ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

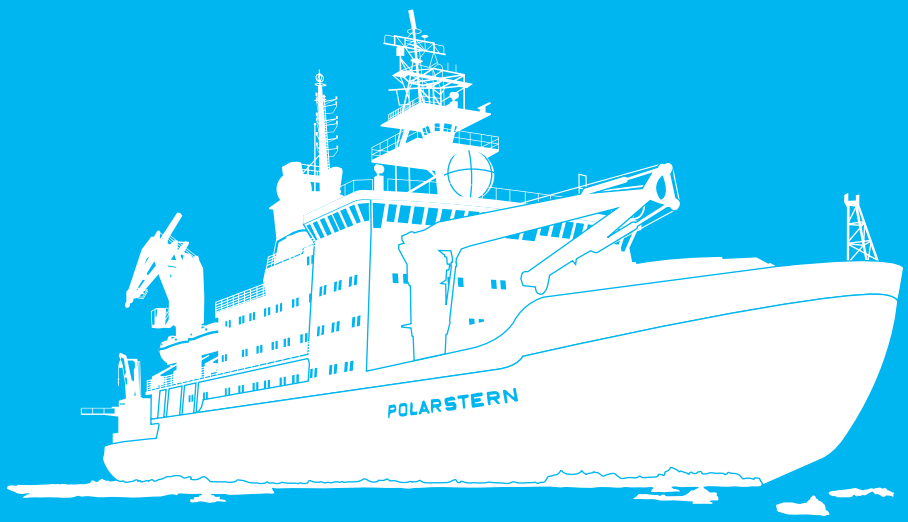
EXPEDITION PROGRAMME PS126

Polarstern

PS126
Bremerhaven - Bremerhaven
24 May 2021 – 28 June 2021

Coordinator: Ingo Schewe

Chief Scientist: Thomas Soltwedel



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Bremerhaven, April 2021

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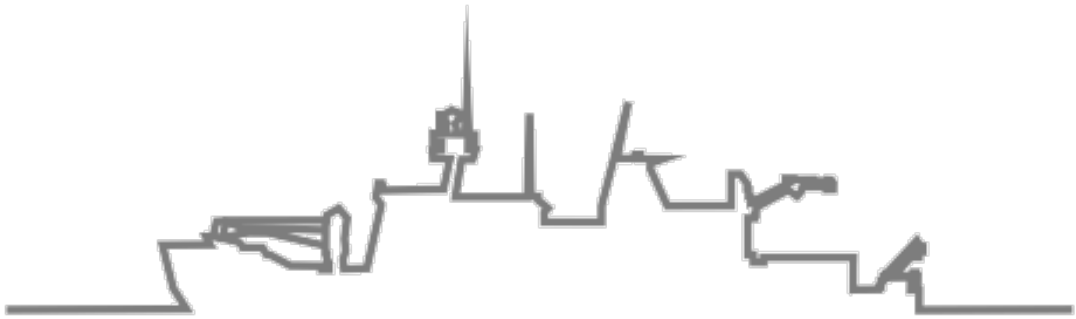

LTER HAUSGARTEN 2021

Long-Term Ecological Research at an Arctic marine Observatory

Chief scientist
Thomas Soltwedel

Coordinator
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CONTENTS

1. ÜBERBLICK UND FAHRTVERLAUF

Thomas Soltwedel[1] [1]DE.AWI

Die FS *Polarstern* Expedition PS126 wird am 24. Mai 2021 in Bremerhaven beginnen und in die Framstraße zwischen Grönland und Spitzbergen führen. Die 6,5-wöchige Expedition soll genutzt werden, um Beiträge zu verschiedenen nationalen und internationalen Forschungs- und Infrastrukturprojekten (FRAM, INTAROS, ICOS, SIOS, ARCHES) sowie dem Forschungsprogramm „Changing Earth - Sustaining our Future" („Erde im Wandel - Unsere Zukunft nachhaltig gestalten") des Alfred-Wegener-Instituts Helmholtz-Zentrum für Polar- und Meeresforschung (AWI) zu leisten. Im Topic 6 “Marine and Polar Life: Sustaining Biodiversity, Biotic Interactions and Biogeochemical Functions” (Subtopics 6.1 “Future ecosystem functionality” und 6.3 “The future biological carbon pump”) des neuen Forschungsprogramms werden die mit steigenden Wassertemperaturen und dem Rückgang des Meereises verbundenen Ökosystemverschiebungen im Pelagial und im tiefen Ozean ermittelt und quantifiziert und Rückkopplungsprozesse auf ozeanographische Prozesse untersucht. Die Untersuchungen beinhalten die Identifizierung räumlicher und zeitlicher Entwicklungen in der Funktion ausgewählter Plankton- und Benthos-Gemeinschaften sowie den Aufbau eines umfassenden Repositoriums für Beobachtungsdaten. Im Rahmen des Subtopics 6.4 „Use and misuse of the ocean: Consequences for marine ecosystems“ werden darüber hinaus der Eintrag von Plastikmüll in den Ozean, vertikale Plastikflüsse von der Meeresoberfläche zum Meeresboden und die Wechselwirkungen zwischen Plastik und marinen Organismen untersucht.

Die Arbeiten stellen einen weiteren Beitrag zur Sicherstellung der Langzeitbeobachtungen am LTER Observatorium HAUSGARTEN dar, in denen der Einfluss von Umweltveränderungen auf ein arktisches Tiefseeökosystem dokumentiert wird. Diese Arbeiten werden in enger Zusammenarbeit der HGF-MPG Brückengruppe für Tiefsee-Ökologie und -Technologie, der PEBCAO-Gruppe („Phytoplankton Ecology and Biogeochemistry in the Changing Arctic Ocean“) des AWI und der Helmholtz-Nachwuchsgruppe SEAPUMP („Seasonal and regional food web interactions with the biological pump“) durchgeführt.

Die Expedition soll darüber hinaus genutzt werden, um weitere Installationen im Rahmen der HGF Infrastrukturmaßnahme FRAM (Frontiers in Arctic marine Monitoring) vorzunehmen. Das FRAM Ocean Observing System wird kontinuierliche Untersuchungen von der Meeresoberfläche bis in die Tiefsee ermöglichen und zeitnah Daten zur Erdsystem-Dynamik sowie zu Klima- und Ökosystem-Veränderungen liefern. Daten des Observatoriums werden zu einem besseren Verständnis der Veränderungen in der Ozeanzirkulation, den Wassermasseneigenschaften und des Meereisrückgangs sowie deren Auswirkungen auf das arktische, marine Ökosystem beitragen. FRAM führt Sensoren in Observationsplattformen zusammen, die sowohl die Registrierung von Ozeanvariablen, als auch physiko-chemischer und biologischer Prozesse im Ozean erlauben. Experimentelle und ereignisgesteuerte Systeme ergänzen diese Beobachtungsplattformen. Produkte der Infrastruktur umfassen hochaufgelöste Langzeitdaten sowie Basisdaten für Modelle und die Fernerkundung.

Die technisch und logistisch sehr aufwendige Expedition PS126, während der neben einem autonomen unbemannten Fluggerät (Unmanned Aerial Vehicle, UAV) auch verschiedene autonome, in der Wassersäule (Autonomous Underwater Vehicle, AUV) und auf dem Tiefseeboden agierende Unterwasserfahrzeuge (Benthic Crawler) zum Einsatz kommen sollen, wird am 28. Juni 2021 in Bremerhaven enden.

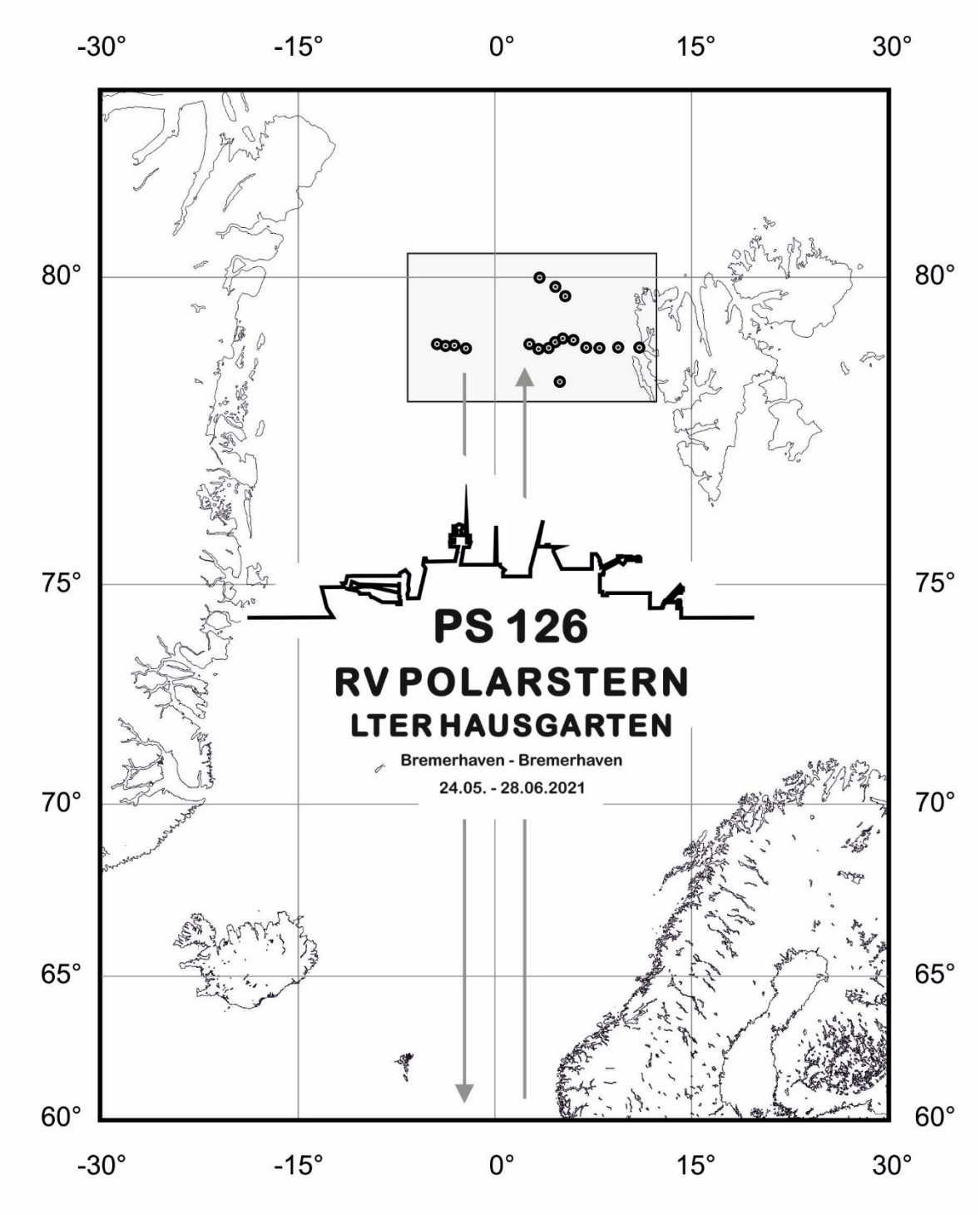

Abb. 1: Das Untersuchungsgebiet der Polarstern-Expedition PS126
Fig. 1: Study area of Polarstern expedition PS126

SUMMARY AND ITINERARY

The RV *Polarstern* expedition PS126 will start on 24 May 2021 in Bremerhaven and lead to the Fram Strait between Greenland and the Svalbard archipelago. The expedition will contribute to various large national and international research and infrastructure projects (FRAM, INTAROS, ICOS, SIOS, ARCHES) as well as to the new research programme „Changing Earth - Sustaining our Future" („Erde im Wandel - Unsere Zukunft nachhaltig gestalten") of the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI). In Topic 6 “Marine and Polar Life: Sustaining Biodiversity, Biotic Interactions and Biogeochemical Functions” (Subtopics 6.1 “Future ecosystem functionality” and 6.3 “The future biological carbon pump”) of the new research programme, ecosystem shifts in the pelagic and deep ocean associated with water temperature increase and sea ice retreat are identified and quantified, and feedback processes on oceanographic processes are investigated. These studies include the identification of spatial and temporal developments in the function of selected pelagic and benthic communities and the establishment of a comprehensive repository of observational data. In Subtopic 6.4 “Use and misuse of the ocean: Consequences for marine ecosystems”, the input of plastic waste into the ocean, the vertical fluxes of plastic from the sea surface to the seafloor and the interaction between plastic and marine biota are investigated.

The work projected will support the time-series studies at the LTER (Long-Term Ecological Research) observatory HAUSGARTEN, where we document Global Change induced environmental variations on a polar deep-water ecosystem. This work is carried out in close co-operation between the HGF-MPG Joint Research Group on Deep-Sea Ecology and Technology, the PEBCAO Group (“Phytoplankton Ecology and Biogeochemistry in the Changing Arctic Ocean”) at AWI and the Helmholtz Young Investigators Group SEAPUMP (“Seasonal and regional food web interactions with the biological pump”), representing a joint effort between the AWI, the MARUM - Center for Marine Environmental Sciences, and the University of Bremen.

The expedition will further be used to accomplish installations for the HGF infrastructure project FRAM (Frontiers in Arctic marine Monitoring). The FRAM Ocean Observing System aims at permanent presence at sea, from surface to depth, for the provision of near real-time data on Earth system dynamics, climate variability and ecosystem change. It serves national and international tasks towards a better understanding of the effects of change in ocean circulation, water mass properties and sea-ice retreat on Arctic marine ecosystems and their main functions and services. FRAM implements existing and next-generation sensors and observatory platforms, allowing synchronous observation of relevant ocean variables as well as the study of physical, chemical and biological processes in the ocean. Experimental and event-triggered platforms complement the observational platforms. Products of the infrastructure are continuous long-term data with appropriate resolution in space and time, as well as ground-truthing information for ocean models and remote sensing.

During the technically and logistically very challenging expedition we will, amongst others, use an Unmanned Aerial Vehicle (UAV) and different autonomous underwater vehicles, which will operate in the water column (Autonomous Underwater Vehicle, AUV) and on the deep seafloor (Benthic Crawler). The cruise will end on 28 June 2021 in Bremerhaven.

2. LTER HAUSGARTEN - IMPACT OF CLIMATE CHANGE ON ARCTIC MARINE ECOSYSTEMS

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Objectives and scientific programme

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 the Earth and its life. The past decades have seen remarkable changes in key arctic variables, including a decrease in sea-ice extent and sea-ice thickness, changes in temperature and salinity of arctic waters, and associated shifts in nutrient distributions. Since 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. 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.

Benthos, particularly in deep waters, is a robust ecological indicator for environmental changes, as it is relatively stationary and long-lived and reflects changes in environmental conditions in the oceans (e.g. organic flux to the seabed) at integrated scales (Gage and Tyler 1991; Piepenburg 2005). 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 Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI) established the deep-sea observatory HAUSGARTEN, which constitutes the first, and until now only open-ocean long-term observatory in a polar region (Soltwedel et al. 2016).

HAUSGARTEN is located in the eastern Fram Strait and includes 21 permanent sampling sites along a depth transect (250 - 5500 m) and along a latitudinal transect following the 2500 m isobath crossing the central HAUSGARTEN station (Fig. 2.1). 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. Regular sampling as well as the deployment of moorings and different stationary and mobile free-falling systems (Bottom-Lander, Benthic Crawler), which act as local observation platforms, have taken place since the observatory was established in 1999. Frequent visual observations with towed photo/video systems allow the assessment of large-scale epifauna distribution patterns as well as their temporal development.

