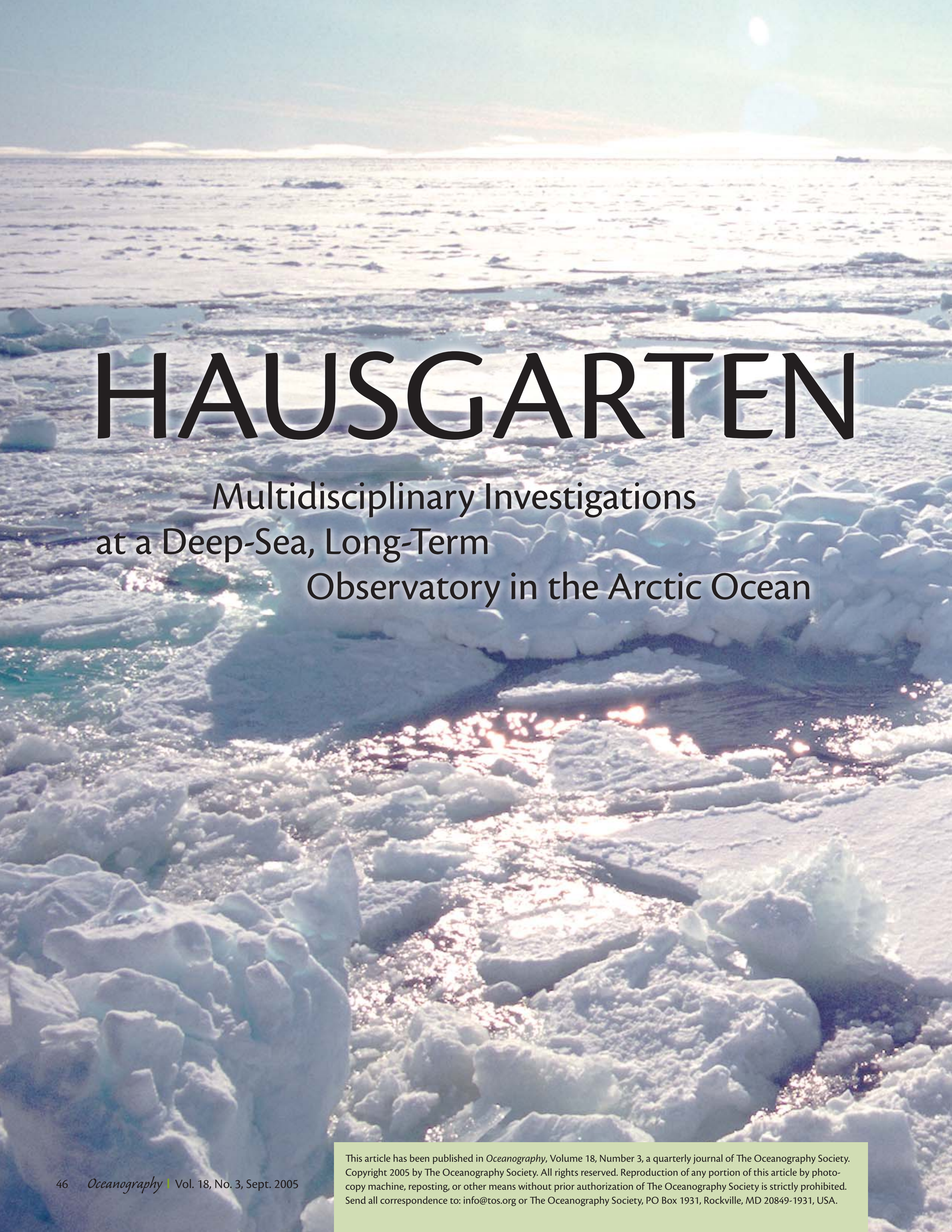

HAUSGARTEN

Multidisciplinary Investigations at a Deep-Sea, Long-Term Observatory in the Arctic Ocean

BY THOMAS SOLTWEDEL, EDUARD BAUERFEIND, MELANIE BERGMANN, NATALIYA BUDAEVA, EVELINE HOSTE, NINA JAECKISCH, KAREN VON JUTERZENKA, JENS MATTHIESSEN, VADIM MOKIEVSKY, EVA-MARIA NÖTHIG, NADIA-VALÉRIE QUÉRIC, BURKHARD SABLOTNY, EBERHARD SAUTER, INGO SCHEWE, BARBARA URBAN-MALINGA, JAN WEGNER, MARIA WLODARSKA-KOWALCZUK, AND MICHAEL KLAGES

THE MARINE ARCTIC has played an essential role in the history of our planet over the past 130 million years and contributes considerably to the present functioning of Earth and its life. The global cycles of a variety of materials fundamental to atmospheric conditions and thus to life depend to a significant extent on Arctic marine processes (Aargaard et al., 1999).

The past decades have seen remarkable changes in key Arctic variables. The decrease of sea-ice extent and sea-ice thickness in the past decade is statistically significant (Cavalieri et al., 1997; Parkinson et al., 1999; Walsh and Chapman, 2001; Partington et al., 2003; Johannessen et al., 2004). There have also been large changes in the upper and intermediate layers of the ocean, which have environmental implications. For instance, the deep Greenland Sea has continued its decadal trend towards warmer and saltier conditions, with a corresponding decrease in oxygen content, reflecting the lack of effective local convection and ventilation (Dickson et al., 1996; Boenisch et al., 1997). Changes in temperature and salinity and associated shifts in nutrient distributions will directly affect the marine biota on multiple scales from communities and populations to individuals, consequently altering food-web structures and ecosystem functioning (Benson and Trites, 2002; Moore, 2003; Schumacher et al., 2003; Wiltshire and Manly, 2004; Perry et al., 2005). Today, we do not know whether the severe alterations in abiotic parameters represent perturbations due to human impacts, natural long-term trends, or new equilibriums (Bengtson et al., 2004).

Because Arctic organisms are highly adapted to extreme environmental conditions with strong seasonal forcing, the accelerating rate of recent climate change challenges the resilience of Arctic life (Hassol, 2004). The entire system is likely to be severely affected by changing ice and water conditions, varying primary production and food availability to faunal communities, an increase in contaminants, and possibly increased UV irradiance. The stability of a number of Arctic populations and ecosystems is probably not strong enough to withstand the sum of these factors, which might lead to a collapse of subsystems.

To detect and track the impact of large-scale environmental changes in the transition zone between the northern North Atlantic and the central Arctic Ocean, and to determine experimentally the factors controlling deep-sea biodiversity, the German Alfred Wegener Institute for Polar and Marine Research (AWI) established the deep-sea, long-term observatory HAUSGARTEN, representing the first, and by now only, open-ocean, long-term station in a polar region.

LONG-TERM TIME-SERIES STUDIES provide the opportunity to investigate subtle habitat changes, irregularly spaced stochastic events, and complex interdependent ecological phenomena that affect biogeochemical cycles in the world ocean (Karl et al., 2001). The most recognized multidisciplinary, marine, long-term stations are situated in the northeastern and central Pacific, in the western and eastern Atlantic, and in the North Sea. The California Oceanic Cooperative Fisheries Investigations (CalCOFI) were already established in 1949 to measure the physical and chemical properties of the California Current System and to map the distribution and abundance of phytoplankton, zooplankton, and fish eggs and larvae (more information is available at http://www.calcofi.org). Investigations at Helgoland Reede in the German Bight started in the early 1960s (Franke et al., 2004). Since then, temperature, salinity, nutrient concentrations, and plankton compositions were registered on a daily base. CalCOFI and investigations at Helgoland Reede provide by far the longest and most complete time series for marine plankton. BATS (Bermuda Atlantic Time-Series Study) and ESTOC (European Station for Time-Series in the Ocean, Canary Islands) represent oceanographic long-term stations in the western and eastern Atlantic (Michaels and Knap, 1996; Neuer and Rueda, 1997). Whereas monthly observations at ESTOC off northwest Africa started in 1994, investigations at the BATS site in the Sargasso Sea were already taken up in the late 1980s. At the same time, the long-term station HOT (Hawaii Ocean Time-Series) (Karl and Lukas, 1996) in the central Pacific was established with a spectrum of measurements and sampling programs almost identical to BATS (Karl et al., 2001). Goals of time-series research at HOT and BATS are to better understand basic processes controlling ocean biogeochemistry on seasonal and decadal time scales, to determine the role of oceans in the global carbon budget, and ultimately to improve our ability to predict the effects of climate change on marine ecosystems. It is assumed that these climate changes will be particularly intense in polar regions, with most severe impacts in the Arctic (Hassol, 2004). Therefore, we decided to establish our long-term observatory HAUSGARTEN at northern high latitudes where we expect to see future changes in the marine ecosystem even at great water depths.

