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Report on the Young Scientists Conference on Marine Ecosystem Perspectives

Gilleleje, Denmark

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International Council for the Exploration of the Sea

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Report on the Young Scientists Conference on Marine Ecosystem Perspectives

Chair: Peter Grønkjær

Co-Chairs: Fredrik Arrhenius, Anna Ingvarsdóttir, and Stefan Neuenfeldt

Introduction

This report contains the proceedings and abstracts of papers and posters presented at the Young Scientists Conference on Marine Ecosystem Perspectives held in Gilleleje, Denmark 20–24 November 1999.

Sponsors

The Conference was organised by The International Council for the Exploration of the Sea in cooperation with The Danish Academy of Technical Sciences and The Royal Danish Academy of Sciences and Letters. It was sponsored by The Danish Ministry of Education, The Danish Ministry of Food, Agriculture and Fishery, The Danish Research Council, Knud Højgaards Foundation, and the European Commission DG XII.

Objective

The objective of the Conference was to provide an international forum where young marine scientists from many countries could meet at an early stage of their career to experience international scientific cooperation and to establish networks. At the same time it gave them an opportunity to contribute to the international scientific work that forms the basis for managing the marine environment.

Theme

The Conference theme focused on marine ecosystem interactions. The following four topics were considered;

- Human influence on marine ecosystems.
- Top-down or bottom-up control in marine processes.
- Influence of hydrographic processes on energy transfer in the planktonic ecosystem.
- Modelling ecological processes.

Proceedings

The Conference opened with a lecture on the role of ICES and the state of the marine ecosystem research, followed by keynote lectures on each of the four workshop themes, delivered by invited senior scientists. Six senior scientists were present throughout the Conference. The Conference and the workshops were chaired by young scientists. Presentations of papers and posters, followed by discussions, took place in three parallel running workshops covering the four topics. (Topic 2 and 3 were combined in one workshop).

Reports from the workshops were presented and discussed in plenum on the last day of the Conference. Participants were requested to fill in a questionnaire for evaluation of the Conference. Recommendations on follow-up activities including publication were prepared. A number of social events were arranged to facilitate a broad spectrum of communication between the participants.

Participants

A list of participants, invited speakers, and members of the Conference Steering Group is given in Appendix 1.

93 young scientists participated in the Conference. (See Appendix 1). Except for a few, they were all between 25 and 35 years. The following countries were represented (numbers of participants in brackets): Australia (1), Belgium (2), Canada (6), Denmark (4), Estonia (4), Finland (2), France (4), Germany (10), Greece (2), Iceland (2) Iran (1), Ireland (1), Italy (3), Israel (1), Latvia (4), Lithuania (4), Netherlands (1), Norway (6), Pakistan (1), Poland (5), Portugal (3) Russia (4), Spain (3), Sweden (2), UK, Scotland (2), UK (6), USA (7).

Recommendations

At the final plenary session it was recommended that ICES should maintain a web-site and e-mail address lists in order to facilitate communication within the networks which had been established at the Conference and to extend these networks.

It was also recommended that ICES should be requested to continue to organise activities for young scientists and consider funding of such activities e.g., in cooperation with other national or international organisations in order to allow non-ICES Member Countries to participate. This was strongly supported by the participants in an evaluation carried out on the last day of the Conference.

It was recommended to have the proceedings of the Conference and extended abstracts published in the ICES *Cooperative Research Report* Series, and have selected papers or groups of papers presented for publication to the ICES Journal of Marine Science and to other peer reviewed journals like the Journal of Plankton Ecology and the Journal of Ecological Modelling.

View from the Chair – Peter Grønkjær

Five years ago Mr Edgar M. Thomasson, then ICES librarian, suggested a Conference for young scientists as a joint venture between ICES and the Danish Institute for Fisheries and Marine Research. Ed's argument was:

"There must be many young scientists loaded with good ideas who have not yet joined the international scientific community. Let us get a hold of them and bring new talent and energy into the ICES system. Let us give young scientists a chance to experience international scientific co-operation at an early stage in their careers and to begin to establish their own research networks".

Now, five years and a very successful ICES Young Scientists Conference on Marine Perspectives later, everyone involved in the ICES YSC agrees that Ed's original idea was excellent and the proposed objectives for the Conference a good framework for the organisers.

On 20 November 1999, ninety-three young scientists from 26 countries representing all of the five continents, 12 chairs & invited speakers, and a three-person secretariat arrived in the small fishing village of Gilleleje, Denmark. Here, one hour north of Copenhagen, Gilleleje Konference and Feriecenter provided the perfect setting for the four day jam-packed scientific and social programme.

This ICES *Cooperative Research Report* contains the abstracts of the papers and posters presented by the participants. The scientific programme was made up of four parallel workshop sessions and two plenary sessions. The workshops, each chaired jointly by a young and an "old" scientist, were structured around groups of two to four papers within a given subject area. These papers then acted as starting points for half to full hour discussions pertaining to the subject.

In workshop 1 on "Human influence on marine ecosystems" one of the main topics was how to assess the human impact and how to determine the level of ecosystem change that we are willing to accept as a consequence of human activity. The latter was a major point of discussion throughout the whole workshop, whereas assessment of human impact was the objective of a range of papers on combined biological, chemical and physical studies, sediment profile images, stable isotopes and impact modelling. A one-day session was dedicated to the effects of fishing on the ecosystems

Workshops 2 and 3 were combined into one session. Although "Bottom-Up" has been put forward as the prime mechanism controlling the energy flow and recruitment in marine ecosystems, the papers presented show that not all participants share this view. The papers on grazing, predation, prey quality, and tropho-dynamics advocate the prominent role of "Top-Down" control in a wide range of primarily coastal ecosystems. Another recurring theme was the discussion on how far "Up" or "Down" the effects of e.g., nutrient loading or fishery could be felt; an important question that is still open. This discussion was influenced by the presentations relating to the role of hydrographic processes on energy transfer, where it was concluded that these processes have an important impact on the distribution of phyto- & zooplankton, and early life stages of a range of marine species. Consequently these processes will influence the relative strength of "Top-Down" and "Bottom-Up" control. An interesting turn in this workshop was the discussion pertaining to the differences between marine and freshwater ecosystems. Many interesting ideas of how theory developed in freshwater ecosystems could be applied and tested in marine ecosystems, especially in lagoons, fjords and semi-enclosed seas, were presented.

The workshop on "Modelling ecological processes" included a broad variety of different problem settings and model types. The papers and posters presented took a modelling approach to most of the topics covered in the other workshops e.g., fishery effects on ecosystems, nutrient cycling, transport of holoplankton and the early life stages of marine species, recruitment and trophic interactions. Nevertheless, the participants concluded that independent of the specific aim of the study four issues should be considered in order to improve future modelling activities. These were 1) the interaction between scales, 2) the inclusion of process analysis, 3) modern statistics & data exploration and finally 4) complexity of the model relative to the data used to drive the model.

If the success of a Conference is measured by the extent to which the participants presented interesting and well-prepared papers & posters, engaged in discussions and worked to meet the objectives of the Conference, this one was a huge success.

The objectives of the Conference as proposed by Ed Thomasson five years ago were to

- get young people networking,
- give them a chance to present their work to peers and not to the usual crowd of extremely experienced and intensely intimidating "old" scientists

and finally

- expose them to ICES and the scientific community.

I think the Scientific Steering Committee share the view of most participants when we say that the Conference met these objectives. The questionnaires and the discussion during the final plenary session confirm this and the recommendations that are being sent to ICES include the holding of an ICES Young Scientists Conference No. 2!

Acknowledgements

The participants wish to thank the ICES delegates, the Scientific Steering Committee, Jorgen Møller Christensen, Lena Larsen, Jane Ugilt and Keith Brander for their enthusiasm and support – financial and otherwise.

Workshop 1

Human Influence on Marine Ecosystems

The young scientists of today are the scientific community of tomorrow

Katherine Richardson – Invited Speaker

Dept. of Marine Ecology, University of Aarhus, Denmark

The world of science and the business of being a scientist are changing. I argue that while you "young scientists" here today have, undoubtedly, received excellent supervision and training in conduction of research you probably received little training that prepares you to meet the new demands that will be placed on the scientific community in the 21st century. To be a successful scientist in the coming decades will, I believe, require more than "simply" doing good research. Until recently, research funding came readily and often without a requirement that the scientist justify his/her choice of research topic to the surrounding society. Those days are, in my opinion, gone forever. The ability to communicate ideas and results to a broad (and non-scientific) audience will be a requirement for a successful career in the future. I also believe that scientists of the 21st century will have to be more willing to actively participate in social decision making in issues concerning the sea than we have been used to. Issues that must be addressed include whether we as a society should actively "manage" the ocean. Should we fertilize the ocean to increase fish yield or increase drawdown of CO_2? Should we actively create new habitats, e.g., artificial reefs? Should we consciously alter the shape of food webs and direct the flow of carbon and energy in marine ecosystems? And so on. If scientists don't seriously address these issues, commercial interests alone may direct the future of ocean management. Finally, the scientists of the 21st century must be ambassadors for the scientific process in general and the natural sciences in particular. Never in recent times, has public respect for and trust in scientists been lower and recruitment of young people to the natural sciences is suffering in the entire ICES area. There are tough challenges facing the young scientists of today and, on some fronts, I am afraid the legacy you have inherited from your supervisors – my generation – is not as rich as it could be. Despite the challenges (or maybe because of them?) I believe the decades that lie in front of us will be exciting. Lots of new and exciting results are waiting to be found, communicated to, and used by society and I look forward to seeing your contributions to that process.

Benthic communities in space and time: does a marine outfall make any difference?

Hermínia Maria Cardoso de Castro[1], S. Silva, A. M. Rodrigues; and V. Quintino

[1]Campus Universitario de Santiago, Departamento de Biologia, Aveiro 3800 Portugal.

[e-mail: hcastro@bio.ua.pt]

Marine outfalls are being increasingly used as a way of reduced impact waste disposal due to the high dilutions it is possible to achieve. This work presents the follow up of benthic communities of an urban wastewater marine outfall, located near Lisbon, Portugal. The present study was conducted during 1997, three years after the beginning of the discharges, as a part of the monitoring program for this outfall. The samples were taken in January, April, June and October, aiming to analyse both the sedimentary and the biological data in order to follow up the seasonal succession and eventual modifications induced by the wastewater discharge. Whenever possible, the data was compared to the reference situation, characterized by Quintino and Rodrigues (1995), in order to evaluate the magnitude of the change eventually brought about by the outfall. The overall data points out some evidence that the system is going through the initial stages of organic enrichment, namely due to the decrease in the redox potential in the sediment, the introduction of species regarded as opportunists, organic enrichment indicators and scavengers (e.g., *Capitella spp, Nassarius reticulatus, Pariambus typicus*) and, eventually, the generalized increase in the abundance, species richness and biomass. However, some of these indicators, namely the opportunist species, did present a clear seasonal appearance, suggesting that there is not, up to the moment, an installed disturbance causing permanent changes in the benthic environment.

Anthropogenic disruption of a shallow soft bottomed benthos

Tom Manning

Castle Road, Kilkenny Ireland.

[e-mail: manning@iol.ie]

Traditional approaches to marine Environmental Impact Assessment (EIA) of a soft, shallow seafloor have included characterisation, baseline and monitoring directive. Drawing from the study of selected representative elements, such as certain macrobenthic fauna and their associated habitats, scales of natural change in the system and references to differentiate anthropogenic influence are derived. A progressive

approach to marine benthic monitoring should have more of a focus on the successional model. Organism-sediment relations are related to dynamical aspects of the end member seres. Functional types are the biological units of interest, their definition not demanding a sequential appearance of particular species-genera. An inverse methods approach used with in situ measurements of structural features and deducing dynamics from structure is recommended using Sediment Profile Imagery, REMOTS and organism-sediment indices.

Impact assessment of the Iranian coral reef resources in the Persian Gulf area

Mohammad Reza Shokri,[1] Mohammad Reza Sheikholeslami & Peyman Eghtesadi Araghi

[1]Iranian National Center for Oceanography (INCO), Living Resources Department 51, Bozorgmehr Ave., P.O.Box:14155-4781 , Tehran, 14168, Iran.

[e-mail: mrshokri@angelfire.com]

The Persian Gulf provides an extreme environment for its coral fauna compared to other parts of the world. In terms of biodiversity, reefs in the Persian Gulf are relatively impoverished compared to those in the open Indian Ocean. However, they still represent the richest biological community found in this area, and support many endemic species unique to this region.

The coral reefs of Iran stretch from the north-western part to south-eastern part of the Persian Gulf, around 17 islands and along one coastal district. The reefs are of the fringing type and include about 35 species. Iranian coral reefs are subject to different natural and human impacts. Extreme environmental conditions, tropical storms, coral bleaching and crown-of-thorns starfish (*Acanthaster planci*) are the main natural impacts. The human impacts result from resource extraction related activities (i.e. non-rational exploitation of living resources), poorly controlled development (i.e. poor land use practices and tourism-related activities) and pollution related activities (i.e. pollution from land-based activities, maritime transportation and oil exploration and regional conflicts).

Among human impacts, the pressure of oil industry and maritime transportation are the most important, while poor land based practices, pollution from land based activities, non-rational exploitation from marine living resource and tourism related activities are less destructive. Taking into account the fact that the corals of the Persian Gulf live under extreme environmental conditions (i.e. high and low water temperatures and high salinity beyond the optimum tolerance ranges for reef corals) it seems necessary to reduce the human induced impacts on these ecosystems.

Therefore, it is necessary to, first, characterize the importance of different impacts and next to reduce their pressure on the Iranian coral reef resources. A first step would be to establish a regular monitoring program to document the level of any human-induced or natural impacts on coral reefs and secondly to launch an effective integrated coastal zone and marine resource management program. Particularly in islands having coral reefs it is important to introduce them as national marine protected areas or wildlife refuges, in which nearly all destructive activities related to the marine fauna and flora are banned. There is also a need for implementation of guidelines and regulations for all activities such as construction, tourism, shipping etc. in which necessary predictions and precautions are included to prevent the probable pressure on coral reef resources.

DISCUSSION

The discussion following these three talks first addressed the methodology used to assess human impact on benthic communities. The workshop agreed that indicator species have to be considered in a methodological context and one needs to consider all the causes of variability that they may be subject to, and not only the variability caused by human enterprise. Monitoring indicator species may be, but is not always, expensive. An inexpensive program to measure and monitor macro algae and their grazers that enlisted enthusiastic volunteer samplers was presented. The point was made that this kind of program furthermore enhances public interest in environmental issues. It was argued that the monitoring of indicator species does not give warnings about environmental change in due time for managers and decision-makers to mitigate the effects of the human impact. More sophisticated methods, such as the sediment image profiler presented by Tom Manning, should be considered. Some of these methods will also allow precise identification of the sources of pollution, which can then lead to prosecution of those responsible.

Moreover, when planning programmes to measure environmental impacts one should consider and define what kind of impact (anoxic conditions, large algal blooms, species change etc.) one is hoping to avoid and what kind of impact would be accepted. The range of disciplines represented at the Conference does not include environmental economists. Their inclusion might have been useful in order to help with posing questions, which are likely to draw government and public attention and to suggest ways of balancing the importance of different elements in the environmental systems being studied.

A review of the anthropogenic activities associated with the Lagos Lagoon ecosystem, Nigeria

Victor Oladapo Ladipo

Nigerian Institute for Oceanography and Marine Research, Lagos, Nigeria

Present address: College of Fisheries Science,

University of Tromsø, N-9034 Tromsø, Norway.

[e-mail: voladipo@iname.com]

The Lagos Lagoon is the largest of the four lagoon systems along the West and Central African coastlines. It

covers 700 km^2, a brackish coastal lagoon, on the western part of Nigeria. The fisheries resource of the lagoon based on a rich multi-species aquatic resources (Ezenwa, 1981) which serves as a source of income and food for the large population of Lagos. Extensive work on the available aquatic resources has been carried out, especially the distribution of teleost fish fauna in relation to the salinity (Fagade and Olaniyan, 1972, Ezenwa, 1981, and Fagade, 1969) and benthic organisms (Ajao, 1990). However, massive population increase due to increasing industrialization in Lagos (Nigeria's economic capital) has made gradual changes in its ecosystem inevitable, mainly as a result of the interaction between natural processes and man's activities The various anthropogenic activities in the form of both local point sources and non-local sources has greatly affected the habitat leading to a decrease in species richness, composition, abundance of aquatic resources and health hazards on the consumers.

Some Nigerian researchers have evaluated the human activities. Principals among these are the industrial effluents which contribute the most to the ecosystem changes. This is mainly due to the presence of over 60% of the countriy's industries in this area. The waste includes petroleum products, dyes from textiles industries and effluents from small scale industries, for example saw-dust and wood shavings particulates from the local timber industries at the Oko-baba logging post. These have greatly contributed to the pollution as they are all directly discharged into the lagoon. In fact, an average of 29.5 million litres of untreated sewage was discharged annually between 1986–1990 (Ajao and Fagade 1990). Another major contributor is the domestic wastes, this includes house-holds faecal and urinary outputs and sewages. Moreover, sand-mining and dredging from the lagoon has made a significant contribution. According to Awosika and Dublin-Green (1994) over 100.22 million tonnes of sand was dredged between 1984–1995 to sand-fill and mould blocks for various housing projects and to combat the perennial coastal erosion of the recreational beaches. Other activities include thermal pollution in the Egbin area of the lagoon, as a result of the presence of the 1,320 MW thermal station, agricultural and farm run-offs and the use of DDT which unfortunately is neither banned nor restricted in Nigeria (Ajani and Ladipo, 1998).

Information on the effects man's activities as it relates to the finfish species composition and distribution in the lagoon is limited, but Ajao and Fagade (1990) and Akpata (1980) have highlighted some effects.

In conclusion, the general observation is that changes in the physio-chemical conditions have played a great role in the decline of the aquatic resource biodiversity. The need to rectify these anomalies is urgent, as the importance of the lagoon not only lies in providing food, but also employment for the local fishermen who are already withdrawing from the trade. I would recommend that tough guidelines and standards for both domestic and industrial pollution control are implemented specifying the establishment of central waste treatment. This should be combined with effective monitoring approaches and associated interpretive techniques required to allow an objective assessment of the cumulative impact of localized effects on the resources. Moreover, the scientific knowledge needed to make such an assessment possible should be high on the list of research priorities as this vital information is limited and almost irrelevant in the view of the broad range of pollution sources. Finally, the population should be made aware of the severe effects of pollution.

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The effects of high inorganic N:P ratios in the Elbe River plume on the phytoplankton spring bloom in the German Bight: results of combined field and enclosure studies

Silke Rick[1], Hans-Josef Rick[2] & Uwe Brockmann[3]

[1]Academy of Natural Sciences, Estuarine Research Center, St. Leonard, Maryland. [2]Institut für Meereskunde, Kiel, Germany. [3]Universitaet Hamburg, Institut für Biogeochemie und Meereschemie
[Corresponding author: rick@acnatsci.org]

The aim of the interdisciplinary project KUSTOS (Coastal fluxes of matter and energy: the transition land-ocean in the southeastern North Sea) was to analyze and quantify fluxes of matter and energy from the land to the ocean throughout the coastal region of the German Bight. In spring 1995 the project focused on the study of biogeochemical turnover processes under high ambient inorganic N:P ratios in the Elbe River plume. Biological and chemical changes in a watermass were characterized by tracking the initial water for 10 days with a drifting buoy. Additionally, larger grids of stations were sampled repeatedly on a short time scale before, during and after the drift investigation. Towards the end of the initial bloom DIP and DSi were depleted, while nitrate

concentrations remained in a surplus of up to 40 μM, indicating a phosphorus limited system. The situation observed in the field was later reconstructed in an enclosure experiment to study the reaction of phytoplankton to varying salinity and increasing N:P ratios in a more controlled environment. A hydrodynamic model was applied to the grid data for a broad estimation of the range of biologically induced changes in a large region of the German Bight. These results can be compared to the data from the drift investigation and in the enclosures. Taken together the results show that carbon fluxes in a coastal, non-steady state system can be strongly underestimated when calculated based on nutrient consumption and the Redfield ratio.

Micro-organisms on a heavily used sandy beach in the Southern Baltic

Anetta Ameryk, Z. Mudryk, B. Podgorska

Marine Biology Center, 5 Sw. Wojciecha str, Gdynia 81–347, Poland.

[e-mail: ameryk@cbmpan.gdynia.pl]

The microbiological study was carried out monthly for one year on a sandy beach heavily used by tourists in Sopot (Poland). Sand cores were taken at profiles perpendicular to the coastline at a depth down to 10 centimetres. The microbiological analyses included enumeration of fungi, yeast, heterotrophic bacteria and actinomycetes.

Substantial differences in the number and distribution of the microorganisms were found at the different sampling sites. The microorganisms were most abundant in the dune site and less were found at the water line. They reached maximum values in September and in October, and a minimum was noted from December to May. Heterotrophic bacteria were the most common of all investigated microorganisms whereas actinomycetes were found in the lowest numbers.

Fish processing influence on coastal ecosystems of the Krabovaya Bay, Shikotan Island (Kurile Islands, Russia)

Tatyana M. Malinovskaya

Institute of Marine Biology Academy of Sciences, Far East Branch of Sciences, Vladivostok 690041, Russia.

[e-mail: inmarbio@mail.primorye.ru]

For many years the fish processing plants' influence on marine ecosystems of Shikotan Island (Kurile Islands) has been studied (Kussakin, 1994). Changes in the species composition, decrease of biodiversity and production were shown. The greatest changes were observed in Krabovaya Bay since this is a bay of fjord type with weak water exchange. The fish processing plants situated in the innermost part of the bay let out non-treated waste directly into the shallow part of the bay. As a result, a dense layer of waste, several centimetres thick, has developed along the northern coast of the bay. As O.G. Kussakin reported the eutrophication first results in a strong increase of the benthos biomass. Then the ecosystem degrades to total destruction. In 1987 only one species (*Capitella capitata*, Polychaeta) was found in the innermost part of Krabovaya Bay, while in 1963 24 species and in 1949 38 species were found. In the 1990s these investigations were complemented by research of heavy metal levels in common species of marine organisms. The concentrations of Zn and Cu in brown *seaweed Fucus evanescens* collected at the northern coast were 3–6 times greater than levels of these metals in seaweeds from background areas on the outer coast of Shikotan Island. In 1997 the improvement in the condition of coastal waters was shown concurrently with significant reduction in the fish processing plant size and a partial regeneration of ecosystems took place. The number of species amounted to 15 in the innermost part. The average concentrations of Cu and Zn in seaweeds decreased to background level even at the site where the highest pollution degree was found in 1991.

Planktonic ecosystem impacts of salmon cage aquaculture in a Scottish sea loch

Nuria Navarro

Centre for Coastal and Marine Sciences, Dunstaffnage Marine Laboratory, P.O. Box 3, Oban, Argyll PA34 4AD, Scotland, UK.

[e-mail: nna@wpo.nerc.ac.uk]

The objective of this work is to investigate the effects of salmonid cage-culture effluents (metabolic waste products and uneaten food) on planktonic community structure and microplankton ecosystem function in a sea loch. This subject has received little attention, so the expected database will contribute to an understanding of the effect of aquaculture on semi-enclosed environments and will also be used to develop models of sea loch ecosystem dynamics. A programme of field observations was undertaken at an intensively farmed Scottish sea loch (Loch Fyne) over a complete seasonal cycle. Salinity/temperature profiles and water samples were collected from three depths at each of four stations located at different proximity to the fish farm. The water samples were analysed for inorganic (NH_4, NO_3, PO_4, SiO_2) and organic nutrients (nitrogen, phosphorus) and the abundance and biomass of bacteria, ciliate protozoan and nanoflagellate protozoan. Results to date reveal higher concentrations of ammonia, organic phosphorus and nitrogen at the stations near the fish farm during most months. They also show higher abundance of bacteria, nanoflagellates and ciliates. This suggests that fish farm effluents are enhancing local concentrations of organic and inorganic nutrient. The associated higher abundances of heterotrophic microorganisms near the fish farm suggest that these nutrients may in turn be directly or indirectly enhancing microbial activity. This would seem likely as bacteria are major consumers of dissolved organic matter, and are then themselves consumed by protozoans.

Distribution of biomass and abundance of Gammarids in the littoral zone of the Gulf of Riga, NE Baltic Sea, related to different environmental gradients including eutrophication

Kaire Parts

Estonian Marine Institute, Department of Biology, Marja 4D, Tallinn 10617, Estonia.

[e-mail: kairep@klab.envir.ee]

Changes in trophic conditions of coastal sea have a great variety of effects on the coastal ecosystem. These effects include both the qualitative and quantitative changes on community or ecosystem level as well as variability on species or taxonomic group level. Usually these processes are quite difficult to describe due to great amplitude of natural variability, especially in the conditions of low salinity in the NE Baltic Sea.

The purpose of the study is to relate the distribution of different *Gammarus* species to region, substrate, salinity, nutrient concentration, macrozoobenthos and macrophytobenthos in the Gulf of Riga.

Sampling was performed on 11 transects situated around the whole coastline of the Gulf of Riga in the summers 1995 and 1996. Samples were collected by divers using "Tvärminne sampler" (on sandy or gravel bottoms) and "Suction sampler" (on rocky bottom).

Gammarids occurred in all transects, except at transect 6 where benthic invertebrates were not found. The highest abundance of gammarids was observed in the southern part of the Gulf of Riga and the lowest in the northern part of the Gulf.

The abundance and biomass of gammarids increased with depth whereas their proportion in the macrozoobenthic community decreased. Optimum depth remained between 2 and 3 m. It can be explained by the presence of luxurious benthic vegetation at that depth interval which offers gammarids better protection and conditions for feeding.

Salinity in the study area remains between 5 and 6.6‰. Gammarids had higher biomasses at salinities between 5.4 and 5.6‰. Gammarids had lowest abundances and biomasses at salinities higher than 5.7‰.

Gammarids are euryedaphic in the Gulf of Riga. Ten different bottom types were distinguished and only on 2 of them (sandy and sandy gravel bottoms) gammarids were not found. Gammarids had higher abundances on gravely sand and stone bottoms. Despite their higher abundance on gravel bottoms, gammarids had higher biomasses on stone bottoms. The relationship is probably indirect as the distribution of *Fucus vesiculosus* and *Cladophora rupestris* is linked to the type of substrate.

The highest number of gammarids was found in *Fucus vesiculosus* and *Cladophora rupestris* communities. Secondly, they preferred unvegetated areas and the community of *Furcellaria lumbricalis*. Gammarids had low abundances in the communities of *Myriophyllum spicatum, Zannicelia palustris, Cladophora glomerata* and *Potamogeton pectinatus*. Although the abundances of gammarids were high in *Fucus vesiculosus*, higher biomasses were observed in the *Cladophora rupestris* community.

Eutrophication level is higher in the southern part of the Gulf and the Pärnu Bay area. This study showed that the abundance of gammarids was higher at more eutrophied areas. It seems that the positive effect on the gammarid population in areas with moderate eutrophication level is caused by increased development of epiphytic and epilitic vegetation. So the effect of eutrophication on the gammarid population is more or less indirect through response of other elements of coastal ecosystem on increased trophic conditions.

Acoustic based methods to prevent the mortality of some marine mammals species due to marine human activities

Giuseppa Buscaino, A. Bonanno, A. Cuttitta, Gualtiero Basilone, C. Fortuna

Instituto di ricerche sulle Risorse Marine e l'Ambiente-C.N.R. via L. Vaccara,61 – 91026 Mazara del Vallo (TP) Italy.

[e-mail:mazzola@irma.pa.nr.it; basilone@irma.pa.cnr.it]

In this work we address the problem of the interaction between marine mammal populations and human activities at sea. The possibility to control the behaviour of marine mammals using acoustic stimuli can be very important in order to prevent their mortality and to avoid interference with a lot of marine activities, including fishing.

The scientific and technical objectives of our work concern the implementation of an electro-acoustic prototype for controlling the behaviour of some species of marine mammals, particularly dolphins, in their natural environment. Verifying the efficiency and reliability of the acoustic prototypes we considered mainly the applications to the fishery problems.

Research was conducted on the effects of different acoustic signals on the hearing apparatus of dolphins by means of laboratory, dolphinarium and at sea experiments.

This study was conducted following two different lines of investigation:

1. the quantification and mapping of dolphin by-catches which occurred during small pelagic fishery operations in Sicily;
2. the study of the effects of acoustic signals, different by nature and structure, on dolphin behaviour evaluating the possibility of repelling dolphins from an area of the sea where fishing operations are taking place.

To achieve the first objective, we planned to conduct census investigations and sighting campaigns in different Sicilian fisheries. The acquisition of census data was to

be performed using both log-books and interviews with the local fishermen therefore depending entirely on their co-operation.

While following the second line of investigation, we carried out experiments in a dolphinarium aimed at selecting acoustic stimuli capable of keeping dolphins away from a certain area of the sea. The statistical analysis of our results allowed us to select a set of signals to be used for controlling dolphin behaviour at sea. In addition, we developed an electro-acoustic prototype capable of emitting underwater acoustic signals. Finally, we implemented an experiment at sea with working fishing vessels to verify the operation and the effectiveness of our acoustic prototypes in repelling dolphins from a certain sea area. The experiments carried out at sea demonstrated that the acoustic signals used to provoke psychologically repelling stimuli (bottlenose dolphin and killer whale calls), worked well only for a short time.

Therefore we plan to start with a physiologically based new project comprising the following tasks:

1. Theoretical studies of Rice-Transmitting System (RTS) of dolphins;
2. Tank experiments;
3. Theoretical evaluation of the Natural Frequencies of Resonance (NFR) of main components of the Rice-Transmitting System (RTS) of dolphins;
4. Tank experiments in order to measure the actual natural oscillations of the different components of dolphin RTS;
5. Design and realisation of an experimental prototype to be used in the subsequent steps, namely during floating cage and open sea experiments;
6. Floating cage and open sea experiments to evaluate the efficiency of selected signals on live animals;
7. Planning and production of a set of final series prototypes and their testing during real fishing actions which are to be conducted in different sea areas.

Assessment of commercial fish stocks by hydroacoustics in the Baltic Sea Lithuanian economic zone

Justas Poviliunas, A. Astrauskas, E. Bernotas, T. Didrikas

Architektu 83–81, Vilnius 2049, Lithuania.

[e-mail: astrauskas@aiva.lt]

Investigations were conducted during 1996–1998 in the Baltic Sea Lithuanian Economic Zone (LEZ). In 1996–1997 a portable scientific echosounder SIMRAD EY 200P was used, whereas in 1998 – SIMRAD EY 500. Trawling was used to determine fish species composition. In 1996 the herring stock biomass was estimated to be 90 500 tons in the surveyed area, while in 1997 it was 62 870 tons and in 1998 only 52 100 tons. Generally, herring stock biomass has been decreasing year by year since 1993 (referring to Latvian hydroacoustic researches in the LEZ in 1993–1995). For instance, herring stock biomass decreased in 1998 by a factor of 2.6 when compared to 1993. However, only 27 to 37% of the total allowable catches of herring in the LEZ were taken during 1993–1998. Sprat stock biomass has been keeping at a rather stable level during the period for 1993–1998. In 1996 the sprat stock was estimated to be 76 700 tons in the surveyed area, whereas in 1997 it was 78 660 tons and in 1998 57 700 tons. During 1993–1998 only 7.5 to 53.2% of the allowable catches of sprat were taken. However, because of the present fishing intensity in the other parts of the Baltic Sea the sprat stock could possibly decrease markedly. Smelt stock biomass was estimated to be about 2 100 tons in the LEZ in November 1998.

Economic consequences of different pikeperch management regimes in Pärnu Bay (NE Gulf of Riga, Baltic Sea) in 1960–1998

Margit Eero

Estonian Marine Institute, Viljandi Road 18B, Tallinn 11216, Estonia.

[e-mail: margitee@ut.ee]

Some fish stocks in Estonian coastal waters have recently decreased which probably has been caused by increasing fishing mortality. In this study the economic consequences of the implementation of various exploitation regimes of pikeperch in Pärnu Bay have been compared. This is the first attempt to evaluate differences in exploitation pattern of a fish stock at the Estonian coast in economic terms. Historical data which includes official catches, percentage of age-groups in catches and mean weight of age-groups has been used for the period 1960–1998. Based on the catch curves and the VPA, the number of fish, biomass, spawning stock biomass and fishing mortality of pikeperch age-groups has been estimated in Pärnu Bay in 1960–1998. In the 1990s pikeperch spawning stock biomass has sharply decreased to the lowest level of the period considered. Although several strong year classes have hatched, they have been removed by intense fishery before they could have increased the spawning stock biomass. In the period 1960–1990, 5-year-old fishes formed the biggest part of pikeperch stock biomass, but later on the share of 4-year-old individuals in the biomass has become the biggest because the older individuals have been fished out.

Following the increase in demand for pikeperch in the 1990s, the average fishing mortality of the stock in the period 1993–1996 increased to more than twice the mortality rate in the years 1960–1992. In the 1990s pikeperch exploitation included younger age groups than in the earlier period. Despite the continuously high fishing mortality rate the pikeperch catches have decreased sharply since 1997. Therefore, it is evident that the pikeperch stock is in a very bad, pre-depletive condition in Pärnu Bay.

The rationality of exploitation of pikeperch is analysed separately in the periods 1960–1992 and 1993–1996 with

clearly differing exploitation intensity. The yields resulting from fishing mortalities in the periods 1960-1992 and 1993–1996 have been compared with the theoretical yield from the mortality pattern corresponding to the maximum long-term yield per recruit. The results show that in the period 1960–1992 the fishing mortality rate was reasonably close to the optimum but since 1993 the growth overfishing of pikeperch in Pärnu Bay has caused an annual loss of at least 35% of the possible catch. This has resulted in considerable decrease of income of fishermen and also affected the fish processing, marketing and employment.

Pikeperch is an economically important species in the Estonian coastal fishery, especially in Pärnu Bay. Present management of the pikeperch stock in Pärnu Bay is very unfavourable. Because of the removal of young age-groups before the end of their fast growth and too intense exploitation, the long-term profit from pikeperch fishery is remarkably lower than it could be when the stock was exploited more reasonably. Furthermore pikeperch recruitment overexploitation probably takes place in Pärnu Bay. This results in a spawning stock unable to produce year classes numerous enough to maintain the stock level. Therefore, the risk exists that in the future pikeperch may lose its previous position in the Pärnu Bay ecosystem.

Multispatial assessment of Icelandic flatfish stocks

Hreidar Thor Valtysson

University of Akureyri, The Marine Research Institute, Glerargata 36, Akureyri 600, Iceland.

[e-mail: hreidar@unak.is]

Fisheries in Iceland have been going through changes in the last decades, as the catches of cod have been declining and other species targeted in turn. A good example of this is the flatfish fishery using Danish seines. Since 1984, catches of various flatfish species have increased substantially and rapidly, but the knowledge about these species has been lagging behind, causing concerns about overfishing. This study is based on my M.Sc. thesis from the University of British Columbia, and is on a multispatial, multispecies assessment of some of the Icelandic flatfish stocks, using various models and sources of data. The focus here is on the witch flounder (*Glyptocephalus cynoglossus*) which has sustained catches of 1 000 to 4 500 tonnes annually since 1986, but usually less than 100 tonnes per year before that. Biomass index from an annual trawl survey shows a decline since that time and models based on other information agree on that. The fishing grounds however show different effects of the fishing and the likelihood profiles of the results are different. A brief summary is also provided on results for megrim (*Lepidorhombus whiffiagonis*), American plaice or long rough dab (*Hippoglossoides platessoides*), dab (*Limanda limanda*), lemon sole (*Microstomus kitt*), and plaice (*Pleuronectes platessa*) and a brief comparison of the effects of the fisheries on these species.

