Risk assessment of harmful types of plastics in the marine environment

This report presents the results of a risk assessment of residual chemical additives, monomers and degradation products present in microplastic (MP) particles in the marine environment. Seven cases of different polymer types and product groups are defined that represent the most significant exposures of MPs, and thus potential highrisk cases towards marine organisms. Risk Quotients (RQ) are calculated for three trophic levels, i.e. pelagic/planktonic zooplankton: copepod, benthopelagic fish: atlantic cod and seabird: northern fulmar. Danish Miljøkvalitetskrav (MKK) and European Environmental Quality Standard (EQS) values are used as toxicity threshold values. RQ larger than unity, which indicates potential risk, is estimated for copepod and cod (pelagic community) and the flame-retardant pentabromdiphenylether (PeBDE) used in polyurethane (PUR), the biocide tributyltin (TBT) used in polyvinylchloride (PVC) and PUR, and the flame-retardant hexabromocyclododecane (HBCD) used in expanded polystyrene (EPS). The highest estimated RQ for fulmar (secondary poisoning) is 0.1 for PeBDE used in PUR.
Copepods boost the production but reduce the carbon export efficiency by diatoms

The fraction of net primary production that is exported from the euphotic zone as sinking particulate organic carbon (POC) varies notably through time and from region to region. Phytoplankton containing biominerals, such as silicified diatoms, have long been associated with high export fluxes. However, recent reviews point out that the magnitude of export is not controlled by diatoms alone, but determined by the whole plankton community structure. The combined effect of phytoplankton community composition and zooplankton abundance on export flux dynamics, were explored using a set of 12 large outdoor mesocosms. All mesocosms received a daily addition of minor amounts of nitrate and phosphate, while only 6 mesocosms received silicic acid (dSi). This resulted in a dominance of diatoms and dinoflagellate in the +Si mesocosms and a dominance of dinoflagellate in the -Si mesocosms. Simultaneously, half of the mesocosms had decreased mesozooplankton populations whereas the other half were supplemented with additional zooplankton. In all mesocosms, POC fluxes were positively correlated to Si/C ratios measured in the surface community and additions of dSi globally increased the export fluxes in all treatments highlighting the role of diatoms in C export. The presence of additional copepods resulted in higher standing stocks of POC, most probably through trophic cascades. However it only resulted in higher export fluxes for the +Si mesocosms. In the +Si with copepod addition (+Si +Cops) export was dominated by large diatoms with higher Si/C ratios in sinking material than in standing stocks. During non-bloom situations, the grazing activity of copepods decrease the export efficiency in diatom dominated systems by changing the structure of the phytoplankton community and/or preventing their aggregation. However, in flagellate-dominated system, the copepods increased phytoplankton growth, aggregation and fecal pellet production, with overall higher net export not always visible in term of export efficiency.

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Metagenomic insights into zooplankton-associated bacterial communities
Zooplankton and microbes play a key role in the ocean's biological cycles by releasing and consuming copious amounts of particulate and dissolved organic matter. Additionally, zooplankton provide a complex microhabitat rich in organic and inorganic nutrients in which bacteria thrive. In this study, we assessed the phylogenetic composition and metabolic potential of microbial communities associated with crustacean zooplankton species collected in the North Atlantic. Using Illumina sequencing of the 16S rRNA gene we found significant differences between the microbial communities associated with zooplankton and those inhabiting the surrounding seawater. Metagenomic analysis of the zooplankton-associated microbial community revealed a highly specialized bacterial community able to exploit zooplankton as microhabitat and thus, mediating biogeochemical processes generally underrepresented in the open ocean. The zooplankton-associated bacterial community is able to colonize the zooplankton's internal and external surfaces by using a large set of adhesion mechanisms and to metabolize complex organic compounds released or exuded by the zooplankton such as chitin, taurine and other complex molecules. Moreover, the high number of genes involved in iron and phosphorus metabolisms in the zooplankton-associated microbiome suggests that this zooplankton-associated bacterial community mediates
specific biogeochemical processes (through the proliferation of specific taxa) that are generally underrepresented in the ambient waters. This article is protected by copyright. All rights reserved.

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Corresponding author: De Corte, D.
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**Towards control of unwanted cyst-forming dinoflagellates in aquaculture systems: Knockout and recovery of Pfiesteria sp. after peracetic acid exposure**

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Corresponding author: Pinyol Gallemi, A.
Contributors: Pinyol Gallemi, A., Pedersen, L., Koski, M.
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Acute and semi-chronic toxicity of vanadium tested on copepods of the species Temora longicornis

General information
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Organisations: National Institute of Aquatic Resources, Section for Oceans and Arctic, Department of Environmental Engineering, Environmental Chemistry, Technical University of Denmark
Contributors: Kristiansen, M. H., Iversen, N. H., Koski, M., Trapp, S.
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Ecological effects of scrubber water discharge on coastal plankton: Potential synergistic effects of contaminants reduce survival and feeding of the copepod Acartia tonsa

To meet the oncoming requirements for lower sulphur emissions, shipping companies can install scrubbers where the exhaust is sprayed with seawater and subsequently discharged to the sea. The discharge water has a pH around 3 and contains elevated concentrations of vanadium, nickel, lead and hydrocarbons. We investigated 1) the threshold concentrations of scrubber discharge water for survival, feeding and reproduction of the copepod Acartia tonsa, 2) whether the effects depend on the exposure route and 3) whether exposure to discharge water can be detected in field-collected organisms. A direct exposure to discharge water increased adult copepod mortality and reduced feeding at metal concentrations which were orders of magnitude lower than the lethal concentrations in previous single-metal studies. In contrast, reproduction was not influenced by dietary uptake of contaminants. Scrubber water constituents could have synergistic effects on plankton productivity and bioaccumulation of metals, although the effects will depend on their dilution in the marine environment.

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Ecological effects of scrubber water discharge on coastal plankton: Potential synergistic effects of contaminants reduce survival and feeding of the copepod *Acartia tonsa*

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**Feeding on dispersed vs. aggregated particles: The effect of zooplankton feeding behavior on vertical flux**
Zooplankton feeding activity is hypothesized to attenuate the downward flux of elements in the ocean. We investigated whether the zooplankton community composition could influence the flux attenuation, due to the differences of feeding modes (feeding on dispersed vs. aggregated particles) and of metabolic rates. We fed 5 copepod species-three calanoid, one harpacticoid and one poecilamastoid-microplankton food, in either dispersed or aggregated form and measured rates of respiration, fecal pellet production and egg production. Calanoid copepods were able to feed only on dispersed food; when their food was introduced as aggregates, their pellet production and respiration rates decreased to rates observed for starved individuals. In contrast, harpacticoids and the poecilamastoid copepod *Oncaea* spp. were able to feed only when the food was in the form of aggregates. The sum of copepod respiration, pellet production and egg production rates was equivalent to a daily minimum carbon demand of ca. 10% body weight (1) for all non-feeding copepods; the carbon demand of calanoid copepods on dispersed food was 2-3 times greater, and the carbon demand of harpacticoids and *Oncaea* spp. feeding on aggregates was >7 times greater, than the resting rates. The zooplankton species composition combined with the type of available food strongly influences the calculated carbon demand of a copepod community, and thus also the attenuation of vertical carbon flux.

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Organisations: Section for Marine Ecology and Oceanography, National Institute of Aquatic Resources, Universite de Bretagne Occidentale
Contributors: Koski, M., Boutorh, J., De La Rocha, C. L.
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Prevalence and risk factors associated with *Theileria parva* infection in cattle in three regions of Tanzania

Ticks and tickborne diseases (TBDs) are serious constraints to cattle production in Tanzania and other tropical and subtropical countries. Among the TBDs, East Coast fever (ECF) is the most important as it causes significant economic losses to the cattle industry in Tanzania. However, control of ECF in Tanzania has continued to be a challenge due to inadequate epidemiological information. The main objective of this study was to determine the epidemiological situation of *Theileria parva* infections in cattle kept under pastoral and agro-pastoral farming systems in Mara, Singida, and Mbeya regions of Tanzania. Blood samples were collected from 648 cattle in the three regions. Genomic DNA was extracted and amplified in a polymerase chain reaction (PCR) using *T. parva*-specific primers targeting the 104-kD antigen (P104) gene. In addition, information was collected on the possible risk factors of *T. parva* infection (animal age, region, animal sex, tick burden, tick control method, and frequency of acaricide application). The prevalence of *T. parva* across the three regions was 14.2%. There was variation in prevalence among the three regions with Mara (21.8%) having a significantly higher (p = 0.001) prevalence than the other regions. Moreover, Mbeya exhibited relatively lower prevalence (7.4%) compared to the other regions. Factors found to be significantly associated with an animal being PCR positive for *T. parva* were region (p = 0.001) and tick burden (p = 0.003). Other factors were not found to be significant predictors of being PCR positive for *T. parva*. The present study showed high variation in tick burden and *T. parva* prevalence across the regions. Therefore, different strategic planning and cost-effective control measures for ticks and *T. parva* infection should be implemented region by region in order to reduce losses caused by ticks and ECF in the study area.

