Appendix 3: Marine observatories and ecosystem time series

i. Project aims

The goal of this initiative is to establish a Svalbard Marine observatory system based on the ARCTOS mooring network, the Hausgarten mooring system and long term hydrography, zooplankton and benthos data series

This is done to:

- Investigate the spatial distribution of zooplankton and benthos by use of existing data and new data collected by remote sensing techniques.
- Investigate seasonal and diel vertical migration by use of sediment traps and acoustic methods.
- Assess Arctic pelagic and benthic ecosystem changes in relation to climate factors such as sea ice, hydrography, NAO and AO indices.
- Set a baseline for future monitoring programmes with respect to megafaunal communities and food web structure at selected stations.
- Identify thresholds that can change arctic marine food webs and energy transfer.

ii. Background

Long time series of marine fauna and flora in the Arctic are rare. This is not surprising since the area is only accessible by means of expensive modern infrastructure and instrumentation. However, since the 1970's, Norwegian scientists have both jointly with other international partners and independently been investigating the fjords and coastal areas of the arctic archipelago of Svalbard and surrounding seas.

More recently, these research co-operation activities have been formalised through participation in the ARCTOS network, the leading European network of Arctic marine ecologists (6 Norwegian, 6 Nordic and 22 International institutions). The network enhances co-operation on basic and applied Arctic research and education supported by a world class Arctic research infrastructure.

These research groups unquestionably have access to the best available data to assess past changes in shallow Arctic pelagic and benthic ecosystems. In particular, this long-term co-operation has provided good baseline data from Kongsfjorden (site of large-scale Norwegian and EU research facilities), Isfjorden, Hornsund and Rijpfjorden. In 1996, a transect of ten stations (NPI) was established from the inner part of the Kongsfjord to outside the shelf break at five discrete depth strata (Fig. 1), and has been sampled several times a year. The data have been continuously processed until summer 2006. Additionally, a large data set has been gathered on community structure, fatty acid trophic markers and stable isotopes of zooplankton, fish and marine birds. Although measurements on salinity and temperature date back to Nansen and Helland Hanse 1906, time-series data are only available from 1994 onwards (summer, autumn). Further information is available on the taxonomic composition of phytoplankton (from 2006). Data on the taxonomic composition and structure of soft sediment environments have been gathered approximately every fifth year since 1997 by Akvaplan-niva and the Institute of Oceanology, PAS and unique 20 years data series of hard bottom community data maintained by Akvaplan-niva, UNIS and UoT. The state of the Kongsfjorden and Fram Strait ecosystem has been reviewed by Hop *et al.* (2004, 2006), the zooplankton by

Kwasniewski *et al* (2003) and the potential effect of climate swings by Falk-Petersen *et al.* (2007).

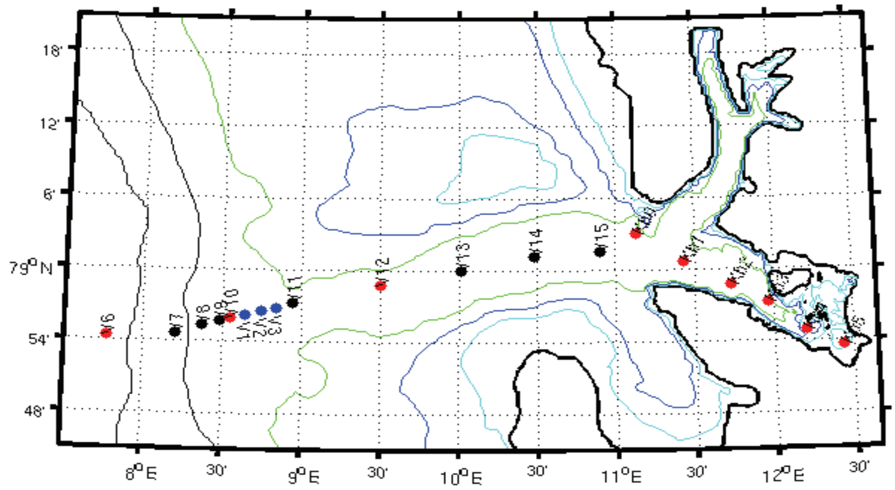


Figure 1: Sampling transect from the inner part of the Kongsfjord to outside the shelf break (1200 m). Sampling takes place several times a year.

