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Ecosystem mapping in the Central Arctic Ocean (CAO) during the MOSAiC Expedition

Final Report

Specific Contract
EASME/EMFF/2018/1.3.2.2/03/SI2.805469

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LIST OF ABBREVIATIONS

Term	Description
AWI	Alfred-Wegener-Institut (Bremerhaven, Germany)
CAO	Central Arctic Ocean
CINEA	European Climate, Infrastructure and Environment Executive Agency (successor of EASME)
CTD	Conductivity, Temperature, Density measuring device
DG MARE	Directorate-General for Maritime Affairs and Fisheries
DSL	Deep Scattering Layer
DVM	Diel Vertical Migration
EASME	Executive Agency for Small and Medium-sized Enterprises (predecessor of CINEA)
EC	European Commission
EEZ	Exclusive Economic Zone
EFICA	European Fisheries Inventory in the Central Arctic Ocean Consortium
EMFF	European Maritime and Fisheries Fund
EU	European Union
EU CFP	EU Common Fisheries Policy
FishCam	Deep-sea camera system deployed by the EFICA scientists during MOSAiC
FWC	Framework Contract
JGI	Joint Genome Institute (USA)
LOKI	Light frame On-site Key species Investigation
mcs	MOSAiC Central Storage (database)
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
PCR	Polymerase Chain Reaction
ROV	Remotely Operated Vehicle
RV	Research vessel
SAS	Synoptic Arctic Survey (a scientist-driven initiative aiming at collecting primary ecosystem data in the Arctic Ocean 2020-2022)
SC	Specific Contract
SC03	Specific Contract 3
SLU	Swedish Agricultural University, Department of Aquatic Resources (Lysekil, Sweden)
SFPs	Standard Fish Protocol Sheets
SOPs	Standard Operation Protocols
SU	Stockholm University (Sweden)
Team ATMO	The MOSAiC Team collecting atmospheric data (mainly physical)
Team BGC	The MOSAiC Team collecting biogeochemistry data (mainly chemical)
Team ECO	The MOSAiC Team collecting ecosystem data (mainly biological)
Team ICE	The MOSAiC Team collecting ice data (mainly physical)
Team OCEAN	The MOSAiC Team collecting water column data (mainly physical)
WMR	Wageningen Marine Research (The Netherlands)

ABSTRACT

Ecosystem mapping in the Central Arctic Ocean (CAO) during the MOSAiC Expedition

As a result of global warming, the marine ecosystem around the North Pole, the Central Arctic Ocean (CAO), is in fast transition from a permanently to a seasonally ice-covered ocean. The sea-ice loss will enable summer access to the CAO for non-icebreaking ships, including fishery vessels, in the near future. However, the lack of knowledge on the CAO ecosystem impedes any assessment of the sustainability of potential future fisheries in the CAO. Taking a precautionary approach, nine countries and the EU established in 2021 the *Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean*, which a.o. includes mapping and monitoring of the CAO ecosystem before any commercial fishery is initiated. To reduce the existing lack of knowledge, the EFICA Consortium participated, together with ca. 250 on-board scientists, in sampling and data collection of ecosystem data during four legs of the international MOSAiC expedition in 2019-2020. This report describes the field work performed by the EFICA scientists using water-column acoustics, deep-sea video recording, and fish and eDNA sampling for targeting zooplankton and fish. Further ecosystem data (physical, chemical and biological) were collected by the EFICA scientists in collaboration with other scientists on-board. Together with this report, a metadata database containing lists of all collected samples and data that are relevant for future fishery assessment studies was delivered to the European Commission.

RÉSUMÉ

Cartographie de l’Ecosystème de l’Océan Central Arctique (CAO) au cours de l’expédition MOSAIC

L’écosystème marin des régions du Pôle Nord, l’océan central arctique (CAO), historiquement couvert de glace de façon permanente, subit actuellement une transition rapide vers une glaciation saisonnière du fait du réchauffement climatique. Cette diminution de la banquise entrainera dans un futur proche l’accès estival pour les navires, dont les bateaux de pêche, à l’océan central arctique, sans besoin de recourir à des brises glaces. Cependant, l’absence de connaissances suffisantes sur l’écosystème CAO empêche toute évaluation de la durabilité de futures pêcheries potentielles au sein de CAO. Partant du principe de précaution, neuf états ainsi que l’Union Européenne ont établi en 2021 le *Traité pour la prévention de pêcheries non régulées en haute mer dans l’océan arctique central*. Ce traité inclut la mise en place d´une cartographie et une surveillance de l’écosystème CAO préalable à toute éventuelle pêcherie commerciale. Afin de pallier au manque de connaissances actuel, le consortium EFICA a contribué à l’effort conjoint des 250 chercheurs présents à bord pour collecter des échantillons et données de l’écosystème CAO, et ce au cours des 4 tronçons de l’expédition internationale MOSAIC en 2019-2020. Le rapport ci-joint décrit le travail de terrain des scientifiques du groupe EFICA, réalisé à l’aide de mesures acoustiques sous-marines le long d´un gradient vertical de la colonne d’eau, d’enregistrements vidéos à basse profondeur, ainsi que de prélèvements de poissons et d’échantillons pour l’analyse d’ADN environnemental (eDNA) provenant de zooplancton, phytoplancton et de poisson. Par ailleurs, la collaboration entre l’équipe EFICA et les chercheurs à bord a permis de collecter des données physiques, chimiques et biologiques pour une meilleure description de l’écosystème. En complément de ce rapport, un registre de données répertoriant l´ensemble des échantillons et des données collectés ayant une importance pour les études concernant une pêcherie future dans le CAO, a été fourni à la Commission Européenne.

EXECUTIVE SUMMARY

Within the Framework Contract (FWC) "Provision of Scientific Support to the High Seas Fisheries in the Central Arctic Ocean (CAO)", the Contractor (the EFICA Consortium) has collected ecosystem data in the CAO to support the Joint Program of Scientific Research and Monitoring (JPSRM) of the "Agreement to prevent unregulated high seas fisheries in the Central Arctic Ocean"[1] that entered into force on 25 June 2021.

The work reported here was carried out within Specific Contract SC03 (under the FWC): "Ecosystem mapping in the Central Arctic Ocean (CAO) during the MOSAiC Expedition" (11 July 2019 – 10 July 2021). The international MOSAiC expedition was a transpolar drift expedition with the German research icebreaker *Polarstern* anchored to the sea ice, that took place 20 September 2019 - 12 October 2020. The target area of the expedition was the Eurasian Basin of the Arctic Ocean and the Fram Strait gateway (**Figure 1**). Most of this area is situated within the High Seas portion of the CAO.

The objective of SC03 was to collect new field data for addressing the four questions proposed for the mapping phase of the JPSRM by the Fifth FiSCAO Meeting[2], and further developed in the First PSCG Meeting[3], by expert groups appointed by the Signatories of the Agreement. These four questions are:

(1) What are the distributions of species with a potential for future commercial harvests in the High Seas portion of the CAO?
(2) What fish species are currently present in the High Seas portion of the CAO?
(3) What are the trophic linkages among fishes and between fishes and other taxonomic groups?
(4) What are the likely key ecological linkages between potentially harvestable fish stocks of the High Seas portion of the CAO and adjacent shelf ecosystems?

Figure 1: The *Polarstern* track during the MOSAiC expedition (red = drift with scientific work, white = transits), and the ship anchored to the sea ice in the Arctic winter. © Markus Rex (ship photograph), 2019

[1] EU (2019) Agreement to prevent unregulated High Seas fisheries in the Central Arctic Ocean. *Official Journal of the European Union* L 73, 3–8.
[2] FiSCAO (2018) Final Report of the Fifth Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean. FiSCAO. 45 pp.
[3] PSCG (2020) Report of the 1st meeting of the Provisional Scientific Coordinating Group (PSCG) of the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean. PSCG. 63 pp.

For addressing these four questions, the EFICA Consortium has collected hydroacoustic data, deep-sea video recordings, fish samples and environmental DNA (e-DNA) samples. The deliverables of SC03 consist of metadata, i.e., a compilation of data and samples collected during the expedition, but no further data or sample analyses. These metadata were compiled in 15 Excel files that together constitute the "SC03 Metadata Database".

During the expedition, the EFICA field scientists contributed extensively to collecting the MOSAiC Core Parameters, and the EFICA Consortium has therefore access to EFICA-relevant physical, chemical and biological ecosystem data that – in combination with the EFICA-specific data – allow for food-web analyses and ecological modelling to address the four research questions for the MOSAiC study area (within a future SC under the FWC).

Some tentative results and conclusions based on the observations made during the MOSAiC expedition fieldwork are presented below (1-10). However, please note that these results and conclusions are only preliminary and not quantitative. They must be confirmed by detailed studies of the MOSAiC data and samples before they are scientifically valid.

(1) Routine fisheries assessments are normally based on trawling and hydroacoustics in combination, but logistical difficulties prevent such activities in the CAO. While trawled nets cannot be applied in the CAO today due to its thick ice cover, also acoustic data collection is problematic because hydroacoustic backscatter from organisms is distorted by noise from ice-breaking. Since the MOSAiC expedition was a drift expedition, the latter difficulty could be overcome, but systematic fish sampling remained a challenge.

(2) The unique, one-year long hydroacoustic dataset collected by the EFICA Consortium during the transpolar drift suggests that fish occur in a continuous deep scattering layer (DSL) in the "warm" Atlantic water layer of the Amundsen and Nansen basins at ca. 200-500 m of depth. This confirms the results from a previous study carried out in summer 2016 with the Swedish icebreaker *Oden* at 13 discrete hydroacoustic stations along a transect from 83.2 °N in the Nansen Basin, across the Eurasian Basin, the North Pole and the Lomonosov Ridge, to 82.4 °C in the Canada Basin[4].

(3) Similar to the 2016 study, the hydroacoustic signals during the MOSAiC transpolar drift suggested that the DSL over the deep Amundsen Basin contains low abundances of zooplankton and small fish (roughly <15 cm long).

(4) The hydroacoustic dataset from Leg 5 of the MOSAiC transpolar drift suggested that fish abundance in the DSL could be higher closer to the Lomonosov Ridge.

(5) In contrast to the deep basins, fish abundance was high in the DSL at the inflow of Atlantic water to the CAO near the Yermak Plateau north of Svalbard. These fish have the possibility to enter the CAO with the Atlantic water inflow.