HAUSGARTEN OBSERVATORY is located in Fram Strait (Figure 1a), the only deep connection between the central Arctic Ocean and the Nordic Seas, where exchanges of intermediate and deep waters take place (Rudels et al., 2000; Fahrbach et al., 2001). Hydrographic conditions in the HAUSGARTEN area are characterized by the inflow of relatively warm and nutrient-rich Atlantic Water (AW) into the central Arctic Ocean (Manley, 1995). This advection of AW primarily controls the climate of the

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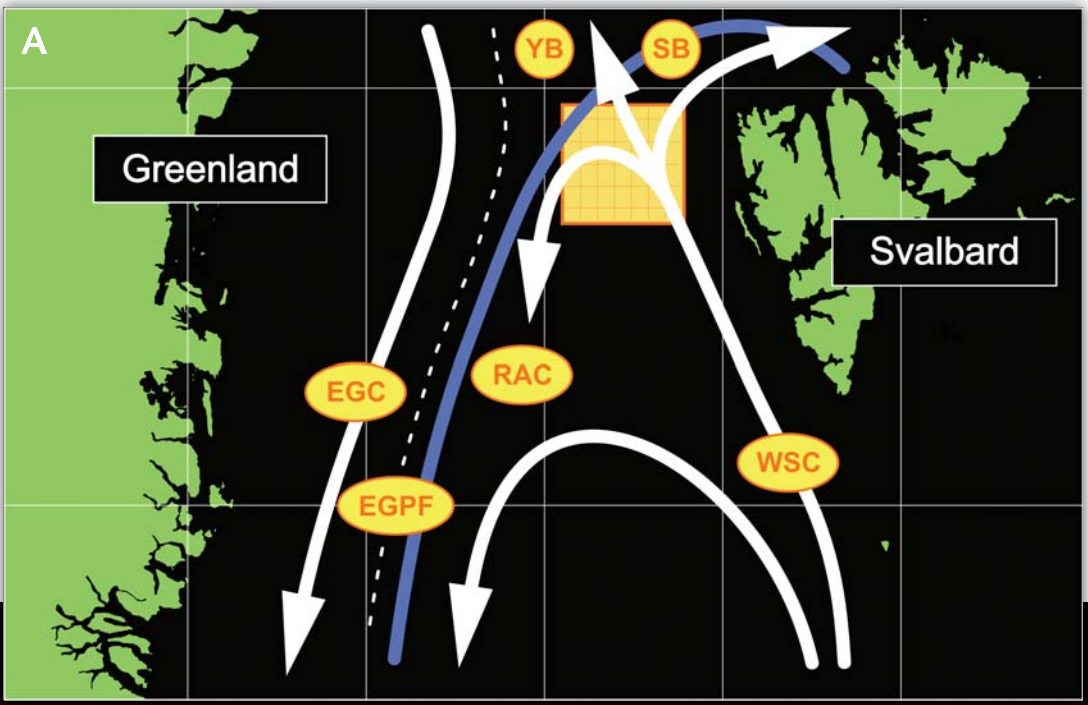


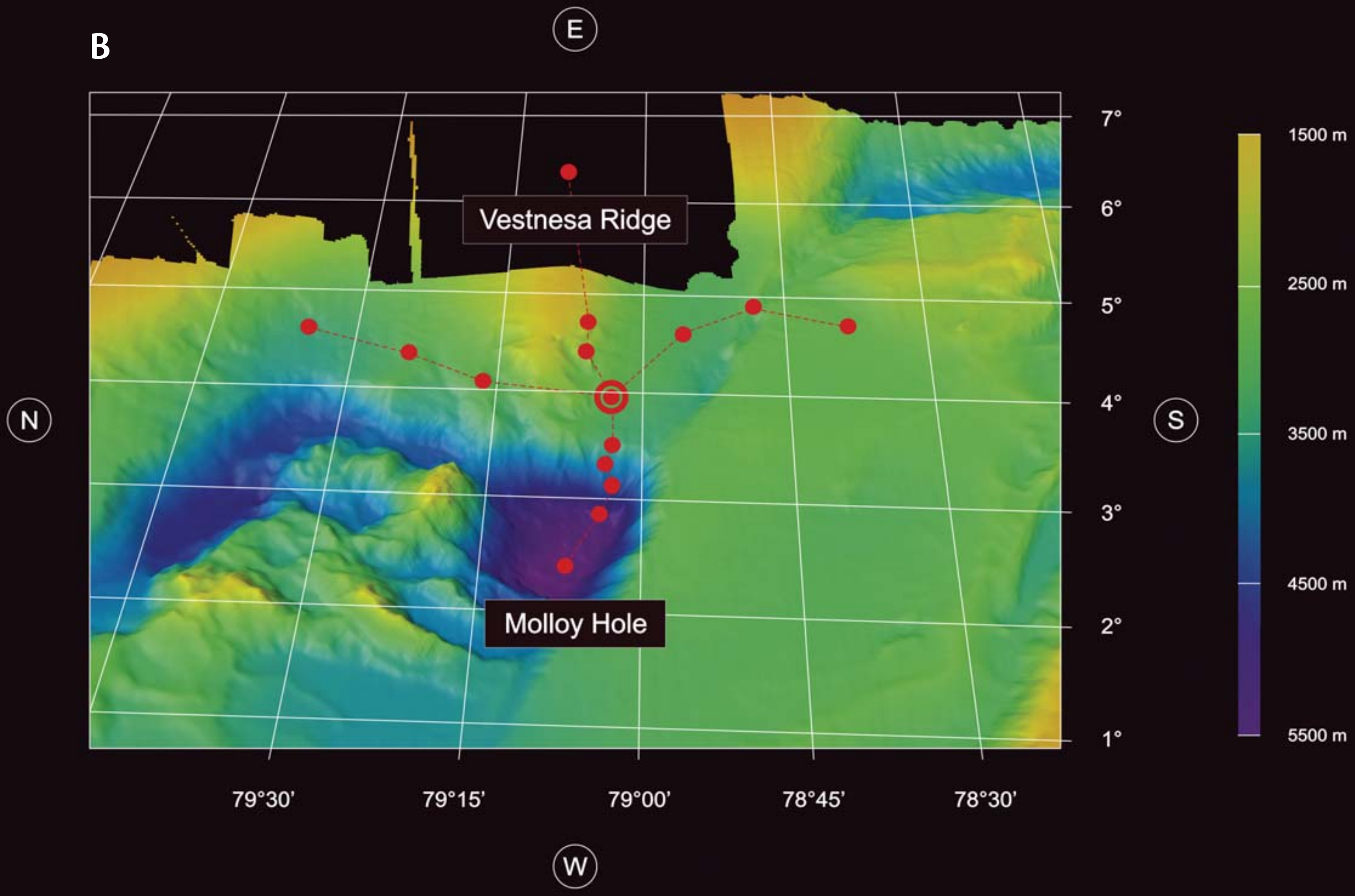
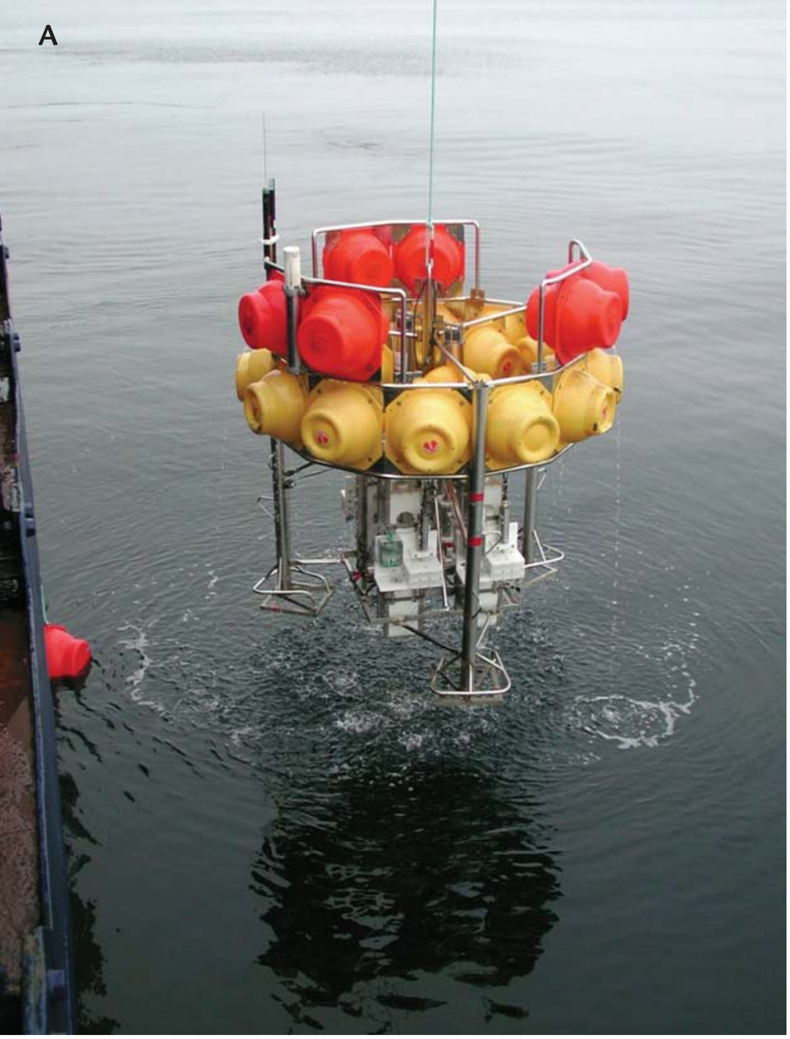