The first ARCTOS bio-physical marine observatories was established in Kongsfjorden in 2005 and we now operate two large (Kongsfjorden and Rijpfjorden) and 4 small marine observatories (Figure 2). A new large observatory is going to be established on the shelf north of Nordaustlandet in 2008. The large marine observatory (Figure 3), continuously record phytoplankton biomass (fluorescence), vertical migration of zooplankton (ADCP), species composition of plankton (sediment traps), direction and speed of currents (ADCP), temperature and salinity (CTD and termistors) and sedimentation (traps). The large mooring is operating and maintained by SAMS and the smaller by UNIS

Fig 2. ARCTOS marine observatories.
Large observatory maintained by SAMS and small by UNIS

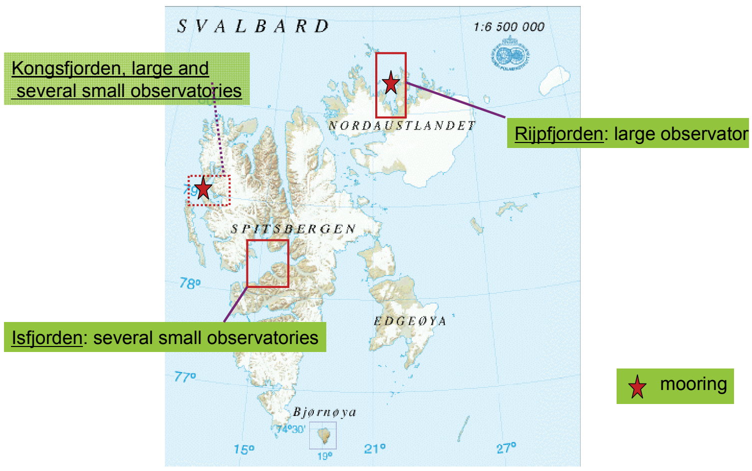
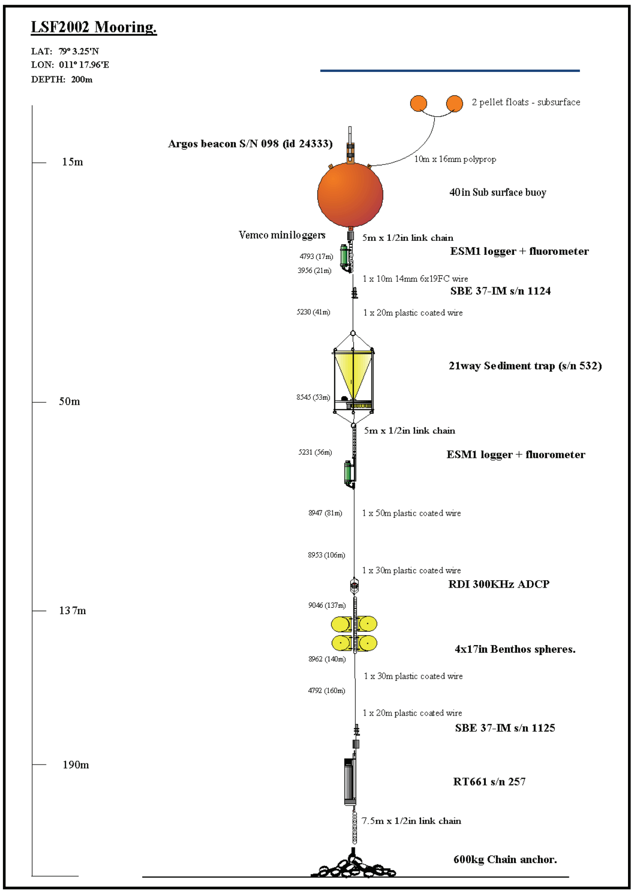


Fig. 3.



Concurrent with the efforts made by ARCTOS, the Alfred Wegener Institute for Polar and Marine Research (AWI) established the 'HAUSGARTEN' in 1999 as the first and only long-term deep-sea observatory at high latitude (Soltwedel *et al.,* 2005). It comprises 15 permanent sampling stations along a bathymetric transect from the Vestnesa Ridge to the Molloy Hole (1200-5500 m) and a latitudinal transect along the 2500 m isobath. These transects cross at the central HAUSGARTEN station, which serves as an experimental area for long-term experiments (Fig. 2). Long-term investigations at HAUSGARTEN comprise various compartments of the ecosystem, including the water column and the deep seafloor. Repeated sampling and the deployment of moorings and long-term free-falling systems (bottom landers) has been conducted on an annual basis since 1999 and yielded an unrivalled time-series data set.