(6) Atlantic cod (*Gadus morhua*) and armhook squid (*Gonatus fabricii*) were sampled/observed in the DSL of the deep Amundsen Basin. These records are much further north than expected for these Atlantic species. However, they were very few; only three Atlantic cod were sampled in the central Amundsen basin despite intensive fishing efforts throughout the entire expedition.

(7) Larger fish (roughly up to ca. 60 cm long) were observed on the echosounder with maximally about two individuals passing under the ship per hour in the beginning of Leg 1 when Atlantic cod and ice cod (*Arctogadus glacialis*) were sampled. On the video recordings, armhook squid was observed at a maximum rate of about six individuals per 24 hours passing the camera. Fish were observed on the video recordings only very rarely and could not be identified because they moved too fast.

[4] Snoeijs-Leijonmalm P. et al. (2021) A deep scattering layer under the North Pole pack ice. Progress in Oceanography 194:102560. [https://doi.org/10.1016/j.pocean.2021.102560]

(8) The sampling efforts performed by the EFICA scientists suggested that longlines and fishing rods are effective for targeting larger fish species, such as Atlantic cod (*Gadus morhua*) and the Arctic endemic ice cod (*Arctogadus glacialis*) in the DSL. However, the smaller fish species tentatively detected by hydroacoustics during the entire transpolar drift, were not sampled. This suggests that other methods need to be developed for sampling them.

(9) The gillnets that were deployed during the transpolar drift were not successful, probably because the fish biomass along the MOSAiC track was extremely low.

(10) Future sustainable commercial fisheries in the deep Eurasian Basins do not seem feasible given the extremely low fish biomass and the fact that the productivity of the CAO ecosystem is expected to remain very low for a long time, even if the ice would disappear completely and the inflow of Atlantic water to the CAO would increase by global warming.

The work reported here may contribute to developing the data sharing protocol and the joint monitoring program of the JPSRM, including the development of methods for fish sampling under a 2-m thick ice cover when fish abundance in the DSL is very low. Future analyses of the data and samples collected during the MOSAiC expedition can provide information on the identity (e-DNA), size, density and biomass of pelagic living organisms 11-1000 m, the ecological living conditions for fish, food availability, food quality for juvenile and adult fish, and the potential for fish production in the CAO ecosystem. It should be noted that the collected data concern the deep Eurasian Basins of the CAO (not the ridges), and the inflow area of Atlantic water to the CAO.

This SC03 Final Report summarises the deliverables of SC03 (**Chapter 2**), the organisation and conditions for the execution of SC03 (**Chapters 3-6**), detailed records of the events and fieldwork carried out during the MOSAiC expedition (**Chapters 7-11**), the SC03 Metadata Database Manual (**Chapter 12**), and the SC03 Media Archive (**Chapter 13**).

1 INTRODUCTION

The marine ecosystems of the Arctic Ocean are experiencing rapid change. This includes the Central Arctic Ocean (CAO), i.e., the deep basins and ridges around the North Pole that previously were permanently covered by thick sea ice. In the past couple of decades, up to 40 % of the CAO has been ice-free during summer. This reduction in sea-ice coverage in the CAO is transforming a basically inaccessible marine ecosystem into a new type of ecosystem with seasonal changes in sea ice cover.

In response to the increasing accessibility of the CAO, the "Agreement to prevent unregulated High Seas fisheries in the CAO" between the European Union and nine countries (Canada, the People's Republic of China, the Kingdom of Denmark in respect of the Faroe Islands and Greenland, Iceland, Japan, the Republic of Korea, the Kingdom of Norway, the Russian Federation, the United States of America) was signed in October 2018. The Agreement entered into force on 25 June 2021 after it had been ratified by all ten Signatories. The Agreement takes a precautionary approach by essentially preventing any fishery in the Arctic High Seas, until a sound scientific knowledge base is available about the present fish stocks, the ecosystems sustaining them, and their expected fate in a changing Arctic Ocean.

There is almost no knowledge on the presence and distribution of fish populations in the rapidly changing CAO. The objectives of SC03 were to collect new field data for addressing the four questions proposed for the mapping phase of the JPSRM by the Fifth FiSCAO Meeting[5], and further developed in the First PSCG Meeting[6], by expert groups appointed by the Signatories of the Agreement. These four questions are:

(1) What are the distributions of species with a potential for future commercial harvests in the High Seas portion of the CAO?
(2) What fish species are currently present in the High Seas portion of the CAO?
(3) What are the trophic linkages among fishes and between fishes and other taxonomic groups?
(4) What are the likely key ecological linkages between potentially harvestable fish stocks of the High Seas portion of the CAO and adjacent shelf ecosystems?

Critical gap analyses performed by the EFICA Consortium within a previous Specific Contract (SC02)[7] highlighted that the knowledge gaps for the CAO are enormous and obstruct any quantitative analyses of its fish stocks (**Figure 2**). This was in agreement with the conclusions from the Fifth FiSCAO Report[4]. While data for the physical environment in the CAO (oceanography, bottom topography and ice-cover dynamics) would be sufficient, it is the massive lack of biological and ecological data that makes fish stock modelling and assessment impossible.

The work performed under specific Contract SC03 constituted the first systematic effort to map fish populations present on the Eurasian side of the CAO and provides information for future mapping and monitoring surveys as envisioned in the Agreement. SC03 enabled the EFICA Consortium to take part in the international MOSAiC drift expedition in order to collect primary data on the marine ecosystem, focusing on fish stocks and associated

[5] FiSCAO (2018) Final Report of the Fifth Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean. FiSCAO. 45 pp.
[6] PSCG (2020) Report of the 1st meeting of the Provisional Scientific Coordinating Group (PSCG) of the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean. PSCG. 63 pp.
[7] Snoeijs-Leijonmalm P. et al. (2020) Review of the research knowledge and gaps on fish populations, fisheries and linked ecosystems in the Central Arctic Ocean (CAO). EU Publications, European Commission, 80 pp.

parameters in the CAO. The EFICA Consortium prepared the expedition during the EFICA SC04 Workshop in Brussels on 17-18 June 2019[8].

For addressing the four questions proposed for the mapping phase of the JPSRM, and knowing the gaps in the scientific knowledge about the CAO ecosystem, a list of relevant ecosystem parameters for fish stock modelling and assessment was prepared (**Table 1**). The aim of SC03 was to collect these parameters as often as possible during the MOSAiC expedition.

Table 1: Ecosystem parameters relevant for fish stock modelling and assessment to be collected within SC03 during the MOSAiC expedition. These data are subdivided into two data categories: EFICA-specific data and EFICA-relevant MOSAiC Core Parameters = shared expedition data measured collectively by the >300 scientists on board, PELAGIC habitat = water column, SYMPAGIC habitat = ice-associated, nekton = actively swimming organisms (fish and squid).

Habitat / discipline / organisms	Type of data (sampling method)	Relevance for fish stock modelling and assessment	Parameters	Data category
Ship data	Documentation of ship track	Geographical positions of data and sample collections	Date, time, geographical position, ship speed, water depth, distance along track (hourly data)	EFICA-relevant MOSAiC Core Parameters
PELAGIC Oceanography	Physical water column data (CTD)	Physical living conditions for pelagic fish in the CAO	Temperature, salinity	EFICA-relevant MOSAiC Core Parameters
SYMPAGIC Ice physics	Physical ice-habitat data (ice cores)	Physical living conditions for sympagic juvenile fish	Temperature, salinity, snow depth, melting stage	EFICA-relevant MOSAiC Core Parameters
PELAGIC Biogeochemistry	Chemical and biological water-column data (CTD)	Nutrients and productivity indicate the potential for pelagic fish production	Dissolved nutrients, particulate C and N, chlorophyll, HPLC pigments	EFICA-relevant MOSAiC Core Parameters
SYMPAGIC Biogeochemistry	Chemical and biological ice-habitat data (ice cores)	Nutrients and productivity indicate the potential for sympagic juvenile fish production	Dissolved nutrients, particulate C and N, chlorophyll, HPLC pigments	EFICA-relevant MOSAiC Core Parameters
PELAGIC Invertebrates	Zooplankton data (plankton nets)	Food availability and food quality for pelagic fish	Species composition and abundance, Cand N, food quality, trophic biomarkers	EFICA-relevant MOSAiC Core Parameters
SYMPAGIC Invertebrates	Ice fauna data (ROV net)	Food availability and food quality for sympagic juvenile fish	Species composition and abundance, Cand N, food quality, trophic biomarkers	EFICA-relevant MOSAiC Core Parameters
PELAGIC Nekton	Physical and biological water-column data (hydroacoustics)	Living conditions, size, density and biomass of fish and zooplankton at 11-1000 m depth	Acoustic backscatter	EFICA-specific data

[8] EFICA Consortium (2019) EFICA Workshop in preparation for the Polarstern and Oden expeditions for 2019 and 2020. Report to EASME/DG MARE. 32 pp.

PELAGIC Nekton	Visual observations with deep-sea camera (FishCam)	Identity of pelagic living organisms, abundance of fish in relation to that of squid, jellyfish, siphonophores	Video recordings	EFICA-specific data
PELAGIC Nekton	Fish sampling with passive gear (longlines, gillnets, angling)	Presence, distribution and ecology of pelagic fish	Length, weight, age, genetics (fin clip), food-web structure (stomach contents, stable isotopes), food quality (fatty acids)	EFICA-specific data
SYMPAGIC Nekton	Fish data (ROV net)	Presence, distribution and ecology of sympagic fish	Length, weight, age, genetics (fin clip), food-web structure (stomach contents, stable isotopes), food quality (fatty acids)	EFICA-relevant MOSAiC Core Parameters
PELAGIC e-DNA	Bioinformatic analyses of the MOSAiC Core metagenomic data set	Presence and distribution of fish, squid, their predators and their prey	Sequences of mammal fish, squid, and zooplankton species	EFICA-specific data
SYMPAGIC e-DNA	Bioinformatic analyses of the MOSAiC Core metagenomic data set	Presence and distribution of fish, squid, their predators and their prey	Sequences of mammal fish, squid, and zooplankton species	EFICA-specific data