Figure 1. (A) Deep-sea long-term observatory HAUSGARTEN in the eastern Fram Strait, west off Spitsbergen. The blue line is the mean position of the recent ice edge. YB: Yermak Branch; SB: Svalbard Branch; EGC: Eastern Greenland Current; RAC: Return Atlantic Current; EGPF: East Greenland Polar Front; WSC: West Spitsbergen Current. (B) Three-dimensional display of HAUSGARTEN bathymetry. Red dots indicate permanent sampling sites; red circle is the experimental area at the central HAUSGARTEN station.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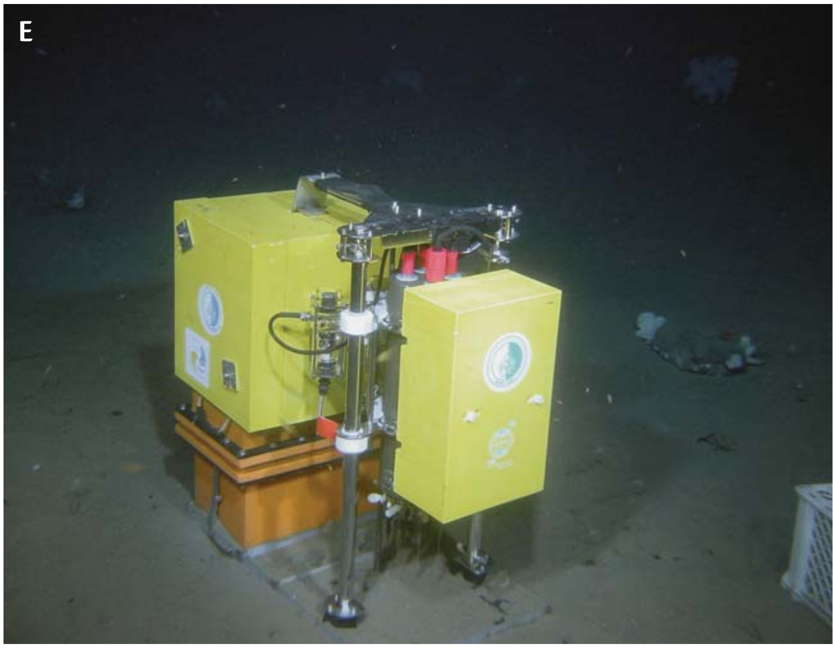
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Figure 2 (opposite page). A selection of instruments used for investigations at the deep-sea, long-term observatory HAUSGARTEN. (A) Free-falling system (Bottom-Lander) to conduct observations, measurements, and experimental work at the seafloor. (B) The remotely operated vehicle (ROV) *VICTOR 6000* (Institut français de recherche pour l'exploitation de la mer [Ifremer], Issy-Les-Moulineaux, France) is regularly used for photo/video surveys, targeted sampling, and experimental work at the seafloor. (C) The autonomous underwater vehicle (AUV) of the Alfred Wegener Institute for Polar and Marine Research will be used for large-scale water column studies. (D) Carrousel of sampling bottles of a sediment trap deployed at HAUSGARTEN; differing amounts of particulate matter in monthly exchanged bottles demonstrate pronounced seasonal variations in fluxes to the seafloor. (E) ROV-operated autonomous microprofiling unit used to assess *in situ* remineralization rates at the seafloor.

Nordic Seas and the Arctic Ocean. At 78-80°N, about 22 percent of the northward flowing AW (West Spitsbergen Current [WSC]) is re-circulated within the Return Atlantic Current (RAC). At about the same latitude, the remaining AW splits up into the Svalbard Branch (33 percent of WSC waters), following the perimeter of the Svalbard islands, and the Yermak Branch (45 percent of WSC waters), flowing along the western and northern flanks of the Yermak Plateau, a sub-sea peninsula to the northwest of Svalbard. Recent years exhibited a strong increase in the annual mean net heat transport within WSC waters, with the strongest increase in the Yermak Branch (Schauer et al., 2004). The cooler, less-saline Polar Water exits the central Arctic Ocean as the Eastern Greenland Current (EGC) in western parts of the Fram Strait, separated by a frontal system (East Greenland Polar Front [EGPF]) from the water masses at HAUSGARTEN observatory (Figure 1a). Circulation patterns in Fram Strait result in a variable sea-ice cover, with permanent ice-covered areas in the west, permanent ice-free areas in the southeast, and seasonally varying ice conditions in central and northeastern parts (i.e., in the wider HAUSGARTEN area). The dramatic decrease in summer sea-ice extent observed over the last decades will cause an ongoing northward shift of the ice-edge related primary production.

The bathymetry at HAUSGARTEN is characterized by a submarine projection from the Svalbard continental margin (Vestnesa Ridge; approximately 1000-2000 m water depth) and a deep depression (Molloy Hole) with a maximum depth of 5669 m (Klenke and Schenke, 2004), adjoining the ridge to the west (Figure 1b). Steepest parts of the slope reach up to 40° inclination between 4000 and 5000 m water depth. Near-surface sediments in the HAUSGARTEN area are dominated by silioclastic components that are supplied by sea ice, downslope transport from the Svalbard shelf, and advection from distal source areas with surface and bottom currents. As a special feature, Vestnesa Ridge exhibits numerous small (50-300 m in diameter) pockmarks caused by episodic methane release (Vogt et al., 1999).