Assessment of the stock structure of blue whiting (*Micromesistius poutassou*) in the N-Atlantic using nuclear genomic RFLP's

Ólöf Yrr Atladóttir[1], Anna Kristín Daníelsdóttir[1], Godfrey M. Hewitt[2]

[1]Marine Research Institute of Iceland, c/o Biotechnology House, Keldnaholt, IS-112 Reykjavík, Iceland.

[e-mail: oatla@itis.is.]

[2]School of Biological Sciences, UEA, Norwich NR4 7TJ UK.

In the past years the use of genetic markers to assist in defining stock structure within fisheries has become more common. The available markers are proliferating, as are the questions addressed by population genetic research. Various types of genetic markers exist at both the protein and DNA level, each with their advantages and disadvantages[6].

Protein electrophoresis preceded direct DNA examination and is still widely used because of its cost efficiency and possibilities of fast results[6]. However, levels of polymorphism detected are sometimes very low and the method has been increasingly criticised because of suspected selection on some of the markers used[2,6,14]. Another big disadvantage is that bands (alleles) with the same electric charge and migration distance are not necessarily homologous[15].

In the past two decades the emphasis of molecular genetic studies has shifted from studies of proteins to direct studies of DNA because of the increased resolution and wealth of information that such markers can provide. With the development of the Polymerase Chain Reaction (PCR) new possibilities opened up for studies on the phylogenies and population genetics of fish[5] and facilitated the utilisation of DNA in population studies[2]. Among these newer methods are restriction fragment length polymorphism (RFLP) studies of mitochondrial DNA and of nuclear DNA[2,5,6].

Marine fish stocks are now increasingly being investigated with the help of molecular techniques in order to find genetic differences between presumed stocks, using either nuclear allelic types or mitochondrial DNA haplotypes[5]. Population genetics have become an increasingly important factor in decision making within fisheries management, as well as serving as an important tool for answering ecological, evolutionary and phylogeographical questions concerning life in the oceans.

The blue whiting is a rather small, pelagic member of the gadoid family, ranging in the NE-Atlantic from approximately 82°N to 26°N. A population also exists in the Mediterranean[3]. Although blue whiting has not been of considerable interest to the fishing industry, lately the never-ending search for a greater variety of marine resources has led to an increased interest in this abundant species and consequently the need to understand its stock structure has grown.

The bulk of studies on the stock structure of blue whiting have focused on morphological aspects, i.e. mean number of vertebrae, growth rate, otolith structure[3] and parasites[10]. Blue whiting has been divided into stocks on the basis of morphometric analysis[9] and Bussman (1984)[4] combined a morphometric approach with iso-electric focusing of eye lens proteins. A haemoglobin polymorphism and its frequency has been described by Møller and Nævdal (1969)[13]. None of these studies have proven to be conclusive. Recently, an analysis of blue whiting allozymes[7,8,11,12] has revealed three polymorphic loci which showed significant geographic heterogeneity and pointed to potentially isolated populations in the Barents Sea and Romsdalsfjord[8].

In this study the stock structure of the blue whiting in the NE-Atlantic and the Mediterranean is assessed using random nuclear RFLP´s. It is hoped that by direct analysis of variability within the nuclear genome it will be possible to elucidate further significant breeding units of this increasingly important species.

The project's aims are to investigate multiallelic nuclear gene sites in blue whiting throughout its range to gain more information about the division of the species into genetically distinct populations. It is a part of a larger study funded by the European Union (FAIR CT95–0282), where the stock structure of four gadoid species is analysed with various genetical methods. Genetic markers previously used in studies on Atlantic cod have been developed for blue whiting and are being used in screening for polymorphisms that could reveal micro- and macrogeographical distinctions.

Samples were taken from six locations in the NE-Atlantic and one in the Mediterranean. Gills were collected and preserved in 96% ethanol and biological data (length, weight, sex, maturity and age) was recorded for each individual.

Genomic DNA was extracted and precipitated using a modified version of the phenol-based method described by Taggart *et al.*[8] DNA was resuspended in 10 mM Tris or T.E. and re-precipitated[17] when necessary, to attain a sufficient concentration for digestion and hybridisation purposes (at least 0.3 mg/ml).

Samples were digested overnight with *Dra*I and *Taq*I, respectively. Under optimal conditions 7 mg of genomic DNA were digested with each enzyme, with deviations corresponding to the quality and availability of sufficient quantities of DNA. Digestions were stopped using 0.2 M EDTA and 6x loading buffer and electrophoresed for 16–18 hours in 0.8% agarose at 52 V and 45–49 mA. A l-HindIII ladder was electrophoresed with the samples as a reference.

After visualisation in ethidium bromide, electrophoresed DNA was Southern blotted to nylon membranes (Hybond-N+) under vacuum using Vacugene XL at 50 mbars. DNA was denatured for 40–60 minutes, depending on the thickness of the gel, neutralised for the same length of time and transferred in a 20xSSC blotting buffer for 60–80 minutes. Membranes were baked for 2 hours on 80°C to bind the DNA.

Probes, originally isolated and developed for cod (*Gadus morhua*) by Pogson et al.[14] were PCR-ed by an adaptation of the reaction conditions described by them[14].

Probes were labelled with the ECL direct nucleic acid labelling and detection system that is based on enhanced chemiluminescence and utilises the enzyme horseradish peroxidase for labelling[1].

Labelled probes (300–600 ng) were hybridised to membranes using the procedure described for the ECL direct nucleic acid labelling and detection system. Band patterns were visualised according to the same procedure. Hybridised membranes were exposed to an X-ray film for 4–16 hours.

Band sizes are evaluated and scored with the help of the computer program DNAfrag and data analysis is performed using various computer packages, e.g., Genepop[15] and Arlequin[16].

Initial screening of 47 enzyme/probe combinations has revealed eight polymorphic loci in blue whiting, somewhat less than previously found in Atlantic cod[14]. Seven are used in this project, four based on DraI restrictions and three based on TaqI restrictions.

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Marine ornithofauna and beached bird surveys in January and March 1999 in the Russian part of the Curonian Spit

Ismail Nigmatoulline

Department of Ecology & Zoology, Kaliningrad State University,Kaliningrad, Russia.

[e-mail: sqid@atlant.baltnet.ru]

Oil is the one of the most dangerous chemical substances for marine ecosystems due to the great effect and mobility of oil pollutants in the sea environment. The problem of oil pollution monitoring in the coastal region of the National Park of Russia "Curonian Spit", Baltic Sea, has lately taken on special significance due to the Oil Company "LUKoil" plans to begin oil extraction on the shelf only 22 km from the National Park. All traditional monitoring facilities are very expensive and usually don't provide a full picture of the situation. Instead beached birds surveys show more promise. This method uses the proportion of oiled corpses of dead seabirds on beaches as a parameter for the oil pollution monitoring. Another aspect of the marine oil pollution is the protection of the marine ornithofauna. For this detailed data on species and numbers composition and territorial distribution of water birds in the Curonian spit area which is one of the Baltic Sea protected areas (BSPA) is needed. It's also important to establish the significance of this area for water birds over-wintering and rest during migrations. These aspects of their ecology are very poorly understood. The main goal of this investigation is the study of species composition, numbers and distribution of marine birds and oil pollution of beached birds in the the coastal line zone of the National Park "Curonian Spit" during wintering and spring migration seasons. The land-based water-birds accounts and first Beached Bird Surveys in the Baltic coastal zone of the Russian National Park the "Curonian spit" were carried out in January and March 1999. These investigations were conducted using the route method. The total length of the Russian seashore of the spit is 47 km; from this 44 km were covered in winter and 40 km in spring. The differences between winter and spring distances were due the sharp change in the weather at the end of March survey. The route was divided into three parts, that were investigated on subsequent days from sunrise to 0.5 hour before sunset. The birds were counted at the maximum distance of 0.2–0.5 km from the observer (depending on the viewing conditions) using field glass 12x35. The species composition, numbers and some peculiarities of distribution of the water birds (Gaviiformes, Podicipitiformes, Pelicaniformes, Anseriformes, Charadriiformes) in the period of wintering (January 1999) and in the period of spring migration (second part of March 1999) were studied. Based on these data the absolute density of water birds (the total for all counted species and by each species) was calculated. During Beached Bird Surveys the beach territory and avandunes along the account's routes was investigated. In the beached birds description discovered birds were marked on a map together with the locality of corpses found (supralittoral, middle part of the beach, foot of avandune or avandune). Species identification and if possible sex determination was carried out. Peculiarities of feathering, the condition of these birds (stage of decomposition, the presence of signs of damage from predators and/or vultures), the character and depth of oil contamination, the condition of the beach part and its pollution by oil products, the presence of snow and ice cover on the shore was noted. At the base following numbers were calculated, the values of relative density distribution of beached birds (number of specimens per km of beach), species composition and relative density by each species, proportion oiled birds (the share of birds with deep contamination was noted separately) and distribution of these oiled birds relative to the density. In total 5 656 birds belonging to 19 species (5 families) were counted: 920 specimens of 13 species (4 families) in January and 4 736 specimens of 18 species (5 families) in March. Densities were 82.1 birds/km^2 in January and 269.7 in March. The most numerous species were *Clangula hyemalis* (32% of total in January; 44.6% in March), *Larus argentatus* (33.9%; 12.5%), *Melanitta fusca* (14.1%; 22.3%). Their densities were 26.25 spec./km^2 in January and 119.9 spec./ km^2, 27.9 spec./ km^{2}and 33.8 spec./ km^2, 11.6 spec./ km^2 and 60.1 spec./km respectively. The maximum value of density was determined for *Clangula hyemalis* in March – 203.9

spec./ km^2 in the middle part of the route between settlements Rybachiy and Lesnoje. In that time there was only 42.2 spec./ km^2 in the part between Lesnoje and Zelenogradsk city. Another example is *Larus argentatus* whose density was 87.9 spec./ km^2, 11.1 spec./ km^2 and 5.4 spec./ km^2 in January and 74.8 spec./ km^2, 16.3 spec./ km^2 and 3.9 spec./ km^2 in different parts in March respectively. Not so numerous species also have well-defined distribution in the coastal zone: they prefer one or other part of area. One species – *Gavia arctica* – was observed only once (1 spec. in March; 0.021% of total in this month). 84 km of beaches and dunes along the account's routes were surveyed for stranded birds. 31 beached birds were revealed: 1 corpse in January and 30 in March. 8 birds were identified only to genus (2 genus) and 23 to species (7 species). The most numerous species were *Larus canus* (100% from total in January and 8 corpses (26.7%) in March), *Clangula hyemalis* (5 corpses (16.7%) in March), *Larus argentatus* and *Podiceps cristatus* (3 corpses (10%) for each). 7 corpses (23.3% in March) of *Larus* sp. were found was not determined to species, they were non-complete corpses. Average relative density of beached birds was 0.37 spec./km: 0.023 in January (*Larus canus* only) and 0.75 in March. Stranded birds were evenly distributed in all 3 parts of the route, but there was a relative density up to 4 corpses per km in some local places. The maximum density among all species was 0.25 spec./km for *Larus canus* in March in the part between Lesnoje and Zelenogradsk (0.2 spec./km in total). 18 corpses (58.06%) were oiled. Average relative density of oiled birds was 0.21 spec./km. There were no oiled birds in January, whereas the relative density of oiled birds in March was 0.45 spec./km (60% of corpses oiled). The most numerous species of oiled birds were *Larus canus* (4 corpses, 22.22% of all oiled birds, 0.1 spec./km in March), *Larus argentatus*, *Larus sp*.(?) and *Clangula hyemalis* (3 corpses, 16.66%, 0,75 spec./km for each). There were 4 deep oiled corpses (12.9% of all stranded and 22.22% of oiled), all from different species (*Podiceps cristatus, Cygnus sp., Larus canus, Larus argentatus*). Most of them (3 corpses) were found in the middle part of the route. 28 corpses (90.32%) were damaged by carnivores or vultures. Most of them were oiled. Only 2 corpses (22.22%) of *Larus canus* and 1 corpse (100%) of *Gavia arctica* weren't damaged.

In conclusion, the wintering marine ornithofauna in the area of the Russian part of the Curonian Spit is poorer than in the early period of spring migrations. This area wasn't defined for any species of bird as an area of international wintering significance. But we need to use aerial and ship observation methods to investigate areas that are more remote from the coast. Uneven distribution is shown for most of the water birds species in the area of investigation. The main habitat factors must be studied to explain the nature of this kind of distribution. The number of birds increase in the period of migrations. It's one of the reasons why the number of stranded birds also increase in March. Other causes are the winter storms and onshore winds that affect the birds mortality and stranding. The proportion of oiled corpses is high, but the period of observation was too short for conclusions regarding the general situation. In perspective, as a result of the ornithological monitoring we'll be able to control oil pollution more effectively in this part of the Baltic and to take all necessary measures for environmental protection more efficiently.

Physiological disturbances at critically high temperatures: A comparison between stenothermal Antarctic, and eurythermal temperate eelpouts

Claudia Tesch[1], P. van Dijk, I. Hardewig, H. O. Pörtner

[1]Alfred-Wegner-Institute for Polar and Marine Research, Columbusstr. Bremerhaven 27568, Germany

[e-mail: clautesch@t-online.de]

The survival of ectothermic organisms and thus the distribution of species is closely related to the ambient temperature regime. Therefore the effect of gradually increased water temperature on the metabolism of Antarctic eelpout (*Pachycara brachycephalum*) and temperate North-Sea eelpout (*Zoarces viviparus*) was investigated. Standard metabolic rate was similar in cold adapted *P. brachycephalum* and cold adapted *Z. viviparus* in the low temperature range, indicating that Antarctic eelpout show no metabolic cold adaptation according to the original definition by Wohlschlag´s definition. However, they do show a compensatory increase of oxygen consumption compared to warm acclimated eelpout.

The intracellular pH in *Z. viviparus* white muscle follows alphastat-regulation over the whole investigated temperature range (3–24 °C) dropping by –0.016 U/°C. In Antarctic eelpout white muscle pH declined with a range of 0.015 U/°C between 0 and 3°C, but deviated from alphastat at higher temperatures indicating that thermal stress leads to acid-base disturbances.

The upper critical temperature limit (Tc II) as characterised by a transition to anaerobic metabolism was found to be between 21°C and 24°C for *Z. viviparus* and around 9°C for *P.brachycephalum*. In both species a rise of succinate concentration in the liver tissue turned out to be the most useful indicator of Tc II.

Based on our results and on literature data, impaired respiration in combination with circulatory failure is suggested as the final cause of heat death. Our data suggest that the southern distribution limit of *Z. viviparus* is correlated with the limit of thermal tolerance. Therefore, it can be anticipated that global warming would cause a northern shift in the distribution of this species.

Relationship between heterozygosity and fluctuating asymmetry in wild and cultured stocks of gilthead seabream (*Sparus aurata* L.)

Jorge Palma[1], J. A. Alarcon, C. Alvarez, E. Zouros, A. Magoulas, and J. P. Andrade

[1]*Universidade do Algarve, U.C.T.R.A., Campus de Gambelas, Faro 8000, Portugal.*

[e-mail: jpalma@ualg.pt]

Genetic variation is important in maintaining the developmental stability and biological potential of fish stocks. Genetic differences among stocks, or changes within a stock, can result in asymmetry between paired body parts (Hubert & Alexander, 1995).

A number of studies in recent years have examined relations between enzyme heterozygosity and fluctuating asymmetry (FA) (Leary *et al.*, 1983) which is commonly described as being small random departures from bilateral symmetry (Palmer, 1996). Results from these studies supported the hypothesis that individuals or populations having higher heterozygosity also display higher developmental homeostasis, reflected by lower degrees of bilateral asymmetry of meristic traits (Crozier, 1997).

The present study tried to verify the occurrence of this hypothesis in populations of wild and cultured *Sparus aurata* (L.) from five different countries.

A total of 252 wild specimens of gilthead sea bream were captured along the coasts of France (n=23, Oleron island, FrW), Portugal (n=50, Ria de Aveiro Lagoon, PtW), Atlantic Spain (n=48, Cadiz, SpAtW), Mediterranean Spain (n=51, Alicante, SpMW), Italy (n=40, Trieste, ItW) and Greece (n=40, Mesologgi Lagoon, GrW) (Figure 1). Original sample sizes ranged between 40 and 51. All individuals showed adult morphology and were rather similar in size. Additionally, 5 samples of 50 individuals each (250 in total), were obtained from aquaculture farms located in Portugal (Tavira, PtR), Atlantic Spain (Cadiz, SpAtR), Mediterranean Spain (Murcia, SpMR), Italy (Trieste, ItR) and Greece (Leros Island, GrR) (Figure 1).

Muscle and liver samples were analysed for 26 enzyme loci (AK-1, AK-2, ADA, ADH, DIA-1, END1, END2, EST, GPI1, GPI2, G3PDH, IDDH, IDHP, LDH-1, LDH-2, LDH-3, MDH-1, MDH-2, MDH-3, MEP-1, MEP-2, PGM, PGDH, SOD-1, SOD-2 and XDH) and for three microsatellite locus (Sa26, Sa32 and Sa41). Meristic characters were counted on the left and right side of each fish and comprised: pectoral fin rays and upper and lower gill rakers of the first branchial arch.

The asymmetry value for each fish (AVF) was produced: $AVF=\Sigma|c_{ir}-c_{il}|,|$,where *cir* and *cil* are the number of counts for the right and left side, respectively. The MAV (mean asymmetric value) was calculated as an additional index for comparison with the allozymes heterozygosity: $MAV= \Sigma(x_{ij}*j)/z_i$, where *xij* is the number of fish in each degree of heterozygosity *i*, and degree of asymmetry *j*, and z_i is the total number of asymmetric fish for each heterozygosity class. Within-sample relationships between heterozygosity (allozyme and microsatellites) and asymmetry (FA and AVF) were examined at an individual level using the Spearman rank correlation test. The FA, AVF and heterozygosity were compared between samples using the Wilcoxon signed rank test. FA was analysed according to the steps suggested by Pomory (1997).

From the 26 loci screened, 11 showed to be polymorphic (EST, GPI-2, IDDH, IDHP, LDH-2, MDH-2, MDH-3, PGM, PGDH, SOD-1, SOD-2), from which five were polymorphic in all samples (EST, GPI-2, IDHP, PGM, PGDH).

From the microsatellites analysis, high percentages of heterozygous individuals were found in the majority of the samples.

FA occurrence was proved to exist in 83.87% of the samples. Italian and Spanish samples (both W and R) presented high levels of asymmetry. The Greek wild sample was the least asymmetric.

The wild samples were quite similar, with a marginal degree of heterogeneity; the opposite occurred for the reared samples. MAV values were higher for all heterozygosity classes among cultured samples when compared with the wild samples.

All reared samples (except SpMR), presented lower allozyme heterozygosity values and higher values of FA (except for pooled FA in ItW) than the wild samples This might indicate a loss of genetic variability of the reared populations.

Although microsatellite values were always higher for the reared samples (except for the Greek samples), this could be attributed to the mixed origin of founding populations and/or the renewal practice of the stocks. Differences between natural and cultivated samples could be justified by the presence of most of the rare alleles in the wild population, which might have disappeared in the reared ones through genetic drift effect.

FA levels were generally quite low which agrees with other studies (e.g., Crozier (1997)). The comparative analysis of the reared and wild populations suggests that this developmental stability appears to be weaker in the reared samples.

The majority of the meristic traits did not show high values of FA, which indicates that the mechanisms of developmental stability were present. No destabilisation on the development seems to be occurring, with exception of the SpAtR, SpMR, ItR and ItW. The higher asymmetry obtained in these samples could be related to environmental stress and rearing conditions.

Wild populations from France, Portugal, Spain (Atlantic and Mediterranean) and Greece, as well as the cultivated populations from Portugal and Greece, reflect more stable environmental and culturing conditions. The present study does not clearly indicate a distinct pattern of geographic differentiation for either wild or cultivated samples.

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Salmonid egg incubation under various temperature regimes and proposal of suitable thermal conditions for incubation in a water re-use system

Egidijus Leliuna

Grybo 1-19, Vilnius 2000, Lithuania.

[e-mail: egidijus.leliuna@gf.vu.lt]

Temperature takes a significant role in fish rearing and particularly at the earliest stages of embryonic development. The object of this study involves measurements of morphological qualities of salmon (*Salmo salar* L.) and sea trout (*Salmo trutta trutta* L.) eggs. Also data on the success of embryonic development under conditions of various temperature regimes is presented. Sea trout eggs were hatched under conditions of "optimal" (4.0–6.0˚C) and "natural" (0.4–3.5˚C) temperature regimes. Salmon eggs were hatched under conditions of "half-natural" (2.0–4.6˚C) temperature regime. Rates of embryonic loss due to the temperature regime dynamics (sea trout – 9.6%, 42.5%; salmon – 17.1% respectively) were determined by the eggs individual characteristics. In 1998 a new salmon rearing plant has started operating near the river Zeimena (Lithuania, Svencioniai district). Here fish are hatching and starting to feed in a water recirculating system. This technology is a completely new approach in salmon rearing in Lithuania. Recovery of salmon resources in Lithuania and participation in the IBSFC (International Baltic Sea Fishery Commission) Salmon Action Plan are the main goals of the hatchery. In accordance with some of the data presented in this study, a new scheme of thermal conditions is proposed for salmonid rearing in the Zeimena recirculating system. This proposal is supported by the idea to feed more features of the natural ecosystem to the recirculating system and thus increase the adaptation of the artificial population to the natural river conditions. Monthly water temperature fluctuations in river Zeimena are the basis for this suggestion. Some data on the salmon and sea trout catch in Lithuanian economic zone in the Baltic Sea is presented also.

The effects of sediment extraction on macrobenthic communities in the southern Baltic Sea

Jochen Christian Krause

BfN-INA Insel Vilm, Lauterbach a. Rugen 18581, Germany.

[e-mail: jochen.chr.vilm@t-online.de]

Beginning in the 1970s basic research work on the ecological implication of marine sediment extraction has focussed on the coastal waters of the UK and the Netherlands which are the largest producers of sand and gravel in Europe. Recently the amount of marine sediment extraction in the Baltic Sea region has considerably increased. Unlike in the NE Atlantic the sand layers in the Baltic Sea are geologically young and form only thin layers. Therefore, and because of different environmental conditions in the Baltic (e.g., brackish water), severe ecological impacts were predicted. To analyse the effects on the ecosystem a four step programme was designed considering most effected the macrobenthic communities. The first step was a faunistic assessment of representative prospective extraction areas. Based on the results, macrobenthic species supposed to be sensitive to dredging activities were identified. Following the physical parameters of the sediment (grain size, C_{org}, C/N ratio, O_2 and S^{2-} – gradients), the water column (salinity, temperature, O_2–saturation) and the macrobenthic communities have been investigated before and after 320.000 m^3 had been dredged from a regular extraction field for a beach nourishment project. The paper presents the partly tremendous changes of the sea floor. These changes will be discussed in the light of step three of the project, in which (in laboratory experiments) the effects of dredging were simulated and tested on a supposed sensitive species. Finally the results will build the scientific basis for international and national legislation initiatives towards a more sustainable use of marine sediments in the Baltic Sea.

Resistance to oxygen deficiency of the polychaete *Travisia forbesii* Johnston 1840

Elke Körner

University of Rostock, Fachbereich Biologie, Freiligrathstr. 7/8, Rostock 18051, Germany.

[e-mail: ek@bio3.uni-rostock.de]

The growing demand for sand and gravel has recently increased marine sediment extraction in the Baltic Sea. One major effect of dredging sediments is the alteration of the seafloor topography. The furrows created by

mining activities function as a collector for fine sediment and organic matter and thus enhance the occurrence of oxygen deficiency zones in previously well oxygenated areas. *T. forbesii* is a typical inhabitant of those coastal zones which are affected by sediment extraction. Therefore it was chosen as a model organism for studying survival strategies and re-colonisation processes in the area concerned. To evaluate the metabolic and respiratory potential of this species under low oxygen concentration LT_{50} and caloric measurements are performed. The first results show a moderate tolerance to suboxic and hypoxic conditions. The experiments with direct and indirect calorimetry measured as metabolic heat production and oxygen consumption suspect *T. forbesii* to be an oxyconformer. The paper presentation will give an outline of the final results and will discuss the re-colonization potential of *T. forbesii* as a sensitive element of the original macrofaunal community.

Lateral distribution patterns of phytoplankton in a Brazilian tidal mangrove creek (*Bragança, Pará*)

Ursula Werner[1], D. Schories

[1]Mathildenstr. 91, Bremen 28203, Germany.

[e-mail: usc@uni-bremen.de]

Species composition and lateral distribution patterns in the abundance and biomass of phytoplankton were studied in a mangrove channel of the upper part of the Caeté estuary (Bragança, Pará, Brazil). The study was part of the German/Brazilian project MADAM (Mangrove Dynamics and Management).

The mangrove fringed estuary of the River Caeté is a macrotidal system and is characterised by a semidiurnal tidal cycle. In its upper part the blind ending channel Furo do Meio was chosen as study site. The tidal amplitude in the inner part of the channel is between 2,7 m – 4,9 m. Time of investigation included dry season and the beginning of the rainy season (30.10.1997–20.1.1998). A 3 km long transect was set along the part of the channel which contains water at low tide. Three stations, one at the end of the channel, one in the middle and one in the outer part of the channel were chosen for a closer investigation of phytoplankton species composition, abundance and biomass. Other parameters investigated were the chlorophyll *a* content, salinity, the seston content and the depth of the euphotic zone. Samples were taken at the peak of low- and high tide.

Species composition of phytoplankton: 112 species of Bacillariophyceae, 5 genera of Pyrrophyceae and two species of Cyanophyceae were found. Common species were *Chaetoceros sp*. I, Skeletonema costatum, Pennate I, *Delphineis c.f. surirella*, *Brockmanniella c.f. brockmanii* and three species of the genus *Thalassiosira*. Nearly all of the identified species are described as marine species, indicating that the species composition is mainly influenced by the water masses of the marine part of the estuary. Species numbers were high compared to other mangrove areas (Tundisi *et al* 1973; Kuttner, 1974; Ricard, 1984). This may be explained by differences in the strength of the tidal currents, as more than 50% of the species found in our investigation area are resuspended benthic microalgae. Cell-length or -diameter of most algae were smaller than 40 µm, thus nanoplankton contributed the largest fraction.

During the time of investigation the abundance varied between 3 and 55 million cells * l^{-1}, the biomass between 268–2497µg * l^{-1}, the chlorophyll a values between 1,9 and 90 mg*m^3.

At low tide, average abundance was up to 80%, biomass up to 52% and chlorophyll *a* values are up to 40% higher than at high tide, due to a higher number of resuspended benthic microalgae in the water column. Thus the tidal influence leads to a pronounced short term variability in the phytoplanktonic system. At low tide, blooms of presumably resuspended cynobacteria occurred in irregular intervals in the water column, contributing at one time more than 80% to the total abundance.

Distribution patterns of planktonic and resuspended benthic algae: At both tides biomass, abundance and chlorophyll *a* content in the inner part of the channel were higher than in the outer part. At high tide the lateral differences of abundance and biomass were more pronounced than at low tide, with the abundance being 60–69% and the biomass being 35–40% higher at the inner station than at the station at the mouth of the creek. Also, the greatest increase in abundance and biomass from high to low tide was found at the outer station. This indicates that the incoming water-masses of the nearby estuary were poorer in abundance and biomass of phytoplankton. However, the depth of the euphotic zone was shallower at the inner part of the creek and the seston content was generally higher in the inner part at both tides. This indicates that the depth of the euphotic zone is most likely not a major factor controlling the growth of phytoplankton, but might be a better availability of nutrients. It was therefore concluded, that the mixture of the water-masses from the creek and the nearby estuary is incomplete, so that there might exist a lateral trapping of water at the inside of the channel, which leads to longer-lasting, better environmental conditions for phytoplankton growth.

Interactions between coastal water areas modified by human activity and harmful algae adaptation strategies

Esther Garcés[1], Mercedes Masó, Magda Vila and Jordi Camp

[1]Institut de Ciències del Mar, P. Joan de Borbó, s/n, 08039 Barcelona, Spain.

[Corresponding author: e-mail: esther@icm.csic.es]

One of the risks of coastal regions on a world wide scale is the increase in Harmful Algal Blooms (HAB) and their linkage with the anthropogenic activities. Three possible explanations for this increase have been suggested: 1) the increase in the study and knowledge of the species due to control in waters dedicated to the farming of fish and shellfish, 2) stimulation due to the effect of

eutrophication caused by anthropogenic activities, and 3) increase in the geographical dispersion due to the transport of cysts of resistance in ballast water or to the movement of stocks of molluscs from one area to another. However there is a fourth aspect which has hardly been considered, but which may be the most relevant for coasts of seas which are calm, have no tides, and are very humanised (e.g., the Mediterranean basin). This stems from the capacity of dinoflagellates to colonise, establish themselves, remain and proliferate in areas created or modified by human activity, making good use of their adaptability potential, and laying the bases for a later speciation. In the last decades, there has been an elevated population growth in the coastal area and a clear trend towards the exploitation of the coastline for recreational purposes. This is causing a significant increase both in nutrients and in confined areas (ports, breakwaters, semi-closed beaches, etc.). The increasing confinement generates zones with particular characteristics: high water stability, water residence time and important pool of discharged nutrients, both factors favouring the development of dinoflagellate proliferations. The genus *Alexandrium* is the group of dinoflagellates which proportionally causes most HABs in the Mediterranean Sea. This genus includes species that cause PSP (paralytic shellfish poisoning). Three species of the genus *Alexandrium* are selected to give some clues in relationship with the increase of HABs of this genus in the Mediterranean, specifically the Catalan coast Two of them are well known (*A. minutum* and *A. catenella*) and one has been recently described (*A. taylori*). These three species are provoking new incidents (appeared over the last decade in the Mediterranean) associated with areas modified by human activities. The blooms are recurrent and frequently cause public health, economic, and political problems.

Alexandrium minutum is the toxic species (PSP) most widespread in the Mediterranean basin. Since the first bloom description in the Mediterranean (Halim, 1960) and until the the end of the eighties the presence of this species in the Mediterranean has been very sporadic. From the nineties references have increased 80% in semi-closed areas such bays and harbours. In the case of the Catalan coast, the species appears along a wide area of the Catalan Coast but it only proliferates massively in concrete harbours and in addition, recurrence is evident at least in one of them. From 1996, the year when the HAB monitoring of harbours began the number of harbours where *A. minutum* blooms occurs increased with 6 new localities. The other example, *Alexandrium catenella*, a PSP producer, has been reported as rare in the Mediterranean oceanic waters by Margalef and Estrada (1987). Since the first detection of a bloom event in Barcelona harbour in 1996, there has been growing evidence of the increase in abundance and geographical diffusion of *A. catenella* in the Catalan Coast. In late spring 1998, the first toxic event was described in the Mediterranean Sea, not only in some harbours but in open-sea waters. *Alexandrium taylori* was described in 1994 in the Atlantic, with unknown distribution beyond its type locality. *A. taylori* does not appear to be mentioned in the Mediterranean prior to its identification at La Fosca (Catalan coast). Since then, several descriptions in the Mediterranean basin have been recorded. The descriptions have mainly been from 18 beaches, where in addition recurrence is evident in many of them.

In conclusion, the species presented (*A. minutum, A. catenella, A. taylori*) are responsible for new, emergent problems and we can foresee from the advance of the species biogeography that *Alexandrium* blooms in Mediterranean coastal waters are increasing. There is a great significance of the sheltered waters as a favourable influence in the organism's population growth and as seedbeds to maintain a high number of resting cysts. The interaction between these areas and the different life history and behaviour strategies is the key mechanism to be studied. Moreover other emerging questions must be solved: What is the interaction between mesoscale blooms and the blooms linked to man made sheltered areas? Could the adaptability potential of *Alexandrium* together with the existence of man made sheltered areas be laying the bases of a later speciation? And finally, how important are the increase of man made sheltered areas in the world wide increase in HABs ?

Anyway, if new studies confirm the significant influence of coastal sheltered areas (harbours, beaches) on recurrent HAB events, new measures of coastal management will have to be formulated.

Algal biodiversity: its status, perspective, application

Pavel Prosselkov

Ben-Gurion University of Negev, Institute for Applied Biosciences, P.O. Box 653, Beer-Sheva 84105, Israel.

[e-mail: prosselkov@hotmail.com]

It is almost impossible to point to any ecological meeting where the issue of biodiversity is overlooked. Unfortunately, algae have been always omitted from the debate possibly because of underestimation of the role they play. The economic importance of algae was not sufficiently recognized (Norton *et al.*, 1996). But we know that algae form the base of the food chain for 71% of the world's surface because they are the only significant primary producers in the oceans (Norton *et al.*, 1996), for example commercial fisheries and aquaculture depend, directly or indirectly, on algae. Moreover, there are no good descriptions of the algal resources. We still continue to discover new species. In most phyla the number of described taxa is just a fraction of those awaiting discovery, e.g., Sournia et al. (1991) estimated that over 21% of marine phytoplankton species are insufficiently known or doubtful entities. For example, we only recently accepted the existence of picoplankton. Really, can it be true that there are several hundred species of Chlamydomonas or Chlorella, but very few species in most other related genera? The current state of phycology has an urgent need to inventory the world of algae and to conserve species in culture collections.

There is no doubt that powerful molecular techniques will soon be an indispensable tool for the algal taxonomist and will revolutionize algal systematics just as the electronic microscope has done (Norton *et al.*, 1996). But we are still far from understanding how to employ its power for monitoring or assessment tasks. To study the algal biodiversity the classical approaches of biology and ecology of algae must be complemented with molecular biology tools. For example, an interesting point for future application of knowledge of biodiversity might be the development of specific molecular probes which give us the possibility very quickly to follow the changes of phytoplankton compositions upon different ecological conditions. On this basis a prediction of phytoplankton behaviour can be created (e.g., the appearance of harmful algal blooms). The biggest technical barrier here is how to get enough nucleic acid from a few or even single cells for getting the required signals, because many species do not grow under laboratory conditions.

We have to understand the biodiversity to be able to preserve the natural resources of our planet and to estimate the possible impact of human activity. What could be done in this field? First, we need to collect our knowledge and to evaluate it. To establish the current status of algal biodiversity the compilation of some lists has already been started. They consist of all necessary information for initiating work on assessment of global algal biodiversity (Lists 1–5, only headings of the lists are shown here, for the full versions ask the author; all lists are still under construction).

1. The worldwide algal culture collection list (List 1). Currently it comprises more than 250 existing algal culture collections. The list has been run through the algal discussion groups several times, and now with the help of Bill Silvert it is available online (http://www.mar.dfo-mpo.gc.ca/science/mesd/he-/toxins/algalist.doc). In the near future it is planned make a personal contact with the curators who responsible for their holdings to recheck all data. Unfortunately, we still do not have complete information concerning collections in Africa, Asia and former socialist countries including Russia.

2. The next list, compilation of which will be completed in 2000 is about algal strains worldwide. This list will show how many strains or species we have in stocks, which part of the diversity we can preserve and which species are still left to be cultivated. This is a demanding work, but judging from the international response this list is appreciated.