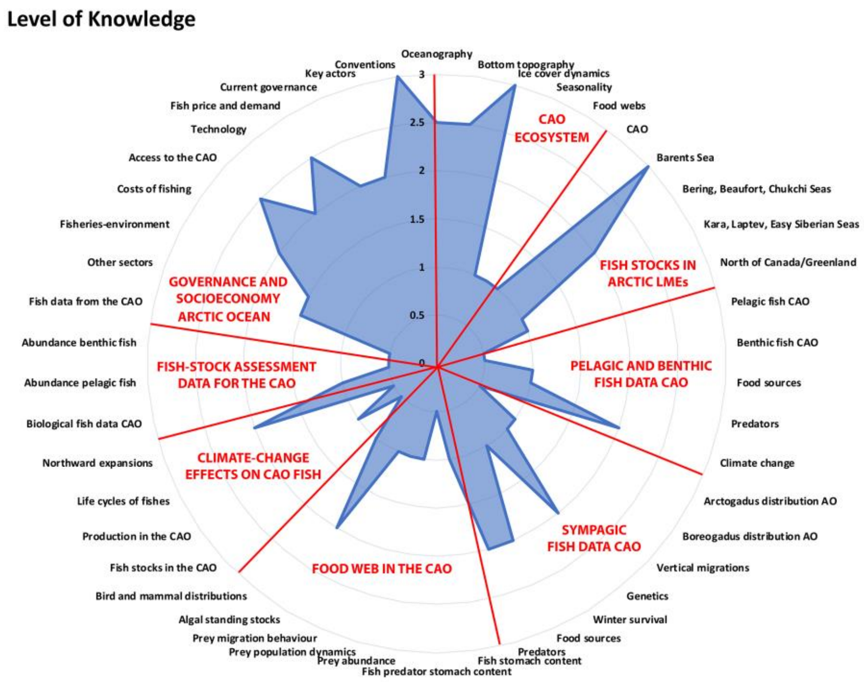

Figure 2: Radar chart summarising the gap analyses in Snoeijs-Leijonmalm et al. (2020)[9]. On the axis the estimates of the severity of the knowledge gaps are given: 0 = no knowledge, 1 = serious lack of knowledge, 2 = insufficient knowledge, 3 = sufficient knowledge available for fish stock modelling and assessment. The larger the blue area is in the direction of a specific subject, the smaller the relative knowledge gap on this subject.

[9] Snoeijs-Leijonmalm P. et al. (2020) Review of the research knowledge and gaps on fish populations, fisheries and linked ecosystems in the Central Arctic Ocean (CAO). EU Publications, European Commission, 80 pp.

2 THE DELIVERABLES OF SC03

2.1 The SC03 Tasks

The three SC03 tasks were defined as "logistics", "fieldwork", and "delivery" (**Figure 3**). The execution of these tasks were fulfilled according to the SC03 Contract (**Table 2**).

Table 2: The SC03 tasks and the dates on which these tasks were concluded and delivered to CINEA / DG MARE.

Task	Description	Date concluded
Task 1 Logistics	Mobilisation of research facilities and equipment to Tromsø (Norway) before 20 September 2019, and offloading the ship after the expedition in Bremerhaven (Germany)	14 October 2020
Task 2 Fieldwork	Data and sample collection during the MOSAiC expedition	2 October 2020
Task 3 Delivery	Inception Report First Progress Report Interim Report Second Progress Report Final Report	18 September 2019 5 December 2019 10 July 2020 11 January 2020 17 May 2021
	Kick-off Meeting (Brussels) First Progress Meeting (Brussels) Interim Meeting (on-line due to COVID19) Second Progress Meeting (on-line due to COVID19) Final Meeting (on-line due to COVID19)	11 September 2019 12 December 2019 11 September 2020 8 February 2021 10 May 2021
	EFICA Standard Operation Protocols (SOPs) for MOSAiC EFICA Standard Fish Protocol Sheets (SFPs) for MOSAiC	18 May 2020 18 May 2020
	Delivery of the "Biweekly Reports" directly from the *Polarstern*	20 September 2019 – 17 May 2020
	SC03 Metadata Database Manual (**Chapter 12**)	17 May 2021
	SC03 Metadata Database consisting of 15 EXCEL files: *Database File 01 - Explanations_210616.xlsx* *Database File 02 – Logbook Device Operations_210621.xlsx* *Database File 03 - SHIP_DATA_210616.xlsx* *Database File 04 - PEL_PHYS_210616.xlsx* *Database File 05 - ICE_PHYS_210616.xlsx* *Database File 06 - PEL_BGC_210618.xlsx* *Database File 07 - ICE_BGC_210618.xlsx* *Database File 08 - PEL_INV_210621.xlsx* *Database File 09 - ICE_INV_210618.xlsx* *Database File 10 - PEL_ACOUST_210621.xlsx* *Database File 11 - PEL_VIDEO_210618.xlsx* *Database File 12 - PEL_FISH_210616.xlsx* *Database File 13 - ICE_FISH_210618.xlsx* *Database File 14 - PEL_DNA_210621.xlsx* *Database File 15 - ICE_DNA_210618.xlsx*	17 May 2021
	Media archive consisting of press releases and public media outputs related to SC03 (**Chapter 13**)	17 May 2021

2.2 The types of data and samples collected within SC03

During the MOSAiC fieldwork, the EFICA scientists collected the following five types of data and samples:

(1) Hydroacoustics using the EK60 and EK80 echo sounders of the *Polarstern* for later data analyses (within a new SC) of fish and fish prey (zooplankton) distributions and biomass, and their physical environment (e.g., water layers of different densities).
(2) Video recordings using the EFICA custom-built deep-sea camera system (FishCam) for later video analyses (within a new SC) to identify fish, squid, siphonophores (zooplankton colonies some of which can produce acoustic backscatter) and fish prey species (zooplankton) at mesopelagic depths.
(3) Fish samples for later laboratory analyses (within a new SC) of age, condition (indices, chemical analyses), prey (stomach and hindgut contents), the stock origin (population genetics), and the previous living conditions of the fish (otolith stable isotope analyses)
(4) e-DNA samples for later bioinformatics of the MOSAiC Metagenomic dataset and specific gene analyses (within a new SC) to identify fish, squid, siphonophores, fish prey species (zooplankton) and fish predator species (mammals)
(5) MOSAiC Core Parameters: EFICA will need to relate its fish and food-web data to environmental and biological data for fish stock modelling and assessment in the CAO. The EFICA field scientists have extensively contributed to collecting the MOSAiC Core Parameters during the MOSAiC expedition, which therefore are available for later analyses (within a new SC).

2.3 Standardisation and logbooks

Standard Operation Protocols: The EFICA scientists on board *Polarstern* during Leg 1 successfully set up the EFICA data and sample collection in the field and in the on-board laboratories. Before MOSAiC Leg 1 started, the EFICA scientists on board *Polarstern* produced the "EFICA Standard Operation Protocols for MOSAiC" (SOPs) and the "EFICA Standard Fish Protocol Sheets for MOSAiC" (SFPs) during the transit to the CAO based on the discussions during the EFICA SC04 Workshop in Brussels (SC04) on 17-18 June 2019[10]. These SOPs and SFPs were tested and continuously updated during Leg 1 as experience was gained about what worked well and what not. The aim of these standard documents was to ensure continuity in the fundamental data collection methods throughout the entire expedition.

Logbooks: The EFICA scientists on board *Polarstern* delivered two types of Logbooks for MOSAiC: "Biweekly Reports" and "Device Operations". The Biweekly Reports contained the expeditions events relevant for SC03 in a narrative style. The Device Operations consisted of an on-board electronic logbook that was updated before and after each scientific operation from the ship or on the ice by all expedition participants. Device Operations was directly coupled to the sampling device used, as well as to sampling day, time, the ship's position and other basic ship data.

2.4 Sampling efficiency

The EFICA scientists on board *Polarstern* collected hydroacoustic data when the ship was drifting with the ice from leaving the Russian EEZ on 1 October 2019 until 2 October 2020 = 367 days. On 44 days no data were recorded, which predominantly depended on extra transits to and from Svalbard due to Covid19. Efficiency of data collection was 88 % for the entire year (**Table 3**). Hydroacoustic data were collected on 50 additional days during

[10] EFICA Consortium (2019) EFICA Workshop in preparation for the *Polarstern* and *Oden* expeditions for 2019 and 2020. Report to EASME/DG MARE. 32 pp.

the transits between Legs 4 and 5, and after Leg 5 to Bremerhaven (**Figure 1**). A portion of these data, i.e., when the ship was in open water or lying still, can probably be used.

The FishCam recorded video movies for in total 86 days. This is only about 28 % of the available time (**Table 3**). Deploying equipment from the sea ice comes with high risks; many colleagues have lost their equipment during the MOSAiC expedition. The FishCam depended on electricity and data connections with the ship. Due to storms, unpredictable ice dynamics and chewing by foxes and polar bears (**Figure 3**). There was also a systemic breakdown of the FishCam in November 2019, and an emergency recovery that destroyed the fibre-optic cable in March 2020. After repair, the FishCam could not be re-deployed during Legs 4 and 5 due to instable ice conditions and limited team capacity

Altogether, 45 longlines to obtain fish samples were deployed. The aim was to deploy two longlines per week for 31 weeks. Thus, efficiency was 73 % (**Table 3**). This is the efficiency of deployment of the gear, not the sampling success. In most cases it was known on forehand that most probably no fish would be sampled because the backscatter on the echosounder indicated that barely any fish seemed to be present. Collection of fish samples with longlines (and fishing rods) was only successful in the beginning of Leg 1 (central Amundsen Basin), at the end of Leg 3 (inflow of Atlantic water to the CAO), and during Leg 4 (south of the CAO). The gillnets that were deployed during MOSAiC were never successful for taking fish samples.

Seawater and ice samples for e-DNA analyses were collected every week during the 38 active science weeks of the expedition, which means 100 % efficiency (**Table 3**).

Figure 3: Curious polar bears inspecting the cabling on the ice at the MOSAiC ice floe during MOSAiC Leg 1. © AWI, 2019

Table 3: Summary of the EFICA achievements during MOSAiC Legs 1-5 compared to optimal execution (i.e., without any disturbances).