> The marine Arctic has played an essential role in the history of our planet over the past 130 million years and contributes considerably to the present functioning of Earth and its life.

The HAUSGARTEN observatory includes 15 permanent sampling sites along a depth transect from Vestnesa Ridge to the Molloy Hole (1000-5500 m) and along a latitudinal transect following the 2500 m isobath crossing the central HAUSGARTEN station (Figure 1b), which serves as an experimental area for long-term experiments at the deep seafloor. Repeated sampling and the deployment of moorings and different long-term lander systems (Figure 2a), which act as local observation platforms, has taken place since the observatory was established in summer 1999. Frequent visual observations with towed photo/video systems allow the assessment of large-scale distribution patterns of larger epibenthic organisms. At regular intervals, a working-class remotely operated vehicle (ROV) (Figure 2b) is used for targeted sampling, the positioning and servicing of autonomous measuring instruments, and the performance of *in situ* experiments and geo-referenced video footage. A 3000-m-depth-rated autonomous underwater vehicle (AUV) (Figure 2c) will extend our sensing and sampling programs in the near future; first scientific missions at HAUSGARTEN are projected for autumn 2005. Multidisciplinary research activities at HAUSGARTEN cover almost all compartments of the marine ecosystem from the pelagic zone to the benthic realm, with some focus on benthic processes (Box 1).

WATER-COLUMN STUDIES AT HAUSGARTEN comprise the assessment of physico-chemical parameters as well as flux measurements of particulate organic matter to the deep seafloor.

Whereas currentmeters in long-term moorings and free-falling devices provide information on current speeds and directions at various heights above the seafloor, repeated conductivity-temperature-depth (CTD) casts at the permanent stations allow the identification of temporal temperature and salinity variations. Transmissiometers and oxygen sensors attached to the CTD provide additional information on suspended matter and remineralization processes in the water column.

The amount of biomass produced in the photic zone, in combination with degradation processes in the water column, determines the quantity of organic material being transferred to the deep seafloor, where it represents the major food source of the benthos (Wassmann et al., 1991). At high latitudes, the ice cover and its seasonal variation not only influence the timing and amount of the production in the water column, but to a high degree also the amount and temporal pattern of subsequent particle fluxes (Ramseier et al., 1999; Peinert et al., 2001). At HAUSGARTEN, we use samples obtained by annually moored sediment traps to trace the seasonal development of the pelagic system during the course of the year and to unveil processes governing sedimentation. Despite some uncertainties in respect to their effectiveness, sediment traps are, at present, the only tools that allow the collection of settling particles for later chemical and microscopic analysis in the laboratory. Whereas chemical and biogeochemical analyses yield an overview of the amount and composition of elements of the organic material, microscopic inspections and determinations of organisms and their remains reveal possible changes in species composition or key species due to modifications in water masses and concomitant changes in pelagic system structure as a possible result of climate change.

Settling particulate matter at HAUSGARTEN shows pronounced seasonal patterns (Figure 2d) and has a quite variable composition, consisting of particulate organic matter and minerogenic particles, principally deriving from two major sources: export from the photic zone and lateral advection. Our studies reveal that sea ice and material incorporated therein play an important role in the dispersion of particulate matter of marine and terrestrial origin. This material, originating from the nearby Svalbard archipelago as well as from the Siberian shelf seas and the adjacent hinterland, is released during ice melt in the Fram Strait (Hebbeln, 2000; Dethleff et al., 2000).

BOX 1: MEASUREMENTS AND SAMPLING AT HAUSGARTEN

PELAGIC ZONE

- temperature
- salinity
- currents (speed, direction)
- particle flux (biogenic, lithogenic)

BENTHIC BOUNDARY LAYER

- oxygen concentrations
- nutrients
- bacterial densities
- near-bottom currents in high-resolution

SEDIMENT-WATER INTERFACE

- carbon remineralization (oxygen microelectrodes, sediment community oxygen consumption)

SEDIMENTS

- granulometry
- porosity
- organic carbon
- carbonates
- opal
- C/N ratios
- biomarker (e.g., alkenone, n-alkanes)
- organic matter input (phytodetrital pigments)

BENTHIC ORGANISMS

- bacteria (activities, densities, biomasses)
- meiofauna
- macrofauna
- megafauna, including demersal fish (densities, biomass, dispersion, biodiversity)

THE SEDIMENT-WATER INTERFACE is characterized by drastic changes in solute and particle concentrations, and the current regime at the seafloor. Along such gradients, nutrients (e.g., nitrate and silicate) as well as other trace elements liberated by the remineralization of organic matter are released from the sediments into the bottom water. Oxygen, which is respired within the sediments primarily by aerobic remineralization processes, is supplied by the bottom water via diffusion through the sediment-water interface. As subject to bottom currents, suspended matter (including particulate organic material, representing the basic food source for benthic organisms) is transported along or accumulated at the sediment surface. Whereas many research activities focused either on the investigation of the sediment or the water column, the work at HAUSGARTEN aims to develop an integrated understanding of the entire transition zone of the sediment-water interface, which includes all important parameters and exchange processes.

Most of the organic carbon arriving at the deep seafloor is remineralized beneath the sediment-water interface, consuming dissolved oxygen as a primary electron acceptor. Therefore, measurements of pore-water oxygen profiles provide a suitable tool for the determination of C_{org} fluxes through the sediment-water interface and of C_{org} remineralization rates. In order to avoid sampling and pressure artifacts during core retrieval it is, however, highly desirable to measure these O_2 micro-profiles *in situ* (Glud et al., 1994; Sauter et al., 2001), for example, by means of a deep-sea micro-profiler mounted into a free-falling device or, as shown in Figure 2e, by means of an autonomous system handled by a ROV.

Although the particular sensitivity of the polar regions to climate change has been recognized for many years, only few flux studies exist for polar deep-sea sediments (e.g., Schlüter et al., 2000). For example, the global estimate of sedimentary C_{org} fluxes by Jahnke (1996) is limited to below 60° latitude. For the central Fram Strait at 79°N, Sauter et al. (2001) measured flux rates from *in situ* pore water oxygen profiles to be 1.62 mg C m^{-2} d^{-1} at water depths of 1950 m. This particular station was obviously influenced by ice-edge-induced primary production and subsequently higher input of organic matter to the seafloor. At the central HAUSGARTEN site (2500 m water depth), in a generally ice-free area, we calculated flux rates to be significantly lower (0.52 mg C m^{-2} d^{-1}) (E.J. Sauter, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, unpublished data).

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BENTHIC INVESTIGATIONS AT HAUSGARTEN comprise biochemical analyses to estimate the input of organic matter from phytodetritus sedimentation and activities and biomasses of the small sediment-inhabiting biota as well as assessments of distribution patterns of benthic organisms (covering all size classes from bacteria to megafauna) and their temporal development.

Plant pigments represent a good indicator for the input of phytodetritus to the seafloor, and they can rapidly and reliably be analyzed with a standard fluorometer (Shuman and Lorenzen, 1975). Bacterial exo-enzymatic activity is estimated using model substrates (like fluorescein-di-acetate, FDA) in *ex situ* incubation experiments (Köster et al., 1991). Bulk parameters like sediment-bound phospholipids (indicative of cellular membranes) provide biomass estimates for benthic microorganisms comprising bacteria, yeasts, fungi, protozoa, and metazoan meiofauna (Findlay et al., 1989).

