predator-prey interactions.

Artificial evolution of *Calanus'* life history strategies under different predation levels

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Predation risk and food availability are key environmental features in shaping life history strategies and behaviour. Predation from planktivorous fish represents a major mortality source for the copepod *Calanus finmarchicus* in the Norwegian Sea. It has been suggested that high predation risk explains the prevalence of only one annual *C. finmarchicus* generation in the Norwegian Sea (Kaartvedt, 2000). This study uses an individual-based model (IBM) with artificial evolution (Strand *et al.*, 2002) to investigate the effect of varying levels of predation risk on the behaviour and life history strategy of *C. finmarchicus.*

The model consists of a 1 m vertically resolved domain [0,2000 m] and relies on light, daily temperature and phytoplankton densities taken from the NORWECOM model (Aksnes *et al.*, 1995) run for the southern Norwegian Sea. The strategies are optimised by using a genetic algorithm (Holland, 1992). The time step of the model is one hour, simulated at a day-to-day basis over the entire year and repeated 500 times to evolve good life history and behavioural traits. Life history traits including ascent day, overwintering depth, timing of fat allocation, and fat/soma ratio needed to descend to overwintering, and behavioural positioning are evolved in this manner. Active movement is calculated using an artificial neural network with information about predation risk, depth, phytoplankton density, and individual weight (Huse *et al.*, 1999).

The basic run yielded a population with two annual generations, ascent from overwintering in February–March and two waves of descent in late June and July respectively (Figs. 1A and B). In the simulation with increased predation risk, ascent is delayed by 10 days and there is pronounced diel vertical migration in the older stages (Fig. 1C). Descent was initiated in early June and only one annual generation

was produced (Fig. 1D). The overwintering depth was also much deeper in the simulation with increased predation risk compared with the basic run (Figs. 1A and C). The study shows that changing the magnitude of predation risk can have a profound effect on life history and behavioural strategies in *C. finmarchicus*, and thus supports the hypothesis that predation from planktivorous fish is important in shaping the life history of *C. finmarchicus* (Fiksen and Carlotti, 1998; Kaartvedt, 2000). The approach illustrated here (Huse, in prep.) yields a population of individuals with robust strategies that for example can be implemented in 3D biophysical ocean models.

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Figure 1. Simulated population dynamics in C. finmarchicus where life history strategies and behaviour are evolved under low (A, B) and high (C, D) predation pressure from fish. The colours indicate the different Calanus stages. C5 individuals were categorized as Adult upon initiating ascent from overwintering.

Egg production in marine fish

Olav S. Kjesbu, Anders Thorsen, Merete Fonn, Maria Krüger-Johnsen, Per Solemdal, Arild Slotte, Tara Marshall and Richard D.M. Nash.

The principal objective of this research program is to develop egg production models for the key fish species, with special focus on North-east Arctic cod, Arcto-Norwegian haddock and Norwegian spring-spawning herring, based on the combined effects of food abundance and temperature on gonad production and maturation.

Both recruitment research and fisheries management have traditionally assumed that spawner biomass is directly proportional to total egg production. Recent studies have shown that the individual fecundity (egg number) and egg quality are highly variable in long-lived species such as Atlantic cod (Kjesbu *et al.*, 1998; Lambert and Dutil, 2000). Fecundity of individual females is a function of the size of the female, its nutritional condition and environmental conditions (Fig. 1). Scaling these individual-based data up to the stock level using the demographic information available from assessments and surveys has shown that spawner biomass is not proportional to total egg production (Marshall *et al.*, 1998; Köster *et al.*, 2001). There are also strong indications in the literature that age structure (Marteinsdottir and Thorarinsson, 1998) and proportion of repeat versus recruit spawners (Kjesbu *et al.*, 1996) in the spawning stock of Atlantic cod significantly affect subsequent recruitment success.

The aims of this research program are twofold: to determine relationships that will allow the estimation of realised fecundity (egg production) in individual fish and then to apply these relationships to populations so that historical changes in egg production can be undertaken. Fecundity is usually presented as potential fecundity (previtellogenic oocytes in the ovary prior to spawning) and realised fecundity (eggs that are spawned) (Murua and Saborido-Rey, 2003). In most species the standard technique for estimating fecundity is to estimate the number of oocytes in the ovary. Whilst fecundity can be measured (oocytes counted up to 4 months prior to spawning (Kjesbu, 1994))

Figure 2. The change in relative fecundity with mean oocyte diameter of North-east Arctic cod.

laboratory studies indicate that as the oocytes increase in diameter as the fish progresses toward spawning so the number of oocytes (fecundity) decreases (see Fig. 2). This reduction in number between potential and realised fecundity is considered to be atresia (see Ma *et al.*, 1998). The levels of atresia in cod are also related to the condition of the fish, increasing rapidly with reductions in condition (Harðardóttir *et al.*, 2003) and in laboratory studies, if condition is too low then the fish may reabsorb all their eggs and skip spawning (Kjesbu *et al.*, unpublished data). In the wild, to date spawning Arcto-Norwegian cod have rarely been found in such poor condition that extreme levels of atresia (skipping spawning) are suggested.

North-east Arctic cod is a good model species to examine historical changes in egg production. There is a long time-series of data that covers much of the biological characteristics of the stock; environmental data for the region and the predator/prey relationships for cod are relatively simple (capelin is the principal prey (Bogstad and Mehl, 1997)). In addition both the cod and capelin stocks are assessed by ICES so there is information on the stock sizes and structure (ICES, 2004a; b). Recent studies on fecundity of NE Arctic cod approaching the spawning grounds have found a link between the relative fecundity (numbers of eggs per unit length of female) and the condition factor, capelin abundance and thermal regime (Thorsen *et al.*, unpublished data). A relationship such as this allows the egg production to be estimated for the whole NE Arctic cod stock for the time period 1948 to the present. The structure of the NE Arctic cod stock has changed considerably over the years, with a general decline in mean length and a general increase in relative condition factor of spawning females from 1946 to the present (Marshall *et al.*, in prep). This can affect the egg production, as the sex ratio is biased in favour of females

Figure 1. Schematic diagram of the factors that influence fecundity in fishes and the principal factors that can be measured to predict the fecundity of an individual fish.

Figure 3. The reproductive potential of the North-east Arctic cod population between 1946 and 2002. Reproductive potential is measured as the total potential egg production of the stock.

at larger sizes (Marshall *et al.*, in prep). Also, since about 1990 the pattern of maturity of females has changed with the proportion of smaller fish being mature having increased considerably. These large changes give insight in to the dynamics of the stock both under high exploitation levels but also under a range of environmental conditions.

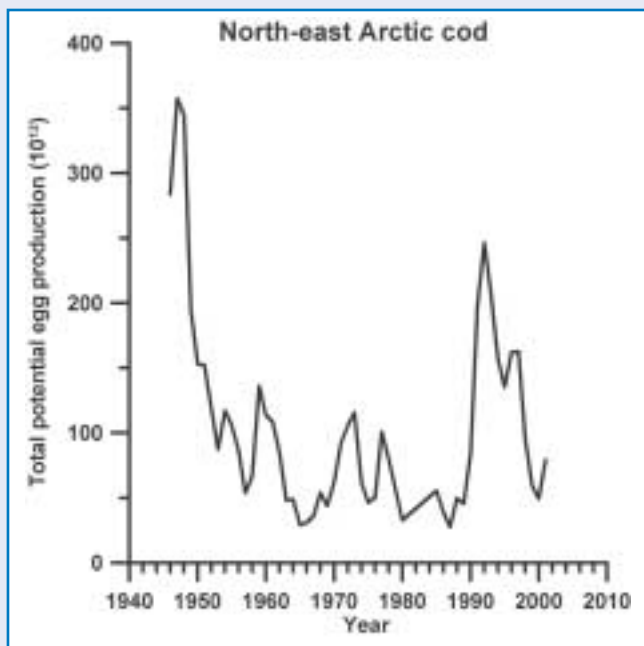The initial step for estimating the egg production over time is to convert the population size (numbers at age) estimated by Virtual Population Analysis (VPA) (ICES, 2004a) to a population length frequency of females (Marshall *et al.*, unpublished data). Using a length-weight relationship estimated each year (Marshall *et al.*, 2004) the weight-at-length is estimated and this is converted to a relative condition factor (Scott *et al.,* in press). Fecundity for each length class is estimated from a simple relationship incorporating length and relative condition (Marshall *et al.*, in prep). Using the numbers of females and the fecundity per length class the total egg production can be estimated. In this way the historical change in the NE Arctic cod stock is presented as the change in total egg production or stock reproductive potential (Marshall *et al.*, 2003) rather than the traditional Spawning Stock Biomass used in standard stock assessments (ICES, 2004a).

The relevance of this research to the theme of climate change is that under various climate change scenarios there will be changes in the environmental factors and also in the available prey for cod (in this case principally capelin). Given a set of prey and environmental conditions it will be possible to estimate the reproductive potential of the North-east Arctic cod stock, and with incorporation of recruitment models examine the population dynamics of this species under different environmental conditions.

This research will also examine the population egg production in Arcto-Norwegian haddock (1950 to the present) and Norwegian spring spawning herring (1938 to the present).

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Larval cod in ponds and models: The role of habitat selection

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Individual based models (IBMs) provide a method for specifying physiological and developmental features, differences in the history of individuals and therefore recognition of critical or sensitive periods in the early life history of fish. Growth of a cod larva is largely determined by prey density and environmental conditions in addition to larval size. Building on previous process-based models, we developed an IBM including larval foraging, metabolism, temperature- and food-limited growth, and environmental factors such as temperature, turbulence and light. Using data from a macrocosm study on growth and feeding of Atlantic cod (*Gadus morhua L.*), we verify the model by simulating the experiment. Temperature and zooplankton abundance (Fig. 1a; b) from the experiment are used as forcing of the IBM and a variety of variables from the simulations are compared with rearing experiment data,

e.g. prey preference, larval body size, and specific growth rates. We also explore the implications of habitat selection by the larvae and how this affects realised growth rates. This is done by assigning various vertical behavioral rules to individual larvae. The simulated specific growth rates (Fig. 2b) are compared with the observed cod larvae distribution (Fig. 2a) in the macrocosm.

The model suggests that larvae are not food limited in the pond, despite periods with very low prey availability. This IBM will be embedded in a 3D physical model to study drift trajectories and growth patterns of Northeast Arctic cod offspring from the spawning grounds in Lofoten to the Barents Sea. A trans-Atlantic collaboration with the US-GLOBEC also opens for the application of the model on Georges Bank and for model inter-comparison in different regions.
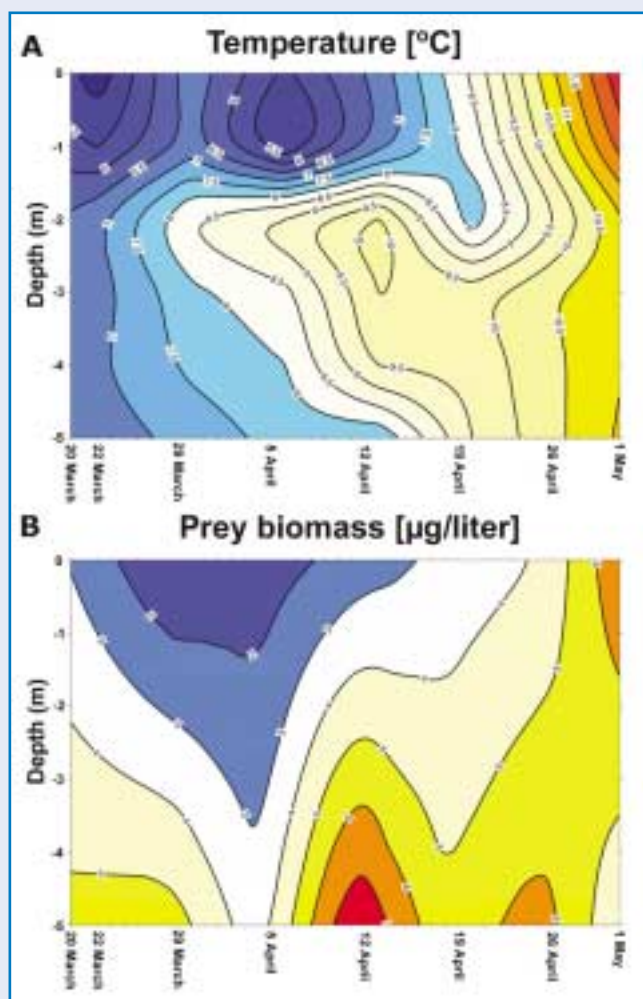
Figure 1. a) The distribution of temperature with time and depth in the macrocosm. Very low values at the surface were caused by periods of cold weather which coincides with high abundance of cod larvae observed at the bottom. b) Total biomass distribution in the macrocosm (in µgdw L⁻¹). Prey density and temperature are the main determinants of growth rates in the pond.
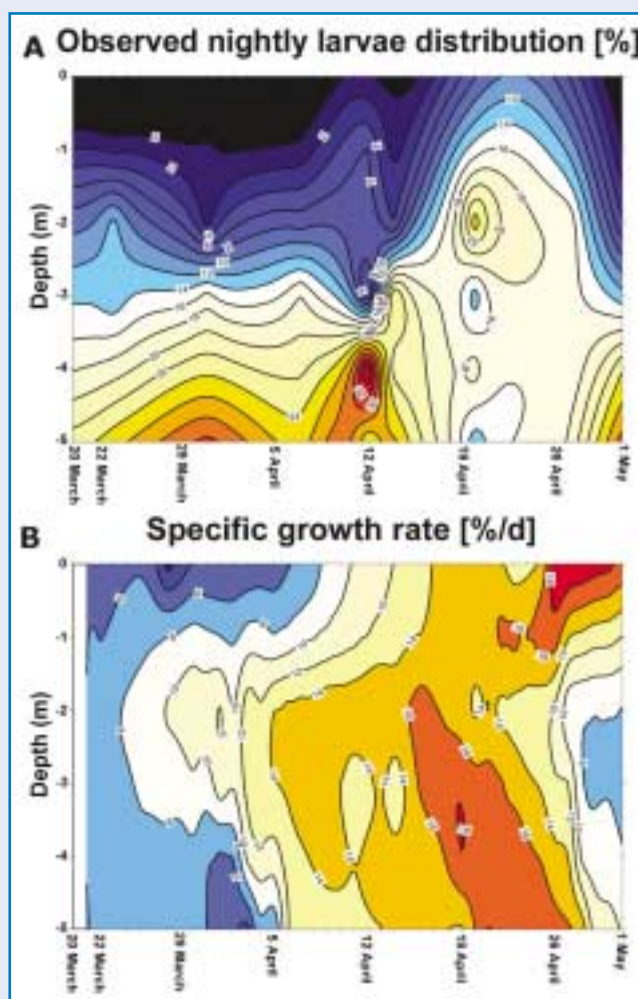
Figure 2. a) Observed distribution of cod larvae in the macrocosm (% per metre). Samples were made at night to reduce net avoidance of larger larvae. b) The modelled specific growth rate as a function of depth and time. The growth rates are typically higher below 2 metres depth where the temperature increases and prey density is higher. Towards the end of the macrocosm experiment the temperature has mixed throughout the water column and this clearly affects the growth rates.

Buoyancy of eggs of Norwegian coastal cod from different areas along the coast

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According to Pogson and Fevolden (2003) the population structure of cod in northern Norwegian areas has been a controversial topic for several decades. A number of publications have suggested that there are genetic differences between coastal cod, which are stationary and spawn along the entire Norwegian coast, and north-east Arctic cod which is highly migratory and spawns mainly near the Lofoten Islands. This has led to the conclusion that they are two separate populations. There are, however, also authors who state that the genetic analyses should be interpreted with caution and that there is no clear genetic difference between migratory cod and stationary cod. Mork *et al.* (1985) suggested that the genetic differentiation of Atlantic cod, covering most of the species range, was weak. Also within the coastal cod, both genetic (Knutsen *et al.*, 2003) and behavioural (Salvanes *et al.*, 2004) differences have been observed between different areas along the coast. Actually, the results presented by Pogson and Fevolden (2003) suggested that there were a higher degree of similarity between Arctic and coastal cod than among coastal cod sampled from different populations along the coast.