**General information**

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Organisations: National Institute of Aquatic Resources, Section for Oceans and Arctic, University of Zambia, Sokoine University of Agriculture, Hankyong National University

Contributors: Kerario, I. I., Simuunza, M. C., Chenyambuga, S. W., Koski, M., Hwang, S., Muleya, W.

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Web of Science (2017): Indexed yes

Original language: English

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A marine eutrophication impacts assessment method in LCIA coupling coastal ecosystems exposure to nitrogen and species sensitivity to hypoxia

Characterisation modelling in Life Cycle Impact Assessment (LCIA) aims at quantifying potential impacts of anthropogenic emissions. It delivers substance-specific Characterisation Factors (CF) expressing ecosystem responses to marginal increments in emitted quantities. Nitrogen (N) emissions from e.g. agriculture and industry enrich coastal marine ecosystems. Excessive algal growth and dissolved oxygen (DO) depletion typify the resulting marine eutrophication. LCIA modelling frameworks typically encompass fate, exposure and effect in the environment. The present novel method couples relevant marine biological processes of ecosystem’s N exposure (Exposure Factor, XF) with the sensitivity of select species to hypoxia (Effect Factor, EF). The XF converts N-inputs into a sinking carbon flux from planktonic primary production and DO consumed by bacterial respiration in bottom waters, whereas EF builds on probabilistic Species Sensitivity Distribution (SSD) methodologies to quantify potential species losses from hypoxia. Results show 2 orders of magnitude global spatial differentiation on a Large Marine Ecosystems (LME) spatial resolution. Adding an N-fate model completes CFs for anthropogenic N-forms, thus producing comparative environmental sustainability indicators of human activities as applied in Life Cycle Assessment (LCA) of product systems.

**General information**

Publication status: Published
Coupling ecosystems exposure to nitrogen and species sensitivity to hypoxia: modelling marine eutrophication in LCIA
Characterisation modelling in Life Cycle Impact Assessment (LCIA) quantifies impacts of anthropogenic emissions by applying substance-specific impact potentials, or Characterisation Factors (CF), to the amount of substances emitted. Nitrogen (N) emissions from human activities enrich coastal marine ecosystems and promote planktonic growth that may lead to marine eutrophication impacts. Excessive algal biomass and dissolved oxygen (DO) depletion typify the ecosystem response to the nutrient input. The present novel method couples a mechanistic model of coastal biological processes that determines the ecosystem response (exposure) to anthropogenic N enrichment (eXposure Factor, XF [kgO2·kgN-1]) with the sensitivity of species exposed to oxygen-depleted waters (Effect Factor, EF [(PAF)·m3·kgO2·kgN-1], expressed as a Potentially Affected Fraction (PAF) of species). Thus, the coupled indicator (XF*EF, [(PAF)·m3·kgN-1]) represents the potential impact on benthic and demersal marine species caused by N inputs. Preliminary results range from 2 (PAF)·m3·kgN-1 (Central Arctic Ocean) to 94 (PAF)·m3·kgN-1 (Baltic Sea). Comparative contributions per country or watersheds can also be obtained. Further adding environmental fate modelling of N emissions completes the CF for eutrophying emissions making it a useful contribution for sustainability assessment of human activities, as applied in Life Cycle Assessment (LCA).

General information
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, National Institute of Aquatic Resources, Section for Marine Ecology and Oceanography
Contributors: Cosme, N. M. D., Koski, M., Hauschild, M. Z.
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Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2015 › Research

Exposure factors for marine eutrophication impacts assessment based on a mechanistic biological model
Emissions of nitrogen (N) from anthropogenic sources enrich marine waters and promote planktonic growth. This newly synthesised organic carbon is eventually exported to benthic waters where aerobic respiration by heterotrophic bacteria results in the consumption of dissolved oxygen (DO). This pathway is typical of marine eutrophication. A model is proposed to mechanistically estimate the response of coastal marine ecosystems to N inputs. It addresses the biological processes of nutrient-limited primary production (PP), metazoan consumption, and bacterial degradation, in four distinct sinking routes from primary (cell aggregates) and secondary producers (faecal pellets, carcasses, and active vertical transport). Carbon export production (PE) and ecosystems eXposure Factors (XF), which represents a nitrogen-to-oxygen 'conversion' potential, were estimated at a spatial resolution of 66 large marine ecosystem (LME), five climate zones, and site-generic. The XFs obtained range from 0.45 (Central Arctic Ocean) to 15.9kgO2kgN-1 (Baltic Sea). While LME resolution is recommended, aggregated PE or XF per climate zone can be adopted, but not global aggregation due to high variability. The XF is essential to estimate a marine eutrophication impacts indicator in Life Cycle Impact Assessment (LCIA) of anthropogenic-N emissions. Every relevant process was modelled and the uncertainty of the driving parameters considered low suggesting valid applicability in characterisation modelling in LCIA.

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Publication status: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, National Institute of Aquatic Resources, Section for Marine Ecology and Oceanography
Contributors: Cosme, N. M. D., Koski, M., Hauschild, M. Z.
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From nitrogen enrichment to oxygen depletion: a mechanistic model of coastal marine ecosystems response

Nitrogen (N) emissions from anthropogenic sources may enrich coastal waters and lead to marine eutrophication impacts. Processes describing N-limited primary production (PP), zooplankton grazing, and bacterial respiration of sinking organic carbon, were modelled to quantify the potential dissolved oxygen (DO) consumption as a function of N input. Such indicator is the basis for an eXposure Factor (XF) applied in Life Cycle Impact Assessment (LCIA) to estimate impacts from N enrichment. The Large Marine Ecosystems (LME) biogeographical classification system was adopted to address the spatial variation of the modelled parameters and to characterise spatially differentiated N-emissions. Preliminary XF results range from 0.5 kgO2·kgN⁻¹ in the Central Arctic Ocean to 16 kgO2·kgN⁻¹ in the Baltic Sea, out of a total of 66 LME-dependent XFs. All the relevant processes were included in a mechanistic model and the uncertainty of the driving parameters is considered low. The presented XF estimation method contributes with a central component for site-dependent characterization factors (CFs) for marine eutrophication, to be coupled with environmental fate of N emissions and effects of oxygen depletion on biota.
The effect of zooplankton on the efficiency of the biological carbon pump

General information
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Organisations: National Institute of Aquatic Resources, Centre for Ocean Life
Contributors: Koski, M., Pankoke, L. M.
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Does copepod size determine food consumption of particulate feeding fish?
The climate-induced reduction in the mean copepod size, mainly driven by a decrease in the abundance of the large Calanus finmarchicus around 1987, has been linked to the low survival of fish larvae in the North Sea. However, to what extent this sort of reduction in copepod size has any influence on adult particulate feeding fish is unknown. In the present study, we investigated the hypothesis that the availability of the large copepods determines food consumption and growth conditions of lesser sandeel (Ammodytes marinus) in the North Sea. Analysis of stomach content suggested that food consumption is higher for fish feeding on large copepods, and additional calculations revealed how handling time limitation may provide part of the explanation for this relationship. Comparing stomach data and zooplankton samples indicated that lesser sandeel actively target large copepods when these are available. Finally, we observed that the length of lesser sandeel began to decrease in the late 1980s, simultaneously with the C. finmarchicus decline.

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Organisations: National Institute of Aquatic Resources, Section for Marine Living Resources, Centre for Ocean Life, Section for Ecosystem based Marine Management
Contributors: Deurs, M. V., Koski, M., Rindorf, A.
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The Biological carbon pump in the North Atlantic
Mediated principally by the sinking of organic rich particles from the upper ocean, the Biological Carbon Pump (BCP) is a significant component of the global carbon cycle. It transfers roughly 11 Gt C yr⁻¹ into the ocean's interior and maintains
atmospheric carbon dioxide at significantly lower levels than would be the case if it did not exist. More specifically, export by the BCP in the North Atlantic is ∼0.55–1.94 Gt C yr−1. A rich set of observations suggests that a complex set of processes drives this export. However, significant uncertainties exist regarding the BCP in the North Atlantic, including both the magnitude of the downward flux and the ecological, chemical and physical processes by which it is sustained and controlled. Our lack of detailed mechanistic understanding has also hindered modelling attempts to quantify and predict changes to the BCP. In this paper, we assess current knowledge concerning the BCP in the North Atlantic in order to identify priorities for future research, as well as suggesting how they might be addressed.

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The Mystery of Microsetella – Combination of egg- and broadcast spawning in an Arctic fjord?
Different life-history stages of the pelagic harpacticoid Microsetella norvegica were sampled in a Greenland fjord, to investigate how this slowly growing species can achieve high abundances at low temperatures. We expected low but continuous reproduction coupled with a low mortality, but observed the opposite: a short reproductive period with high estimated weight-specific egg production and egg mortality, and indication of a life-history strategy combining the advantages of egg carrying with egg production rates independent of temperature.