   After both of these lists are finished all collections will be rearranged according to the number of the strains they hold. There is also the possibility to do interesting work on the geographical distribution of algal culture collections in different parts of the world and to compare it with the sites of high or low levels of algal diversity. The results can be further used to concentrate our forces on exploration of still poorly-studied locations. The same work might be also done on species level comparing the number of species isolated from the specific sites with the amount of their natural habitats. These lists will stimulate the activity of algal culture collections, they will help them in inventarization of their holdings (because some of the collections do not even have the printed description of their strains); they will also inform the worldwide community about the existence of the collection; these lists may also be helpful in communicating and working with the public.

3. The next one is a list of toxic algal strains worldwide. Despite there being already several published ones I have decided to compile an electronic version of the list which will be regularly updated.

4. The list on literature on global algal biodiversity will also be helpful in achieving of the goals of the work.

5. And the last one – the list on the role of algae and algal-human interactions.

How can we employ our knowledge concerning algal biodiversity? As can be seen, there are three possibilities:

- to assess the human impact, that is the usage of biodiversity as a marker of intensity of the natural resources exploitation;
- to predict the behaviour of the algal systems (sometimes, the tiny, subtle alga (e.g., phytoflagellate) can tell us much more about the future behaviour of the biosystem than a huge amount of widely distributed ones, e.g. diatoms);
- to look for a suitable object for any biotechnological approaches (the maintenance of algae may be a key factor in exploiting algae as a source of natural products).

In conclusion it is worthwhile to reconsider the idea that algae will probably inherit the earth and therefore we have more than ever reason to define the status of algal biodiversity, to think about its possible perspective and to look for its possible application.

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Improved nitrogen removal from sewage reflected in δ^{15} N values in *Fucus vesiculosus*

Candida Savage

Stockholm University Systems Ecology Department, Stockholm 106 91, Sweden.

[e-mail: candida@system.ecology.su.se]

Himmerfjärden, a 30 km-long narrow bay on Sweden's Baltic coast, receives treated sewage from 240 000 people at its landward end. During the 23 year period that the Himmerfjärden has been monitored, increasingly efficient nitrogen reduction procedures have been implemented, with the sewage plant now achieving over 90% denitrification efficiency. As the inorganic nitrogen in the sewage water is enriched in ^{15}N relative to normal seawater through denitrification, an analysis of the distribution of ^{15}N in the bay tells us the impact area of the sewage nitrogen from the discharge point. The attached alga, *Fucus vesiculosus*, takes up nitrogen during the winter season which it uses for growth in spring and summer. Sampling the growth tips of Fucus can therefore provide an integrated picture of the fate of sewage nitrogen in a coastal bay. δ^{15}N values for *Fucus vesiculosu*s collected in 1989, when the denitrification process was operating at about 70% efficiency, were uniformly high (11–13%) in the algae growing near the sewage treatment plant to 15km downstream (Hobbie *et al.*, unpublished). Beyond 15km to 30km away from the outfall where the water exchanged with the open Baltic Sea, there was a linear decrease of the Fucus δ^{15}N to background levels of about 4%. After the implementation of 90% nitrogen reduction in the sewage treatment plant, the gradient in δ^{15}N values was less pronounced with Fucus δ^{15}N values of 8% immediately outside the sewage plant and decreasing to 4% about 10km downstream from the outfall. It appears therefore that even though the improved denitrification process produces isotopically heavier effluent, the smaller quantity of nitrogen being discharged from the sewage treatment plant is being more effectively diluted which accounts for the lighter isotopic signal in the Fucus samples. A gratifying feature is that Fucus δ^{15}N = 4 % in the outer part of the Himmerfjärden for the sampling occasions in 1989 and 1999, which augurs well for the use of nitrogen stable isotopic ratios in *Fucus vesiculosus* to monitor changing nitrogen reduction procedures in a sewage treatment plant.

DISCUSSION

This discussion emphasized the need to educate resource users about the sustainable use of the resources. The vocabulary normally used by ecologists might be too specific to ensure the public's attention and understanding of the issues, hence the use of metaphors was suggested. An example of this was comparing the extirpation of a species to removing books from a public library and burning them. Another possible way of making ecological impacts understandable is to explain them in economic terms. For instance can the economic value of nutrient cycling be estimated and expressed in proportion to e.g., GNP. On the other hand the scare tactics rooted in public health concerns should be used with caution and on a limited basis otherwise this issue will be devaluated in the public opinion. Furthermore the scientists need to create awareness of the research problems, to be able to demonstrate the need for a particular study, and to come up with practical, understandable solutions to the problem at hand.

The perceived gap between "pure" and "applied" science is a stumbling block on the road to science based management of the ecosystems. The feeling was that a range of research types are needed, and that scientists should do away with the idea that "basic is better". The gap between experimental and field research was also discussed. In particular, it was suggested that field researchers could benefit from greater understanding of experimental work (e.g., temperature effects on fish growth). The need to initiate baseline data collection was also put forward as a priority in relation to ecological impact studies.

Polychlorobiphenyls and pesticide residues in monkfish and black scabbard from the Rockall Trough

Sophie Mormede and I. M. Davies

FRS Marine Laboratory Aberdeen, PO Box 101, Victoria Road, Aberdeen, AB11 9DB, Scotland, UK.

[e-mail: mormedes@marlab.ac.uk]

Polychlorobiphenyls (PCBs) and pesticide residues were determined in monkfish (*Lophius piscatorius*) and black scabbard (*Aphanopus carbo*) caught in the deep-water (650–1000m) continental slope of the Rockall Trough west of Scotland. Monkfish muscle and liver tissues were analysed, as well as black scabbard muscle, liver and gill tissues. Median concentrations of ?CB (26 congeners), HCB, Σchlordane, ΣDDT and dieldrin ranged from 250 to 1000, 18 to 25, 75 to 130, 300 to 450 and 22 to 38µg/kg lipid weight respectively in all organs. Although the higher concentrations, on a wet weight basis, were found in liver tissues, there were no significant differences in these concentrations between organs on a lipid weight basis.

All concentrations of contaminants in black scabbard and monkfish muscle and liver tissues were at least five times lower than the UK and strictest European dietary guidelines. Levels reported by McKenzie (1999) for shallow-water monkfish are similar to those reported in this study. The deep-water monkfish analysed during this study present levels of CBs and OCPs higher than shallow water monkfish coming from background areas, but lower than those from industrialised areas such as the Clyde Sea, although HCB and ΣDDT were higher in deep-water fish than shallow water fish coming from both uncontaminated and contaminated areas around Scotland (McKenzie, 1999).

The only paper reporting organic contaminant concentrations in deep-sea black scabbard is Kramer *et al.* (1984), for one 106 cm long fish caught in Madeiran

waters at a depth of about 800m; the levels reported are 10 to 30 times higher than those measured in this study. None of the following deep-water studies sampled the same species as the current study, so any comparisons will include inter-species differences, as well as geographical differences, local environment factors, etc. Berg *et al.* (1997) analysed eight deep-sea species for organic contaminants, and the levels varied to up to a factor 10 within a single area, sampling and analysis method. The concentrations found during this study were similar to those published by Berg *et al.* (1997) and Hale *et al.* (1991); and 4 to 20 times higher than the ones found by Barber and Warlen (1979) in *Antimora rostrata* livers. They are similar or lower to those published by Lee *et al.* (1997), and up to 100 times lower than those reported by Melzian *et al.* (1987) in deep-sea fish caught near former waste disposal sites and a contaminated bay outflow in the eastern Pacific.

ΣChlordane was mainly composed of transnonachlor (about 55%) and α-chlordane (about 25%) for both species in all tissues. ΣDDT was mainly composed of p,p'-DDE in both species (50–65%), then equivalent percentages of p,p'-DDD and p,p'-DDT (20%) in black scabbard. Female monkfish presented a higher percentage of p,p'-DDD (25%), whereas male monkfish presented a higher percentage of o,p'- DDT, the other compounds accounting for less than 10%. The ΣCB/ΣDDT ratio was higher in monkfish than in black scabbard, and in both species was significantly higher in muscle tissue than in liver and gills. This may be due to the different patterns of metabolism in different organs, liver presenting the lowest ratio of all organs which may reflect its role in metabolising some CBs. The p,p'-DDE/ΣDDT ratio was not significantly different between species, at about 0.58, but presented a wider range in black scabbard samples.

The distribution of the CBs (normalised to CB153) showed differences between organs. CBs 28, 31, 44, 49, 52, 70, 74, 101 and 110 were found almost exclusively in muscle tissues, and are virtually undetectable elsewhere for both species. ΣCB and CBs 118 and 149 present the same pattern, but with measurable concentrations in livers and gills, although much lower than in muscle tissue. CBs 138, 180, 187 and p,p'-DDE present higher levels in muscle tissue for monkfish and in liver and gill tissues for black scabbard. Finally, HCB and CBs 105, 128, 156, 170 and 194 are present in relatively high proportions in black scabbard livers and gills in comparison to black scabbard muscle and to monkfish tissues, with very low levels in any monkfish tissues.

In monkfish, HCB, ΣCB and ΣDDT expressed on a wet weight basis were correlated with length, weight, and each other. On a lipid weight basis, levels of most detected pesticides were positively correlated with each other in both monkfish and black scabbard. In the same way and in black scabbard only, a set of CBs were positively correlated with each other, namely CBs 28, 31, 49, 70, 74, 101, 110, 118 and 149.

Both species could be separated using discriminant analysis, presenting statistically different patterns in levels of these contaminants. Within species, a separation was achieved between the muscle, gill and liver tissues levels in black scabbard, but not in monkfish.

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Effects of endocrine disrupting chemicals on crustacean larvae

Zoë Billinghurst, A. S. Clare, and M. H. Depledge

Marine Biological Association of the UK, Citadel Hill, The Hoe, Plymouth, PL1 2PB, UK.

[e-mail: ZB@wpo.nerc.ac.uk]

The increasing occurrence of environmental oestrogens in the aquatic environment presents cause for growing concern for human and wildlife populations. Significant information on the impacts of these chemicals on terrestrial and aquatic vertebrates has been published, but very little information is available concerning the impacts of these chemicals on aquatic invertebrates. Aquatic invertebrates are potentially one of the groups of animals most at risk from exposure to endocrine disrupting chemicals (EDCs) including, more specifically, environmental oestrogens, and preliminary

evidence supports the fact that they will be sensitive to the action of EDCs. Invertebrates underpin a large number of ecosystems and are economically and commercially important, three factors which in themselves should instil concern over the preservation of the biodiversity of these animals. Furthermore, data on the impacts of EDCs on sessile, aquatic invertebrates may provide the basis for the development of biomarkers to detect low level contamination of water with EDCs, at specific locations, and prevent further contamination.

Preliminary experiments were carried out using the larvae of the barnacle *Balanus amphitrite*. Larvae were exposed to the natural oestrogen, 17 ß oestradiol (E2), at naturally occurring concentrations and the synthetic oestrogen 4-n-nonylphenol (NP), at environmentally realistic levels. The results of these experiments showed significant behavioural and biochemical effects of E2 and NP on exposed barnacle larvae compared to the control animals. The settlement of the cyprid larvae was significantly inhibited following exposure to NP and E2 during settlement assays, and the production of a larval storage protein, cyprid major protein (CMP), was significantly increased following similar exposure of the larvae from release until the cyprid stage (8 days). In neither of the experiments was there clear evidence that the cause of the abnormal response was endocrine disruption.

Subsequently experiments have been carried out with the barnacle *Elminius modestus*. The aims of these trials were to identify sensitive periods during larval development and to determine the impacts of exposure on the timing of development. Barnacle larvae develop to juveniles via three main stages: nauplii, cyprid and spat, then juvenile and adult. Developmental, behavioural and biochemical assays were carried out to generate a detailed picture of the effects of the contaminants on these crustaceans. The assays that were used included a settlement assay with one-day and three-day-old cyprid larvae, monitoring the timing of development and determining the impacts of 24 hour, pulsed exposures. The concentrations of NP that were used were in the region of 0.01 μgl^{-1} and 10 $\mu g\ l^{-1}$, and E_2 was used at a concentration of 10 $\mu g\ l^{-1}$. Settlement of day 1 cyprids was enhanced by exposure to both E_2 and NP in all the trials carried out, similar results were obtained when day 3 cyripds were used in the assay. The timing of development of larvae exposed to NP and E_2 from release until the cyprid stage was significantly effected by exposure: stage 6 nauplii developed in less time in the exposed systems compared to the animals in the control treatments, as did the cyprid stages. However, settlement was not significantly different between the larvae in the exposed and control treatments in these trials, when exposure was throughout the duration of larval development. No concentration dependent response curve was observed in any trial.

Larvae were exposed sequentially to 24 hours 1.0 $\mu g\ l^{-1}$ NP, from release until the cyprid stage. Exposure on days 0–5 had no impact on cyprid development, but exposure on days 6, 7 and 8 inhibited cyprid development. Following long-term (12 month) exposures juveniles in all treatments were smaller than the control animals, however, the proportion with well developed ovaries did not vary significantly from the control population.

Preliminary data indicates that larvae exposed to E_2 and NP experience DNA damage and this may have serious long-term impacts. Further experiments are required to determine whether exposure of these crustacean larvae to EDCs has ecological implications, either to the barnacle populations, carnivores that feed on them or resulting in ecosystem disruption.

Spatially explicit and integrated modelling of human influence on marine ecosystems in the Netherlands

Johannes Gerrit Hartholt

P.O. Box 20907, EX The Hague, 2500 Netherlands.

[e-mail: h.harholt@rikz.rws.minvenw.nl]

At the Dutch National Institute for Coastal and Marine Management/RIKZ scientific knowledge concerning human influence on the marine ecosytem of the Dutch Continental Shelf and the Wadden Sea is implemented in policy oriented models. Two aspects of this type of modelling have to be considered: a) the geographical distributions of the human influence as well as the characteristics of the marine ecosystem are not homogeneous and b) the different types of human influence can be evaluated separately but the effects on the marine ecosystem are a result of the combination of the different activities. Therefore the ambition is to model the human influence in a spatially explicit and integrated way. The first step in the modelling approach was to distinguish the driving forces exerting environmental pressure on the marine ecosystem. Both driving forces and the resulting pressures have been mapped. At present, the response variables in the model are 32 selected species considered to be indicative for the quality and the integrity of the marine ecosystem. Response functions translate environmental pressure into effects on recruitment and mortality of these species. Many assumptions had to be made for the relevant parameters. As a consequence, the model can not be validated and has a high level of redundancy. Relevant output of the model is a ranking of human activities according to their contribution to population effects on the selected species. Further model development considers the incorporation of other response variables indicating functional properties of the ecosystem and properties related to nature and environmental policy objectives.

What problems should we be addressing in marine ecology?

Keith Brander – Invited Speaker – Co-Chair

ICES, Palaegade 2–4, DK–1261 Copenhagen K, Denmark

[e-mail : keith@ices.dk]

The sea is an alien environment – we do not live there and our experience of it is mainly indirect. Most of what we know about the sea comes from science, whereas our knowledge of the terrestrial world is also based on personal experience and accumulated cultural knowledge.

Because biological production in the sea is fundamentally different (small plants throughout the photic zone) the way in which we harvest marine production is also different. We crop "wild" stocks of carnivores and do not control the inputs (nutrients, light) pests or competitors.

Food production is only one of the goods and services provided by the marine ecosystem and may be quite minor in global terms, compared with the value of nutrient recycling, amenity and others (Costanza *et al.*1997). Marine ecosystems matter because of their role in regulating CO_2 and other biogeochemical cycles; because they biodegrade waste products; for biodiversity, intrinsic value, tourism and recreation.

Compared with our knowledge of biological production on land we are remarkably ignorant of marine production. This is because the sea is unfamiliar, plankton production is mostly invisible and very hard to measure, sampling is difficult and costly, we have very few seasonal or long term time series and the resources being applied to marine ecosystem research are very small.

The topics we should be addressing concern ecosystem functioning and resilience, patterns and causes of ecosystem change, response to global change, biodiversity. The research aims might be to:

- quantify the contribution of marine ecosystems to human welfare
- evaluate how resources should be deployed to protect welfare
- provide a credible basis for advice on sustainable resource management and protection of the marine ecosystem

and specific problems include:

- how plankton production affects fisheries
- how to measure 1^o and 2^o production
- causes of geographic, seasonal and inter-annual variability in production
- effects of human activities and evidence of alteration of the marine ecosystem

Even a rather narrow utilitarian view of the world must include healthy ecosystems as a prerequisite for sustainable economic systems and for the maintenance of human health and quality of life.

Costanza *et al*. 1997. Nature, Vol 387, 15 May 1997.

DISCUSSION

This discussion took its outset in the problem of the increasing levels of potentially harmful chemicals in the environment. It was questioned how realistic the application of the precautionary principle was, given the widespread uses of these chemicals and the rapidly increasing numbers of different chemicals, whose long term effects on the ecosystems for the most part are unknown. The public and commercial interest in these chemicals makes it extremely difficult to use the precautionary principle and fully test all xenobiotics before they are released.

It was further discussed whether the use of assays with laboratory animals to determine toxicity was subject to a systematic bias due to the use of hardy animals that are easy to handle in a laboratory situation. The tolerance and behaviour of these animals might be different from what is observed in most other species and hence compromise the results and conclusions reached.

An important issue that was treated in the discussion was the ranking of human activities in relation to their environmental impact. It was concluded that this ranking, as well as assessment of the cost incurred in mitigating the impact, is an important task for the scientific community and decision-makers in order to ensure that the public gets value for the money they spend. This ranking must be performed using all available knowledge and must be updated as new knowledge becomes available. The ranking could also help in guiding research towards relevant areas.

A comprehensive understanding of the constraints and pressures within the political decision-making process is not apparent to most of us. In this system microeconomics may dominate over macroeconomics, which could influence the proposed ranking of environmental concerns. Once again the importance of efficient communication with the decision-makers and the ability to communicate scientific knowledge was stressed.

Hypotheses regarding the fishing effects on the demersal fish community dynamics

Fabian Blanchard

IFREMER, Centre de Brest, BP 70, 29280, Plouzané, France.

[tel: +33 (0) 2 98 22 49 28; fax: +33 (0) 2 98 22 46 53; e-mail : fblancha@ifremer.fr]

Analyses of data from the Gulf of Maine, Georges Bank and the Scotian Shelf have demonstrated that the total biomass density of demersal fish is quite stable in time facing to the individual species biomass density

(Hennemuth 1979, Murawski *et al.*, 1991, Duplisea *et al.*, 1997). This feature is interpreted according to the hypothesis of energy limitation at the system level (Steele 1965) and community dynamics controlled by relationships between species. This assumption is tested in two temperate regions, the Bay of Biscay and the Gulf of Lions (France). The coefficients of variation of biomass densities for the whole demersal fish assemblage and for individual species are analysed on a decade scale, using scientific survey data. Results are consistent with the hypothesis: the variability of the total biomass is lower than the variability of the species biomass.

Moreover, according to Levine (1976) and Vandermeer (1980), quoted by Huston (1994) "when the frequency of predation is so high that it is essentially continuous, it can alter the strength of competitive interactions and allow the coexistence of competitive species". Pimm (1984) defined the interaction strength between two species as the magnitude of biotic interactions. Therefore, the temporal coefficient of variation of the total biomass density should increase when the interaction strength in the community dynamics decreases. Then it is suggested that fishing, removing biomass density, could move the community below the energy limitation threshold, altering the biotic interaction strength, and increase the total temporal variability.

The total biomass density, its temporal variability, and the fishing level are then compared in the Bay of Biscay, the Gulf of Lions and the Scotian Shelf. The fishing level is measured by the fishery productivity, according to Caddy *et al.* (1995). The fishery productivity is the annual landings of demersal fishes per surface area of the continental shelf. This measurement expresses the biomass harvested by area unit. The total biomass density variability increases when the fishery productivity increases. As a consequence, coexistence of individuals of competitive species should be favoured and the spatial segregation caused by competition (Finger 1982, Weisberg 1986, Wang and Tzeng 1997, Vehanen *et al* 1999) should decrease. Species-area curves are the number of new species encountered when the sampling area increases. Then the slope of the linearized species-area curves quantifies the segregation (Whittaker 1960). The spatial segregation and the fishery productivity are compared in an unfished Kenyan Lagoon (from the work of McClanahan 1994), the Bay of Biscay, the Gulf of Lions and the French Guyana Shelf (from scientific surveys). The spatial segregation decreases when the fishery productivity increases. It is concluded that energy limitation could be a conservative property of the dynamics of demersal fish communities and that harvesting should decrease the biotic interaction strength and the spatial segregation.

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Variability in the growth of turbot in the Baltic Sea central area

Didzis Ustups

Latvian Fisheries Research Institute, Daugavgrivas 8, Riga 1007, Latvia

[e-mail: ustups@latfri.lv]

This study presents the variability of growth of turbot in the Latvian coast area, the central Baltic Sea. Turbot is one of five *Pleuronectiformes* species inhabiting the Baltic Sea. Its biology and the condition of the stock is little known. Research on turbot is impeded by the fact that one of the main spawning places is situated in the Pape – Perkone protected area, close to the Butinge oil terminal

The research on turbot in Latvia began with the introduction of the commercial fishery on turbot in 1994. Turbot is a commercially significant fish of the Baltic Sea with one of the highest market prices. The intensity of the commercial turbot fishery increases every year. With the increase of intensity of the fishery, total catch per year has not been raised and the sharp decrease of catch per unit effort has been registered. Under these conditions special attention has to be paid to possible changes in the biology of turbot in order to determine the influence of the intensified fishery on turbot growth. The main aim of the study is to describe the growth of turbot and define the possible reasons for the observed changes.

Materials were collected in the Baltic Sea central area in 1998 during commercial and inventory fishing and with beach seine. Otoliths were collected from 369 fishes (228 female, 141 male). From each turbot one otolith was analysed. When possible the dorsal (symmetric) otolith was used for ageing of fish and structural measurements of the otolith.

The length at the time when the annulus is completed was backcalculated according the following equation (van Leeuwens and Rijnsdorp 1986):

BLx = ((OLx -1/2OL1) / (OLt - 1/2OL1)) * Lt

Where:

BLx = backalculated fish length at time x

Lt = fishlength at time t

OL1= width of 1st annulus

OLx = width of xth annulus

Olt = width of total otolith

Analysis of Variance was used in order to determine which generations were significantly different from others

Results

A linear model between fish length and otolith length is adequate and describes 92.8 % variability in fish length, thus the method used could be acknowledged as correct

The distribution of backcalculated lengths of the one-year old turbots was compared with the length distribution of turbot from beach seine catches from Kolka (Irbe strait) collected in June–July. Backcalculated length was on average 2–3 cm larger than lengths from beach seines.

Analysis of length distributions of backcalculated and beach seined turbots shows that backcalculated length is bigger. This has also been observed in the North Sea (van Leeuwen & Rijnsdorp, 1986).

The reasons for this difference can be the following:

Beach seine material is sampled in June – July, when formation of the hyaline zone is not complete.

One-year old turbot were sampled with beach seine in the Irbe strait coastal area, whereas material sampled for backcalculation was sampled in the central Baltic Sea. Taking into account the general trend of increased fish growth to the South, corrections could be made on the basis of different geographical sampling places.

Differences (3–4 cm) in the year 1991 could be caused by different sampling time.

Taking these factors into account we could conclude that there is no principal difference in these data, which indicates that the backcalculation method is correct.

Reasonable growth differences among generations were registered only during the first two years of life, therefore only the first two years were analysed.

Significantly larger average length has been registered for both one-year and two-year old males and females of the 1996 generation, plus one year old males of the 1995 generation. Preliminary analysis suggests that one-year old individuals of the 1997 generation were smaller than the others.

Thus according to Multiple Range Tests and Fisher's least significant difference (LSD) procedure, we can identify two significant different periods:

year 1991–1994;

year 1995–1996.

The year 1997 could be related to none of the groups described above, as hyaline zones were not completely formed.

Fishery could be one of main reasons for the increase of the growth rate in 1995 and 1996. There are several indirect arguments. Since 1994–1995 commercial fisheries of turbot started and the significant decrease of CPUE in 1997 was observed. Sharp changes of CPUE indirectly shows changes in density of the population. On the bases of these changes, the growth rate of turbot could be changed. Fishing decreases population size and provides the rest of the specimens with better food conditions and directly influences recruitment success.

Hydrographical conditions could be another reason for the growth changes. Surface water temperature during summer 1996 and 1997 were above the average.

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Modelling the effects of fishing on the age structure, feeding ecology and mean trophic level of Atlantic cod (*Gadus morhua*) on Georges Bank

David A. O'Brien

Chesapeake Biological Laboratory, 1 Williams Street, Solomons, MD 20688, USA.

[e-mail: obrien@cbl.umces.edu]

An age-based trophic model of Atlantic cod was developed from literature-derived data on growth, mortality and diet specific to the Georges Bank stock. The mean trophic level (MTL) for each age class increased steadily from 3.0 (age 0) to almost 4.3 (age 10), reflecting ontogenetic shifts in diet over the life span of cod. The model was used to estimate the MTL of cod cohorts under varying fishing pressure. Increased fishing mortality (F) increased the relative contribution of young cod to the total caloric intake of the cohort by selectively removing older fish. An increase in F from 0.0 to 1.0 resulted in a shift in overall cohort diet from primarily pelagic (finfish) to primarily benthic (crustaceans and mollusfs), and a concomitant decrease of cohort MTL from 3.92 to 3.64. Assuming a trophic transfer efficiency of 10%, increasing F from 0.0 to 1.0 also resulted in a 48% decrease in the biomass of primary producers required to support a given biomass of cod. These results suggest that sustained high levels of fishing pressure may have shifted the ecological role of cod in the Georges Bank system through alteration of the population age structure.

The influence of the Baltic Sea Lithuanian coastal fishery on commercial fish populations

Tomas Zolubas

Fishery Research Laboratory, P.O. Box 108, Klaipeda 5800, Lithuania.

[e-mail: ztl@is.it]

The coastal waters of Lithuania down to 20 m depth take up a relatively small part of the whole economic zone area (ca 7%). However, a lot of juveniles of marine, freshwater and migratory fish species are living and feeding here. In addition, some marine species have spawning grounds in this area. In the coastal zone there are no local commercial fish species populations. Thus only common marine fish stocks and fish common to the Curonian Lagoon can be caught.

Fishing efforts in the coastal zone of Lithuania increased enormously from 1992 to 1999 after private coastal gill net fishing commenced. Before this the zone was under military protection and almost all fishing activities were prohibited. Therefore it has been necessary to establish the influence of the fishery in coastal waters on natural fish resources.

One of the main factors which influence the commercial fish species population age structure and abundance is fishing gear selectivity and level of fishing intensity. Hence investigation on the possible influence of undersized fish bycatch in coastal gill nets fishery was established.

According to current Lithuanian fishing regulations, the allowable bycatch of undersized fish may not exceed 10% of the numbers of fish caught. Permissible mesh size of gill nets for commercial coastal fishing is 16–24 mm and 50–130 mm. According to the results of investigations, the catches of gill nets with 50 mm mesh size consist of about 40% of undersized flounder and pike-perch and about 90% of undersized turbot. These facts show that fishing rules for coastal zone are still incorrect and must be revised.

From the official catch statistics of 1996–1998 catches in the coastal zone in percent of total catches amounted to: 0.01-6% for sprat (*Sprattus sprattus balticus* (Schneider)), roach (*Rutilus rutilus* (L.)), bream (*Abramis brama* (L.)), cod (*Gadus morhua callarias* (L.)), herring (*Clupea harengus membras* L.), 8-33% for perch (*Perca fluviatilis* L.), flounder (*Platichthys flesus trachurus* Duncker), pike-perch (*Stizostedion lucioperca* (L.)), smelt (*Osmerus eperlanus* (L.)), and 40-96% for salmon (*Salmo salar* L.), trout (*Salmo trutta trutta* L.), vimba (*Vimba vimba* (L.)), whitefish (*Coregonus lavaretus* L.), turbot (*Psetta maxima* (L.)) catches. Juveniles of flounder and turbot were caught almost exclusively in the coastal zone. So it is important to choose such gear types and characteristics (especially mesh size of gill nets) that bycatch of flatfishes juveniles be reduced.

Based on gill net selectivity for undersized fish, taking into account the percent of catch in the coastal zone for the species, fishery regulation in coastal zone must have high priority for salmon, trout, whitefish, vimba, pike - perch, flounder and turbot. Other species such as smelt, perch, bream, roach, herring, sprat, cod don't need special fishery regulation.

Current status and future prospects of groundfish stocks around Greenland

Christoph Stransky

Federal Research Centre for Fisheries, Institute for Sea Fisheries, Palmaille 9, Hamburg 22767, Germany.

[e-mail: stransky.ish@bfa-fisch.de]

The groundfish fauna on the West and East Greenland shelves has provided extensive fish resources since the 1950's when large-scale trawling activities began. Over the past two decades, these fish stocks were subject to substantial changes in biomass, abundance and mean individual weight. This study provides an overview of the current status and historical development of commercially important groundfish stocks off Greenland using long-time commercial data and survey results of

the annual German groundfish survey, carried out in autumn since 1982. First results from the most recent survey in October/November 1999 are presented to give an indication on the future prospects of the commercially important fish stocks.

The Greenland groundfish fauna is dominated by few, mainly boreal species. Biomass and abundance estimates for the whole groundfish assemblage for 1982–1999 indicated relatively short-term changes, and a continuous downward trend in mean individual weight was apparent. Comparatively high biomass values, observed in the late 1980's, were due to large catches of cod (*Gadus morhua*) off West Greenland, while the late 1990's present a high level of biomass and abundance due to very large occurrences of young redfish (*Sebastes* spp.) off East Greenland.

After a sharp decrease in biomass in the late 1960's, the cod stock off West Greenland showed a slight recovery during the late 1980s. Since 1992, cod biomass off Greenland is stagnating on a very low level below 15,000 tons. Critically low bottom water temperatures and a weak spawning stock biomass are considered to be responsible for the collapse of the cod stock. The mean individual weight of four- and five-year-old cod showed a highly significant correlation ($p < 0.001$) with the bottom temperature on Fylla Bank, which was found to represent the whole survey area very well. Large occurrences of 0-group-cod, as indicated by the Icelandic 0-group survey off West Iceland in summer 1999, were not found on the East Greenland shelf during the recent German cruise in autumn 1999. During the past decade, catches of golden redfish (*Sebastes marinus*) were relatively poor and did not reach the 1986 level of 300,000 tons. Deep-sea redfish (*Sebastes mentella*), however, showed a distinct increase in abundance from 1995 to 1997 and a considerable decrease during the last two years. The size groups between 25 and 30 cm contributed more than 90% of the abundance and biomass of all redfish found in the survey area around Greenland. The average growth rate of this strong year-class, indicated by the length distribution trend, varies around two cm per year. The length distribution of pelagic redfish in the Irminger Sea, derived from the international oceanic redfish survey in June/July 1999, showed a distinct peak around 29 cm in addition the characteristic mean length peak of 35 cm. On the East Greenland shelf, however, the 28–30 cm peak disappeared almost completely, suggesting a strong migration of redfish from East Greenland into the Irminger Sea stock. The mean individual weight of Atlantic wolf-fish (*Anarhichas lupus*) and long rough dab (=American plaice, *Hippoglossoides platessoides*) decreased continuously over the past two decades. Biomass and abundance indices of halibut (*Hippoglossus hippoglossus*) were relatively low during the recent eight years, and the mean individual weight fluctuated between 2 and 20 kg.

While the demersal fishery off West Greenland remains on a very low level since 1991, large-scale shrimp trawling was established during the past few years. By-catches of young fish in the shrimp fisheries might reduce the chances of a recovery of the commercially important fish stocks in this area within the next few years.

Changes in the fish communities of the Norwegian Sea during the last decades – a period with fluctuating fisheries for pelagic fishes

Otte Bjelland

Institute of Marine Research, P.O. Box 1870, Bergen 5024, Norway.

[e-mail: otte@imr.no]

This study focuses on the pelagic fish communities of the Norwegian Sea during a period with pronounced changes in the fisheries, stock sizes and migrations of important species such as herring and blue whiting. The study presents results obtained by analysing trawl catches made during Norwegian summer cruises, primarily during the last decade. The dynamics of the species composition, abundance and distribution are described. During the last decades the spawning biomass of Norwegian spring spawning herring has fluctuated extensively. It was nearly depleted at the end of the 1960s, and slowly recovered during the 1970s and early 1980s. The spawning stock increased from about 1 million tonnes in 1987 to about 10 million tonnes in 1998. At the same time there has been a change in feeding migration patterns, which has resulted in a gradual extension of the feeding areas into the central parts of the Norwegian Sea. It has been suggested that other pelagic planktivores replaced herring in the Norwegian Sea after the herring stock collapse in the late 1960s, and blue whiting could be such a species. During the 1970s the fisheries for blue whiting gradually increased reaching a maximum annual catch of about 1 million tonnes in 1979–80. During the late 1970s and 1980s the fishery for mackerel in the Norwegian Sea also increased, with annual catches reaching more than 100 000 tonnes. If the ideas concerning replacement of depleted stocks are valid for the pelagic fish communities of the Norwegian Sea, one might expect that the growth of the Norwegian spring spawning stock during the 1990s would have serious effects on the distribution and abundance of other pelagic planktivores. The results of this study indicate negative effects on some species, while other species, e.g., blue whiting has increased in abundance during the last part of the 1990s.

Effectiveness of the Nordmore grate system in reducing bycatch of regulated groundfish in the Gulf of Maine northern shrimp (*Pandalus borealis*) fishery

Lisa C. Hendrickson[1] and R. A. Richards

[1]NFSC/NMFS, 166 Water Street, Woods Hole, MA 02543, USA..

[Corresponding author: lisa.hendrickson@noaa.gov]

Demersal trawl fisheries have been shown to impact the Northwest Atlantic continental shelf ecosystem: via changes in the biotic community structure, due to high fishing mortality on targeted species and/or bycatch species, as well as habitat alteration. Estimated bycatch ratios (weight of bycatch: weight of shrimp) in the small-mesh trawl fishery for northern shrimp in the Gulf of Maine have ranged from 0.8–1.6. Because many of these bycatch species are overexploited groundfish, the Nordmore grate system has been required in shrimp trawls since April of 1992. We examined the effect of the grate on reducing the bycatch of thirteen regulated groundfish species and its size selective effects on shrimp catches and discard species. Shrimp fishery observer data collected before and after grate implementation were analyzed and included bycatch and discard rates, shrimp catch rates, and size compositions of shrimp and discarded finfish after accounting for possible effects of changes in annual abundance. Bycatch (kg/hr) and discard (kg/hr) rates were significantly reduced with the grate for ten of the thirteen species, but increased significantly for the other three species. The ANCOVA models explained little of the variance of these rates. For six species tested for discard rate in numbers (number discarded/hr), the grate had no significant effect. However, the proportion of tows with zero bycatch of each species was significantly higher with the grate for five of the six species, suggesting that sampling effects were important. The grate did not shift selectivity toward small individuals, because pre- and post-grate length compositions of discard species and shrimp showed no apparent difference. Shrimp catch rates were significantly higher with the grate.

DISCUSSION

Drawing conclusions from terrestrial to marine ecosystems is difficult, as the role of the ecosystem components is different. In the marine ecosystem the carnivores are to a large extent prey to higher level carnivores, which is not often the case in terrestrial ecosystems. In the discussion on the effects of fisheries on the marine ecosystems this finding was important because fishing on a single species often removes both a potential predator and potential prey. Hence the ecosystem effects of biomass removal in the marine environment may not be as easy to predict as in terrestrial systems It was shown that fishing could increase biomass variability and decrease spatial segregation in fish, which was argued to be an indication of energy limitation as a conservative property in demersal fish communities. Moreover, examples of increase in individual turbot growth following increase in fishing intensity supported this hypothesis. The indirect effect of fishing was exemplified by a change in age structure of cod, which was found to change the stock's mean trophic level and hence its ecological role. When this happened other species appeared to take over the niche left vacant by the removal of large cod, – a scenario which has also been suggested for other fish stocks. It was pointed out that these effects of fishing were not properly understood.