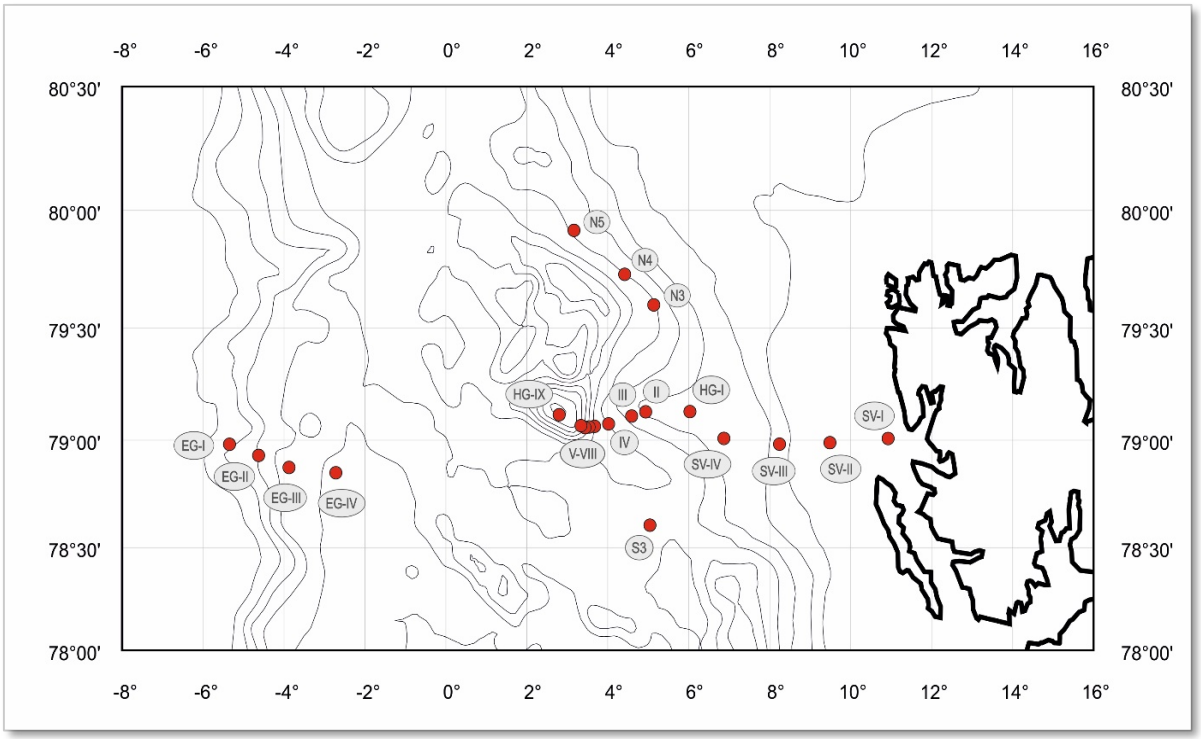

Fig. 2.1: Permanent sampling sites of the LTER Observatory HAUSGARTEN in Fram Strait

Geographical features in the HAUSGARTEN area provide a variety of contrasting marine landscapes and landscape elements (e.g. banks, troughs [marine valleys], ridges and moraines, canyons and pockmarks) that generally shape benthic communities over a variety of different scales (Buhl-Mortensen et al. 2010; 2012). The habitat-diversity (heterogeneity) hypothesis states that an increase in habitat heterogeneity leads to an increase in species diversity, abundance and biomass of all fauna groups (Whittaker et al. 2001; Tews et al. 2004). Improved technologies, particularly the recent deployment of acoustic and side-scan sonar systems at depth by AUV and towed camera sleds within the Deep-sea Research Group (Purser et al. 2019) has indicated the high-resolution topographical variability of many deep-sea areas, including HAUSGARTEN (Schulz et al. 2010; Taylor et al. 2016; Purser 2020). So far, the time-series stations maintained across the region do not capture the high degree of local heterogeneity (in terms of physical seafloor terrain variables such as slope, rugosity, aspect, depth). Therefore, during RV *Polarstern* expedition PS126, dedicated attempts to collect spatial data to capture the role of this heterogeneity in biodiversity and biomass estimation are planned to complement investigations on the temporal variability of benthos in the HAUSGARTEN area.

Work at sea - pelagic work

Measurements of the vertical flux of particulate matter at HAUSGARTEN have been conducted since the establishment of the observatory. By means of these measurements we are able to quantify the export of organic matter from the sea surface to the deep sea, and trace changes in these fluxes over time. The organic material which is produced in the upper water layers or introduced laterally from land is the main food source for deep-sea organisms. Measurements of organic matter fluxes are conducted by bottom-tethered moorings carrying sediment traps

at approx. 200 and 1,000 m below sea-surface, and about 200 m above the seafloor. In addition to moored sediment traps, autonomous infrastructure will be deployed on the HAUSGARTEN moorings to track seasonal changes in the dissolved and particulate constituents of the upper water column. These include remote access water samplers (RAS) that are programmed to collect and preserve water samples (~0.5 L). Besides sediment traps and RAS, the moorings are equipped with current meters, self-recording CTD's, and a suite of biogeochemical sensors. During the RV *Polarstern* expedition PS126, we will recover moorings and instruments that were deployed during the expedition PS121 in summer 2019.

At the central HAUSGARTEN site HG-IV and the station F4 (Fig. 2.1) we will recover and redeploy special moorings with profiling winch systems carrying a sensor package. These devices have been partly developed at AWI and conduct measurements within the upper 200 m of the water column at regular preprogrammed intervals (once a day). At present, the sensor package consists of instruments for measuring oxygen, conductivity, temperature, pressure, chlorophyll fluorescence and carbon dioxide or particles.

At all stations where moorings are deployed, we will conduct CTD/Rosette Water Sampler casts from the surface close to the seafloor. Water samples will be taken for the analyses of chlorophyll *a*, particulate organic carbon and nitrogen (POC/N), particulate phosphorous, biogenic particulate silica (bPSi), total particulate matter (seston), calcium carbonate ($CaCO_3$), and the stable isotopes content ($\delta^{15}N/\delta^{13}C$) in the particulate matter. This work as well as the sampling and sensing at the other HAUSGARTEN stations will be conducted in close cooperation with the PEBCAO Group (Plankton Ecology and Biogeochemistry in a Changing Arctic Ocean) at AWI (see Chapter 3).

Work at sea - benthic work

The current cruise will complete the dataset over a 20-years time span and will serve to detect long-term changes of benthic communities. The composition, diversity, density and biomass of benthic communities will be analysed together with environmental data to detect changes due to environmental regime shifts in the deep sea of the Fram Strait. Within a complementary sampling design covering all size classes of benthic communities from meio- to megafauna. In addition, we want to encounter the habitat-diversity (heterogeneity) hypothesis on local scales, combining terrain parameters and sedimentary parameters with meio-, macro-, and megafaunal distribution patterns and diversity indices across deeper parts of the Kongsfjord canyon off NW Svalbard.

Long-term meiobenthic study

Virtually undisturbed sediment samples retrieved by a video-guided multiple corer (MUC) will be analysed for the quantitative and qualitative assessment of the small benthic biota (size range: bacteria to meiofauna). As part of doctoral dissertation, horizontal and vertical meiofauna distribution patterns will be examined with special focus on the density and diversity of nematode communities, thereby continuing a unique time-series started in the year 2,000.

Sediments retrieved by the MUC will further be analysed for various biogenic compounds to estimate the input of organic matter to the seafloor, benthic activities (e.g. bacterial exoenzymatic activity) and the total biomass of the smallest sediment-inhabiting organisms. Results will help to describe ecosystem changes in the benthos of the Arctic Ocean. In addition, these samples will serve as background information for various biological experiments investigating the causes and effects of gradients on biodiversity patterns and community composition of benthic organisms to be installed at the central HAUSGARTEN station during future expeditions.

Long-term macrobenthic study

Macrobenthos in the HAUSGARTEN area has only sporadically been analysed over the past 20 years, thereby focusing on depth gradients (Weslawski et al. 2003; Wlodarska-Kowalczuk et al. 2004; Käß et al. 2019), horizontal distribution patterns (Budaeva et al. 2008), latitudinal gradients (Vedenin et al. 2016), and the temporal variability between 2003 and 2007 (Vedenin et al. 2019). Macrofauna sampling during RV *Polarstern* expedition PS126 will continue the time-series work to allow the assessment of long-term changes in this size category of benthic organisms at HAUSGARTEN.

Samples will be obtained using a 0.25 m² USNEL giant box corer (GBC). Particularly for deep-sea samples the box corer is a preferred sampling gear, as it provides reliably deep and relatively undisturbed sediment samples (Gage and Bett 2005). Box-corer samples will be divided into subsamples and sieved over 500 µm sieves. The macrofauna in the sieve residues will be preserved for later taxonomic analysis in the laboratory.

Long-term megabenthic study

The Ocean Floor Observation System (OFOS) will be deployed along previously established and analysed camera tracks to assess interannual dynamics of megafauna on the seafloor at selected stations (HG-I, HG-IV, N3, S3; Fig. 2.1). The system will be towed at 1.5 m altitude for 4-hours. A subset of images will be analysed and compared with previous data to assess interannual dynamics of megafaunal assemblages. The imagery will also be used to quantify litter on the seafloor (see Chapter 9: Fram Pollution Observatory).

During RV *Polarstern* expedition PS126 traditionally imaged OFOS tracks will be revisited, with the Ocean Floor Observation and Bathymetric System (OFOBS) deployed to augment the still and video image time-series data with concurrently collected multibeam sidescan mapping data. This spatial data will continue to develop the high resolution seafloor topographical maps of the HAUSGARTEN being compiled during the FRAM project. Also during PS126, the AUV 'PAUL 3,000' will be deployed to map extended areas of HAUSGARTEN seafloor using the new benthic payload module (hosting high resolution stills camera and sidescan sonar systems).

Small-scale heterogeneity and biodiversity

The RV *Polarstern* expedition PS126 will further be used to study small-scale spatial heterogeneity and potential shifts in benthic diversity across a deep-sea canyon system north-east of HAUSGARTEN station HG-II (Fig. 2.1) in a multidisciplinary approach. The Ocean Floor Observation and Bathymetric System (OFOBS) and an Autonomous Underwater Vehicle (AUV) will deliver high-resolution topographical variability and biodiversity data of megafauna across the canyon, which will be combined with classical point sampling (MUC, GBC) to cover sediment parameters, as well as biodiversity data on meiobenthos and macrobenthos. Multibeam data (retrieved by OFOBS) will deliver terrain parameters such as bathymetry, backscatter, slope, aspect, rugosity, curvature, and the bathymetric position index. Megafauna density and composition will be determined by image analysis (OFOBS), meiofauna by a TV-guided MUC, and macrofauna by the 0.25 m² USNEL box corer (GBC).

Larval ecology in the high Arctic

Benthic invertebrates are extremely important in the polar regions. They dominate seafloor communities in both abundance and biomass. Still, very little is known about how these organisms reproduce. Foundational research in the early 20th century in Greenland suggested

that polar invertebrates had non-pelagic development, meaning they either brood or have demersal, lecithotrophic larvae. These strategies were considered adaptive in a food-poor environment and became entrenched under the name “Thorson’s Rule” (Thorson 1950). More recent research in Antarctica has revealed that while a large number of species reproduce via lecithotrophic larvae, the most abundant species reproduce via planktotrophic larvae (Poulin et al. 2002). We aim to characterize the developmental modes of Arctic deep-sea larvae in order to test Thorson’s Rule.

The deep sea is a food-poor environment, so we expect larvae to be primarily lecithotrophic. Larval traps previously deployed in the Fram Strait in 2017 – 2019 collected low abundances of larvae in the water column, which suggests that Arctic larvae may be demersal. Our objectives for this project include collecting larvae from benthic habitats in the Fram Strait, determining if these larvae are planktotrophic or lecithotrophic based on morphology and biochemical analysis, and matching larvae to adults using genetic analysis and describing the larval forms of Arctic species whose larvae have never been observed

Our most important goal during PS126 is to collect larvae. Sampling will primarily be conducted using a free-fall lander with an attached plankton pump (McLane WTS-LV). Two landers will be used for a total of eight deployments at stations S3, HG-IV, N3, and N5 (~2500 m), plus shallower rocky reef environments (~1800 m) in a parallel transect. Sampling stations are shown in Fig. 2.2 and Table 2.1.

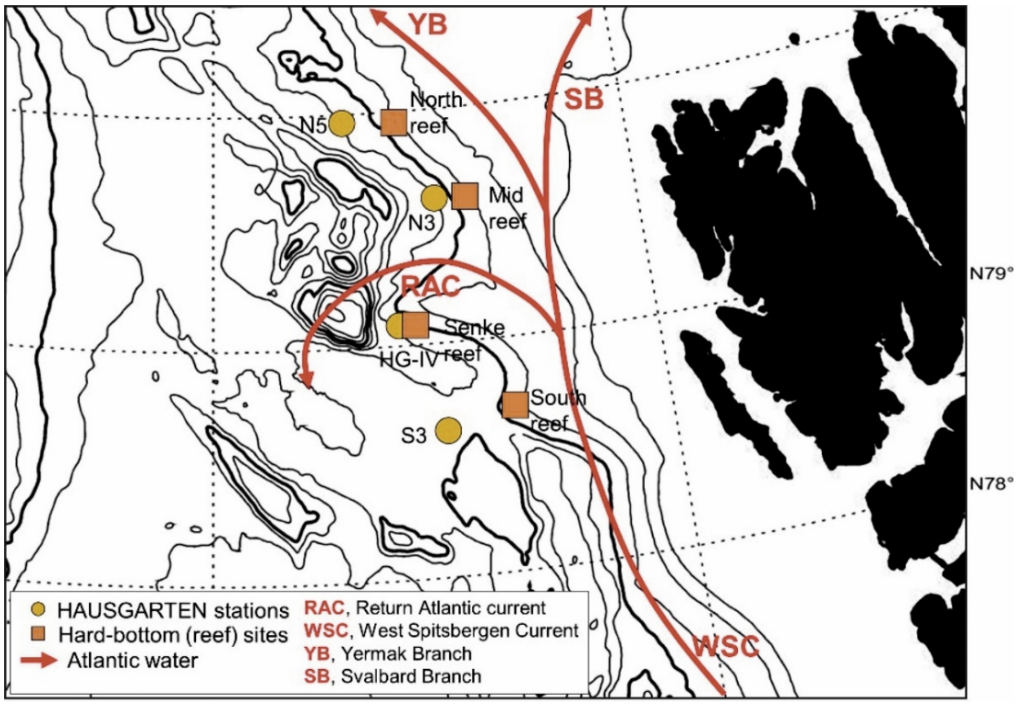

Fig. 2.2: Lander deployment sites in the eastern Fram Strait

Each lander deployment will include 24 hours on the seafloor, during which time the plankton pumps will each filter 30 L seawater per minute. Larvae and other benthic zooplankton will be collected on filters, which will be removed and analysed in the laboratory on board RV *Polarstern*. Larvae will be sorted by hand using dissecting microscopes and individually preserved in small vials using 95 % ethanol. Preservation in ethanol enables genetic analysis,

which will be undertaken in the laboratory at WHOI following the cruise. If a large number of individuals of one morphotype is collected, a sub-set of larvae may be frozen for biochemical analysis at WHOI or used in feeding experiments and then frozen.