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Contributors: Koski, M., Swalethorp, R., Kjellerup, S., Nielsen, T. G.
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Web of Science (2014): Impact factor 2.407
Web of Science (2014): Indexed yes
Original language: English
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Copepods use chemical trails to find sinking marine snow aggregates

Copepods are major consumers of sinking marine particles and hence reduce the efficiency of the biological carbon pump. Their high abundance on marine snow suggests that they can detect sinking particles remotely. By means of laboratory observations, we show that the copepod Temora longicornis can detect chemical trails originating from sinking marine snow particles (appendicularian houses). The chemical cue was detected by copepods from a distance of >25 particle radii, with the probability of detection decreasing with distance. The behavior of T. longicornis following the trail resembled the behavior of males tracking pheromone trails, although with a lower tracking velocity. Upon finding a house, the copepod would attach for a short period (10–30 s) and feed intensively. Due to short residence times, daily feeding rates were moderate. Our results demonstrate that even T. longicornis, a species usually considered a microparticle feeder, is able to detect and feed on marine snow aggregates. If similar behaviors are displayed by the more dedicated aggregate-feeding copepods, a topic that remains unexplored, the effect of copepods on vertical flux attenuation may be significant.

The effect of egg versus seston quality on hatching success, naupliar metabolism and survival of Calanus finmarchicus in mesocosms dominated by Phaeocystis and diatoms

We studied the effect of a developing Skeletonema marinoi/Phaeocystis spp. bloom on Calanus finmarchicus hatching success, early naupliar survival and metabolism. Our focus was (1) on the development of reproductive rates during a bloom initiation, peak and decline in relation to the production of potentially toxic algal metabolites and (2) on the proportional importance of female nutrition versus naupliar food environment for the production of viable nauplii. Despite polyunsaturated aldehyde (PUA) production by both S. marinoi and Phaeocystis sp., we did not observe any harmful effects on hatching success or naupliar survival and condition in any stages of the short-term (
Biological processes in the North Sea: comparison of Calanus helgolandicus and Calanus finmarchicus vertical distribution and production

Comparison of abundance, vertical distribution and reproduction of the cousin species, the boreal Calanus finmarchicus and temperate Calanus helgolandicus was carried out on four cruises in July and August north of the Dogger Bank, North Sea. During this period, the water column was highly stratified with a tidally generated deep chlorophyll maximum at 30 m depth. When co-occurring, a separation of the species was evident, where C. finmarchicus preferred colder (9°C) deeper waters, while C. helgolandicus stayed in the warmer (16°C) surface waters. Egg production rates (EPRs) were not statistically different between the species, and the population egg production depended primarily on female abundance and was generally higher for C. finmarchicus. EPRs of the Calanus spp. were best explained by the abundance of autotrophic and heterotrophic dinoflagellates, flagellates and ciliates. Hatching success remained over 90% at all times but the estimated naupliar survival (N1–N6) was only 9%. The chlorophyll maximum supported highest faecal pellet production and egg production at the stations close to the bank. This study shows that C. finmarchicus can remain reproductively active in the North Sea ecosystem longer than previously thought, and with warmer surface temperatures retreat to cooler, deeper waters utilizing the deep chlorophyll maximum. This implies that C. finmarchicus cannot be reliably sampled with the Continuous Plankton Recorder during summer.

General information
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Organisations: Section for Ocean Ecology and Climate, National Institute of Aquatic Resources
Contributors: Jonasdottir, S., Koski, M.
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Peer-reviewed: Yes

Biological processes in the North Sea: vertical distribution and reproduction of neritic copepods in relation to environmental factors

We studied the vertical distribution and reproduction of dominant neritic copepod species in the Dogger Bank area and surrounding North Sea to reveal (i) if these species are concentrated in the subsurface chlorophyll maximum layer, (ii) if the chlorophyll maximum offers superior food conditions for reproduction compared with surface waters and (iii) if the secondary production is thus higher in the frontal areas with a subsurface chlorophyll maximum. In addition, we wanted to (iv) identify the most important environmental factors determining the reproduction of neritic copepods in the North Sea.
We observed a higher egg production of cultured Acartia tonsa when fed with the seston from chlorophyll maximum, but no evidence of a higher copepod abundance in this layer. Secondary production was highest at the station closest to the upwelling of new nutrients, although seasonal differences in environmental variables probably overrode the differences between frontal and stratified stations. Copepod egg production on an annual basis seemed to be best predicted by the body size and specific fatty acids, with a high egg production, but low hatching success associated with a high EPA:DHA ratio. Total secondary production of small copepods seemed mainly related to the species composition, suggesting that factors controlling abundance of specific species rather than reproduction might be more important in determining the secondary production of copepods.

Copepods and the biological pump: The potential effects of large vs. small copepods on vertical flux

Egg and faecal pellet production and egg hatching success of the calanoid copepod Calanus finmarchicus were monitored over a period of 14 days (14-28 April, 2008) while fed water from 4 differently treated mesocosms and ambient water. Two of the mesocosms used were inoculated with the polyunsaturated aldehyde (PUA)-producing diatom Skeletonema marinoi, while 2 received only nutrient additions with or without silica. The mesocosms developed blooms of S. marinoi, mixed diatoms or the haptophyte Phaeocystis pouchetii, respectively. Faecal pellet production of C. finmarchicus increased with increasing food availability. Egg production increased with time in all mesocosms to a maximum single female production of 232 eggs female-1 day-1 (average of 90 eggs female-1 day-1) and followed the development of ciliates and P. pouchetii, but was not affected by the observed high (up to 15 nmol L-1) PUA production potential of the phytoplankton. The hatching success of the eggs produced on the mesocosm diets was high (78-96%) and was not affected by either aldehydes in the maternal diet or exposure to the dissolved aldehydes in the water.
Strain-related physiological and behavioral effects of Skeletonema marinoi on three common planktonic copepods

Seasonal changes in food quantity and quality of the common North Sea copepods Temora longicornis and Pseudocalanus elongatus: a bioassay approach

We evaluated the food quantity and quality over a seasonal cycle for the development and egg production of the common North Sea copepods Temora longicornis and Pseudocalanus elongatus, using a bioassay approach. Seston was sampled from December to October from a well-mixed water column of the Marsdiep (Dutch Wadden Sea) and fed to cultured copepods at a constant temperature of 15 degrees C, thus excluding seasonal effects of temperature, body size, age, and maternal nutrition. Copepod response was evaluated by measuring egg production and juvenile development, while the
seston quantity and quality were measured as the concentrations of chl a, specific phytoplankton pigments, particulate organic carbon (POC), particulate organic nitrogen (PON), fatty acids, and sterols. The egg production of both copepods was low when feeding on seston collected in winter, but increased to peak values with the seston from the spring bloom in March-April. The juveniles of both species were able to complete their development only in spring experiments. A multiple regression analyses and comparison to a good-quality standard food of the same concentration suggested that, in an annual scale, the egg production and development of T longicornis mainly depended on phytoplankton concentration, while the egg production and development of P. elongatus appeared also to benefit from detritus or heterotrophic food sources. The present study did not detect an influence of a specific food quality variable; however, an unexplained high juvenile mortality in summer suggests that all factors are not understood yet.

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Effects of carbon-dioxide-induced acidification on algal quality for copepod reproduction
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Glutathione transferase activity and oocyte development in copepods exposed to toxic phytoplankton
Organisms present a series of cellular mechanisms to avoid the effects of toxic compounds. Such mechanisms include the increase in activity of detoxification enzymes [e.g., 7-ethoxyresorufin-O-deethylase (EROD) and glutathione S-transferase (GST)], which could explain the low retention of ingested toxins generally observed in copepods. In addition, decreasing gross growth efficiency (GGE) of copepods with increasing concentration of toxic diets could be caused either by a high expenditure coping with toxins (e.g., increase in the activity of detoxification enzymes) or by a deterioration of reproductives tissues. To assess the effect of toxic phytoplankton on the activity of detoxification enzymes and on oocyte maturation of Acartia tonsa and Temora longicornis, feeding and egg production experiments were carried out with a variety of toxic diets and an adequate non-toxic food control (Rhodomonas spp.) all provided as single species diets. Toxic diets included the nodularin-producing cyanobacterium Nodularia spumigena, the dinoflagellates Alexandrium minutum and A. tamarense, which contained Paralytic Shellfish Poisoning (PSP) toxins, the dinoflagellate Prorocentrum lima with Diarrhetic Shellfish Poisoning (DSP) toxins and the haptophyte Prymnesium parvum, which produces ichtyotoxins with haemolytic activity. Feeding on toxic diets was lower than on Rhodomonas spp., except for A. minutum and A. tamarense. In addition, toxic diets negatively affected reproduction in both copepod species with the production of oocytes and oocyte development impaired with A. minutum and N. spumigena. While the negative effect of N. spumigena seemed to be connected to gonad atresia likely caused by severe food limitation (starvation), the negative effect of A. minutum could have been either caused by a direct effect of saxitoxins or nutritional inadequacy on oocyte production. We could not detect EROD activity in the copepods, while the activity of GST was generally higher with the non-toxic food control and positively related to the feeding and egestion rates, suggesting relation to feeding conditions rather than to exposure to
toxic diets. No relationship was found between GGE and CST activity. Our results refute the hypothesis that toxic diets, provided at ecologically relevant levels, would induce cellular mechanisms in copepods regarding GST activity. GST activity thus seems to play no role in detoxification of copepods confronted with toxic phytoplankton. Toxin detoxification and its cost for copepods still remain an open question. (C) 2008 Elsevier B.V. All rights reserved.