There was consensus that more knowledge is needed on the biology of the exploited fish species in order to better manage and protect the fisheries resources. This knowledge could also be used to develop selective fisheries practices that would minimise the impact on non-target species and minimise the chance that the target stocks get depleted.

The workshop also discussed the potential for increasing the fisheries yield by fertilising the sea. Whether fertilisation will result in a trophic cascade resulting in increased fish biomass is very difficult to predict and the risk of adverse effects is eminent, hence it was agreed that these efforts are premature.

Effect of multiple stressors on the ecosystem: Mesocosm studies at the Patuxent River (Chesapeake Bay)

Silke Rick[1], Denise Breitburg[1], Gerhardt Riedel[1] & James Sanders[2]

[1]Academy of Natural Sciences, Estuarine Research Center, 10545 Mackall Road, St. Leonard, Maryland 20685, USA. [2]Old Dominion University, Dep. Of Ocean, Earth and Atmospheric Sciences.

[corresponding author: rick@acnatsci.org]

Nutrient and contaminant inputs to estuaries and coastal seas are globally ubiquitous problems that have caused and are continuing to cause fundamental changes in the structure and function of coastal ecosystems. The translation of the effects of multiple stressors through the food web was studied at the Patuxent River, a sub estuary of the Chesapeake Bay. Funding for the multi-investigator project COASTES (Complexity And Stressors in Estuarine Systems) was provided by NOAA Coastal Projects from 1995 to 1999 to investigate the role of complexity in an ecosystems response to stressors. Systems with rising trophic complexity (phytoplankton, phytoplankton + copepods, phytoplankton + copepods + fish, phytoplankton + copepods + fish + molluscs, + benthos organisms) were studied in 1 m^3 mesocosms for their response to nutrient enrichment and metal contamination as separate or combined stressors. Experiments were conducted over different seasons with the naturally occurring phytoplankton community, while the dosage of nutrients and metals always remained equal. The reaction of the ecosystem on the input of toxicants varied strongly, depending on the nutrient supply and the magnitude and kind of nutrient limitation at the time of pollution exposure. Additionally the season in which an input of

pollutants occurred, strongly influenced the consequences of pollutant input with regard to the naturally occurring species succession and their sensitivity. This can be of major importance in the evaluation of toxicity levels of a pollutant. Diverse factors that regulate the bio-availability of a toxicant in the water added to further variability in the observed effects. Cumulative and interactive effects of toxicants and nutrients were also tested in laboratory experiments with reduced trophic complexity. Several phytoplankton species, that had been important during the mesocosm runs, were investigated e.g., as monocultures. The intensity of response in the phytoplankton depended on the type of stressor applied. *Dactyliosolen fragilissimus* showed a non-linear response to rising arsenic concentrations in the media. Cumulative effects of toxicants as well as interactive processes between metals and nutrients were observed. The toxicity of the metals varied strongly with nutrient availability and complexing capacity of the media. Experiments with *Dactyliosolen fragilissimus, Chaetoceros gracilis*, and *Thalassiosira weisflogii* provided evidence for strong species specific differences in the responses to stressors.

Species diversity and ecosystem function in the coastal zone controlled by nutrient loading and consumer pressure

Boris Worm and H. Lotze

Dalhousie University, Biology Department, Halifax, Nova Scotia B3H 4J1, Canada.

[e-mail: bworm@is.dal.ca]

Humans strongly influence coastal ecosystems via changes in nutrient status (eutrophication) and consumer density and diversity (harvesting). This can trigger food-web changes across several trophic levels. We present results from comparative field experiments and field surveys in the coastal Baltic and NW Atlantic ecosystems. We show how the response of coastal primary producers (macroalgae) to eutrophication is mediated by changes in the abundance and diversity of consumers (grazers and predators). In the Baltic, eutrophication shifts structurally complex rockweed communities to low-diversity assemblages of fast-growing annual algae. Grazers control annual algal recruitment and indirectly enhance rockweed dominance. With increasing eutrophication annual algal growth becomes decoupled from herbivore control, with an apparent threshold of 100–150% increase in nitrogen availability. Similarly, in the NW Atlantic, rockweed communities become replaced by annual algae or filter-feeders in the course of increasing eutrophication. Grazer abundance seems to determine whether annual algae or filter-feeders dominate. These results illustrate how multiple human influences interfere with food-web regulation in the coastal ocean, with negative effects on species diversity, fishery yield, carbon storage and nitrogen retention. Combining pollution control with marine conservation efforts is necessary to restore these valuable ecosystem services.

Factors structuring coastal zooplankton distribution: eutrophication or climate?

Anda Ikauniece

Marine Monitoring Center, Institute of Aquatic Ecology, University of Latvia, 8 Daugavgrivas, Riga LV 1007, Latvia.

[e-mail: anda@monit.lu.lv]

Although the coastal zone of the Gulf of Riga is not particularly distinct by its geomorphological features, the environmental conditions there differ significantly from the open part of the Gulf. During previous investigations also horizontal gradients of temperature and salinity have been found along the coast. According to nutrient and chlorophyll concentrations, zoobenthos abundance and numbers of bacterioplankton, the coastal zone could be divided in several regions with different levels of eutrophication. Here we tried to answer the question whether mesozooplankton biomass distribution follows the pattern of water trophy or is it more influenced by hydrological factors? The results suggest dynamics of water masses - wind-caused mixing and upwellings are more important than the availability of food (phytoplankton abundance) even in summer. The hydrological factors mentioned have mostly negative effect on biomass numbers. Thus the high variability of zooplankton abundance should be considered assessing the nutrient flows through the coastal pelagic ecosystem.

DISCUSSION

This section was dedicated to a discussion on the interaction and cumulative effect of multiple stress factors. The marine environment is exposed to a wide variety of stress factors. It is therefore obvious that studies focusing on a single factor may miss out on some very important ecosystem processes that occur due to the interaction of two or more stress factors. As an example of this it was shown how the combined effect of eutrophication and overharvesting of grazers could alter a coastal food web by impeding the herbivore control of the macro algae communities. Another less obvious interaction discussed was the effect of nutrients on bioavailability of heavy metals. The discussion highlighted the need for multidisciplinarity in the study of how stress factors interact and affect the ecosystems.

The importance of communication: the FUNDY FORUM as an example in the Bay of Fundy

Maxine Westhead

Bedford Institute of Oceanography, P.O. Box 1006, B500 Dartmouth, Nova Scotia B2Y 3P2, Canada.

[e-mail: westheadm@dfo-mpo.gc.ca]

The Bay of Fundy, shared by New Brunswick and Nova Scotia, Canada, is a beautiful and unique area. Home to the highest tides in the world, it supports a wide variety of activities such as fishing, eco-tourism, whale watching, research, and more. The rich marine waters

provide livelihood for many individuals, and the health of the Bay is vital to their traditional way of life. Communication and information exchange are necessary for a greater understanding of the Bay of Fundy's unique ecosystem and coastal communities. The Fundy Forum, a dynamic web site and email discussion list server, provides an open and unbiased venue where groups and individuals can gather 'virtually', and work collectively for the health of the Bay of Fundy. Scientists may sometimes forget the importance of communicating their knowledge to the public, don't know how to communicate effectively with non-scientists, or simply don't have the time. Since January of 1998, I have been working towards increasing communications in the Bay of Fundy area between scientists, non-government organizations, the general public, the fishing community and anyone else interested in the Bay of Fundy. I will pass on the knowledge, experience, and lessons learned I have come across during my time with the Fundy Forum, while stressing the importance of discussion and information sharing.

Workshops 2 and 3

Top-Down or Bottom-Up Control in Marine Processes and Influence of Hydrographic Processes on Energy Transfer in the Planktonic Ecosystem

These two workshops were combined during the meeting and are therefore presented together here.

Summary

The joint workshop on the importance of top-down and bottom-up controls and the influence of hydrographic processes featured a very diverse group of presentations. Five major themes were identified, and within each theme, the importance of both physical and biological drivers was emphasised so that synthesis of the two overall workshop topics could be achieved.

A) Top-down and bottom-up controls

In several talks and posters, the importance of bottom-up controls was emphasised. In particular, there were many instances where nutrient availability or physical factors, such as temperature, salinity, or turbulence, strongly influenced primary production and algal community composition. In some situations, top-down control was recognised as a potential determinant of food web dynamics. In these cases, the abundance of consumers was markedly increased or decreased by factors such as advection or fisheries practices. Top-down and bottom-up controls most likely occurred simultaneously and with variable levels of importance, which greatly complicates quantitative evaluation of their respective influences in marine ecosystems. Food web theory developed in freshwater ecosystems suggests that top-down controls can be very important, and are most readily demonstrated via large-scale experimental manipulations.

B) Recruitment processes

Hydrographic factors, bottom-up controls, and predation shaped bloom and recruitment dynamics of marine biota. Hydrographic forces were important in delivering larvae to suitable nursery areas. Other physical factors in the environment, such as temperature, were important determinants of larval survival. Biotic forces included food quality in the nursery habitat and the presence of predators. In many cases, the importance of a hydrographic or trophic driver was dependent upon its timing. For example, under some conditions, noxious algal blooms could be controlled if top-down control (zooplankton grazing) begins before bottom-up forces (nutrient inputs) occur.

C) Environment and distribution

Large-scale environmental variables were shown to have strong influence over many biotic processes. In particular, temperature, salinity, stochastic climate events, and hydrographic processes such as upwelling and eddy formation at multiple scales were found to affect the abundance, species composition, and spatial distribution of phytoplankton, zooplankton, and macroinvertebrate larvae. Land use patterns and runoff levels influenced the concentration and stoichiometry of the dissolved nutrient pool, further shaping the distribution and composition of phytoplankton blooms. At a more local scale, the factors that govern primary production and food availability for primary consumers are physical factors, such as turbulence and sinking rates, although biological interactions can mediate these processes. Thus, the distribution of different biota is dependent upon a suite of physical and chemical variables, species-specific tolerances for those variables, and feedbacks from biological processes. These variables and processes can interact at multiple spatial and temporal scales.

D) Distribution patterns

Several presentations closely paralleled those of the previous session, as factors influencing the distribution of zooplankton and invertebrates were discussed. These factors included physical drivers, and also the relative importance of top-down and bottom-up controls, which were shown to be dependent on spatial scale and on the ability of predators to move between different habitat patches. Models are an important means of predicting distributional patterns of marine organisms at both small and large scales. Such models include multiple linear regression and neural network models that distinguish key parameters that affect distribution of biota; sensitivity analyses that measure interaction of environmental parameters; physical models that predict dispersion patterns; and more complex models, such as Markov Chains, that identify retention zones and allow one to quantify the dual importance of physical and biological factors that influence distribution.

E) Transfer through food webs

Presentations and posters concerning transfer of materials through food webs showed how such transfers could clarify trophic relationships, spatial distribution of biota, and the relative importance of biological vs. physical transfers of materials in marine habitats. Tracer techniques, including measurement of stable and radioactive isotopes, are useful in estimating most likely trophic linkages in food webs and in determining migratory patterns of consumers; such

information is crucial in determining community structure and, therefore, the probable importance of top-down and bottom-up controls in food webs. Vertical transfer of nutrients and other materials from near-surface waters to deeper waters, which has traditionally been viewed as a passive sinking process, may also occur via active vertical migration of food web components such as zooplankton. Food web dynamics may also have feedbacks onto physical processes, such as small-scale water movements that are influenced by temperature and may therefore be affected by phytoplankton density and light absorbance.

F) Conclusions

Top-down and bottom-up controls were both demonstrated to play roles in control of marine food webs. Their respective influences need to be quantified, which can be accomplished through experimentation, long-term studies, and consideration of life histories of community members. Hydrodynamic processes further contribute to food web regulation, particularly by influencing distribution of plankton and early life stages of larger organisms. Food web theories developed in other systems, particularly freshwater ecosystems, should be applied and tested in marine systems, although expectations for open and relatively closed marine systems will differ. Commercial fishing is a potential form of top-down control on marine food webs and should be regarded as a dynamic predation pressure.

Hydrographic processes are important regulators of material transport, and the study of marine food web controls must include the dynamic variables of the physical environment in which the food webs exist.

Vertical fluxes are primarily physical processes, mediated somewhat by biology, that are pivotal to determining nutrient budgets. Systems such as lagoons, fjords, and semi-enclosed seas enable the study of individual physical and biological processes in relatively simple spatial and temporal settings; theory derived from such studies can then be tested in more complex, open systems. The spatial and temporal scales in which both food webs and hydrographic processes are studied are important, and researchers must be prepared to consider larger scales than the ones at which their studies are being conducted.

A) Top-down and bottom-up controls

Trophic dynamics in Chesapeake Bay

Derek M. Orner

NOAA/NMFS Chesapeake Bay Office, 410 Severn Avenue, Suite 107A, Annapolis, MD 21403, USA.

[e-mail: derek.orner@noaa.gov]

In complex ecological systems, like the Chesapeake Bay, several factors usually contribute to observed 'problems'. The dynamics of an ecosystem are seldom so cut and dried as to allow one to point to a single factor in explaining an observation. A combination of several factors is usually required. Chesapeake Bay monitoring data are showing declining trends in some fish species, long-term declines in mesozooplankton populations, changes in the composition of phytoplankton communities, mixed trends in nutrients and long-term declines in water clarity. These trends are occurring in the Chesapeake Bay mainstem and in the lower reaches of its major tributaries. Significant declines in important forage species, possibly brought on by mesozooplankton declines and/or fishing activities might be limiting food for important forage fish (i.e. menhaden and anchovy) and larvae of higher level consumers (i.e. weakfish and striped bass). These food shortages are exacerbated by crowding caused by diminished available habitat because of water quality limitations, principally temperature (surface) and dissolved oxygen (bottom). Many factors must be investigated to determine the causes of changes among trophic levels.

Top-down modification of plankton species composition in North Norwegian fjords: Implications for vertical carbon flux

Marit Reigstad

Norwegian College of Fishery Science, University of Tromsø, N-9037 Tromsø, Norway.

[e-mail: maritr@nfh.uit.no]

Spring bloom events in northern coastal waters is bottom-up controlled, based on winter accumulated nutrients. Increased day-length and decreased vertical mixing triggers the onset, and diatoms and the colonial prymnesiophyte *Phaeocystis pouchetii* usually dominate the bloom. Inter-annual variation in the relative contribution from diatoms and *P. pouchetii* is observed, but the regulation mechanisms so far are uncertain. Studies from Balsfjord, Northern Norway in 1996 during a *P. pouchetii* dominated spring bloom, showed a delayed diatom bloom until June in spite of high silicate concentrations. Diatoms were present in low concentrations from the spring bloom onset in late March, but the main diatom biomass build-up and the silicate consumption took place two months later. Microzooplankton concentrations were also low until they increased in July. The abundance of flagellates was high during spring, and nutrients and food should thus have been in excess for both diatoms and ciliates. We suggest that selective grazing from mesozooplankton during the early bloom reduced the microzooplankton concentration and the accumulation of diatoms. *P. pouchetii* (colonies or single cells) and other flagellates were less exposed to mesozooplankton grazing and favoured through top-down regulation of their predators. Diatom and microzooplankton biomass increased when the mesozooplankton biomass was reduced in June/July. Flagellates were kept below a critical concentration of

100 mg C m^{-3} when the microzooplankton biomass exceeded 5 mg C m^{-3}.

A different scenario characterised the spring in 1997, when diatoms were dominating the spring bloom and *P. pouchetii* was hardly present. The mesozooplankton biomass this year was only 1/3 of the biomass measured in 1996 (~ 1500 and 500 mg DW m^{-2} in 1996 and 1997, respectively). The implication for the vertical carbon flux was considerable. During the year of *Phaeocystis sp*. dominance and high mesozooplankton abundance, faecal pellets dominated the vertical carbon export in spring, with moderate contributions from phytoplankton carbon. On the contrary, low mesozooplankton biomass and a diatom dominated phytoplankton community resulted in an increased total vertical carbon flux, as well as a change in the composition of the settling material. Diatoms were the major contributors to the carbon sedimentation during spring 1997, and the vertical flux of faecal pellets was significantly reduced compared to the previous spring. Situations similar to 1996 have been observed during earlier investigations, indicating that an inter-annually variable mesozooplankton biomass advected into the fjord can act as a regulating mechanism for the spring bloom species composition and the total amount and composition of vertical carbon exported. Low mesozooplankton abundance and high phytoplankton export in three adjacent fjords during spring 1997, suggests that large-scale advective processes are important for the mesozooplankton abundance in north Norwegian fjords and thus the phytoplankton development and the vertical carbon export.

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Plankton community structure and its influence on the flux of organic carbon by copepod faecal pellets

Juanita Urban-Rich

Louisiana Universities Marine Consortium, Chauvin, LA 70344 USA.

[e-mail: jurban@lumcon.edu]

The particulate organic carbon concentration in copepod faecal pellets was positively correlated with chlorophyll concentrations in different geographical study sites (Barents Sea, North Atlantic, Arabian Sea, Equatorial Pacific and Antarctic). However, the type of food and quality of food present also influenced the amount and type of carbon available for vertical flux via copepod faecal pellets. Two specific studies, Balsfjord Norway and the Antarctic Polar Front, were examined in greater detail for the effects of seston (e.g., phytoplankton and protist) abundance and composition on the vertical organic carbon flux through large (>200 μm) copepod faecal pellets.

In Balsfjord Norway, faecal pellet production rates, organic carbon and amino acid concentration and composition were monitored during a spring bloom in April–May 1994. Over the course of the bloom, the plankton composition changed from primarily diatoms to mainly *Phaeocystis pouchetti*. Faecal pellet production rates, pellet dry weights and total amino acid carbon concentrations were positively correlated with chlorophyll concentrations over the course of the spring bloom. As chlorophyll levels increased total organic carbon content in the pellets increased but then declined more slowly than chlorophyll such that the pellet carbon was not correlated with chlorophyll. However, examining the relationship between faecal pellet carbon content and phytoplankton composition revealed that carbon concentrations in the faecal pellets were lower when diatoms comprised >50% of the available food items. Laboratory studies have shown that diatom diets result in the lower pellet carbon density than flagellate diets (Hansen *et al.*, 1996). To my knowledge, this is the first field study that has shown for the mixed community of mesozooplankton (>500 μm) the carbon content of the pellets can be seen to reflect a change in diatom to flagellate diet. Over the course of this study the zooplankton community composition did not change significantly, *Calanus finmarchicus* comprised (75% of the copepods present. While total amino acid carbon content was correlated with chlorophyll levels the distribution of the amino acids in terms of particulate (PAA) and dissolved (DAA) ratios was not related to the amount or type of food available. The DAA:PAA appeared related to timing or quality of the food rather than plankton composition. Early in the spring bloom the faecal pellets contained a high DAA:PAA ratio and would thus contribute dissolved amino acids to the upper water column. After the peak of the bloom, the DAA:PAA ratio was much less than 1, thus pellets could contribute more to the flux of amino acids.

During the U.S. JGOFS Antarctic polar front (APF) study, experiments and samples were taken on two cruises, December 1997 (spring-phytoplankton bloom) and February–March 1998 (summer). Faecal pellet carbon content from all the major copepods (>200 μm) was measured using the high temperature combustion method (Urban-Rich *et al.*, 1998). In the spring, the phytoplankton bloom was underway and was dominated with diatoms. Carbon content of the faecal pellets produced during the spring was lower than those produced during the summer. Combining the data from the two cruises revealed a log-log negative correlation between faecal pellet carbon and chlorophyll or particulate biogenic silica. This suggests that when diatoms (silica containing plankton) were dominant the carbon content of the pellets from all major copepods is lower. Shipboard grazing studies were conducted during the summer cruise to monitor the type of plankton ingested by the copepods north and south of the polar

front and at the polar front. South of the APF, diatoms comprised a significant fraction of the food grazed and this was reflected in the low, 0.31 C:Si ratio of copepod faecal pellets compared to north of the APF where microzooplankton and flagellates were ingested and there was high, 3.85 C:Si ratio.

Combining the results from these studies with work done previously in the Equatorial Pacific, Arabian Sea, North Atlantic and Barents Sea (Urban-Rich *et al.*, 1999) reveals that the dominate part of the diet of copepods can be determined from the carbon content of the faecal pellets. Diatom diets from a mixed community of copepods feeding on natural seston results in a lower carbon content per unit available food then do flagellate or mixed diets. However, faecal pellet production rates were correlated to water temperature and total chlorophyll levels less than to food type. Therefore the flux of dissolved and particulate organic carbon through copepod faecal pellets will be lower during a diatom bloom than during a flagellate or mixed seston situation. This might have implications for the flux or cycle of organic carbon during iron enrichment studies.

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Can silicate and turbulence regulate the vertical flux of biogenic matter? A mesocosm study

Camilla Svensen[1], J. K. Egge[2], and J. -E. Stiansen[3]

[1]The Norwegian College of Fishery Science, University of Tromsø, N–9037 Tromsø, Norway. [2]Department of Fisheries and Marine Biology, University of Bergen, HIB, N–5020 Bergen, Norway. [3]Institute for Marine Research, P.O. Box 1870, N–5024 Nordnes, Norway.

[e-mail: camillas@nfh.uit.no]

A mesocosm experiment was designed in order to test bottom-up effects on the vertical flux of biogenic matter. The experiment consisted of eight enclosures all fertilised with nitrogen and phosphate (NP), while four of the enclosures received added silicate as well (NPS). Turbulence in two levels ("high" and "low") was generated in all enclosures. We hypothesised that silicate has a strong regulating effect on the vertical flux of biogenic matter by favouring the growth of diatoms, while the NP enclosures would be dominated by non-sinking flagellates. We further hypothesised a higher loss rate of diatoms in the high-turbulent than in the low turbulent environment caused by diatom aggregate formation. In the silicate enriched enclosures the diatoms contributed in average with 90% of the flux of phytoplankton carbon (PPC), while *Phaeocystis* sp. contributed with more than 80% of the PPC in the NP enclosures during the last part of the experiment. The sedimentation of chlorophyll *a* (Chl *a*) in the NPS enclosures was stable and low (15 mg Chl *a* m^{-2} d^{-1}) compared to the NP enclosures (up to 80 mg Chl *a* m^{-2} d^{-1}). The two levels of turbulence had an effect on the suspended phytoplankton community, while this was not reflected in the sedimented material. In conclusion, silicate had a regulating effect on the vertical flux by creating a stable loss of diatoms, while turbulence regulated the phytoplankton community but not the sedimentation of biogenic matter.

Top-down food web controls: what marine ecologists can learn from freshwater examples

Christopher J. Harvey – Invited Speaker

Center for Limnology, University of Wisconsin, 680 N. Park Street, Madison, WI 53706-1492, USA.

[e-mail: cjharvey@students.wisc.edu]

There is a growing interest in the importance of top-down control in marine food webs. Top-down control, whereby consumers directly or indirectly influence organisms at lower trophic positions in a food web, has been demonstrated most dramatically in studies of freshwater lakes. Experimental manipulations of whole lakes have shown that fishes play important roles in food web structure of lakes ranging from small lakes in relatively undisturbed watersheds to the Laurentian Great Lakes, USA. In these case studies, the addition or removal of predatory fishes caused cascading biomass changes at all trophic levels, including phytoplankton, and thereby affected ecosystem production. Top predators also influenced the size distribution of lower trophic levels, affected nutrient cycling and stoichiometry, and even altered biogeochemical fluxes such as the exchange of CO_2 across the atmosphere-water interface. Several common themes emerge from these studies: 1) the importance of top-down control was determined by changing top predator biomass significantly (i.e., an order of magnitude increase or decrease) and rapidly; 2) a generalist grazer (e.g., cladoceran zooplankton such as *Daphnia* sp.) with a strong and rapid numerical response to predation was present; 3) food web structure is simple, in that highly adapted trophic niches, functional redundancy, and omnivory are relatively unimportant; and 4) the studies were conducted at appropriate spatial and temporal scales (i.e., whole-ecosystem studies conducted for many years).

Applying concepts and food web theory developed in lakes to marine systems is complicated by many factors: marine systems are larger, more species-rich, and have complex physical drivers. Much of the information on

species abundance or biomass in marine systems comes from fisheries data, which are nonrandom data and are therefore biased. Furthermore, fisheries have been operating in most marine food webs for many years; thus the major manipulations in top predator biomass have already occurred and their impacts on the system have diminished. Thus fisheries fail to act as a well-designed experimental manipulation. However, there are many opportunities for ecologists to determine the role of top-down control in marine food webs. These opportunities include: relatively simple food webs; new and emerging fisheries; marine protected areas (MPAs) or other no-fishing zones; active adaptive fisheries management; and dynamic food web models. Several recent examples from the literature illustrate the use of such opportunities, including studies of salmon-zooplankton-phytoplankton food webs in the North Pacific Ocean and sea otter-sea urchin-kelp food webs of the North American west-coast. Determining the role of top predators in marine ecosystems is critical because commercial fisheries are removing the upper levels of so many food webs, and the impact of these species in ecosystem function must be determined.

Top-down control of *Pseudocalanus elongatus* through clupeid predation in the central Baltic Sea

Christian Möllmann

Institute of Marine Sciences, Dept. of Fishery Biology, Düsternbrooker Weg 20, 24105 Kiel, Germany.

[e-mail: cmoellmann@ifm.uni-kiel.de]

Sprat (*Sprattus sprattus*), the most important planktivore in the pelagic system of the open central Baltic Sea showed an extreme increase in stock development during the last decade. This development was to some extent caused by reduced predation mortalities through the Top-predator in the system, i.e. cod (*Gadus morhua*). One of the major food organisms of clupeids, the copepod *Pseudocalanus elongatus* showed in parallel a declining trend in population size, which is in general attributed to decreasing salinities in the area. The present study addresses the hypothesis that predation by the populations of sprat and also of herring (*Clupea harengus*), another important planktivore, contributes to the dynamics of *P. elongatus*. Therefore daily population consumption rates of sprat and herring for each quarter between 1977 to 1996 were calculated by applying models of gastric evacuation on a time-series of clupeid stomach contents and performing Multispecies Virtual Population Analyses. Predation rates were compared to corresponding production rates of *P. elongatus*, derived via abundance and temperature time-series.

Meso- and microzooplankton as food resources for fish larvae in the Baltic Sea, Gulf of Riga

Solvita Strake[1], E. Boikova[1], and N. Kondratjeva[2]

[1]Institute of Aquatic Ecology, Dep. of Marine Ecology, Latvian University, Salaspils, Miera 3, LV-2169; [2]Latvian Fisheries Research Institute, Riga, Daugavgrivas 8, LV -1007

[e-mail: solvita@hydro.edu.lv].

Fish larvae's growth rate depends on food availability and quality although the knowledge of interactions between fish larvae and micro- and mesozooplankton community as food resources is scarce in the Baltic Sea. The Baltic Sea near-shore areas present a remarkable fish spawning and fish larvae feeding habitat. In the eutrophied habitat of the Gulf of Riga, most of the fish larvae belongs to the Baltic herring (*Clupea harengus* L.) stock. In the 1990s the herring larvae relative amount in catches in July between 0-10 m was variable during the years. In 1995 their density represents 93.5% from the total fish larvae and ichthyoplankton communities, in 1996 and 1997 – 78.7% and 74.8%, respectively, but in 1998 only 58.2%. The distribution of herring larvae is closely related to the eutrophication gradient in 1995 and shows a clear impact on the micro- and mesozooplankton standing stock. In 1995 in the eastern part of the Gulf influenced by the river's outlet, the larvae reached 6500 ind/per 15 minutes trawling and the food resources - 416 mg/m^3. However, in the next year - 1996, they diminished 6 fold and this tendency was also seen in 1997 and 1998. Average data of micro- and mesozooplankton through the years are also variable: 2070, 662 and 1187 mg/ m^3 in 1996, 1997 and 1998, respectively. During the summer the newcomer carnivore cladoceran *Cercopagis pengoi* from the Ponto – Caspian region could play an important ecological role. The highest abundance values were observed in the eastern part of the Gulf – 474 ind/ m^3 in the shallow water (0–4 m) in 1998. *Cercopagis pengoi* has successfully adapted to the local conditions in the Gulf of Riga. However, although it may represent an important additional source of food for adult herring, it could be a strong competitor with herring larvae for food resources – microzooplankton.

B) Recruitment processes

Prey-quality threshold as a potential triggering mechanism of algal blooms and its sensitivity to varied hydraulic conditions

Daniel L. Roelke and Y. Buyukayes

Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX, 77843-2258,USA. [Internet: http://wfscnet.tamu.edu/faculty/roelke/frontR.htm

email: droelke@unix.tamu.edu]

Coastal wetlands have enormous ecological, environmental, and economic value because they provide essential habitat for wildlife and fish, protect surface and subsurface water resources, allow control of flood and storm water, and are areas of recreation. The state of Texas has about 7% of the coastal wetlands in the United States, and these wetlands serve as nursery grounds for over 95% of the recreational and commercial fish species in the Gulf of Mexico. In addition, they provide breeding, nesting, and feeding grounds for more than 1/3 of all threatened and endangered animal species in North America. Since the 1800s, however, Texas has lost more than half of its original wetlands, including more than 200,000 acres since 1952. A major factor contributing to the decline and disappearance of coastal wetlands is alteration of freshwater inflow.

Mixing of freshwater with seawater, and nutrient input from freshwater inflow are essential for maintaining structure and productivity of coastal wetlands. Damming of rivers and creation of reservoirs to meet anthropogenic water requirements reduces base flow to wetland ecosystems. In arid areas such as the coastal bend of Texas, this effect is exaggerated. As a result, salinity increases and fertility and productivity declines in wetland ecosystems that receive less freshwater inflow. It is important to the environment and to the economy that the health of these wetlands be sustained. The challenge for resource managers is to figure out how to allow human manipulation of freshwater to meet anthropogenic requirements while maintaining the quality of coastal wetlands. This requires fundamental information on how physical and biological processes that govern ecosystem structure and function are affected by changing hydraulic conditions. The following research addresses this issue through numerical modelling and laboratory experimentation.

Simulations representing varied hydraulic conditions were conducted using a detailed numerical model that depicted a planktonic foodweb. Pools of the model included multiple inorganic nutrients (dissolved inorganic nitrogen, phosphorus, and silica), multiple phytoplankton competitors (N-specialist, P-specialist, and intermediate group), the microbial loop (labile organic nitrogen, bacteria, microflagellates, and ciliates), and copepods. Model results indicated that the nutritional "quality" of phytoplankton might influence phytoplankton succession patterns, accumulation of algal biomass, and secondary productivity. During model simulations, as in the natural environment, the nutritional quality of the algae varied with its physiological state. At times of nutrient-limitation, algae characteristic of having very low nutrient cell-quotas dropped below a "food-quality" threshold where copepods were unable to sustain a viable population, *regardless of the phytoplankton density*. In other words, the nutrients gained by copepods when feeding on the low-quality algae did not result in enough reproductive growth to offset other losses, such as respiration, mortality, and flushing. In the absence of a grazer an algal bloom ensued.

The timing of the onset of bottom-up and top-down control of phytoplankton was important in these simulations. For example, when top-down control began *before* bottom-up control, the algae were of high quality when grazing activity was greatest, copepod growth and accumulation of biomass followed, and phytoplankton biomass was diminished. But when top-down control began *after* bottom-up control, the algae were of low quality when grazing activity was greatest, copepod growth was not great enough to offset losses, and an algal bloom resulted. This latter scenario was sensitive to some abiotic conditions that included: *magnitude, mode*, and *ratio* of nutrient loading. Manipulation of these abiotic processes effected the timing of the onset of bottom-up and top-down control of phytoplankton, which made it possible to prevent an algal bloom, maintain phytoplankton diversity, and enhance secondary productivity.

For each of the simulations representing the varied hydraulic conditions the controlling process that prevented an algal bloom differed. The process that was impacted by the magnitude change simulation was simply greater phytoplankton growth rates from all three groups in response to higher initial nutrient concentrations, which resulted in greater growth and accumulation of biomass of copepods before the phytoplankton prey reached a starved condition. During the mode change simulation, the P-specialist and intermediate group gained a competitive advantage over the N-specialist under conditions of pulsed nutrient loading because they were characteristic of greater specific growth rates. The N-specialist was the only phytoplankton group characteristic of having a starvation condition below the food-quality threshold of the copepods. Its poorer performance under conditions of pulsed nutrient loading allowed for greater growth and accumulation of biomass of the copepods, i.e., greater grazing pressure on all phytoplankton groups, which in turn prevented an algal bloom. Similarly, the ratio change simulation, i.e., altering the N:P ratio of the incoming nutrients, gave the P-specialist and intermediate group a competitive advantage over the N-specialist, which again allowed for adequate copepod growth and prevented an algal bloom.

To explore a portion of the model results, microcosm laboratory experiments were conducted were the succession of a phytoplankton and zooplankton community from a tidal creek of a Texas wetland where followed under conditions of continuous and pulsed nutrient loading. The hydraulic and nutrient loading

conditions were set according to the natural conditions in the tidal creek. Experimental treatments differed in that one incubator received nutrient loading in a continuous fashion, and the other incubator received nutrients in a pulsed manner, i.e., one pulse every three days. Over the course of the experiment the total nutrients loaded and the amount of flushing to each incubator were identical.

Consistent with the model simulations, the incubator receiving continuous nutrient loading failed to support enough secondary productivity to offset losses, i.e., adult and nauplii copepods, rotifers, and ciliates were flushed from the incubator. In the absence of grazing pressure the phytoplankton community bloomed and phytoplankton species diversity declined. The incubator receiving pulsed nutrient loading showed a very different succession pattern. In this incubator secondary productivity was supported and accumulation of zooplankton biomass occurred. The phytoplankton did not bloom due to high grazing pressure, and phytoplankton species diversity remained high. Model simulations suggest that a bloom-forming mechanism involving food-quality thresholds may have been at play during these experiments. However, further experimental work is necessary before this can be concluded.

Abundance and distribution of ichthyo-larvae from the upper pelagic waters of the north western Arabian Sea, during different monsoon periods 1992–1994

Samina Kidwai and S. Amjad

National Institute of Oceanography, ST 47, Block 1 Clifton, Karachi-75600, Pakistan.

[e-mail: skidwai@cyber.net.pk]

The ichthyo-larval distribution and abundance in the surface and sub-surface waters of the north-western Arabian Sea was discussed in relation to the hydrographical features of the area. The data used in this study were obtained from the five NASEER (North Arabian Sea Environment and Ecosystem Research) cruises carried out during different monsoon periods between 1992 and 1994.

The distribution patterns showed that there were no particular areas of exceptionally high fish larval concentration nor any fixed fish areas. However, a weak concentration of fish larvae was observed at the stations south east of Karachi. This area forms the Indus Delta, influenced by the mangrove forest and it is recognized as a breeding and nursery ground of commercially important fin and shellfish. Data from December and March (winter northeast monsoon and spring pre-southwest monsoon, respectively) showed that the maximum numbers of fish larvae were along the west coast of Pakistan from Pasni to Karachi, where the shelf is narrow and the sampling station are close to the coast.

The observed larval distribution patterns were discussed in relation to the drift factor theory, the wind circulation patterns, the up-slopping phenomenon on the west coast, the shift and presence of the pycnocline and the oxygen minimum zone during the summer monsoon period.