Salvanes *et al* (2004) states that evolution of genetically differentiated sub-populations in species distributed over wide range of environments is likely as long as there are mechanisms ensuring local retention of early life stages (Asplin *et al.*, 1999). Vertical distribution of the eggs is one factor which will affect their transport. Because of the often strong vertical shear in circulation, eggs distributed in the upper water column will have a different transport than eggs distributed deeper. Transport in surface waters will favour advection away from spawning areas close to the shore and in fjords, while deeper eggs will have a higher degree of retention in the spawning areas. In this study, the buoyancy of eggs from Norwegian coastal cod from four localities (Porsanger, Tysfjord, Helgeland and Øygarden) along the Norwegian coast was investigated (Fig. 1). The broodstock was collected in the different areas during the spawning season in 2002 and transported to Parisvannet field station where pairs of male and female were set up in individual tanks and spawning monitored. The eggs in this experiment were collected during the spawning season in 2004. Buoyancy of the eggs was measured using a density
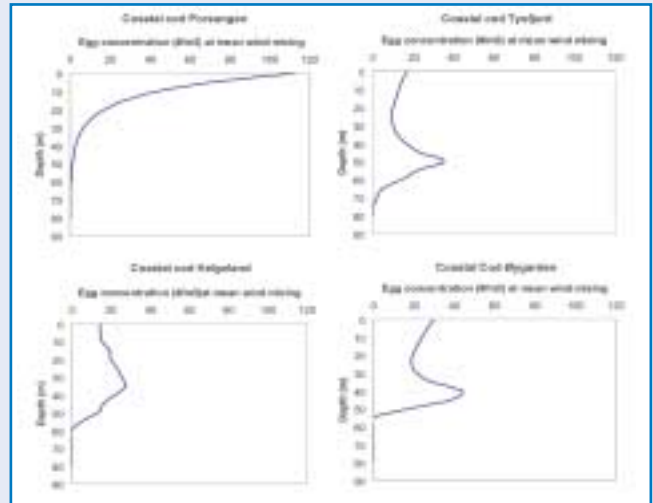

Figure 2. Modelled vertical distribution of cod eggs from the four localities at a wind speed of 6 m s⁻¹.

gradient column and eggs from 22 families were investigated. Based on these measurements and the in situ salinity structure at the different localities, the vertical distribution of the eggs was modelled using a model developed by Sundby (1991). The results showed that there were differences in buoyancy and in vertical distribution (Fig. 2). The eggs from cod sampled in the northernmost locality (Porsanger) had high buoyancy and were mostly distributed in the upper water column similarly to eggs from north-east Arctic cod, while the eggs from the other localities were heavier and had a peak in vertical distribution at 30–50 m. The implication of this is that the eggs from Porsanger will have a higher probability of being transported away from the spawning areas and into the Barents Sea while eggs from the other localities will have a higher degree of retention. The next step will be to model the horizontal transport of the eggs using 3D modelling to better understand how the observed differences in vertical distribution will influence transport.

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Figure 1. The circles indicate origins of the four groups of cod broodstock used in the experiment.

Egg production of Calanus finmarchicus in the Norwegian Sea

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The spawning of *Calanus finmarchicus* is often considered to be closely related to the spring phytoplankton bloom. But according to Kaartvedt (2000) this is a simplification, which does not appear to be completely correct, since data from the Norwegian Sea have shown that *C. finmarchicus* ascends from the overwintering depths as early as 1-2 months before the bloom (Niehoff *et al.*, 1999). In fact, spawning females may be more abundant prior to the bloom than during the bloom (Niehoff *et al.*, 1999 as cited in Kaartvedt, 2000). Previous studies of egg production in the Norwegian Sea are often based on single station or one section of stations (Niehoff *et al.*, 1999; Niehoff and Hirche, 2000). This is the first basin scale study on egg production of *C. finmarchicus* in this area. Egg production experiments were carried out onboard R/V "Sarsen" from 25 April to 10 June 2003, and a total of 30 experiments were conducted using females collected throughout the survey area (Fig. 1). Twenty experiments were conducted at each station and one female was used in each experiment. The animals were placed in bottles with a false bottom consisting of 180 μm plankton net and kept at in situ temperatures for 24 hours. When eggs were spawned they sunk through the net while the females remained in the upper compartment. This was done to reduce the probability of predation from the females on the eggs. After the experiments were terminated, eggs were counted and the individual daily egg production calculated. From each station, the average individual daily

Figure 2. Population egg production of Calanus finmarchicus (eggs m^{-2} day^{-1}).

egg production was calculated based on all 20 experiments. The temperature in the experiments ranged from 0.5°C to 8°C.

The development of the phytoplankton bloom during the survey was assessed using integrated values of chlorophyll a in the upper 100 m (Fig. 1). High values of chlorophyll a was observed in the eastern part of the Atlantic water while lower concentrations were found close to the Norwegian coast and in the central Norwegian Sea. Also in the western part of the survey area, close to Jan Mayen, high concentrations of chlorophyll a were found. This indicated that there was a bloom situation in the eastern part of Atlantic water Arctic water near Jan Mayen while the Norwegian coastal water was in a post-bloom situation and the central Atlantic water in a pre-bloom situation.

The abundance of females was highest in the southwestern corner of the survey area (pre bloom water) decreasing northwards and eastwards. Mean individual daily egg production ranged from 0 to 62 eggs female^{-1} day^{-1} (Fig. 1). The highest egg production was observed in, and close, to the eastern bloom area and also at two stations in the post bloom area east of the bloom. Average egg production was significantly higher in bloom waters (24.08 eggs female^{-1} day^{-1}) compared to post bloom waters (18.38 eggs female^{-1} day^{-1}) and pre bloom waters (9.80 eggs female^{-1} day^{-1}). Based on the abundance of females and the individual egg production, the daily population egg production was calculated (Fig. 2). Even though the abundance of female

Figure 1. Mean individual egg production (eggs female^{-1} day^{-1}) of Calanus finmarchicus is shown as filled circles and the integrated chlorophyll a concentration (upper 100 m) as contours, for the survey lasting from 25th April to 10th May.

C. finmarchicus was higher in the western pre-bloom area the average population production was higher in bloom water (213682 eggs m^{-2} day^{-1}) compared to pre bloom waters (141410 eggs m^{-2} day^{-1}) and post-bloom waters (78773 eggs m^{-2} day^{-1}). But still, the population egg production was considerable in the pre-bloom area mainly because of the high abundance of females in this area. The pre-bloom will also normally last longer than the bloom (Niehoff *et al.* 1999) increasing the importance of this period for spawning of *C. finmarchicus*.

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Predator-prey encounters in turbulent waters

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With reference to studies of predator-prey encounters in turbulent waters, we demonstrate the feasibility of an experimental method for investigations of particle fluxes to an absorbing surface in turbulent flows. A laboratory experiment is carried out, where an approximately homogeneous and isotropic turbulent flow is generated by two moving grids. The simultaneous trajectories of many small neutrally buoyant polystyrene particles are followed in time. Selecting one of these to represent a predator, while the others are considered as prey, we obtain estimates for the time variation of the statistical average of the prey flux into a suitably defined "sphere of interception". The variation of this flux with the radius in the sphere of interception, as well as the variation with basic flow parameters is well described by a simple model, in particular for radii smaller than the integral length scale, which is here in the range of 20–25 mm, while the inner scale (Kolmogorov scale) is typically $\frac{1}{4}$ mm.

The turbulence is generated by the motion of two plastic grids, in the top and bottom of a tank with 320 x 320 x 450 mm^3 inner dimensions. The motions of small polystyrene particles of size 0.5–0.6 mm are followed with 4 video-cameras, and the simultaneous positions of typically 500–1000 particles recorded at time intervals of 1/25 s. By a tracking procedure it is then possible to link the positions of particles, and thus follow their individual motions in 3 spatial dimensions and in particular also to deduce their time varying velocity (Ott and Mann, 2000).

With the records of simultaneous particle trajectories being available, we can now select one to represent the predator and label all the others as prey. We then select a predetermined radius *R* in the sphere of interception, and then remove all the particles which happen to be inside this sphere. During the subsequent Lagrangian motion of the reference "predator", we count the number of prey entering its co-moving sphere of interception between successive time steps. Each time a particle enters, it is "eaten" in the sense that it is removed from the database. By repeating the procedure, we reduce the signal-to-noise level, and obtain an estimate for the prey flux to a predator, with given radius and turbulence parameters. Experimentally obtained scaling laws with radius *R* and turbulent dissipation rate e are shown in Figures 1 and 2. The results agree well with simple models, which can be obtained by dimensional reasoning (Mann *et al.*, 2002).

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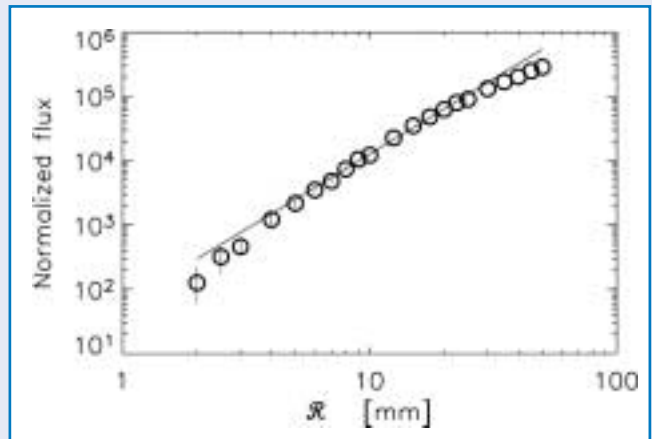
Figure 1. The normalized average prey flux to a moving predator, shown for different radii, R, in the sphere of interception, for fixed turbulent energy dissipation, ϵ. A theoretical $R^{7/3}$ line is inserted for reference.
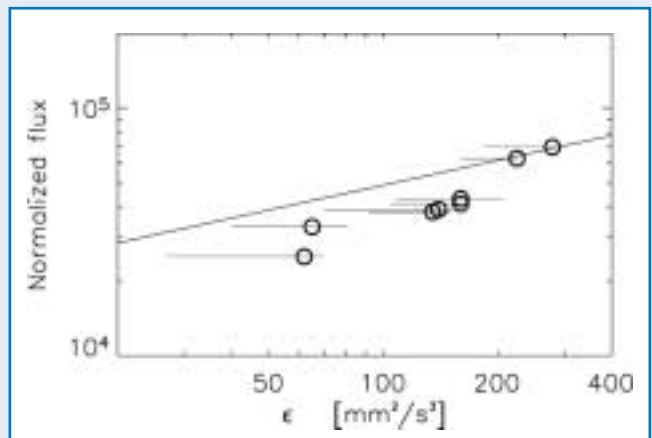

Figure 2. Variation of the normalized average prey flux to a moving predator, for fixed R = 20 mm, and varying ϵ, in units of mm^2/s^3. A theoretical $\epsilon^{1/3}$ line is inserted for reference.

Spatial shifts in spawning habitats of Arcto-Norwegian cod induced by climate change

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The Arcto-Norwegian cod migrates from the feeding areas in the Barents Sea southwards along the Norwegian coast to spawn in March and April. The spawning areas are located along a 1400 km long coastline with the main spawning area Lofoten, at the geographical centre, the Møre spawning district at the southern fringe and the Finnmark spawning district at the northern fringe. The recruitment to the cod stock shows large interannual variations strongly influenced by interannual variations in the sea temperature. In contrast, the timing of the spawning is insensitive to interannual temperature variations. There has been observed a weak long-term change of about one week in the spawning period from the 1930s to 1980s. Although the timing of spawning shows little variation from year to year, the relative contribution to egg production of the various spawning districts show large interannual variations but these variations do not correlate with the interannual temperature variations. However, we have revisited old time series from the Norwegian Directorate of Fisheries (NDF) and found that on an interdecadal time scale there has been a long-term change in the importance of the various spawning districts. During the warming of the mid 20th century, spawning in the two northernmost spawning districts, Troms and Finnmark, increased in magnitude while the spawning intensity in the southernmost district, Møre, decreased (Fig. 1). During the cooling in the 1960s and 1970s the situation shifted back to that of the cool period before the 1930s with no spawning in the eastern part of Finnmark. The time series from NDF ended in the mid 1970s, so unfortunately we have not been able to investigate possible shifts during the recent warming of the 1990s and the first years of the present century. However, reports from the fishing fleet during spring 2004 show that spawning Arcto-Norwegian cod again visited the eastern parts of Finnmark. Recent reports from East Finnmark show that the same is now happening in spring 2005. Hence, there exists an interdecadal shift in the spawning locations of Arcto-Norwegian cod towards the north in warm periods and towards the south in cool periods (Fig. 2).
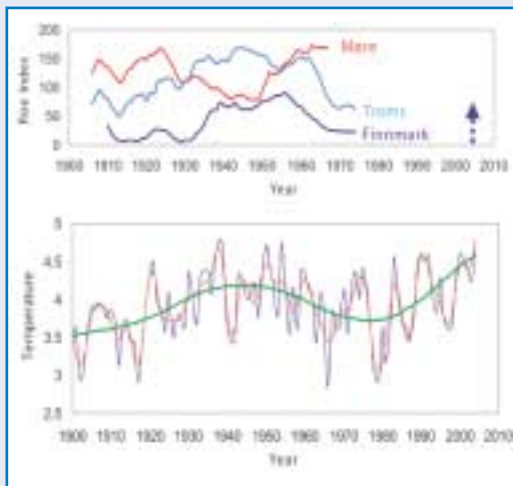
Figure 1. Upper panel: Roe indices (liters of roe delivered per tons of gutted cod during the spawning fishery) from Arcto-Norwegian cod caught at the southernmost spawning district Møre, and the two northernmost spawning districts Troms and Finnmark. Time series ended during the mid 1970s. The blue arrow indicate qualitative observations on new cod spawning fishery in East Finnmark during the spawning seasons of 2004 and 2005. Lower panel: Temperatures in the Barents Sea represented by the Kola Section. The three curves are annual means, 5-years running mean and 30-years low-pass Butterworth filter.
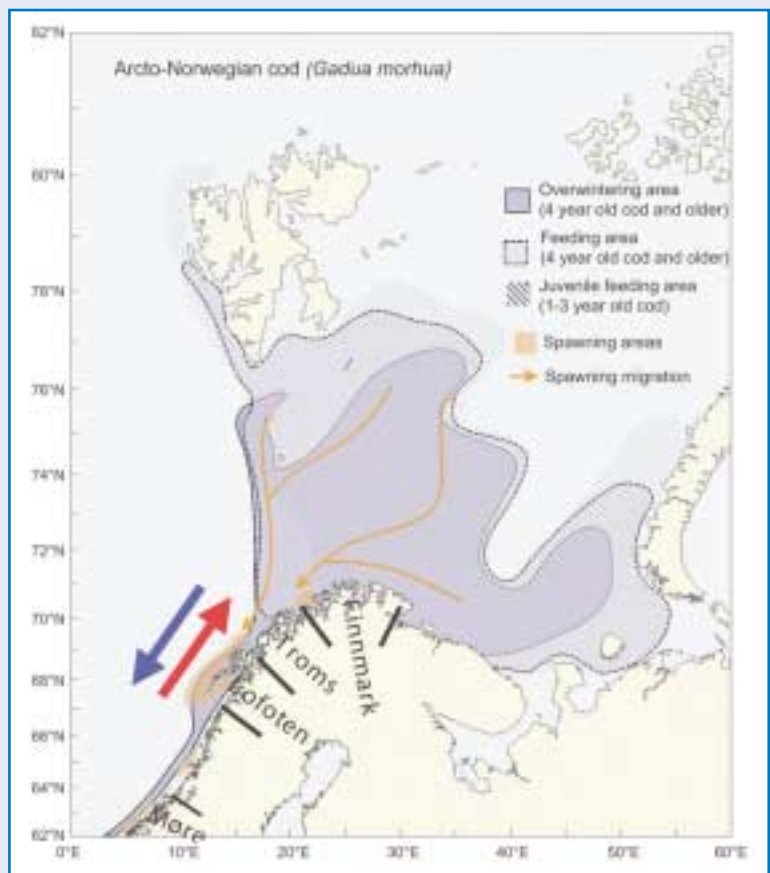

Figure 2. Feeding areas of Arcto-Norwegian cod in the Barents Sea and spawning areas along the Norwegian coast. During interdecadal warm periods the intensity of spawning is displaced northwards along the coast (red arrow). During interdecadal cool periods the intensity of spawning is displaced southwards.

Possible connectivity between Arcto-Norwegian cod and Norwegian Coastal cod – a model approach

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There are two cod populations spawning along the Norwegian coast; the Arcto-Norwegian cod (ANC) and the Norwegian Coastal cod (CC). They are managed as two separate populations with implications on stake holders decisions regarding quotas, fishing tools, minimum catch size, fishing bans (locations and periods) etc.