### General information
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- Organisations: Section for Ocean Ecology and Climate, National Institute of Aquatic Resources
- Contributors: Kozlowsky-Suzuki, B., Koski, M., Hallberg, E., Wallén, R., Carlsson, P.
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- Web of Science (2009): Indexed yes
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- Source ID: 229132
- Research output: Contribution to journal

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**Copepod reproduction is unaffected by diatom aldehydes or lipid composition**

We investigated whether reduced reproductive success of copepods fed with diatoms was related to nutritional imbalances with regard to essential lipids or to the production of inhibitory aldehydes. In 10-d laboratory experiments, feeding, egg production, egg hatching success, and fecal pellet production of Temora longicornis were measured for six different diatom species as well as for a nondiatom control diet (Rhodomonas sp.). The experiments were accompanied by determinations of fatty acids, sterols, and polyunsaturated aldehydes (PUA) in the food. Although diatoms were generally ingested at high rates, they yielded a variable egg production response in copepods, ranging from high egg production in four species (two strains of Thalassiosira rotula, Chaetoceros affinis, and Thalassiosira weissflogii) to low egg production in two species (Leptocylindricus danicus and Skeletonema costatum). Egg hatching rates decreased after 4 d in all diatom treatments, irrespective of the egg production rate and without any relationship to diatom aldehyde production. Similarly, no evidence was found that diatoms are per se nutritionally inferior to nondiatom food. The lack of a distinct mechanism for the observed inhibitory activity of diatoms suggests that the cause(s) might be more complex. We suggest, as one possible explanation, that hatching-specific nutritional deficiencies might be induced by incomplete digestion following from the low gut passage time of diatoms, as indicated by a strong correlation between egg viability and fecal pellet production.

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- Contributors: Dutz, J., Koski, M., Jonasdottir, S.
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- URLs:
"Good" and "bad" diatoms: development, growth and juvenile mortality of the copepod Temora longicornis on diatom diets

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Contributors: Koski, M., Wichard, T., Jonasdottir, S.
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Production, oxygen respiration rates, and sinking velocity of copepod fecal pellets: Direct measurements of ballasting by opal and calcite

Production, oxygen uptake, and sinking velocity of copepod fecal pellets egested by Temora longicornis were measured using a nanoflagellate (Rhodomonas sp.), a diatom (Thalassiosira weissflogii), or a coccolithophorid (Emiliania huxleyi) as food sources. Fecal pellet production varied between 0.8 pellets ind(-1) h(-1) and 3.8 pellets ind(-1) h(-1) and was significantly higher with T. weissflogii than with the other food sources. Average pellet size varied between 2.2 X 10(5) mu m(3) and 10.0 X 10(5) mu m(3). Using an oxygen microsensor, small-scale oxygen fluxes and microbial respiration rates were measured directly with a spatial resolution of 2 mu m at the interface of copepod fecal pellets and the surrounding water. Averaged volume-specific respiration rates were 4.12 fmol O-2 mu m(-3) d(-1), 2.86 fmol O-2 mu m(-3) d(-1), and 0.73 fmol O-2 mu m(-3) d(-1) in pellets produced on Rhodomonas sp., T. weissflogii, and E. huxleyi, respectively. The average carbon-specific respiration rate was 0.15 d(-1) independent on diet (range: 0.08-0.21 d(-1)). Because of ballasting of opal and calcite, sinking velocities were significantly higher for pellets produced on T. weissflogii (322 +/- 169 m d(-1)) and E. huxleyi (200 +/- 93 m d(-1)) than on Rhodomonas sp. (35 +/- 29 m d(-1)). Preservation of carbon was estimated to be approximately 10-fold higher in fecal pellets produced when T. longicornis was fed E. huxleyi or T. weissflogii rather than Rhodomonas sp. Our study directly demonstrates that ballast increases the sinking rate of freshly-produced copepod fecal pellets but does not protect them from decomposition.

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Production, oxygen respiration rates, and sinking velocity of copepod fecal pellets: Direct measurements of ballasting by opal and calcite

Production, oxygen uptake, and sinking velocity of copepod fecal pellets egested by Temora longicornis were measured using a nanoflagellate (Rhodomonas sp.), a diatom (Thalassiosira weissflogii), or a coccolithophorid (Emiliania huxleyi) as food sources. Fecal pellet production varied between 0.8 pellets ind(-1) h(-1) and 3.8 pellets ind(-1) h(-1) and was significantly higher with T. weissflogii than with the other food sources. Average pellet size varied between 2.2 X 10(5) mu m(3) and 10.0 X 10(5) mu m(3). Using an oxygen microsensor, small-scale oxygen fluxes and microbial respiration rates were measured directly with a spatial resolution of 2 mu m at the interface of copepod fecal pellets and the surrounding water. Averaged volume-specific respiration rates were 4.12 fmol O-2 mu m(-3) d(-1), 2.86 fmol O-2 mu m(-3) d(-1), and 0.73 fmol O-2 mu m(-3) d(-1) in pellets produced on Rhodomonas sp., T. weissflogii, and E. huxleyi, respectively. The average carbon-specific respiration rate was 0.15 d(-1) independent on diet (range: 0.08-0.21 d(-1)). Because of ballasting of opal and calcite, sinking velocities were significantly higher for pellets produced on T. weissflogii (322 +/- 169 m d(-1)) and E. huxleyi (200 +/- 93 m d(-1)) than on Rhodomonas sp. (35 +/- 29 m d(-1)). Preservation of carbon was estimated to be approximately 10-fold higher in fecal pellets produced when T. longicornis was fed E. huxleyi or T. weissflogii rather than Rhodomonas sp. Our study directly demonstrates that ballast increases the sinking rate of freshly-produced copepod fecal pellets but does not protect them from decomposition.
Prymnesium parvum exotoxins affect the grazing and viability of the calanoid copepod Eurytemora affinis

The calanoid copepod Eurytemora affinis from the northern Baltic Sea was exposed to cell-free filtrates of the toxic haptophyte Prymnesium parvum as well as to cell mixtures of P. parvum and Rhodomonas salina. To test the effects of P. parvum exudates and allelopathy on selective grazers, copepods were incubated (1) in increasing concentrations of cell-free filtrates of P. parvum in the presence of good food (R. salina), (2) in 1:1 cell mixtures at 2 cell concentrations of P. parvum and R. salina and (3) in R. salina cell suspension, which was used as a control for good-quality food. P. parvum cultures were grown in nutrient-balanced (+NP) or limited (-N or -P) media to obtain different levels of toxicity. Survival, ingestion, faecal pellet production rates and egg production were measured over 3 d, together with measurements of P. parvum toxicity (hemolytic activity) (HA). Most of the copepods incubated in high-filtrate concentrations died or became severely impaired, although (HA) in filtrates was under the detection limit. Further, the ingestion and faecal pellet production rates were suppressed in the highest filtrate concentrations in nutrient-limited treatments. Higher cell density in cell mixtures resulted in significantly lower faecal pellet production, although survival remained high. Our results show that HA is not a good overall indicator of the total harmful effects of P. parvum on grazers. Besides monospecific P. parvum diets, filtrates and cell mixtures have negative effects on grazers, and these effects are stronger under nutrient-depleted conditions; however, the presence of good-quality food lowers harmful effects for copepods. The negative effects caused either by direct intoxication or by food limitation following from strong allelopathic effects of P. parvum on other components of nano- and microplankton suggest that P. parvum blooms have a realistic potential to be deleterious for copepod secondary production, irrespective of the presence of alternative food sources.

Disruption of microbial food web and inhibition of metazooplankton development in the presence of iron and DOM-stimulated Baltic Sea cyanobacteria

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High reproduction of Calanus finmarchicus during a diatom-dominated spring bloom

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Contributors: Koski, M.
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Supplemental effects of diet mixing on absorption of ingested organic carbon in the marine copepod Acartia tonsa

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Contributors: Thor, P., Koski, M., Tang, K., Jonasdottir, S.
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The fate of discarded appendicularian houses: degradation by the copepod, Microsetella norvegica, and other agents

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Publication status: Published
Organisations: Section for Ocean Ecology and Climate, National Institute of Aquatic Resources
Contributors: Koski, M., Møller, E., Maar, M., Visser, A.
Zooplankton grazing on Phaeocystis: a quantitative review and future challenges

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Life-stage-specific differences in exploitation of food mixtures: diet mixing enhances copepod egg production but not juvenile development

Development, egg production and hatching success of the calanoid copepods Temora longicornis and Pseudocalanus elongatus were measured in food mixtures to test their ability to obtain a complete nutrition by combining different nutritionally poor food species. In all the food mixtures used, the copepods failed to moult past the first copepodite stage, and the mortality was high. In sharp contrast, mixing two nutritionally poor food species often resulted in egg production which was not significantly different from nutritionally high quality food, although hatching success in many mixtures was low. Whereas egg production was significantly correlated with particulate organic nitrogen in the diet, and independent of the highly unsaturated fatty acids (HUFAs), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), hatching increased with increasing DHA and EPA concentration. Growth and juvenile mortality were, however, independent of either nitrogen or HUFAs in the diet. Our results show that adult copepods are effective in combining their nutrition from several food sources, whereas juveniles are not. We suggest that there are species- and life-stage-specific differences in nutritional requirements and/or in the ability to digest and/or assimilate essential nutrients from food mixtures, which may significantly contribute to the success of copepod populations in nature.