Analyzing various biogenic sediment compounds (BSC) along a latitudinal transect from HAUSGARTEN into ice-covered regions to the north, we found that phytodetritus from primary organic matter produced in ice-free areas in the south and transported within the WSC as well as the reaction of the small-scaled benthic biota to this lateral input of organic matter could be traced, at least, up to 120 nm into permanent ice-covered regions (Soltwedel et al., 2000; Schewe and Soltwedel, 2003). At HAUSGAR-

TEN, repeated analyses of BSC revealed interesting trends in the long-term view (see below).

Benthic bacteria are probably the most important organisms in deep-sea sediments, representing up to 90 percent of the total benthic biomass (Rowe et al., 1991; Tietjen, 1992; Pfannkuche, 1993). Sediment-inhabiting bacteria play a major role in the remineralization of organic matter at the seafloor. They are known for their ability to rapidly process nutritious components of any kind of incoming organic matter (Turley and Lochte, 1990; Lochte, 1992; Poremba, 1994), and thus might serve as good indicators for environmental changes. To analyze spatial and temporal patterns of bacterial community dynamics at HAUSGARTEN, we evaluate bacterial abundances, cell viability, and secondary production measured by the incorporation of radio-labeled (H^3) thymidine and (C^{14}) leucine. Applying a new staining technique (Live/Dead® Bacterial Viability Kit, BacLight™), Quéric et al. (2004) showed that, similar to the water-depth-dependent patterns of bacterial abundance, highest values for active bacteria could be found in sediments of the most shallow sampling stations, significantly decreasing with increasing water depth (Figure 3).

Like bacteria, meiobenthic organisms (size class: 32-1000 µm) are supposed to respond rapidly to environmental changes. Meiobenthic taxa are not only numerous, but also diverse and therefore ideal model organisms to study benthic ecosystem processes (Heip et al., 1985; Thistle, 2003). The impact of changes in food availability and other environmental variables on meiobenthic communities at HAUSGARTEN is studied along latitudinal and longitudinal transects.

Investigating the response of ice-edge induced particle flux along the 1000 m isobath in northerly direction from ice-free to ice-covered areas north of HAUSGARTEN, we found that within the foraminiferans, generic diversity was clearly reduced in the sector of highest phytodetritus deposition (Figure 4), indicating that strong pulses of phytodetritus deposition might act as disturbances to the benthic community (Schewe and Soltwedel, 2003).

Our investigations along the depth transect crossing Vestnesa Ridge down to the Molloy Hole (Figure 1b) focus on the two most abundant metazoan meiobenthic taxa in the Arctic deep sea, nematodes and copepods, which will be identified up to species level. Species diversity, trophic diversity, and size spectra of nematode communities (Wieser, 1960) and copepod ecotypes are analyzed. Biomass of the nematodes and copepods is estimated from size measurements of the animals according to Andrassy (1954) and Warwick and Gee (1984), respectively.

At the deepest HAUSGARTEN station (5500 m water depth), we unexpectedly found extremely high meiofauna abundances (2153 to 2968 ind. /10 cm^3), compared to other abyssal and hadal regions

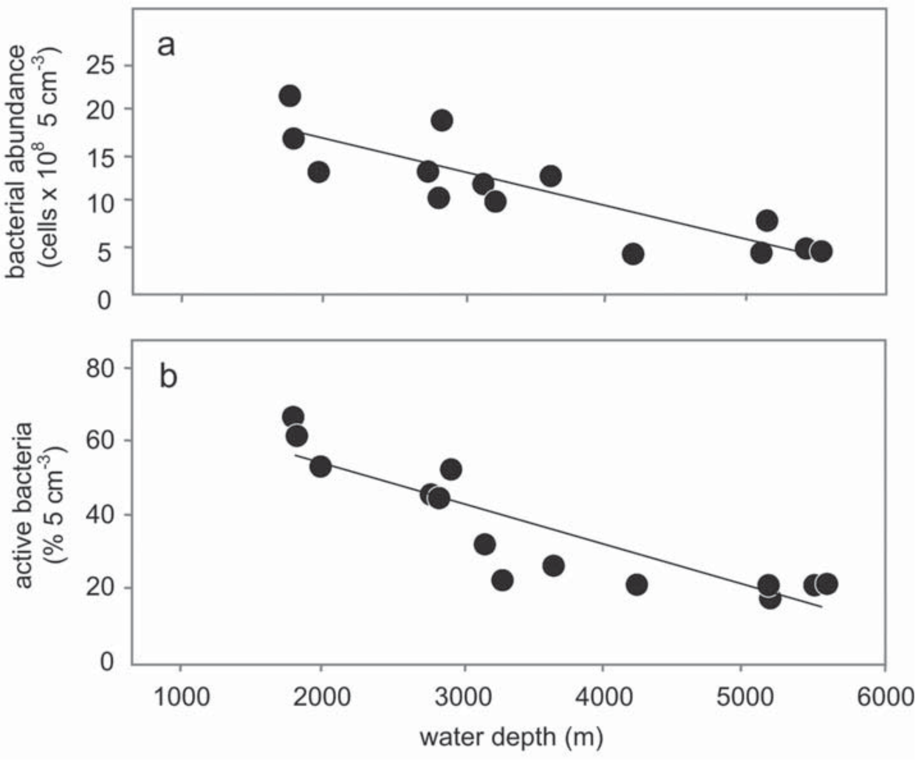

Figure 3. Bacterial abundance (a) and viability (b) in surface sediments along the HAUSGARTEN depth transect showed decreasing values with increasing water depth (modified from Quéric et al., 2004).

of the world ocean (Soltwedel et al., 2003). The analysis of biogenic sediment compounds (e.g., chloroplastic pigments, particulate proteins) confirmed comparably high amounts of organic matter in the sediments, presumably favoring increased faunal densities and biomasses. Obviously, the Molloy Hole acts like a huge natural sediment trap, accumulating organic matter at the bottom of the deep, and consequently allowing a comparably rich benthic community with surprisingly high meiofauna numbers. In comparison to other/shallower oceanic regions, the nematode community of the Molloy Hole consisted of relatively small specimens, which could not be explained by reduced food availability at the seafloor (Soltwedel et al., 2003).

Macrobenthos studies at HAUSGARTEN also focus on the patterns of standing stock, composition, and diversity. Organisms were identified to the lowest possible taxonomic level and become weighed for biomass estimations. Wlodarska-Kowalczuk et al. (2004) demonstrated a relatively low diversity of the macrobenthos at HAUSGARTEN compared to temperate seas, which is most probably related to the relative immaturity of Arctic fauna and the geographical isolation of the Greenland-Icelandic-Norwegian Seas from the Atlantic pool of species. Macrobenthos biomass, however, is comparable to values reported for the same depth ranges in lower latitudes. We found no depth-related pattern in diversity measures (Hurlbert rarefraction, Shannon-Wiener, and Pielou eveness index) along the HAUSGARTEN depth transect; the classic increase of species richness and diversity with depth could not be confirmed by our investigations.