ANC and CC spawn at several locations along the Norwegian coast, with the ANC eggs, on average, more buoyant than the CC eggs (Solemdal and Sundby, 1981; Kjesbu et al., 1992). There is partly horizontal and temporal overlap of ANC and CC eggs on the spawning grounds in the Vestfjord, with their individual neutral buoyancies determining the vertical distribution, as the only source of vertical separation.

The slight differences in observed buoyancy of ANC eggs and CC eggs will have the potential to create differential drift patterns of the two stocks in the way that CC eggs will, on average, be transported northwards at greater depths than that of the ANC eggs. Hence, differences in mean buoyancy of eggs contribute to separate them geographically, while deviations from the mean buoyancy, which may give eggs of equal buoyancy, contribute to mix them geographically and allow exchange of individuals between respective habitats.

Simulations with a regional ocean model (ROMS – http://marine.rutgers.edu/po/models/roms/) indicate that particles released in the Vestfjord will diverge horizontally when they are kept fixed at different depths. Particles close to the surface are more likely to be transported into the nursery grounds of Arcto-Norwegian cod in the Barents Sea. Contrary, particles transported at deeper levels of the water column are more likely to end up along the Norwegian coast and into the fjords (Fig. 1).

Interaction between lateral mixing caused by winds and topographic effects, and the features of the local currents is the cause for this divergence. The Norwegian Atlantic Current (NwAC) flows along the continental shelf edge, bifurcating northwest of the Tromsøflaket (71°N, 18°E), with a branch entering the Barents Sea along the wedge-shaped Norwegian Coastal Current (NwCC) close to the Norw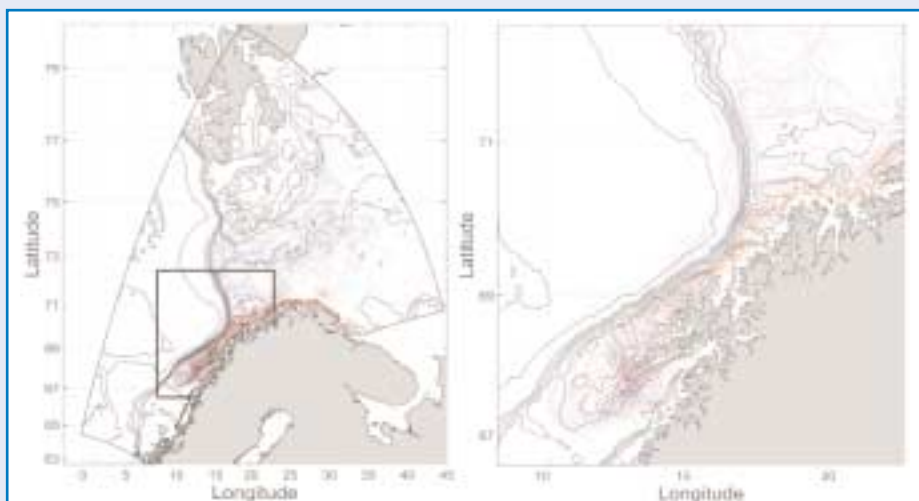egian Coast and the other branch following the shelf edge towards the western Barents Sea and Spitsbergen. When particles are released at the same geographical location in the Vestfjord, the ones closer to the surface will experience the most lateral mixing and have the highest fraction of particles displaced out into the NwAC. The implication for the drift of eggs is clear; a higher fraction of eggs close to the surface will be laterally spread out into the NwAC than for eggs drifting at greater depths. This will precondition further larval drift differently and may result in CC juveniles to sense the bottom, and consequently settle to the bottom, at an earlier stage and closer to the coast than the more offshore-drifting ANC juveniles. Differences in the environmental conditions along the individual drift paths will set the premise for the later achieved individual meristic characters.

Buoyancy differences between ANC and CC eggs do exist, causing separation of ANC and CC during the period of pelagically free drift from the spawning area to the area where the juveniles settle to the bottom and become more stationary. This supports the idea that ANC and CC are two separate populations. On the other hand, the neutral buoyancy of the eggs also overlaps, causing the drift paths to overlap, enabling a potential connectivity between ANC and CC as the 0-group juveniles are mixed at the nursery grounds. Studying the simulated inter-annual 0-group distributions for eggs with neutral buoyancies representative for ANC and CC eggs would enlighten the long-term relation between separation and mixing and will be a natural line of progress for the current study.

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Figure 1. A sample of simulated drift trajectories for larvae at different depths (1, 10, 20 and 30m) and time of hatching for a period ranging from spawning in the Vestfjord, (68°N, 14°E) until 0-group stage 1985 (4–6 months old). Drift routes ending up close to the coast are coloured red and the ones spread out into the Barents Sea are coloured blue.

How important is transport and temperature for the success of pre-recruits of Arcto-Norwegian cod?

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Temperature has been identified in field studies as the most influential physical parameter on growth and recruitment for Arcto-Norwegian cod. However, it has been pointed out by many authors that temperature, in this context, has not only direct effects on the cod, but also indirect effects through lower trophic levels. Moreover, it has been discussed that temperature might also be a proxy for other climate parameters, such as the advection of zooplankton-rich Atlantic Water from the Norwegian Sea onto the adjacent shelves (Skjoldal and Rey, 1989; Helle and Pennington, 1999; Sundby, 2000). The present paper analyses the direct quantitative effects of temperature on larval and juvenile growth from spawning in Lofoten until the 0-group fish settle in the Barents Sea. The approach taken is that of a modelling study supported by analysis of existing data on fish stocks and climate. The spawning grounds of the Arcto-Norwegian cod (ANC) are located along the coast of mid and northern Norway, particularly in the Lofoten and Vesterålen area where up to 70% of the spawning occurred from 1983 to 1985 (Sundby and Bratland, 1987). Compared to other Atlantic cod (*Gadus morhua* L.) stocks there is a long route of pelagic free drift for the offspring from spawning in March until early May along the coast to the juveniles settle to the bottom in the Barents Sea in September to October. During this critical period with respect to formation of year-class strength, the eggs, larvae and juveniles drift from 600 to 1200 km.

The eggs and larvae are carried towards the northeast by the Norwegian Coastal Current (NwCC). Lateral spreading takes part of the population into the Norwegian Atlantic Current (NwAC), which flows parallel to the NwCC and is warmer than the NwCC at the time of spawning. Five months after spawning they are surveyed pelagically by the international 0-group survey, and are found spread over the entire area

Figure 1. Observed 0-group distribution of cod in 1985 (left) and 1986 (right).

occupied by Atlantic waters in the Barents Sea (ICES, 1985, 1986). At this point in the season the NwCC has become the warmer water mass of the two. From this stage and onwards, the juveniles become more stationary. Correlation analysis indicates high correlation of both the early juvenile stage and 0-group stage with the 3-year old fish (Ottersen and Loeng, 2000; Sundby *et al.*, 1989). Hence, the year classes of cod are generally determined during the drift phase from the spawning grounds to the nursery grounds.

A regional ocean model system (ROMS – http://marine.rutgers.edu/po/models/roms/) is set up for the habitat of ANC. The ocean model simulates transport of larvae and juveniles, while keeping a record of the individual temperature histories enabling calculation of temperature dependent growth, from spawning until settlement at the nursery grounds. Temperature-growth relations from two studies were included (Otterlei *et al.*, 1999; Björnasson and Steinarsson, 2002). The years 1985 and 1986 were chosen to model because of their differences both in distribution and

Figure 2. Simulated distribution of 0-group cod late August, 4 to 6 months old depending on time of release, with atmospheric forcing from 1985 (left panel) and 1986 (right panel) and all particles released inside the Vestfjord, the main spawning site. The colour scale indicates wet weights in mg.

the individual weight of the 0-group fish (Fig. 1). Also, the total abundance of 0-group larvae was higher in 1985 than in 1986, and the centre of biomass was further to the west. The distribution in 1985 covered a larger area than in 1986 and the average length of 0-group cod, and therefore the weight (Ellertsen *et al.*, 1989), were significantly lower in 1986 than in 1985 (Ottersen and Loeng, 2000). To what degree will the models be able to reproduce measured larval distributions? In what way will vertical distribution of larvae and juveniles affect 0-group distribution and weight? Will the time of spawning affect growth and distribution of 0-group cod?

The simulations reproduce the observed key features of 0-group cod distributions for the two years 1985 and 1986. (1) The simulated area-dependent weight distributions indicate larger larvae and juveniles in the western parts of the Barents Sea than further east, (2) the centre of gravity is more eastern in 1986 than in 1985, (3) the distributions are limited to Coastal and Atlantic Water masses and (4) prolonged transport time from the spawning ground to the nursery ground due to retention above bank structures along the shelf. This indicates that transport and temperature-dependent larval growth alone can reproduce key features of the 0-group weight distribution and concentration in the Barents Sea.

The vertical placement of larvae is shown to have a significant impact on both the later horizontal distribution and weight. Larvae drifting close to the surface are more likely to end up in the central or western Barents Sea, while larvae further down in the water column are more likely to end up close to the Norwegian coast and to the eastern Barents Sea. Earlier spawned larvae have a higher mean and standard deviation of 0-group weights and are geographically more widespread as a consequence of longer transport time and stronger winds earlier in the year. However, the temperatures experienced by the individuals and the 0-group distributions by August are both less dependent on the time of spawning than on the vertical placement of the larvae. Food availability is not considered in the model in its present form. However, this might affect the dependence of the growth on time of spawning due to the 'match-mismatch' of prey and predators (Hjort, 1914).

Using inter-annual variations on these boundaries, in the same way as for the atmospheric forcing, is considered to be the most important factor to improve the model results. This would also enable us to estimate year-to-year variations in recruitment, as this is linked to abundance of 0-group cod (Sundby *et al.*, 1989) and their condition (Ottersen and Loeng, 2000). This is one of the topics we plan to pursue. Also, a more sophisticated individual based model where growth depends on food availability, turbulence and light, in addition to transport and temperature, is needed. This will, among other things, enable us to find the optimum behaviour concerning the trade off between feeding and favourable temperature.

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Variability in advective losses of *Calanus finmarchicus* in the Nordic Seas

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Climate variability causes variability in the environment of organisms, and thereby has an effect on their growth, fecundity and survival. Planktonic organisms are transported with the currents. Therefore, as opposed to non-drifting organisms, plankton may experience the spatial variability of advective systems as temporal variability. Using a regional ocean circulation model, we have used a particle tracking model to study the spatial and inter-annual variability in *Calanus finmarchicus'* risk of being advected out of the Nordic Seas population, and the significance of seasonal vertical migration patterns. We found that spatial variability was higher than inter-annual variability during the period 1988–1991. Variability between forcing years and between different seasonal vertical migration patterns were of approximately the same size. Average retention was 40% after 1 year in simulations with diffusion and advection and 42% in simulations with advection only. The average retention at the end of a 4 year sequence was 10 and 12%
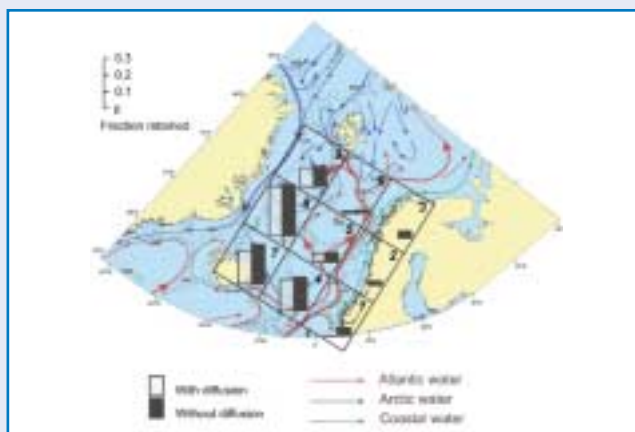

Figure 1. The model area with the 9 numbered sub-areas shown. Proportions of individuals initiated in each sub-area that are retained within the entire study-area after 4 years (1988–1991, average for all behaviours) are shown for the simulations with and without diffusion. Main currents are indicated with arrows.
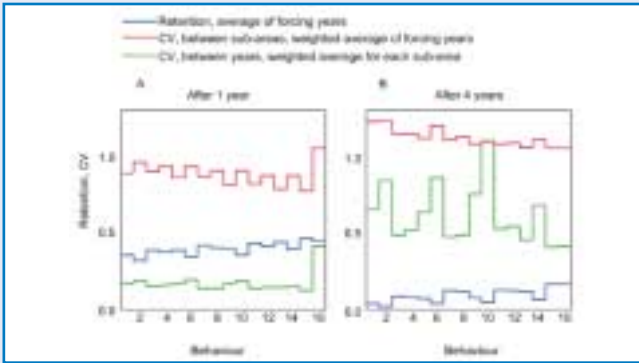
Figure 2. Retained fractions after 1 (A) and 4 (B) years with variability between years and between sub-areas for all behaviours. Simulations were run with diffusion.

with and without diffusion respectively. Individuals initiated in the western sub-areas had the highest retention. Sub-areas along the Norwegian coast showed little or no retention after 4 years. Our results suggest that *C. finmarchicus* experience larger inter-generational variability in risk of being lost from the Nordic Seas population due to the spatial variability of its domain than from the inter-annual variability in advective fields. Hence, to the extent that behaviour has influence on advective loss risk, *C. finmarchicus* should have evolved behavioural strategies that are robust towards strong temporal variability in advection.

The cause and the effect of the 18.6 year nodal tide in the Barents Sea

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The lunar node is the intersection between the moon plane and the ecliptic plane to the sun. This intersection moves 360° in 18.6 years and causes the lunar nodal cycle (Fig. 1). A 5 degree oscillation between the planes causes an oscillating gravity force and a 18.6 year tide on the earth. This small lunar nodal tide may have an important influence on climate change dynamics.

A wavelet analysis of time series from the Barents Sea has identified a lunar nodal tide spectrum of 18.6/3=6.2, 18.6 and 18.6*3= 55.8 years that influences Atlantic inflow to the Barents Sea. This lunar nodal spectrum is identified in the vertical tide, the Kola section temperature and salinity, Barents Sea ice extent and the NAO winter index. The phase relation between the lunar nodal cycles indicates there is the time delay of about a year from the Kola section temperature to Barents Sea ice extent and the NAO winter index. The NAO winter index has a dominant cycle of about 4*18.6=74.4 years (Fig. 2). This cycle has the same cycle time and cycle phase as the mean 74 year cycle from ice extent in the Greenland Sea and the Barents Sea. The close relation
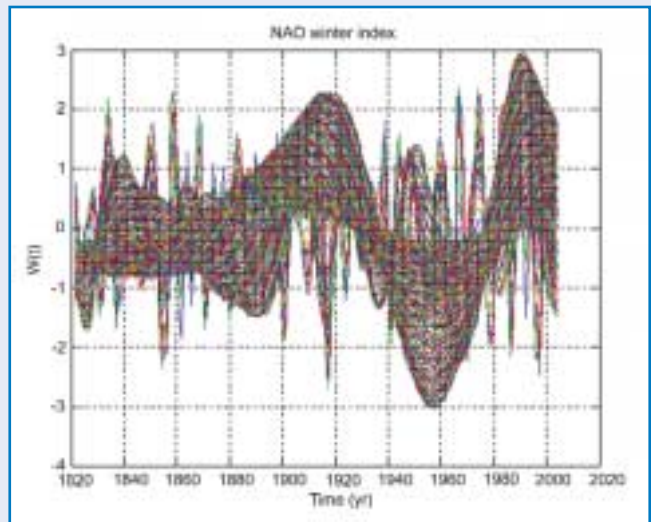
Figure 2. Wavelet spectrum of the NAO winter index that shows the dominant 74 year cycle.

between the long-term tides, Arctic ice extent and the NAO winter index indicates that the NAO winter index fluctuation has a major influence from Arctic ice extent. This indicates that Arctic ice is an isolator between the cold air and a warm sea in the winter time (Yndestad, 2004).

The identified lunar nodal cycles have a time variant phase. The identified 18.6 year cycle has a phase reversal related to a sub-harmonic cycle of 4*18.6=74.4 years. This phase-reversal is identified in the Faroe-Shetland time series and the Barents Sea time series (Yndestad *et al.*, 2004). The phase-reversal represents a regime shift that may by caused by interference between cycles in the lunar nodal spectrum.