General information
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Post-bloom feeding of Calanus finmarchicus copepodites: Selection for autotrophic versus heterotrophic prey

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Toxic haptophyte Prymnesium parvum affects grazing, survival, egestion and egg production of the calanoid copepods Eurytemora affinis and Acartia bifilosa

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Trophic significance of solitary cells of the prymnesiophyte Phaeocystis globosa depends on cell type

With the use of five different isolates of Phaeocystis globosa solitary cells from the North Sea, we conducted experiments to reveal whether grazing and development of the nauplii of the calanoid copepod Temora longicornis varies in response to the cell type. Two P. globosa strains representing nonflagellated cells were ingested at intermediate to high rates and resulted in high survival and development, comparable to the Rhodomonas sp. control. In contrast, the response to three mesoflagellate strains was highly variable. Feeding on two of these strains was avoided, whereas the third strain was ingested; however, the mesoflagellates induced poor survival and development regardless of the feeding response. These observations differ from previous results, which generally demonstrate microzooplankton feeding on Phaeocystis. The morphological characterization of strains, together with mixture experiments, revealed that neither the production of transparent exopolymer particles and chitinous threads nor toxicity can explain the observed response. The cohesion of the threads into pentagonal stars was observed only in the avoided mesoflagellate and might cause a mechanical hindrance for the ingestion of mesoflagellates. Our results suggest that grazing loss and trophic transfer efficiency might be overestimated when solitary cells are treated as a single functional group with regard to their trophic position.

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Benthic life in the pelagic: Aggregate encounter and degradation rates by pelagic harpacticoid copepods

We measured field abundances, feeding rates, swimming behavior, and particle colonization of two harpacticoids, the pelagic Microsetella norvegica and the semibenthic Amonardia normanni, to examine (1) if aggregates have a significant role in harpacticoid nutrition and (2) if harpacticoids contribute significantly to aggregate degradation. Neither of the harpacticoids was able to feed efficiently on suspended food, while both grazed well on attached food, indicating that pelagic harpacticoids depend on food attached to surfaces, such as those offered by marine aggregates. We estimated that the two harpacticoids are able to search substantial volumes of water for aggregates (up to 1.2 L d(-1)), and that during bloom conditions in the North Sea, reported aggregate concentrations allow M. norvegica to daily encounter about three aggregates. High short-term hunger-induced feeding rates observed in A. normanni indicate that at least some harpacticoid species can fill their gut during few short visits to aggregates. Harpacticoids may cause substantial degradation of aggregates of <1 cm (5-100%) when their abundance exceeds 10(5) m(-2), which is not atypical during summer in temperate waters.

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Selective grazing of Temora longicornis in different stages of a Phaeocystis globosa bloom - a mesocosm study

Selective grazing of a calanoid copepod Temora longicornis was measured during different stages of a Phaeocystis globosa bloom, in order to reveal (1) if T longicornis feeds on single cells and/or colonies of P. globosa in the presence of alternative food sources, (2) if copepod food selection changes during the initiation, maintenance, collapse and decay of a P. globosa bloom and (3) if P. globosa dominated food assemblage provides a good diet for copepod egg production. Our results show low but constant feeding on small colonies of P. globosa, irrespective of the type or concentration of alternative food sources. In contrast, feeding on single cells was never significant, and the total contribution of P globosa to carbon ingestion of T longicornis was minor. T longicornis fed most actively on the decaying colonies, whereas during the peak of the bloom copepods selected against P globosa. Mostly, T longicornis fed unselectively on different food particles: before the bloom, the major part of the diet consisted of diatoms, whereas during and after the bloom copepod diet was dominated by dinoflagellates and ciliates. Egg production was highest during the decay of the bloom, coinciding with highest proportional ingestion of heterotrophic organisms, but was not seriously reduced even during the peak of the bloom. We conclude that P globosa blooms should not threaten survival of copepod populations, but the population recruitment may depend on the type (and concentration) of the dominant heterotrophs present during the blooms. Due to relatively unselective grazing, the impact of T longicornis to the initiation of a Phaeocystis bloom is considered small, although grazing on decaying colonies may contribute to the faster termination of a bloom. (C) 2005 Elsevier B.V. All rights reserved.

Role of essential lipids in copepod nutrition: no evidence for trophic upgrading of food quality by a marine ciliate

The ciliate Strombidium sulcatum was used to feed and grow young stages of the copepods Temora longicornis (Muller) and Pseudocalanus elongatus (Boeck). The ciliate was cultured in the laboratory using either bacteria or the green alga Dunaliella sp. as a food source. Young copepodites of both copepod species consumed S. sulcatum at significant rates, but after 3 d, weight-specific ingestion decreased more than 2-fold. Larvae and copepodites feeding on S. sulcatum developed at suboptimal rates, survived poorly and showed abnormal morphology in comparison to control individuals fed a good-quality Rhodomonas sp. diet. The specific mass of fatty acids in S. sulcatum was much lower than in the Dunaliella sp. diet. However, the fatty acid composition of the protozoan more or less resembled that of the food, lacking long-chain
highly unsaturated fatty acids (HUFAs). Sterols only occurred in Dunaliella sp., although in low abundance of unuseful 
Delta7 sterols. Obviously, S. sulcatum did not biochemically enhance bacterial or algal food for subsequent use at higher 
trophic levels, and only transferred fatty acids without further conversion. The results indicate a deficiency in the ciliate of 
HUFAs and sterols which are essential nutrients for copepod growth. Apart from energy, ciliates seem to contribute little 
nutritive value to the diet of higher trophic levels, and this may limit secondary production during periods of low algal 
abundance.

Development and grazing of Temora longicornis (Copepoda, Calanoida) nauplii during nutrient limited Phaeocystis 
globosa blooms in mesocosms

Feeding, reproduction and toxin accumulation by the copepods Acartia bifilosa and Eurytemora affinis in the presence of 
the toxic cyanobacterium Nodularia spumigena
Influence of diet on copepod survival in the laboratory

Selective feeding of Temora longicornis adults vs. nauplii in a Phaeocystis dominated mesocosm

Strain-specific grazing and development on Phaeocystis globosa by nauplii of Temora longicornis
Copepod hatching success in marine ecosystems with high diatom concentrations.
Diatoms dominate spring bloom phytoplankton assemblages in temperate waters and coastal upwelling regions of the global ocean. Copepods usually dominate the zooplankton in these regions and are the prey of many larval fish species. Recent laboratory studies suggest that diatoms may have a deleterious effect on the success of copepod egg hatching. These findings challenge the classical view of marine food-web energy flow from diatoms to fish by means of copepods. Egg mortality is an important factor in copepod population dynamics, thus, if diatoms have a deleterious in situ effect, paradoxically, high diatom abundance could limit secondary production. Therefore, the current understanding of energy transfer from primary production to fisheries in some of the most productive and economically important marine ecosystems may be seriously flawed. Here we present in situ estimates of copepod egg hatching success from twelve globally distributed areas, where diatoms dominate the phytoplankton assemblage. We did not observe a negative relationship between copepod egg hatching success and either diatom biomass or dominance in the microplankton in any of these regions. The classical model for diatom-dominated system remains valid.