As the cruise plan permits, we would also like to use a multi-net midi to collect larvae from the water column. Larvae could be sorted live from multi-net tows conducted by the zooplankton group (if permitted), or additional tows could be conducted at stations S3, HG-IV, N3, and N5. A couple short moorings may be deployed with sediment traps to collect settling larvae.

Tab. 2.1: Planned stations for plankton pump lander deployment

Station	Approx. Lat.	Approx. Long.	Depth (m)	Notes
S3	78.607	5.063	2500	
HG-IV	79.068	4.160	2500	
N3	79.598	5.196	2500	
N5	79.943	3.120	2500	
South reef	78.617	6.802	1800	New station
Senke reef	79.102	4.533	1800	Sampled with ROV in 2019
Mid reef	79.669	5.562	1800	New station
North reef (N4½)	79.943	4.374	1800	Sampled with ROV in 2019

The sampling undertaken during PS126 is to our knowledge the first time that zooplankton will be collected using a high-volume pump from a benthic habitat in the Arctic. This sampling may reveal novel specimens, including larval forms of species whose pelagic stages have not previously been observed. It would be a very exciting result to match the larvae we collect to adults that are common in the Fram Strait benthic environment and describe the larval forms of some Arctic deep-sea species.

We anticipate that the majority of larvae we collect will be large and yolky, indicating they are lecithotrophic. Biochemical analysis may reveal that the carbon and nitrogen isotope ratios of these specimens match their parents. If this is the case, we can conclude that the larvae have been provisioned with organic matter by their parents and are indeed lecithotrophic.

Sample and data management

Sample processing will be carried out at AWI. Data acquisition from the several types of investigation will be differently time-consuming. The time periods from post processing to data provision will vary from one year maximum for sensor data, to several years for organism related datasets. Until then preliminary data will be available to the cruise participants and external users after request to the senior scientist. We plan that the full data set will be available at latest about two years after the cruise. Samples taken for faunal analyses, which cannot be analysed within two years after the cruise, will be stored at the AWI for at least ten years and available upon request to other scientists. Data will be made available to the public via PANGAEA (https://pangaea.de) in accordance with current institute data policies. Macrobenthic data will be deposited as well in the CRITTERBASE ecological information system at AWI. Imagery will also be uploaded to PANGAEA as well as to the online image annotation portal BIIGLE.

Larval specimens will be returned to Woods Hole Oceanographic Institution following the expedition and used for genetic and biochemical analyses. Benthic (non-larval) zooplankton

from the pumps will be made available to the zooplankton group on board for preservation, if they desire. Data on the abundances and morphotypes of larvae collected during each of our pump deployments will be made available through the PANGAEA data repository within two years of the expedition.

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3. PEBCAO - PLANKTON ECOLOGY AND BIOGEO-CHEMISTRY IN A CHANGING ARCTIC OCEAN

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Objectives

The Arctic Ocean has gained increasing attention in recent decades due to the drastic decrease in sea ice and increase in temperature, which is approximately twice as fast as the global average. It is also expected that the chemical equilibrium and the elemental cycling in the surface ocean changes due to ocean acidification. The effects of such changes on the polar plankton ecology and biogeochemical processes (PEBCAO) can only be detected through long-term observations.

The PEBCAO group began its studies on plankton ecology in the Fram Strait (~79°N) in 1991 and intensified its efforts in 2009. Since then, we have combined classical bulk measurements of biogeochemical parameters, microscopy, optical methods, satellite observations, and molecular genetic approaches in a holistic approach. By doing so, we have compiled comprehensive information on annual variability in plankton composition, primary production, bacterial activity and zooplankton composition.

Our long-term observations so far, have already revealed important patterns and changes in diversity. For instance our results clearly indicate that chlorophyll-a (chl-a) values increase in summer in the eastern but not in the western Fram Strait (Nöthig et al. 2015; 2020). This is in accordance to the increasing contributions of *Phaeocystis pouchetii* and nanoflagellates to the summer phytoplankton community. The concentration of dissolved organic carbon (DOC) was relatively stable over the last two decades, but we observed a slight decrease in the particulate organic carbon (POC) during the summer months (Engel et al. 2019). This could suggest that the phytoplankton composition affected the POC. We also observed that *Themisto compressa*, an invading amphipod species, increased in abundance (Kraft et al. 2013, Schröter et al. 2019). All this suggests that the ecosystem in Fram Strait is subject to profound changes, likely induced by climate conditions, which warrants further, sustained observation.

As of 2014, the PEBCAO group is also a member of the FRAM (Frontiers in Arctic marine Monitoring) Ocean Observing System team and provides baseline information for water column monitoring of plankton ecology, biogeochemical parameters, and microbial (prokaryotic and eukaryotic) biodiversity. We are also involved in the development of automatic platforms and sampling technology for long-term observation in the Arctic Ocean with a main focus on the LTER observatory HAUSGARTEN.

The overarching objectives of PEBCAO are to improve the mechanistic understanding of biogeochemical and microbiological feedback processes in the Arctic Ocean, to document ongoing and long-term changes in the biotic and abiotic environment and to assess the potential future consequences of these changes. In particular we aim to identify climate-induced changes in the biodiversity of pelagic ecosystems and, concomitantly, in carbon cycling and sequestering. The PEBCAO objectives are addressed using a range of methodologies.

Primary production is expected to increase in the changing Arctic Ocean, however, it is currently unclear if this will lead to increased export of particulate organic carbon or if dissolved primary production will remain at the surface, fuelling heterotrophic bacteria. Heterotrophic bacteria play a vital role in global biogeochemical cycles. To fully assess bacterial activity, we will measure bacterial production and use three techniques (including Winkler titration, optodes, and ETSvitro) to measure bacterial respiration in the Fram Strait. By linking compound dynamics with rate measurements and community structure, we will gain further insights into the flow of carbon through the Arctic food web. To address the effects of global change on microbial biogeochemistry in the Arctic Ocean, we will also continue to monitor concentrations of organic carbon, nitrogen, and phosphorus, as well as specific compounds like amino acids, carbohydrates, and gel particles. To assess cell abundances, we will sample for microscopic counts and flow cytometry that allows to determine phytoplankton (<50 µm), bacteria, and viral abundances. In addition, we will perform rate measurements of phytoplankton primary and heterotrophic bacterial production. Phytoplankton primary production will be distinguished into particulate primary production (carbon remaining in the cells) and dissolved primary production (organic carbon subsequently released by cells).

We expect that the small algae at the base of the food web gain importance in mediating element and matter turnover as well as energy fluxes in Arctic pelagic systems. In order to detect changes, also in this smallest fraction of the plankton, traditional microscopy will be complemented by molecular methods that are independent of cell-size and morphological features. The assessment of the biodiversity and biogeography of Arctic phytoplankton will be based on the analysis of ribosomal genes with next-generation sequencing technology, Automated Ribosomal Intragenic Sequence Analysis (ARISA), and quantitative PCR. Many zooplankton species are affected by the changes at the base of the food web as they rely on phytoplankton as food source.

Similarly, the zooplankton community composition may shift due to the increasing inflow of warmer Atlantic water into the Fram Strait. Altered zooplankton trophic interactions and community compositions will have consequences for the carbon sequestration and flux. Most of our knowledge on zooplankton species composition and distribution has been derived from traditional multiple net samplers, which integrate depth intervals of up to several hundred meters. Nowadays, optical systems, such as the zooplankton recorder LOKI (light frame on-sight key species investigations), continuously take pictures of the organisms during vertical casts from 1,000 m to the surface. Linked to each picture, hydrographical parameters are being recorded, i.e. salinity, temperature, oxygen concentration, and fluorescence. This will allow us to exactly identify distribution patterns in relation to environmental conditions.

For the first time, we will also include research dedicated to protistan parasites. These are severely understudied in the marine realm although they are likely to affect the population dynamics of phytoplankton (including bloom timing and magnitude) and zooplankton. We will therefore conduct a baseline study of the diversity of different parasite groups and their association with potential hosts. This investigation will also form the basis for future biogeographic studies. The analyses will combine different microscopy techniques (LM, SEM, CFLM) as well as molecular data, the latter facilitating observation of parasitism even at times where easily discernible parasite life-cycle stages are absent.

Ocean colour remote sensing allows for estimating the overall phytoplankton biomass (indicated by chl-a concentration), distinctive major groups (abbreviated as phytoplankton functional types, PFT) and coloured dissolved organic matter (CDOM) at global and high temporal (daily) scales not met by our joint sampling during the expedition. However, at high latitudes, ocean colour satellite data has sparse coverage due to the presence of sea ice, clouds and low sun elevation. To complement remote sensing data, underway spectrophotometry and hyperspectral radiometry enables to obtain attenuation and absorption data which can be further processed to chl-a and marker pigment concentrations, PFT chl-a

and CDOM (Liu et al. 2018, 2019; Bracher et al. 2020) at high sampling resolution for the surface waters crossed during the entire cruise and for the underwater light profile at the CTD stations. However, the derivation of these final biogeochemical products requires the verification with direct analysis of these parameters on regularly sampled discrete water in order to quantify the potential and limitations in terms of uncertainties of these optically derived biogeochemical parameters. In conjunction with satellite data (e.g. products from Losa et al. 2017; Oelker et al. 2020; Xi et al. 2020) these discrete and continuously sampled data sets are of high value to upscale biogeochemical or phytoplankton quantities at higher resolution and better coverage. In addition, these data serve for validating ocean colour products from the Sentinel-3 OLCI and the Sentinel-5P TROPOMI sensors. The group of Astrid Bracher is part of the Sentinel-3 Validation Team and the PI of the ESA study Sentinel-5P Ocean Colour. Overall the cruise data provide a fundamental contribution for further development of hyper- and multispectral ocean colour satellite retrievals focusing on fluorescence and absorption signals.

In summary during PS126 the following topics are covered:

- Monitoring plankton species composition and biomass distribution
- Determination of autotrophic and heterotrophic microbial activities
- Monitoring biogeochemical parameters
- Investigation of selected phyto- and zooplankton (including their parasites)
- Determination the composition of organic matter and gel particles
- Investigation of the amount and composition of CDOM and their interplay with phytoplankton
- Characterisation of the underwater light field and its interplay with optical constituents, such as phytoplankton and CDOM abundance and composition.

Work at sea

Biogeochemical and biological parameters from rosette samples, including the automated filtration system for marine microbes AUTOFIM

We will sample Arctic seawater with the CTD/Rosette Water Sampler at the main HAUSGARTEN/ FRAM stations at 5-10 water depths (details see below). Water samples for CDOM absorption analysis are filtered through 0.2 µm filters and analysed on-board with a 2.5-m path length liquid waveguide capillary cell system (LWCC, WPI). Particulate and phytoplankton absorption coefficients are determined with the quantitative filter techniques using sample filtered onto glass-fibre filters QFT-ICAM and measuring them in a portable QFT integrating cavity setup after Röttgers et al. (2016). Measurements for alkalinity will be performed on board. Primary and bacterial production measurements will be performed on board using ^{14}C bicarbonate and ^{3}H leucine.

Incubations and measurements for the determination of oxygen will be performed according to three methods: *i)* we will titrate according to Winker (1988), *ii)* we will use optical sensors, and *iii)*, we will apply the ETSvitro method. The ETSvitro or enzymatic in vitro electron transport system method measures the reduction of tetrazolium salts that serve as a proxy for the respiratory activity.

In addition, we will collect particles close to the surface (~10 m) with the **auto**mated **fi**ltration system for marine **m**icrobes AUTOFIM (Fig. 3.1). Using AUTOFIM, we will collect seawater samples at regular intervals (~1° longitude/latitude and ~50 km in the study area) starting as soon as possible after RV *Polarstern* has left Bremerhaven. AUTOFIM allows filtration of a sampling volume of up to 5 litres. Twelve filters can be automatically taken in a row and stored in a sealed sample archive. Prior to the storage, a preservative can be applied to the filters to

prevent degradation of the sample material that will be used for eDNA analyses with special emphasis on eukaryotic microbes.

All other samples will be partly filtered and preserved or frozen at -20°C and partly at -80°C for further analyses. At the home laboratory at AWI, we will determine the following parameters to describe the biogeochemistry, biomass and abundance/biodiversity:

- Chlorophyll *a* concentration (total and fractionated)
- Phytoplankton pigments and major groups (HPLC)
- Dissolved organic carbon (DOC)
- Particulate organic carbon (POC)
- Total dissolved nitrogen (TDN)
- Particulate organic nitrogen (PON)
- Particulate biogenic silica (PbSi)
- Dissolved organic phosphorus (DOP)
- Transparent exopolymer particles (TEP)
- Coomassie-stainable particles (CSP)
- Dissolved combined carbohydrates and hydrolysable amino acids
- Phytoplankton, protozooplankton, bacterial and viral abundance
- Phytoplankton and bacterial production
- Bacterial respiration
- Molecular based information (18S metabarcoding) on community structure, diversity and distributional patterns of protists

Fig. 3.1: The fully automated filtration module AUTOFIM is installed on RV Polarstern in the so-called "Bugstrahlruderraum" (Bow thruster room) close to the inflow of the ship's pump system. AUTOFIM is suited to collect samples with a max. volume of 5 litres; filtration can be triggered on-demand or after fixed intervals

Mesozooplankton sampling

The composition and depth distribution of mesozooplankton will be determined by means of vertical Multi-net tows. Five depth stratified samples will be taken from 1,500 m depth to the surface (1,500 – 1,000 - 500 – 200 – 50 – 0 m). The samples will be preserved in 4 % formalin buffered with hexamethylentetramin and analysed later in the laboratory. In addition, we will deploy the LOKI from 1,000 – 0 m water depth. LOKI is equipped with a 6.3 Mio camera, taking pictures at a rate of up to 20 frames sec^{-1}. LOKI also measures salinity, temperature, O_2 concentration and fluorescence. During the cast, all data will be automatically stored on an internal hard drive. On-board, we will download images, and sensor and metadata, which all will later be analysed at AWI.

Continuous optical measurements

Continuous inherent optical properties (IOPs) with a hyperspectral spectrophotometer: For the continuous underway surface sampling an *in-situ* spectrophotometer (AC-S; WETlabs) will be operated in flow-through mode to obtain total and particulate matter attenuation and absorption of surface water. The instrument is mounted to a seawater supply taking surface ocean water (Fig. 3.2). A flow-control with a time-programmed filter is mounted to the AC-S to allow alternating measurements of the total and the CDOM inherent optical properties of the seawater. Flow-control and debubbler-system ensure that water flows through the instrument with no air bubbles.