There was no statistically significant difference, using ANOVA, in the overall abundance between the sampling periods and sampling stations. The cumulative relationship between some abiotic (surface temperature, salinity, oxygen and wind speed) and biotic (overall standing stock of zooplankton and fish larval) parameters were generally found to be weak. Although the relation somewhat strengthened at the onset of the southwest monsoon in May (r^2=0.50), it plunged and leveled off from August to December (r^2=0.27) and it was observed to be at its lowest (r^2=0.19) in January, during northeast monsoon.

The roles of larval settlement and post-settlement predation in determining recruitment of the surfclam, *Spisula solidissima*

Eric Weissberger[1] and J. P. Grassle[2]

[1]School of Environmental Science, Engineering, and Policy, Drexel University, 32nd and Chestnut Streets, Philadelphia, PA 19104, USA.. [2]Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, NJ 08903, USA.

[e-mail: ejw@drexel.edu]

The surfclam, *Spisula solidissima*, is a commercially important bivalve in shallow continental shelf habitats along the east coast of the United States. This species has variable recruitment; strong year classes occur every 4–5 years inshore. Two hypotheses to explain the temporally variable recruitment are yearly variations in larval supply and variation in post-settlement predation. Benthic core samples taken at Beach Haven Ridge, New Jersey, USA, from 1993–1996 indicate yearly variation in the magnitude of surfclam larval settlement, from 1.0 x 10^4 clams m^{-2} to 2.4 x 10^5 clams m^{-2}. Larval settlement also varied spatially. Settlement coincides with the relaxation of nearshore, early summer upwellings. Only with a large settlement event did any surfclams survive to the following year. Most clams settling in summer disappeared by autumn. Predation is a likely explanation or the disappearance. Many juvenile predators were found at Beach Haven Ridge, including the sea star *Asterias forbesi*, the naticid snails *Euspira heros* and *Neverita duplicata*, the shrimp *Crangon septemspinosa*, and several crabs including Pagurus longicarpus, *Carcinus maenas*, and *Cancer irroratus*. The number of naticid-bored surfclam shells in the core samples suggests that naticid snails never account for > 25% of surfclam mortality. Laboratory studies on feeding rates of sea stars and naticid snails indicate that sea stars are more voracious, and that feeding rates increase with temperature. This suggests that when surfclams settle in the warm summer waters, their predators are feeding at their maximum rates. Based on field abundances and laboratory feeding rates, sea stars and moon snails alone are capable of substantially reducing the density of a recently-settled surfclam cohort. A large settlement of

surfclams may overwhelm predators' feeding abilities, allowing survival of some clams to the following year.

C) Environment and distribution

Marine snow: Formation mechanisms, fate, implications

Thomas Kiørboe – Invited Speaker

Danish Institute for Fisheries Research, Charlottenlund Castle, DK–2920 Charlottenlund, Denmark.

[e-mail: TK@DFU.MIN.DK]

The formation and degradation of marine snow aggregates have large scale implications for the retention and loss of elements from the upper ocean, and for the arrival rate of organic matter at the sea bed. However, the formation and degradation of aggregates are governed by processes occurring at a much smaller scale (mm-cm). Aggregates can form by physical coagulation. Small primary particles collide due to turbulent fluid shear, because they sink at different velocities, or because of Brownian motion. Depending on the surface properties of the particles, they may stick upon collision and form an aggregate. Classical coagulation theory describes mathematically the dynamics of this process, and I demonstrate by laboratory experiments that phytoplankton cells may form aggregates exactly as predicted by the classical theory. As the cells form subsequently larger aggregates, they sink faster. One can imagine that at some point phytoplankton growth is balanced by aggregation and sinking, and the system will come into equilibrium. Thus, aggregation may both govern the vertical flux of particulate material, and control the dynamics of phytoplankton populations. Selected examples from field studies in simple systems (spring blooms, where grazing can be ignored) demonstrate how coagulation theory accurately predicts phytoplankton population dynamics and vertical fluxes. In more developed and complex planktonic systems, grazing and other heterotrophic processes cannot be ignored. Aggregates are concentrated sources of organic material, and many plankton organisms appear specifically adapted to feed on marine snow. Microbial activity on aggregates may be high, leading to both hydrolysation and remineralisation of organic material in the aggregates. Also, aggregates may house an abundant zooplankton fauna, dominated by small crustaceans, particularly copepods of the genus *Oncaea*. Compared to the ambient water, zooplankters are relatively more enriched on aggregates than micro-organisms. Cm-sized aggregates are typically inhabited by 10–100 zooplankters. Budgetary considerations suggest that microbes and zooplankters may cause short turnover times of aggregates within the euphotic zone. Thus, aggregation does not necessarily imply vertical flux. The degradation processes are important for the retention of limiting elements in the euphotic zone. The high abundance of zooplankters on marine snow aggregates implies that the zooplankters must be able to remotely locate sinking aggregates. By means of a model that describes the fluid disturbance generated by a sinking aggregate, as well as the distribution of solutes around a leaking aggregate, I examine the possibility that copepods can detect aggregates at distance by hydromechanical and/or chemical cues. The hydromechanical disturbances (deformation rate) generated by sinking aggregates are very weak and would require unusual high sensitivities to be registered. *Oncaea* and other copepods inhabiting marine snow aggregates are typically equipped with short antennae, a morphology which appears inconsistent with a high sensitivity to fluid deformation. Amino acids leak out of aggregates due to microbial activity, and the sinking aggregate thus paints a chemical trail in its wake. I hypothesise that copepods encountering this trail may be able to follow it to the aggregate. There is evidence that amino acid concentrations down to 10^{-7}-10^{-8} M are sufficient to elicit behavioural responses in copepods. From estimates of aggregate amino acid leakage rates and assumptions of copepod behaviour, such a threshold concentration leads to encounter rates with aggregates that can account quantitatively for the observed association between marine snow aggregates and colonising copepods.

Influence of different scale hydrographic processes on cyanobacterial blooms in the Gulf of Finland (Baltic Sea)

Inga Kanoshina and U. Lips

Estonian Marine Institute, Marja 4D, 10617 Tallinn, Estonia.

[e-mail: inga@sea.ee]

Blooms of filamentous cyanobacteria are of major environmental concern in the Baltic Sea area because of their toxicity and fertilising effect on the ecosystem through nitrogen fixation. Long-term variability in extension and intensity of cyanobacterial blooms in the Baltic depends on changes in river load of nutrients, water exchange with the North Sea, meteorological conditions etc. The spatial distribution of these blooms is usually connected to the physical variability of the water body. The cyanobacterial bloom in the Baltic Sea is dominated by *Aphanizomenon flos-aquae* and *Nodularia spumigena* and takes place in July–August. Other less abundant species present in the bloom are *Anabaena* species. There are little differences in the main two species ecological niches. *Nodularia* has a higher temperature optimum than *Aphanizomenon*. You can find *Aphanizomenon* filaments in the water even in wintertime. There is a difference in irradiance tolerance too: *Aphanizomenon* is usually found down in the mixed layer, but *Nodularia* concentrates near the surface.

Investigations of bloom development using different approaches have been carried out in the Gulf of Finland in recent years: routine monitoring at fixed stations, unattended measurements at commercial ferries and multi-disciplinary meso-scale surveys by research vessels. The ship-of-opportunity technique allows the observation of the upper layer dynamics from meso- to basinwide scale with high temporal and spatial frequency

at low cost. This research strategy is useful *inter alia* for studying the generation of phytoplankton blooms. To investigate the development of blooms in relation to the meso-scale hydrographic processes (upwelling/-downwelling, eddies and current jets, fronts) multi-disciplinary measurements from research vessels during special expeditions are necessary. These multi-disciplinary measurements reveal high spatial and temporal variability of the phytoplankton community under complex hydrodynamical influence.

In the present paper, the following two data sets are analysed. During three years 1997–1999 unattended measurements from a commercial ferry along a transect between Tallinn and Helsinki were conducted. The influence of wind and temperature on cyanobacterial bloom development was investigated. During two years 1996–1997 – 10–day multidisciplinary measurements were carried out at the entrance area to the Gulf of Finland to investigate the influence of different hydrodynamical processes on the phytoplankton bloom development. In general, the summers of 1996 and 1998 were cold and therefore no big cyanobacterial bloom developed. In 1997 and 1999 the summers were warm and intensive blooms of cyanobacteria occurred.

The intensive bloom always begins after the surface water temperature has risen to 16ºC. The average temperature in 1996 and 1998 stayed around 14–15ºC which probably did not allow *Nodularia* akinetes to germinate – thus no big bloom formed. During the warm summers of 1997 and 1999 there were intensive blooms in the Gulf of Finland. On the basis of unattended measurements, the main difference between these blooms occurred in the community structure. Compared to 1997 data, the observed higher *Nodularia* biomass in 1999 is probably caused by the higher water temperature in that year. A difference in bloom distribution across the Gulf was also observed. In 1997 the bloom was mainly concentrated in the northern part and in 1999 to southern part of the Gulf. The differing behaviour described can be explained by differences in the prevailing wind field in 1997 and 1999. In 1997 north-easterly winds prevailed that caused an upwelling along the Estonian coast and the bloom drifted to the north. In 1999 south-westerly winds prevailed during the bloom period that caused the opposite scenario in comparison to the 1997 situation.

In 1996, during the first phase of the multi-disciplinary experiment, downwelling near the Estonian coast brought a saltier water mass from the open sea to the study area, temperature was low and dinoflagellates prevailed in the phytoplankton community. During the second phase, after downwelling relaxation, an anticyclonic eddy and related current jet formed. Temperature, together with phytoplankton biomass, rose at all stations. In the low saline eddy periphery *Aphanizomenon* prevailed inside the eddy and the community structure remained unchanged. The measured production rates inside the eddy were higher than outside which allows us to speculate that production is controlled by vertical physical processes there and the clear dominance of *Aphanizomenon* outside the eddy was caused by the advection from other parts of the Gulf with the jet. This case study showed that temporal variability of pelagic biological parameters at fixed position can mainly be explained by horizontal patchiness related to meso-scale hydrodynamical processes.

In 1997 the measurements across the front had been made. Higher production values and cyanobacterial biomasses were found in the vicinity of the salinity front. Thus, meso-scale front dynamics may create favourable conditions for phytoplankton biomass accumulation and higher production.

The dependence of the DIN:DIP balance in the Gulf of Riga on the land-based nutrient load

Laur Mägi and U. Lips

Estonian Marine Institute, Paladski Rd 1, 0001 Tallinn, Estonia.

[e-mail: laurm@phys.sea.ee]

According to the recent investigations (HELCOM, 1996; Seppälä *et al.*, 1998, Mägi and Lips, 1998), the nitrogen-phosphorus balance in the Gulf of Riga has changed during the 1990's compared to the situation in the late 1980s (HELCOM, 1990; Yurkovskis *et al.*, 1993). Until the 1990s, the limiting nutrient for the phytoplankton in the Gulf of Riga was phosphorus, but in the 1990s it was mostly nitrogen limited.

Since the river runoff (~36 km^3 per year) is about 10% of the volume of the Gulf of Riga (420 km^3), the influence of the river input in the basin is noticeable. Most of the freshwater (~90%) enters the Gulf of Riga from five rivers (Daugava, Lielupe, Gauja, Salaca and Pärnu) which are mainly located on the southern and eastern sides of the Gulf. The Daugava river alone, located in the southern part of the Gulf of Riga, gives about 75% of the total run-off. The river water is the main source of nutrients for the Gulf of Riga, about 100 000 tons of total nitrogen and 2 000 tons of total phosphorus per year (Laznik *et al.*, 1998). The molar DIN:DIP ratio in the river water is about 90, which is about five times higher than in the Gulf.

To study the variations in nutrient concentrations and the driving forces of existing trends, data sets on hydrographic-hydrochemical parameters in the Gulf and on river run-off that have been made available during the Gulf of Riga Project were used. On the basis of this data, the long-term (1977–1995) changes in the nutrient contents in the Gulf of Riga in connection with the variation of the river run-off were estimated. To calculate the total amounts of nutrients in the Gulf, the same interpolation routine as described in Wulff and Rahm (1988) was used. To determine the magnitude of the influence of the river input to the temporal variation, monthly horizontal distributions of nutrient concentrations in the euphotic layer of the Gulf in 1994 and 1995 were calculated.

Changes of average inorganic nitrogen concentration in the Gulf of Riga in the 1990s if compared to the late 1980s are in correlation to the decreased river inflow. Less redundant nitrogen per unit area could cause the

detected shift from a mainly P-limited to mainly N-limited Gulf in the 1990's. In the years 1994 and 1995, phosphorus was the main limiting nutrient only during the periods of strong river input. In the horizontal scale, the euphotic layer in the Gulf of Riga is mainly divided into two parts, the south-eastern part is P-limited and the north-western part is N-limited. The actual location of the transition between the different types of nutrient limitation depends on the magnitude of the river inflow and the prevailing circulation scheme in the Gulf of Riga.

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Springtime phytoplankton pigments near Iceland

Ása Gudrun Kristjánsdóttir

Marine Research Institute, Skúlagata 4, P.O. Box 1390, 121 Reykjavik, Iceland.

[e-mail: asa@hafro.is]

Phytoplanktonic pigments, particularly chlorophyll a, the pigment that is central in light capture in photosynthesis, have long been recognised as an indicator of oceanic phytoplankton biomass. Over the last half century, the oceanographic distribution of chlorophyll a has been studied by spectrophotometry. However, spectrophotometry gives an overestimation of chlorophyll a, especially where the phytoplankton population is declining, because chlorophyll a is not separated from some of its degradation products. Over the last fifteen years the development and application of high performance liquid chromatography (HPLC) methodologies has facilitated both a more accurate estimate of chlorophyll a and separation and quantification of many other phytoplankton pigments. Some of these pigments can be used as chemotaxonomic biomarkers, which makes it possible to use this technique to trace the development and composition of a phytoplankton population. This technique is especially valuable when, as is normally the case, nano- and picoplankton (0.5–5.0 μm) are abundant (Gieskes, 1991). These small phytoplanktons have previously been missed in cell counts based on microscopic observation because they are difficult to detect and because of loss through preservation damage. The aim of this project was to relate pigment patterns to hydrographic variations (t, S, nutrients) and to phytoplankton composition.

In the spring of 1999, samples were collected at two sections in different hydrographic regimes, at the Krísuvík section and the Siglunes section. The Krísuvík section is at the south coast of Iceland, in the spawning grounds of cod and haddock. The stations close to the coast are in the coastal current where the surface water is strongly influenced by runoff but offshore is essentially Atlantic water with $S > 35$. Due to the fresh water inflow the water close to the coast is stratified early in spring. The fresh water distribution is strongly affected by winds. Depth profiles (0–50 m) were taken at 7 stations

in April and again in May. The Siglunes section extends across the shelf off central N-Iceland. The length of the transect, 200 km, is ten times the length of the Krísuvík section. The surface water of this section ranges from Coastal to Atlantic and furthest north to Arctic Water. The Atlantic Water inflow to the shelf area north of Iceland is variable between years. The density stratification in the Arctic Water begins earlier than in Atlantic Water because of low salinity water from melted ice that makes the density stratification strong. Stratification is necessary for the phytoplankton bloom but if the stratification is too strong, the nutrients in the photic zone are utilized to exhaustion and the bloom declines. Fertility of this area is therefore dependent on the advection of nutrient rich Atlantic Water. Depth profiles (0–50 m) were taken at 8 stations in May. The samples were analysed using the high performance liquid chromatography (HPLC) technique.

In the beginning of April, stratification due to salinity was evident over the whole Krísuvík section. Nutrient concentrations were high at all stations. The chlorophyll *a* concentration was high especially at the deepest stations where it reached 6 µg/L in the surface. The fucoxanthin pigment indicated that diatoms were dominant. The ratio of 19´hexanoyloxyfucoxanthin to fucoxanthin, which is an indicator of the ratio of prymnesiophytes to diatoms, was about 0.3, indicating that there were some prymnesiophytes at all stations. Chl *b* was around 0.4 µg/L at the deepest stations and somewhat lower at the stations closer to the coast. Interestingly, the Chl *b* concentration did not decrease as much with depth as the other pigments did. This was reflected in a change of chl *b*/ chl *a* ratio. The chl *b*/ chl *a* ratio in green algae has been found to change from 0.3 in the surface to 1.4 at greater depth, as adaptation to lower light levels (Everitt et.al., 1990). It was not possible to determine the composition of the "green" algae group, since chloropyll *b* and divinil chlorophyll *b* are not separated by the HPLC method used and the accessory caroteinoids, vialoxanthin (chlorophylls) and zeaxanthin (prochlorophylls), were not analysed.

In the beginning of May stratification was strong at the stations close to the coast, where the nutrient concentrations had decreased but were still not limiting growth. Chlorophyll *a* concentration reached 5 µg/L in the surface at the stations closest to the coast. However, at the deepest stations stratification was weak, nutrients concentrations high and chlorophyll a concentration low. This change from earlier conditions was probably due to the effect of advection or upwelling of oceanic water. Silicate concentration was high close to coast, due to the fresh water runoff. Fucoxanthin was the main pigment detected. Microscopic cell count revealed complete dominance of diatoms. The ratio of 19´Hexanoyloxy fucoxanthin to fucoxanthin was around 0.3 indicating there were some prymnesiophytes. Microscopic cell count revealed only few prymnesiophytes (*Phaeocystis pouchetii*). It is possible that prymnesiophytes, which are much smaller than diatoms, were missed in the microscopic cell count. When diatoms and prymnesiophytes are present together it is difficult to calculate the relative contribution from each algae class based solely on pigment data, because the algae classes both contain fucoxanthin and the ratio of hex/fuc in prymnesiophytes is very variable. In *Phaeocystis pouchetii* for example, this ratio has been found to vary from 0.3 to 3.3 (Everitt et.al., 1990). Chl *b* concentration was low. Peridinin, which is an indicator of dinoflagellates, was not detected in April or in May, dinoflagellates were very scarce in the optical microscope cell count as well.

At the Siglunes section late in May, the stratification was weak at the upmost 50 m except closest to the coast and at the station furthest from the coast. The variation of pigment concentration with depth was small except closest to the coast. There was a gradual increase in chlorophyll *a* concentration with distance from the coast, reaching 6 µg/L. Fucoxanthin was the main auxiliary pigment detected, it's concentration increased as the chl *a* concentration with distance from the coast. Peridinin was not detected and dinoflagellates were very scarce in the optical microscope cell count. There was a decrease in the ratio of 19´-hexanoyloxyfucoxanthin to fucoxanthin, with distance from the coast. Microscopic cell count revealed complete dominance of diatoms where this ratio reached minimum. Diatoms were still dominant close to land but there were also some prymnesiophytes. Silicate concentration was limiting close to the coast. These results indicate that the diatom bloom was at maximum offshore and had already passed its maximum inshore.

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Investigation of echinoderm larvae and their living conditions in the Norwegian Sea

Irene Prokopchuk and Evgeniy Sentyabov

PINRO, 6 Knipovich Street, 183763 Murmansk. Russia.

[e-mail: borisber@pinro.murmansk.ru]

Echinoderm larvae as a component of zooplankton are consumed by plankton-eating fish such as herring and blue-whiting. These larvae are a very interesting subject for investigation as they differ significantly from adult specimens.

The species composition, abundance, distribution and living conditions of echinoderm larvae in the Norwegian Sea in June 1997–1999 were investigated.

Representatives of different classes have various larval forms with their specific peculiarities. Larval development of echinoderms is completed by metamorphosis, which is caused by a difference in

structure of pelagic larva and demersal imagined specimen. We investigated mainly pelagic planktotrophic larvae that occur in plankton. Larvae from 4 classes of *Echinodermata* occur in plankton samples: *Asteroidea, Echinoidea, Holothurioidea*, *Ophiuroidea.*

The larvae of two species of brittle stars, three species of sea urchins, one species of sea star and one species of sea cucumber were identified.

The larvae of brittle stars (ophiuroids) have a stage of a specific planktonic larva, called *ophiopluteus*. These larvae have typical long processes or arms (up to 4 pairs). The presence of an internal skeleton consisting of two symmetric halves is a peculiarity of the ophiuroid larvae (Mortensen, 1927). Ophiuroid larvae pass two stages prior to metamorphosis, – ophiopluteus I and ophiopluteus II, that differ from each other by a degree of development of the body elements. Metamorphosis of brittle stars, as that of sea urchins and sea stars, is of catastrophic character, i.e., the organs and tissues of the larva are destroyed and reorganised.

The larva of the sea urchins (echinoids), called *echinopluteus,* is similar to that of brittle stars. However it differs in the following: it has shorter arms, the number of arms is greater (from 4 to 6 pairs in different species) and its body is larger in size. In contrast to the ophiuroid larvae the larval skeleton of sea urchins consists of several pairs of parts (Mortensen, 1927). Echinopluteus passes three stages – echinopluteus I, echinopluteus II and echinopluteus III.

Larvae of sea stars (asteroids) and sea cucumbers (holothurians) have a different principle of structure and do not have an internal skeleton. The sea star larvae develop with early bipinnaria and later brachiolaria stages. The bipinnaria has numerous small arms and an oblong body. The brachiolaria is far larger and has longer arms and is provided with specific organs of attachment, helping the larva to hold on to the substrate during metamorphosis.

In the samples we found holothurian larvae at the pentactula stage, that was identified as *Psolus phantapus*. This species develops with pelagic lecitotrophic larva which has 5 primary tentacles and several ambulacral feets (usually two). The tentacles are usually hidden, however they can move outside in well-developed larvae. The metamorphosis is of evolutive character, i. e., transition into an adult specimen is accompanied by less sharp re-organization.

The relationship between shape and structure of larvae, water density and area of larvae distribution in the Norwegian Sea was investigated.

Among the larvae of echinoderms the ophiuroids larvae were the most frequent in the samples. They were distributed over the whole area of the Norwegian Sea. In June, ophiopluteus stage II were the most abundant. The young larvae (ophiopluteus I) were found in the south part of the Norwegian Sea. In 1998 we found a single specimen westward from 8°W and metamorphosing ophioplutei and fully formed brittle-stars ready to settle to the bottom were found in June. The wide distribution of brittle star larvae in the survey area is linked to the shape of their body, particularly their long postero-lateral arms. These arms act as a parachute. The larvae of sea urchins, sea stars and sea cucumbers do not have such long arms. They tend to live in the shallow coastal areas of Norway and at the banks of the Faroe and Shetland Isles.

The larvae of the brittle stars are distributed in the upper layer of sea, in the Modified North Atlantic Water. This water penetrates into the Norwegian Sea through the Iceland-Scotland Ridge with the North Atlantic – Norwegian Atlantic Current (Hansen, 1985).

The Norwegian Atlantic Current is divided into two strong branches (Western and Eastern), that flow to the north - north-east of the sea. The waters of the Norwegian Current branches transport less than 10% of the total amount larvae from the plankton of the shallow areas into the open sea (Mileikovsky, 1985).

Brittle star larvae are most abundant in waters with temperatures from 7°C to 9°C and salinity between 35.1–35.2. The temperature range of their habitat shifted somewhat to higher temperatures from 1997 to 1999, whereas the salinity level remained the same. This can be due to a large-scale warming of the Atlantic waters in the Norwegian Sea. The echinoplutei inhabit waters at temperatures of 8°C to 9.5°C and salinity 31.5–35.1. Asteroid larvae are registered in waters of a rather wide range of temperatures, i. e. from 6°C to 11°C and with two ranges of salinity, 33.1–33.9 and 35.2-35.3. For the larvae of holothurians a narrower limit of values of these two parameters is seen, 8–9°C and 35.1–35.2 respectively. The larvae of sea urchins, sea stars and sea cucumbers are found near the Faroe and Shetland Islands and at the shelf of Norway. Very wide temperature/salinity ranges are found in their habitats in the coastal waters where the influence of the low salinity of the Baltic or Norwegian Coastal Current takes place, as well as from freshwater runoff.

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Impact of unusual hydro-climatic events on the zooplankton coastal community of the eastern Ligurian Sea, from 1985 to 1995 (Gulf of Tigullio-Italy)

Priscilla Licandro and F. Ibanez

LOBEPM- Observatoire Oceanologique, BP 28,- Villefranche-sur-mer, 06230, France.

[e-mail: licandro@obs-vlfr.fr]

Multi-year variations of zooplankton abundance and composition were studied in a coastal area in the Gulf of Tigullio (Eastern Ligurian Sea) in relation to unusual meteorological and hydrological events, between 1985 and 1995. These events were considered as 'disturbances' in the ecological sense of discrete events determining significant changes in the planktonic community structure (Picket *et al.*, 1989).

Disturbances were statistically identified by the D2 to the centroid method (Ibanez, 1981) which detect the date of maximal change in a multivariate time series. Disturbances related to meteorological and hydrological variables were compared with changes in zooplankton community structure (disjunctions) which were identified by chronological clustering with contiguity constraint (Legendre *et al.*, 1985).

During the nine years studied disturbances could explain around 50% of total disjunctions and there were 1 to 7 disturbances year^{-1} so that according to Reynolds (1993) the studied area can be classified as "infrequently disturbed". 62% of unusual events were related to hydrological events of strong currents directed E-W (the water mass circulation in the Gulf is principally driven by the Ligurian Current from east to west which can run seasonally in a west-east direction) or by currents that flow into the Gulf from the south. Strong winds and precipitation particularly abundant explain 50% of unusual events which are related to changes in zooplankton assemblages.

A biological characterisation of each cluster of observations (months) was statistically done using the indicator value (INDVAL) index (Legendre and Legendre, 1998), allowing to relate temporal changes of zooplankton species with environmental disturbances. For example, the epiplanktonic species of medusa *Liriope tetraphylla* showed the maximum inter-yearly abundances in correspondence of unusual events due to strong current entering into the Gulf from the south. On the contrary, events related to current flowing out from the Gulf directed southward or unusual events of low salinity seems responsible for an abrupt decrease of *L. tetraphylla* after its maximum inter-yearly abundances.

A previous study in the same area (Licandro and Ibanez, submitted) already pointed out that hydrological conditions, as well as atmospheric pressure and water temperature, were the factors which better discriminated the characteristic periods of different associations of zooplankton species showing similar variations in time.

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D) Distribution patterns

Modelling spatial variation of surface zooplankton biomass along a 50°N to 50°S transect of the Atlantic

Rachel S. Woodd-Walker[1], K. S. Kingston[1], and C. P. Gallienne[2]

[1]Institute of Marine Studies, University of Plymouth, Drake Circus, Plymouth PL4 8AA, United Kingdom. [2]CCMS-Plymouth, Prospect Place, West Hoe, Plymouth PL1 3DH, United Kingdom.

[e-mail: rwoodd-walker@plymouth.ac.uk].

Sampling on four Atlantic transects between UK and Falkland Islands was carried out during spring and autumn as part of the Atlantic Meridional Transect (AMT) programme (Robins and Aiken, 1996). These 50°N to 50°S transects cross several ocean regions. An optical plankton counter (OPC-1L) sampled continuously across the transects from the ships uncontaminated seawater supply, giving a surface profile of zooplankton abundance and size. Measurements of underway fluorescence derived chlorophyll, sea surface temperature and salinity were also taken from the uncontaminated seawater supply. In addition, sea surface height was derived from TOPEX imagery. Diel time, a sine wave, which was positive in the day, negative at night and zero at dawn and dusk, was used to code for diel migration. The relationship between zooplankton biomass and these variables was investigated using multiple linear regression (backward elimination) and neural network (feed forward network) techniques. In the analysis, loge transformed biomass was used to reduce the impact of extreme values. Two transects were used to develop the models, and two to test the generalisation capabilities of the models.

Multivariate analysis (linear regression) explained up to 55% of the observed variation in the transformed biovolume. Latitude, temperature, density, chlorophyll, TIR, diel time were the significant parameters. The model demonstrated the impact of hydrographic variables and diel migration on the surface zooplankton community. Performance was improved by dividing the transect into regions based on copepod taxonomy (r^2=0.59). However for both models testing on novel data from two transects resulted in reduced performance (r^2=0.34 and 0.42 respectively).

Neural networks, starting with the same set of variables, showed an increased performance over the multivariate analysis, being able to explain up to 78% of the variability. An optimised model accounted for 77% of the variance in the original data. However, it showed greater generalisation capabilities (r^2=0.47) than either the original neural network model (r^2=0.37) or the multiple linear regression models. The model suggests that further improvements in generalisation capabilities may be obtained by training the network on a wider range of data sets. Significant parameters, temperature, salinity, chlorophyll and diel time, were very similar to the regression model.

Sensitivity analysis carried out on the neural network model suggested that complex non-linear interaction between the parameters was occurring. In different oceanographic regions the impact of input parameters effected the predicted zooplankton biomass differently, both qualitatively in the nature of their impact, and quantitatively in the magnitude of the impact.

In conclusion, zooplankton abundance has been shown to be largely accounted for by the ocean physics, with parameters having complex, non-linear interactions, which vary between regions. The time of day influences the amount of zooplankton in the surface layer. Multiple regression and neural networks are complimentary approaches together giving insight and understanding to the controls on zooplankton abundance.

Impact of hydrological and meteorological conditions on the spatial distribution of zooplankton and larvae and juveniles of smelt (*Osmerus eperlanus*) in the Vistula Lagoon (southern Baltic Sea)

Piotr Margonski

Sea Fisheries Institute, Department of Oceanography, ul. Kollataja 1, 81-332 Gdynia, Poland.

[e-mail: pmargon@mir.gdynia.pl]

The potential impact of meteorological and hydrological parameters on the distribution of zooplankton and smelt larvae and juveniles has been analysed during six subsequent cruises with different distribution patterns (17–18 June, 1–2 July, 15–16 July, 29–30 July, 12–13 August and 26–27 August). The Spatial distribution of smelt was described on the basis of 15 stations sampled during each cruise in the Polish part of the Vistula Lagoon. Zooplankton abundance and biomass were calculated at 5 stations. Meteorological data were collected in Tolkmicko Harbour, about 15 meters above sea level using Automatic Weather Station (10 minutes' mean velocity of the wind, wind gust and momentary values of the wind direction). Water current was measured using S4 current meters at two locations: at the Russian–Polish border and in the western part of the Polish part of the Vistula Lagoon. The spatial distribution pattern of zooplankton and smelt larvae and juveniles has been influenced mainly by the direction and velocity of the winds and by movement of the large water masses. During calm weather (low wind velocity and variable wind direction) smelt gathered in the central part of the investigated area. The gentle winds with stable direction for several days were pushing zooplankton and smelt larvae to the other side of the lagoon. The strong winds caused juveniles, especially, to try to find the calm and shallow waters on the side from which the wind was blowing. The movements of large water masses along the lagoon changed significantly the horizontal distribution of zooplankton and smelt juveniles, dragging or pushing them from one site to another.

Modelling the effect of advection and diffusion on the distribution of zooplankton using Markov Chains

Natacha Bianca Bernier, K. R. Thompson, and J. Sheng

Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada.

[e-mail: natacha@phys.ocean.dal.ca]

Introduction: The Gulf of St. Lawrence (GSL) is a semi-enclosed sea off the east coast of Canada. The overall mean circulation is generally counter clockwise at about 10 cm/s. There are, however, a number of smaller closed circulation cells embedded within this broad flow, including one just to the west of Anticosti Island. Such closed cells are believed to play a role in determining the recruitment to commercially important fish stocks in the region and hence the yearly changes in fish abundance (e.g. Iles and Sinclair, 1982). Like many other fishing areas, the GSL's landing quotas are generally decreasing and the identification of retention zones and their influence on the distribution of plankton may be a useful step toward better management and protection of the fisheries resources of the area.

Thompson *et al.* (1997) suggested that Markov Chain theory may provide a useful way of modelling the dispersion of particles in time varying flow fields. In this study, the method is used to predict areas of retention within the GSL. The method is then extended to include biological structure. It thus combines both physical and biological forcing in order to better quantify the dispersion of zooplankton and fish larvae.

Approach: Current fields were calculated using a fully non linear, three dimensional baroclinic model forced by synoptic winds, fresh water inflow, temperature and salinity (Sheng *et al.*, 1998). More than 40,000 particles

were then tracked using the model generated time and space varying current fields. The initial position of particles and their position after 15 days were recorded.

The GSL was partitioned in 64 grid of boxes and the particle positions were transformed from latitude and longitude into box position. The probability that a particle initially in box j will be in box i as time advances from t to $t + \Delta t$, P_{ij} say, was calculated by simply finding the proportion of particles initially in box j that moved to box i after Δt =15 days. Repeating this calculation for each box in turn allowed us to generate the 64x64 one-step transition probability matrix, P. The k step transition probability matrix is then calculated using

$P^k=P^{(k-1)}P$

$P_{ij}^{(k)}$, the (i,j) element of $P^{(k)}$ is the probability that a particle initially in box j will be in box i after k steps. It is based on the sum over all possible intermediate states that a particle can follow when going from an initial state to some later state at time k.

Transition matrices can also be calculated for a number of horizontal grids at various vertical levels. This allows us to model the effect of buoyancy effects and behaviour. The matrices that are thus generated take on a particularly simple block form that allows ready calculation of the probability that a particle initially in box j and level l will move to box i and level m after k steps.

Results: By raising P to the power of k we were able to estimate the proportion of particles that remained trapped for period longer then 15 days. Two retention zones, and a corridor of rapid dispersion, were identified. One of the retention zones is located west of Anticosti Island. At that particular location, it was found that roughly 33% of particles remained after 15 days.

The columns of the matrix represent the location of particles after 15 days while the rows are the sources. The transition matrix therefore provides an estimate of the travel time between pairs of boxes. Similarly, the origin of the particles that are transported and retained off the west coast of Newfoundland, the second retention zone, were mapped out. The Cabot Strait was identified as a strong flushing corridor as expected. Particles that are transported towards the Strait are quickly removed from the GSL and flushed out onto the Scotian Shelf.

Conclusions: The Markov Chain approach for predicting retention zones and areas of rapid dispersion could become a powerful tool for biologists in their assessment of larval fish dispersal and should be further explored. We used the approach to identify retention zones in the GSL including one off the west coast of Newfoundland and one in the estuary of the GSL. It can also provide statistics of mean residence time and mean travel time. Finally, it is potentially useful for embedding biological models in physical models.

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Interactions between zooplankton predator and prey behaviour in shaping predation rates

Josefin Titelman

Danish Institute of Fisheries Research, Kavalergården 6, 2920 Charlottenlund, Denmark.

[e-mail: jti@dfu.min.dk]

Initial experiments where nauplii were exposed to a suction driven flow field revealed that *Temora longicornis* nauplii require higher deformation rates to elicit escape jumps than do *Acartia tonsa* nauplii. This suggests that *Temora* may be more susceptible to predation than *Acartia*. However, the encounter rate between predator and prey depends highly on how well the predator perceives the prey. To estimate the hydrodynamic signals generated by the two prey species (and thus their relative likelihood of being detected) their motility behaviour was quantified from video films. *Acartia* jumps frequently, while *Temora* swims in a smoother fashion and rarely jumps. This implies that a predator, such as a larger copepod, may perceive the signal of an *Acartia* nauplius more readily than that of a *Temora* of the same size. To test the combined effects of prey escape and swimming behaviour on predation rates, *Centropages typicus* females were offered the two types of prey alone as well as in mixtures. Clearance rates were approximately 3 times higher on *Temora* than on *Acartia* nauplii, both in single and mixed species treatments. This suggests that the relative difference in clearance can be attributed to prey behaviour as opposed to predator choice. The differences in clearance rates will be discussed using simple models, which incorporate aspects of zooplankton behaviour such as motility aspects and perceptive abilities of both predator and prey.