Development of Baltic Sea zooplankton in the presence of a toxic cyanobacterium: a mesocosm approach
Cyanobacteria blooms are common in the Baltic Sea and are considered to be a poor food source and sometimes toxic to zooplankton. Most experiments demonstrating harmful effects have been short-term incubations with monocultures or
simple mixtures of food. In this study, a mesocosm approach was used to examine zooplankton responses over generation timescales. A toxic strain of the cyanobacterium Nodularia spumigena was added to bag enclosures of ambient water. The initial mesozooplankton concentration was either reduced by prescreening the water or enriched with locally caught zooplankton. Experiments ran for 15 days, long enough to monitor reproductive success and development of the next mesozooplankton generations. There was no major harmful effect on the zooplankton assemblage, even though the concentration of the toxin nodularin was in the upper range of field observations. The copepod Eurytemora affinis, rotifers Synchaeta spp. and the cladoceran Bosmina longispina maritima were able to develop and reproduce successfully in the presence of N. spumigena. The only species showing impaired recruitment was the copepod Acartia bifilosa. The general lack of population level effects from N. spumigena in this study can be reconciled with previous observations of adverse effects. Cyanobacteria alone may be poor food and toxic to zooplankton, but in the mesocosms a rich assemblage of microbiota developed, similar to that associated with blooms in the field. We suggest that, in the context of otherwise food-depleted summer situations in the open Baltic Sea, zooplankton can derive benefit from cyanobacteria bloom assemblages.
Stoichiometry of mesozooplankton in N- and P-limited areas of the Baltic Sea

The Baltic Sea is a very suitable site for stoichiometric studies, since its subbasins differ in their concentration of elemental components, and primary production can therefore be either nitrogen or phosphorus limited. To reveal if the nutrient limitation of mesozooplankton mirrors that of the primary producers, carbon, nitrogen and phosphorus content of both seston and grazers (Acartia sp., Centropages hamatus, Daphnia cristata, Eurytemora affinis, Limnocalanus macrurus, Temora longicornis) were measured in midsummer in the Baltic proper, the Gulf of Finland and the Gulf of Bothnia. The mineral ratios of the different taxa were equal, apart from L. macrurus with notably higher C:P and N:P ratios. Molar C:N ratios were relatively stable (5.1-6.3), whereas C:P and N:P ratios fluctuated more (41-144 and 6.6-24). However, zooplankton elemental composition and limitation did not depend on the limiting nutrient of the phytoplankton, the seston mineral ratio or the sea area. Both the seston-zooplankton elemental imbalance and the food threshold ratio indicated phosphorus limitation of most of the grazers. While L. macrurus may be C or N limited, the possible P deficiency of the other studied taxa suggests that the Baltic Sea zooplankton may act as a potential phosphorus sink, as the freshwater secondary producers do.

Feeding interactions of the copepods Eurytemora affinis and Acartia bifilosa with the cyanobacteria Nodularia sp. Short Communications

We measured ingestion and clearance rates of two Baltic Sea calanoid copepods, Eurytemora affinis and Acartia bifilosa, on toxic and non-toxic cyanobacteria Nodularia sp. using the isotope technique. Eurytemora affinis fed actively on the non-toxic strain and moderately actively on the toxic strain, whereas A. bifilosa totally avoided feeding on both strains. This suggests that A. bifilosa rejected cyanobacterial filaments due to their nutritional inadequacy or difficult manageability. The different response of E. affinis to the non-toxic and toxic strains, in turn, shows that this copepod species was able to sense the presence of the toxin in cyanobacterial filaments and therefore fed less on the toxic strain. The interaction between A. bifilosa and Nodularia sp. was further examined (with the particle counting method) by measuring the clearance rates of A. bifilosa on edible green flagellates in the presence of cyanobacteria. The presence or concentration of toxic Nodularia sp. did not affect grazing rates of A. bifilosa on Brachionomonas submarina. Since earlier studies have shown that ingestion of Nodularia sp. decreases egg production and increases mortality in E. affinis, we suggest that the occurrence of Nodularia sp. blooms in the Baltic Sea may favour individuals of copepod species capable of selective feeding, such as A. bifilosa.
Carbon : nitrogen ratios of Baltic Sea copepods - indication of mineral limitation? Short Communications

The carbon (C) and nitrogen (N) content and the C:N ratio of two common calanoid copepods, Eurytemora affinis and Acartia bifilosa, were measured during spring and summer at the SW coast of Finland, northern Baltic Sea. The C:N ratio of both copepod species was low and stable (4-4.5), irrespective of sampling time, which implies N limitation at least during intermediate to high food concentrations in spring and early summer. In addition, experiments were conducted to reveal whether the diet of copepods affects their C and N content. Adding green algae Brachiomonas submarina in concentrations of 50-500 \( \mu \text{g C l}^{-1} \) to

Is Prymnesium patelliferum toxic for copepods? Grazing, egg production, and egestion of the calanoid copepod Eurytemora affinis in mixtures of "good" and "bad" food

The potentially toxic, bloom-forming prymnesiophyte Prymnesium patelliferum was offered to the copepod Eurytemora affinis as a sole food and in mixtures with the green alga Brachiomonas submarina and the chrysophyte Pseudopedinella elastica. Filtration, ingestion, egg and faecal pellet production, and mortality were measured. In addition, videofilm was used to check the condition of copepods and possible changes in feeding behaviour due to different food species. With both B. submarina and P. elastica as a sole food, filtration, ingestion, egg production, and egestion were generally high and mortality low. In contrast, when fed with P. patelliferum, egg production and egestion were low. Mortality of copepods fed high concentrations of P. patelliferum was high, but copepods fed low concentrations survived generally well, both in single-species experiments and in mixtures. However, there were no significant differences in ingestion rates between algae species or concentrations. Thus, differences in ingestion of P. patelliferum could not explain the lower mortality in lower concentrations. We conclude that lethal effects were connected to toxic cell exudates, and thus independent on ingestion. When P. patelliferum was mixed with other species (1:1), egg production was equally high (P. elastica), or even higher (B. submarina), than with P. elastica and B. submarina alone. We conclude that even though P. patelliferum is harmful for copepods if offered as a sole food species, it can add to nutritional quality of other species in mixtures. In the experiments this may have been due to P. patelliferum containing specific nutritionally important components lacking from green algae, such as polyunsaturated fatty acids.
Reproduction and survival of the calanoid copepod *Eurytemora affinis* fed with toxic and non-toxic cyanobacteria

Reproduction (egg production and hatching success) and maintenance (mortality and carbon and nitrogen content) of the calanoid copepod *Eurytemora affinis* were measured at 5 concentrations (ca 50, 100, 200, 400 and 600 μg C l⁻¹) of toxic and non-toxic strains of the cyanobacterium *Nodularia* sp. and the green alga *Brachiomonas submarina*, and in 3 different mixtures of these species (1:1, 8:1 and 1:8). In addition, females with egg-sacs were collected from the sea and exposed to different concentrations of *Nodularia* sp., to find out whether cyanobacterial exudates disturb hatching of eggs produced in natural food conditions. With the *B. submarina* diet copepod egg production was high (maximum ca 7 eggs female⁻¹ d⁻¹), and increased with increasing food concentration, whereas with both toxic and non-toxic *Nodularia* sp. diet egg production was comparable to that in filtered sea water (0 to 2 eggs female⁻¹ d⁻¹), irrespective of food concentration. With both toxic and non-toxic *Nodularia* sp., copepods produced deformed egg-sacs, and hatching success was low, while eggs produced in natural food conditions hatched well, with the exception of those exposed to a high concentration of toxic *Nodularia* sp. Mortality of *E. affinis* fed with toxic *Nodularia* sp. was high, whereas high concentrations of non-toxic *Nodularia* sp. kept copepods alive. No beneficial effects of *Nodularia* sp. in mixtures with *B. submarina* were observed. However, mortality in mixtures with toxic *Nodularia* sp. was low, hatching success generally high and no deformed egg-sacs were produced, which indicated that copepods were able to avoid feeding on toxic algae. Our results suggest that, in addition to its toxic effect, *Nodularia* sp. lacks certain essential elements needed for copepod reproduction. However, the non-toxic strain is sufficiently high in food quality to sustain maintenance of *E. affinis*, if offered in large quantities.

Seasonal development of mesozooplankton biomass and production on the SW coast of Finland

Seasonal development of mesozooplankton abundance, biomass and production were studied on the SW coast of Finland in three hydrographically distinct areas with different phytoplankton dynamics. In addition, the present species composition was compared to that at the beginning of the century, using a multidimensional scaling analysis. Mesozooplankton biomass and production were dominated by only a few species: the largest part of the production in the archipelago and open sea areas (11.3 g C m⁻² year⁻¹ and 28.1 g C m⁻² year⁻¹, respectively) consisted of that by raptorial and suspension-feeding calanoid copepods (*Acartia bifilosa* and *Eurytemora affinis*) and of that by rotifers (*Synchaeta baltica*), while annual mesozooplankton production in the bay area (10.5 g C m⁻² year⁻¹) was mainly due to production of filter-feeding cladocerans (*Daphnia cucullata* and *Bosmina longispina*) and predatory cyclopoid copepods (*Thermocyclops oithonoides*). The food chain in the bay area seemed to be based on heterotrophic organisms; the dominant rotifers and cladocerans were feeding on bacteria and were in turn eaten by cyclopoid copepods. Salinity and trophic status of the area seemed to be the main factors determining species composition, while seasonal development of biomass and production were mostly affected by temperature and, probably, predation. The slight change in species composition in the study area since the beginning of the century may be due to increased salinity.

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Sedimentation of copepod fecal material in the coastal northern Baltic Sea: Where did all the pellets go?