EFICA method	Projected optimal execution	Achievement	Reason for difference between optimal execution and achievement	Risk assessment
Hydro-acoustics	Data collection from leaving the Russian EEZ on 1 October 2019 until 2 October 2020 = 367 days	**Efficiency 88 %** Data available for 323 days	- On 33 days (17 May–18 June) no data could be collected during the extra transits to and from Svalbard due to Covid19 - On 9 days no data were recorded due to technical difficulties or calibrations. - On 2 days the Expedition Leader commanded bottom profiling	Low-risk data collection because the echosounder was integrated with the ship
Deep-sea video recording	Data collection from deployment on 23 October 2019 until 20 September 2020 = 312 drift days	**Efficiency 28 %** Good video recordings are available for 86 days (1,938 hours of video recordings).	- FishCam breakdown in November 2019 - Destroyed electricity and fibre-optic cables throughout expedition - Emergency recovery in mid-March 2020, which destroyed the fibre-optic cable - Re-deployment not possible during Legs 4 and 5 due to instable ice conditions and limited team capacity	High-risk data collection due to storms, instable sea ice, and animals interfering with cables on the ice
Fish samples	Sample collection with longlines on average twice a week from 28 October 2019 until 4 June 2020 = 31 weeks (62 deployments)	**Efficiency 73 %** Longline deployments were performed 45 times	- Storms, too cold weather - The decision was made to deploy a longline only once a week when hardly any fish occurred on the echosounders and more than twice a week if more fish would be abundant on the echosounders (the latter did not happen often)	High-risk sample collection due to storms, too low temperatures so that scientists were not allowed on the ice, and instable sea ice
Water and ice samples for e-DNA analyses	Sample collection once a week (seawater and ice) from 21 October 2019 until 20 September 2020 = 312 drift days (38 active weeks)	**Efficiency 100 %** DNA samples from ice and/or water were taken every active week	- The ice hole next to ship was part of the time unavailable for collecting water samples from the ship with the large CTD	Medium-risk sample collection, operated from the ship, but dependent on availability of an ice hole next to the ship, but alternatively water samples could be taken from the ice (at OCEAN City) with a smaller CTD

2.5 Overview of EFICA-specific data and sample collections

Hydroacoustics: Backscatter from zooplankton and fish were detected in the Central Arctic deep scattering layer (DSL) at 200-500 m of depth (the Atlantic water layer) during Leg 1 (**Figure 4**), similar to observations in summer 2016 from the Swedish icebreaker *Oden*[11]. Abundances of fish were generally very low. Inside the CAO, single fish tracks could always be distinguished, which means that swarms were never observed. In the beginning of Leg 1, higher abundances were sometimes observed, and the backscatter target strength suggested mainly small fish (roughly <15 cm long). However, some backscatter indicating also larger fish (roughly up to ca. 60 cm long) passing under the ship at a rate of max. two of these larger fish per hour. Further north, fish density decreased to almost zero. There seemed to be a vertical movement of the scattering layer related to light. In the beginning of October (when there was still twilight), the upper limit of the scattering layer was at 300 m. In the second half of October there was a diel vertical migration (DVM) pattern of the upper limit between 300 m in light and 200 m in darkness. Later on, during the Polar Night with 24 hours of darkness, the upper limit was constantly around 200 m, sometimes even up to 100 m.

There was very little backscatter from fish on the echosounders between February and early May. In agreement with these observations, also the zooplankton net sampling indicated that the MOSAiC ice floe was in a region with very low biomass in general. Further analyses of the data are expected to provide evidence for very low biomass of fish and zooplankton, because then the MOSAiC data that can be quantitatively compared with data from other areas. During the transition from Polar Night to the Polar Day from mid-March to early April, the data showed a clear DVM pattern in the higher zooplankton-related frequencies. Shortly before leaving the ice floe on 17 May, *Polarstern* approached the inflow area of Atlantic water into the Arctic basin, and strong backscatter of larger fish emerged on the echosounder. This was continued in the beginning of Leg 4. Fish signals weakened towards the end of Leg 4, after the MOSAiC ice floe had left the Yermak Plateau. During the new drift near the North Pole on a new ice floe (Leg 5), acoustic signals indicating fish were repeatedly observed, which is consistent with the hydroacoustic data and longline catches in the beginning of Leg 1.

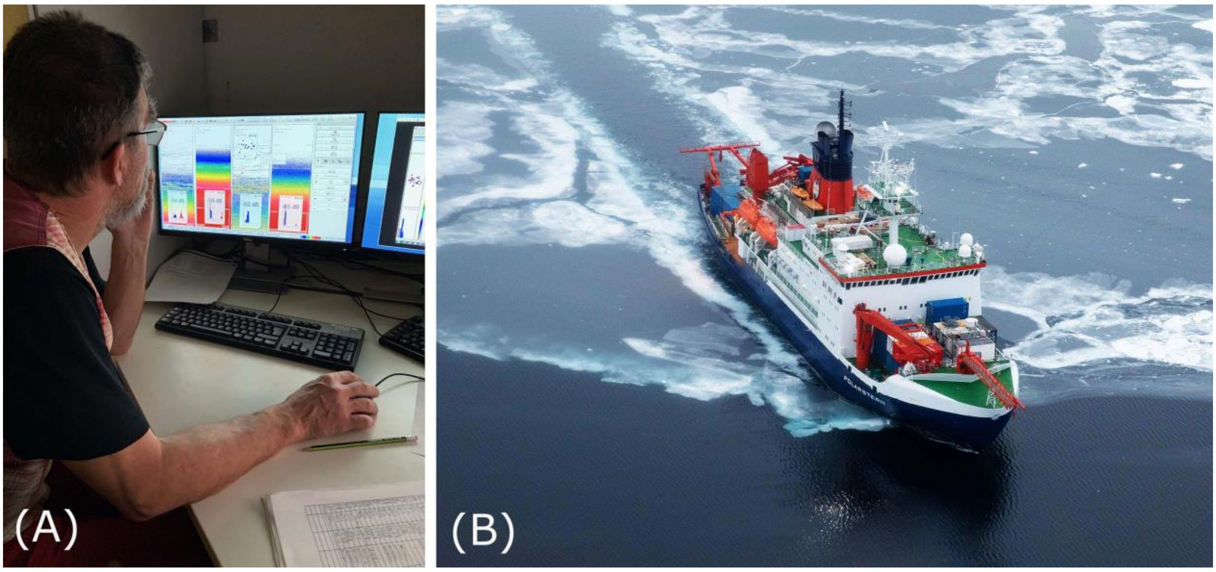

Figure 4: (A) On Leg 1, the echosounders of the *Polarstern* were turned on by the EFICA scientists on board. (B) Acoustic data collection started immediately after leaving the Russian EEZ, still close to the ice edge, on 1 October 2019 and – except for during one major break of 33 days (Table 3) – continuous data were collected until 2 October 2020.

[11] Snoeijs-Leijonmalm P. et al. (2021) A deep scattering layer under the North Pole pack ice. Progress in Oceanography 194:102560. [https://doi.org/10.1016/j.pocean.2021.102560]

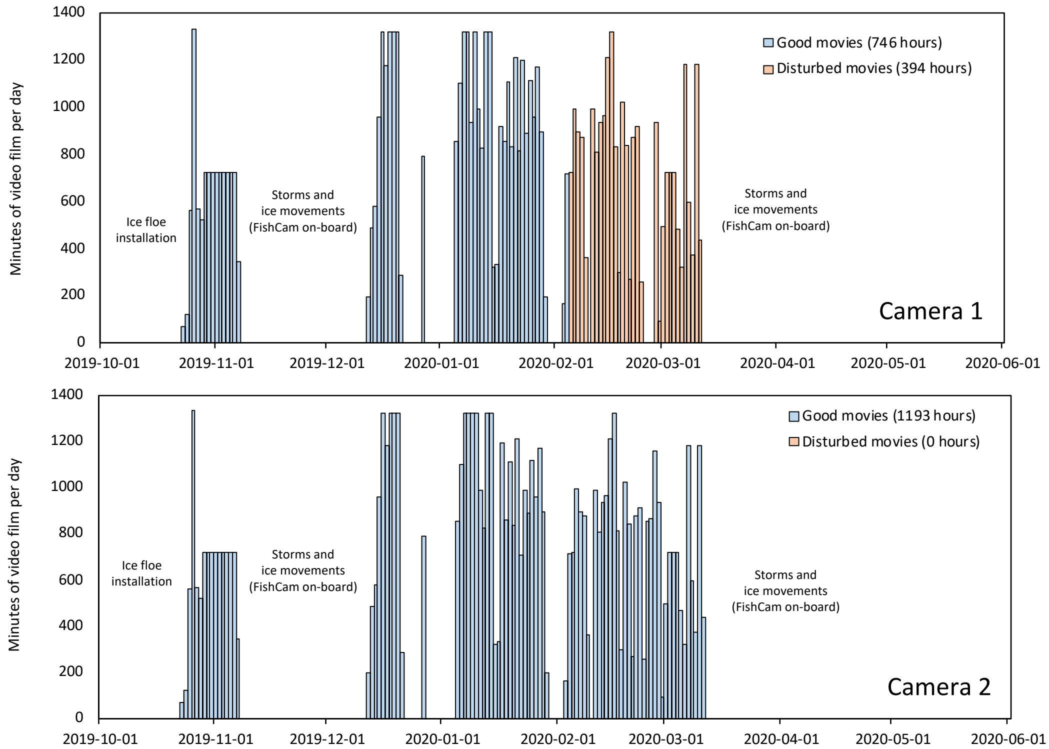

Figure 5: Analysis of the number of days the two video cameras of the FishCam were recording video movies. The disturbed movies (orange bars) were due to a stray rope hanging in front of the side-ward looking Camera 1. This rope did not originate from the FishCam.

FishCam video recordings: Altogether, 1,938 hours of usable video recordings were collected with the two video cameras mounted on the FishCam system (**Figure 5**). These observations covered the greater part of the drift across the Amundsen Basin. Only four fish were preliminary observed on the video recordings. Three of these fish were unrecognisable because they moved away from the light at great speed. A fourth small fish had recognizable features of lanternfish, and was tentatively identified as *Benthosoma glacialis* (**Figure 6**). The Atlantic species armhook squid (*Gonatus fabricii*) (**Figure 6**) was regularly observed in the DSL on the videos from the FishCam, but always with relatively low abundances (max. six squids passed the camera per day).

Figure 6: Images from the FishCam video recordings. (A) a small fish with recognisable features of lanternfish, tentatively identified as *Benthosoma glacialis*. (B) the armhook squid (*Gonatus fabricii*).

Zooplankton such as jellyfish, copepods, amphipods, chaetognaths and siphonophores were regularly observed. The squids seemed to be attracted by the FishCam lights, but the fish seemed to avoid the light. Each FishCam camera house was accompanied by one Luxus High-Power LED light with an output of 6000 lumen of white light, i.e., a complete mixture of all of the wavelengths of the visible spectrum (380-750 nm). For future similar studies, it may be discussed if red light should be used instead, because red light seems to be less likely to stress deep-water organisms.