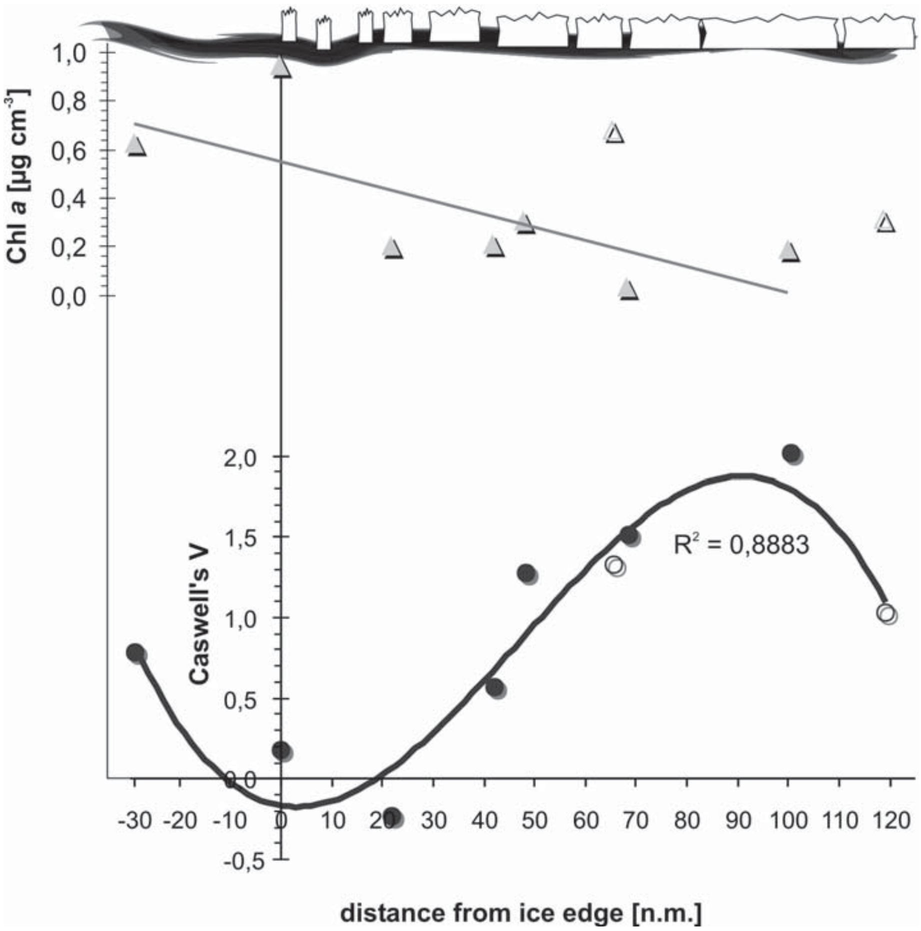

Figure 4. Varying amounts of organic matter in surface sediments (chloroplastic pigments [chlorophyll *a*, Chl *a*] indicating phytodetritus sedimentation) significantly affects foraminiferal diversity (Caswell's V) along a latitudinal transect from ice-free to permanently ice-covered regions (from Schewe and Soltwedel, 2003).

At the central HAUSGARTEN site (2500 m water depth), attempts were made to analyze critical scales of inner heterogeneity in macrobenthic communities. Although the material is still under evaluation, preliminary results reveal the presence of a single community with some inner patches, each of several kilometers in size (N. Budaeva, P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, unpublished data).

Megabenthos is defined as benthic organisms large enough to be recognized and characterized by means of optical seafloor imaging. Since 1999, large-scale distribution patterns of megafaunal assemblages at HAUSGARTEN have been observed by towed photo/video systems and by means of a ROV. Sporadic sampling of megafauna for taxonomic identification and evaluations of the photo and video footage has been carried out using Agassiz trawls, epibenthic sleds, and occasionally also the slurp gun of a ROV. Image analyses revealed a distinct faunal zonation along the depth transect and a transition zone in community composition at about 3350 m (Jaeckisch, 2004). This depth seems to be the lower boundary for specific species, for example, the pyconogonid *Colossendeis proboscidea*, the holothurian *Irpa abyssicola*, and the crinoid *Bathycrinus* sp. Repeated optical observations in distinct regions will help to trace predicted shifts in community composition due to environmental changes.

> The entire system is likely to be severely affected by changing ice and water conditions, varying primary production and food availability to faunal communities, an increase in contaminants, and possibly increased UV irradiance.

Image material also revealed a considerable degree of habitat diversity in the HAUSGARTEN area. The sediment-water interface is shaped by a variety of abiotic and biogenic structures that affect the colonization and biodiversity by megafauna, and probably also smaller sediment-inhabiting organisms. Regularly occurring dropstones have been found to host a specific hard substrate community at high latitudes (Dickmann et al., submitted).

Demersal fish constitute an important fraction of the benthic megafauna present at HAUSGARTEN. Despite their abundance, little is known about their biology and functional ecological role. Stomach contents analysis and tissue samples taken for stable radio isotope analysis not only allow us to study the fishes' feeding behavior and trophic level, but also to determine their functional ecological role. Such analyses ultimately enable us to assess the predation pressure exerted on other benthic biota and to determine how demersal fish structure the benthic assemblages. Together with stable isotope analyses of tissue samples from megafaunal organisms, this may also allow us to reconstruct benthic food webs at HAUSGARTEN. Preliminary results from stable isotope analysis indicate a range in the mean δ^{15}N of 15.78‰ at the shallowest stations (1000-1500 m), and of 24.56‰ at the central HAUSGARTEN site (2500 m). Assuming a stepwise enrichment of 3.8‰ per trophic level (Hobson and Welch, 1992), the megafaunal food web at shallow and mid-water depths thus consists of four and six trophic levels, respectively (M. Bergmann, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, unpublished data).

IN SITU EXPERIMENTS to determine experimentally the factors controlling biodiversity in the deep sea were carried out since the establishment of HAUSGARTEN observatory in 1999. Cages were placed on the sediment to study the development of infaunal communities not affected by disturbances introduced by larger benthic organisms, for

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example, the disruption of the sediment structure and predation (Figure 5). Various artificial substrates (pieces of wood, plates of stone and Perspex™), trays containing sediments enriched with organic matter varying in quantity and quality, and artificial large food-falls (outsized pieces of organic matter sunken to the seafloor, for example, dead fish or marine mammals) were placed at the bottom to investigate the succession in colonization of empty spaces in an environment short in hard substrates on which to settle and to investigate the attraction of infrequently supplied organic matter to the benthic community. Mimics were deployed to study effects of small biogenic structures on sediment-inhabiting microorganisms. The use of a ROV (Figure 2b) is clearly a prerequisite for such experimental work at the deep seafloor.

Most of the experiments are currently under evaluation, however, the large food-fall experiments already revealed some interesting results. In an innovative approach, Premke et al. (2003) used a scanning sonar system (SSS) for the long-range detection of scavenging amphipods (mainly *Eurythenes gryllus*), approaching in response to artificial food-falls lowered to the deep seafloor by means of a free-falling device. The SSS allows the detection of single objects larger than 2 cm at a maximum distance of 50 m in a horizontal plane. Our experiments revealed that chemoreception