Figure 1. Time series of NAO winter index, the 18.6 yr cycle and the dominant 18-yr wavelet cycle. The 18-yr cycle has phase-reversals at about 1885 and 1960.

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What happens with the Arcto-Norwegian cod if the thermohaline circulation slows down?

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A reduction of the thermohaline circulation (THC) might have a strong impact on the Northeastern Atlantic ecosystem. We address this potential challenge by studying the effects of THC changes on larval drift and development of Arcto-Norwegian Cod (ANC), as several studies have shown that there is a close link between the condition of cod at the 0-group stage and the year class strength of the 3-group fish. The approach taken is that of a modelling study supported by analysis of existing data on fish stocks and climate. A regional model (ROMS) is forced by a global climate model in which the hydrological cycle of the Nordic Seas is perturbed. The impact of the anomalous circulation and ocean temperature on ANC in its habitat, as simulated by ROMS, is investigated by using an individual based model to simulate growth of the larvae and juveniles along their resulting drift paths. The Nordic Seas are dominated by the near surface inflow of warm and salt Atlantic Water (AW), driven by prevailing southwesterly winds (Furevik and Nilsen, in press) and thermohaline circulation (THC) (Broecker, 1991). That is, ocean circulation driven by density differences. The relative importance of winds versus density differences is, however, not yet clear (Hansen and Østerhus 2000; Blindheim, 2004). Because of the massive heat transport by the AW, atmospheric and oceanic cold fronts are pushed northwards giving a maximum deviation of air temperature from the latitudinal mean in the northeastern North Atlantic of about 10°C. Sediment cores have revealed that the THC has undergone major changes in the past (Sarnthein et al. 1994; 1995). In this regard several authors have discussed the possibility of non-linear behaviour of the THC (Manabe and Stouffer, 1988; Rahmstorf, 1994). A THC collapse is now widely discussed as one of a number of "low probability – high impact" risks associated with global warming (Integration – www.pik potsdam.de/~stefan/Projects/integration/). More likely than a breakdown of the THC, which only occurs in very pessimistic scenarios (Rahmstorf and Ganopolski, 1999), is a weakening of the THC by 20–50%, as simulated by many coupled climate models (Rahmstorf, 1999).

Significant changes of the THC will affect ecological processes across a broad range of temporal and spatial scales. Atlantic cod (Gadus morhua L.) is one of the major North Atlantic fish resources and Arcto-Norwegian cod (ANC) is the larger of these cod stocks. By existing data on ANC and climate it has been well documented that weak year classes always occur during cold years, and that strong year classes occurs during warm years (Sætersdal and Loeng, 1987; Ellertsen et al., 1989; Ottersen and Sundby, 1995; Ottersen and Loeng, 2000). This relationship between recruitment and temperature is partly, directly through feeding intensity and metabolic rates (Otterlei et al., 1999), and partly, indirectly through lower trophic layers, as temperature in the Barents Sea is a proxy for the advection of zooplankton-rich AW from the Norwegian Sea and onto the shelves, e.g. the Barents Sea and the shelf off Norway (Skjoldal and Rey, 1989; Helle and Pennington, 1999; Sundby, 2000). Existing knowledge on cod and climate may be used to infer the consequences of a permanent change in the physical state of the environment occupied by cod.

A regional ocean model system (ROMS – http://marine.rutgers.edu/po/models/roms/) is set up for the habitat of ANC. ROMS is forced with initial- and boundary conditions from a simulation with the Bergen Climate Model (BCM), in which the hydrological cycle is perturbed, resulting in a weakened THC from 18 to 12 Sv (1Sv equals 1mill. m³/s) and a subsequent reduced inflow of AW to the Barents Sea. As a consequence, the temperature in the Barents Sea is reduced by up to 3°C. ROMS simulates transport of larvae and juveniles, while keeping a record of the individual temperature histories enabling calculation of temperature dependent growth, from spawning until settlement at the nursery grounds. Temperature-growth relations from two studies were included (Otterlei et al., 1999 and Björnasson and Steinarsson, 2002). What are the qualitative and quantitative effects of a substantial reduction of the THC on growth, distribution and recruitment of ANC?
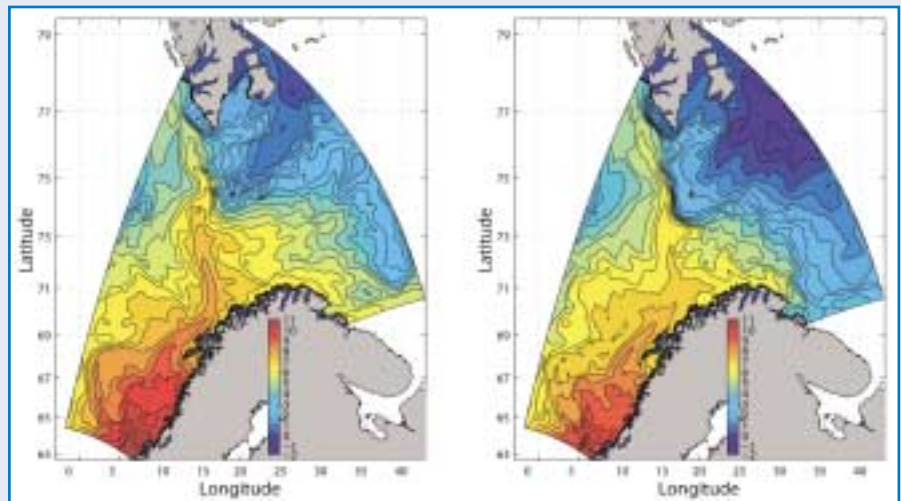

Figure 1. Temperature averaged for May, June and July at 100m depth for simulated fields with forcing fields from the BCM control run (left panel) and the BCM perturbed run (right panel).

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In conclusion, the present description of a reduction in the THC by 35% results in:

1) An increased flow west of Spitsbergen, while the inflow to the Barents Sea is considerable reduced.

2) A southward and westward shift in the distribution of cod year classes from the Barents Sea onto the narrow shelves of Norway and Svalbard.

3) A reduced individual growth of the pelagic juveniles with a subsequent poorer year classes, most probably less than 10% of the strong year classes of today (Ellertsen *et al.*, 1989).

4) An increasing number of larvae and juveniles advected towards the western parts of Spitsbergen and possibly further into the Arctic Oceans where they are unable to survive.

A southward shift of the spawning areas along the Norwegian Coast will enhance this development (Sundby and Nakken, submitted).

Figure 2. Simulated distribution of 0-group cod late August, 4 to 6 months old depending on time of spawning, with ocean and atmospheric forcing from the ctrl run (left panel) and +50 run (right panel). All particles are released inside the Vestfjorden, the main spawning site. The colour scale indicates wet weight in milligram.

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2nd China-Japan-Korea Joint GLOBEC Symposium
27-29 November 2004, Hangzhou, China

The China-Japan-Korea Joint GLOBEC Symposium attendees

China-Japan-Korea Joint GLOBEC Symposium

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The 2nd China-Japan-Korea Joint GLOBEC Symposium was held in Hangzhou, China on 27–29 November 2004, sponsored by the China GLOBEC Programme. Three countries, China, Japan and Korea are active in GLOBEC studies in the northwest Pacific, one of the highest fish production waters 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 study. All three countries have national GLOBEC research programmes and have made good progress in recent years. The China-Japan-Korea Joint GLOBEC symposium provides a vital forum for exchanging new information and discussing research findings in the region.

The symposium was the second joint GLOBEC regional meeting for exchanging research results and discussing the cooperation among the three countries. Prof. Qisheng Tang from China, Prof. Yasunori Sakurai from Japan and Prof. Im Sang Oh from Korea were members of the organising committee of the GLOBEC symposium. After the first China-Japan-Korea Joint Symposium, held in December 2002 in Korea it shows that the region continues to develop a very dynamic, highly effective and supportive GLOBEC network. The central theme of the second symposium was the relationship between environmental variation and ecosystem responses in the Northwest Pacific region. The symposium focused on:

● Ecosystem structure and Food web trophodynamics
● Physical-biological processes and models.

There were 62 participants at the joint symposium, and Dr. Manuel Barange, Director GLOBEC International Office, offered his congratulation to the meeting. The scientists in the three countries contributed fifty-two papers to the symposium (25 oral presentations and 27 posters). Chinese GLOBEC provided 28 papers, Japanese 10 papers and Korean 14 papers. At the first session Prof. Im Sang Oh reported on 'Korea GLOBEC', Prof. Yasunori Sakurail reported on 'The Overview of Japan GLOBEC and Related Research Projects in Japan', and Prof. Qisheng Tang on the 'Overview of Chinese National GLOBEC program'.

Many excellent papers were given on the change in ecosystem structure and community structure of living resources in the Yellow Sea, the East China Sea, the Japan/East Sea, Korean waters and its adjacent regions. Prof. Yasunori Sakurai gave an impressive presentation on 'A New Scenario of Stock Fluctuation of Ommastrephid Squids Related to Climate Change'. Dr. Hyun-cheol Kim presented a paper on 'Year-to-year Variation of Phytoplankton Bloom and Wind in the East Sea'; Dr. Song Sun reported on 'Population Dynamics of the Dominant Copepod *Calanus sinicus* in the Yellow Sea' and Dr. Tian Yongjun gave a speech on 'Long-term Change in the Production of Large Predatory Fishes in the Japan Sea during 1958-2003 in Relation to Climate Changes with Special Reference to Yellow Tail'. Profs. Jing Zhang and Michio J. Kishi informed on the 'Biogeochemical Aspects in the China-GLOBEC Study and Modeling Interannual and Decadal Variability of Pacific Saury'.

At the end of the symposium a round table discussion was chaired by Prof. Jilan Su. It was noted that GLOBEC is entering its Integration and Synthesis for the next 5 years. Integration and Synthesis will need more cooperation and collaboration especially in the regional studies. The importance of database building and publication of the papers from the symposium were also discussed during the meeting. The next joint China-Japan-Korea GLOBEC symposium will be held in 2007 in Japan.

Over-summering Strategy of *Calanus sinicus*

Sun Song, Institute of Oceanology, Chinese Academy of Sciences (sunsong@ms.qdio.ac.cn)

Ling Tong, Manuel Barange, Francisco Werner, and Sun Song at the IGBP Scientific Committee meeting in Beijing, China, February 2004.

Calanus sinicus is an ecologically important copepod species found over shelf waters of west North Pacific, from Japan to Vietnam. It is the main food source of many commercially important fishes, such as anchovy and mackerel. In the Bohai Sea, Yellow Sea and East China Sea, it is the dominant zooplankton species, accounting for 80% of the total zooplankton biomass. *Calanus sinicus* is the target species in the China GLOBEC "Marine Ecosystem Dynamics and Sustainable Utilization of Biological Resources in the Yellow Sea and the East China Sea". Intensive research has been carried out on the *Calanus sinicus* life cycle and its population dynamics, especially its over summer strategy in the Yellow Sea.

The Yellow Sea is a marginal sea located between China and Korea, with an average depth of 44m. It is greatly affected by climatic and geographical conditions. Fresh water input in the west, the Yellow Sea Warm Current and the Kuroshio Current invades from the south, and the Yellow Sea Cold Water Mass (YSCWM) exists in central areas in the summer for almost four months.

Low temperatures and a strong thermocline are the main features of the YSCWM, which becomes recognisable in July, and disappears after November. During this period, surface temperature increases from 23°C in July to 27°C in August and then decrease to 23°C in September, whereas bottom temperature remains constant at 9–12°C. A very strong thermocline is found above the YSCWM with a maximum temperature gradient of about 6°C m^{-1}. Bottom temperatures outside the YSCWM were usually 16 to 20°C, and surface temperature was 26 to 28°C. Vertical mixing in the south of the YSCWM most possibly resulted from the upward invasion of the Kuroshio Warm Current, which in shallow coastal areas was due to tidal mixing.

In March, the *C. sinicus* population began to develop in the Yellow Sea coastal shallow water along the Shandong Peninsula and Sudong Bank. April to May is a crisis period for the *C. sinicus* population recruitment when the number of the female adults, body size, egg production rate and hatching rate all affect the recruitment of the population. Peak abundance was reached in June and in July, when surface temperature increases beyond 23°C in the coastal area, *C. sinicus* began to move its distribution centre towards the central part of the cold bottom water of the YSCWM and the deep water side became more abundant than the shallow water side. In August, when the temperature of the surface and coastal shallow water exceed 27°C, *C. sinicus* disappeared from the coastal shallow high temperature water and its distribution center moved to the central part of the YSCWM, where the temperature is low and the food concentration was also very low. A special life strategy was adopted where the diel vertical migration almost stopped and only existed in a few female adults which did not pass the thermocline. *In situ* experiments demonstrate that the combination of the temperature and food concentration will keep the *C. sinicus* in the CV stage, missing a diapause period. The abundance of the *C. sinicus* in the deep water side of the YSCWM was much higher than that of the coastal area on the Chinese side. At the marginal edge of the YSCWM, diel vertical migration still exists, CV develop to adults and produce eggs, but the mortality was high and the egg production rate and hatching rate was low due to poor food supply and quality. From September, the distribution centre began to move to the Chinese coastal areas and in October and November, the thermocline became weak and the *C. sinicus* migrate to the coastal waters whilst current system transports them to the other areas.

Comparing the life histories of *Calanus sinicus* and *Calanus finmarchicus*, it seems that both of them will pass a diapause period, and during this time, the CV copepodite is the dominant stage in the population composition, the difference is that *C. finmarchicus* stay in the deep water over winter, but the *C. sinicus* stay in the deep water over summer.
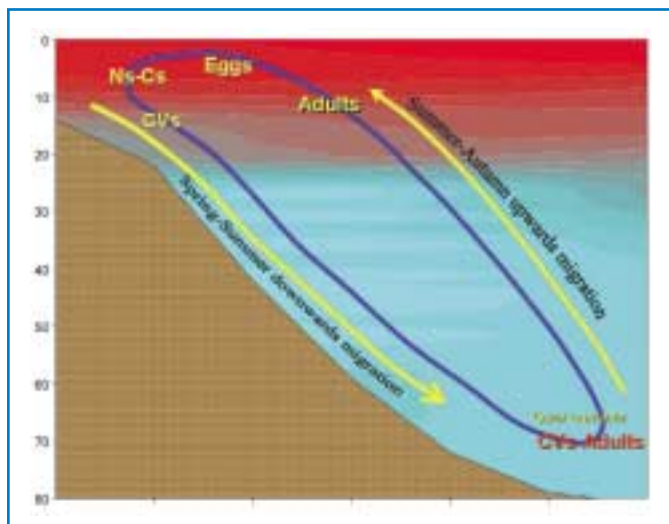

Figure 1. Climate and Calanus sinicus – the general picture.

Focus 3 Working Group – Modelling and Predictive Capabilities

Brad de Young, Memorial University of Newfoundland, Canada (bdeyoung@physics.mun.ca)

Our working group seeks to stimulate activity and work to integrate and communicate ideas developed during GLOBEC programs and in other programs with interests parallel to those of GLOBEC. We have chosen to identify and prioritise modelling activities in GLOBEC and to set-up sub-groups to work on identified projects. Over the past three years we have tried to avoid meetings for the sake of meetings, and have focused on activities that produce concrete results that stimulate the GLOBEC community or the broader science community. Our approach is to identify problems or areas of interest and then create sub-groups to tackle these problems. Our primary area of interest is modelling, although we have also worked on problems of data collection and interpretation.

We supported a workshop on zooplankton sampling using the Optical Plankton Counter (OPC). The workshop's objectives were to help OPC users to shorten their trial periods, and to move to the next stage using OPC data in the context of ecosystem and food web studies. To achieve these objectives, OPC users need to work together towards ensuring the quality of OPC data acquisition, improving both efficiency and quality control of OPC post data processing and developing models to analyse spatio-temporal variability and population dynamics rates. A report and active web page were produced as a result of this workshop.

In 2003, the working group focused on the development of basin and global scale models of marine ecosystems. Two meetings were held in Harlow, England at which drafts of a working paper were developed. This group focused on two issues important to GLOBEC (i) how to represent life-history in a model that allows appropriate resolution and fidelity and (ii) how to extend the regional models of GLOBEC to the basin scale. The goal of the working group was to construct a conceptual approach that would guide GLOBEC researchers and stimulate the wider scientific community. Many different goals were considered through the process from writing a short paper for wider readership to producing a longer review report that would have more detail but reach a narrower audience. We chose the focused route and produced a manuscript that was published in Science (de Young et al., 2004). This follows from our discussion in Qingdao where we decided to aim for primary rather than grey-literature publications. We remain convinced that such an approach has the greatest impact on the scientific community.