Fish sampling: Altogether, 58 fish were collected from the mesopelagic zone (ca. 200-500 m) during MOSAiC Legs 1-4 (**Figure 7**, **Table 4**). Surprisingly, four fish were sampled from the High Seas portion of the CAO in the beginning of Leg 1: three Atlantic cod (*Gadus morhua*) and one ice cod (*Arctogadus glacialis*). Zooplankton sampling with a ring net during Leg 2 yielded one black seasnail (*Paraliparis bathybius*), an Arctic benthopelagic deep-water fish. In the end of Leg 3 (May), after leaving the High Seas but still in the CAO, 11 fish were sampled: three Atlantic cod, six haddock (*Melanogrammus aeglefinus*), and two beaked redfish (*Sebastes mentella*). During Leg 4 (July), 42 fish were sampled on and in the vicinity of the Yermak Plateau: seven Atlantic cod, 33 haddock, and two beaked redfish. Observations with an under-ice ROV (Remotely Operated Vehicle) indicated frequent occurrence of sympagic (ice-associated) juvenile polar cod (*Boreogadus saida*) at the ocean surface associated with the sea ice, but they were very difficult to catch. Sampling by the MOSAiC Core Programme on ice fauna yielded 18 individuals of sympagic juvenile polar cod: Leg 1 = 2, Leg 4 = 11, Leg 5 =5.

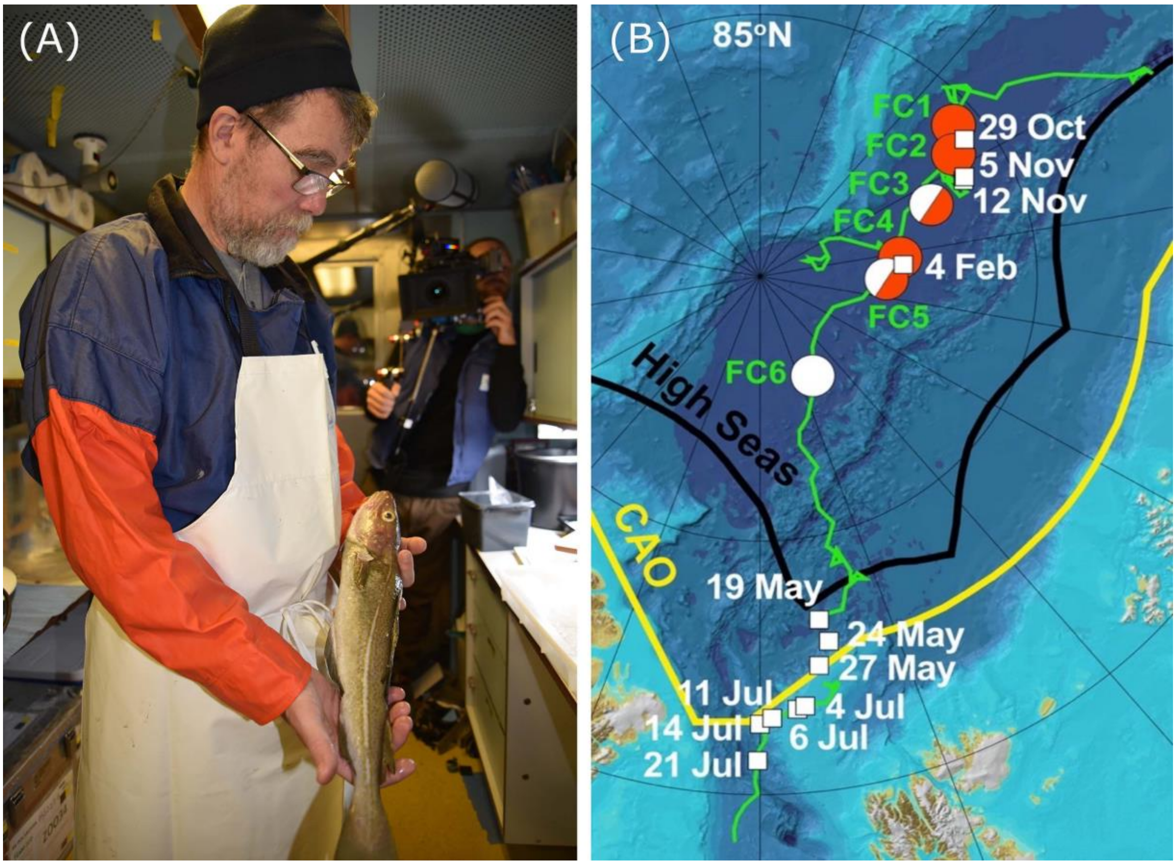

Figure 7: Data collection on fish and squid during the MOSAiC transpolar drift expedition. (A) The first fish sampled during the expedition: an Atlantic cod (*Gadus morhua*). (B) Map showing the stations where 58 fish were sampled (white squares), fish were observed on video (white circles), squid were observed on video (red circles, or both fish and squid were observed on video (combined white and red circles) in the mesopelagic zone (ca. 200-500 m of depth) in the CAO and in the inflow area of Atlantic water into the CAO. The black line denotes the border of the central Arctic High Seas area, the yellow line denotes the border of the Central Arctic Ocean as defined by the Arctic Council (Figure 12). © Pauline Snoeijs-Leijonmalm (A), 2019

e-DNA sampling: Within the MOSAiC Core Parameter programme, Team ECO jointly collected 1,467 DNA samples from seawater and ice, covering the entire drift trajectory (**Table 3**). These samples will be extracted at the AWI and sequenced at the Joint Genome Institute (USA). The costs for 800 of samples (to be selected according to sample identity and good DNA yield) are already covered by research grants. EFICA can use the resulting large MOSAiC Core metagenomic dataset, as well as aliquots of extracted DNA, for estimating the occurrence of fish, squid, siphonophores, fish prey (zooplankton), and fish predator (mammal) species. This can be achieved by direct bioinformatic analyses of the core dataset and by using the DNA aliquots for PCR (polymerase chain reaction) to amplify specific genes with subsequent bioinformatic analyses.

Overview of EFICA-specific data and sample collection: A full summary of the metadata per MOSAiC leg and in total is provided in **Table 5**. The spatial distribution of EFICA-specific sampling, i.e., those data and samples collected to directly address mesopelagic fish and their ecology as described above, is shown in **Figure 8**.

Table 4: Summary of the mesopelagic fish metadata (Database File 12). Altogether, 58 fish were sampled in the water column. All fish were sampled with lines (longlines or fishing rods), except for the black seasnail that was caught in a zooplankton ring net (1 m diameter, 150 µm mesh size).

Date	Average Latitude (°N)	Average longitude (°E)	Average station depth (m)	Deployment depth (m)	Number of individuals	Species
29 Oct 2019	85.67	125.21	4387	427-300	2	Atlantic cod
05 Nov 2019	85.94	118.47	4410	475-200	1	Ice cod
12 Nov 2019	86.03	117.56	4412	400-250	1	Atlantic cod
04 Feb 2020	87.48	95.18	4424	2000-200	1	Black seasnail
19 May 2020	83.26	8.95	3713	400-200	4 1	Haddock Beaked redfish
24 May 2020	82.73	10.23	1862	350-250	2 2 1	Atlantic cod Haddock Beaked redfish
27 May 2020	82.38	8.30	1107	250-150	1	Atlantic cod
04 Jul 2020	81.71	6.75	728	500-300	4 8 1	Atlantic cod Haddock Beaked redfish
06 Jul 2020	81.69	5.37	762	500-300	1 2	Atlantic cod Haddock
11 Jul 2020	81.45	1.49	1246	500-300	14	Haddock
14 Jul 2020	81.38	0.25	2273	500-300	3 1	Haddock Beaked redfish
21 Jul 2020	80.61	-0.57	2845	500-300	2 6	Atlantic cod Haddock
Total					58	

Table 5: Summary of the EFICA-specific data and samples in the SC03 Metadata Database Files 10, 11, 12, 14, and 15. Numbers refer to number of samples collected for each parameter, if not indicated otherwise. Some fish were frozen intact, and will be dissected in connection with sample analysis.

Device / species / parameter	Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	Total
***Polarstern* Echosounders**						
Hydroacoustic data (drift days)	72	72	83	53	31	311
Hydroacoustic data (transit days)	1		18	29	12	50
Total hydroacoustics (days)	**73**	**72**	**101**	**70**	**42**	**360**
FishCam						
Usable video files (hours)	**356**	**1,397**	**185**			**1,938**

Pelagic fish samples						
Arctogadus glacialis						1
Fish body	1					1
Fish fin clip	1					1
Fish gonad	1					1
Fish hindgut	1					1
Fish liver	1					1
Fish muscle tissue	2					2
Fish otoliths	1					1
Fish stomach	1					
Gadus morhua						
Fish body	3		3	7		13
Fish fin clip	3		3	4		10
Fish gonad	3		3	4		10
Fish hindgut	3		3	4		10
Fish liver	3		13	8		24
Fish muscle tissue	6		5	12		23
Fish otoliths	3		3	4		10
Fish stomach	3		3	5		11
Intestines			3			3
Melanogrammus aeglefinus						
Fish body			6	33		39
Fish fin clip			6			6
Fish gonad			6	5		11
Fish hindgut			6			6
Fish liver			15			15
Fish muscle tissue			12	12		24
Fish otoliths			6			6
Fish stomach			6			6
Intestines			6	2		8
Paraliparis bathybius						
Fish body		1				1
Fish otoliths		1				1
Sebastes mentella						
Fish body			2	2		4
Fish fin clip			2			2
Fish gonad			2			2
Fish hindgut			2			2
Fish liver			5			5
Fish muscle tissue			4			4
Fish otoliths			2			2
Fish stomach			2			2
Intestines			2			2
Total fish tissue samples	**36**	**2**	**131**	**102**		**271**
e-DNA samples						
Automated filtration for marine microbes	1	6	85	57	138	287
CTD AWI-OZE	153	144	42	128	91	558
CTD OCEAN City			62			62
Underway water sampling	17					17
Ice corer Kovacs Mark II	90	106	115	214	40	565
Ice corer Kovacs Mark V					2	2
Total e-DNA samples	**85**	**101**	**113**	**202**	**42**	**1,491**