We investigated the sedimentation of copepod fecal pellets in three different sea areas representing a sheltered bay, an archipelago area, and the open sea on the southwestern coast of Finland in the northern Baltic Sea. Fecal carbon sedimentation was always 99% of copepod fecal material was remineralized within the mixed water layer (0-20 m). However, in the area and season dominated by the large calanoid copepod Limnocalanus macrurus (bay station in spring), fecal carbon sedimentation was an order of magnitude higher than at the other two stations. From June onwards, when the bay station was dominated by cyclopoids, the situation changed: the fecal carbon sedimentation remained 30% lower in the bay than in the archipelago, although the fecal carbon production was estimated to be 2 times higher in the bay. Furthermore, pellet fragmentation (percentage of broken pellets of total fecal carbon sedimentation) was highest in spring and autumn at all areas and increased towards the open sea, resulting in more efficient loosening and breakup of pellets. The overall contribution of copepod feces to vertical carbon export in the northern Baltic Sea appears to be small, but seasonal and spatial variations in hydrography and mesozooplankton community structure significantly affect the fecal pellet sedimentation rates.

The effect of temperature, food concentration and female size on the egg production of the planktonic copepod Acartia bifilosa: Short Communications

Egg production of a brackish water calanoid copepod Acartia bifilosa was measured in the laboratory in different chlorophyll (Chl) a concentrations (0-24 μg l(-1)) and temperatures (4-24 degrees C), and the cephalothorax length and carbon content of females were determined. Egg production was positively correlated both with Chl a concentration and with temperature; highest egg production was obtained with 14-20 μg Chl a l(-1) and at 13-18 degrees C. There was also a significant positive correlation between egg production and female length-specific carbon content (μg C μm(-1)). However, no correlation was observed between egg production and cephalothorax length of females. Female carbon content changed during the 3 day experiments; carbon content was positively related to Chl a concentration and negatively related to temperature. We conclude that food availability (Chl a concentration), rather than temperature, limits the egg production of A. bifilosa in the present study area in the northern Baltic Sea. Further, both food concentration and
temperature affect egg production not only through the direct effect on the numbers of eggs produced per female, but also through their effect on female carbon content.

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**Effect of food quality on rate of growth and development of the pelagic copepod Pseudocalanus elongatus (Copepoda, Calanoida)**
Rates of body growth, development and egg production of Pseudocalanus elongatus were measured in the laboratory, in relation to the taxonomy and physiology of algal food. Four types of experiments were performed to measure the copepod's response to (1) 7 algal species of similar size and shape, but different taxonomic groups, (2) inferior food species that were offered with good food as a check of toxicity, (3) nitrogen limitation and the growth rate of food species, and (4) highly unsaturated fatty acids that were supplied with inferior food to test for lack of essential fatty acids. Grazing was measured to check that the offered food was really ingested. The best food species proved to be Rhodomonas sp., which induced a fast rate of development, good somatic growth and egg production and low mortality. The development rate was almost equally fast with Thalassiosira weissflogii, Gymnomdinum simplex and Tetraselmis suecica, but the rates of somatic growth or egg production were lower and mortality generally higher than with Rhodomonas sp. Three algal species, Dunaliella sp., Amphidinium sp. and Chrysochromulina polylepis, were poor food; copepod development was not completed, the rates of somatic growth and egg production were low and mortality was high. Ingestion was equally high with most of the species; only C. polylepis was not eaten. No clear toxic effects were found when the 3 poor-food species were offered in mixtures with Rhodomonas sp. N-limited Rhodomonas sp. did not reduce the rate of copepod development in comparison to a N-replete culture; however, N-limited T. weissflogii reduced the development rate to the low level of poor-food species. No effect of different growth rates of Dunaliella sp. was found. Lipids rich in highly unsaturated fatty acids supplied with Dunaliella sp. did not substantially improve the slow development and low egg production observed with this species. The weight-specific somatic growth rate was always higher than the weight-specific egg production rate, especially with less optimal food, which seems to hamper the estimation of the secondary production of copepods based on egg production alone. It is concluded that large differences in the food quality of different algal species are due to differences in digestibility or in mineral and biochemical composition.
Seasonal occurrence and hatching of calanoid eggs in sediments of the northern Baltic Sea

The seasonal occurrence and hatching of benthic eggs of calanoid copepods were studied for 1 yr in the surface sediments at 2 sites (a 33 m deep archipelago area and a 42 m deep site in an enclosed bay) off the SW coast of Finland, northern Baltic Sea. Eggs were abundant at both sites (up to 4 and 6 x 10^6 eggs m^-2). At the archipelago site, most eggs belonged to Acartia bifilosa and A. tonsa; at the bay site, eggs of Eurytemora affinis and Acartia spp. occurred. At the archipelago site, the egg numbers in the surface sediment followed closely the seasonal abundance of the planktonic Acartia spp. females. The eggs collected from the sediment were incubated at temperatures corresponding to the in situ bottom temperatures. Hatching of the A. bifilosa eggs occurred throughout the year, but it was most intensive in autumn when water stratification broke and the deep water warmed up to 13 degrees C. It is suggested that a large number of the A. bifilosa eggs sink to the bottom prior to hatching in shallow coastal areas of the Baltic Sea. Hatching of the benthic eggs occurs throughout the year and the rate of naupliar emergence from the sediments depends on benthic conditions and processes (e.g. temperature, sediment resuspension and bioturbation). At the bay site, where the surface water layer was hydrographically separated from the deep water, the coupling between the benthic egg abundance and the planktonic populations was not so obvious. The dominant species E. affinis carries its eggs in an egg sac until hatching, and probably only the diapause eggs, which are produced in autumn, fall to the bottom. A. tonsa was abundant in the water column at both study sites in autumn, even outnumbering other Acartia spp., in some samples. The eggs of the species only hatched in autumn, when the incubations were conducted at 10 to 13 degrees C. It is probable that A. tonsa spends most of the year as benthic resting eggs in the northern Baltic Sea. In contrast, A. bifilosa and E. affinis occurred in the plankton in winter at both study sites, though in low concentrations. They thus have 2 possible sources of recruitment when conditions are again favourable for population growth in spring: hatching of benthic eggs and reproduction by the overwintering population.

Seasonal and long-term variations in the body size of planktonic copepods in the northern Baltic Sea

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Projects:

**Environmental neutral aquaculture water treatment (MIVANAK) (39295)**
Despite a transition from flow-through systems to more advanced open water reuse aquaculture systems (e.g. model trout farms), the need for water treatment still exists. In brackish and saltwater reuse systems, blooms of toxic microalgae in an example of a recently new challenge.

The purpose of this project is to further develop current aquaculture water treatment practice and reduce the total amount of disinfectants used.

The project includes 3 different work packages, investigating:
- ecological consequences of continuous application of peroxycetic acid.
- toxicological effects of easy degradable disinfectants.
- alternative biological methods to control / avoid blooms of toxic heterotrophic dinoflagellates.

Trials will include mesocosmos experiments where disinfectants are added continuously or by daily pulses over a prolonged period of time where phyto- and zoo-plankton abundance and compositions will be investigated. Other trials will be made in batch experiments with pure algae cultures, as will prolonged continuous peroxyacid application experiments be made.

This project is coordinated by DTU Aqua.

The project is funded by the Environmental Protection Agency's Programme for Pesticide Research.

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Keywords: Research areas: Aquaculture & Marine Populations and Ecosystem Dynamics

**Trait Ecology of Plankton in a Changing Marine Environment**

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Samfinansieret - Andet
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Award relations: Trait Ecology of Plankton in a Changing Marine Environment

Project: PhD

**Baltic zooplankton; eco-physiology and adaptation**

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Award relations: Baltic zooplankton; eco-physiology and adaptation

Project: PhD

**Enzyme Immobilisation and Bioprocessing**

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The early life of eel in the Sargasso Sea – Influence of oceanography and climate (SARGASSO-EEL) (39107)

The recruitment of the European eel has been in dramatic decline during the last 30 years, and is at a severe low of only 3-5% of earlier magnitude. This change and its influence on the eel fishery have led to an intensified research in the oceanic phase of the European eel.

In order to contribute to further understanding of the life cycle of eel the Danish eel expedition set out in 2014 for the eel spawning grounds in the Sargasso Sea. Here a consortium of Danish scientists and international collaborators focused on the linkages between oceanography, biological production, eel spawning and the growth and drift of eel larvae.

During the expedition, a wide range of organisms was collected: From the smallest plankton of less than a millimeter to very large fish. A number of research groups are now working on samples and data from the expedition and assembling information on key processes in the early life of eels. Preliminary findings indicate that biological and physical changes have taken place in the spawning areas that may affect the eel larvae’s chances of survival and their journey to Europe.

The project was coordinated by DTU Aqua.

The project is funded by the Carlsberg Foundation and Danish Centre of Marine Research (cruise).

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Collaborators: Leibniz-Institute of Freshwater Ecology and Inland Fisheries, University of Alaska Fairbanks, Aarhus University, University of Copenhagen, Université de la Méditerranée Aix-Marseille II, Pierre and Marie Curie University - University of Paris VI, Sir Alister Hardy Foundation for Ocean Science (SAHFOS), University of Rhode Island, International Council for the Exploration of the Sea

Project: Research

Sustainable technologies to control microalgae in land based saltwater recirculating systems (39032)

Land based salt water recirculating systems is a potential alternative to fish farming in net pens. This purpose of this project was to test different solutions on how to control unwanted microalgae growth thereby addressing a potential challenges associated with land based farming.