Our working group has several different projects active at the moment. We are planning to meet in late September in Aberdeen to focus on a couple of activities and make synthesis plans for the coming year. François Carlotti is working on plans to hold a joint workshop with members of the Focus 2 Working Group (Process Studies) on linking experimental and modelling approaches to pelagic biological studies. This workshop will link those who are making and interpreting at-sea observations, leading to process understanding, with those who seek to represent these processes in numerical models. Present plans call for this workshop to be held in France in the spring of 2006. This workshop would represent the culmination of discussion that has been ongoing for several years with the Process Studies working group, seeking to find common ground to link work on modelling and process studies.

The development of a trophic focus as an approach to modelling was central to the Science paper but still requires some practical implementation. At a meeting in Bergen, in the spring of 2004, we agreed to work towards the development of practical approaches of this conceptual model by looking at three different species of planktivorous fish. The link between zooplankton and higher trophic levels, it was argued, could best be made through studies on fish that feed directly upon zooplankton. While there is much work on such fish within SPACC, there were other higher latitude species that had received less attention from GLOBEC: capelin, sand lance and saury; planktivorous fish that provide the opportunity to consider both Atlantic and Pacific ecosystems. The key question will be the interaction between the target species and their predators and prey. The self-sustainability of local-populations is an important issue for sand lance but not for capelin or saury. Similarly, migration cycle dynamics are important for capelin and saury but not for sand lance. Two key questions for all species are (a) How to close the biological life cycle and (b) What is the relative importance of temperature and food on growth? Central model issues are how to represent early life history mortality and density dependence and the role of schooling behaviour. We are still working on this topic which will be one focus for discussion in Aberdeen.

Recent discussions within the working group have centered on approaches to synthesis. We have several ideas percolating that remain open for consideration. One idea is to work on the general ecological problem of the comparison and determination of ecosystem structure and function. In what ways has GLOBEC contributed to our general picture of marine ecosystem function? Is there a general conceptual understanding (synthesis) of the marine ecosystem that could be transferred from one system to another and enable prediction (reproduction) of the general features of contrasting systems? How should the experiences from GLOBEC feed back to the next generation of textbooks of marine ecology? Current ecological thinking does not encompass some of the ecosystem processes that are being highlighted by GLOBEC studies so further development is required.

Another idea that we have considered is how ocean ecosystems will respond to a changing climate. Clearly this problem is of wide general interest and there are many different approaches that one could take to this problem. One approach, on which a sub-group is now focused, is how one would, or could, measure changes in marine ecosystems to identify dramatic changes such as regime shifts. The final idea that we have on the table at the moment is to address the management and societal application of GLOBEC science. Such a topic, at the heart of synthesis, would certainly require collaboration with the Focus 4 Working Group (Feedback from Marine Ecosystem Changes).

While we have many different projects active this year, we remain open to new ideas. We will focus on one or two projects for the coming year and develop plans for future projects. You can become involved by expressing an interest in an active project, such as one of those listed above, or by suggesting topics for future projects. Or you can simply follow our activities through reports and publications as they appear in the literature and on the GLOBEC webpage (www.globec.org).

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New members of the GLOBEC SSC

Three new members have joined the GLOBEC SSC in 2005, replacing Tim Baumgartner, Celia Marrase and Ana Parma, who are thanked for their support to GLOBEC during their mandates.

Ruben Escribano

Ruben Escribano is currently Associate Professor of the Department of Oceanography at Universidad de Concepción, Chile, and Director of the Marine Biology Station at Dichato. He is also one of the Principal Investigators of the Center for Oceanographic Research in the eastern South Pacific (FONDAP-COPAS) at Universidad de Concepción. He holds a Ph.D. in Biology in the field of zooplankton ecology. In 1991, Ruben was an OPEN (Ocean Production Enhancemente Network) Postdoctoral Fellow in the Biology Department at Dalhousie University. In 1992 he returned to Chile to become a full-time Professor at Universidad de Antofagasta, where he worked on spatial distribution and secondary production of copepods in the coastal upwelling system off northern Chile. Since 2002, when he moved to Universidad de Concepción, his research with zooplankton has been linked to themes that are part of the COPAS Center scientific objectives in the Humboldt Current system. These are: 1) zooplankton responses to ENSO (El Niño/La Niña) variability, 2) the influence of the oxygen minimum zone on zooplankton distribution, adaptation and life cycles, and 3) zooplankton ecology at mesopelagic depths. For more than 8 years he has been the Chilean representative to GLOBEC and currently is member of the Editorial Board of Journal of Plankton Research.

He is also interested in issues related to marine biodiversity and thus became President of the South American Steering Committee for Census of Marine Life (CoML-SA) and is a member of the Scientific Steering Committee of CMarZ (Global Census of Marine Zooplankton).

Some selected publications:

Escribano R., D. Daneri, L. Farías, V.A. Gallardo, H.E. González, D. Gutierrez, C. Lange, C.E. Morales, O. Pizarro, O. Ulloa and M. Braun. 2004. Biological and chemical consequences of the 1997–98 El Niño in the Chilean coastal upwelling system: a synthesis. Deep-Sea Research II, 51(20–21): 2389–2411.

Hidalgo P., **Escribano R.** and C.E. Morales. 2004. Annual life cycle of the copepod *Eucalanus inermis* at a coastal upwelling site off Mejillones (23°S) northern Chile. Marine Biology DOI 10.1007/s00227-004-1487-3.

Torres C. and **R. Escribano.** 2003. Growth and development of *Calanus chilensis* nauplii reared under laboratory conditions: testing the effects of temperature and food resources. Journal of Experimental Marine Biology and Ecology 294: 81–99.

Giraldo A., **R. Escribano** and V. Marin. 2002. Spatial distribution of *Calanus chilensis* off Mejillones Peninsula (northern Chile): ecological consequences upon coastal upwelling. Marine Ecology Progress Series 230: 225–234.

Escribano R., V. Marin and P. Hidalgo. 2001. The influence of coastal upwelling on the distribution of *Calanus chilensis* in the Mejillones Peninsula (northern Chile). Implications for its population dynamics. Hydrobiologia 453/454: 143–151.

Hidalgo P. and **R. Escribano**. 2001. Succession of pelagic-copepod species during the period 1996/1998 in northern Chile: the influence of the 1997-98 El Niño. Hydrobiologia 453/454: 153–160.

Ulloa O., **R. Escribano**, S. Hormazabal, R. Quinonez and R. Gonzalez. 2001. Evolution and biological effects of the 1997–98 El Niño in northern Chile. Geophysical Research Letters 28: 1591–1594.

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Escribano, R. and P. Hidalgo. 2000. Spatial distribution of copepods during coastal upwelling in a northern area of the Eastern Boundary Humboldt Current. Journal of the Marine Biological Association of the United Kingdom 80: 283–290.

Escribano R. and I.A. McLaren. 1999. Production of *Calanus chilensis* from the upwelling area of Antofagasta, northern Chile. Marine Ecology Progress Series 177: 147–156.

Jim Hurrell

Jim Hurrell is a senior scientist and Director of the Climate and Global Dynamics Division (CGD) of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. His research has centred on empirical and modelling studies and diagnostic analyses to better understand climate, climate variability and climate change. He has authored or co-authored more than 60 peer-reviewed journal articles and book chapters, as well as dozens of other planning documents and workshop papers. He has convened over one dozen national and international workshops and he has served several national and international science-planning efforts. Currently, he is extensively involved in the World Climate Research Programme (WCRP) on Climate Variability and Predictability (CLIVAR), and he serves as co-chair of Scientific Steering Committee of US CLIVAR. He is recognised worldwide as an expert on the North Atlantic Oscillation (NAO), one of the most prominent and recurrent patterns of atmospheric circulation variability. In particular, his work has been foremost in the field at illustrating that the NAO and its time dependence are central to the global change debate. He was lead editor on the 2003 American Geophysical Union Geophysical Monograph "North Atlantic Oscillation: Climatic Significance and Environmental

Impact." A total of 42 specialists participated in writing the material for the book, which for the first time brought together atmospheric scientists, oceanographers, paleoclimatologists, and biologists to present a state-of-the-art assessment of the current understanding of this dominant climate phenomenon and its environmental and societal consequences. Jim also served as a co-editor of an Oxford University Press book entitled "Marine Ecosystems and Climate Variation: the North Atlantic" published in May 2004.

NAO related work: Refereed publications

Hurrell J.W., M.P. Hoerling, A. Phillips and T. Xu. In press. Twentieth Century North Atlantic climate change. Part I: Assessing determinism, Climate Dynamics.

Hoerling M.P., **J.W. Hurrell**, T. Xu, G. Bates and A. Phillips. In press. Twentieth Century North Atlantic climate change. Part II: Understanding the effects of Indian Ocean warming. Climate Dynamics.

Hurrell J.W., Y. Kushnir, M. Visbeck and G. Ottersen. 2003. An overview of the North Atlantic Oscillation. The North Atlantic Oscillation: Climatic Significance and Environmental Impact. In: J.W. Hurrell, Y. Kushnir, G. Ottersen and M. Visbeck (Eds.). Geophysical Monograph 134: 135.

Hoerling M.P., **J.W. Hurrell** and T. Xu. 2001. Tropical origins for recent North Atlantic climate change. Science 292: 90–92.

Hurrell J.W., Y. Kushnir and M. Visbeck. 2001. The North Atlantic Oscillation. Science 291: 603–605.

Visbeck M., **J.W. Hurrell**, L. Polvani and H.M. Cullen. 2001. The North Atlantic Oscillation: Past, present and future. Proceedings of the National Academy of Sciences 98: 12876–12877.

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Hurrell J.W. and H. van Loon. 1997. Decadal variations in climate associated with the North Atlantic oscillation. Climatic Change 36: 301–326.

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Hurrell J.W. 1995. Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. Science 269: 676–679.

Editorships

Volume editor: The North Atlantic Oscillation: Climatic Significance and Environmental Impact. American Geophysical Union, Geophysical Monograph, 2003, 134: 279pp.

Co-editor: Marine Ecosystems and Climate Variation: The North Atlantic. Oxford University Press, 2004, 227pp.

Marten Scheffer

Prof. Dr. Marten Scheffer (PhD 1992, biology Utrecht University) is head of the Aquatic Ecology and Water Quality Management group (http://www.dow.wau.nl/aew/) at Wageningen University. His work has focused on stability properties of aquatic as well as terrestrial ecosystems. He is a member of the editorial boards of the journals 'Ecosystems' and 'Ecology and Society' (formerly 'Conservation Ecology').

He is well known for his work on ecology and stability of shallow lakes (for further information and reviews see website http://www.dow.wau.nl/aew/publications). More recently, he has expanded his stability theory to cover ecosystems in general. His 2001 Nature publication on this topic is considered to mark a major paradigm shift in ecology. As a follow-up he is now writing a book on 'Stability of Ecosystems' for Princeton University Press.

Scheffer also has a strong interest in interdisciplinary work. Not only did he cooperate to work on unraveling the drivers of dynamics of a range of contrasting natural systems such as lakes, coral reefs and dry forests, he also worked with economists, sociologists and anthropologists on topics ranging from dynamics of public opinions, optimal use of natural resources and collapse of ancient cultures.

Selected key publications

Schippers P., M. Lurling and **M. Scheffer**. 2004. Increase of atmospheric CO_2 promotes phytoplankton productivity. Ecology Letters 7: 446–451.

Van Nes E.H. and **M. Scheffer**. 2004. Large species shifts triggered by small forces. American Naturalist 164: 255–266.

Janssen M.A., T.A. Kohler and **M. Scheffer**. 2003. Sunk-cost effects and vulnerability to collapse in ancient societies. Current Anthropology 44: 722–728.

Scheffer M. and S.R. Carpenter. 2003. Catastrophic regime shifts in ecosystems: linking theory to observation. Trends in Ecology and Evolution 18:648–656.

Scheffer M., S. Szabo, A. Gragnani, E.H. van Nes, S. Rinaldi, N. Kautsky, J. Norberg, R.M.M. Roijackers, and R.J.M. Franken. 2003. Floating plant dominance as a stable state. Proceedings of the National Academy of Science of the United States of America 100: 4040–4045.

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Scheffer M., S.R. Carpenter, J.A. Foley, C. Folke and B. Walker. 2001. Catastrophic shifts in ecosystems. Nature 413: 591–596.

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Focus 4 Working Group – Feedbacks from marine ecosystem changes – the human dimensions

The goal of GLOBEC is to "advance our understanding of the structure and functioning of the global ocean ecosystem ... and its responses to physical forcing so that a capability can be developed to forecast the responses of the marine ecosystem to global change". For the most part, "global change" has been interpreted to mean "climate change", and the majority of GLOBEC activities have examined marine ecosystem responses to natural climate variability and change. But for many places the more immediate causes of change, at least to fisheries systems, are direct human interactions such as contaminants, habitat degradation, and intensive fishing. The big challenge for GLOBEC is to distinguish between ecosystem changes caused by the impacts of climate change, and those due to direct human interventions. In addition, there are important feedbacks from changes in marine systems (whether caused by natural or human drivers) which affect human communities and societies. Examples include the societal impacts of the collapse of the northern cod off Newfoundland and Labrador, the social transitions resulting from shifts in the composition of marine resources in historical Greenland, and the implications to the fishery and to society of effective dissemination of climate information in Peru during El Niño events.

Focus 4 of GLOBEC has the responsibility of addressing this challenge, but it also includes feedbacks (in general) to the Earth system from global changes that occur in marine ecosystems. The general objective of Focus 4 as written in the GLOBEC Science Plan is to cooperate with other ocean, atmosphere, terrestrial and human global change research programmes to estimate feedbacks from changes in marine ecosystem structure to the global earth system. The Focus has three research activities:

4.1 Ecosystem – climate interactions on multiple scales and their influences on basic biological processes throughout the food web;

4.2 Earth System impacts from changes in marine ecosystems;

4.3 Social impacts of changes in marine ecosystems.

As the GLOBEC program has developed, research relating to Activities 4.1 and 4.2 has largely been considered by other GLOBEC Focus groups (for example, some of the issues under Activity 4.1 are being considered by Focus 3 on modelling) and by other IGBP core programs (for example, SOLAS is investigating marine gases and their interactions with the atmosphere and climate). The human dimensions of marine ecosystem changes and the interactions with social scientists, however, are new. It is these activities that the fourth Working Group of GLOBEC has chosen as its focus.

The objectives of GLOBEC's Focus 4 Working Group are to:

1. *Understand the interactions between marine coastal communities and global changes in marine ecosystems.*

2. *Understand the capacity of these communities (both natural and human) to adjust to these changes.*

3. *Understand the linked consequences of these adjustments for both the natural marine and human coastal communities.*

The Focus 4 Working Group had two exploratory meetings to build bridges and to develop a common vision and language between natural and social scientists on marine ecosystem changes and human community responses. These meetings were in Sidney, Canada, in June 2002 and in Banff, Canada, in June 2003. They produced the following publications:

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

Perry R.I and R. Ommer (Eds). 2002. Global Changes in Marine Communities: Who Done It? GLOBEC Focus 4 Workshop Report. GLOBEC International Project Office, Plymouth, UK. Available at: http://www.pml.ac.uk/globec/ structure/fwg/focus4/publications.htm (A shorter version of this report is available in the GLOBEC International Newsletter 8(2): 34–37, 2002).

Ommer R.E, B. Neis and I. Perry. 2003. Socio-ecological health: identifying resilience and vulnerability in coastal communities of fish and fishers. GLOBEC International Newsletter 9(2): 16–17.

These workshops identified two central questions:

1. How do marine ecosystem changes affect coastal communities?

Marine ecosystem changes can elicit a variety of responses: there may be no change in the coastal community; the change may be positive; or the change may be negative for the community.

1a. *What types of marine ecosystem changes create these different responses?*

1b. *What are the strategies (as either conscious responses or innate characteristics) on the part of coastal communities that lead to resilience (or vulnerability) to marine ecosystem changes?*

2. What are the reciprocal effects of human responses on marine ecosystems?

2a. *When, and under what conditions might coastal community responses to marine ecosystem changes exacerbate or ameliorate these changes in marine ecosystems?*

2b *What are the characteristics of, or mechanisms within, marine ecosystems that result in vulnerability or resilience to these human responses to change?*

It was also recognised that several issues complicate the study of these questions, in particular issues of:

1. Scale

● What are the scales at which marine ecosystems and coastal communities interact?