HAUSGARTEN has seen major changes over the monitoring period: the most prominent is that both the surface and the deep waters have warmed by 0.025°C between 2001 and 2004 (Schauer *et al.,* 2004, Soltwedel *et al.,* 2005) concurrent with a decrease in the phytodetrital flux to the seafloor and sediment-bound organic matter. A decline in organic matter input will affect the entire deep-sea ecosystem, which - in the absence of light - relies on the carbon flux from the euphotic zone and shelf. Indeed, data from Hoste *et al.* (2007) indicate a decline in the microbial biomass of sediments and changes in meiofaunal densities at some stations over the sampling period. Recently, a comparison of seafloor images from 2002 and 2004 showed a significant decrease in total megafaunal densities and individual species (unpublished data). These findings indicate that serious changes are already taking place at various levels of biological organisation. The AWI Deep-Sea Research Group has thus gained extensive expertise in multi-disciplinary research and collation of time-series data at deep high-latitude locations.

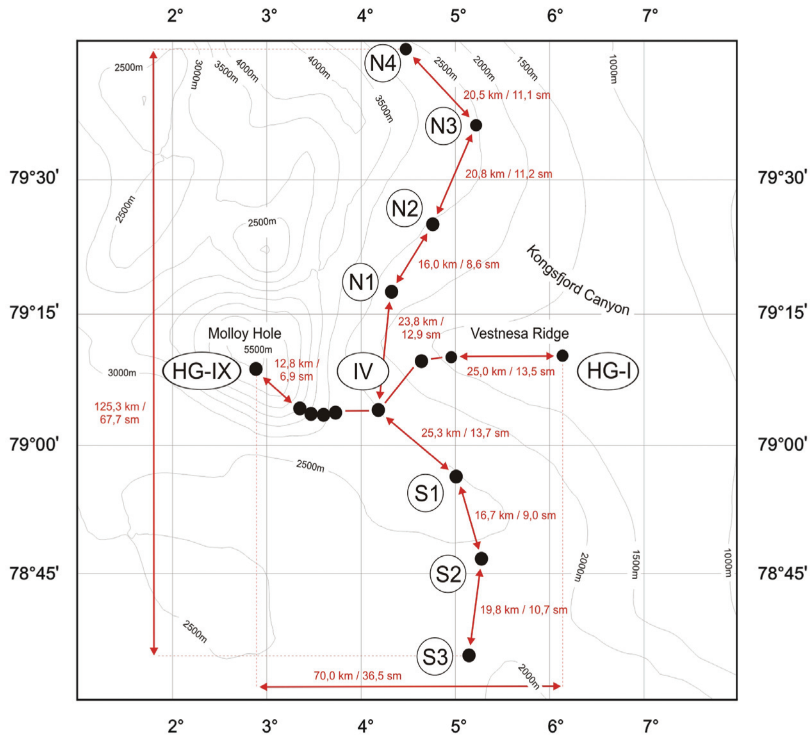


Figure 2: HAUSGARTEN observatory. At station S3 and IV *in situ* experiments have been installed since 1999. At S3, IV and N3 (since 2007 N4) moorings are re-deployed every year.

It has been hypothesized that one major impact of global change is a shift in the quantity and quality of food available (McMahon et al., 2006; Carroll and Carroll, 2003). For example, some models project increased pelagic productivity and recycling in the Arctic while benthic systems become impoverished due to a decline in nutrients reaching the seafloor (keynote lecture by Louis Fortier, 42nd European Marine Biology Symposium). If we see a decline in key species, the trophic level of their predators may change as they starve or switch to other prey. To assess how changes at one level impinge on other compartments of the ecosystem, we propose to optimise the scientific outcome of the two sampling programmes by combining the Kongsfjord and HAUSGARTEN transects. By chance, the shallowest AWI sampling station lies only some 25 nautical miles northwest of the deepest station of the Kongsfjord transect. This collaboration between AWI and ARCTOS will yield a more complete data set spanning from shallow to deep water stations. Such a programme will yield data necessary to understand ecosystem function for the purpose of establishing the *status quo* for future monitoring.