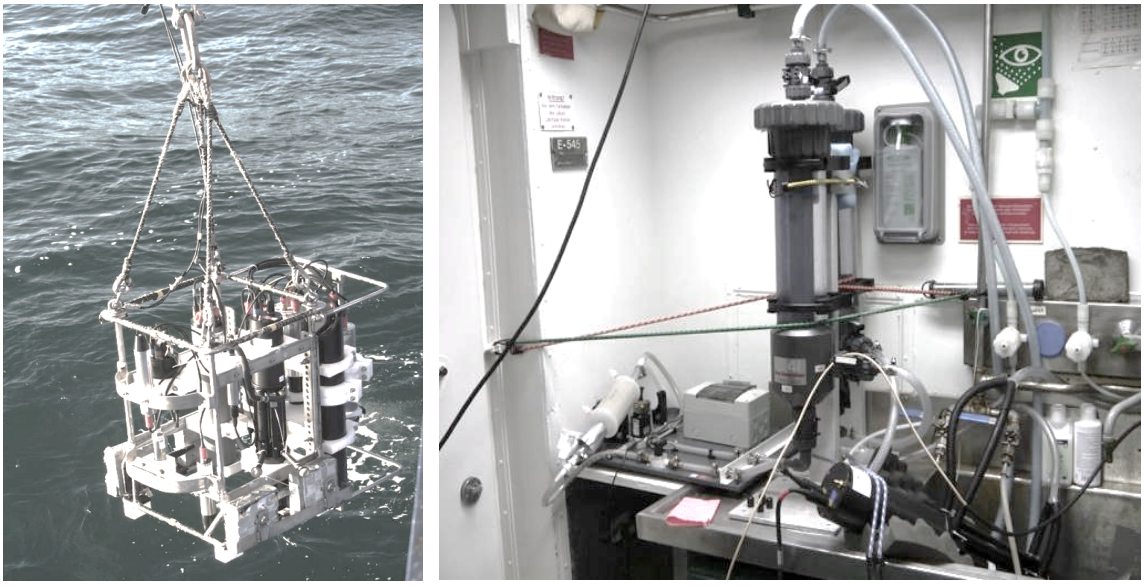

Fig. 3.2: Left: Underwater light field measurements (during FRAM expedition PS99) with TRIOS RAMSES radiometers detecting the hyperspectral up- and down-welling radiation and WETLABS AC-s (including data logger and battery) measuring extinction and absorption within the surface water profile. In addition, on the right of the frame there is a SUNA nitrate sensor. Right: Continuous measurements of the extinction and absorption of light in Arctic surface waters using a WETLABS AC-s mounted to the RV Polarstern surface seawater pump system. From those measurements, the absorption and scattering of particles and CDOM is determined for the whole spectrum in the visible resolved with about 3 nm resolution. The data then can be decomposed various specific algorithms to determine the particle size distribution and the various phytoplankton pigment composition.

A second AC-S instrument is mounted on a steel frame together with a depth sensor and a set of hyperspectral radiometers (Ramses sensors from TRIOS, Fig. 3.2) and operated during CTD stations out of the shade. The frame is lowered to maximal 120 m with a continuous speed of 0.1 m sec^{-1} or during daylight with additionally stops at 2, 4, 6, 8, 10, 12.5, 15, 20, 25, and 30 m to allow a better collection of radiometric data (see below). A second set of hyperspectral radiometers will be mounted at the ship's portside during underwater light stations. These instruments will be used to start developing an underway system to acquire quality controlled remote sensing reflectance data important for developing ocean colour algorithms and for Sentinel-3 and Sentinel-5P validation.

The Apparent Optical Properties of water (AOPs) (mostly light attenuation through the water column) will be estimated based on down-welling and up-welling irradiance measurements in the surface water profile (down to the 0.1 % light depth) from the radiometers calibrated for the incident sunlight with measurements of a radiometer on deck and directly from the radiance and irradiance above water radiometry. The second AC-S will measure the inherent optical properties (IOPs: total attenuation, scattering and absorption) in the water profile.

Expected results

The continuously measured optical data are used via using semi-analytical techniques to determine the spectrally resolved underwater light attenuation and the concentration of optical constituents, such as chl-a concentration, CDOM absorption and particle backscattering, but also for validating satellite ocean colour retrievals following formerly established procedures for FRAM cruises PS93.2, PS99 and PS107 (see Bracher et al. 2015; Liu et al. 2018; Liu et al. 2019).

We expect a new data set for late spring/early summer to extend our long-term measurements allowing to elucidate further changes in the Fram Strait pelagic environment due to Global Change and/or other environmental shifts.

Data management and samples

During our cruises, we sample a large variety of interrelated parameters. Many of the samples (i.e. pigment analyses, particulate matter in the water column, optical measurements, etc.) will be analysed at AWI and at GEOMAR within approximately one year after the cruise. We plan that the full data set will be available at latest about two years after the cruise. Samples taken for microscopical analyses, which cannot be analysed within two years after the cruise, will be stored at the AWI for at least ten years and available upon request to other scientists. Data will be made available to the public via PANGAEA (https://pangaea.de). In accordance with current institute data policies. ACs data are foreseen to be uploaded to the FRAM data portal as raw data immediately after the cruise and as calibrated data set after carefully executing quality controls and calibrations with discrete water sample measurements. Image material and associated metadata will be uploaded to the planktonnet database (https://planktonnet.awi.de) and these data sets will be integrated into PANGAEA. All image material in planktonnet will be publicly available. Uploads will be made incrementally as phytoplankton analyses progress.

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4. SEAPUMP - THE ROLE OF SETTLING AGGREGATES IN THE BIOLOGICAL PUMP

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Morten Iversen[1] (not on board)

Grant No. AWI_PS126_03

Rationale

Anthropogenic activities have increased atmospheric carbon dioxide (CO_2) levels to above 400 ppm, higher than at any point during the past 2 to 5 million years. Small and large settling aggregates in the ocean are thought to be the most important drivers for oceanic carbon sequestration. Aggregation of organic matter in surface waters and subsequent settling to the deep ocean allows for further uptake of atmospheric carbon dioxide by the ocean. In this way, the oceans have the capacity to sequester large amounts of atmospheric CO_2 by exporting biologically fixed carbon to the deep ocean. The sinking aggregates also feed life below the ocean's surface sustaining the biomass of deep sea fish and other organisms and determine sediment formation on the seafloor. However, most of the organic matter produced by phytoplankton in the surface ocean is eaten by small animals or degraded by bacteria before it sinks deeper than 100 m water depth. This means that the carbon dioxide is only removed from the atmosphere for a few weeks before it is outgassed from the ocean again. Hence, settling aggregates need to sink below 1,000 m depth to be removed from the atmosphere for more than 1,000 years and only those particles reaching the seafloor will have their organic matter stored for millennia. Unfortunately we know very little about processes that remove and transform the particles as they sink through the water column and, hence, the sequestration of atmospheric carbon dioxide in the world's oceans is only poorly understood. Only by understanding those processes can we make any hopes of bringing the carbon that we have released via fossil fuel burning back into the ocean floor. Since the end of the 19th century we humans have added more carbon dioxide to the atmosphere than accumulated there in a 5,000- year period when the last Ice Age came to an end. Back then, the ice shields covering North America and parts of Eurasia (combined continental landmass of Europe and Asia) melted and caused a 130 m sea level rise.

Objectives and scientific programme

Our main objective during the cruise is to quantify attenuation and export of organic carbon flux through the water column. This will be done by high resolution investigations of particle dynamics in the water column. We will do this by looking at both large and small scale, i.e. on a whole water perspective using *in-situ* optics on short time-scale or on a long-term perspective using the moored BioOptical Platform, BOP (Fig. 4.1), and the SWIPS-Particle Camera to quantify vertical particle and aggregate abundance and size-distribution in the upper few hundred meters of the water column on a temporal resolution of days to week throughout a full year (SWIPS) and by measurements size-specific sinking velocities and microbial respiration of settling aggregates at one depth throughout a full year (BOP).

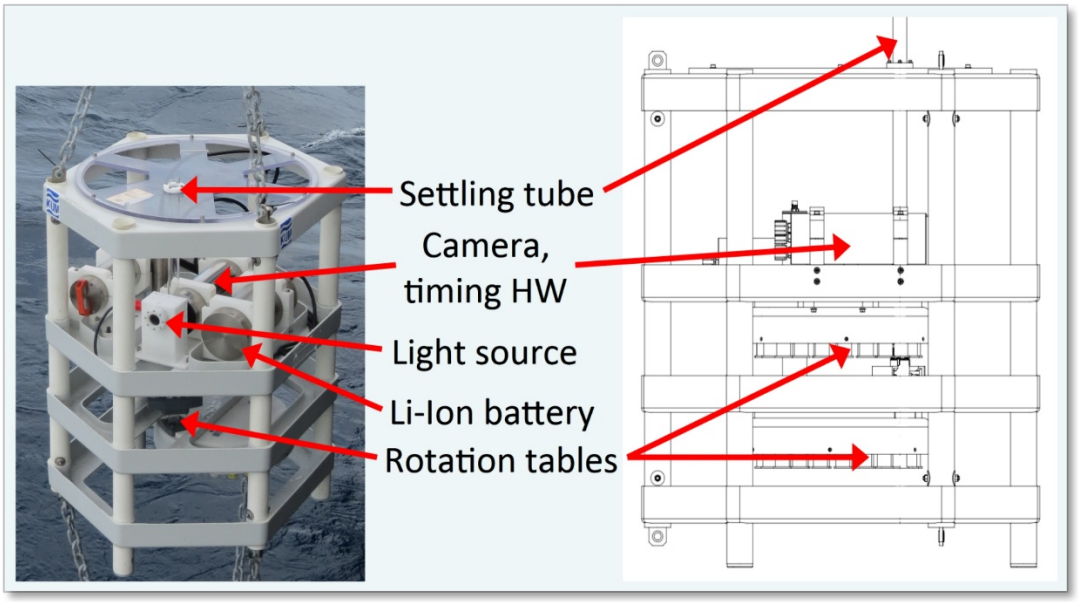

Fig. 4.1: Configuration of the BioOptical Platform BOB

Work at sea

We will recover and re-deploy the BioOptical Platform (BOP) to measure size-specific settling velocities of individual particles in relation to their type and composition throughout a whole year. The system has been an integral part of the LTER HAUSGARTEN mooring-array since 2015. This time we will deploy a modified extended version of the BOP, where we will deploy a prototype BOP which enables *in-situ* oxygen respiration measurement in the collection cups of the system throughout the whole year. This prototype was developed at AWI together with an Austrian company developing and manufacturing opto-chemical oxygen sensor systems.

Moreover, we will recover the SWIPS-Particle Camera, which was deployed for the first time during RV *Polarstern* expedition PS121 (2018). This system was developed at the AWI in collaboration with the Deep-Sea Research Group (Normen Lochthofen) at AWI. Subsequently, we will investigate the status of the system with regard to functionality and possible necessary improvements as well as evaluate the collected data in terms of particle statistics over depth and time.

To determine vertical aggregate abundance and size-distribution during the cruise, we will deploy a profiling *In-situ* Particle Camera (Fig. 4.2). This will be done in combination with deployments of the ship's CTD/Rosette Water Sampler, Multi-nets and LOKI for zooplankton distributions (in collaboration with the PEBCAO group (Barbara Niehoff) at AWI. The vertically changing particle concentrations and size distribution determined with the *in-situ* optical systems will be combined with data for the vertical distribution of zooplankton to study the interactions between settling aggregates and zooplankton and the impact from zooplankton flux feeding and carbon export.

Fig. 4.2: Deployment of the In-situ Particle Camera in coastal waters off western Spitsbergen

Expected results

The vertically particle concentrations and size distribution determined with the *in-situ* camera systems will be used to derive high vertical resolution of carbon flux. By linking this to vertical distribution of zooplankton from the LOKI camera system, we will determine depth-specific carbon degradation rates. These high-resolution carbon fluxes will enable the determination of carbon-specific turnover rates in different water layers through the water column. While the vertical profiles from the *in-situ* camera provides snap-shots of carbon export and aggregate distributions at specific stations during the expedition, the SWIPS particle camera was mounted on an underwater winch for two years, providing vertical aggregate abundance and size-distribution throughout the two-years deployment. Therefore, we expect to get vertical aggregate size-distribution and abundance in the upper 150 m for every second day during a two-year period. The SWIPS particle camera was deployed in combination with the Bio-Optical Platform (BOP), which provide image data to determine aggregate sizes and size-specific sinking velocities as well as sampling aggregates in gel traps for determinations of aggregate types, structure and composition throughout the deployment period. This will provide unprecedented information on seasonal aggregate dynamics including abundance, size-distribution, size-spectra, size-specific sinking velocities, types and composition.

All this data contributes to the long-term observations in the Fram strait helping to understand the pelagic environment and carbon export and attenuation mechanisms during the polar day and night.

Data management

Analysis of BOP, SWIPS and *In-situ* Particle Camera data is quite time consuming and will therefore be done in the home laboratories at AWI and MARUM. All data will be archived, published and disseminated according to international standards by in the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de) within two years after the end of the cruise at the latest.

5. EFFECTS OF RISING TEMPERATURES AND NITROGEN LIMITATION ON ARCTIC MICROPLANKTON COMMUNITY STRUCTURE

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Grant No. AWI_PS126_04

Objectives and scientific programme

Microplankton communities play a fundamental role within marine ecosystems by providing organic matter to oceanic food webs and by fostering major biogeochemical cycles (Katz et al. 2004). Currently, they are facing drastic alterations of their abiotic environment due to Climate Change (Doney et al. 2012), especially in the Arctic (Miller et al. 2010). For arctic marine microbes, two highly important aspects of Climate Change are rising temperatures and a decrease in nitrogen supply via increased stratification. Instead of acting independently, their effects on species' performance seem to interact strongly (Gerhard et al. 2019; Marañón et al. 2018; Thomas et al. 2017). Furthermore, they influence the various groups within the communities differently and thus shape the outcome of competition, facilitation, herbivory and parasitism (Bestion et al. 2018; Boyd et al. 2018; Branco et al. 2020). Although the resulting structural composition of microplankton communities affects processes relevant for Climate Change itself (e.g. the biological carbon pump (Guidi et al. 2009; Lafond et al. 2020), little is known about the mechanisms governing community assembly.

Most studies investigating the effect of multiple drivers on microplankton communities focus on culture experiments with single strains or populations (Boyd et al. 2018). Bearing in mind the multitude of interactions within complex microplankton communities, the outcome of single species experiments might not reflect the actual situation in the field (Celiker and Gore 2014; Turcotte et al. 2012). In fact, the presence of another species in an experimental setting seems to alter their reactions to abiotic change (Hall et al. 2018) and some authors stress that even two-species interactions are poor predictors for whole community responses (McClean et al. 2019). Furthermore, relatively small changes within some functional groups could have large knock-on effects on other groups (Camarena-Gómez et al. 2018). Rather than understating the detailed physiological insight gained from single-species experiments, this highlights the importance of additionally performing experiments with natural assemblages including several species and groups. Of particular interest is the question, which members of a multispecies community will prevail the prospective changes in abiotic conditions. Identifying the characteristics of these so-called "winner species" is an essential part of assessing future microplankton community resilience and functioning (Hoffmann and Sgró 2011).

Therefore, the aim of our work during the expedition PS126 is to generate experimental data which helps to understand the interactive effects of rising temperatures and nitrogen limitation on the structural composition of arctic microplankton communities. Our main objective is to determine principles that govern the assemblage of these communities with a focus on the role of taxonomy and functional traits as well as the characteristics of successful community members.