● How do different groups or users perceive and use "scale"?

● Mismatch of the scales of environmental change compared with scales on which humans have the ability to change and adapt.

● Up- and down-scaling, i.e. how to move between scales when the drivers may be global but the impacts local?

2. Knowledge

● "Open" and "closed" knowledge systems – e.g. publicly available, local knowledge, or group-based.

● How best to exchange information, in particular scientific information of marine ecosystems and its changes?

● How best to incorporate scientific and local knowledge networks into decision-making?

3. Values

● How is value assigned to various marine ecosystem states, e.g. is an ecosystem which supports Atlantic cod inherently better than one which supports northern shrimp?

● How to determine discount rates which incorporate future generations and different cultural values?

These are all questions and issues that Focus 4 is examining.

GLOBEC Focus 4 Membership, 2005–2007

The formal membership of the Focus 4 Working Group was constituted in 2004, with membership as indicated in the following table. The Working Group has two key goals for 2005, which will be discussed at its next meeting from 31 August–2 September 2005 in Victoria, Canada and which will contribute significantly to the Integration and Synthesis activities of the entire GLOBEC program. These are: 1) to develop an "appraisal" paper on inter-dependent changes in marine ecosystems and fishing-dependent human communities; and 2) to develop plans for a major symposium on coupled marine ecosystem-human community interactions in the face of global changes. The appraisal paper will take a case-study approach to compare and contrast situations in which there have been major marine ecosystem changes and the human coastal community responses (or lack of responses), i.e. to identify what makes for resilient (or vulnerable) coastal communities. The symposium will expand on the "appraisal" paper and include more global examples; it is tentatively planned for 2007.

Core Membership (* Co-Chairs):

Rosemary Ommer* (History)
Ian Perry* (Fisheries Oceanography)
Kenneth Broad (Anthropology)
Patrick Lehodey (Fisheries Oceanography)
Barbara Neis (Sociology)
Kevin Stephanus (Economics)
Ana Parma (Fisheries)
Renato Quiñones (Marine Ecology)
Svein Jentoft (Socio-economics)
Jiehua Lu (Demography)

Affiliated Members:

Rashid Sumaila (Economics)
Molly McCammon (Public Policy)
Ujjayant Chakravorty (Economics)
Nigel Haggan (Management)
Celia Marasse (Marine Ecology)

Impacts of climatic, anthropogenic and human forcing on long-term changes of the Black Sea ecosystem

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An important principle of environmental science is that changes introduced in single components of systems are likely to have consequences elsewhere in the same system. The Black Sea suffered from severe ecological changes during the last three decades due to a collection of concurrent perturbations. They were associated with strong impacts of the bottom-up (i.e. eutrophication) and top-down (i.e. overfishing and introduction of alien exotic species) controls as well as climate. The radical changes in the ecosystem have been triggered by an extraneous increase of nutrient and contaminant loads from rivers discharging into the northwestern continental shelf (Fig. 1a) as well as trophic cascades introduced by the overexploitation of fish resources during the early 1970s. Climatic effects have also contributed to the reorganisation of the Black Sea ecosystem since the 1980s and 1990s and have been characterised by dramatic variations in the regional climate (Daskalov, 2003; Oguz, in press). When combined with the physical constraints of long residence time of water masses in the surface layer due to very limited water exchange laterally through the Bosphorus Strait and vertically across the permanent pycnocline, the poorly-productive Black Sea prior to the late 1960s has become susceptible to notable structural transformations (Oguz, in press).

The most important feature of the eutrophic Black Sea was enhanced biological activity and diversion of the classical

phytoplankton-zooplankton-fish food chain to an alternative pathway of phytoplankton-zooplankton-opportunistic species-gelatinous carnivores. The phytoplankton community structure has been modified substantially in terms of species succession, intensity, frequency and areal extension of blooms. The data based on all available measurements within the deep basin during summer–autumn months (Fig. 1c) suggest an order of magnitude increase in the biomass from 1 g m^{-2} during the 1960s to about 10 g m^{-2} in the 1970s and up to 20 g m^{-2} at the end of the 1980s (Mikaelyan, 1997). As also shown in Figure 1c, the same signature is noted from a sharp increase in the summer surface chlorophyll concentrations from 0.1 to 0.5 mg m^{-3} (Vedernikov and Demidov, 2002; Yunev et al., 2002).

Trophic cascade by overfishing has started concurrently with eutrophication during the early 1970s as a result of depletion of medium and large pelagic fish catches (Fig. 1f). The smaller and lower valued planktivorous fishes (mainly anchovy and sprat) then acted as the main predators in the ecosystem, which led to doubling of their total catch at the end of the 1970s (Fig. 1f). A new and different type of top-down cascade process started operating on the lower levels of the food web with some decline in mesozooplankton biomass (Fig. 1d; Kovalev et al., 1998) and a similar level of increase in phytoplankton biomass during the 1970s (Fig. 1c). The increase encountered in total phytoplankton biomass, therefore, was not a result of eutrophication alone, but a process that included overfishing effects as well. Moreover, the period of pronounced increase in phytoplankton biomass during the 1980s (Fig. 1c) is well correlated with the sharp drop in winter temperature values (Fig. 1b). The cold and severe winters apparently promoted a higher rate of nutrient supply from the chemocline zone, and thus led to higher rate of spring phytoplankton production. We note in Figure 1b the coldest and most severe winter conditions of the last century took place during 1980–1993 with the basin-averaged, winter (December–March) mean sea surface temperatures (SST) as low as ~7.2°C.

A more pronounced impact of overfishing was felt later when the small pelagic stocks were overfished during the 1980s. Once the small pelagics became the main target of industrial fishery, their catches started decreasing and were gradually shifted towards newly recruited, small sized fish groups. The catches finally exceeded a sustainable level in 1987/1988 (Daskalov, 2002; Gucu, 2002), and collapsed in 1989–1990 (Fig. 1f). As the small pelagic fish stocks were exploited, their niche was gradually replaced by gelatinous zooplankton (jellyfish Aurelia aurita, in particular) and other opportunistic species (e.g. Noctiluca scintillans). Their food competition and predation on eggs and larvae of small pelagics then led to the domination of gelatinous carnivores in the ecosystem at the expense of small pelagics. The total gelatinous biomass, dominated by the jellyfish Aurelia aurita, reached 1.5 kg m^{-2} during the mid-1980s, and finally attained the peak value of about 2.5 kg m^{-2} in 1989 when the population of ctenophore Mnemiopsis leidyi was exploded (Fig. 1e). Strong predation by Mnemiopsis on eggs and the early life stages of small pelagics, and their food competition for mesozooplankton against small pelagics have been suggested as possible causes for decline of the anchovy fishery (Kideys, 2002) as an alternative mechanism to the recruitment failure arising from
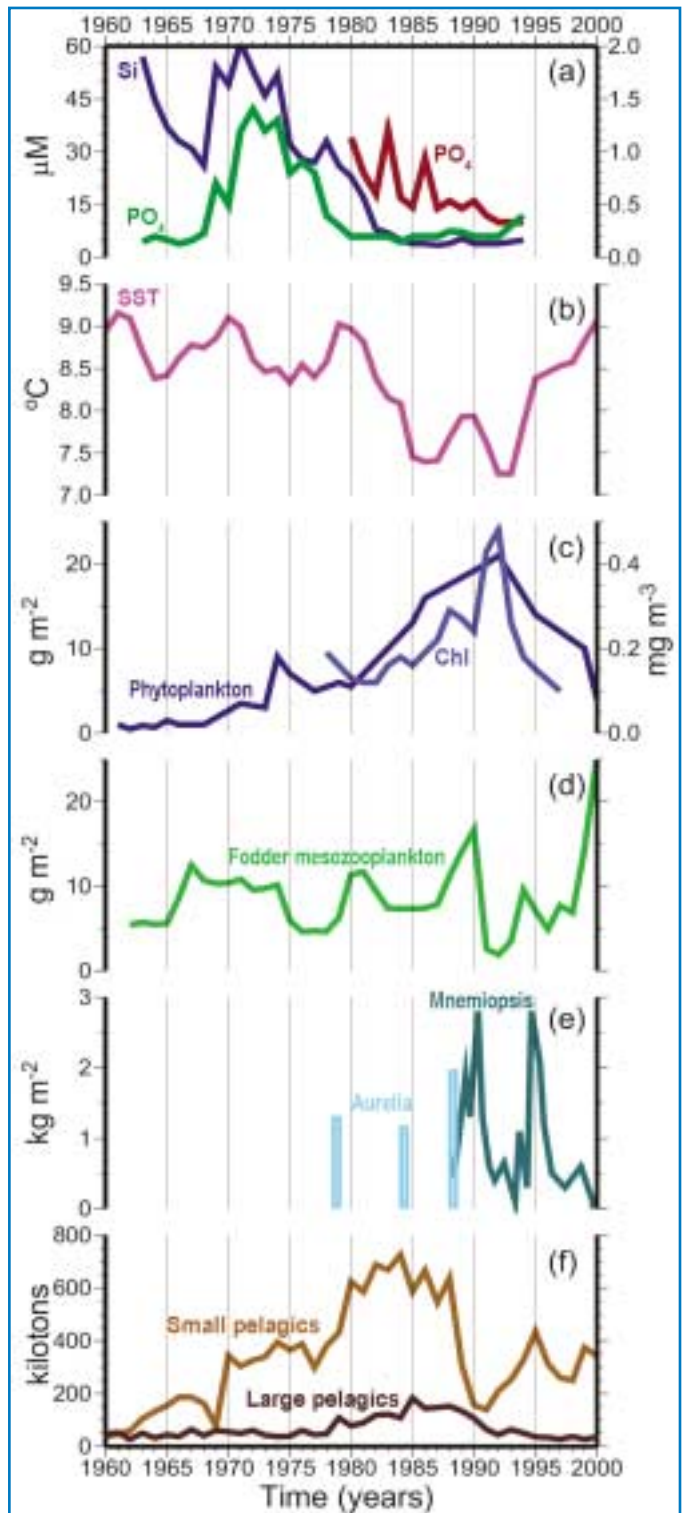

Figure 1. Temporal variations of the (a) annual-mean and water column averaged silicate, phosphate and nitrate concentrations measured at a station 20 nautical miles offshore of Constantza along the northwestern coast (note that the maximum scale is 30 µM for nitrate compared to that of 60 µm used for silicate on the left axis), (b) winter (December–March) mean sea surface temperature (°C), (c) water column integrated phytoplankton biomass (g m^{-2}),and surface chlorophyll concentration (mg m^{-3}); both of them are given as the averages of the summer–autumn periods, (d) annual-mean mesozooplankton biomass, (e) the gelatinous carnivores Aurelia biomass (vertical bars) and Mnemiopsis biomass (continuous line) as the averages of yearly measurements at all stations in the northeastern sector of the Black Sea, (f) the annual fish catches (in kilotons) of small pelagics and the sum of medium and large pelagics. Except otherwise indicated, all the data represent averages of the available measurements within the interior basin at depths greater than 1500 m.

overfishing during the 1980s (Gucu 2002; Bilio and Niermann, 2004). The available data seem to indicate that these two effects appear not to be alternatives, but they are complementary with strong feedback to each other.

The 1992–1993 period was a very special era for the Black Sea ecosystem. The *Mnemiopsis* biomass decreased sharply to around 0.5 kg m^{-2} immediately after their dramatic outbreak (Fig. 1e). The mesozooplankton biomass also exhibited a similar sharp drop from 17 g m^{-2} during 1990 to around 2-4 g m^{-2} during 1991–1993 (Fig. 1d). They were accompanied with the lowest level of fish stocks (Fig. 1f) and highest level of phytoplankton biomass (Fig. 1c) since the 1960s. These changes observed in biological structure seem to be closely related to the severity of winters and their response on the subsequent spring and summer months. Even though bottom-up conditions were quite favourable for mesozooplankton production, and there was no appreciable top-down grazing pressure from their predators (i.e., fish and gelatinous carnivores), the spring mesozooplankton production was affected unfavourably by very low temperatures of about 5–6°C in February–March. It also negatively affected overwintering and growth of *Mnemiopsis* populations for a few years.

As soon as the cold climate cycle ended in 1994–1995, a reverse trend was observed within the next two years characterised by increases in biomass of mesozooplankton and *Mnemiopsis*, as well as in fish catch, and decrease in phytoplankton biomass. *Mnemiopsis* biomass immediately attained its peak value observed at the end of the 1980s. These changes however do not necessarily represent a sign of improvement in ecological conditions in response to some protective measures imposed for controlling anthropogenic nutrient loading and overfishing (Kideys, 2002).

Starting by 1995, the Black Sea physical climate has entered into a warming cycle, prolonged up to 2002 at a rate of ~0.2°C per year for the sea surface temperature (Fig. 1b), as well as accompanying increases in the mean sea level and the net annual mean fresh water flux. From the fisheries perspective, the positive impacts of the climatic warming were to provide more suitable spawning and overwintering grounds for anchovy, and to promote more efficient growth of plankton communities by increasing their metabolic processes. Its negative impact, on the other hand, was weakening or disappearance of the major late winter–early spring peak of the classical annual phytoplankton biomass structure due to reduced upward nutrient supply from the chemocline under the conditions of less efficient vertical turbulent mixing and upwelling rate and stronger stratification (Oguz et al., 2003). As a result, the total annual phytoplankton biomass was reduced by at least 50% after 1996 (Fig. 1c). Its effect was reflected at higher trophic levels in terms of reduced stocks of mesozooplankton and gelatinous carnivores (Fig. 1d), and pelagic fish (Fig. 1f) during the 1996–1998 periods. We note that, the total fish catch was still dominated by small pelagics (less than 30 cm) without any major contribution from other groups with high economical value.

Towards the end of the decade, the Black Sea ecosystem has been influenced by a new invader ctenophore Beroe ovata, a predator of *Mnemiopsis*. It has been introduced into the Black Sea with ballast waters in 1998, acclimated quickly and easily to the Black Sea conditions, and spread a year later over the northwestern, northeastern and southern Black Sea, and started depleting *Mnemiopsis* stocks (Fig. 1e). Following the settlement of Beroe, high values of *Mnemiopsis* biomass were only limited to 1–2 months during the late summer, as compared to 8–9 months from early spring to late autumn prior to the settlement of Beroe. Predation of *Mnemiopsis* was immediately reflected by 2–3 fold increase in the mesozooplankton biomass (Fig. 1d), and ichthyoplankton biomass and fish stocks (Shiganova et al., 2003). The latter was also suggested by a gradual increase in the fish catch data after 1998 (Fig. 1f).

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OFCCP Workshop on the Application of Stable Isotopes in Pelagic Ecosystems, La Paz, B.C.S., Mexico, 31 May–1 June 2004

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Introduction

The objective of the GLOBEC multinational programme, OFCCP (Oceanic Fisheries and Climate Change Project) is to investigate the effect of climate change on the productivity and distribution of oceanic tuna stocks and the fisheries for them in the Pacific Ocean, with the goal of predicting short- to long-term changes and impacts related to climate variability. One of the four main focus areas relevant to OFCCP's objective is studies of the trophic structure in pelagic ecosystems.

Pelagic open-ocean ecosystems support important fisheries for tunas and other upper-level predators in all the world's oceans. These fishes are wide-ranging, generalist predators with high energy requirements, and as such, are key components of the ecosystems. Ecological relationships among large pelagic predators, and between them and animals at lower trophic levels, are not well understood. Given the need to evaluate the implications of fishing activities on the underlying ecosystems, it is essential to acquire a reliable understanding of the trophic structure in these vast ecosystems (Fig. 1).

Knowledge of the trophic ecology of predator fishes has historically derived from diet studies. Stomach contents however, provide only a relative snapshot of the most recent meal at the time of day the animal is captured and under the conditions required for its capture, and can under represent organisms that are digested quickly. Stable isotopes of carbon and nitrogen, on the other hand, integrate information on all components of the diet into the animal's tissues. Stable C and N isotopes are used with increasing frequency for determining trophic interactions among consumers, and for tracking energy or mass flow through the trophic pathways of ecological communities (Fig. 1). This technology is only now being applied in pelagic marine systems that support tuna production.