Variation in top-down and bottom-up control of marine bivalves at differing spatial scales in Chesapeake Bay

Rochelle D. Seitz[1] and R. N. Lipcius[2]

[1]Postdoctoral Fellow, Smithsonian Institution, Smithsonian Environmental Research Center, Edgewater, MD 21037, USA. [2]Virginia Institute of Marine Science, The College of William and Mary, Gloucester Point, VA 23062, USA.

[e-mail: seitz@vims.edu.]

Determining the causes of spatial and temporal variation in population abundance has been the focus of much work in ecology. Most field experiments emphasize processes at spatial scales of centimeters to tens of meters. At spatial scales greater than one kilometer, the structuring forces in benthic populations remain largely unknown. Predation is an important controlling factor in marine benthic systems at the local scale (e.g., rocky intertidal systems: Paine, 1966, Menge and Sutherland, 1987). Alternatively, nutrient enrichment is important in freshwater systems (McQueen *et al.*, 1989). Marine systems, however, are generally more complex than freshwater systems (Strong, 1992), making it more difficult to track the effects of changing food availability through the food web. As a consequence, few studies in marine and estuarine systems have examined the importance of both predation (top-down) and food availability (bottom-up) in controlling benthic populations. Herein, we compared the relative influence of top-down and bottom-up factors to population abundance of an infaunal clam (*Macoma baltica*) in two ecosystems differing in scale by an order of magnitude - the York River, 30 km long, and the Rhode River, 3 km long – in Chesapeake Bay.

In the York River, two river zones (upriver and downriver) separated by 20 km were compared in terms of *Macoma* abundance and survival, predator abundance, and food availability. In this large-scale system, predators do not easily migrate between the two zones. *Macoma* abundance was ten-fold greater upriver than downriver, predator abundance was five-fold greater upriver, and predation was only important upriver, where food availability for predatory crabs was elevated. In this large-scale system, predators are not capable of traveling between upriver and downriver habitats where food availability differs, and consequently, they remain primarily where their prey are abundant. Predators do not drive prey distribution, but instead, prey abundance appears to drive predators. Therefore, bottom-up factors are principally important at such large scales.

In the Rhode River, a smaller-scale system, two habitats (mud and sand) were compared in terms of *Macoma* abundance, survival and growth, predator abundance, and food availability. In this system, predators can easily move amongst habitats of differing food availability (Hines *et al.*, 1995). *Macoma* abundance and predator abundance were both three-fold greater in mud versus sand. Control of clam survival and abundance by predation occurred in sand, the habitat where ambient clam abundances were low. Growth and abundance of clams were elevated in mud habitats where food availability (sedimentary organic carbon) was greater. In this smaller-scale system, both top-down and bottom-up forces contributed to habitat-specific patterns in benthic population abundance.

In systems of both large and small scale, the joint effects of top-down and bottom-up factors may be apparent. However, the relative importance of the two likely changes with the scale of the system, with the ability of predators to move amongst habitats, and with differences in food availability. In our study, at small scales (i.e. the Rhode River) clam abundance was driven by crab predation and food availability, whereas at large scales (i.e., the York River), only food availability controlled the abundance of clams, which subsequently drove the abundance of their crab predators. Though variation in the relative importance of top-down and bottom-up forces with differences in scale has been theoretically proposed (Menge and Olson, 1990), this study provides empirical evidence for the importance of spatial scale. Hence, studies attempting to determine controlling factors in marine benthic systems must examine the importance of both top-down and bottom-up factors. Furthermore, these studies must consider the influence of spatial scale upon these factors.

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E) Transfer through food-webs

General biology and factors limiting fish macroparasites' communities of the Baltic Sea (Lithuanian coastal zone) and the Curonian Lagoon

Egidijus Bacevicius

Fishery Research Laboratory, P.O. Box 108, 5800 Klaipeda, Lithuania.

[e-mail: ztl@is.lt]

Parasite communities found in fresh and brackish-water fish species differed by their origin, land structure as well as seasonal and spatial variation patterns.

The formation of marine and fresh water fish and their parasite communities in this area occurred in the post-glacial period. Therefore, parasites and their host species have spread both from Caspian and North Atlantic areas. Parasite and fish communities, due to both physical and biological factors, developed features typical for the southern Baltic region (estuarine and marine conditions).

In this study, I summarize both literature and my own data on brackish and fresh water fish and parasite systems. Fish biology, population structure, feeding habits, distribution of fish belonging to different trophic groups (10 from the Baltic Sea and 9 from the Curonian Lagoon) as well as development cycles, population structure and biodiversity of metazoan parasites and their intermediate hosts were analysed.

Both brackish and fresh waters were dominated by polivalenthic (nonspecific) fish parasites with a development cycle consisting of more than one intermediate stage. Biodiversity of parasite species in fresh water was higher than in the brackish Baltic Sea (63/13). Highest numbers of species were from the following taxa in brackish waters: *Acanthocephala* (5), *Nematoda* (3) and *Cestoda* (3), while in fresh water – *Trematoda* (20), *Monogenea* (20), *Cestoda* (10), *Nematoda* (6), *Acanthocephala* (2), *Crustacea* (2). Intermediate hosts of fish parasites in fresh water were *Bivalvia* (3), *Gastropoda* (5), *Insecta* (3), *Crustacea* (3) and *Pisces* (3), while in brackish water– *Crustacea* (3), *Gastropoda* (2), *Oligocheta* (1) and *Pisces* (2). Fish macroparasite infestation was correlated to fish age (body length), feeding habits (consecutive change of trophic niches) and migration. Macroparasite diversity and abundance were similar within particular fish trophic groups. The highest parasite diversity and infestation degree was among benthofagous fish.

Turbot (*Psetta maxima*) sex dimorphism plays a role, through food size selection, in the infestation rate of the cestode *Bothriocephalus gregarius*. In females between 0–40 cm body length, the infestation rate with *B. gregarius* was similar to in males. However, when females reached 45 cm they preferred feeding on bigger fish such as herring, sprat and therefore, the average number of *B. gregarius* gradually decreased, while in males, that continued to feed on small fish such as gobiids, the numbers of this cestode increased.

We found several variations in the parasitic diversity, abundance and dominating patterns (prevalence of *Cucullanellus minutus* and *Argulus foliaceus* during the summer, glochidians of *Anodonted* prevail in the early spring, while *Cucullanus heterochous* perdominate in the winter-spring seasons).

In case of the "unsuitable host" acanthocephalans, e.g., *Echinorhynchus gadi*, *Pomphorhynchus laevis* did not develop and were eliminated from the parasite community.

In flounder (*Platicthys flesus*) a strong immune response reaction has been observed. Number of "mummified worms" and histological changes were correlated with fish age (r= – 0,78).

During summer and autumn in the coastal zone near the estuary of Curonian Lagoon, several freshwater fish metazoan parasites (*Digenea*, *Diplozoon sp*. *Ergasilus*, *Argulus foliaceus, Pradilepus scolecina, Proteocephalus sp, Filometra sp., Camallanus lacustris*, etc.) were found. However, they could not complete their entire life cycle in this environment and were counted as individuals eliminated from the parasitic community.

Due to a decrease of the salinity in the sea area, some of the marine macroparasites became scarce or even absent from this region in the last decade.

Neither enzooses nor noticeable damage to fish organisms were observed. All parasites found were in univoltic (in brackish and fresh water) or bivoltic (in fresh water) developmental stages.

The main factors limiting biodiversity of parasites and their intermediate hosts were considered to be salinity, temperature, and bottom type.

Factors influencing the distribution and nutritional condition of estuarine fish larvae: a multivariate approach

Eduardo Esteves[1], T. Pina[2], A. Chícharo1, and J. P. Andrade[1]

[1]UCTRA, Universidade Algarve, Campus de Gambelas, 8000–810 Faro, Portugal.. [2]IPIMAR - CRIP Sul, Av. 5 de Outubro, 8700–305 Olhao, Portugal.

[e-mail: eesteves@ualg.pt]

Fish larvae were collected monthly between March and September 1997 in the estuaries of the rivers Mira and Guadiana (South Portugal). Hydrological parameters were registered and zooplankton samples were obtained simultaneously. Densities of fish larvae (ind.100 m^{-3}) were calculated from 211 samples and individual RNA/DNA ratios were obtained for 346 larvae, using a fluorimetric method for nucleic acid quantification in fish larvae. Correlating variables were further studied using a multiple (forward stepwise) regression analysis.

Temperature, salinity and Secchi depth gradients were evident in both rivers through the study period. Densities of fish larvae during the day did not exceed 40 ind.100 m^{-3}, whereas values obtained during diel collections were

higher, particularly in the river Guadiana. Density maxima of about 45 and 85 ind.100 m^{-3} were calculated for clupeids in the rivers Mira and Guadiana, respectively. Gobiidae and Blennidae larvae were irregularly more abundant with maximum densities >300 ind.100 m^{-3}. Calculated densities varied by two orders of magnitude. In both rivers, microzooplankton consisted almost entirely of crustacean nauplii (often representing >80% of sample abundance), copepodites (8–27%), and bivalve (7.5–32%) and gastropod larvae (3–12%). Diel sampling revealed a different microzooplanktonic composition among rivers. The composition of mesozooplankton samples was different between estuaries. In river the Mira, hydromedusae, mysids, decapods (zoea/mysis) and copepods commonly represented about 5–40% of sample abundance. In the river Guadiana, copepods, cladocerans and decapods (zoea/mysis) were the most abundant taxa. The distributions of fish larvae and their potential prey were almost always in counter-phase, i.e. higher values of fish larvae corresponded to minima of potential prey abundance. In contrast, predators and larval fish distributions frequently overlapped. This was particularly evident for gobiids-apendicularians and clupeids-mysids/apendicularians interactions.

Larval densities were significantly correlated ($p<0.001$) with temperature and the abundance of several taxa of potential prey and predators. Significant correlation coefficients varied between -0.57 (gobiids – temperature) and 0.73 (clupeids – cladocerans), with most values within the range 0.40–0.60. Among those variables, only temperature and the abundance of mesozooplankters were included in the empirical models calculated. Most of the models included two independent variables except for that describing the spatial distribution of clupeids in the river Guadiana. The former equations accounted for about 55% to 63% of the variance of log (larvae density) whereas the later model only explained 31.5% of the variance

RNA/DNA ratios correlated significantly ($p<0.001$) with several taxa of potential prey ($r<0.55$) and particularly with predators/competitors ($0.39<r<0.70$). Significant coefficients of correlation varied between –0.46 (blennids – decapod nauplii) and 0.70 (clupeids – mysids). Nevertheless, temperature and the abundance of potential prey, namely dinoflagellates, crustacean nauplii, copepodites and bivalve larvae, constituted the majority of the independent variables included in the empirical models obtained. Models explained about 43.1 – 94.8% of the variance of RNA/DNA or log (RNA/DNA). Higher values of r^2 were obtained for models calculated from data collected in river Mira ($r^2>0.73$) than for equations derived for river Guadiana ($r^2<0.61$).

This study reinforced the idea that temperature and salinity are determinant for larval abundance distribution. In both the Mira and Guadiana rivers, certain taxa that correlated significantly with larval abundance are described in the literature as potential prey, namely crustacean nauplii, copepodites and bivalve or gastropod larvae. The positive correlations could result from the active search for patches of prey. Larvae probably undergo vertical and/or horizontal displacements as a function of potential prey and aggregate at certain depths, where food concentration is higher. The abundance distribution of larvae is also significantly correlated with several taxa referred to in the literature as (invertebrate) predators of both fish eggs and larvae. The co-occurrence of predators and larvae might constitute a trophic advantage for predators and potentially increase predatory efficiency. However, some authors stressed the predatory potential of those taxa based on inversely related population dynamics. Our results suggest that predation, in association with temperature, are the major factors controlling the abundance distribution of fish larvae.

Temperature was negatively correlated with RNA/DNA ratios, which could be due to the reduced activity of ribosomes at lower temperature values, and the necessary higher content of RNA to maintain the same activity level whereas the DNA content stays unchanged. In this study, the variability of larval nutritional condition seems related more closely to prey availability than with the other variables. Notwithstanding, the significant correlation obtained between the condition of fish larvae and the abundance of potential predators could be related to the removal, through predation, of larvae in poor condition. The diminished ability of larvae in poorer condition to escape predators, feed and compete for food items accelerates the starvation process.

Concluding, the distribution of fish larvae seems conditioned by temperature and predation pressure, whereas their nutritional condition is dependent on temperature and prey availability. These later variables are further controlled by predation, through its effect on larval mortality. Considering the issues of accuracy and precision, our analyses are intended to be indicative of general trends and relative importance of environmental and biological factors. In future studies, both sample number and frequency should be increased. This will provide further insight into the mechanisms that regulate fish recruitment.

Detecting pan-Atlantic migration in salmon (*Salmo salar*) using ^{137}Cs

Strahan Tucker[1], I. Pazzia1, D. Rowan[†], and J. B. Rasmussen[1]

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[1]Department of Biology, McGill University, Montreal QC, H3A 1B1, Canada / Centre de Recherche sur le Saumon Atlantique (CIRSA).. [†]Department of Radiological Health Sciences, Colorado State University, Ft. Collins CO, 80523, USA.

[e-mail: strahant@hotmail.com]

Total abundance of North American origin Atlantic salmon (*Salmo salar*) has recently declined to approximately 45% of average numbers from previous decades (Anonymous, 1998). Sources of marine

mortality are poorly understood since there is a lack of basic knowledge about the distribution of salmon in the ocean (Friedland, 1998). It is generally thought that salmon originating from North American rivers feed on the Grand Banks, in the Labrador Sea and along the coast of Greenland with only a small percentage (< 1%) ranging as far east as Iceland and the Faroe Islands (Mills, 1993). However, these are inferences based on the recapture of very few tagged individuals and information from limited surveys of salmon abundance in the North Atlantic.

Cesium-137 (^{137}Cs) is a nuclear fission product that is rapidly taken up by biota, transferred efficiently through the food chain, and retained with a biological half-life of several years in large fish (Rowan and Rasmussen, 1994, 1996). There is a pronounced East-West gradient of ^{137}Cs in the waters of the North Atlantic (Aarkrog *et al.*, 1992; Kershaw *et al.*, 1992; IAEA, 1998) due to the combined effect of the Sellafield (UK) nuclear reprocessing plant on the Irish Sea, and the Chernobyl nuclear accident. Thus, concentrations are highest in the Irish, North and Norwegian Seas, with values ranging from 10–150 Bq·m^{-3}, whereas on the Grand Banks and Labrador Sea, concentrations are less than 1.5 Bq· m^{-3}. This range in values is subsequently reflected in fish, including Atlantic salmon, caught in those waters. Based on our present ideas on migration patterns of salmon, most returning North American fish would be expected to have levels from 0.15–0.65 Bq·kg^{-1}, with only a few specimens reaching 1 Bq·kg^{-1}. Our observed range of ^{137}Cs values for returning 2 sea-winter (2SW) and 1SW salmon from the Ste-Marguerite River, Canada, caught during the summers of 1995 and 1996 was very different from what we expected as there was a 66-fold difference in ^{137}Cs levels (0.10–6.6 Bq·kg^{-1}). This range would suggest that these salmon had consumed prey with different ^{137}Cs concentrations and subsequently fed in different areas of the ocean. The most frequently occurring values for returning salmon were in the 0.15–1.0 Bq·kg^{-1} range expected for fish feeding in the NW Atlantic to the Iceland region, however a full 43% of the fish exceeded this range and indeed, we obtained salmon with concentrations up to 6.6 Bq·kg^{-1}. As many as 28% of the fish had values above 1.3 Bq·kg^{-1}, consistent with fish feeding beyond Iceland. In addition, 59% of 1SW salmon had concentrations exceeding 1.3 Bq·kg^{-1}. Thus, fish returning to the Ste-Marguerite River exhibit virtually the entire range of ^{137}Cs concentrations seen previously across the entire North Atlantic. The data suggest that salmon of North American origin are using European feeding grounds much more than previously thought and suggest that their marine life history is in fact pan-oceanic. Although only limited monitoring of salmon for ^{137}Cs has been carried out in Europe (Kershaw *et al.*, 1992), the few fish collected show a similar pattern to the one observed here (0.18-5.3 Bq·kg^{-1}), suggesting that fish returning to British rivers also use a wide range of feeding grounds. This then only emphasises the importance of collective management and conservation measures by all North Atlantic nations.

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Distribution, life history, and population genetics of glacier lanternfish (*Benthosema glaciale*) in Norwegian waters

Jon Bent Kristoffersen

Department of Fisheries and Marine Biology, University of Bergen, PO Box 7800, 5020 Bergen, Norway.

[e-mail: Jon.Kristoffersen@ifm.uib.no]

The mesopelagic fish *Benthosema glaciale* is common in the Norwegian Sea and in deep fjords. During daytime most individuals are caught between 200 m and 400 m, while at night parts of the population migrate towards the surface. It is rarely recorded over the shallow shelf area west of Norway, as these areas seem too shallow to meet the daytime depth requirements of *B. glaciale*. To investigate whether separate populations exist in fjords and the Norwegian Sea, *B. glaciale* was collected in two west Norwegian fjords and at several locations in the Norwegian Sea. Age structure, growth, and gonad weight were investigated, and allozyme variation was examined with gel electrophoresis. The allozyme variation indicated that each fjord had its own population, while in

the Norwegian Sea a single population seemed to exist. Fish from the Norwegian Sea had a slower growth rate and a larger maximum size than fish from the fjords, and their otolith morphology was also different. No genetic heterogeneity was detected between males and females, or between age groups or year-classes. Within each area, no significant genotype effects were detected on the investigated life history parameters. However, in the two fjords, individuals which were heterozygous for the enzyme *PGM** tended to have a higher survival than homozygotes.

The vertical export of carbon and nitrogen caused by zooplankton vertical migration

Toby Jarvis

University of the Highlands and Islands, Dunstaffnage Marine Laboratory, PO Box 3, Oban, Argyll, Scotland PA34 4AD, UK.

[e-mail: tt@soc.soton.ac.uk]

It has been recognised for some time that zooplankton vertical migration represents a potential sink for elements such as carbon and nitrogen in the ocean, and as such may prove to be of significance in global biogeochemical cycles. A new technique for quantifying this "active" material flux has been devised, but has thus far received only limited application in the field. The purpose of this study is to continue to apply and refine the technique for a variety of areas and seasons. To date (November 1999) three week-long sampling cruises in the Clyde Sea Area, West Scotland have been undertaken. Further cruises are planned for December, January, April and June at the same site in order to complete a year-long time-series study. Sampling will also be carried out in other geographical locations in order to provide comparative data and to enhance the scope of the work. Ultimately it is planned to use these data to develop and parameterise mathematical ecosystem models in order to assess the role of the zooplankton within global biogeochemical cycles.

Biologically-induced circulation at fronts

Andrew M. Edwards[1], T. Platt[1], and D.G. Wright[2]

[1]Biological Oceanography Division, Bedford Institute of Oceanography B240, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada. [2]Ocean Circulation Section, Bedford Institute of Oceanography B240, Dartmouth, Nova Scotia, B2Y 4A2, Canada.

[e-mail: andy@caligo.bio.dfo.ca]

An intriguing question in oceanography concerns the extent to which the biological component of the ecosystem can influence the physical component. The presence of phytoplankton in a body of water affects the penetration of irradiance through the water column. This influences the temperature of the water. Previous modelling studies have quantified this effect, and have shown that the influence of phytoplankton upon sea-surface temperature can be as much as 4 degrees Celsius in a month. The temperature variations subsequently alter the density distribution of the water. If the phytoplankton concentration varies horizontally, then the resulting density distribution will create a horizontal pressure gradient. Here we consider such a horizontal gradient of phytoplankton associated with a frontal region, and present, to our knowledge, the first calculations of the velocities induced by the resulting pressure gradient. Our aim is to determine whether the resulting induced velocities are significant, by means of a simple model.

We consider a frontal region which has a high biomass of phytoplankton on one side, and low biomass on the other. Irradiance will thus penetrate deeply through the water column on the low-biomass side, but be attenuated nearer the surface on the biomass-rich side due to absorption by phytoplankton. Thus the near-surface water will get heated more on the biomass-rich side than on the clearer side, resulting in lower-density surface water on the biomass-rich side, and a subsequent horizontal pressure gradient.

The results from our model, using a typical set of parameter values, show the formation of cross-frontal eddies induced by the phytoplankton gradient, together with an along-frontal jet. The cross-frontal velocities are of the order of a few millimetres per second. However, the along-frontal velocities (providing a geostrophic balance) reach a maximum of 1.5 cm s^{-1}, which occurs at the sea surface. Reducing the vertical eddy viscosity (a particularly uncertain parameter to quantify) causes the cross-frontal eddies to be confined nearer to the sea surface, and the along-frontal jets to have a maximum velocity below the sea surface; the maximum velocity reaches 1.9 cm s^{-1}. The effects of varying the other parameters have also been computed, and shall be reported in detail elsewhere.

Our model consists of the steady-state momentum equations, including Coriolis, pressure-gradient and viscous effects. The phytoplankton biomass varies in the cross-frontal x-direction by means of a simple tanh function of x, going from low biomass to high biomass as x increases (across the front). The attenuation coefficient of irradiance is a linear function of the biomass, and from this we express the irradiance as a function of x and depth z. The resulting temperature and density changes are calculated, giving the resulting pressure gradient in the x-direction. There is no pressure gradient in the y-direction; the biomass is assumed to extend homogeneously in the y-direction. The resulting momentum equations are solved analytically, giving an equation for each of the x, y and z components of the induced velocity. Typical parameter values are used to then calculate the resulting velocity field.

We conclude that the resulting biologically-induced velocities that we have computed are not going to be dominant in frontal regions, but are certainly not insignificant. However, under certain conditions, the velocities could indeed become important. These results raise the speculation that a self-sustaining patch of phytoplankton could arise, whereby the induced

velocities bring nutrients to the surface waters, and the phytoplankton set up a physical environment in which they can 'feed themselves'.

Age, growth and hatching date of larval and juvenile spring- and autumn-spawning herring (Clupea harengus L.) from the Vistula Lagoon (southern Baltic) based on length frequency distribution and otolith analysis

Dariusz P. Fey

Sea Fisheries Institute, Department of Oceanography, ul. Kollataja 1, 81-332 Gdynia, Poland.

[e-mail: dfey@mir.gdynia.pl]

Growth rates, hatching-date distribution and otolith microstructure of larval and juvenile herrings from the Vistula Lagoon were studied in 1998. Data on herrings from both the spring and autumn populations were included in the analysis. Hatchingdates back-calculated from otoliths of spring-spawning herrings ranged from April 10 to May 28, however, only a few larvae were born after May 10. Appearance of three cohorts was evident. Autumn larvae were hatched between Oct 20, 1997 and Jan 8, 1998. The average growth rate calculated for each specimen of spring-spawning herring lay between 0.32 and 0.63 mm/d with higher values for juveniles when comparing to larvae. There were also differences in growth rate between specimens from separate cohorts. The temperature and zooplankton data were used in order to explain the differences in growth rate between cohorts. Hatching and spawning time as well as the time of emigration from the lagoon were related to the temperature and zooplankton data. The average growth rate of autumn-spawning larvae ranged from 0.16 to 0.23 mm/d and was related to the hatching time - the growth was higher for specimens hatched later in the previous year. Data on growth estimated from the length frequency distribution were included as well. Additionally, the marginal increment analysis was used to investigate influence of environmental variables on the growth and condition of the early life stages of Baltic herring spawning in the Vistula Lagoon.

Using stable isotopes to study food webs of large aquatic systems

Christopher J. Harvey – Invited Speaker

Center for Limnology, University of Wisconsin, 680 N. Park Street, Madison, WI 53706-1492, USA.

[e-mail: cjharvey@students.wisc.edu]

Ecologists who wish to determine the roles of bottom-up and top-down control in a food web must first establish an understanding of the predator-prey relationships in the system. Traditional methods of food web analysis, such as gut content analysis, direct observations, or experimental manipulations of key food web components, may be difficult in large aquatic systems such as marine systems because of a variety of logistic constraints. An alternative to these methods is stable isotope analysis, in which the ratios of heavy-to-light isotopes of key elements in the tissues of food web components act as naturally occurring tracers of food web linkages. For example, the stable isotope ratio of nitrogen, $\delta^{15}N$, increases by approximately 3.5% in the tissues of a consumer relative to its diet, and thus acts as an indicator of relative trophic position. Conversely, the stable isotope ratio of carbon, $\delta^{13}C$, changes only slightly from diet to consumer, and thus can be used to trace the bases of production that support a consumer. By analysing the $\delta^{15}N$ and $\delta^{13}C$ of key food web components, one can imply the most likely trophic relationships within the food web and compare those with the relationships implied from gut content data. Furthermore, the complementarity of gut content data and stable isotope data can be evaluated via dynamic models that link growth to stable isotope ratios. Fish bioenergetics models predict the growth and consumption of fishes under a variety of conditions (body size, temperature, diet composition, diet quality) defined by the user. Laboratory studies have shown that the stable isotope ratios of fish tissues are almost entirely dependent upon growth derived from a particular diet. Thus, the relationship between growth and stable isotope ratios can be incorporated into a bioenergetics model. One can then set up modeling scenarios to determine the likelihood that a fish's diet, implied from gut content analysis, produced the stable isotope ratios found in that fish's tissues. This method of diet validation may prove useful in large aquatic systems for which quantitative dietary analysis via traditional methods is difficult or unfeasible.

Poster Presentations

Dynamics of benthic assemblage in relation to food availability in a brackish basin of the Western Mediterranean Sea (Italy)

Francesca Rossi[1], S. Como, S. Corti, and C. Lardicci

[1]Dipartimento di Scienze dell'Uomo e dell'Ambiente, Via Volta 6, 56126 Pisa, Italy.

[e-mail: fncrss@discat.unipi.it]

Annual seasonal fluctuations in deposit feeders macrobenthic assemblage and in its main food resources were preliminarily investigated. Food resources were estimated as lipids, proteins and carbohydrates sediment contents and as microphytobenthic biomass.

From autumn 1996 to autumn 1997, in a Mediterranean intertidal brackish basin, we collected sediment for macrofauna and biochemical analyses (chlorophyll-a, lipids, proteins and carbohydrates) using a three way nested sampling design.

Data showed a trend of seasonal and shorter-term variability in food resources and in macrobenthic assemblage dynamics. Microphytobenthic biomass fluctuated highly within seasons and the highest values of chlorophyll-a were measured in autumn 1997. Values of chlorophyll-a to phaepigments ratio larger than one were measured during autumn-winter indicating a microalgal biomass availability. Labile organic matter degradable components fluctuated both within and among season,s showing higher concentrations in summer and autumn 1997. In particular, at the beginning of summer 1997, a larger amount of labile organic matter and a sharp increase of protein compounds was measured. Those results evidenced a higher availability in food quality and quantity during the early summer. Macrozoobenthic assemblage species composition differed among all seasons (SIMPER analyses), evidencing peaks in species-abundance in winter-spring following a microalgal biomass increase and in summer-autumn 1997 after the highest values of labile organic matter. In particular, during winter-spring *Perinereis cultrifera*, which feeds on diatoms and macroalgal debris, and the surface deposit feeders, *Streblospio shrubsolii* and *Desdemona ornata*, increased. *Streblospio shrubsolii* and *Desdemona ornata* showed also a second peak respectively in summer-autumn 1997. Furthermore large numbers of individuals were counted during autumn 1997 but not in autumn 1996. The highest abundance of subsurface deposit-feeders *Capitella cf. capitata*, and Oligochaeta were found during summer-autumn 1997.

In natural habitats, biotic factors (e.g., nutritional resources availability) and environmental conditions may act to regulate growth and reproduction of deposit-feeders populations. Nevertheless, despite no cause-effect pattern having been found in this preliminary study, it may be hypothesised that temporal changes of sediment nutritional values might affect the population dynamics of macrobenthic deposit feeders. Studies at large temporal scales and suitable field experiments are needed to test this hypothesis.

Spatial variability of a benthic assemblage in an area of the Gulf of Follonica (Western Mediterranean Sea, Italy) influenced by a coastal power station

Francesca Rossi[1], S. Como, F. Maltagliati, and C. Lardicci

[1]Dipartimento di Scienze dell'Uomo e dell'Ambiente, Via Volta 6, 56126 Pisa, Italy.

[e-mail: fncrss@discat.unipi.it]

Due to the increased use of power plants, the impact of heated effluent discharge on the marine environment should be assessed. Improved procedures for a reliable detection and interpretation of environmental impacts are also needed. In the present study, the influence of a coastal power station thermal discharge on spatial variability abundance of macrobenthic assemblages in the Gulf of Follonica was investigated using Beyond BACI design and analysing two spatial scales of variability.

In September 1996, macrobenthic assemblages were collected in a location exposed to a thermal discharge (TDL) and in three control locations (CL). Four sites for each location were sampled.

The analyses on species composition indicated a high variability at small and large spatial scale both for TDL and CL. Furthermore, spatial variability in species composition among the three CL was comparable to the variability between TDL and CL. The Beyond BACI analyses performed on the most abundant species and on the total number of individuals showed no differences among TDL both at small (site) and at large (location) spatial scales.

These results showed that the differences for TDL were probably due to the natural variability of this area. Therefore, despite the long period of discharge (21 years) and temperature stress related to the sampling period, heated effluent appeared not to influence the spatial variability of the assemblage. Nevertheless, the thermal discharges could influence the seasonal dynamics of the communities rather than their spatial distribution and future researches with appropriate sampling design are needed.

Does choice of habitat for settlement affect growth of juvenile cod?

Karin Hüssy

Danish Institute of Fisheries Research, Department of Marine Fisheries, Charlottenlund Slot, 2920 Charlottenlund, Denmark

[e-mail: kh@dfu.min.dk]

Demersal juvenile Baltic cod were collected in two different areas at Rønne Bank (Baltic Sea) to determine the habitats influence on fish growth rates. One area was located at a water depth of <20 m and a temperature of 12.5°C, the other area on the lower slope of the Bank at a depth of 40 m and temperatures of 12.5°C above the thermocline (at 30 m) and 6.5°C below it. The growth of the fish from settlement to capture was assessed by otolith microstructure analysis. The stomach contents were analysed for prey composition. Fish from the Bank had larger otolith size/fish size ratios and smaller increment widths, indicating inferior growth. The otolith microstructure of fish from the deep area showed frequent subdaily increments. Stomach contents revealed that fish on the Bank consumed smaller meals consisting primarily of amphipods, while fish from the deep area consumed larger meals consisting of mysids, polychaets and fish. These results imply that Rønne Bank is less suitable as a nursery for newly settled juvenile Baltic cod than the areas on the slope of the Bank, even though the water temperature is the optimum temperature for growth. The observed difference in diet suggests that the lower growth rates on the Bank could be attributed to inferior feeding conditions, while the otolith microstructure suggests that cod from the deeper areas optimise their growth by vertical migrations.

Correlations between oceanographic features and anchovy (*Engraulis encrasicolus*) early life stages distribution and abundance in the Strait of Sicily

Gualtiero Basilone[1], A. Cuttitta[1], A. Bonanno[1], J. Delgado[2], L. Quintanilla[3], Giuseppa Buscaino[1], and R. Chisesi[1]

[1]IRMA-CNR, via L. Vaccara 61, 91026 Mazara del Vallo (TP), Italy]. [2]Dept of Applied Physics, University of Malaga, Campus de Teatinos, E.T.S.I. Telecommunication, 29071 Malaga, Spain. [3]Instituto Espanol de Oceanografia, Porto Pesquero s/n, 29640 Fuengirola, Spain.

[e-mail: basilone@irma.pa.cnr.it

The present paper illustrates some results of the work carried out under the EEC project "Distribution, biology and biomass estimates of the Sicilian Channel anchovy", aiming at the identify the spatial distribution of European anchovy (*Engraulis encrasicolus*) in the Sicilian Channel. The goal was to estimate the anchovy population biomass by means of two independent methods, the Daily Egg Production Method (DEPM) and the echo-acoustic method (echosurvey), and finally to identify the main environmental factors affecting distribution and abundance of the anchovy's early life stages.

The objectives were accomplished by means of two oceanographic multidisciplinary surveys, carried out during 1997 (ANSIC-0797) and 1998 (BANSIC-0698) coinciding with the peak spawning period of the anchovy.

The hydrographic sampling was carried out by alternating the CTD (rosette) casts every two transects and every two stations within each transect. Likewise Bongo 40 oblique plankton tows (200 (m mesh) were carried out to provide information on the egg and larval distribution. These tows followed a similar sampling scheme as that described for the CTD casts. In order to assure the maximum limit of anchovy egg vertical distribution (Palomera, 1991), tows were carried out from 100 m depth, whenever possible.

A total of 1439 anchovy eggs and 392 anchovy larvae were captured during BANSIC 0698 with Bongo-40 hauls. These represented 49% and 22% of the total fish egg and larval catches.

The distribution patterns respectively show the main spawning ground in front of Sciacca (NW of south Sicily) and the highest concentration of larvae in the opposite tip of the south eastern part of Sicily.

The most relevant feature, as a result of the anchovy egg and larval spatial distribution, is the linkage observed between the spawning strategy and the transport by current. The principal surface current is the AIS (Atlantic Ionian Stream), derived from MAW (Modified Atlantic Water). It flows following the bottom topography and impinges on the principal spawning ground off the coast of Sciacca.

From a physical viewpoint the area off Sciacca can be regarded as almost motionless, due to the bifurcation of the AIS into two branches. The main branch heads towards the south-east, producing the along shore transport of developing anchovy eggs towards the south-east. The minor branch heads offshore closing a cyclonic gyre and it can be the cause of offshore advection, as observed from minor offshore-localised egg and larval concentrations found in the 1997 and 1998 surveys.

The important role played by advection was established, on one hand, by the spatial distribution patterns for larvae along the south coast of Sicily showing the maximum larval concentration off Cape Passero. On the other hand the size distribution pattern for larvae indicated that size increased as we move toward the south east. In other words, Cape Passero not only registers the maximum density of individuals but also the individuals of the greater sizes. The regular higher larval concentrations off Cape Passero address the question of whether there are physical arguments supporting this pattern. The continental shelf breaks down abruptly to the east of Sicily. This situation influence the vorticity associated with the AIS, creating a retention zone off Cape Passero. This type of circulation provides suitable conditions to consider the Cape Passero zone as an area

of retention. From a biological point of view, this type of physical characteristic could facilitate the necessary conditions for growing and feeding (Bakun, 1996), permitting that area to be definedas a potential nursery ground.

Modelling the trophic transfer of beta radioactivity in an aquatic ecosystem

Johanne Tang Dalsgaard

Afd. For Havfiskeri, Charlottenlund Slot, 2920 Charlottenlund, Denmark.

[e-mail: jtd@dfu.min.dk]

An approach for modelling the trophic transfer of beta radioactivity within the marine food web of Enewetak Atoll, Micronesia, is presented. For a decade the atoll was used for nuclear testing and based on the vast amount of scientific literature on the atoll, a mass-balance trophic model of the windward reef was constructed, using the Ecopath modelling software. Ecopath uses as its basic inputs the biomass, production/biomass, and food consumption rates of the various functional groups in the ecosystem, along with a diet matrix. Based on these inputs it estimates the flow of biomass between the functional groups and presents the corresponding predation mortalities in a matrix where the columns represent the intake of, and the rows the losses of, biomass from the groups. A set of first-order differential equations, relating the intake and loss of biomass to the amounts of radioactivity in the groups, was then set up. The equations were integrated over time and calibrated by minimising the sum of squared deviations between the observed and predicted levels of radioactivity, thus mapping the transfer of radioactivity onto the transfer of biomass. The original food web / mass-balance model, which was constructed without reference to the data on radioactivity, was subsequently re-calibrated to achieve a match between the food web and the radioactivity data. The results predict that there is a time lag between the observed maximum of radioactivity and the trophic position of the groups, and that beta radioactivity is not bioaccumulated up through the food web.