Work at sea

In order to set up our experiments, water will be sampled via CTD bound Rosette Water Sampler at three stations: one at the beginning of the expedition, one after three weeks (middle) and one at the end of the cruise. This enables us to run a first experiment for three to four weeks during the expedition and to set up a second experiment on board, so that it can be continued in the facilities of the Alfred Wegener Institute after arrival in Bremerhaven. The third sampling is planned as a backup if the first or second sampling will fail by the transfer into the long-term incubation. The long-term incubation is sensitive to marine snow formation and bacterial growth and therefore might needed to be repeated. One part of the sampled water will be sterile-filtrated to serve as fresh medium for successive dilutions and the other part will be filtered through a 150 µm nylon mesh (to exclude mesozooplankton) and arranged in a classical dilution micro-grazing experiment (see Landry and Hassett 1982). The whole set-up will be run at three different temperatures in temperature-controlled containers on board. After 72 hours, the most diluted treatments at each temperature will be transferred into a long-term experiment including two nitrogen levels (N-replete and N-limited) with four to five replicates per treatment combination (Fig. 5.1). Approximately every three to five days, communities will be diluted with filtered seawater and added nutrients (with or without nitrogen) to produce a bottleneck and to sample all parameters of interest (pH, POC/PON, POP, Chl a, nutrients, microscopy, flow cytometry). Parts of those samples will be stored at -20 °C/-80 °C for later analyses of DNA and RNA.

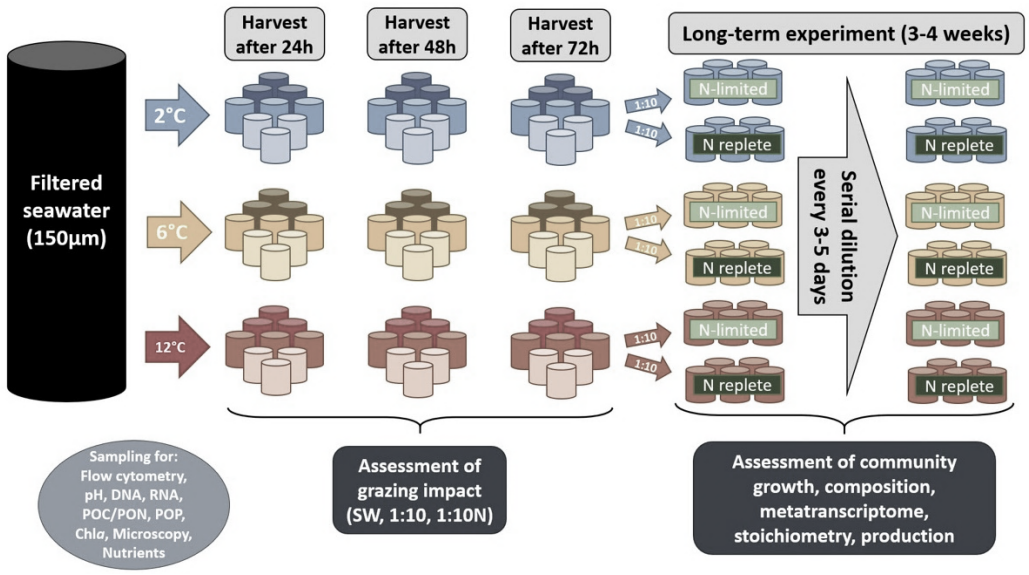

Fig. 5.1: Experimental design of full-factorial dilution experiments; different shades represent different dilutions and/or nutrient treatments. Note that the number of replicates in the long-term experiment depends on preceding growth rates.

Expected results

We expect the outcome of our experiments to contribute to the general understanding of microplankton community assembly and how it is modulated by rising temperatures and nitrogen limitation. The relative importance of functional traits and taxonomic identity as well as characteristics of prevailing species should be identified. Differences within and among treatments could shed light on alternative stable states and the resilience of specific sets of

species within a community. Furthermore, the generated data could help to improve future microzooplankton grazing experiments by assessing the impact of temperature and different nutrient levels on phytoplankton community composition within grazing experiments. Finally, the results will be compared to similar experiments which have been performed in the North Sea to gain an insight into differences and similarities in responses among arctic and temperate communities. The output of our experiments will be highly relevant to the new Helmholtz Research Programme "Changing Earth – Sustaining our Future", Subtopic 6.2 (Adaptation of marine life: from genes to ecosystems) and partly Subtopic 6.1 (Future ecosystem functionality).

Sample and data management

Scientific data will be submitted to PANGAEA (www.pangaea.de) upon publication as soon as the data is available and quality-assessed. We expect all data to be available within a maximum of two years after completion of the expedition. Molecular data (DNA and RNA) will be archived, published, and disseminated within one of the repositories of the International Nucleotide Sequence Data Collaboration (INSDC, www.insdc.org) comprising of EMBL-EBI/ENA, GenBank and DDBJ). Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

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6. NUTRIENTS AND CARBON BUDGETS – QUANTIFYING AND UNDERSTANDING CHANGE

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Sinhué Torres-Valdés[1] (not on board)

Grant No. AWI_PS126_05

Outline

The study of the Arctic Nutrient and Carbon budgets is of relevance in order to understand biogeochemical processes at the pan-Arctic scale and their status at any given time, their role in ocean productivity and the climate system. Current gaps in knowledge concerning nutrient and carbon biogeochemical cycles at the pan-Arctic scale stem from the lack of information necessary to constrain their budgets. Available computations (Torres-Valdés et al. 2013, MacGilchrist et al. 2014; Torres-Valdés et al. 2016) indicate the Arctic Ocean (AO) exports phosphate, dissolved organic phosphorus, silicate, dissolved organic nitrogen and dissolved inorganic carbon (DIC) to the North Atlantic. These computations also suggest net nitrate transports are balanced despite known large losses due to denitrification. The silicate export derives largely from riverine inputs, suggesting alterations in river loads might have an impact on exports too, potentially modifying the stoichiometric abundance of nutrients. Overall, there are still unknowns with regards to understanding sources and sinks of these biogeochemically relevant variables. Under ongoing and predicted climate change, identifying and quantifying sinks and sources becomes essential to: *i)* generate baseline measurements against which future change can be evaluated, *ii)* assess the impact of climate change on biogeochemical processes (e.g. primary production, organic carbon export, remineralisation), *iii)* understand the complex interaction between biogeochemical and physical processes, and how such interactions affect the transport of nutrients downstream and the capacity of the AO to function as a sink of atmospheric CO_2, and to *iv)* determine whether long-term trends occur, for instance. Available AO nutrient and carbon budgets derive from transport calculations across the main gateways (Fram Strait, the Barents Sea Opening, Bering Strait and Davis Strait). However, these are mostly based on summer time measurements. Hence, it is necessary to generate continuous observations in order to evaluate budgets over seasonal and longer time scales.

With the aim of addressing the above issues, we started deploying FRAM sensors and remote access samplers to generate continuous observations of nutrients and DIC in Fram Strait, targeting core (~250 m) and surface waters of the West Spitsbergen Current and the East Greenland Current.

During RV *Polarstern* expedition PS114 in 2018 (von Appen 2019) we deployed four package sensors (Fig. 6.1) at selected locations, targeting sub-surface and core waters of the East Greenland Current and West Spitsbergen Current (moorings EGC-5, F4S-3, and F4W-1). During the expedition PS121 the instrumentation deployed during PS114 was recovered and a similar set up of instruments was deployed (Metfies 2020). Likewise, during PS126 we will *i)* recover the instrumentation deployed in 2019, collect samples from the RAS and retrieve sensor data, and *ii)* deploy new biogeochemical sensor packages in order to continue our time series. These deployments will allow us to generate data that we will eventually use to assess nutrient and carbon variability in waters flowing in and out of the Arctic Ocean across Fram Strait, within the context of the Arctic Nutrient and Carbon Budgets.

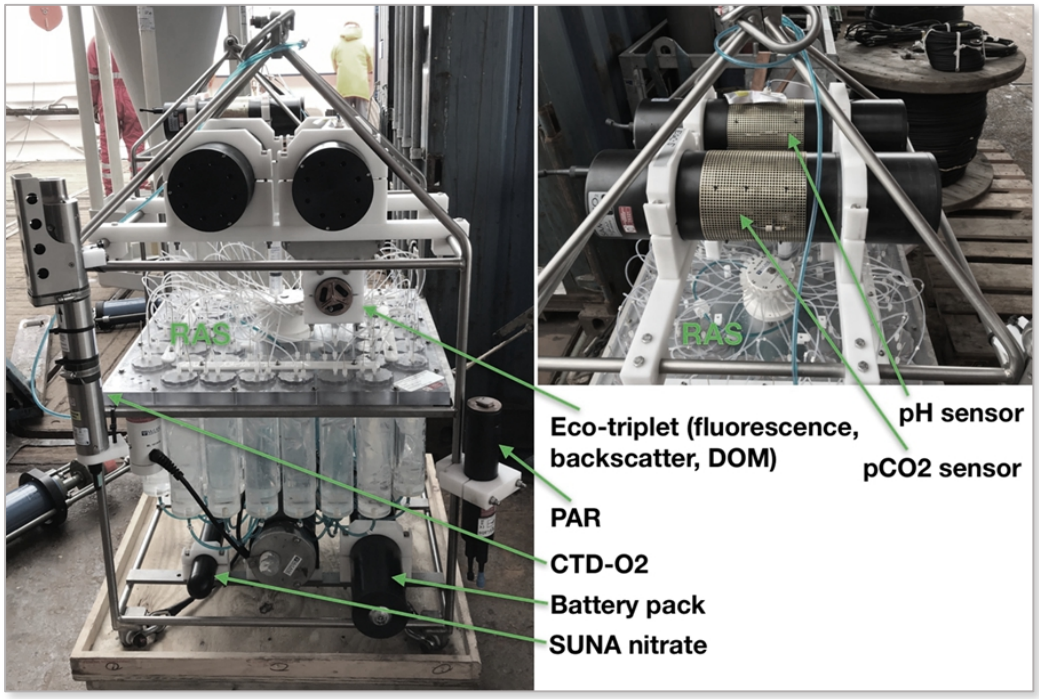

Fig. 6.1: Biogeochemical Sensor Packages, consisting of a Remote Access Sampler (RAS) with a Nitrate, pCO_2, pH, CTD-O_2, PAR, and Eco-triplet sensors attached

Objectives

Our long-term observational objective, is to generate high quality data of important biogeochemical variables at temporal resolution higher than that allowed by ship-based observations alone. Our scientific long-term objective, is to use the newly generated data to contribute towards the understanding of the Arctic Ocean nutrient and carbon budgets and thus, biogeochemical cycles, via addressing our scientific questions: 1) What is the amplitude of the annual cycle of nutrient and carbon concentrations in outflowing and inflowing Waters? 2) What is the evolution of nutrient pools (i.e., inorganic versus organic) through the annual cycle? 3) How does the amplitude and evolution of nutrients reflect on the AO nutrient budgets (as assessed at Fram Strait)? 4) How does the amplitude of the carbon annual cycle reflect in the AO carbon budget (including assessment of the anthropogenic component)? 5) How do the nutrient and carbon seasonal cycles evolve in relation to physical (e.g., convection, eddies) and biological processes (e.g., primary production, phytoplankton phenology)? E.g., what and/or to what extent physical/biological processes control nutrient stoichiometry decoupling? 6) What can we learn about denitrification from the evolution of the N:P ratio of core outflowing and inflowing waters? Our ultimate goal is to publish our research in scientific journals. Furthermore, we aim to extend the use of the data we generate via collaboration, so that our partners within the FRAM project and beyond can benefit from our efforts in order to address scientific questions which are beyond our own expertise. The deployment of RAS is done in coordination with Drs Katja Metfies and Matthias Wietz, who use RAS samples for phytoplankton and bacterial genetic analyses, respectively. Currently, nutrient data generated from the initial deployments in 2016 and 2017 are contributing to scientific manuscripts concerning i) microbial dynamics in Fram Strait (Wietz et al., in preparation) and ii) the effects of sea ice on the ecosystem, from water column to depth, from the range of multidisciplinary observations as part of FRAM (von Appen et al., in preparation).

Work at sea

1) prepare and deploy sensors and RAS (Fig. 6.1). Each package consists of a RAS with a SUNA nitrate, pH, pCO_2, CTD-O_2, PAR and Eco-triplet sensors attached. PAR and Eco-triplet in surface deployments only. RAS and sensors will be programmed to take samples and measurements for 1 year, rather than the two years until the next expected recovery. This is to maximize temporal resolution and avoid the risk of malfunction.
2) because of changes in the expedition due to corona constrains and reduction of team capacity during PS126, we will focus on the collection seawater samples at all stations, for later analysis of dissolved inorganic nutrients back in the laboratory at the AWI. This time we will not be able to collect samples for carbonate system variables.
3) recover RAS and sensors from our second deployment, and split RAS samplers in aliquots to cover our work on nutrient chemistry, and also work on bacterial genetics (Matthias Wietz, AWI/MPIMM) and phytoplankton genetic (Katja Metfies, AWI).

Expected results

Provided the RAS and sensors functioned as programmed, recovering our biogeochemical packages would yield a second full year of observations of biogeochemically relevant variables from the West Spitsbergen and East Greenland Current. An example of the seasonal cycle of nitrate and phosphate in surface waters of the West Spitsbergen Current is shown in Fig. 6.2. This figure shows the seasonal cycle of nitrate + nitrite (NO_3 + NO_2) and phosphate (PO_4). Concentrations are at a minimum at the start of sample collection during the productive season. Nutrient concentrations then recover towards winter time as convection mixes surface waters with nutrient-rich deep waters. Concentrations then decrease as the new productive period begins. Interestingly, these data show a decoupling of these two nutrients, with nitrate + nitrite seemingly decreasing earlier than phosphate. These data also show that samples taken one hour apart from each other, as indicated by the symbol colours, may collect water with different chemical and physical characteristics, indicating the dynamics of the region.

Unfortunately, space restrictions on-board PS121 resulted in not enough berths being available. Because of this, samples were not analysed on-board, but collected for later analyses. Their analysis is still pending, however, we expect this will take place after returning from PS126.

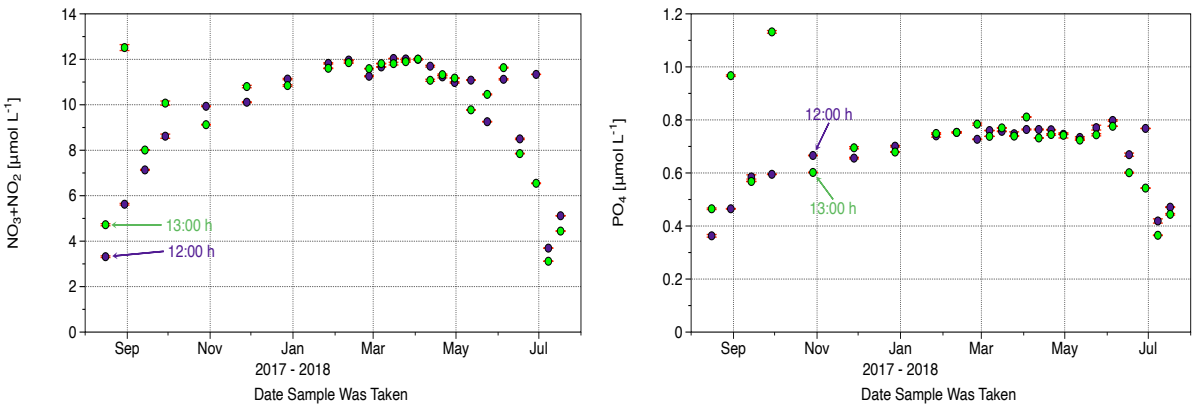

Fig. 6.2: Seasonal cycle of nitrate + nitrite (NO_3 + NO_2) and phosphate (PO_4) from a RAS deployment at 23 m depth in the West Spitsbergen Current, from September 2017 to July 2018

Data management

Once data is generated and quality controlled, these will be submitted to the PANGAEA data repository (www.pangaea.de). In the initial stage we will request a 2 year embargo so as to allow us to assess the data and write it up as we addressed our scientific questions. It must be pointed out that only during PS114 we were allowed enough berths to carry out the analysis of nutrient samples onboard. This data set has been already submitted to PANGAEA (https://doi.org/10.1594/ PANGAEA.907355). On PS121 this was not possible because not enough berths were allocated to our team which led to us only being able to carry out our sample collection program. Additionally, analysis has not been possible because our analytical system was used for the MOSAiC Drift Expedition. Thus, samples collected during PS121 are still waiting to be analysed. During PS126 we are in the same position and thus, only a reduced sample collection program will be possible. We expect that analysis of samples collected during PS121 and PS126 will be done on the second half of 2021. In the meantime, other data sets have been made publicly available via PANGAEA already, e.g., Torres-Valdés, Sinhue; Morische, Annika; Wischnewski, Laura (2019): Revision of nutrient data from *Polarstern* expedition PS101 (ARK-XXX/3). Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, PANGAEA, https://doi.org/10.1594/PANGAEA.908179, as well as Torres-Valdés, Sinhue; Morische, Annika; Wischnewski, Laura (2019): Nutrient measurements from *Polarstern* cruise PS99.2 to Fram Strait (LTER HAUSGARTEN). Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, PANGAEA, (https://doi.org/10.1594/PANGAEA.906132).