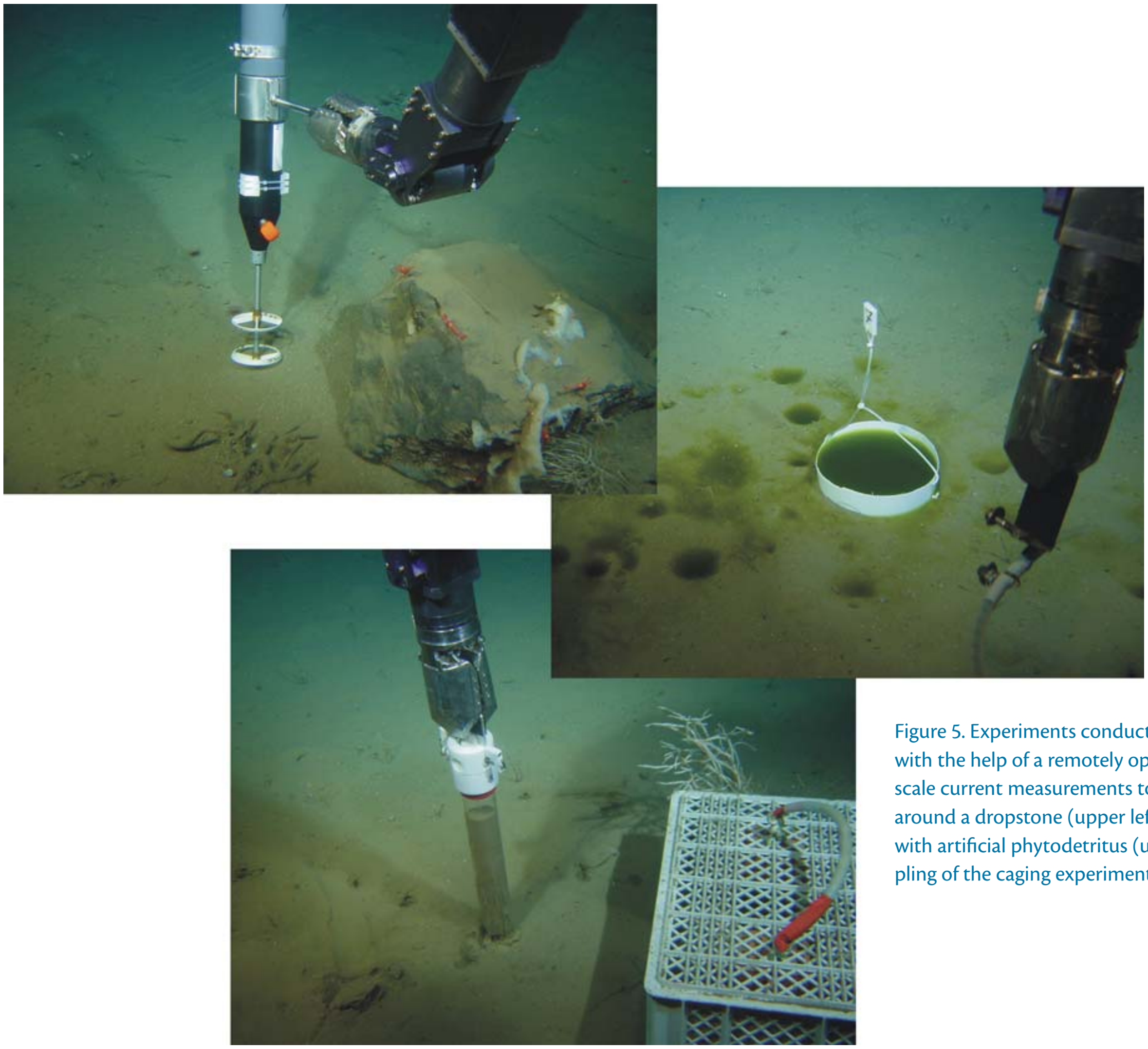

Figure 5. Experiments conducted at HAUSGARTEN with the help of a remotely operated vehicle: small-scale current measurements to assess the flow field around a dropstone (upper left), feeding experiments with artificial phytodetritus (upper right), and sampling of the caging experiment (bottom).

must be the main sense used to locate the carcass. The fast arrival (within minutes) and the rapid bait consumption observed at HAUSGARTEN imply a feeding strategy of *Eurythenes gryllus* where high-energy expenditures for locomotion are outweighed by the ingestion of large amounts of carrion (Figure 6).

SIX YEARS OF INVESTIGATIONS AT HAUSGARTEN are certainly too short to produce a sound database to evaluate ecosystem shifts in relation to environmental changes. Nevertheless, our data exhibit some interesting trends. At the moment, we do not know whether these trends indicate lasting alterations of the system or simply reflect natural variability on multi-year time-scales, for example, in relation to variations in the Arctic Oscillation. Water temperatures in Fram Strait significantly increased over the last few years (Schauer et al., 2004). Between the summers of 2003 and 2004, a large tem-

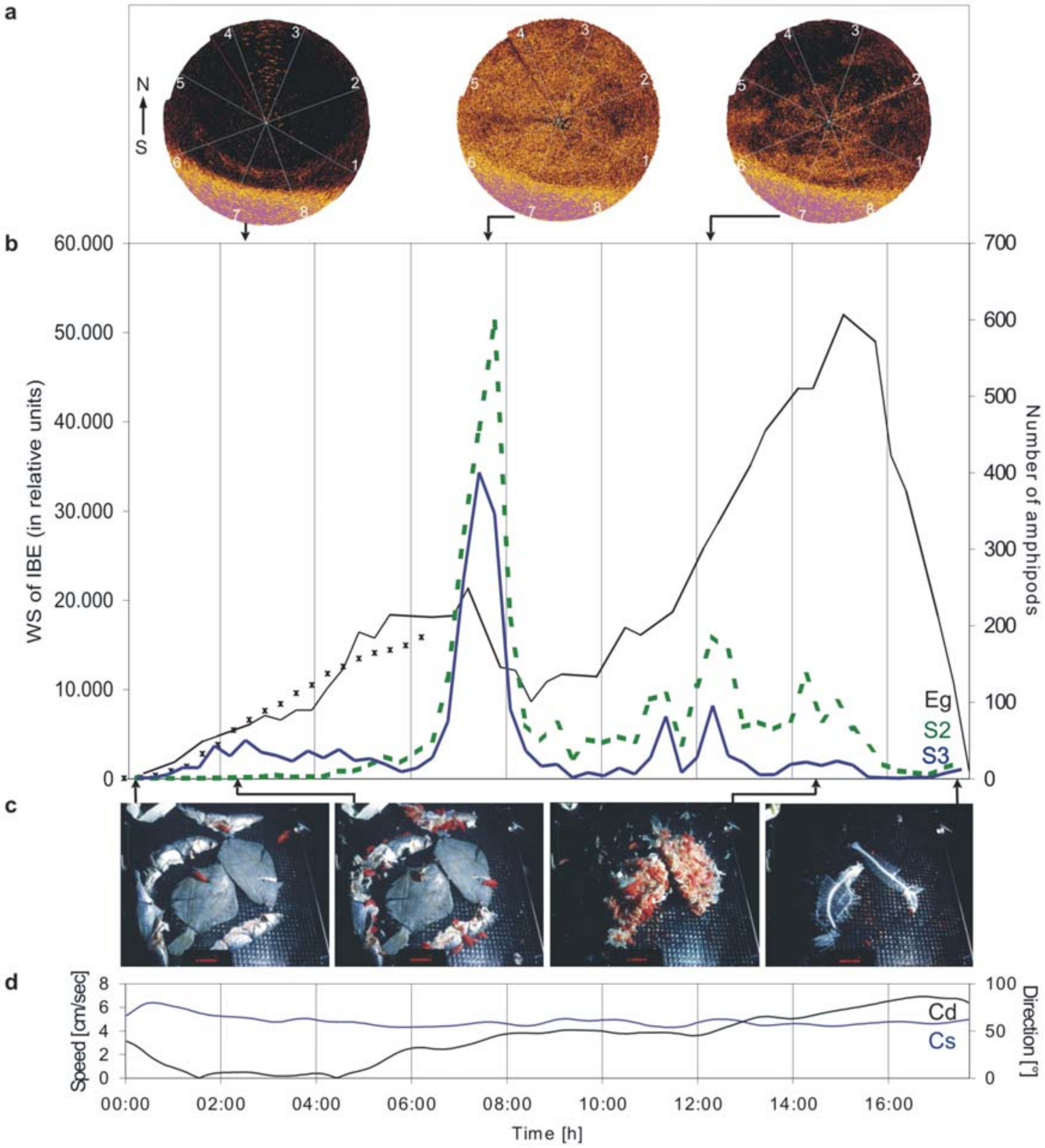

Figure 6. Results from a food-fall experiment at HAUSGARTEN: temporal patterns of amphipod arrival. (a) Sonar data plotted in polar projection at different time intervals; (b) Spatio-temporal patterns of the weighted sum (WS) of the integrated backscatter energy (IBS) in sectors 2 (S2) and 3 (S3) together with the number of amphipods (Eg = *Eurythenes gryllus*) vs. bottom time; (c) Time-lapse photograph sequence of bait deployment at different time intervals; (d) Current speed and direction vs. bottom time at 2 m above the seafloor (from Premke et al., 2003).

perature increase of 0.6°C was observed within the upper 500-1000 m of the water column (A. Beszczynska-Möller, and A. Wisotzki, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, unpublished data). Our own temperature records covering the years 2001 through 2004 exhibited not only small seasonal variations, but also an overall slight temperature increase even at 2500 m water depth at the central HAUSGARTEN station (Figure 7). Analyses of various biogenic sediment compounds between the summers of 2000 and 2004 revealed a generally decreasing flux of phytodetrital matter to the seafloor, and subsequently, a decreasing trend in sediment-bound organic matter and total microbial biomass (estimated from phospholipids measurements) in the sediments (Figure 8). An ongoing trend in decreasing organic matter input will certainly affect the entire deep-sea ecosystem.