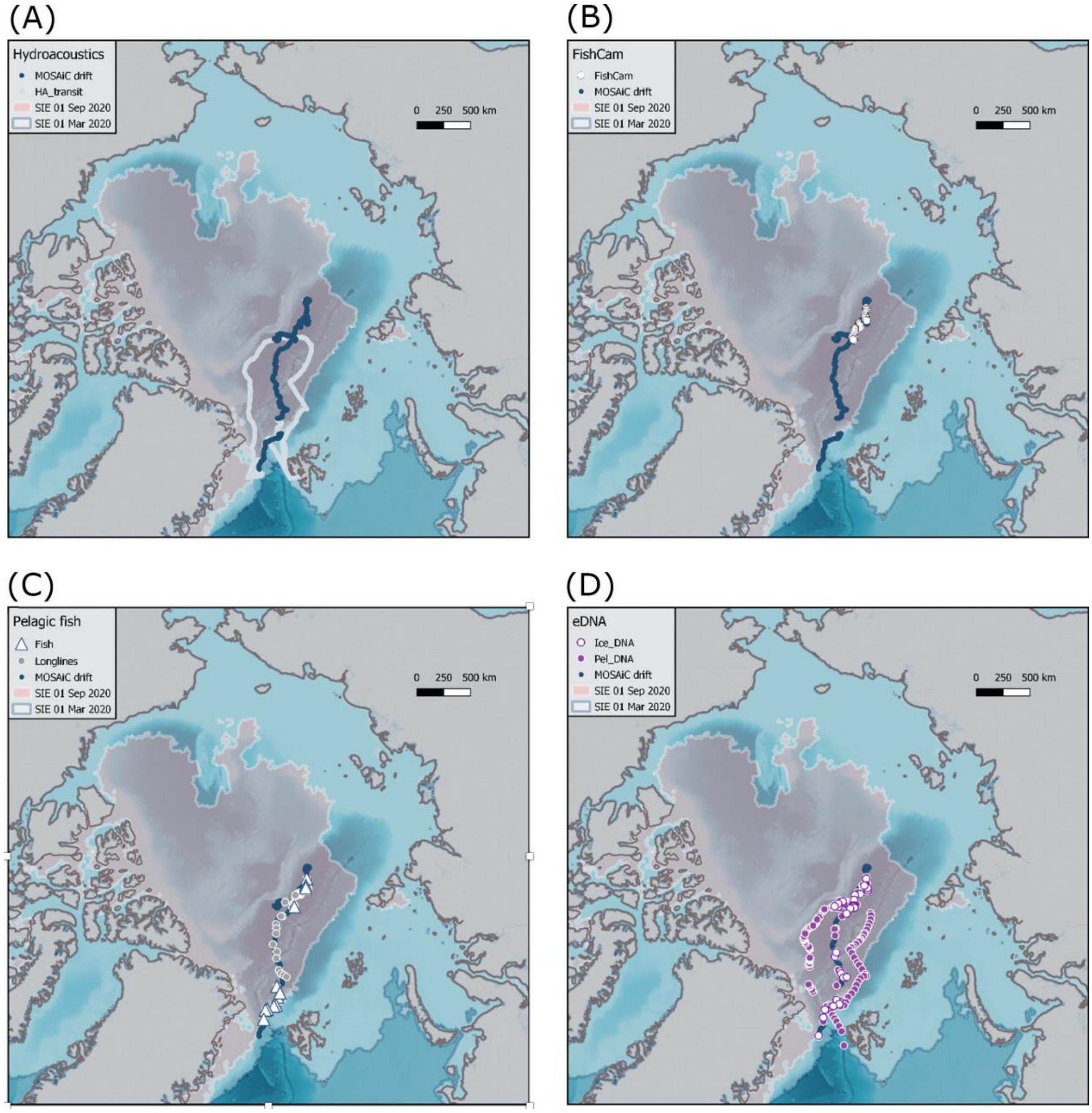

Figure 8: Spatial distribution of the EFICA-specific data and sample collection: (A) Hydroacoustic measurements, (B) FishCam video recordings, (C) Line deployments and mesopelagic fish sampled, (D) e-DNA sampling. Stable grey colour = land; blue shading indicates bathymetric contours; grey shading indicates the sea-ice extent in the Arctic Ocean on 3 March 20 (darker grey) and 1 September 20 (lighter grey), respectively (from the National Snow & Ice Data Center, www.nsidc.org).

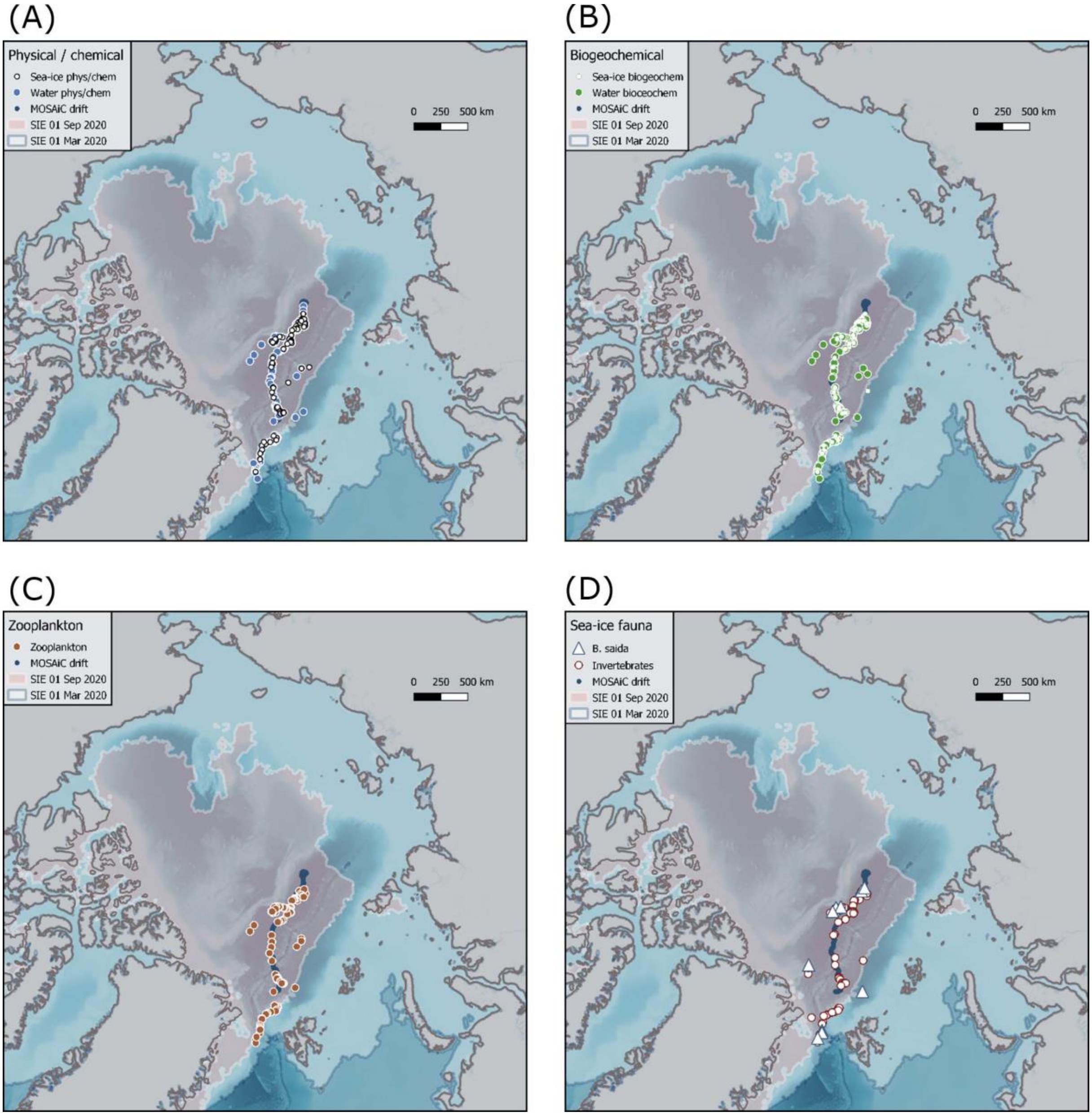

Figure 9: Spatial distribution of sampling the EFICA-relevant MOSAiC Core Parameters: (A) physical and chemical profiles, (B) biogeochemical sampling, (C) zooplankton sampling, and (D) sea-ice fauna sampling, including the ice-associated polar cod *Boreogadus saida*. Stable grey colour = land; blue shading indicates bathymetric contours; grey shading indicates the sea-ice extent in the Arctic Ocean on 3 March 20 (darker grey) and 1 September 20 (lighter grey), respectively (from the National Snow & Ice Data Center, www.nsidc.org).

2.6 Overview of EFICA-relevant MOSAiC Core Parameters

The MOSAiC Core Parameters in the SC03 Metadata Database Files 04-09 and 13 are considered essential for addressing the four questions proposed for the mapping phase of the JPSRM (see **Chapter 1**). These parameters were sampled within the joint MOSAiC Core Parameter sampling programme of the MOSAiC Teams BGC, ECO, ICE and OCEAN. The EFICA scientists on board have actively and significantly contributed in collecting these data (four legs, six berths, 80-90 % of the total working time on-board) and can therefore use them for further detailed analyses to interpret the EFICA-specific data. The spatial distribution of these selected MOSAiC Core Parameters is shown in **Figure 9** and a summary of the metadata per MOSAiC leg and in total is given in **Table 6**.

Altogether, the MOSAiC field teams sampled 286 CTD profiles and 230 ice cores for physical-chemical parameters of the water column and the sea ice, respectively. Physical-chemical parameters included temperature and salinity profiles of the water column (surface to bottom) and of ice cores, as well as texture samples of sea-ice cores and $\delta^{18}O$ (the ratio of the stable oxygen isotopes ^{18}O and ^{16}O). These parameters are essential to determine the water masses in which fish and their prey dwell, as well as the sea-ice habitat properties for sympagic juvenile polar cod and ice-associated prey.

Furthermore, the MOSAiC field teams collected 4,888 and 3,739 samples for biogeochemical parameters from the water column and the sea ice, respectively. The biogeochemical samples were primarily collected with the CTD rosette sampler from the surface to the seafloor, and from ice cores. Biogeochemical parameters essential for addressing the four questions proposed for the mapping phase of the JPSRM (see **Chapter 1**) include chlorophyll-a concentration, pigment composition (HPLC), phytoplankton species composition and abundance (microscopy), particulate organic carbon and nitrogen (POC/N), and nutrient concentrations. These parameters are needed to quantify the potential of the ecosystem to sustain minimum biomasses of zooplankton and fish in terms of primary productivity, carbon sources, phytoplankton communities and trophic transfer efficiency.