The influence of the environment on the RNA/DNA and protein/DNA ratios of anchovy larvae (*Engraulis encrasicolus*)

Teodoro Ramírez

Instituto Español de Oceanografia, Centro Oceanografico de Málaga, Puerto Pesquero s/n, 29640 Fuengirola (Málaga), Spain.

[e-mail: teodoro.ramirez@ma.ieo.es]

The RNA/DNA ratio represents an index of the cell's metabolic rate, thereby it is useful for indicating the nutritional condition and the growth rate of fish larvae (Buckley, 1984; Ferron and Leggett, 1994). The protein/DNA ratio is an index of cellular size, and it also has been related to larval growth and condition. Well-fed and fast-growing larvae have higher RNA/DNA and protein/DNA ratios than slow-growing or starving larvae.

The aim of this work was to use the RNA/DNA and protein/DNA ratio to establish differences in nutritional status between larval populations from different areas.

Anchovy larvae were collected in June 1996 in the northwestern Mediterranean Sea from two areas with distinct hydrographic characteristics: Cape of Creus and the Ebro Delta. At all stations, temperature, salinity and fluorescence were registered by means of a CTD probe, and microzooplankton was sampled. The sampling of these parameters was repeated after 10 days, while anchovy larvae were collected only during the second sampling period.

The variation of environmental parameters over time were considered, in order to study the influence of the environment on biochemical parameters. Differences in biochemical parameters between areas were tested by ANCOVAS using larval weight as covariant. Differences in hydrographic parameters and microzooplankton biomass between areas were tested by means of the Mann-Whitney U-test. Statistical tests were considered significant at $p<0.05$.

Temperatures in the area off the Ebro Delta were slightly higher than in the area off the Cape of Creus ($p<0.05$). The average temperature in the area off the Cape of Creus was 17.6 ºC while in the Ebro Delta it was 18.4ºC. In both areas a significant increase in temperature was observed over time ($p<0.010$). No significant differences in fluorescence were found among areas ($p>0.05$). However fluorescence decreased significantly ($p<0.010$) over time at all stations from both areas. During the first sampling, microzooplankton biomass was higher in the area off the Cape of Creus, mean value 24 mg/m^3, than in the area off the Ebro Delta, mean value 5 mg/m3. In the Cape of Creus a significant decrease of biomass (-21 mg/m^3) was observed over time, whereas in the Ebro Delta microzooplankton did not show a significant change. The variation of microzooplankton biomass showed a strong relationship with temperature at larvae capture date ($r^2=0.64$, $p<0.0029$).

The individual RNA/DNA ratio decreased significantly with larval weight ($r^2=0.41$, $p<0.0001$). On the contrary, the protein/DNA ratios, an index of cellular size, showed a significant trend to increase with larval weight in both areas ($r^2=0.06$, $p<0.0009$). ANCOVAS showed that there were significant differences ($p<0.05$) in biochemical parameters between both areas. Anchovy larvae from the area off the Ebro Delta presented higher average RNA, DNA and protein content than larvae from the Cape of Creus. However, larvae from the Cape of Creus had significantly higher average values of RNA/DNA and protein/DNA ratios than larvae from the Ebro Delta. The mean RNA/DNA ratio was 7.12 for larvae from the Cape of Creus and 6.40 for larvae from the Ebro Delta, while the mean protein /DNA ratio was 30.44 and 24.16 for larvae from the Cape of Creus and the Ebro Delta respectively.

Average RNA/DNA ratio at each station was negatively correlated with the increase of temperature over time

(r^2=0.45, p<0.023) and with temperature at larvae capture time. Likewise, they showed positive but no statistically significant trends to increase with the net variation of fluorescence (r^2=0.30, p<0.0786), and to decrease with the variation in microzooplankton biomass (r^2=0.30, p<0.0802). Protein/DNA ratio was also negatively correlated with the net variation in temperature (r^2=0.53, p<0.0111) and they show a negative trend to decrease with variation in microzooplankton biomass (r^2=0.22, p<0.14564). Average RNA exhibited a negative relationship with temperature variation (r^2=0.31, p<0.0444). However DNA and protein content showed an almost significant negative relation with the net variation in temperature (r^2=0.36, p<0.0501 and r^2=0.36, p<0.0520, respectively). Positive but no significant trends were observed for RNA, DNA and protein with microzooplankton biomass variation.

When multiple regression analysis was applied with RNA, DNA and protein as dependent variables, both temperature and microzooplankton biomass variations over time emerged as significant factors, explaining more than 70% of variability of these parameters. In the case of RNA/DNA and protein/DNA ratios, temperature variation was the only significant factor.

The results indicated that larvae from the Cape of Creus were in better nutritional condition than larvae from the Ebro Delta, however the differences observed in biochemical ratios between areas can be attributed to the different environmental conditions in each area more than to a different nutritional status. In general, the lower temperatures observed in the area off Cape of Creus appeared to be the main cause for the higher RNA/DNA and protein/DNA ratios found in larvae from the Cape of Creus compared with larvae from the Ebro Delta. Several authors have found a negative relationship between RNA/DNA ratio and water temperature (Goolish *et al.*, 1984; Ferguson and Dazzmann, 1990): fish acclimated to cold temperature had higher RNA/DNA ratio than warm acclimated ones. These authors reported that the decrease in RNA/DNA ratio with temperature was due to a compensatory mechanism for lower RNA activity, which produces an increase in RNA concentration. In this study RNA showed a negative trend with temperature, although DNA and protein content also did.

The nutritional status of fish larvae depends on the food availability, and the RNA/DNA ratio in fish larvae has been correlated with prey density (Buckley, 1984; Ferron and Leggett, 1994). The unexpected negative relations between biochemical indices and the variation in microzooplankton biomass can be explained by a strong relationship between the variation of microzooplankton biomass and temperature. The lack of a clear simple relation between biochemical ratios and microzooplankton biomass may suggest that the ratios would reflect microzooplankton composition better than total quantity of microzooplankton. Likewise, temperature may have more influence on biochemical parameters than food availability. In the multiple regression model applied to RNA, DNA and protein, temperature coefficients were always higher than microzooplankton coefficients, showing that temperature affected biochemical parameters more than microzooplankton biomass.

In conclusion, temperature was the main environmental factor which affected the RNA/DNA and protein/DNA ratios. Whereas temperature and microzooplankton biomass variation significantly affected to RNA, DNA and protein. Biochemical parameters used in this study can be successfully used to distinguish between larval populations inhabiting different environments.

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The effect of momentum and buoyancy fluxes on the mixed layer depth and their influence on the primary productivity of the North Arabian Sea, during the Northeast and Southwest monsoons of 1992

T. Masood, A. Khan, Samina Kidwai[1], and S. Amjad

[1]National Institute of Oceanography (NIO), St-47, Block-1, Clifton, Karachi 75600, Pakistan.

[e-mail: skidwai@cyber.net.pk]

The Arabian Sea is unique since the time dependent variations in the thermal structure of the sea strongly depends upon the changing winds and solar radiation. This paper examines the seasonal variability of Mixed Layer Depth (MLD) to understand the relationship between the surface fluxes and the mixed layer deepening in the north Arabian sea and how this affects the primary productivity (PP) and Chlorophyll a (Chl *a*).

The meteorological and oceanographic data were collected on board during the deep sea oceanic cruises under the PAK-US joint program (NASEER Project). The momentum and heat fluxes computed during our heat budget studies for the north western Arabian Sea was utilized to compute salt, buoyancy fluxes and Monin-Obukhov length. We examined the relative roles of momentum and buoyancy fluxes in the turbulent kinetic energy (TKE) transfer across the air-sea interface, resulting in the responses in MLD and effects on PP and Chl.

Results indicated that there is a significant variability both seasonally and latitudinally in the mixed layer depths. By comparison, the Northeast (NE) monsoon conditions were more uniform, with a moderately deep mixed layer than Southwest (SW) monsoon conditions where depth varies with latitude. In the NE monsoon in January 1992, the Monin-Obukhov Length (L) was negative while buoyancy flux (Bo) >0 and Stability ratio (D/L) >1. The turbulence was dominated by convection and by deep oceanic mixed layer. On the other hand, in the SW monsoon, August 1992, the L was positive, buoyancy (Bo) <0 and stability ratio (D/L) <1. Therefore, MLD loses its significance deepening and it is dominated by wind stress.

Multiple regression analysis has been used in the past to evaluate the relationships between biotic and abiotic parameters although a strong relationship was not established. We used a stepwise multiple regression analysis and we found a strong relationship between the examined variables probably due the fact that the present study was carried out in the marine compared to the fresh water environment of the past examination.

Multiple Linear Regressions were performed between wind stress, mixed layer depths, buoyancy flux and Primary productivity, Chlorophyll respectively. Very weak relationships were determined using a simple linear regression. However the relations was stronger using a multiple regression analysis, for primary productivity (r2=0.35) and for Chl *a* (r2=0.93), during the Northeast monsoon. There were insufficient data to predict the primary productivity and Chl *a* during the Southwest monsoon. During the Northeast monsoon, the stability ratios was (D/L)>1. Therefore, there is greater predictability during the Northeast monsoon than in the Southwest monsoon condition where the stability ratio (D/L)<1 and thus the system is less predictable.

Key words: North Arabian Sea, Northeast and Southwest monsoon, mixed layer depth, wind stress, heat fluxes, Buoyancy flux, stability ratio, Primary productivity, Chlorophyll *a*.

Microbial processes in *Nodularia spumigena* aggregates

Susanna Hietanen

Finnish Institute of Marine Research, Lyypekinkuja 3 A, PO Box 33, 00931 Helsinki, Finland.

[e-mail: susanna.hietanen@fimr.fi]

Cyanobacterial blooms are a common phenomenon in the Baltic Sea during warm summer months. The dominating bloom-forming cyanobacteria are the nitrogen fixing *Aphanizomenon flos-aquae* and *Nodularia spumigena*. Bacterial associations are different for the *Aphanizomenon flos-aquae* and *Nodularia spumigena* aggregates. For *Aphanizomenon,* which makes tight "needle-stack" bundles, bacteria-cyanobacteria associations are dominating. For *Nodularia*, which makes coiled, loose "spaghetti" bundles, microbial food web associations including bacteria, microalgae, protozoa, metazoa and even mesozooplankton are possible. The apparent massiveness of the cyanobacterial blooms has favoured the concept that cyanobacterial blooms are a net input of nitrogen and carbon to the Baltic Sea. However, this concept neglects the fact that visible cyanobacterial bundles, aggregates, have long been recorded as sites of intense microbiological activity and that heterotrophic processes create strong oxygen gradients inside the aggregates. Inside cyanobacterial aggregates various biologically mediated processes of nitrogen cycle may take place. Microscale anaerobic zonation in aggregates not only allows nitrogen fixation to take place but also allows denitrifiers to convert the fixed nitrogen back to dinitrogen gas. This denitrification process is the main focus of the ongoing project "Bacterioplankton growth and denitrification in cyanobacterial aggregates". The key process to be measured is denitrification as it directly diminishes the nitrogen pool. Some results from research cruises onboard R/V Aranda on summer 1999 will be discussed.

The phytoplankton *in situ* primary productivity approached by the ^{14}C-technique and fast repetition rate fluorometry (FRRF)

Mika Raateoja

Finnish Institute of Marine Research, Lyypekinkuja 3 A, PO Box 33, 00931 Helsinki, Finland.

[e-mail: raateoja@fimr.fi]

Primary productivity and light utilisation of pelagic phytoplankton community was estimated in situ at the entrance of the Gulf of Finland during four days in July 1999, each day consisting of four separate incubation periods. The aim was to study the variable fluorescence technique as a way of measuring primary productivity, compared to the widely used ^{14}C technique. The coefficients of determination in the linear regression analysis between the fluorescence-based in situ electron flow (P_f, mol e-·(mol RC) $^{-1}$·s^{-1}) and in situ ^{14}C -productivity (P_b, mol C·(mol Chl *a*) $^{-1}$·s^{-1}) varied from 84.2 to 99.7% within the incubation periods. After P_f was converted by the fluorescence-based in situ photosynthetic rate (P_r, mol C·(mol Chl *a*) $^{-1}$·s^{-1}), the ratio between the primary production measured by variable fluorescence and ^{14}C -incorporation varied between 0.594-2.963 within the incubation periods, with an average of 1.53. This discrepancy is explained partly by the different interpretations of the two approaches. As primary productivity measured by the ^{14}C technique represents something between gross and net production, measurements based on variable fluorescence are related to gross productivity, and hence, should be higher than ^{14}C estimates. However, the differences in results between the techniques are largely caused by the pre-set constants within the fluorescence-based technique necessary to obtain the carbon-based estimates. These constants include: 1) the photosynthetic quotient (PQ), which depends on the type of the inorganic nitrogen source, and hence, is controlled by the hydrodynamics of the basin, 2) the ratio of photosystem II reaction centres to Chl *a* (n_{PSII}), which changes along the adaptation of the phytoplankton photosynthetic machinery to existing light regime, and nutrient availability.

Workshop 4

Modelling Ecological Processes

Summary of Workshop 4

The workshop on ecological modelling included a broad variety of different problem settings and model types. The workshop participants concluded that, independent of the specific aim of a model study, four different issues form a central future challenge both to understand the dynamics in focus and to improve future modelling activities. It was stressed in the final discussion that these issues are not to be treated independently, but that especially their synergetic effects in any model formulation should be assessed carefully.

A) Scale dependence and interaction

Scale constitutes an important element of a model. Independent, whether temporal, spatial or biotic, knowing over which scales processes act is a key to understanding their dynamics. Meteorological and topographic forcing were demonstrated as examples of processes which act differently on varying temporal or spatial scales. Also scale interaction has been addressed as an important element of understanding processes and patterns. Large scale circulation was demonstrated to result in local pattern, thereby indicating that large scale oceanographic processes can generate smaller scale signals. Vice versa, e.g., small scale extreme events create signals on much larger scales.

B) Process analysis

Whether dealing with individuals, populations, communities or whole ecosystems, the group agreed that a process orientated point of view, focussing on the interactions and coupling between the different components of a process, bears great potential to understand ecological dynamics. Examples of the interaction between physics, nutrients and phytoplankton, interdependency of subpopulations within a metapopulation, and forcing of physical environment on egg and larval drift, to name but a few, have been discussed.

C) Data exploration

Modern advanced statistics offer new ways to explore data. The group discussed pros and cons of the empirical models versus deterministic models. Empirical models offer the opportunity to let the data speak for themselves, rather than incorporating possible erroneous deterministic knowledge in the model formulation. Care has to be taken however, since many empirical models also contain fundamental assumptions, namely homogeneous variance, linearity and normality. It is therefore crucial to analyse the variance structure of the data. It was pointed out that in the future alternative probability-generating functions and their resulting probability distributions could be used to overcome these problems. Generalised additive models (GAM) are a powerful empirical tool, e.g., in assessing habitat preferences, because they are non-linear, non-parametric and non-monotonic. For spatial and temporal analysis, the usage of Geographic Information Systems (GIS), geostatistics and physical models in 1, 2 or 3 dimensions has been discussed. The treatment of missing data was characterised as crucial, and effects of interpolation and binning have been discussed. It has been pointed out that using empirical methods, stock-assessment and stock-recruitment relationships could possibly be re-invented.

D) Model complexity

How to evaluate the necessary respectively useful degree of complexity of models has been focussed. The level of complexity should be driven by the data used and questions posed. Conceptual models were found to be a useful learning tool for summarising or understanding existing processes and information. Especially within approaches for a sustainable marine management, it has to be assessed whether models used will be huge and integrating many components, or simpler nested ones, or something in between.

Modelling as a discipline

William Silvert – Invited Speaker

Emeritus Research Scientist, Bedford Institute of Oceanography, Dartmouth, N. S., Canada B2Y 4A2.

[e-mail: silvert@iname.com]

Modelling is an essential and inseparable part of all scientific, and indeed all intellectual, activity. How then can we treat it as a separate discipline? The answer is that the professional modeller brings special skills and techniques to bear in order to produce results that are insightful, reliable, and useful. Many of these techniques can be taught formally, such as sophisticated statistical methods, computer simulation, systems identification, and sensitivity analysis. These are valuable tools, but they are not as important as the ability to understand the underlying dynamics of a complex system well enough to assess whether the assumptions of a model are correct and complete. Above all, the successful modeller must be able to recognise whether a model reflects reality, and to identify and deal with divergences between theory and data. Theories can be wrong or merely incomplete, and even "raw" data are just the outputs of experimental interpretations, i.e. models. These points will be described with examples from the scientific literature, accompanied by horror stories of modelling projects gone awry.

Sources of uncertainty in ichthyoplankton surveys: Modelling advective losses

Rüdiger Voss

Institute of Marine Sciences, Dept of Fishery Biology, Düsternbrooker Weg 20, 24105 Kiel, Germany.

[e-mail: rvoss@ifm.uni-kiel.de]

A three-dimensional physical oceanographic model was used to simulate the temporal evolution of idealised ichthyoplankton distributions. Five different idealised distribution patterns were entered into the model for the region of the Bornholm Basin, Baltic Sea. The Bornholm Basin is one of the major spawning grounds for cod (*Gadus morhua* L.) and sprat (*Sprattus sprattus* L.) in the Baltic Sea. Therefore a large number of historic survey data as well as material from ongoing investigations are available. The aim of this study was to model the quantitative influence of advective losses out of the surveyed area on the resulting abundance estimates of various early life history stages. The simulations were run for two contrasting meteorological forcing conditions, one representing the situation as observed in May 1988 with mainly calm winds from varying directions, the other showing high wind speeds from mainly western direction, representing the situation in August 1991. For each experiment, a distingtion was made between eggs and larvae of the two species cod and sprat, as these show different vertical distribution patterns. Possible constraints in the accuracy of historic material are discussed in relation to the meteorological forcing conditions.

Modelling of the complete life cycle of fishes: application to the anchovy population

Sami Souissi

INRA-Station d'Hydrobiologie Lacustre, Station Zoologique, B.P. 511, 75 avenue de Corzent, 74203 Thonon-les-Bains, France.

[e-mail: s_souissi@yahoo.fr]

To introduce the concept of simulating the development of the complete life cycle of an exploited species, a model of the development of a fish from egg to adult stage is proposed. The model is stage-structured, and is obtained from a coupling between demographic and growth processes. A bioenergetics model was used, on the one hand, to calculate growth and on the other hand, to estimate the mortality due to starvation. This approach was applied to the anchovy population (*Engraulis encrasicolus*) in the north-western Mediterranean. The growth in length as a function of the age simulated by the model varies according to the external factors: temperature and food encountered during the various phases of the life cycle. We developed an adequate tool to study the determinism of the recruitment of exploited fishes. The numerical simulations are helpful to understand the role of environmental factors like temperature, and food, on the variability of the recruitment. We used the model to propose new parameterisation of the relationship between stock and recruitment.

Use of Geographic Information Systems and statistical tools to study squid resources in the Northeast Atlantic

J. M. Bellido,[2] and G. J. Pierce[1]

[1]Department of Zoology, University of Aberdeen, Tillydrone Avenue, Aberdeen AB24 2TZ, UK. [2]Instituto Español de Oceanografia, Unidad de Cádiz. Muelle pesquero s/n. Ap. 2609, 11006, Cádiz, Spain.

[Corresponding author: j.m.bellido@abdn.ac.uk]

The present work reports results from an analysis of the distribution and abundance of squid *Loligo forbesi* and *Loligo vulgaris*, measured as Landings Per Unit of Effort (LPUE) along Scottish, English and French Atlantic waters. Cephalopod resources are of relatively recent importance to international commercial fisheries, often being regarded as "non-conventional" resources (Boyle, 1990). The abundance and distribution of cephalopod stocks may fluctuate widely from year to year limiting more directed exploitation. According to Caddy and Rodhouse (1998), cephalopod fisheries are among the few still with some local potential for expansion; in fact, as groundfish landings have declined globally, cephalopods landings have increased.

Squid are an important by-catch in UK whitefish and Nephrops fisheries in European waters. The main species landed in UK are veined squid *Loligo forbesi* and

European squid *Loligo vulgaris*, of which only the former is normally caught in Scottish waters (Pierce et al, 1994). Squid are short-lived and their distribution and abundance are thought to be related to environmental variables. Particularly interesting are the relationship described in Waluda and Pierce (1998) and Pierce *et al* (1998a,b) between the sea surface and bottom temperatures in relation to the abundance and distribution of *Loligo forbesi*.

In order to reveal all the characteristics of this species a GIS has been set up. The area under study comprised the region 40.00^o to 65.00^o North and 27.00^o West to 11.00^o East. The "*Loligo GIS*" was developed based on ArcView v. 3.1. although for some analysis PC Arc/Info v. 3.5.1 and UNIX Arc/Info v. 7.11 were used.

Geographical Information Systems (GISs) are sets of computer hardware and software for analysing and displaying spatially referenced features (i.e., points, lines, polygons) with non-geographic attributes (i.e. species, age). There are also various ways of combining and transforming the different variables. One of the most important uses of this type of analysis is the possibility of forecasting the evolution of certain phenomena, permitting selection between several alternatives. Hence, GIS offers a technical means for combining fishery and environmental data into a single data platform and to reveal relationships between the physical environment and fishery abundance.

By this GIS platform, overlay of coverages of available environmental variables was used in a visual analysis of putative links between abundance and environmental conditions. A number of data sets comprising landings, fishing effort, bathymetry and oceanographic parameters have been analysed on a monthly basis for the period January 1980 to December 1997. Generalised Additive Models and geostatistic tools were used to test hypotheses suggested by the GIS.

Fishery data were derived from information on landings and fishing effort held by the Fishery Research Services Marine Laboratory in Aberdeen. Sea surface temperature data were accessed from the National Center Atmospheric Research (NCAR), USA. Other environmental variables were accessed from the International Council for the Exploration of the Sea (ICES) database. Latitude and longitude were calculated by assuming that all catches and fishing were located at the centre of the ICES rectangle to which they refer.

Geostatistics methods are useful for site assessment and monitoring situations where data are collected on a spatial network of sampling locations. *Loligo* populations show highly complex aggregated patterns of spatial distribution. Pierce *et al.* (1994) suggest that LPUE can be used as an abundance index. Following the general argument that *Loligo* is a by-catch so that fishing effort is generally unrelated to its abundance, and that it is sufficiently valuable that discarding is rare, we assume that landings per unit effort can be used as an index of abundance.

Hence, let the density of *Loligo forbesi* be a spatially referenced variable, Z(x), where x is the position of a sampling point in R^n, n=2 for our purposes. Then Z(x) is called a regionalized variable if the value taken by Z at x only depends on its geographical position. All interpolation and contouring methods make the assumption that some type of spatial correlation is present, that is, they assume that a measurement at any point represents nearby locations better than locations farther away. Variogram analysis attempts to quantify this relationship. Variogram parameters were estimated and fitted to a spherical model.

For the purpose of mapping the resource we employed the spatial estimation technique known as point kriging. Kriging is a weighted moving average method used to interpolate values from a sample data set onto a grid of points for contouring. The kriging weights are computed from a variogram, which measures the degree of correlation among sample values in the area as a function of the distance and direction between samples.

The possibility offered by geostatistics is to describe with a model the spatial correlations, then to use this information for estimation. The methods offer a correct solution for estimating the variance of the abundance estimation when the sampling is performed on a regular grid or on fixed stations. By these tools we estimated squid abundance in areas where information from commercial fleets is not available, with a correlation between the observed and expected values between 66% and 88% depending on the month analysed.

Generalised Additive Models were used to perform comparisons of abundance in different years, months and areas and modelling trends in abundance and distribution as a function of spatial position and environmental features. The preliminary models presented here used LPUE as the dependent variable. The independent variables considered were longitude, latitude, SST and month. This analysis includes both spatial and temporal components. Month was included to remove the effect of seasonal differences in abundance and interannual differences are excluded by considering data from each year separately. Cubic spline smoothers were used in the GAM model.

We found clear relationships between seasonality and LPUE as well as LPUE and SST, with the highest LPUE at temperatures of around 11^o C. As expected from previous work, the highest LPUE was found in winter months. Spatial analysis presented as three-dimensional plots describes the distribution of the fishery in June and December in each year.

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The spawning migration in Norwegian spring spawning herring: allocation of energy to migration or reproduction?

A. Slotte[1] and Ø. Fiksen[2] – Invited Speaker

'Institute of Marine Research, P. O. Box 1870, N-5024 Bergen, Norway. [2]Department of Fisheries and Marine Biology, University of Bergen, Bergen High Technology Centre, N-5020 Bergen, Norway.

At present the Norwegian spring spawning herring *Clupea harengus* L. stock winters in fjords of northern Norway, whereas the subsequent spawning occurs at various locations along the coast with a main bulk off the south-western coast. In addition, the distance of the southward spawning migration tends to increase with the length and condition of the fish.

Correspondingly, the present study hypothesised that these herring face a trade off between the costs and benefits of spawning farther south, where hatched larvae have increased survival probabilities as they encounter warmer water during the northward drift in the coastal current. This hypothesis was supported by a model, which quantified the costs and benefits in terms of fitness related to the migration distance on a latitudinal scale and individual fish size. In accordance with the observed spawning distribution, the model predicted optimal spawning off the south-western coast, and that spawning should occur farther south with increasing fish size. Increasing overall area larval mortality rates made southern spawning even more profitable, whereas increased larval retention enhanced survival and shifted optimal spawning grounds northwards.

The ecological hierarchy, model complexity, predictive ability and robust management

Daniel E. Duplisea

Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, England.

[e-mail: d.duplisea@cefas.co.uk]

It is now realised that exploitation of fishery resources is reaching critical levels (Pauly and Christensen, 1995). It is also obvious that this level of exploitation is not going to decrease as the human population increases and the demand for protein sources follows. Concomitantly there is a rapidly increasing awareness that natural systems cannot be exploited without boundary before they collapse and have profound impacts on the human population. Hence, there has been a call for "ecosystem management".

In the fisheries context (and perhaps in any context), it is not obvious what "ecosystem management" is. No doubt, it will involve the development of predictive simulation models. Since we presently assess fish stocks with age-structured single species models, the immediate idea for ecosystem management would be to combine all of these single-species models and fishing by studying the interactions between them. The reasoning behind this approach is that information at all levels of the system (from species to communities) could be provided by such a model. The complexity of such a model, however, would be immense and the uncertainty in predictions very large. This is undesirable for a predictive model. Another approach is to construct models that are question driven; that is, the question and the management goals drives the necessary level of complexity of the model. Hence, ecosystem management is handled by a simple aggregate model containing information passed from more reduced models.

A range of question driven models essentially derives from a different modelling philosophy. This approach realises that ecological models are simplifications and therefore no single model can embody all of the behaviour of the system. This dichotomy is what is termed a "holistic" approach versus a "reductionist" (Dickie and Kerr, 1982) approach or "top-down" versus "bottom-up"(Silvert, 1982). One approach does not replace the other but one can temper the other, e.g., predicted individual species yields derived from single-species models cannot surpass the predicted total system yield predicted by a community based model. Furthermore, management strategies should be examined through the range of models for conformation with the management questions and goals of that model/system level. A management strategy that conforms with the goals at several different levels of complexity can then be considered a robust management strategy.

Deriving robust management strategies as outlined above is difficult because a structure must exist common to all models such that strategies can be mathematically formulated throughout the model range and they must be operational in each model. Therefore, one must establish commonalties in the models that transcend structure and

also make sense ecologically and to the fishing industry and its management. Though there could be several of these, one common structure which does make sense is a size-based approach.

Aquatic ecosystems are strongly size structured from individual organism physiology and trophic interactions up to system-level size-distributions (Dickie *et al.*, 1987). Fisheries are also size-based in that they target large and valuable fish. Fisheries management can also be implemented in a size-based manner by manipulating the relative abundance of fleets and gears.

As an example of this robust management approach, two size-structured models were examined for the optimal size-based management strategy, which would give maximum sustainable value yield (MSY) in a hypothetical system. A length-cohort model was constructed with 10 different species differing in their ecological characteristics and interactions mediated by predation, very similar to a Multispecies Virtual Population Analysis forecast (Magnússon, 1995). A second model of a total system biomass at size without species differentiation was also constructed based on biomass size-spectrum theory (Silvert and Platt, 1981). Both models indicated that a management strategy entailing a small fishing mortality on small fish sizes and a large mortality on large size would achieve the management goal (MSY). As the management goals of each system complexity-level were met by the management strategy it can be said that the strategy transcends model structure and hence is robust.

This hypothetical exercise showed that robust management might be possible with the demands to provide both single-species and ecosystem level management. Further work should be conducted along these lines both to increase the number of models used and to define operational structures on which they could be based. Furthermore, clear management goals must be defined for each level in the ecosystem.

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Fisheries modelling of a pelagic species ecological relationships: a scale-dependent comparison of two geographic segments of the population

C.D. Maravelias[1]

FRS Marine Laboratory, PO Box 101, Victoria Road, Aberdeen AB11 9DB, Scotland. [1]*Present address: National Centre for Marine Research, Agios Kosmas, Hellinikon, GR-16604 Athens, Greece.*

[e-mail: maraveliasc@hotmail.com]

This paper studied the habitat associations of a pelagic species with a range of biotic and abiotic factors at three different spatial scales. Generalized additive models (GAMs; Hastie and Tibshirani, 1986, Maravelias and Reid, 1997) were used to analyse trends in the distributional abundance of a pelagic species in relation to thermocline and water depth, seabed substrate roughness and hardness (*RoxAnn*), sea surface salinity and temperature, zooplankton abundance and spatial location. The North Sea herring was used here as an example. Two geographic segments of the population, those east and west of the Shetland Islands (ICES Div IVa), were examined. The differences in the ecological preferenda of the species in these two distinct geographic areas were elucidated and the degree that these environmental relationships might be modulated by the change of support of the data was also considered.

I examined the data using the Elementary Sampling Distance Unit (ESDU) used in the survey i.e. the 2.5 n. miles, which is the output of the echo-integrator. I ran the same GAMs. having binned the data on 5 n.miles segments, in order to investigate the validity of the ecological relations suggested from the previous step of the analysis, in terms of relative importance, explanatory power and suggested shape of the relationship (smooths). This was also considered as an effective way to handle the spatial autocorrelation of the acoustic data used here (Maravelias, 1999, Maravelias and Haralabous, 1995). Finally, I ran the same GAM on a subset of the whole data set that involved only the data for the locations where I had zooplankton and CTD sampling stations. Results showed that the relative importance of the predictors does not change significantly changing the support of the data. The factors with the highest explanatory power (or strongest effects) were the same in the 2.5 n.miles, 5 n.miles or in the data subset observation window. There was a slight change in the shape of some of the relationships, but that did not alter any of the conclusions. The present results also suggest that the current 2.5 n.miles ESDU is a reasonable sampling scheme that combines the need to reduce the data volume and the loss of the spatial resolution of the data and does not mask the herring-environment relationships.

In terms of the oceanographic and topographic features observed, the study area exhibits differences in spatial

continuity with direction. The area is dominated by the Slope Current which advents water of Atlantic origin into the North Sea via the East Shetland Atlantic Inflow and the Fair Isle Current The Atlantic inflow into the North Sea is responsible for a significant input of warm, nutrient rich water into the northern North Sea, bringing in oceanic planktonic species as well as fish larvae otherwise lost. Since now, the two areas have been examined mainly together (Maravelias, 1997). As a result, the relationships of herring to various environmental factors that have been found, were believed to apply to both areas. The current results indicate that this is not necessarily so. Part of the observed variability of the pre-spawning distribution of herring was found to be explained by different parameters in these two distinct areas. This supports the idea that herring constitute two geographic segments, those east and west of the Shetland isles, and that their spatial distribution seems to be modulated by different variables in these areas. In both areas, zooplankton abundance and seabed substrate were the covariates with the highest explanatory power. For the east part of the isles, a SST of around 12°C (i.e. characteristic of the East Shetland Atlantic Inflow) and the latitude-longitude interaction were also found to modulate the prespawning spatial aggregation of the species. West of the Shetland Isles, the water depth-thermocline depth interaction had a highly significant effect that seemed to govern species clustering to potentially suitable spawning grounds.

Apart from enabling us to conceive further the ecological processes that might influence the prespawning distribution of a commercially important pelagic fish species, the present findings could also be of great assistance in future surveys and stock assessment issues. Perturbations of the ocean environment may induce variability in survey indices that is not related to true changes in abundance. Consistent relationships of fish species with particular ranges of environmental conditions that have also been quantitatively identified, such as those demonstrated in the present study, may be considered as a first step towards incorporating the effects of environmental variability into analyses of abundance indices (Maravelias, 1997, 1999).

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Metapopulation theory and northern cod population structure: interdependency of subpopulations in recovery of a groundfish population

R. Kent Smedbol[1,2] and J. S. Wroblewski[2]

[1]Department of Biology and [2]Fisheries Oceanography Group, Ocean Sciences Centre, Memorial University of Newfoundland St. John's, NF, A1B 3X9 Canada.

[e-mail: ksmedbol@morgan.ucs.mun.ca]

Using metapopulation concepts we propose a model of subpopulation structure within the northern Atlantic cod (*Gadus morhua*) population inhabiting the coastal and offshore regions of eastern Newfoundland and Labrador. A metapopulation is a set of local populations or subpopulations within some larger area (usually the population's range) where typically migration from one to at least one other subpopulation is possible (Hanksii and Simberloff, 1997). We suggest that the metapopulation concept may best explain the historical patterns and present day observations of northern cod distribution. Evidence for subpopulation structure is drawn from a variety of original and published sources. We define subpopulations during the spawning season, in relation to those individual cod associated with the various specific major spawning areas associated with offshore banks and in coastal bays. Putative subpopulations are identified using several criteria: genetic distinctiveness (microsatellite DNA allele frequency variation), variation in life history traits, and residency in or interannual fidelity to discrete spawning areas.

A conceptual model of northern cod metapopulation dynamics is derived from the simple model of Levins (1970). The historical northern cod population is first represented as an unfished metapopulation. We then modify the model to include the influence of fishing harvest on subpopulation extinction. Metapopulation theory predicts that fewer spawning areas are occupied as the population declines. This prediction is validated in that Saglek, Nain, Makkovik and Harrison Banks have had no significant spawning activity since the over exploitation by trawlers during the 1960s. The corollary prediction is that as the population recovers, currently unoccupied spawning areas will be recolonized. The model suggests that a continued moratorium on fishing the remaining subpopulations would promote recolonization and accelerate the recovery of the overall metapopulation.

The influence of stock structure and environmental conditions on the recruitment process of Baltic cod estimated using a Generalised Additive Model (GAM)

Massimilio Cardinale, F. Arrhenius, and P.-O. Larsson

Institute of Marine Research, P.O. Box 4, 453 21 Lysekil, Sweden.