The data included in the manuscripts being currently written (Wietz et al., in preparation; von Appen et al., in preparation) will be submitted to PANGAEA before June 2021. Sensor data in raw format has been combined with other mooring data by Wilken-Jon von Appen and has been submitted to PANGAEA. However, calibrated sensor data will be done gradually by Daniel Scholz and Sinhue Torres-Valdes as it has been taken few years to develop the methods for calibration and we need the *in-situ* data (still in frozen samples) required for calibration. Again, data will be used for answering our scientific questions and will be made available either upon acceptance of publication or by the end of the embargo period.

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7. BENTHIC FLUXES

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Elena Schiller[1];
not on board: Volker Asendorf[2],
Michael Hofbauer[1]

Grant No. AWI_PS126_06

Objectives

Benthic communities are strictly dependent on carbon supply through the water column, which is determined by temporal and spatial variations in the vertical export flux from the euphotic zone but also lateral supply from shelf areas. Most organic carbon is recycled in the pelagic, but a significant fraction of the organic material ultimately reaches the seafloor, where it is either re-mineralized or retained in the sediment record. One of the central questions is to what extent sea-ice cover controls primary production and subsequent export of carbon to the seafloor on a seasonal and interannual scale. Benthic oxygen fluxes provide the best and integrated measurement of the metabolic activity of surface sediments. They quantify benthic carbon mineralization rates and thus can be used to evaluate the efficiency of the biological pump. In order to link long-term variations in surface and sea-ice productivity and consequently in export flux to the seafloor, detailed investigation of the temporal variations in benthic oxygen consumption rates would be very valuable. Yearly measurements with benthic lander provide information on the interannual variations. Benthic crawler, mobile seafloor platforms capable to perform weekly oxygen gradient measurements for a 12-month period, provide information on the seasonal variations. In addition, long-term benthic lander systems equipped with sediment traps and cameras for time-lapse imaging of the seafloor record the supply of organic material throughout the year.

Work at sea

Benthic fluxes

Seafloor carbon mineralization will be studied *in-situ* at sites with varying sea-ice conditions (HG-IV, N4 and EG-II) using a benthic lander system (Hoffmann et al. 2018). The benthic O_2 uptake is a commonly used measure for the benthic mineralization rate. We plan to measure benthic oxygen consumption rates at different spatial and temporal scales.

The benthic lander will be equipped with two different profiling instruments to investigate the oxygen penetration and distribution as well as the benthic oxygen uptake of Arctic deep-sea sediments: *i)* electrode-microprofiler, for high-resolution pore water profiles (O_2, resistivity) across the sediment-water interface, and *ii)* a deep optode-profiler, to measure the entire oxygen penetration depth. The overall benthic reaction is followed by measurement of sediment community oxygen consumption to calculate carbon turnover rates.

Seasonal variations

At two contrasting sites - HG-IV (off West Spitsbergen) and EG-II (off East Greenland) - benthic crawler systems (TRAMPER and NOMAD (Fig. 7.1) will be recovered after their 24-month mission (both systems were deployed in 2019 during RV *Polarstern* expedition PS121). The crawler systems were pre-programmed to perform >100 measurements along a ca 1.5 km transect. TRAMPER (Wenzhöfer et al. 2016) deployed at EG-II uses oxygen optodes to

measure vertical concentration profiles across the sediment-water interface (one set of profiles each week). NOMAD, additionally equipped with benthic chambers and a seafloor imaging and scanning camera system (Lemburg et al. 2018), was deployed at HG-IV. NOMAD will take images of the seafloor combined with a laser scan. From this information we are able to reconstruct the sediment surface at high resolution. When seafloor images and topography scans are overlaid, we will be able to identify hot spots of intensified organic matter accumulation. These two seafloor observations are performed during the 10 m long transect at the beginning of each measuring cycle. At the end of this transect, concentration profiles of oxygen are measured across the sediment water interface. From these profiles diffusive oxygen fluxes can be obtained. Chamber incubations, performed at the same time, provide the total oxygen demand of the seafloor. Both measurements provide information on the oxygen consumption related to carbon mineralization. These cycles are repeated every week for a period of 24-month.

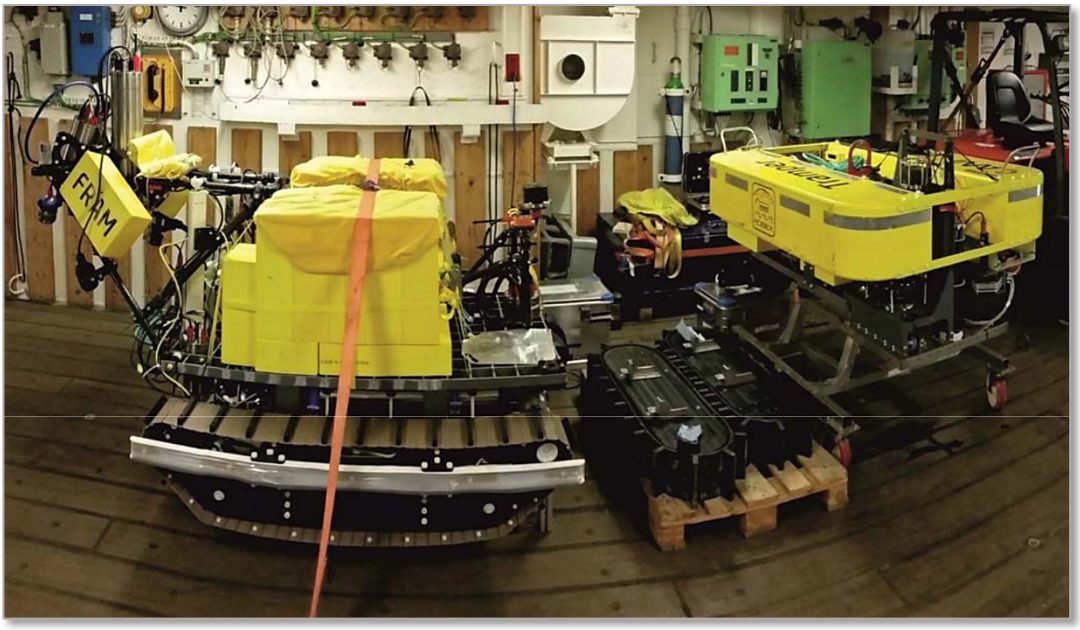

Fig. 7.1: Benthic crawler NOMAD (left) and TRAMPER (right) on board RV Polarstern

Additional we will recover long-term benthic lander systems (equipped with sediment traps, current meters and seafloor cameras) at both sites. Sediment trap samples will provide an estimate on the amount of settling organic matter at the seafloor. Data will be compared with benthic oxygen consumption rates.

At both sites (HG-IV and EG-II), we will re-deploy two crawler systems and long-term lander systems to continue the high-resolution long-term studies of benthic mineralization rates.

Expected results

The overall aim of both crawler and lander deployments is to cover a seasonal cycle of settling organic matter on the seafloor with contrasting and changing food supplies and to resolve the impact on the benthic community respiration activity. Combined with sediment trap and seafloor imaging we expect new insights in the benthic oxygen consumption rates over a full

seasonal cycle. Long-term deployment of both *in-situ* systems further allows interannual variations to be detected. The use of new underwater technologies will thereby enhance our capabilities to improve our knowledge on the effects of Climate Change on the Arctic marine ecosystem.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de) within two years after the end of the cruise at the latest.

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8. PHYSICAL OCEANOGRAPHY

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Wilken-Jon von Appen[1] (not on board)

Grant No. AWI_PS126_07

Objectives and scientific programme

Given the intermittent presence of sea-ice and meltwater in the polar regions, it still unclear what differences there are in the physical conditions that lead to primary production and export production in the Arctic Ocean. The FRAM multidisciplinary observatory attempts to observe the coupling across the system atmosphere, upper ocean, pelagic, and benthic environments.

To determine the seasonal changes in nutrient concentrations in the euphotic zone, water samplers have been deployed since 2016 with the most recent deployment in 2019 (PS121) at approximately 20 m and 80 m depth. In total, 24 discrete samples are being taken with weekly to monthly resolution (depending on season) to follow the biological drawdown of nutrients. The moorings are also equipped with a physical and biogeochemical sensor package including SBE37-SMP-ODO (temperature, salinity, oxygen), SAMI pH, SAMI pCO_2, Wetlabs PAR (photosynthetically active radiation), Wetlabs Ecotriplet (Chlorophyll and CDOM fluorescence plus scattering), SUNA Deep Nitrate, current meters, and Acoustic Doppler Current Profilers. The combination of these sensors and the water samplers, in combination with the deployment of two profiling winches facilitates the assessment of seasonal stratification and nutrient concentrations above and below the pycnocline. The nutrient drawdown enables an estimate of new production. Furthermore, the samples will be used for DNA sequencing to examine seasonal changes in bacterial community structure. The particle samplers collect and preserve filters for DNA extraction and sequencing that together with the fluorescence sensors allow us to track the progression of phytoplankton biomass and community composition over different seasons. These efforts give us a novel year-round description of biological, chemical, and physical processes in the Fram Strait.

Work at sea

Recovery and deployment of moorings

In total nine moorings will be recovered on PS126 (Table 8.1). Five of those moorings will be redeployed with some modifications. This comprises a mooring cluster (F4) in open water in the West Spitsbergen Current. At these clusters measurements as shallow as 20 m depth are performed.

CTD/Rosette Water Sampler casts

The CTD/Rosette Water Sampler will be operated at the standard LTER HAUSGARTEN stations. Water will be collected both on full water column profiles and on profiles to only 300 m depth. Water samples will be run on the Optimare Precision Salinometer for salinity calibration.

Tab. 8.1: Moorings to be recovered and deployed during RV *Polarstern* expedition PS126

Name	Longitude		Latitude		Depth	Top	Deployment time UTC					Deployment station
	Degrees	Minutes	Degrees	Minutes	Meters	Meters	Year	Month	Day	Hour	Minute	
Recoveries												
F4-19	6	59.98 E	78	59.98 N	1212	53	2019	8	22	7	49	PS121/013-1
F4-S-4	6	57.81 E	79	0.71 N	1222	16	2019	8	22	10	36	PS121/013-2
F4-W-2	7	2.14 E	79	0.70 N	1236	125	2019	8	22	13	19	PS121/013-3
HG-IV-W-2	4	23.97 E	79	1.37 N	2473	125	2019	8	26	7	41	PS121/026-1
HG-IV-S-4	4	15.75 E	79	1.34 N	2539	18	2019	8	26	10	21	PS121/026-2
HG-IV-FEVI-40	4	19.92 E	79	0.00 N	2542	64	2019	8	26	14	28	PS121/026-3
HG-EGC-6	5	23.78 W	78	59.75 N	996	47	2019	8	29	10	56	PS121/031-3
HG-N-S-1	3	7.19 E	79	56.64 N	2500	14	2019	9	6	14	7	PS121/044-1
HG-N-FEVI-39	4	30.36 E	79	44.35 N	2657	57	2019	9	7	10	28	PS121/046-3
Deployments												
F4-20	6	59.98 E	78	59.98 N	1212	53	2021					
F4-S-5	6	57.81 E	79	0.71 N	1222	16	2021					
F4-W-3	7	2.14 E	79	0.70 N	1236	125	2021					
HG-IV-FEVI-42	4	19.92 E	79	0.00 N	2542	64	2021					
HG-EGC-7	5	23.78 W	78	59.75 N	996	47	2021					

Expected results

The overall aim of the mooring recoveries and deployments is to characterize the variability, including seasonal cycles and mesoscale features, of physical properties, biogeochemical cycles, and biological processes in the ocean. The collected data will contribute to an improved understanding of long-term changes in the Fram Strait and of physical-biological coupling in the upper ocean.

CTD data will elucidate the distribution of water masses during the cruise, and how that compares to previous expeditions. It will be used to support the interpretation of properties measured from water collected with the CTD bottles.

Data management

The data recorded by the moored instruments that will be recovered on PS126 will be processed after the cruise at AWI and submitted to the PANGAEA data publisher (https://www.pangaea.de). The moorings that will be deployed on PS126 will be recovered in 2022. The data recorded on those instruments will accordingly be processed after recovery and submitted to the PANGAEA data publisher at that time. Likewise, the data collected during PS126 from the CTD will be processed at AWI and afterwards submitted to the PANGAEA data publisher.

9. FRAM POLLUTION OBSERVATORY - MONITORING LITTER AND MICROPLASTIC AT HAUSGARTEN

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Grant No. AWI_PS126_08

Objectives and scientific programme

Marine litter or marine debris has long been on the political and public agenda as it has been recognized as a rising pollution problem affecting all oceans and coastal areas of the world and more than 1300 species (Bergmann et al. 2017a). Over time, larger plastic litter items fragment into smaller particles termed 'microplastics' (<5 mm), which have recently received increasing attention (Ryan 2015) as they can be taken up more readily by a wider range of biota and humans.

Analysis of seafloor photographs (Fig. 9.1) taken for the epibenthic megafauna time series at three stations of the HAUSGARTEN observatory (see Chapter 2) indicate that litter rose almost 30-fold between 2004 and 2017 at the northernmost station and reached densities similar to those reported from a canyon near the Portuguese capital Lisbon (Parga Martínez et al. 2020). This increase has prompted a focused study on litter and microplastic pollution in different ecosystem compartments and repeated sampling campaigns to observe temporal trends.