The prey field was sampled in terms of parameters characterising zooplankton and sea-ice fauna communities, using zooplankton nets with different mesh sizes sampling down to a maximum depth of 2,000 m. Team ECO collected 5,907 zooplankton samples and 1,196 sea-ice fauna samples relevant for addressing the four questions proposed for the mapping phase of the JPSRM (see **Chapter 1**). The prey field-related parameters include carbon and nitrogen content (CN), species composition and abundance, and trophic biomarkers. These parameters are essential to determine the prey field properties in terms of species composition, abundance, biomass and carbon sources. The sea-ice fauna sampling also included the ice-associated fish polar cod *Boreogadus saida*, of which Team ECO sampled 18 individuals using a variety of techniques, such as landing nets, hands and ROVnet.

Table 6: Summary of the EFICA-relevant MOSAiC Core Parameters, showing data and samples in the SC03 Metadata Database Files 04-09 and 13. Numbers refer to number of CTD profiles, ice core profiles or specific samples collected for each MOSAiC Core Parameter.

Device / species / parameter	Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	Total
Database File 04 - PEL_PHYS						
Physical water properties						
CTD AWI-OZE	19	33	7	64	28	151
CTD OCEAN City	30	39	66			135
Total physical water properties	**49**	**72**	**73**	**64**	**28**	**286**
Database File 05 - ICE_PHYS						

Sea-ice properties						
SI_corer_14cm						
SALO18					1	1
T (profiles)			3		1	6
T/S (profiles)					2	2
TEX			1		1	2
SI_corer_7cm						
SALO18 (profiles)	1		1			2
T (profiles)	1		1			2
TEX			2			2
SI_corer_9cm						
SALO18	14	10	26	14	10	74
T (profiles)	24	23	19	10	11	85
TEX	15	9	11	8	11	54
Total sea-ice properties	**55**	**42**	**64**	**32**	**37**	**230**
Database File 06 - PEL_BGC						
Biogeochemical water properties						
CTD AWI-OZE						
Chl_total	33	50	20	74	58	226
HPLC	33	50	18	48	45	225
Microscopy	51	48	16	64	35	215
Nutrients	88	387	153	894	912	2,428
POC/N	41	67	15	56	43	222
OCEAN City CTD						
Chl_total	8	3	33			44
HPLC			31			31
Microscopy			31			31
Nutrients	57	468	825			1,350
POC/N			16			16
Underway Water Sampling						
Chl_total	117					117
Total biogeochemical water properties	**428**	**1,073**	**1,158**	**1,136**	**1,093**	**4,888**
Database File 07 - ICE_BGC						
Biogeochemical sea-ice properties						
Ice Corer Kovacs Mark II						
Chl_total	124	110	286	184	56	736
HPLC	84	109	164	189	34	580
Microscopy	84	106	206	221	35	649
POC/N	88	109	240	174	37	643
Nutrients		320	326	391	62	1,099
Total biogeochemical sea-ice properties	**380**	**754**	**1,222**	**1,159**	**224**	**3,739**
Database File 08 - PEL_INV						
Zooplankton						
Multinet Midi 5 Nets						
CN			178		371	549
Species composition and abundance	22	45	24	35	55	181
Trophic biomarkers			10		204	214
Nansen net						
CN			498			498
Species composition and abundance			45			45
Trophic biomarkers			50			52
Ring net 60 cm in diameter						
CN				96		96
Species composition and abundance				1		1

Trophic biomarkers				3		3
Ring net 1000 µm mesh						
CN	29	159	52	57	45	342
Species composition and abundance	3	7	1	5	4	20
Trophic biomarkers	16	54	28	27	60	186
Ring net 150 µm mesh						
CN	83	966	148	935	1,025	3,157
Species composition and abundance	6	20	1	11	17	57
Trophic biomarkers	29	134	5	51	172	393
Ring net 53 µm mesh						
CN			73			73
Species composition and abundance	5	8	12	6	4	35
Trophic biomarkers			12			13
Total zooplankton	**193**	**1,393**	**1,137**	**1,227**	**1,957**	**5,907**
Database File 09 - ICE_INV						
Sea-ice fauna						
ROVnet						
CN	8	118	367	314	172	979
Species composition and abundance	12	15	25	23	5	80
Trophic biomarkers	8	24	20	9	18	81
Hand Net						
Trophic biomarkers			1			1
Ice Corer Kovacs Mark II						
Species composition and abundance	4	8	7	24	6	52
Seawater tap						
Trophic biomarkers					8	8
Total sea-ice fauna	**32**	**165**	**420**	**370**	**209**	**1,196**
Database File 13 - ICE_FISH						
Ice-associated (sympagic) fish						
ROVnet						
Boreogadus saida	1					1
Hand sampling						
Boreogadus saida				11	3	14
Ice Corer Kovacs Mark II						
Boreogadus saida	1					1
Seawater tap						
Boreogadus saida					2	2
Total sea-ice fish	**2**			**11**	**5**	**18**

3 THE TIME SCHEDULE OF SC03

The EFICA Consortium has followed the original time schedule in the SC03 Contract. The timing and duration of the different tasks and subtasks within SC03 is visualised in a Gantt chart for the time period between 11 July 2019 (the signing of the SC03 contract) and 17 May 2021 (delivery of the Final Report) (**Figure 10**). The SC03 contract ended on 10 July 2021.

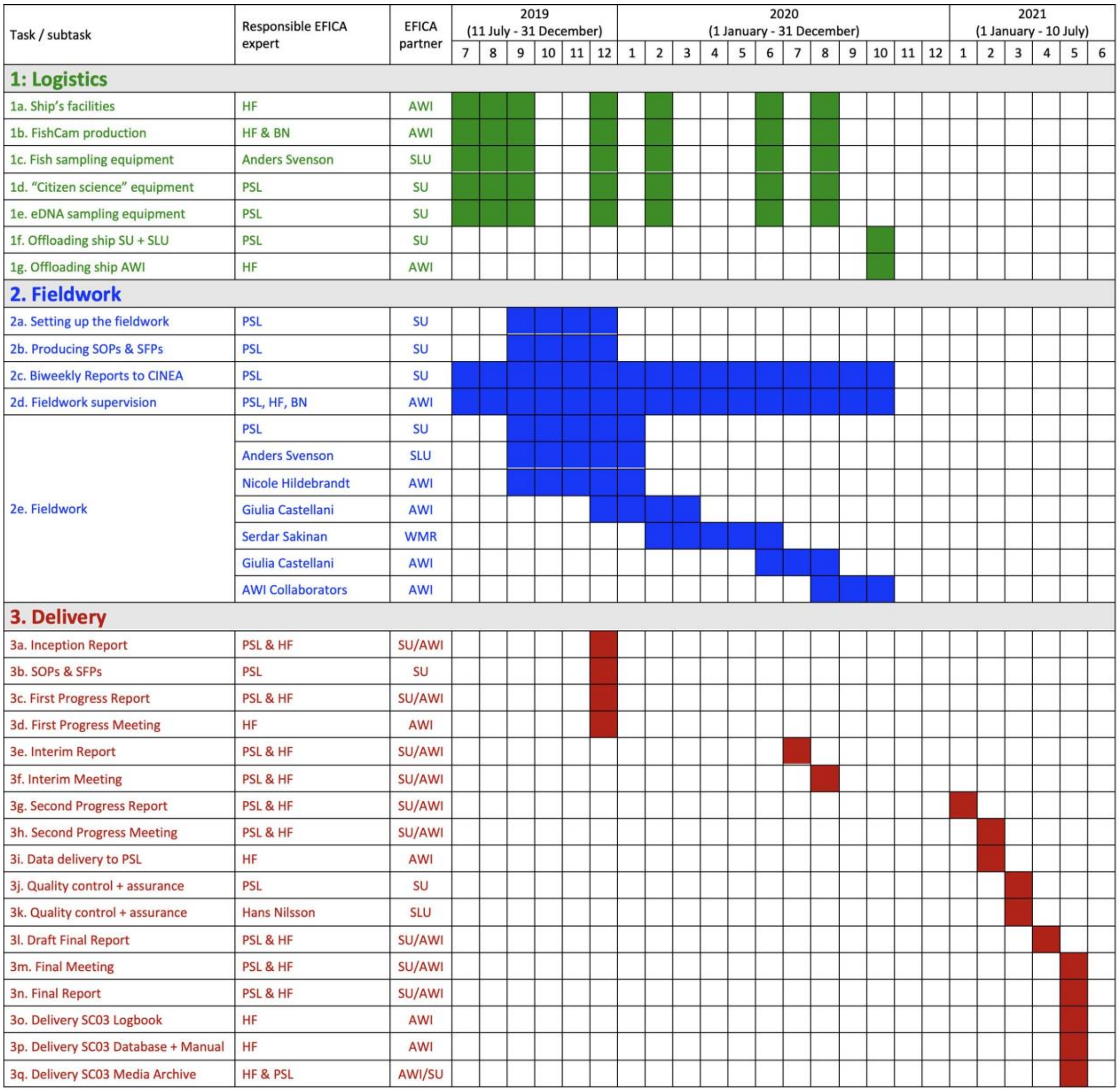

Figure 10: Gantt chart showing the timing and duration of the different tasks and subtasks within SC03, as well as the responsible EFICA partners and experts for each subtask (PSL = the EFICA Consortium and SC03 Coordinator Pauline Snoeijs-Leijonmalm, HF = SC03 Project Manager Hauke Flores, BN = SC03 Co-Project Manager Barbara Niehoff).

4 THE EFICA SC03 SCIENTISTS AND THEIR TASKS

4.1 The SC03 Executive Committee

The EFICA Executive Committee for SC03 consisted of Pauline Snoeijs-Leijonmalm (marine ecologist, EFICA Consortium and SC03 Coordinator, SU – Leg 1), Hauke Flores (ice-fauna expert, SC03 Project Manager, AWI – not on board), Barbara Niehoff (zooplankton expert, SC03 Co-Project Manager, AWI – not on board), Anders Svenson (fish expert and acoustician, SLU – Leg 1), Nicole Hildebrandt (zooplankton expert, AWI – Leg 1), Giulia Castellani (ice-fauna expert and modeler, AWI – Legs 2 and 4), and Serdar Sakinan (fish expert and acoustician, WMR – Leg 3).