[e-mail: mascar@imr.se]

The recruitment process and its underlying mechanisms are among the most studied phenomena in fisheries ecology. Different models has been used to describe and estimate fish recruitment assuming a direct relationship with spawning stock size. Unfortunately, such relationship is often complicated by highly variable environmental conditions, feeding conditions or other factors that can influence and obscure the results of a simple regression analysis between stock and recruitment. We used Generalised Additive Models (GAMs), nonparametric generalisation of multiple linear regression, to investigate the influence of environmental factors and stock structure on recruitment of Baltic cod. The number of old spawner individuals (>5+) was the most significant explanatory variable. The number of young spawners has a positive impact on cod recruitment only at high level of reproductive volume, while old spawners have the highest positive effect at low level of reproductive volume. Therefore, it appears that number of recruits is dependent on the age population structure, with repeated spawners providing the highest survival rate offspring. The implications of the results of this study on the management of fisheries resources are discussed.

Understanding the interactions between nitrogen, phosphorus and nitrogen-fixation: implications for the Baltic Sea

Toby Tyrrell

University of Southampton, Southampton Oceanography Centre, European Way, Southampton SO14 3ZH, UK.

[e-mail: tt@soc.soton.ac.uk]

A model of the ecological competition between nitrogen-fixing and other phytoplankton was inserted into a simple model of the global ocean cycles of nitrogen and phosphorus. The combined model (Tyrrell, 1999) shows that growth penalties inherent in a nitrogen-fixing strategy (for instance, extra energy requirements in order to break apart the N_2 triple bonds, extra structural costs to build vacuoles within which oxygen concentration must be lowered to accommodate oxygen-inhibited nitrogenase enzyme) must cause surface waters to be more deficient in reactive N than in phosphate, relative to organic requirements. A stable population of nitrogen-fixers cannot otherwise be maintained. But perturbing the river inputs to this model ocean only makes a difference to primary production if P inputs are altered. Altering N inputs has no effect. That is to say, the model predicts both that the proximate limiting nutrient is reactive nitrogen, and that the ultimate limiting nutrient is phosphate. The model therefore has the potential to resolve the biologists vs geochemists (N vs P) disagreement about control of oceanic primary production.

There is a reasonable quantitative agreement between literature estimates (derived from laboratory experiments and field observations) and (1) model parameter values, (2) model steady-state standing stocks of nutrients and phytoplankton, and (3) model steady-state N and P fluxes.

There are reasons to believe that this model is also applicable to the Baltic Sea, and that primary production there is also ultimately limited by phosphate, despite proximate nitrogen limitation of the surface waters (Graneli *et al.*, 1990). While nitrogen fixers account for a lot more of total phytoplankton production in the Baltic than in the open ocean, and while nitrogen-fixation accounts for 20% or more of all reactive nitrogen inputs to the Baltic Sea (Larsson *et al.*, 1999), yet nitrogen-fixation also stops just short of bringing reactive nitrogen concentrations up to 16 times phosphate concentrations. During August, towards the end of the best weather for phytoplankton (that is to say, when phytoplankton dynamics can be considered to be most 'in control' of the nutrients) nitrate has been more or less completely stripped out of all surface waters of the Baltic Proper, whereas a small phosphate residual still remains (Figures 2&3, Wulff & Rahm, 1988).

A modelling study, carried out independently of my own and aimed specifically at the Baltic, reached similar conclusions: "Thus, the system appears to be phosphorus controlled, although primary production is still nitrogen limited!" (Savchuck and Wulff, 1999). This model also included nitrogen-fixing phytoplankton separate from other phytoplankton, but competing within more complicated N and P cycles parameterised for the Baltic. Their model shows primary production starting to respond to P reductions on a timescale of 10–20 years. But at the end of 20 years of P reductions, the system was still proximately N limited.

If these models are correct, then they have the following implications for the Baltic Sea proper:

bioassays can reliably determine the proximate limiting nutrient but not the ultimate limiting nutrient.

the observed proximate N-limitation of surface waters is fully compatible with overall P-control of rate of primary production.

reductions in reactive N inputs to the Baltic will increase the numbers of nitrogen fixers but have no other effect, at least when averaged over the whole system.

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An approach to modelling the growth of a zooplanktivore fish (*Sprattus sprattus*) in the Baltic Sea

Patricia Reglero

DIFRES, Charlottenlund Slot, 2920 Charlottenlund, Denmark.

[e-mail: prb@dfu.min.dk]

The aim of this study is to model individual growth histories of a zooplanktivore fish (*Sprattus sprattus*) in the Baltic Sea. Growth is expressed as a balance between the energy obtained from consumption and its allocation into respiration, specific dynamic action, egestion, excretion and growth itself. Consumption is modelled as a process of encounter, ingestion and digestion for a given feeding environment.

Sprat is considered to be a visual predator, feeding mainly on zooplankton. The prey is simulated to be a log normal distribution of different sizes of copepods and the predator is considered to be a visual feeder, considering encounter rate as a function of perception distance, search volume, number of prey items and swimming speed. Ingestion is expressed as a function of encounter rate, time among prey items and handling time.

The optimum prey size spectrum is calculated for different conditions of light (changes in the value of coefficient of absorption (k)) and depth. When light was not included in the encounter rate calculations, the optimal size perceived by the fish is displaced towards bigger sizes than the peak in size prey frequency. The optimal size ingested is displaced even more to bigger sizes compared to the optimum in the prey population and the optimum perceived. When including light (k, depth) into the calculation of the encounter rate, the prey size perceived and ingested varies with those parameters. When depth was kept constant and k variable, it is shown that at higher conditions of light, bigger prey sizes are perceived and even bigger sizes are ingested compared to the mean size of the population. The sizes perceived became more uniform when light decreases and there is less or no selection towards bigger sizes. When light conditions are very poor, the range of sizes perceived decrease, and smaller sizes are perceived better, while there is an optimal ingestion at smaller sizes.

The same pattern is shown when light is constant and depth variable. Towards the surface, bigger sizes than the mean of the population are perceived better and even bigger ones are ingested optimally. With increasing depth, this pattern shifts to a more homogeneous spectrum of sizes perceived and ingested, until, at deeper depths, a selection for smaller sizes was shown. These differences in the size of the prey consumed, when included in the bioenergetic model show important changes in the growth rates. Hence, we concluded different behaviour is shown by the predator in the selection of the prey size considering differences in depth and light condition. Differences in the growth rate values are shown due to this behaviour.

A box model for phytoplankton dynamics at an intensive monitoring station

Baerbel Müller-Karulis

Marine Monitoring Centre, Institute of Aquatic Ecology, University of Latvia, Daugavgrivas 8, 1007 Riga, Latvia

[e-mail: baerbel@monit.lu.lv]

Monitoring programs aim at quantifying changes in the marine ecosystem and attempt to link them to anthropogenic or natural causes. Models can provide a connection between changes in the investigated state variables and the underlying ecosystem processes. To investigate the potential of mathematical models to support the interpretation of monitoring data, a box model describing phytoplankton dynamics at an intensive monitoring station in the Gulf of Riga was constructed. Phytoplankton gain and loss processes are described based on parameters accessible from the monitoring data set. Sensitivity analysis attempts to estimate the role of processes not explicitly covered by the monitoring data.

Exploring feedbacks mechanisms between physical forcing and benthic biological activity in shallow turbid coastal waters by use of a 1D ecological/physical numerical model

Pierre-Philippe Mathieu

C.E.C. Joint Research Center, Space Applications Institute, Marine Environment Unit - TP 690, 21020 Ispra (VA), Italy.

[e-mail: pp.mathieu@altavista.net]

A 1D ecological/hydrodynamical model is used to investigate feedbacks between physical forcing and benthic biology in shallow turbid coastal waters. The integrated bio-physical model encompasses (i) a General Turbulence Ocean Model (GOTM), (ii) a physical sediment submodel (processes of sinking/erosion/ deposition), (iii) a pelagic biological submodel with 4

compartments (Phytoplankton/Nutrients/Zooplankton/ Detritus) and (iv) a benthic submodel for suspension feeders. Various numerical experiments have been designed in order to explore the various interactions between benthic activity and dynamical forcing. Our modelling results indicate several strong coupling mechanisms between biological and physical processes in the benthic layer.

The emergence of patterns in intertidal landscapes: scaling the interaction between environmental complexity and biotic processes

Frederic Guichard and E. Bourget

GIROQ, Universite Laval, Qc G1K7P4 Quebec, Canada.

[e-mail: frederic.guichard@giroq.ulaval.ca]

Understanding the influence of local processes on regional pattern formation is a central problem in ecology. In intertidal ecosystems, experimental studies showed the scale-dependent influence of topographic complexity on benthic communities through hydrodynamic and shading patterns. In order to further explore scaling rules in the cascade of events linking topographic complexity and mussel abundance, we developed a spatially-explicit individual-based simulation coupled to a finite-element hydrodynamic model. The model describes mussel colonisation over a disturbed 1-D intertidal landscape and incorporates mussel growth, recruitment and local spreading. We first explore the case of a subtidal habitat submitted to different frequencies of flow velocity variability. We then simulate an intertidal landscape characterised by specific scales (0.5–2 m) of topographic complexity. Results allowed to determine (1) the relative role of flow velocity and shading patterns in the emergence of observed local patterns of mussel dominance, (2) the influence of space and local environmental complexity on global mussel dynamics, and (3) the influence of external environmental forcing on scaling rules governing the simulated cascade of events (topography – hydrodynamics/shading – mussel abundance). Consequences for the interpretation and prediction of large scale patterns in intertidal ecosystems will be discussed.

The influence of meso-scale ocean processes on Anchovy (*Engraulis encrasicolus*) recruitment in the Bay of Biscay estimated using a 3D hydrodynamic model

Gwenhael Allain

IFREMER, Laboratoire Ecologie Halieutique, BP 21105, 44000 Nantes, France.

[e-mail: gallain@ifremer.fr]

In the Bay of Biscay (ICES area VIII), the anchovy fishery mainly depends on age 1 (80 % of the catches). The understanding and prediction of recruitment is consequently of critical importance for scientific advice and fishery regulation rules. The spawning area is generally limited to the SE Bay of Biscay and seems to be related to physical structures: river plumes, upwelling, shelf break fronts and oceanic gyres (Motos *et al.*, 1996, Borja *et al.*, 1998), where increased productivity potentially occurs.

Meteorological variables (wind, temperature, river discards) are forcing effects on the sea but they are not the processes that effectively govern larvae survival and recruitment. Therefore we used a 3D hydrodynamic physical model (IFREMER, cf. Lazure and Jégou, 1998) which simulates ocean processes occurring over the Biscay French continental shelf to construct environmental variables that describe the physical processes more directly related to recruitment mechanisms.

Fifty-three environmental indices were constructed to describe the inter-annual variations of Gironde river plume, coastal upwelling and stratification / turbulence processes occurring from March to July (spawning and larval development season) on the continental shelf of SE Bay of Biscay (south to 46°30' N). Then we used a procedure to select among them the most correlated indices with recruitment variations over the 12 years 1986 to 1997.

As no "dome" interaction was observed between our variables, multiple linear regression analysis was suitable for studying the links between anchovy recruitment and the environmental indices. Regressions with each set of 1, 2...7 variables were adjusted to the recruitment index. Among the models with highest r^2 for a fixed number of parameters, we have selected the ones whose variables are all significant according to a Student's t test.

The best explanatory model relates to vertical physical processes. The indices selected in this model are: (1) coastal upwelling index (calculated as the vertical current from the bottom to the surface along the Landes coast) with a positive effect on recruitment – (2) high turbulence or stratification breakdown index (describing falls in thermal stratification in July affecting the waters above the whole continental shelf) with a strong negative effect. This model explains 75 % of the recruitment variability observed from 1986 to 1997. The other indices have a smaller explanatory power and a stock effect that we tested also (importance of multiple spawners) is found to be not significant. The number of observations (years) is limited though. A "jack-knife" procedure shows the good robustness of the selected model to the variation of the number of years taken into account.

Anchovy recruitment in the Bay of Biscay from 1986 to 1997 is thus well described as the result of the influences of two exclusive wind regimes: moderate north-easterly winds and westerly gale winds, affecting two vertical oceanic processes crucial for larvae, respectively weak upwelling (enrichment processes) and high turbulence (that would cause "catastrophic" larvae mortality by dispersing their planktonic food in the water column, cf. Lasker 1981). This situation explains why linear regression has been appropriate in this study and why there is no dome-shaped relation of recruitment with

wind as in the « optimal environmental window » theory (cf. Cury and Roy, 1989) adapted to large upwelling systems governed by a single wind regime.

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Modelling tide-topography interaction and its influence on cooling and fertilising surface waters in Cape Trafalgar

Manuel Vargas Yanez

Instituto Español de Oceanografía, Centro de Fuengirola, Puerto Pesquero s/n, 29640 Fuengirola Malaga, Spain.

[e-mail: manolo.vargas@ma.ieo.es]

During July 1994, 1995 and 1996, the Instituto Espanol de Oceanografia carried out three multidisciplinary surveys in the North Western Alboran Sea, Strait of Gibraltar and Gulf of Cadiz, south of the Iberian Peninsula. Conductivity-Temperature-Depth (CTD) data and nutrient measurements revealed the existence of a persistent pool of cool waters at the surface, rich in nutrients and with high fluorescence values off Cape Trafalgar. Sea Surface Temperature (SST) satellite images collected for a long time period helped to check the permanence of this phenomenon. The strong along shore semidiurnal tidal currents and the presence of a submarine ridge, extending offshore, support the hypothesis of tide-topography interaction as the explanation of the cooling and fertilisation of surface waters. Though the model is bidimensional and very simple, it reveals that tidal currents over an obstacle are vertically forced by topography, generating an eddy flux of heat and nutrients responsible for the decrease of surface temperature around the topographic obstacle and the enhancing of biological activity.

Complexity: A help or a hindrance?

Elizabeth Fulton

c/o CSIRO Division of Marine Research, GPO Box 1538, Hobart, Tasmania 7001, Australia.

[e-mail: beth.fulton@marine.csiro.au]

As a more holistic view of ecosystems has developed (and aided by the advent of faster and bigger computers), there has been the temptation and the tendency to develop more complicated models of marine ecosystems in an attempt to gain increased predictive capability. However, it is not at all obvious that the complex model approach has succeeded and a comprehensive attempt to test the proposition that increased complexity begets increased predictive capability is needed. Just such an attempt is being made by simulation testing the performance of a range of simpler (shallow) models against a set of baselines produced by more complex (deep) models (which have different underlying assumptions).

The baselines capture the main features and some of the possible complexities of the real world and come from models constructed by tying the physics of the Port Phillip Bay Integrated Model (Murray and Parslow, 1997) to the ecology of the European Regional Seas Ecosystem Model (Baretta *et al.*, 1995). Thus the models represent a semi-enclosed shallow temperate bay which has a number of interacting functional groups ranging from phytoplankton to fisheries in the water column and bacteria to macrozoobenthos in and on the sediments. The models have been validated by comparing their output to data from real bays with similar physics and by checking for emergent properties and patterns recorded in real systems of a similar form to that being modelled. The baseline output from the deep models is treated in the same way real data would be and simple models are then fitted to it and their performance inspected. This inspection (via comparisons with the baseline itself) will be via a set of indices. The indices will include existing ones (mainly coming from network analysis, such as Finn's recycling and Biomass / Production) and others constructed for the purpose (based on ecological or managerial points of interest, for instance the average size of fish). A close eye will be kept on whether or not the level of model aggregation affects the indices (and thus would cause bias).

Ultimately, the outcomes of this approach should give some insight into the affects of complexity on model performance and prognostic utility, as well as giving some indication as to crucial ecosystem components and the validity of the traditional eutrophication-fisheries modelling dichotomy.

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Nutrient cycles in an estuarine flow ecosystem – the Szczecin Lagoon

Magdalena Wielgat

Sea Fisheries Institute, Department of Oceanography, Kollataja 1, 81-332 Gdynia, Poland.

[e-mail: wielgat@mir.gdynia.pl]

There is a wide range of environmental data on the Szczecin Lagoon (the Odra River estuary) available in the literature or reports of regular monitoring programs conducted by Polish institutions responsible for water monitoring. They comprise information on the riverine run-off and processes taking part in the lagoon. Based on this data a dynamic model will be developed to compare the lagoon ecosystem's changing ability to transform and retain nutrients flowing through the ecosystem. This will be done for individual years from early sixties till the year 1998, that is for the period of time when the most pronounced changes caused by anthropogenic influence have taken place in the Odra estuary. The aim of this poster is to present information (selected from available data) which are critical to understanding changes in the ecosystem functioning over the last decades. These are mainly:

- changes in annual fluctuations of nutrient concentrations in Szczecin Lagoon waters,
- changes in primary and secondary production dynamics,
- increase in nutrient loads discharged by rivers flowing in the lagoon (mainly Odra River),
- interannual dynamic of riverine inflow,
- dynamic of nutrient export via main lagoon outlet (the Swina River) to the Baltic Sea.

This in turn, will allow to properly structure a dynamic model; to recognise the importance of the influence of external forces on the state of the lagoon ecosystem.

Nutrient cycling in pelagic microcosm experiments: a test of modelling approaches

Mariusz Zalewski

Sea Fisheries Institute, Oceanography Department, Kollataja 1, 81-332 Gdynia, Poland.

[e-mail: mariusz@mir.gdynia.pl]

The aim of this paper was to test different algorithms, employed in biogeochemical models, in the short-term simulations of phosphorus and nitrogen cycling. A simple 0-dimensional model of phosphorus and nitrogen cycling in the pelagic system was constructed using the STELLA software environment. The model was calibrated against the results of microcosm experiments with natural sea water, enriched with the additions of Vistula River water. The experiments were performed in six different seasons of the year, thus representing different temperatures and light regimes, different initial nutrient and plankton concentrations, as well as different phyto- and zooplankton compositions. The calibration procedure consisted in searching for the minimum average deviation between empirical data and simulations. Most important model drawbacks were identified. Then, the model was modified by implementing alternative formulations taken from more complex biogeochemical models and calibrated repeatedly. These tests showed which modifications improved the model most effectively.

Evaluation of the effects of meteorological forcing on primary production with a 1-D physical-biogeochemical coupled model

Victor Martinez Vicente[1], J. P. Vanderborght[1], H. Coelho[2], R. Miranda[3], and R. Neves[3]

[1]Université Libre de Bruxelles.[2]Universidade do Algarve. [3]Instituto Superior Tecnico.

[e-mail: vmartine@ulb.ac.be]

The objective of this work is to evaluate the impact of increasing temporal resolution in the atmospheric forcing dataset on the estimations of annual primary production, using a simple one-dimensional model that is based on one-equation turbulent closure and a nitrogen-based ecosystem. Various case studies were tested with the following forcing atmospheric dataset:

- Monthly means heat and momentum fluxes from DaSilva *et al.* (1994) database,
- 6 hourly meteorological data, from ECMWF first analysis data set,
- 3 hourly varying stochastic wind speed (in the x direction),
- 1 hourly varying stochastic wind speed (in the x direction).

Additional tests on the impact of the maximal amplitude of the stochastic variations were performed to simulate the influence of strong winds in annual primary production. This experience was based on the one performed by Elliot *et al.* (1995).

Results from these experiments show that seasonal evolution of the water column driven only by turbulent mixing is well reproduced in all cases, since no major differences appear between the simulated and the measured temperature at La Chapelle Bank (in North Atlantic European Margin).

No relevant differences were founded between annual primary production estimates for the different case studies' runs. However, the tests performed indicate that the turbulent mixing processes account only for the 44% of the total annual primary production measured at the shelf edge. Therefore it is hypothesized that alternative mixing mechanisms must pump nutrients to the surface. Future work will concentrate on the identification and quantification of the different physical phenomena (i.e.

upwelling, breaking of internal waves, bottom induced currents), that account for the rest of the total annual primary production which was not predicted by the seasonal turbulent mixing.

Influence of spatial resolution on the advection of eggs and larvae

Frode Vikebo

Hjelmsvei 5, 5063 Minde, Norway.

[e-mail: frovik@gfi.uib.no]

The spawning areas of the Arcto-Norwegian cod are located along the coast of mid and northern Norway, particularly in the Lofoten region where up to 40 % of the spawning occurs. Compared to other Atlantic cod stocks there is a long route of pelagic free drift for the offspring from spawning in March–April along the coast to the juveniles settle to the bottom in the Barents Sea in September–October. During this critical period with respect to formation of year-class strength the eggs, larvae and juveniles drift from 600 to 1200 km. A first step towards the understanding of the mechanisms behind survival of the offspring is to describe their transport and spreading in sufficient detail. Synoptic hydrographic surveys, satellite-tracked drifters and remote sensing data have shown that there exist a highly complex current pattern for the spawning areas in Lofoten. In addition the bottom topography strongly influence the watermasses and current pattern along the drift route from Lofoten to the Barent Sea. Earlier authors working on simulating the transport and spreading of Arcto- Norwegian eggs and larvae by means of hydrodynamical numerical models have concluded that their models do not have a high enough spatial resolution to realistically describe key features for the transport and spreading, e.g., mesoscale topographic steering and variations in current pattern due to changes in atmospheric forcing on a smaller scale. The present model has a 4x4 km grid resolution, and certain areas of the model are analysed for particular wind events which are not resolved by the standard wind database.

Food selection in North Sea gadoids: What role does prey size preference play?

Jens Floeter and Axel Temming

Universität Hamburg, Institut für Hydrobiologie und Fischereiwissenschaft, Olbersweg 24, Hamburg, Germany.

[e-mail: jfloeter@uni-hamburg.de]

The traditional approach in fishery assessment is age-based, as are recent multispecies fishery assessment models (e.g., Multispecies Virtual Population Analysis (MSVPA). On the other hand trophic interactions between fish are size- rather than age based. Up to date the nature and significance of prey size preference in fish-fish feeding interaction is unclear (e.g., ICES, 1997; Bundgaard and Sparholt, 1992). Therefore the nature of prey size preference in food selection of North Sea cod (*Gadus morhua*) and whiting (*Merlangius merlangus*) was explored, employing a length based approach. Subsequently the significance of the resulting preference function for observed predator stomach content composition had been analysed.

For the assessment of size preference in food selection three parts are essential: A size-structured estimation of abundance of potential prey in the sea. Secondly, the size-structured observed prey items in the diet of predators of a certain length, and a quantifier of preference.

To model the abundance of potential fish prey in the sea International Bottom Trawl Survey (IBTS) catch data were corrected for gear efficiency by application of a species specific correction term, employing an approach similar to that described by Sparholt (1990). The correction term (*availability*) was calculated for each of the 10 standard MSVPA species for which stock numbers were available. All other species which had been found in the predator stomachs, were allocated to one of the 7 groups in which the 10 species had been split by application of knowledge on similarities in their behaviour and autecology. The *availability* – term had been derived as following: For each first-quarter-of-year in the period from 1980 to 1991 the spatially weighted North Sea – wide mean catch-per-unit-of-effort had been calculated as a species specific index of abundance. The availabilities were calculated as the ratio of the species specific index of abundance and the respective stock numbers taken from the 1997 key run of the North Sea MSVPA (ICES 1997a). The IBTS CPUE data were corrected using the *availability* – term delivering an estimation of absolute abundance in the sea. The absolute abundance values had been aggregated over species and by 5 cm length classes in order to provide the raw-data for modelling the size structured abundance of available fish prey in the North Sea. The standard IBTS trawl (GOV – trawl) delivers reliable indices of abundance down to a total fish length of approx. 15 cm, depending on species considered. As the prey range below 15 cm is of greater importance and quantitative data not being available, general size spectrum theory had been applied to the estimations of absolute abundance in order to model the available fish prey in the field over the whole size range necessary for the analysis: To overcome the bias caused by length specific gear selectivity a number spectrum was calculated employing the size range from 15 to 80 cm. The abundance of potential fish prey in the lower size range (3 to 15 cm) was extrapolated linearly. The resulting mean length based number spectra for the first-quarter-of-year of the period from 1980 to 1991 had been taken as an approximation of potential fish prey in the sea.

The information about observed fish prey in the stomachs of cod and whiting had been taken from the International North Sea Stomach Data Base (ICES 1997b), combining all first-quarter-of-year data from 1980 to 1991.

Prey size preference had been quantified by use of Chesson´s alpha (Chesson, 1978) as selectivity coefficient. For the analysis, predator and prey had been

grouped into specific length categories (number of predator and prey size categories was 9 and 7 for cod, respectively 8 and 6 for whiting). Analysed predator length range was 10 cm to 125 cm for cod and 5 cm to 60 cm for whiting. If two or more adjacent predator size classes preferred the same single prey size class and there was an obvious overall trend, it was assumed that this trend was also true within the scale of the prey size class under consideration, i.e. regarding such cases as artificial consequences of too coarse length measurements.

Results showed that the preferred prey length, expressed as percent-of-predator-length, linearly decreases with increasing predator length ($r^2 > 0.9$ for cod and whiting).

The transformation from length based to weight based results revealed that the preferred predator/prey weight ratio is an increasing function of predator size, confirming findings of Bundgaard and Sparholt (1992) for the Baltic Sea cod and contradicting the more traditional hypothesis of a constant optimal predator/prey weight ratio (ICES 1997a). However, North Sea cod seems to prefer larger prey than Baltic Sea cod, which possibly reflects true ecosystem properties but could as well be an effect of the restriction to one prey species in the Baltic Sea study of Bundgaard and Sparholt (1992).

The significance of the observed prey size preference functions for the stomach content composition of North Sea cod and whiting had been assessed by comparing the accumulated fractions of fish prey items in the diet with accumulated fractions of its counterparts in the sea: More than 75 % of fish found in the stomachs of both cod and whiting stemmed from the least preferred 25 % of the size range. Stomach content composition is dominated by prey abundance rather than influenced by prey size preference.

The sensitivity of the resulting prey size preference functions had been tested by application of the two opposite extreme number spectra slopes observed during the period of 1980 to 1991, i.e. 1983 and 1985. The resulting changes in preference function had been minimal. As a second test for robustness of results the extrapolated range of the number spectrum (3 cm to 15 cm) had been varied while the slope of the upper range had been kept as it was. The absolute level of the preferred prey size was a function of the enforced change in the slope; at highly unlikely slopes resulting in values close to those observed in Baltic Sea cod. At all levels of change the observed trend in the prey size preference function remained stable.

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APPENDIX 1

List of Participants

Australia

Elizabeth Fulton
beth.fulton@marine.csiro.au
Workshop 4

Belgium

Victor Martinez Vicente
vmartine@ulb.ac.be
Workshop 4

Canada

Natacha Bianca Bernier
natacha@phys.ocean.dal.ca
Workshop 3

Andrew Edwards
andy@caligo.bio.dfo.ca
Workshop 3

Frederic Guichard
frederic.guichard@giroq.ulaval.ca
Workshop 4

R. Kent Smedbol
ksmedbol@morgan.ucs.mun.ca
Workshop 4

Strahan Tucker
strahant@hotmail.com
Workshop 2

Maxine Westhead
westheadm@dfo-mpo.gc.ca
Workshop 1

Boris Worm
bworm@is.dal.ca
Workshop 1

Denmark

Johanne Tang Dalsgaard
jtd@dfu.min.dk
Workshop 3

Karin Hüssy
kh@dfu.min.dk
Workshop 2

Patricia Reglero
prb@dfu.min.dk
Workshop 4

Josefin Titelman
jti@dfu.min.dk
Workshop 3

Estonia

Margit Eero
margitee@ut.ee
Workshop 1

Inga Kanoshina
inga@sea.ee
Workshop 3

Laur Mägi
laurm@phys.sea.ee
Workshop 3

Kaire Parts
kairep@klab.envir.ee
Workshop 1

Finland

Susanna Hietanen
susanna.hietanen@fimr.fi
Workshop 2

Mika Raateoja
raateoja@fimr.fi
Workshop 3

France

Gwenhael Allain
gallain@ifremer.fr
Workshop 4

Fabian Blanchard
fblancha@ifremer.fr
Workshop 1

Priscilla Licandro
licandro@obs-vlfr.fr
Workshop 3

Sami Souissi
s_souissi@yahoo.fr
Workshop 4

Germany

Jens Floeter
jfloeter@uni-hamburg.de
Workshop 4

Elke Körner
ek@bio3.uni-rostock.de
Workshop 1

Jochen Christian Krause
jochen.chr.vilm@t-online.de
Workshop 1

Christian Moellmann
cmoellmann@ifm.uni-kiel.de
Workshop 2

Christoph Stransky
stransky.ish@bfa-fisch.de
Workshop 1

Claudia Tesch
clautesch@t-online.de
Workshop 1

Rüdiger Voss
rvoss@ifm.uni-kiel.de
Workshop 4

Ursula Werner
usc@uni-bremen.de
Workshop 1

Greece

Teresa Madurell
tmadurel@posidon.ncmr.gr
Workshop 1

Christos Maravelias
maraveliasc@hotmail.com
Workshop 4

Iceland

Olöf Y. Atladóttir
oatla@iti.is
Workshop 1

Asa Gudrun Kristjánssdóttir
asa@hafro.is
Workshop 3

Hreidar Thor Valtysson
hreidar@unak.is
Workshop 1

Iran

Mohammad R. Shokri
mrshokri@angelfire.com
Workshop 1

Ireland

Tom Manning
manning@iol.ie
Workshop 1

Israel

Pavel Prosselkov
prosselkov@hotmail.com
Workshop 1

Italy

Gualtiero Basilone
basilone@irma.pa.cnr.it
Workshop 3

Giuseppa Buscaino
mazzola@irma.pa.cnr.it
Workshop 1

Pierre-Philippe Mathieu
pp.mathieu@altavista.net
Workshop 4

Francesca Rossi
fncrss@discat.unipi.it
Workshop 2

Latvia

Anda Ikauniece
anda@monit.lu.lv
Workshop 1

Baerbel Mueller-Karulis
baerbel@monit.lu.lv
Workshop 4

Solvita Strake
solvita@hydro.edu.lv
Workshop 2

Didzis Ustups
ustups@latfri.lv
Workshop 1

Lithuania

Egidijus Bacevicius
ztl@is.lt
Workshop 2

Egidijus Leliuna
egidijus.leliuna@gf.vu.lt
Workshop 1

Justas Poviliunas
astrauskas@aiva.lt
Workshop 1

Tomas Zolubas
ztl@is.lt
Workshop 1

Netherlands

Johannes Gerrit Hartholt
h.hartholt@rikz.rws.minvenw.nl
Workshop 1

Norway

Otte Bjelland
otte@imr.no
Workshop 1

Jon Bent Kristoffersen
Jon.Kristoffersen@ifm.uib.no
Workshop 3

Victor Ladipo
voladipo@iname.com
Workshop 1

Marit Reigstad
maritr@nfh.uit.no
Workshop 2

Camilla Svensen
camillas@nfh.uit.no
Workshop 2

Frode Vikebo
frovik@gfi.uib.no
Workshop 4

Pakistan

Samina Kidwai
skidwai@cyber.net.pk
Workshop 2

Poland

Anetta Ameryk
ameryk@cbmpan.gdynia.pl
Workshop 1

Dariusz P Fey
dfey@mir.gdynia.pl
Workshop 3

Piotr Margonski
pmargon@mir.gdynia.pl
Workshop 3

Magdalena Wielgat
wielgat@mir.gdynia.pl
Workshop 4

Mariusz Zalewski
mariusz@mir.gdynia.pl
Workshop 4

Portugal

Hermínia Maria Cardoso de Castro
hcastro@bio.ua.pt
Workshop 1

Eduardo Esteves
eesteves@ualg.pt
Workshop 2

Jorge Palma
jpalma@ualg.pt
Workshop 1

Russia

Tatyana Malinovskaya
inmarbio@mail.primorye.ru
Workshop 1

Ismail Nigmatoulline
sqid@atlant.baltnet.ru
Workshop 1

Irene Prokopchuk
borisber@pinro.murmansk.ru
Workshop 3

Evgeniy Sentyabov
inter@pinro.murmansk.ru
Workshop 3

Spain

Nuria Navarro
nna@wpo.nerc.ac.uk
Workshop 1

Esther Garcés i Pieres
esther@icm.csic.es
Workshop 1

Teodoro Ramírez
teodoro.ramirez@ma.ieo.es
Workshop 3

Manuel Vargas Yáñez
manolo.vargas@ma.ieo.es
Workshop 4

Sweden

Massimilio Cardinale
mascar@imr.se
Workshop 4

Candida Savage
candida@system.ecology.su.se
Workshop 1

UK

Zoë Billinghurst
ZB@wpo.nerc.ac.uk
Workshop 1

Daniel Duplisea
d.duplisea@cefas.co.uk
Workshop 4

Sophie Mormede
mormedes@marlab.ac.uk
Workshop 1

Toby Tyrrell
tt@soc.soton.ac.uk
Workshop 4

Rachel S. Woodd-Walker
r.woodd-walker@plymouth.ac.uk
Workshop 3

Stephan A. Arnott
s.a.arnott@udcf.gla.ac.uk
Scotland
Workshop 4

Jose M Bellido
j.m.bellido@abdn.ac.uk
Scotland
Workshop 4

Toby Jarvis
tobyj@dml.ac.uk
Scotland
Workshop 2

USA

Lisa Hendrickson
lisa.hendrickson@noaa.gov
Workshop 1

David A. O'Brien
obrien@cbl.umces.edu
Workshop 1

Derek Orner
Derek.Orner@noaa.gov
Workshop 2

Silke Rick
Rick@acnatsci.org
Workshop 1

Daniel L. Roelke
droelke@unix.tamu.edu
Workshop 2

Rochelle Seitz
seitz@vims.edu
Workshop 2

Juanita Urban-Rich
jurban@lumcon.edu
Workshop 2

Eric Weissberger
ejw@drexel.edu
Workshop 2

Conference Chair and Chair of the Workshop on Human Influence on Marine Ecosystems:
Peter Grønkjær,
Peter.Grønkjær@biology.aau.dk
University of Aarhus,
Denmark

Chair of the Workshop on Top-Down or Bottom-Up Control in Marine Processes:
Fredrik Arrhenius,
fredrik.arrhenius@fiskeriverket.se
Institute of Marine Research,
Sweden

Chair of the Workshop on Influence of Hydrographic Processes on Energy Transfer in the Planktonic Ecosystem:
Anna Ingvarsdóttir,
ingvarsa@abdn.ac.uk
Scotland, UK

Chair of the Workshop on Modelling Ecological Processes:
Stefan Neuenfeldt,
stn@dfu.min.dk
Danish Institute for Fisheries Research,
Denmark

Speakers and Co-Chairs:
Katherine Richardson,
richardson@biology.aau.dk
University of Aarhus,
Denmark

Thomas Kiørboe,
tk@dfu.min.dk
Danish Institute for Fisheries Research,
Denmark

Øyvind Fiksen,
oyvind.fiksen@ifm.uib.no
University of Bergen,
Norway

Sture Hansson,
sture.hansson@system.ecology.su.se
Stockholm University,
Sweden

Christopher J. Harvey,
cjharvey@students.wisc.edu
University of Wisconsin,
USA

Jake Rice,
ricej@dfo-mpo.gc.ca
CSAS – DFO,
Canada

Jonathan Sharples,
Southampton Oceanography Center,
UK

Bill Silvert,
BIO,
Canada

Keith Brander,
keith@ices.dk
ICES, Denmark

Scientific Steering Committee:
Tom Fenchel,
University of Copenhagen,
Denmark

John Pope,
popejg@aol.com
University of Tromsø,
Norway

Jim Kitchell,
University of Wisconsin,
USA

Michael Heath,
heathmr@marlab.ac.uk
Fisheries Research Service,
Scotland, UK

Susanne Bro Rosenørn,
Danish Academy of Technical Sciences, Denmark

Jørgen Møller Christensen,
Denmark

Secretaries:
Secretary for the Scientific Steering Committee:
Lena Larsen,
lena@ices.dk,
ICES, Denmark

Secretary for the Administration:
Jane Ugilt,
ICES, Denmark