A high degree of water reuse and the associated nutrient accumulation may favour growth of microorganisms and thereby deteriorate the biological water quality.

The project included:
- Test of improved mechanical filtration (application of pilot scale protein skimmers on small to medium sized RAS, and application of full scale 4 meter vacuum airlift; an innovative treatment technique tested in full scale RAS)
- Test of chemical water treatment routines using easy degradable disinfectants (Peracetic acid, chloramine-T, hydrogen peroxide) to control and inhibit toxic microalgae,
- Test of electrochemical oxidation disinfection technology to assess the efficacy (radical formation and algicidal effects) of boron doped diamond electrodes.

Numerous batch and pilot scale experiments were made at the section for Aquaculture, Hirtshals. In addition, intensive, diurnal sampling/monitoring and analysis on location was performed on a commercial pike perch RAS facilities facing toxic conditions.
algae problems.
The project is coordinated by DTU Aqua.
The project was funded by the National Environmental Protection Agency through Programme for Development and Demonstration of Bio-technologies (MUDP).

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Collaborators: AquaPri A/S, University of Copenhagen, Billund Aquaculture Service Aps, Electrocell A/S, The Danish Environmental Protection Agency
Project: Research

North Atlantic - Arctic coupling in a changing climate: Impacts on ocean circulation, carbon cycling and sea-ice (NAACOS) (38888)

Climate change is most pronounced at high latitudes, with rapid and dramatic changes observed in sea-ice coverage, circulation and the ecosystem. These changes have profound effects both at the regional scale as well as globally.

The North Atlantic and Arctic Ocean are the headwaters of the thermohaline circulation (THC), the global heat engine responsible, amongst other things, for the relatively mild climate we experience in Denmark. Subtle change in sea-ice formation, deep water circulation, and freshwater supply on a relatively local scale will have repercussions around the world. More subtle still are the feed-back controls these processes have on climate change. Sea-ice coverage and the earth's albedo is one feed-back, but there is also the draw down and sequestering of atmospheric CO2 in deep waters by physical and biological processes. The whole is an intricate weave of interrelated mechanisms: the scientific challenge to draw together expertise across disciplines to address these issues was accomplished; the strategic outcome was a suite of knowledge-based tools designed to reduce the uncertainty and contribute to climate policies.

The NAACOS team comprised a number of well-recognized scientists with profound experience and a significant international collaboration. NAACOS developed and refined oceanographic models using remote sensing and observations to evaluate the impact of high latitude climate change on circulation, deep water formation, sea-ice and carbon flux, and their implications at regional scales.

The project was coordinated by DTU Aqua.
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Collaborators: Aarhus University, Danish Meteorological Institute, DHI Water - Environment - Health, University of Copenhagen, Faroe Research Institute
Project: Research

Arctic plankton in a changing climate (38783)

Climate change impacts the marine arctic environment through changes in ice cover, ice thickness, irradiance, freshwater outflow, concentrations of nutrients and CO2 and the stratification. These factors determine the production, seasonality and fate of the planktonic primary production in the marine ecosystem. Plankton is fueling stocks of fish, marine birds and mammals and through that constitutes the base of the Greenlandic economy.

The aim of the project was to gain knowledge about the interaction between climate, oceanography and plankton in the vulnerable Greenlandic marine ecosystem trough field and laboratory experiments. The project was interdisciplinary and closely coordinated with the other projects under the Greenland Climate Research Centre.

The project was funded by the Commission for Scientific Investigations in Greenland (KVUG), Greenland Climate Research Centre, Danish Centre for Marine Research, and Carlsberg Foundation.

The project was coordinated by DTU Aqua.

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Response of pelagic food webs to warmer, acidified oceans (Pelagic foods) (38923)

Atmospheric CO2 is projected to double by 2100, resulting in increased global temperature, ocean acidification (OA) and changes in the balance of marine ecosystems. A general lack of multifactorial studies means very limited knowledge on the combined effects of these pressures on ecosystem structure and function. Preliminary mono-factorial data indicate important but little studied appendicularians (pan-global pelagic urochordates) may be strongly impacted, directly and indirectly via altered phytoplankton growth and chemical composition. Effects on other key plankton such as copepods may depend on phytoplankton size. Appendicularians repetitively secrete and discard filter-feeding houses. Discarded houses with trapped particles make a significant contribution to global vertical carbon flux. We will study combined effects of temperature and CO2 on these dominant zooplankton by manipulating natural plankton in mesocosms. We hypothesize climate change will impact the important zooplanktonic trophic level through top down altered predation fields and bottom up changes in prey type and size. Copepods are size-selective feeders and recent data suggest appendicularians are bottom up regulated by large and spiny particles. We will test these hypotheses in mesocosms by generating blooms of diatoms (large) or flagellates (small) and evaluate subsequent zooplankton population dynamics. Under these different conditions, we will also examine competitive predatory interactions between copepods and appendicularians, leading to models of projected effects of p(CO2) and temperature on appendicularians and copepods through alterations in phytoplankton community structure and uni-directional predatory pressure. Both appendicularians and copepods are important in oceanic carbon sequestration, but do so via different pathways. Data from these experiments should also have important predictive value on the nature and extent of future carbon sequestration in marine pelagic communities.

EURO-BASIN: European basin-scale analysis, synthesis and integration (EURO-BASIN) (38899)

EURO-BASIN was designed to advance our understanding on the variability, potential impacts, and feedbacks of global change and anthropogenic forcing on the structure, function and dynamics of the North Atlantic and associated shelf sea ecosystems as well as the key species influencing carbon sequestration and ecosystem functioning. Like the entire biosphere, marine ecosystems such as the North Atlantic and its associated shelf sea ecosystems can be characterized by emergent properties controlled by a dynamic network of interactions and relationships and not static entities. This system complexity is what Martin Luther King Jr. called “an inescapable network of mutuality” scientists today define as complex adaptive systems (CASs).

EURO-BASIN has represented the first attempt of creating future prognosis of marine ecosystem states sensitive to CAS dynamics using as its test case the North Atlantic. Long-term prediction of the status of these CAS systems, population dynamics of key species and hence management of marine systems requires the implementation and advancement of an ecosystem approach for the management of marine resources sensitive to CAS dynamics. What is the ecosystem approach? Unlike a single species approach, the ecosystem approach takes into account population and ecosystem responses to changes in the Earth's climate, fisheries, and interactions between them. In EURO-BASIN not only did we monitor and assess how North Atlantic marine ecosystems behaved in the past, but also predict how they will respond under possible future climate change scenarios. Hence, the results of this project have provided important recommendations for better marine resource management in the European Union.

The project had participants from 23 European universities and research institutions as well as collaborations with key institutions and Universities in the US and Canada.

The project was coordinated by Aarhus University, Greenland Institute of Natural Resources.

Collaborators: Aarhus University, Greenland Institute of Natural Resources
The biological pump in the Nordic seas: Copepods and appendicularians as producers and consumers of sinking particles (BIOPUMP) (38757)
BIOPUMP is a research network investigating the vertical flux, its production and consumption, and how it is affected by the climate change. The main activities of the network are annual research workshops concentrating on diverse aspects of vertical flux, such as the role of different zooplankton groups in producing and degrading of sinking particles, and how will the changing temperature and CO2 concentrations of the ocean influence the dynamics of these groups. BIOPUMP is also involved in organizing a Nordic PhD course on vertical flux and factors influencing it.

The project is coordinated by DTU Aqua.

Physical oceanography in Greenland waters under climate change (38767)
Changing climatic conditions will have considerable effects on the seas around Greenland. Melting glaciers, the formation of sea ice, large scale circulation of the Atlantic Ocean as well as more local changes in weather patterns will have direct impact, with cascading effects to biological processes and sustainable harvesting of marine resources. The aim of this project is to prepare modeling tools and analyses to describe expected oceanic conditions around Greenland under climate change. Particular focus will be on coupling these models and process studies to biology, biogeochemical cycling, and sea ice processes, with eventual feedbacks to climate itself.

The project is coordinated by DTU Aqua.

Fatty acids in the marine food chain (38160)
Primary production by autotrophic phytoplankton fuels the marine ecosystem and this energy is passed through the food web by trophic interactions. Understanding how energy flows through these interactions is vital for understanding how marine ecosystems function. The efficiency of energy transfer from primary producers to higher trophic levels depends on the efficiency of secondary producers utilizing the new carbon. This crucial link is still poorly understood and most often we observe that secondary production is not simply correlated with phytoplankton biomass. However, reproduction and growth of secondary producers, such as copepods, depend also on food quality. The goal of this project is to investigate the effect of essential fatty acids on copepod reproduction, growth and survival. Essential fatty acid are the ones the copepod need but has to attain from the food, as it cannot synthesize those de novo. The project is based on series of laboratory, field and mesocosm studies with the focus on understanding how food composition, both chemical composition and type affect growth and mortality all contribution to population dynamics of the copepod species. In addition the project has a strong teaching factor for masters and PhD students in form of advanced summer schools.

The project is coordinated by DTU Aqua.
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