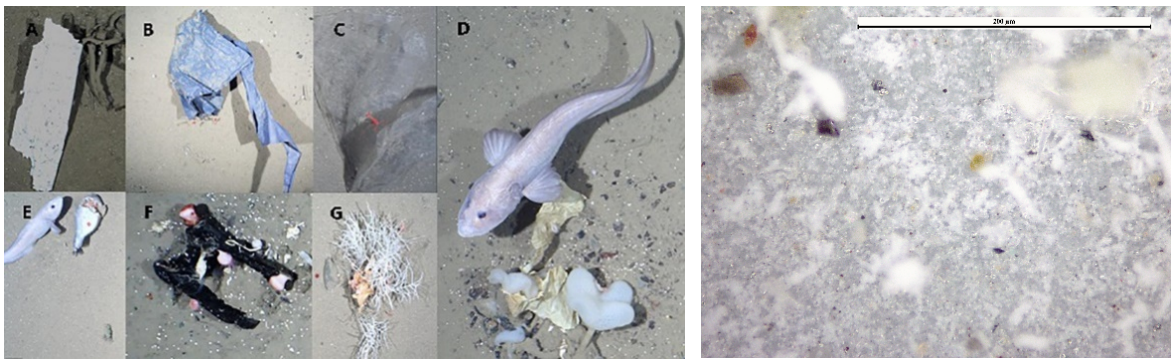


Fig. 9.1: Examples of marine litter and faunal interactions photographed by OFOS at HAUSGARTEN observatory (from Parga-Martinez et al. 2020) and atmospheric microplastics (from Allen et al. 2019)

This research has highlighted that Arctic sea ice, sea surface, water column and deep-sea sediments harbour high levels of microplastic pollution, especially the seafloor, with up to ~13,000 microplastics per kg sediment at the northernmost station (Bergmann et al. 2017b; Peeken et al. 2018; Tekman et al. 2020). Plastic has also invaded the Arctic food web (Trevail et al. 2015; Kühn et al. 2018) including sea ice-associated zooplankton (Botterell and Bergmann, in prep.). Significant quantities of microplastic in Arctic snow samples indicate that atmospheric transport plays an important role (Bergmann et al. 2019). Recent data even suggest that the sea surface acts as a source of airborne microplastic (Allen et al. 2020). Still, on the whole, the role and processes of atmospheric transport of microplastics have not yet received the merited scientific attention although they are considered to play a key role (Zhang et al. 2020).

Work at sea

Observation of litter and microplastic pollution on the seafloor

Transects by the towed camera system OFOBS will conducted during at various HAUSGARTEN stations (HG-I, HG-IV, N3, and S3; Fig. 2.1) and will enable us to assess if marine litter continues to increase on the seafloor. The new footage will extend our image time series that started in 2002. Sediments from the same stations will be sampled to assess microplastic contamination of the seafloor (multiple corer). The results can be combined with results from previous analyses (Bergmann et al. 2017b; Tekman et al. 2020) and allow us to build a time series.

Assessment of litter floating at the sea surface

Observer surveys with a hand-held GPS device will be done from one of the upper decks to assess litter densities at the sea surface when the ship is in transit. The data can be compared with results from previous surveys to delineate temporal trends. A comparison with data from seafloor surveys allows us to assess partitioning of litter in different ecosystem compartments and identify sinks.

Quantification of airborne microplastic

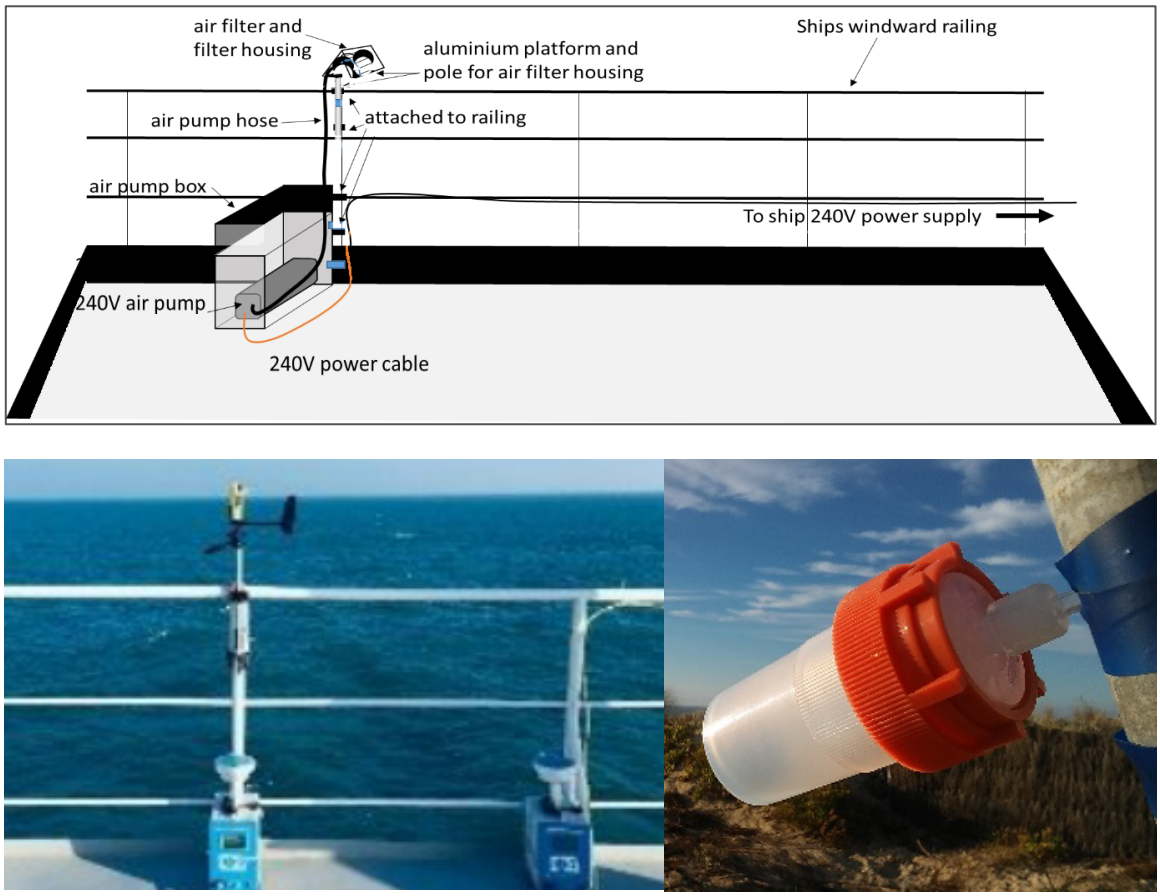
Three active air-pumping devices will be fitted to the Peil-Deck (Fig. 9.1) to quantify airborne microplastic pollution in 24-hour time steps throughout the cruise. The transit from Bremerhaven to the HAUSGARTEN area is of particular interest to delineate large-scale pollution patterns and transport processes. In addition, passive air deposition samples will be collected daily (24-hour time steps) throughout the transit and stationary periods of the Bremerhaven to the HAUSGARTEN area *Polarstern* voyage. The passive samples will be collected using MilliQ flush into a glass or aluminium container. This will then be taken to the *Polarstern* on-board laboratory and filtered onto appropriate (1 µm pore) filters which using glass vacuum filtration device (240 V) and the samples (on filter material) retained for analysis in the University of Strathclyde laboratory. A subsample of the liquid will also be retained (pre filtration) for quantitative mass analysis, decanted into glass vials in the on-board laboratory.

Laboratory work will be conducted during periods of lowest footfall, potentially during evening or out of peak laboratory use hours, to ensure minimum background contamination of the samples. There is very limited marine air sampling published to date (Liu et al. 2019; Wang et al. 2020; Allen et al. 2020), and this survey will be the first high latitude northern hemisphere analysis of marine air microplastic. In addition, snow samples will be gathered during helicopter flights to ice floes to assess atmospheric fallout. The data complement previous measurements (Bergmann et al. 2019) and will support the first atmospheric transport analysis of microplastic in the high latitude and Arctic marine environment.

Expected results

The atmospheric microplastic results expected include between 10-35 atmospheric microplastic samples (in triplicate, subject to wind direction, precipitation and sampling constraints, alongside up to 12 unique deposition samples and up to 10 surface snow samples. These will provide a spatial quantification of atmospheric microplastics, and when combined with back trajectory particle transport analysis will examine where these plastic particles may have come from and the route of atmospheric transportation.

A



B

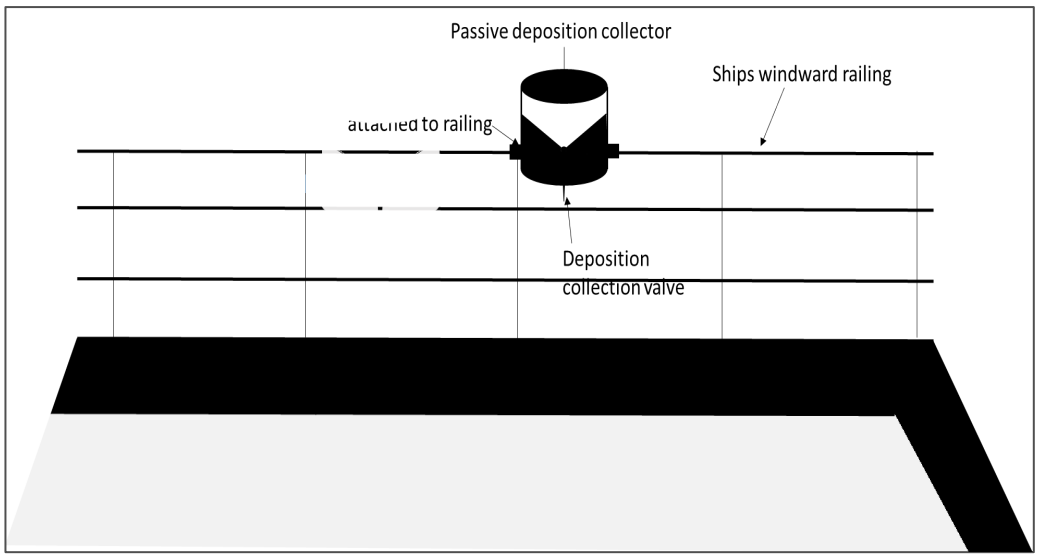


Fig. 9.1: Sketch and photograph of (A) active air-sampling devices and (B) deposition sampler set-up to be used to quantify airborne microplastic

Sample and data management

After the cruise, all imagery will be uploaded to the PANGAEA data repository (www.pangaea.de). Still images will also be uploaded to the BIIGLE image annotation portal BIIGLE to enable image analysis. The analysis results will also be saved to PANGAEA and available as soon as the data are published. We aim to publish in open-access journals so there should be no embargo after publishing. The filters of the atmospheric and snow samples will be analysed at the University of Strathclyde (Glasgow, UK) by Micro-Raman spectroscopy. Sediment samples will be analysed by Micro-FT-IR spectroscopy at AWI Heligoland. When published, all data will be made publically available via PANGAEA and the AWI-operated marine litter portal LITTERBASE (www.litterbase.org).

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10. FRAMJELLY - GELATINOUS ZOOPLANKTON IN THE GATEWAY TO THE ARCTIC: ADVANCED METHODS TO CHARACTERIZE THEIR DIVERSITY, DISTRIBUTION AND ROLE IN THE FRAM STRAIT FOOD WEB

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Grant No. AWI_PS126_09

Objectives

Gelatinous zooplankton, hereafter also referred to as jellies, are fragile, soft-bodied organisms grouping together a number of phylogenetically unrelated taxa: ctenophores, scyphozoans (true jellyfish), hydrozoans (including the colonial siphonophores and hydromedusae), and pelagic tunicates (salps and appendicularians) (Fig. 10.1). Despite their dissimilarities, most of them have in common the alternance between sexual and asexual reproduction, taking advantage of favourable environmental conditions by rapidly growing and multiplying. Because of their fragile bodies, they are easily fragmented or destroyed with traditional net sampling, which is why jellies are often neglected in pelagic studies, or when considered, their biomass and diversity are greatly underestimated (Hosia et al. 2017). Jellies are known to be major drivers of ecosystem changes. Many species cope well with environmental change (warming, eutrophication, oxygen reduction, overfishing) and an increase in jelly biomass, or “jellification” has been observed in several marine ecosystems worldwide (e.g. Richardson et al. 2009). Such gelatinous shifts can affect food web dynamics and cause the collapse of commercially important fish stocks (Purcell 2012).

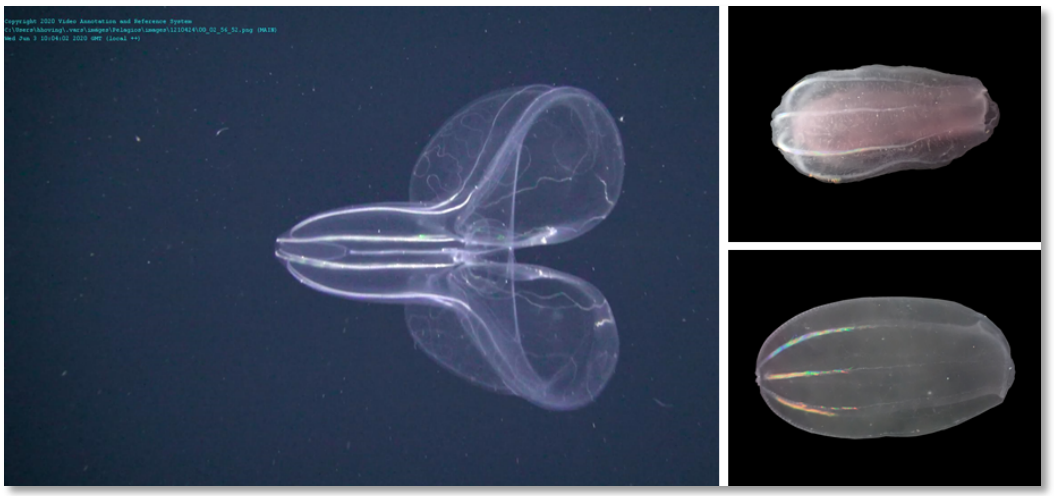

Fig. 10.1: Arctic ctenophores. Left: Bolinopsis observed by PELAGIOS during PS121 (Photo: Henk-Jan Hoving) Right: Beroe species collected around Svalbard during HE560 (Photos: Gerlien Verhaegen)

Because of the significant impacts of climate warming on the Arctic marine ecosystem, a large-scale assessment of its biodiversity is particularly pressing. However, reliable data on the abundance, species boundaries and trophic role of Atlantic and Arctic jellies are virtually inexistent. Hence, jellies have thus far been completely ignored in scenarios of species interactions and range shifts despite their importance in both Atlantic and Arctic ecosystems (Licandro et al. 2015; Mánko et al. 2020). Nonetheless, an increase in advected boreal-Atlantic species is anticipated with the growing Atlantification of the pelagic system. This is illustrated with the recent increase in biomass of the scyphozoan *Periphylla periphylla* in the Barents Sea (Tiller et al. 2017) and its recent first-time appearance in a high-Arctic Svalbard fjord (Geoffroy et al. 2018). The LTER (Long Term Ecological Research) HAUSGARTEN site is one of the most elaborately and intensively sampled pelagic and deep-sea time series and situated at the Atlantic gateway to the Arctic, it is the harbinger of ongoing changes in the Arctic. Yet it currently lacks a component that targets the gelatinous zooplankton community despite their high abundances observed in Fram Strait's surface waters (Havermans, pers. obs.) and their likelihood to undergo community changes.