In order to develop consistent strategies for stable isotope analysis (SIA) and consistent interpretation of the data, a workshop was held under the auspices of OFCCP Theme 2, Food Web Structure in Pelagic Ecosystems. The workshop on "Stable Isotopes in Pelagic Ecosystems" was held from 31 May–1 June 2004 in La Paz, Baja California Sur, Mexico. It was sponsored by GLOBEC; by the Pelagic Fisheries Research Program (PFRP), University of Hawaii; and by the Centro Interdisciplinario de Ciencias Marinas (CICIMAR), La Paz, Mexico. The workshop was a joint activity with Working Group 3 (Trophic Pathways in Open Ocean Ecosystems) of a new GLOBEC regional programme, CLIOTOP (Climate Impacts on Oceanic Top Predators). CLIOTOP has similar objectives as OFCCP, in terms of studying the trophic ecology in pelagic food webs, but the former focuses on comparisons within and between ocean basins worldwide and the latter focuses on comparisons within the Pacific Ocean. At the conclusion of the workshop, a brief business meeting concerning future OFCCP and CLIOTOP activities was held.

The workshop was attended by 27 participants from 5 countries. It was designed to review some of the current stable isotope studies in pelagic ecosystems, to present and compare current methods of SIA, and to exchange ideas on the interpretation of stable isotope data. Studies from the pelagic western, central, and eastern tropical Pacific, eastern Australia ecosystem, eastern tropical Atlantic, and western tropical Indian Ocean were examined. In addition, studies in more localised areas in the Pacific Ocean, including the Hawaiian Islands, southern Baja California, and the Gulf of California, were represented. The long-term goal is to promote inter-ecosystem
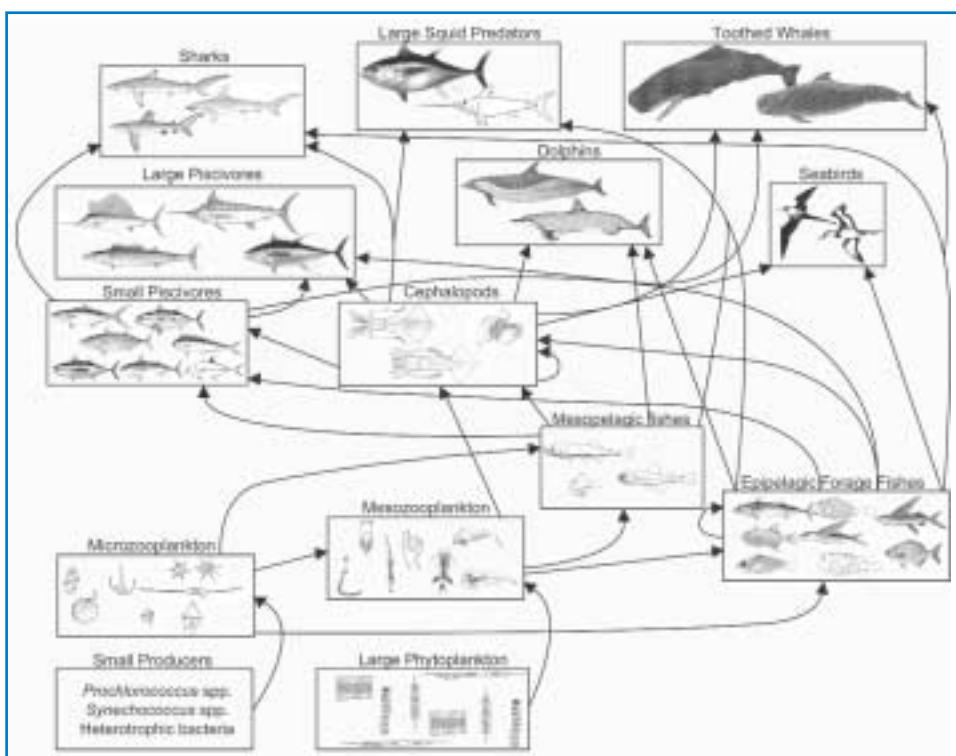

Figure 1. Simplified food-web diagram of the pelagic ecosystem in the tropical eastern Pacific Ocean. The numbers inside the boxes indicate the approximate trophic levels of each group.

comparisons of pelagic food-web structure in the Pacific (OFCCP) and in the Pacific, Atlantic, and Indian Oceans (CLIOTOP) so that top-down (fisheries, predators) and bottom-up (climate) forces are accurately depicted in ecosystem models.

Background

Naturally-occurring stable isotope ratios in animal tissues have been used to reconstruct diets, to trace movements, and to track sources of carbon in the food web. Isotope ratios are expressed as $\delta^{13}C$ and $\delta^{15}N$, which are the normalized $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios of samples to standards, in parts per thousand (‰). Isotopic fractionation of C and N takes place during metabolic processes, with the lighter isotope of each pair differentially excreted relative to the heavier isotope. Nitrogen isotope ratios are often used to estimate trophic position because the $\delta^{15}N$ of a consumer is typically enriched by 3–4‰ relative to its diet (Fig. 2).

Isotope tracers in an animal's tissues reflect not only what an animal eats, but also the environment the animal inhabits and the pollutants that are bioaccumulated. "Residents" should have an average chemical profile that is in equilibrium with the food and water of a home region, while "migrants" are isotope deviants (statistical outliers) from an average profile.

Project overviews

Several participants presented overviews of current projects that apply stable isotope analysis to detect ecological pattern in pelagic marine ecosystems. Three large-scale studies are being conducted in the Pacific, Atlantic, and Indian Oceans. A three-year multinational project, funded by the PFRP, is designed to define the trophic structure, establish an isotope-derived biogeography, and characterise large-scale tuna movements in the pelagic western, central, and eastern tropical Pacific. The project incorporates diet analysis, SIA, and food web modelling. Stomach, muscle, and liver samples are taken from a variety of predator species by observers on tuna fishing vessels, and particulate organic matter (POM), zooplankton, and prey organisms are collected on research cruises.

A component of the THETIS Project (Thons tropicaux environnement, exploitation et interactions dans les
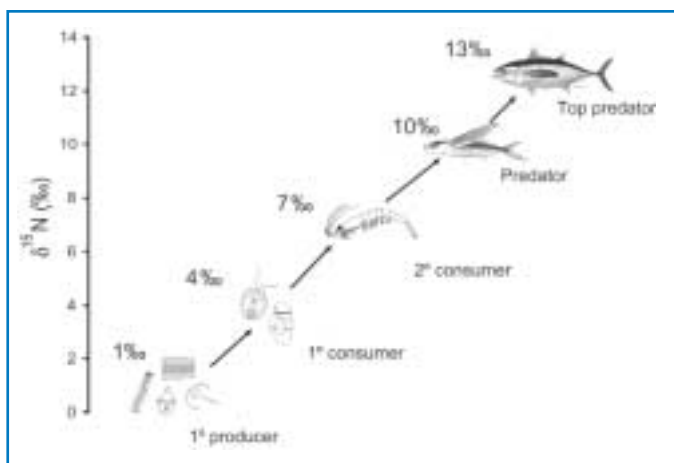

Figure 2. Hypothetical food chain, showing the relative trophic positions of representative functional groups occupying five trophic levels in pelagic marine ecosystems. Typical trophic enrichment of $\delta^{15}N$, ~3‰ per trophic level, is shown for each group.

écosystèmes), funded by IRD, France, is a study of regional characteristics of pelagic food webs, foraging strategies of top predators, and the influence of climate variability on the spatial distribution of fisheries in the eastern tropical Atlantic and the western tropical Indian Oceans. The studies include diet analysis, SIA of predators and their stomach contents, acoustic surveys of tuna forage, and modelling. Sampling of POM, filter-feeders encrusted on oceanographic buoys, and principal prey taxa are also conducted.

A large-scale ecosystem study by CSIRO, Australia, is being expanded with the objectives to identify the main ecosystems of the eastern tuna and billfish fishery (ETBF); to define the trophic structure within these ecosystems with emphasis on the relationship between target, bycatch, and threatened and protected species; to develop quantitative and qualitative models of the ecosystem/s; and to compare the ecosystem/s that underlie the ETBF with those of the warm and cold pools of the equatorial Pacific Ocean. Methods include trophic studies using gut content analysis, SIA, feeding behaviour and modelling.

Two studies that are being conducted by Ph.D. students at CICIMAR, La Paz, Mexico, using SIA were discussed. A study of the influence of environmental and geographic variability on the trophic structure of the copepods and other zooplankton taxa over a broad region of the eastern tropical Pacific (ETP), using stable C and N isotopes, began in 2004. Another study incorporates diet analysis and SIA to infer feeding relationships among yellowfin tuna (*Thunnus albacares*) and two species of dolphins (spotted *Stenella attenuata* and spinner *S. longirostris*) in the ETP.

Two research professors at CICIMAR presented studies that are focused in regions off Baja California Sur (BCS) and the Gulf of California. A study of the trophic variability of sharks off BCS, as inferred from diet analysis and SIA, is in progress. The shark project is the source of data for the theses of four MSc students and one PhD student at CICIMAR. Another CICIMAR professor reviewed the results of a diverse group of completed research on sediments, sea lions, and sperm whale-jumbo squid trophic relationship, using stable isotopes of C and N.

Factors that affect variability in stable isotopes

Inter-ecosystem comparisons require that like tissues are used for SIA. Red muscle samples of yellowfin tuna from the Atlantic were significantly lighter in $\delta^{13}C$ (by about 0.9‰) and heavier in $\delta^{15}N$ (by about 0.7‰) than white muscle samples. Previous studies have shown that within each tissue type (e.g. white muscle), the isotope values are generally consistent throughout the body, but for bigeye tuna (*Thunnus obesus*) in the western Pacific and yellowfin tuna in the Atlantic, the isotope contents of white muscle from several body loci showed average within-fish variability of 0.5 and 1.0‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively. More work is needed to reliably compare within-species stable isotope values of white muscle in the anal area of longline-caught tunas with those of the dorsal musculature of purse-seine caught fish.

Preliminary stable isotope data show considerable within-school variability for the tropical tunas. The expected degree of variability for fish that remain in persistent schools and eat a uniform diet, based on previous studies of snappers, is 1.0–1.5‰ for both $\delta^{13}C$ and $\delta^{15}N$. If within-school variability exceeds 1.5‰, the fish comprising the school were likely

feeding together only very recently. The following considerations may contribute to within-school differences in stable isotope composition. Schooling may be a highly dynamic process. In contrast to diet data, which typically show that tunas from the same school feed uniformly, stable isotopes suggest that tunas caught together often have different feeding histories, which suggests considerable mixing. Individual variability in feeding behaviour, nutritional condition, and size can contribute to within-school variability in stable isotope composition. Tunas feed on deep-dwelling prey to varying degrees, and mesopelagic prey typically have elevated $\delta^{15}N$ content relative to epipelagic prey (see next section). Starvation results in elevated muscle $\delta^{15}N$ due to deamination of the amino acids that make up body proteins. Body size often correlates with increasing stable isotope ratios because larger predators are capable of eating larger prey at higher trophic levels. Some preliminary data presented at the workshop showed this trend, and other data showed contradictory trends, or no trend, with size.

Food web implications

Comparisons of the stable isotope contents of tunas and their typical prey, determined by diet studies, often show a discrepancy in expected isotope enrichment. Average isotope enrichment is expected to be 3.4‰ and 0.7‰ per trophic lever for $\delta^{15}N$ and $\delta^{13}C$, respectively, based on published literature reviews. This discrepancy may imply that some components of the diet are typically not observed in the stomach contents, perhaps prey eaten at night or small prey that are digested quickly.

The tissues of mesopelagic fauna typically have higher $\delta^{15}N$ than those of epipelagic fauna due to changes in the $\delta^{15}N$ of POM and prey items at these depths. Because of fractionation during deamination of amino acids, zooplankton release low-$\delta^{15}N$ ammonium, causing their bodies and faecal pellets to be enriched in ^{15}N. These faecal pellets represent an important mechanism of export of high-$\delta^{15}N$ nitrogen via POM from the surface ocean to mesopelagic depths (Fig. 3). In general, the data demonstrate that predators that feed deeper in the water column (e.g. bigeye tuna) tend to have higher $\delta^{15}N$ values than those that feed in the upper mixed layer (e.g. yellowfin tuna) (Fig. 3). Deep-dwelling fishes like, opah (*Lampris guttatus*),

blue shark (*Prionace glauca*), and lancetfish (*Alepisaurus ferox*) had higher $\delta^{15}N$ than yellowfin and skipjack tuna (*Katsuwonus pelamis*) in waters off New Caledonia. Using stable N isotopes to better understand the bottom-up trophic connections leading to the diverse suites of predators in pelagic ecosystems requires simultaneous isotope analyses of the predators and the base of the various food webs.

Lipid effects on stable isotope analysis

Variable lipid contents of tissues can result in variations in $\delta^{13}C$ values. For example, muscle is composed mostly of protein, while lipids are depleted in ^{13}C relative to protein (by about 4–7‰). No standard protocol yet exists to determine whether lipids should be extracted before SIA or whether mathematical adjustment using the C/N ratio is adequate. A mass-balance equation is used to adjust $\delta^{13}C$ measurements when lipid is not extracted, and its use was recommended only if C/N exceeds 4.8.

Implications of tissue turnover rates on stable isotopes

The isotopic composition of any given organism often depends on the type of tissue analysed. Due to different metabolic rates of different tissues, tissue turnover is variable, and this affects the isotopic composition. Isotopic turnover rates in yellowfin tuna are being analysed at the Hawaii Institute of Marine Biology. A two-pronged approach is used: a naturally-occurring diet shift by juvenile yellowfin in nearshore waters of Hawaii, and an experimental diet shift using captive yellowfin tuna. The tissue turnover rates were of the order of those of mammals and birds, higher than those of ectothermic fishes. The experimentally-measured turnover rate of liver was considerably higher than that of white muscle, which suggests that it is technically feasible to distinguish resident and migrant yellowfin tuna in nature using stable isotopes.

Common priorities of projects that address OFCCP and CLIOTOP objectives

In an effort to develop consistent strategies involving the application of stable isotopes in pelagic ecosystems, and to promote links between new and existing research projects and GLOBEC programmes, the following list of priorities was developed.

1) Inter-laboratory calibration of stable isotope laboratories

2) SIA analysis of a low-level consumer (e.g. barnacles) across ocean basins

3) SIA analysis of common diet taxa across ocean basins (preferably a mesopelagic and an epipelagic species)

4) SIA analysis of the stomach contents of key predator taxa (e.g. tunas)

5) comparisons of the $\delta^{15}N$ and $\delta^{13}C$ of liver and white-muscle for key predator taxa (e.g. tunas)

6) comparisons of island- or seamount-caught tunas with tunas caught in the open ocean in a common geographical area

7) determine trophic-enrichment factors between a low-level consumer (e.g. a planktivore) and key predators (e.g. tunas)

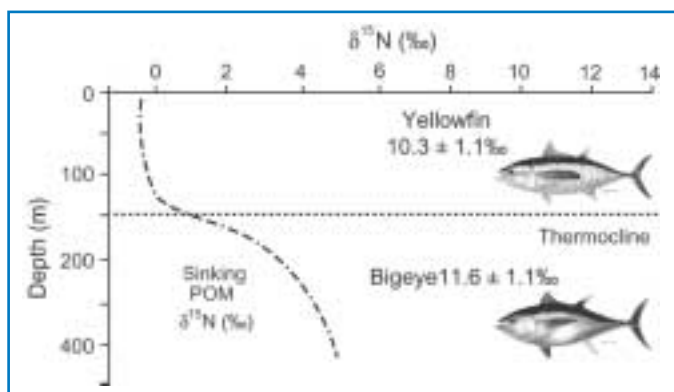8) examine correlations between the stable isotope variability and the biochemistry in ocean regions.

Figure 3. Generalized representation of the $\delta^{15}N$ composition of particulate organic matter (POM) versus depth in the ocean. Enrichment in ^{15}N of sinking POM and of prey organisms imparts higher $\delta^{15}N$ values on deep-dwelling bigeye tuna than on epipelagic yellowfin tuna. Figure from B. Graham, University of Hawaii at Manoa, Hawaii, USA.

CLIOTOP working groups meeting, University of Hawaii, Honolulu, USA, 1–3 December, 2004

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There is an increasing evidence for the impact of climate variability on pelagic ecosystems and their main commercial species (e.g. tuna) at seasonal, inter-annual, or decadal time scales. Studying the bottom-up and top-down effects that control the pelagic ecosystem in the context of climate variability is the challenging objective of the recently implemented GLOBEC CLIOTOP program.