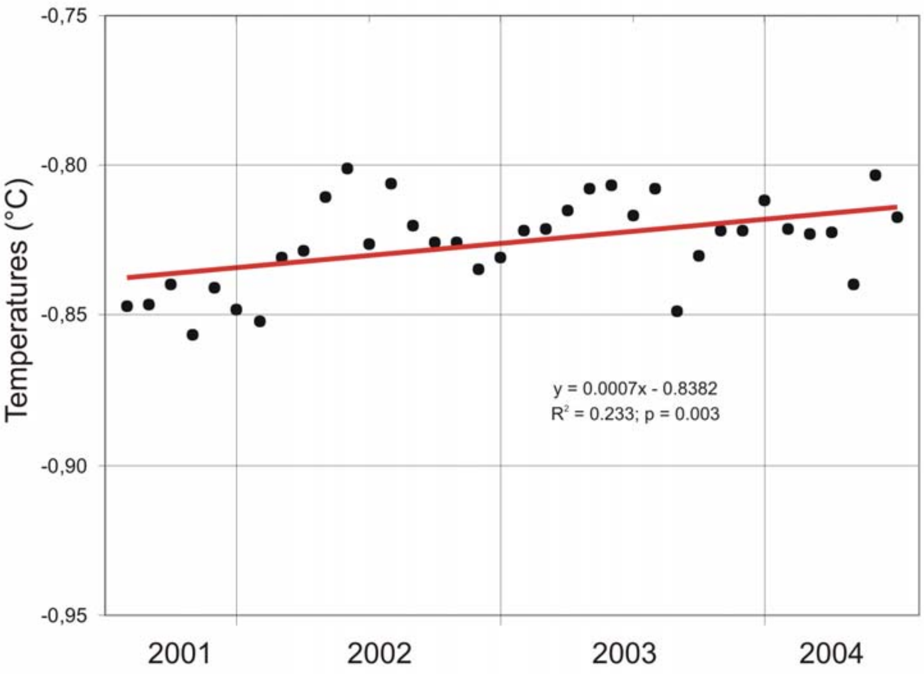

Figure 7. Recent water temperature increase in Fram Strait could also be traced at great depths; bottom temperatures at the central HAUSGARTEN station (2500 m) increased by 0.025°C between summers 2001 and 2004.

FUTURE PERSPECTIVES. There is an increasing awareness about the necessity of long-term records from the deep sea, and especially from the Arctic Ocean. A recent study of the US Polar Research Board calls for the design of an Arctic Observing Network (AON) aimed at the development of concepts for terrestrial, atmospheric, and marine observatories (more information is available at http://dels.nas.edu/prb/aon/). The European Seafloor Observatory Network (ESONET) initiative is a proposed sub-sea component of the European program GMES (Global Monitoring for Environment and Security) to provide strategic long-term monitoring capability in geophysics, geotechnics, chemistry, biochemistry, oceanography, biology, and fisheries (Priede et al., 2004) (more information is available at http://www.oceanlab.abdn.ac.uk/research/esonet.shtml). Within ESONET, HAUSGARTEN observatory is envisaged to become the northernmost node within a network of ten regional deep-sea observatories in contrasting oceanographic regions covering the entire European coastline from the Arctic into the Mediterranean and Black Seas. One aim of ESONET is to connect seafloor observatories via cable to land stations to enable unlimited transfer of energy to the various subsystems and also to allow online data retrieval from a deep-sea observatory in the High Arctic in the near future.

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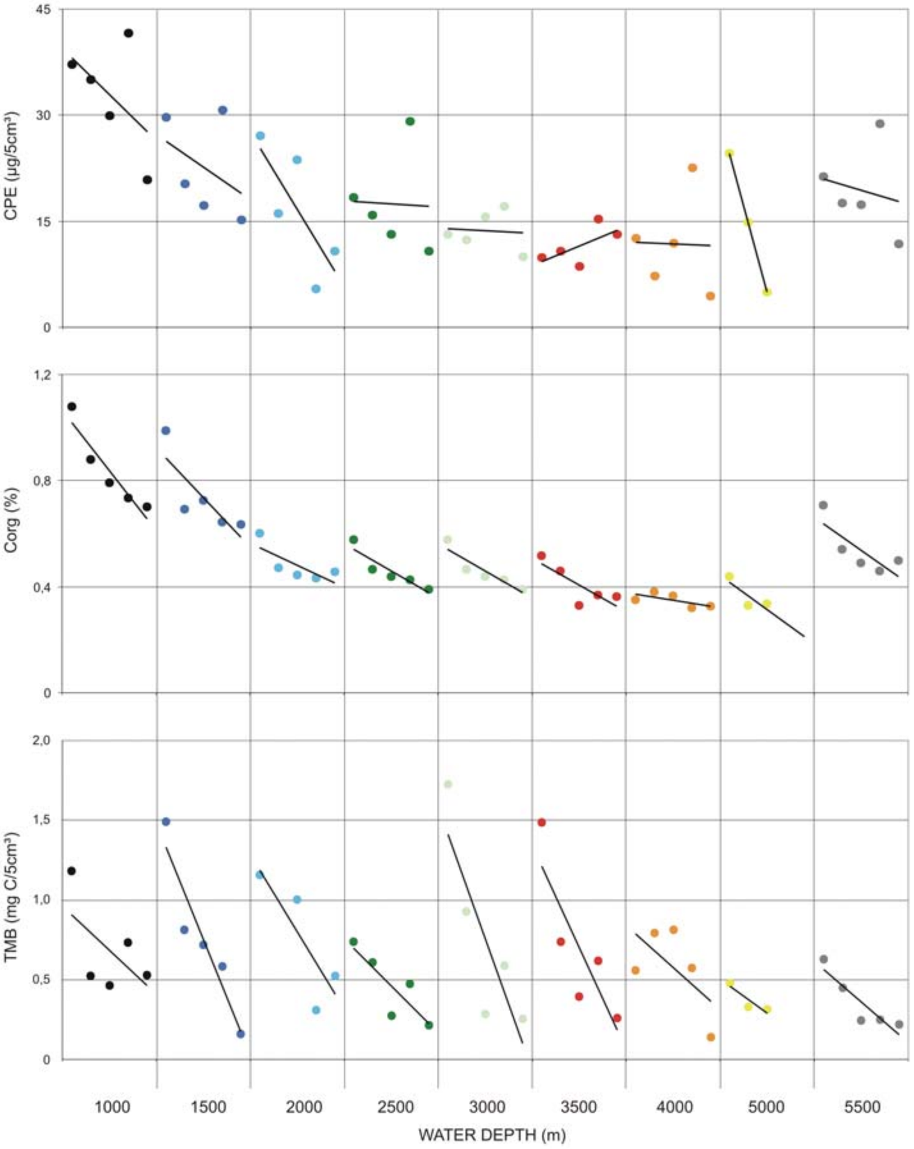

Figure 8. The temporal development of concentrations in chloroplastic pigment equivalents, (CPE), organic carbon (C_{org}), and total microbial biomass (TMB) in sediments along the HAUSGARTEN depth transect between 2000 and 2004 showed generally decreasing values.

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