Jellies not only belong to different taxonomic lineages, they also greatly differ in feeding ecology. Trophic roles can be classified into i) filter feeders and grazers such as tunicates, ii) passive trappers feeding on diverse prey types, such as siphonophores, and iii) active hunters like ctenophores, feeding on zooplankton, ichthyoplankton and other jellies. Many species, such as the dominant ctenophore *Mertensia ovum*, are known to exert a major footprint on lower trophic levels, as it rarely reaches satiation at natural prey densities. However, little is known so far on the variation in feeding habits and spatio-temporal trophic flexibility of jelly populations. Considering that jellies will become more important in many oceans, their ecosystem impact as predators and prey will similarly increase. Until recently, the contribution of gelatinous zooplankton to predators' energy budgets was greatly underestimated. Jellies have a low energy density in comparison to other plankton (Doyle et al. 2007) and have therefore been considered a "trophic dead-end". Since their watery tissues are rapidly digested in predator's stomachs, traditional microscopic analyses have often overlooked the presence of jellies in predator diets, generating an oversimplified view on their role in the food web. Even though the importance of jellies as prey is still difficult to quantify, evidence from molecular diet analyses and *in-situ* observations has proven their top-down control to be much more important than previously assumed. Indeed, many fish, birds, turtles, cephalopods and other invertebrates target jellies as part of their diet (Hays et al. 2018). This concept of jellies functioning as an "energy roundabout" – moving energy through a number of trophic levels, from zooplankton to top consumers (Robinson et al. 2014) – deserves a further validation for polar ecosystems.

Jellies can also be important vectors of carbon to the deep-sea floor. Because of a combination of an assumingly low predation pressure following a bloom event, sinking jellies may represent a fast export mechanism of carbon to the seafloor in the shape of "jelly-falls" (Lebrato et al. 2012). Appendicularians produce several new houses per day, of which the discarded ones sink at fast rates, significantly contributing to the biological carbon pump, which also holds for Arctic regions (Deibel et al. 2005). Once on the seafloor, jelly carcasses may sustain a diverse benthic scavenging community, including amphipods (Havermans and Smetacek 2018).

The overarching goal of the FramJelly project is to establish a comprehensive baseline knowledge of jelly diversity, abundance and distributional patterns and their link to oceanography and primary production. Our integrative jelly surveys will consist of a combination of various net sampling, *in-situ* optical observations and environmental DNA (eDNA) studies. The optimization of eDNA methods will establish a cost-effective monitoring tool, allowing to detect incoming jelly species and changes in community composition based on water sampling. The trophic role of key jelly species in the pelagic food web will be explored as well as the role of jelly-falls sustaining the benthic food web. This knowledge will serve to

evaluate potential distribution shifts of Atlantic and Arctic gelatinous zooplankton species and their consequences for the Arctic food web.

The objectives of the FramJelly project are:

- Study gelatinous species diversity and abundances and link these to environmental parameters. These data will be used for modelling efforts to better understand habitat preference and predicting future niches under warming scenarios *(integrative surveys and Species Distribution Modelling)*;
- Elucidate the trophic role of jellies in the Fram Strait food web. The feeding ecology of dominant jelly species and their role as prey for pelagic predators will be assessed (*net sampling, biomarker and molecular diet analyses*);
- Evaluate the occurrence and importance of (jelly) carcasses as vectors for carbon linking pelagic and benthic food webs and the role of jelly-falls as food for benthic scavengers (*optical surveys, lander deployments with baited traps, biomarker and molecular diet analyses, in-vitro feeding experiments*);
- Characterize the molecular diversity of jelly species encountered in the different water masses and the connectivity of Arctic populations by comparing with specimens collected during other Arctic cruises (e.g. central-Arctic, Svalbard, Greenland) (*net sampling, DNA barcoding and phylogeographic analyses*);
- Optimize eDNA methods for assessing jelly (and other metazoan) diversity in the water column and in the deep-sea sediments. DNA calibration and degradation experiments with different species composition and biomass of jellies will be carried out (*water and sediment sampling, in-vitro experiments, molecular analyses*).

Work at sea

At eight HAUSGARTEN stations (SV-II, SV-IV, HG-I, HG-IX, N5, EG-I, EG-II, EG-III), we will carry out a “basic” jelly programme, including net casts with the Maxi-Multinet, Bongo and jelly nets. At four other stations (N4, HG-IV, S3, EG-IV), we plan to conduct a “full” programme, carrying out – in addition to the aforementioned net sampling – a towed video survey with PELAGIOS II, and a bentho-pelagic survey with the PELAGIOS I mounted on OFOS. At each of the basic stations, we will sample water for eDNA for assessing jelly species diversity at four different depths (surface, Chl max, 50 and 100 m). At the full stations, we plan to have an integrative survey on species diversity and vertical species distributions comparing video surveys, depth-stratified net hauls and water sampling for eDNA from the CTD, at ten different depths over the entire water column. Net sampling at the same depths as the PELAGIOS tows will allow us to capture the observed organisms and to morphologically and genetically validate the *in-situ* identifications. At all stations, we will sample sediment from the multiple corer (MUC) for eDNA studies aiming to detect potential “food falls”. At three stations, we will deploy a free-fall lander equipped with baited traps to sample bentho-pelagic scavenging amphipods.

Optical surveys

In-situ observations can provide novel insights in organism distribution, diversity, ecology and behaviour. Particularly for the fragile gelatinous zooplankton, optical methods have many advantages over traditional net sampling. Towed camera technology PELAGIOS has been developed at GEOMAR to perform deep-sea pelagic video transects down to 3,000 m water depth. This technique has discovered new species and records, their biogeochemical role (Christiansen et al. 2018; Hoving et al. 2018) and regional diversity, vertical distribution and abundance of pelagic fauna (Hoving et al. 2019; 2020). Therefore, to quantify biodiversity and

vertical distribution of gelatinous zooplankton (and other fauna like cephalopods) we will deploy the pelagic towed camera system PELAGIOS II. This system will be towed horizontally via the fibre optic cable at low ships speed (1 knot) at 10 different depths from 35 m to 1900 m. The telemetry transmits a high-resolution preview of the water column and the organisms. The PELAGIOS II consists of a 4k camera, a depth sensor with current meters, and a CTD. The water column in front of the camera is illuminated by LED lights. The videos are annotated using the video and annotation reference system (VARS), and the data is integrated into the Oceanic Biodiversity Observation Database (OBOD) at GEOMAR.

Since many jellies were observed above the seafloor during PS119 (Hoving, pers. obs.), bentho-pelagic surveys (1 h) will be carried out with PELAGIOS mounted on OFOS at different depths (10 m, 25 m, and 100 m) above the seafloor.

Sampling and experiments with live jellies
Gelatinous zooplankton samples for species identification, abundance data, molecular analyses and experimental work will be collected by Multinet, Bongo net and jelly net deployments. The Maxi-Multinet (mesh sizes 330 – 4,000 µm) will be deployed vertically or obliquely through the water column with nine different nets for depth-stratified sampling. Bongo nets (mesh sizes 335 - 500 - 1,000 µm), equipped with a large non-filtering cod-end and a V-Fin depressor will be towed obliquely at a ship's speed of 2 knots and wire length of 60 - 500 m. Vertical Bongo/jelly net deployments at slower speed will allow us to sample organisms in a good state for species identifications and to perform experiments for eDNA calibration.

Jelly abundances will be calculated based on the volume of water sampled and the number of jellies counted per species. Wet weight will also be determined. Freshly caught jellies will be identified to the lowest taxonomic level possible and photographed for posterior identification, with particular attention to identification features (e.g. gonads, manubrium, shape of the umbrella, tentacle arrangement, oral arms) depending on the taxonomic group. Specimens will be measured and preserved in ethanol (voucher specimens) or frozen at -80 °C. Other macrozooplankton such as hyperiid amphipods will be collected for trophic analyses (molecular diet and biomarker analyses), and preserved at -80 °C.

We will carry out several experiments to determine the shedding of DNA by jelly individuals and its detectability over time for different biomasses of one particular ctenophore/hydrozoan species, as well as different species compositions of jellies (ctenophores, hydrozoans). These incubations will last several days and the eDNA present in the water will be monitored over time by filtering water at regular time intervals. Sterivex filters will be frozen at -80 °C and extracted for DNA in the AWI laboratories, whereas the animals will be frozen for determination of body dry mass to obtain eDNA release rates per unit of time and biomass. We also plan to conduct eDNA degradation experiments, from *in-situ* control samples incubated over time, as well as experiments with water where live jellies have been incubated. We will compare different genes and primer sets to test the detectability of the DNA of the different species and use quantitative real-time PCR for comparisons of the eDNA signatures (and their degradation) of the different biomasses.

Expected results

Gelatinous zooplankton species composition and abundances will be determined for each net haul and linked with oceanographic features and primary productivity. Their vertical distribution, abundances and diversity will also be assessed based on the footages from the pelagic and bentho-pelagic surveys. This, together with the results on the species diversity of jellies from the eDNA studies from water samples will allow us to generate a comprehensive overview of the different gelatinous zooplankton communities and small-scale distributions.

These data and video footages will also allow to build a presence dataset of gelatinous zooplankton, including information on the environmental parameters. Together with other datasets of Arctic GZ (e.g. datasets from the Gulf of Alaska and the Chukchi Sea), ecological niche models will be run in three dimensions for each jellyfish species in order to answer questions regarding their distribution, ecology (e.g. limiting environmental factors defining their distribution), and evolution (e.g. speciation mechanisms). This information will be valuable to define the current Arctic ecosystem, but also to predict how climate and environmental change will affect this ecosystem in the future.

The results of our planned biomarker and molecular diet analyses on dominant jelly species will allow us to elucidate longer-term dietary signals (including those characteristic of ice algae versus pelagic flagellates with marker fatty acids) as well as a full characterization of prey spectrum analysis at species level (DNA metabarcoding of gastric pouch contents). The same will be done for macrozooplankton (e.g. hyperiid amphipods) to assess the occurrence of jelly predation in these species.

Jelly specimens will be genetically characterized (or "barcoded") by sequencing the cytochrome c oxidase subunit 1 (COI), 16S rDNA and 18S rDNA to complement existing reference databases, to assess initial genetic variability of morphospecies and reveal their phylogeographic patterns. For widespread species, their genetic connectivity will be assessed between Fram Strait populations and other previously sampled localities (Greenland, Svalbard, central-Arctic). Further molecular analyses of selected taxa so far considered as displaying a bipolar distribution (i.e. *Ptychogena* spp. and *Dimophyes arctica*) will also be compared with the corresponding Antarctic representatives. This will allow to elucidate whether they belong to the same taxa (i.e. there is gene flow between populations) or not (i.e. bipolar speciation).

Results of the eDNA calibration and degradation experiments will allow us to test the effectiveness of different primer sets and yield novel information on the potential of eDNA as a proxy for jelly diversity and species abundances.

If successful, the results of the larval reproduction experiments will constitute the first evidence of this peculiar trait in the genus *Bolinopsis*, and for *Mertensia ovum* in Arctic waters. This will shed light to a so far neglected reproductive strategy, which will be key to better understand several aspects of the population dynamics of these species, and potentially linking its occurrence to different food-availability scenarios.

Data management

Zooplankton samples and Sterivex filters for eDNA studies will be archived and stored at the AWI and GEOMAR. DNA extracts of jellies and eDNA samples from water column and sediment will be stored at -80°C for up to ten years after publication of the results (according to the DFG guidelines for good scientific practice). A voucher collection of ethanol preserved jelly specimens, linked to their DNA extracts, will be kept in a repository at the AWI. Geo-referenced datasets including species inventories, distribution records and abundance data of macrozooplankton from net catches will be submitted to PANGAEA (www.pangaea.de) as soon as the data are available (within six months after the expedition), with an embargo period for max. two years until publications have been finalized. By doing so, every dataset, as a supplement to publications or separately, can be identified, published, cited and shared using a Digital Object Identifier (DOI). Biogeographic datasets will also feed other databases (e.g. OBIS, GBIF). Acquired video footages will be archived in IT storage infrastructures of both GEOMAR and AWI, and metadata will be accessible via the Ocean Science Information System (OSIS, https://portal.geomar.de/osis) within 6 months after completion of the expedition. After quality assessment and annotation, the annotated datasets with images will be submitted to PANGAEA, and released as soon as the results are published (max. two years after the expedition, with a potential embargo period of one extra year). Genetic data obtained throughout the project will be submitted to GenBank during the publication process; results of

the metabarcoding projects will be deposited in the National Center for Biotechnology Information (NCBI). Results of the PS126 expedition will be published in peer-reviewed journals within three years after the cruise.

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DE.Heli-Service	Heli-Service International GmbH Gorch-Fock-Straße 105 26721 Emden/Germany
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Allen	Deonie	UK.USTRAT	Scientist	Microplastic
Bergmann	Melanie	DE.AWI	Scientist	Biology
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Havermans	Charlotte	DE.AWI	Scientist	YIG FramJelly
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Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
Nordhausen	Axel	DE.MPIMM	Technician	Lander/Crawler
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Xi	Hongyan	DE.AWI	Scientist	Marine Optics
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Wenzel	Julia	DE. DWD	Scientist	
Heli-Service				
Enriquez Garcia	Alberto	DE.HeliService	Technician	
Jager	Harold	DE.HeliService	Pilot	
Picard	Xavier	DE.HeliService	Pilot	
Richter	Roland	DE.HeliService	Technician	

13. SCHIFFSBESATZUNG / SHIP'S CREW

No.	Name	Rank
01.	Schwarze, Stefan	Master
02.	Spielke, Steffen	C/Mate
03.	Langhinrichs, Jacob	2.NO Ladung
04.	Fallei, Holger	2nd Mate 2
05.	TBN	2nd Mate 3
06.	Heuck, Hinnerk Soeren	Chief Eng
07.	Brose, Thomas Christian Gerhard	2nd. Eng
08.	Kästner, Manfred Andre	2nd. Eng 1
09.	Haack, Michael Detlev	2nd. Eng 2
10.	Dr. Hofmann, Walter Joerg Walter	Chief Elec.Eng.1
11.	Frank, Gerhard	Elec./Eng. Brücke
12.	TBN	Elec./Eng. Labor
13.	Redmer, Jens Dirk	Elec./Eng. SET
14.	Nasis, Ilias	Elec./Eng. System
15.	Krueger, Lars	Elec./Eng. Winde
16.	Sedlak, Andreas Enrico	Bosun
17.	TBN	MP Rating/D 2
18.	Moeller, Falko	MP Rating/D 3
19.	TBN	MP Rating/D 1
20.	Meier, Jan	MP Rating/M 3
21.	Hilliger, Maik	MP Rating/D 7
22.	Wende, Uwe	AB 1
23.	Schwarz, Uwe	MP Rating/M 1
24.	Gebhardt, Norman	MP Rating/M 2
25.	Rhau, Lars-Peter	MP Rating/M 4
26.	Teichert, Uwe	MP Rating/M 5
27	Sautmann, David	MP Rating/M 3
28.	Neisner,Winfried	Carp. 1
29.	Baecker, Andreas	AB 3
30.	Burzan, Gerd-Ekkehard	AB 9
31.	Preußner, Jörg	Fitter/E 1
32.	TBN	Cook 1
33.	Silinski, Frank	2nd Cook 1
34.	Zahn, Maren	2nd Cook 2
35.	Czyborra, Baerbel	C/Stwd. 1
36.	Braun, Maja Alexandra	Stwd./KS
37.	Silinski, Carmen Viola	2nd Stwd. 1

No.	Name	Rank
38.	Krause, Tomasz	C/Stwd. 1
39.	TBN	2nd Stwd. 3
40.	Arendt, Rene	2nd Stwd. 4
41.	Chen, Quanlun	2nd Stwd. 5
42.	Hu, Guo Yong	2nd Stwd. 6
43.	Goessmann - Lange, Petra	Doc. 1
44.	Stellamanns, Thies Christian	App.MP 1
45.	Lenz, Julien Alexander	App.MP 2