The Pelagic Fisheries Research Program (PFRP) of the University of Hawaii hosted the first meetings of the working groups 2 (Physiology, behaviour and distribution), 4 (Synthesis and modelling) and 5 (Socio-economic aspects and management strategies) of CLIOTOP, back to back with its annual "PI" workshop. This latter provided an ideal introduction to the CLIOTOP meeting as it covered many of the issues that have to be discussed during the CLIOTOP working groups. 42 participants attended the CLIOTOP workshops which started with a general plenary session to present the current developments of the project and to define the first tasks list to be considered by each working group. Then, the three working groups met separately to identify their work plan, time line and milestones and to list the relevant running projects and future studies that should be organised and promoted. These new

studies should be based mainly on an application of the comparative approach which is the cornerstone of CLIOTOP.

Comparing various species, regions and ecosystems by searching for regularities and differences is indeed of fundamental importance for CLIOTOP. Universal patterns would reveal common principles underlying the organisation of ecosystems and their response to climate forcing. Therefore, impacts of both fishing and climate variations on marine ecosystems inhabited by open ocean top predators will be evaluated by analysing and comparing long-term data series, ocean/atmosphere and biogeochemical reanalyses, field observations, *in situ* and laboratory experiments and measurements. In this perspective, working group 2 identified potential pilot activities to be undertaken, including the development of common databases (environment / fisheries / acoustic / physiological experiments / archival tagging) devoted to comparative analysis. Links with working group 4 have also been discussed and common activities such as shared databases and modelling development have been planned.

CLIOTOP also gives significant emphasis to modeling and simulation in a comparative framework to identify the key processes, and to deduce and understand the dynamics of the ecosystem and its constituent populations. Therefore, the working group 4 on modelling and synthesis decided to organise its mid-term work around the comparison of different models (from spatially aggregated and taxonomically disaggregated trophic models such as ECOPATH/ECOSIM applications to spatially-explicit and population dynamics models such as SEAPODYM and APECOSM) in the three Oceans. A workshop is already planned next year in La Jolla (likely to be in October) to actually undertake the first analysis. It should be organised in connection with a meeting of the working group 3 (Trophic pathways in open ocean ecosystems).

Of particular interest for CLIOTOP, socio-economic perspectives and management institutions are the focus of working group 5 which met for the first time in Hawaii. 17 participants were present with an impressive diversity of interests: social and economic aspects of fisheries, bio-economic modeling, policy and law, international management were represented. Despite its obvious and desired heterogeneity (Fig. 1), the group succeeded in drawing a general framework combining a large range of point of view on the Human Dimension of pelagic ecosystems exploitation. This framework will be used to develop pilot studies based on existing projects and approaches. It should also serve as a guide for conducting a "gap analysis" to define new projects to be promoted. Links with working group 4 have been discussed and especially the idea of developing bio-economic models based on the already existing WG4 approaches.

A synthesis report of this meeting as well as the revised science plan of CLIOTOP will be soon available on the GLOBEC web site. For more information, contact Patrick Lehodey, SPC, Noumea, New Caledonia (PatrickL@spc.int) or Olivier Maury, IRD, Sète (maury@ird.fr).
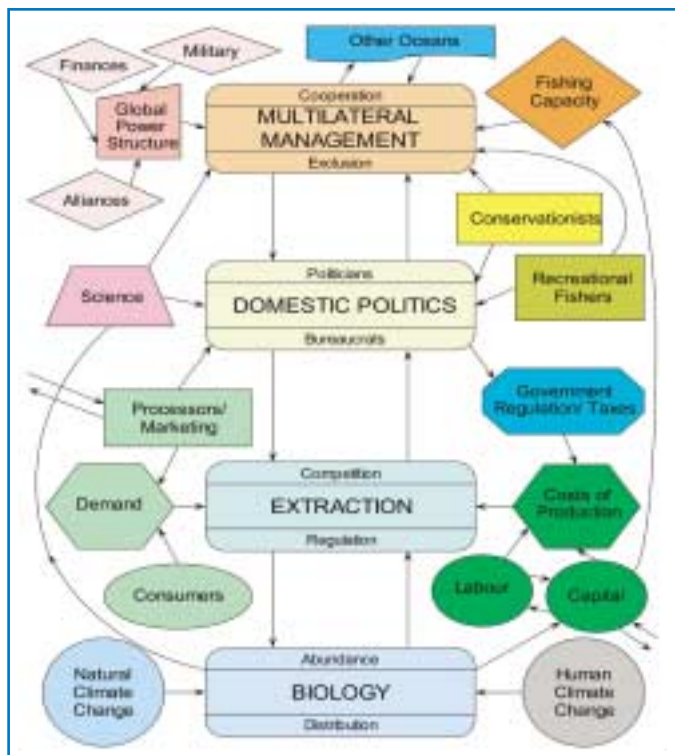

Figure 1. A synthesis of the discussion in Working Group 5 on the human-focused version of the system showing the interplay between resource changes (driven by both harvesting and natural variability) and the development and functioning of international fishery management organizations, through the complexity of the socioeconomic processes, actors, interests, and institutions that drive harvesting and other human activities affecting oceanic top predator species. Figure by D.G. Webster.

German contribution to SO-GLOBEC: LAzarev Sea Krill Study (LAKRIS)

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Project team: U. Bathmann (co-ordinator), subproject leaders: U. Bathmann, W. Hagen,
B. Meyer, M. Rhein, V. Siegel, V. Strass.

The LAKRIS team, from left to right: Volker Siegel, Sören Krägefsky, Boris Cisewski, Wilhem Hagen Bettina Meyer, Susanne Spahic, Volker Strass, Ulrich Bathmann.

Background

The Southern Ocean Global Ocean Ecosystems Dynamics (SO-GLOBEC) program is an international, multidisciplinary effort to understand the physical and biological factors that influence the growth, reproduction, recruitment, and survival of Antarctic krill (*Euphausia superba*) with special emphasis on its overwintering mechanisms. As part of SO-GLOBEC, the LAzarev Sea Krill Study (LAKRIS) aims to quantify seasonal population dynamics and physiological condition of krill with an interdisciplinary approach, in a region of the Antarctic that is poorly sampled and understood.

Much of our knowledge of Antarctic krill comes from a few regions, such as the much-studied Antarctic Peninsula (Hofmann *et al.*, 2004). But it is becoming increasingly clear that the seasonal survival mechanisms of krill are variable, so neither the local environment, (e.g. those along the Antarctic Peninsula) nor the response of krill to it, can be extrapolated easily to a wider area. The LAKRIS project will complement the existing international research activities within SO-GLOBEC and CCAMLR along the west Antarctic Peninsula, Scotia Sea and in the Southwest Indian Ocean Sector (Hofmann *et al.*, 2004, Atkinson 2003, Nicol *et al.*, 2000).

The study area

Within the great current systems encircling Antarctica, there is a hotspot of krill density within a sector defined roughly by the Greenwich Meridian (i.e. the Lazarev Sea) and the west of the Antarctic Peninsula (e.g. Marr 1962, Atkinson *et al.*, 2004). Whether this hotspot itself contains one or several "stocks" of krill and whether these are connected with those in the rest of the Southern Ocean are currently topics of intense debate (e.g. Siegel, 2000; Constable *et al.*, 2003). Understanding krill survival at the seldom-studied eastern extremity of this hotspot may provide some clues in this puzzle.

The Lazarev Sea (Fig. 1.) has been suggested to be the gateway through which the krill population enter the Weddell Gyre (Marr, 1962; Mackintosh, 1973; Maslennikov, 1980). At the 0° meridian krill distribution ranges from approximately 50°S to the Antarctic continent at 70°S – the widest latitudinal range throughout their entire circumpolar distribution. North of 60°S, krill are under the influence of the eastward-flowing Antarctic Circumpolar Current. They are thus downstream of the extensive Scotia Sea populations and reflect spawning success there. But south of 60°S, within the westwards flowing countercurrents of the Lazarev Sea, there is little information on krill spawning and larval occurrence. If, however, the Weddell gyre is the source of high krill densities in the Scotia Sea, then the westward moving water masses of the Lazarev Sea should seed substantial amounts of krill larvae into the system to sustain the large population observed at the northern outflow of the Weddell Gyre.

There are few historical studies of krill in the Lazarev Sea and these focus mainly on adults, there is almost no information on larvae (Makarov and Sysoyeva, 1984; Makarov *et al.*, 1985; Makarov, 1992). A renewal of interest in this important area has led to some recent work on feeding and physiology (Perissinotto *et al.*, 2000; Atkinson *et al.*, 2002; Meyer *et al.*, 2002; Stübing *et al.*, 2003; Schmidt *et al.*, 2003). LAKRIS aims to develop such studies and place them into the wider scale context of krill survival and population dynamics.

The project

LAKRIS will be from September 2005 to December 2009 and include 3 expeditions with RV *Polarstern* (Fig. 2).

1. 2 December 2005–23 January 2006 (confirmed)
2. 17 June 2006–17 August 2006 (confirmed)
3. January–February 2008 (planned)

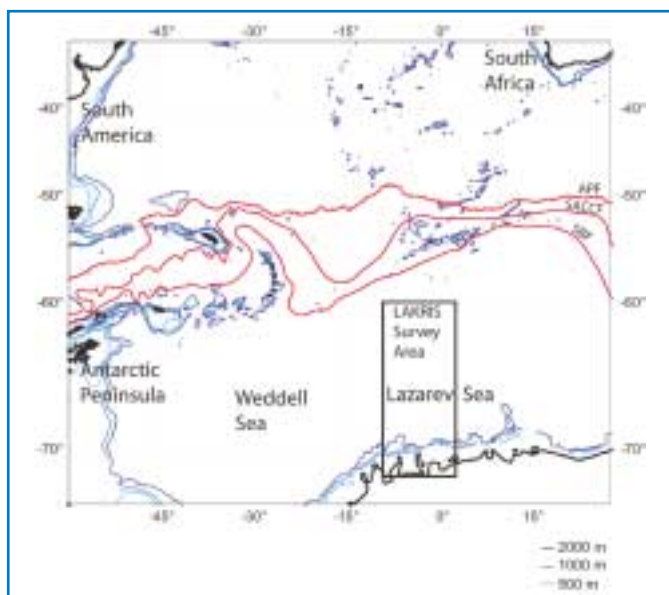The LAKRIS-project is divided into the following 5 subprojects (SP):

Figure 1: Map of the survey area

SP 1: Seasonal and interannual variability in krill demography of high latitude krill stocks in the Lazarev Sea (Volker Siegel).

A standardized RMT (Rectangular Midwater Trawl) net sampling programme will be carried out in the LAKRIS programme during various seasons to collect biological data on the krill population in the southern Lazarev Sea. The main focus will be the estimation of average spatial krill density and the determination of year-class strength in relation to key environmental variables. Reproductive success of the spawning stock will be studied as well as larval distribution and survival during the winter period.

SP 2: Horizontal and vertical distribution of krill and zooplankton in relation to the ocean current system (Ulrich Bathmann).

Diel vertical migration and geographical distribution of target organisms like krill (*Euphausia superba, E. crystallorophias*) copepods (*Calanus propinquus, Rhincalanus gigas, Oithona* spp. and other zooplankters (salps, pteropods, chaetognaths, amphipods) and fish (Myctophiden) are detected by means of a four-split beam acoustic array (38, 72, 120, 200 kHz). Some major questions are: Do organisms migrate daily in relation to the light field, feeding conditions and/or to the predator field? Do populations of different species and/or different developmental stages of one species segregate in certain environmental conditions or different times of the year? How does the ocean current system influence the geographical distribution of zooplankton or krill populations? Is the geographical distribution of species subject to change and if so, what are the possible causes?

SP 3: Effects of water mass circulation and sea ice on the abundance of zooplankton (Monika Rhein, Volker Strass).

This project is aimed at identifying relationships between the physical environment and the abundance of zooplankton in the Lazarev Sea. Special emphasis will be placed on the possible role of the Weddell Gyre circulation in closing the life cycle of krill. The database for this study will be collected by moored instruments to reveal temporal variations, by shipboard observations to map spatial distributions, and will also encompass historical ADCP (Acoustical Doppler Current Profiler) data from the region.

SP 4: Seasonal dynamics of physiological condition of krill with emphasis on the larvae stages (Bettina Meyer).

This subproject will quantify various fitness indicators which will permit the prediction of recruitment success and mortality rates of the following generation and how these factors will be influenced. In adult krill the work will investigate the likely reasons for a metabolic reduction that starts at the onset of winter which does not seem to be caused by food limitation at this time of the year.

SP 5: Seasonal lipid dynamics and energetic adaptations of Euphausia superba, with emphasis on juvenile and adult stages (Wilhelm Hagen)

This subproject will focus on seasonal dynamics of lipid accumulation and utilisation of juvenile and adult stages of krill. Energetic requirements with regard to overwintering strategies and reproductive effort will be quantified using experimental- and field data.

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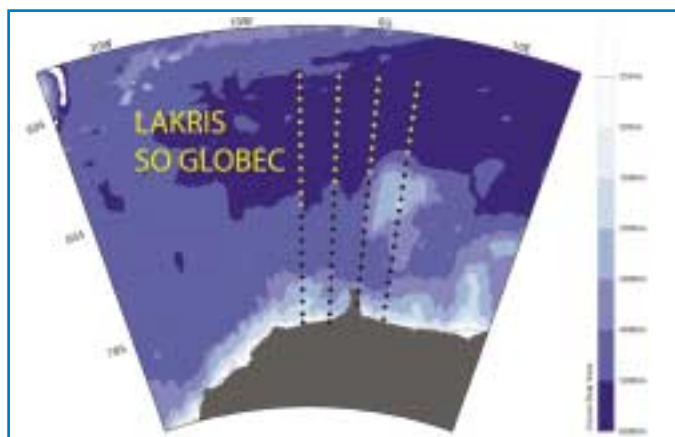
Figure 2: Station grid in the LAKRIS-Project

CALENDAR

12–14 March 2005: Workshop on the impact of basin-scale oceanographic and climate-related processes on the dynamics of plankton and fish populations in the North Atlantic Ocean: analysis, Reykjavik, Iceland

13–18 March 2005: Gordon Research Conference on Polar Marine Science "Climate feedbacks and trophic shifts in polar seas", California, USA

14–15 April 2005: EUR-OCEANS kick-off meeting, Paris, France

16 April 2005: EUR-OCEANS SSC Meeting, Paris, France

20–21 April 2005: UK Marine Productivity joint meeting with the Challenger Society, Cambridge, UK

24–29 April 2005: European Geosciences Union General Assembly, Vienna, Austria

16–21 May 2005: GLOBEC Climate Variability and Sub-Arctic Marine Ecosystems symposium, Victoria, Canada

31 May 2005: GLOBEC Executive Committee Meeting, Rome, Italy

1–3 June 2005: GLOBEC Scientific Steering Committee Meeting, Rome, Italy

4–5 June 2005: GLOBEC/IOC Study Group on Regime Shifts, Rome, Italy

6–9 June 2005: 4th Euro-GOOS Conference, Brest, France

7–9 June 2005: ICES/GLOBEC CCC Workshop on the Impact of Zooplankton on Cod Abundance and Production, Copenhagen, Denmark

19–24 June 2005: Summer ASLO meeting, Santiago de la Compostela, Spain

20–21 June 2005: Workshop on the Economic Effects of Climate Change on Fisheries, Bergen, Norway

27–29 June 2005: AMEMR – Advance in Marine Ecosystem Modelling Research, Plymouth, UK

27–29 June 2005: Coasts and Coastal People – Scenarios of Change and Responses. LOICZ II Inaugural Open Science Meeting, Egmond aan Zee, Netherlands

11–15 July 2005: 9th International Conference on Copepoda, Hammamet, Tunisia

18–22 July 2005: 6th International Crustacean Congress, Glasgow, Scotland

10–12 August 2005: PAGES Second Open Science Meeting, Beijing, China

22–26 August 2005: Dynamic Planet 2005, Cairns, Australia

29 August–1 September 2005: SCOR Executive Committee Meeting, Cairns, Australia

31 August–3 September 2005: GLOBEC Focus 4 WG Meeting, Sidney, Canada

14–16 September 2005: IGBP IPO Executive Officers Meeting, Hyttiala, Finland

20–24 September 2005: ICES ASC, Aberdeen, Scotland

30 September–8 October 2005: PICES XIV Meeting, Vladivostok, Russia

1–3 November 2005: SPACC Workshop on Image Analysis to Count and Identify Zooplankton, San Sebastian, Spain

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