iii. Sampling approach:

1. WATER COLUMN

Arctic *Calanus* are the most important animals in high latitude seas because they convert low energy sugar to high energy. The herbivorous copepods of the genus *Calanus* spp. comprise up to 70- 80% of the zooplankton biomass in Arctic seas (Conover, 1988; Hirche and Mumm,

1992) and constitutes the key link between primary production and higher trophic levels (Falk-Petersen *et al.*, 1990; Falk-Petersen *et al.*, 2007). In this programme, we will study the timing of the bloom on the seasonal and diel migration and the effect through different trophic levels in a high Arctic ecosystem, as well as studying the timing and productivity of key herbivore and carnivore species. Data on algal biomass, zooplankton community structure and abiotic environmental data, high-resolution mooring data of fluorescence and zooplankton seasonal and diel vertical migration will give information on "timing" (Cottier *et al 2006.*,). We intend to study the seasonal and diel vertical migration using a set of remote-sensing techniques such as ADCP, OPC, and echo-sounders. Additional pelagic data will be gained from plankton net hauls and moored sedimentation traps (see below).

Organisms inhabiting the deep sea rely chiefly on the input of organic material from the shallow and productive layer of the ocean. Therefore, estimates on the vertical particle flux are an important component of the sampling activities at HAUSGARTEN. At high latitude, sedimentation and composition of settling particles is governed to a great extent by ice conditions and variations in ice coverage (Bauerfeind et al. 2004, Ramseier et al. 1999). However, sedimentation is also affected by the structure of zooplankton communities in the epi- and mesopelagic zone leading either to a retention or a sedimentation regime (Peinert *et al.*, 1989, Riser *et al.,* 2007, Wassmann, 2001). At HAUSGARTEN, the vertical particle flux has been studied by year-round deployments of moored sediment traps since 2000. These moorings are also equipped with current meters.

Data from the shallow traps (~300 m) are available until 2005. First analyses of the data indicate a co-variation of the total particulate matter flux (TPM) and share of biogenic matter in TPM – flux with the ice conditions. A more detailed microscopic analysis of the intercepted particles is currently under way to evaluate the share and variation of ice related organic matter in the sedimented particle pool. Here, we propose to extend the biochemical and microscopic analyses to samples from deep sediment traps from HAUSGARTEN that could not be processed *hitherto*.

The sediment trap samples regularly contain varying amounts of zooplankton (swimmers). This material has been archived. A detailed analysis of these organisms (species composition, life stages) will allow us to gain insights into the structure of the zooplankton communities during winter, a period for which we usually lack zooplankton samples from this area. This analysis enables us to trace changes in community composition caused by the changing environmental conditions in the northern north Atlantic

2. BENTHIC SYSTEM

2.1 Sediments

The sampling programme at HAUSGARTEN comprises biochemical analyses to estimate the input of organic matter from phytodetrital sedimentation. Plant pigments are a good indicator for the input of phytodetritus to the seafloor and can rapidly and accurately be measured by fluorometry (Shuman and Lorenzen, 1975). To determine the nutrients available to benthic biota the total organic carbon content of sediments is also assessed. To obtain biomass estimates for benthic micro-organisms (bacteria, yeasts, fungi, protozoa and metazoan meiofauna) sediment-bound phospholipids which are indicative of cellular membranes are determined (Findlay et al., 1989). Data are available for all these parameters from 2000 to 2006.

Here, we propose to extend our HAUSGARTEN sampling programme to selected stations of the Kongsfjord transect. Sediment samples will be taken by a video-guided multiple corer or, depending on the sediment characteristics, by a box corer. We propose to analyse the total organic carbon content, phaeopigment concentrations, phospholipids quantities and granulometry of sediment samples.

2.3 Benthic megafauna and demersal fish

Benthic megafauna and fish play an important role in benthic ecosystem function as they control the population dynamics of smaller biota through predation and bio-engineering and recycling of organic matter. Megafauna create mounds, pits and tracks which increase habitat heterogeneity and the diversity of smaller-sized inhabitants (bacteria, meiofauna). Sponges and stalks of sea lilies enhance three-dimensional habitat complexity and present hiding places and secondary habitats to a host of organisms (Hasemann 2006). Sessile organisms, which often belong to the suspension feeders, may be most vulnerable to environmental change since they cannot escape. As megafauna play an important role in ecosystem function and their densities are already in decline (unpublished data) it is of paramount importance to record changes in their abundance, composition and functional diversity over time. The composition and density of megafaunal assemblages can be assessed by analysis of footage from towed underwater cameras. The organisms present on images are identified to species or morphotypes and classified according to life style and feeding behaviour (e.g. sessile suspension feeder, mobile predator). This rather time-consuming process may be accelerated by the use of promising automated image analyses tools developed during the Statoil-funded CORAMM project. Voucher samples taken by trawl or box corer complement camera observations as they allow a direct taxonomic identification (ground-truthing) and thus assessment of diversity. A comparison of images from successive years allows us to assess changes in species' densities.

2.4 Trophic level & food web

Traditional approaches to trophic studies rely on stomach contents analysis together with field and laboratory observations. These approaches are somewhat problematic when working in the deep sea due to restricted access and technical problems: live organisms for experiments are difficult to obtain and stomach contents analyses are hampered by specimen being damaged by sampling and pressure effects. Furthermore, it is difficult to identify the gut contents of species that macerate their prey. In addition, the prey found in stomachs represents only a snapshot in time. In recent years, stable isotope analysis has been established as an alternative approach to determine relative trophic positions of organisms (Peterson & Fry 1987). Naturally occurring stable isotopes of nitrogen (N) show a stepwise enrichment between prey and consumer tissue during assimilation processes (DeNiro & Epstein 1981). Selective metabolic fractionation leads to a preferential loss of lighter isotopes during excretion which is conventionally expressed as $\delta^{15}N$, the ratio of ^{15}N to ^{14}N. Grazing animals thus show ^{15}N enrichment relative to the plants they consume; predators show further ^{15}N enrichment relative to their prey species. This mechanism allows us to establish the relative trophic positions of members of a food web.

Over the past three years, stable isotope analysis has been done at most HAUSGARTEN stations on demersal fish, meio-, macro- and megafaunal organisms, particulate organic matter from surface and bottom waters and sediments (Bergmann *et al.* in preparation). Here, we propose to conduct stable isotope analysis at selected station(s) along the proposed Kongsfjord-HAUSGARTEN transect to understand the links between the water column and the benthic ecosystem. Benthic sampling (multiple and/or box corer and/or trawl) will provide the material required for measurements by continuous flow isotope ratio mass spectrometry. The $\delta^{15}N$ ratio of primary producers from surface waters and bottom particulate organic matter sampled by water samplers provides a reference point for other ecosystem compartments. A combination of our results with those from the water column by the NPI will enable us to collate a unique data set and understand the links between the pelagic and the benthic system.

Partners

- Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, Dr Michael Klages

ARCTOS Partners:

- The Norwegian Polar Institute (NPI), Tromsø, Professor Stig Falk-Petersen
- Akvaplan-niva, Polar Environmental Centre, Tromsø, Dr Michael Carroll
- The Scottish Association for Marine Science (SAMS), Dunstaffnage Marine Laboratory, Oban, UK. Dr Finlo Cottier
- Institute of Oceanology, Polish Academy of Science (IOPAS), Dr Slawek Kwasniewski
- l'Observatoire Océanologique de Villefranche-sur-mer France (LOV), Professor Patrick Mayzaud
- UNIS - The University Centre in Svalbard, Dr Jørgen Berge
- NCFS, University of Tromsø, Tromsø, Dr Marit Reigstad
- University of St Petersburg / AARI. Dr Boris Ivanov

Investments and operational costs:

The sea based research and monitoring platform will need additional instruments to be complete. We see the need to add a number of moorings (1,5 M€), balloons and drones (1,5 M€) and instruments for remote sensing (1 M€). To secure continuous operation and continuous time series from these instruments, we foresee operating costs of another 1 M€ a year. These costs come in addition to ongoing research and monitoring programs and infrastructure that is already in place. Total investments: 4 M€. Operational costs: 1 M€/year.

Contact person: Stig Falk-Petersen, Norwegian Polar Institute

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