4.2 Field scientists

Five EFICA scientists carried out the fieldwork (**Figure 11**, **Table 7**). The EFICA scientific activities were started up during Leg 1. The concentration of on-board competence in the beginning of the expedition was crucial for the success of SC03. Decisions were made about the EFICA routines for the rest of the MOSAiC expedition, and the "EFICA Standard Operation Protocols for MOSAiC" (SOPs) and the "EFICA Standard Fish Protocol Sheets for MOSAiC" (SFPs) were produced. During each of the subsequent Legs 2-4, there was only one EFICA scientist on board *Polarstern*, working in Team ECO consisting of 5-6 other scientists.

The three scientists carrying out the EFICA fieldwork during MOSAiC Leg 1 were Pauline Snoeijs-Leijonmalm (coordination, documentation, compilation of the SOPs and SFPs, FishCam data collection, e-DNA sampling), Anders Svenson (hydroacoustic data collection, fish sampling, fish dissection, FishCam deployment), Nicole Hildebrandt (fish sampling, FishCam deployment). Within the MOSAiC Core Programme, PSL was responsible for water sampling and filtrations (mainly for chlorophyll-a, HPLC pigments, DNA and RNA), NH was responsible for the MOSAiC Core Programme on zooplankton and ice fauna, and AS assisted NH with this. During Leg 2, Giulia Castellani was responsible for the EFICA fieldwork and the MOSAiC Core Programme on ice fauna. During Leg 3, Serdar Sakinan was responsible for the EFICA fieldwork, performed the fieldwork for a Dutch research project on ice fauna, and assisted in the MOSAiC Core Programme on ice fauna. During Leg 4, Giulia Castellani was again responsible for the EFICA fieldwork and the MOSAiC Core Programme on ice fauna. E-DNA sampling for EFICA was safeguarded by Lena Eggers on Leg 2, Anders Torstensson on Leg 3, and John-Paul Balmonte on Leg 4 from the Swedish CN-project led by Pauline Snoeijs-Leijonmalm. During Leg 5, no EFICA scientist was present on-board *Polarstern*. Continuation of hydroacoustic data collection and opportunistic longline fishing was performed by members of Team ECO. The Project Manager Hauke Flores closely supervised from land that these tasks were performed to the highest standard whenever feasible. His main contact on *Polarstern* during Leg 5 was Katrin Schmidt (University of Plymouth, UK). During all five MOSAiC legs, the whole Team ECO collaborated with heavy work on the ice. In the case of EFICA, this help was needed for the deployment (twice) and retrieval (twice) of the FishCam and the calibration of the echosounder. This heavy work on the ice also included maintenance of the infrastructure, such as keeping ice holes open, securing and rescuing electricity and data cables in storms and ice movements, and armed bear-guarding.

Due to logistical difficulties and the worldwide Covid19 pandemic, Leg 3 was prolonged, and the new Leg 5 covered the final phase of the expedition (the originally planned Leg 6). Due to these changes, and personal risk assessments in the light of Covid19, the EFICA scientists assigned to the originally planned Legs 4 and 5, respectively, Hauke Flores and Barbara Niehoff, were not be able to participate. Giulia Castellani, who already successfully performed EFICA data and sample collection on Leg 2, joined the new Leg 4. Since the new Leg 5 essentially replaced the originally planned Leg 6, for which no EFICA berth was planned, there was no EFICA scientist on Leg 5. The new Leg 5 was short (30 days of drift), was conducted from a new ice floe, and constituted in many ways its own mini expedition. Leg 5 included research, but also breaking up the Central Observatory, packing everything, and transit to Bremerhaven (Germany).

Figure 11: The five EFICA SC03 field scientists on the MOSAiC expedition. Leg 1: (A) Pauline Snoeijs-Leijonmalm, (B) Anders Svenson, (C) Nicole Hildebrandt, Legs 2 and 4: (D) Giulia Castellani, Leg 3: Serdar Sakinan. © Esther Horvath (A-C), 2019 © AWI (D,E), 2020

Table 7: List of the EFICA SC03 field scientists, the MOSAiC legs in which they participated and their responsibilities within SC03.

Leg	EFICA scientist	EFICA partner	Responsibilities within SC03	Time on *Polarstern*	Days
1	Pauline Snoeijs-Leijonmalm	SU	Starting up the SC03 fieldwork Compilation of SOPs and CFPs FishCam data quality e-DNA sampling Writing the Biweekly Report	20 Sept - 17 Dec	89
1	Anders Svenson	SLU	Hydroacoustic data quality FishCam deployment Fish sampling	20 Sept - 17 Dec	89
1	Nicole Hildebrandt	AWI	Assisting with FishCam deployment Assisting with fish sampling	20 Sept - 17 Dec	89
2	Giulia Castellani	AWI	Hydroacoustic data quality FishCam data quality Fish sampling Writing the Biweekly Report	17 Dec - 3 Mar	77
3	Serdar Sakinan	WMR	Hydroacoustic data quality	3 Mar - 6 Jun	96

			FishCam data quality Fish sampling Writing the Biweekly Report		
4	Giulia Castellani	AWI	Hydroacoustic data quality FishCam data quality Fish sampling Writing the Biweekly Report	4 Jun - 10 Aug	66

4.3 Land-based advisors

Throughout the expedition, a team of three EFICA scientists, Pauline Snoeijs-Leijonmalm, Hauke Flores and Barbara Niehoff (**Table 8**) supported the EFICA scientist on-board *Polarstern* in – often *ad-hoc* – decision-making and represented the EFICA Consortium in the international Team ECO teleconferences. PSL reported to CINEA/DG MARE, while HF and BN facilitated the communication between the EFICA scientists on board and the MOSAiC leadership (AWI) when necessary, e.g., to safeguard the EFICA priority of hydroacoustic measurements during the entire cruise.

The Project Manager Hauke Flores was responsible for the delivery of the SC03 Metadata Database and for archiving the fish samples at the AWI. Before the expedition started, Hauke Flores, incorporated the EFICA research in the sampling programme of MOSAiC, safeguarded the ship's facilities necessary for SC03, including the two echosounders (EK60, 18 KHz and EK60/80, 38, 20, 120, 200 KHz), negotiated an on-ice deployment station for the FishCam at MET City, laboratory space, and made sure within the AWI that the exclusive use of the hydroacoustic and e-DNA data is safeguarded for the purposes of EFICA according to the SC03 contract. He also facilitated the communication with technical support from the AWI (hydroacoustics) and external service providers (FishCam)

Together with Barbara Niehoff (AWI), Hauke Flores designed the FishCam, ordered and followed its building process, and sent it to Tromsø harbour. Barbara Niehoff was present in Tromsø to load the ship, unpack EFICA equipment and organize the laboratories. Before the expedition, Joakim Hjelm and Jonas Hentati-Sundberg (both SLU) and Fokje Schaafsma (WMR) assisted with advice on the fish sampling protocols. Overall, the practical discussions during the EFICA SC04 Workshop in Brussels on 17-18 June 2019[12], in which scientists from all EFICA Working Groups participated, were taken into account while organising and executing the MOSAiC fieldwork.

Table 8: List of the EFICA SC03 land-based advisors, and their roles and responsibilities within SC03.

EFICA scientist	EFICA partner	Role within SC03	Responsibilities within SC03
Pauline Snoeijs-Leijonmalm	SU	EFICA Coordinator	Overall responsibility Reporting to CINEA/DG Mare Continuous contacts with CINEA/DG MARE Data quality control
Hauke Flores	AWI	SC03 Project Manager	Daily supervision of the fieldwork Reporting to the EFICA Coordinator Co-reporting to CINEA/DG Mare Coordination with AWI services Coordination with external service providers Delivery of Logbook "Device Operations" Delivery of the SC03 Metadata Database Delivery of the SC03 Media Archive Safeguarding the EFICA-relevant MOSAiC Core Parameter data (also after SC03)

[12] EFICA Consortium (2019) EFICA Workshop in preparation for the *Polarstern* and *Oden* expeditions for 2019 and 2020. Report to EASME/DG MARE. 32 pp.

			Safeguarding the exclusive use of the hydroacoustic & e-DNA data (also after SC03)
Barbara Niehoff	AWI	SC03 Co-Project Manager	Coordination with MOSAiC leadership Coordination with Team ECO Reporting to the EFICA Coordinator

5 RESEARCH FACILITIES AND EQUIPMENT

5.1 Mobilisation

The logistic mobilisation phase of SC03 started with the signing of the SC03 contract (on 11 July 2019) and ended when *Polarstern* left Tromsø for the CAO on 20 September 2019. This phase consisted of preparing and packing equipment and consumables, and sending it as cargo to Tromsø harbour. The responsibility for this work was divided among the three EFICA SC03 partners: SU (fish sampling, e-DNA sampling), AWI (FishCam) and SLU (fish sampling).

The objectives of SC03 Task 1 (Logistics) were to safeguard that the EFICA scientists and all equipment would arrive on board *Polarstern* in time, and get access to the ship's facilities necessary for the execution of SC03, so that the EFICA fieldwork could be carried out. Everything was taken on board before *Polarstern* left Tromsø on 20 September 2019. Task 1 was purely organisational in a practical way, and consisted of building and testing new equipment, purchasing instruments and consumables, booking travels and hotel rooms in Tromsø, etc. The respective Subtasks within Task 1 (**Table 9**) were carried out as planned.

Table 9: Subtasks within Task 1 (Logistics) and division of responsibilities among the three EFICA SC03 partners.

Subtask	Task description	EFICA partner	Responsible EFICA scientist
1a	Safeguarding the ship's facilities necessary for SC03, including laboratory space, EK60 and EK80 acoustic equipment, on-ice station for the FishCam,	AWI	Hauke Flores
1b	Ordering the FishCam and sending it to Tromsø harbour	AWI	Barbara Niehoff and Hauke Flores
1c	Collecting and purchasing equipment and consumables for routine fish sampling (longlines and nets, winch) from the ice and sending it to Tromsø harbour	SLU	Anders Svenson
1d	Collecting and purchasing equipment and consumables for "citizen science" fish sampling and sending it to Tromsø harbour Purchasing bait (shrimps and squid) in Tromsø	SU	Pauline Snoeijs-Leijonmalm
1e	Collecting and purchasing equipment and consumables for e-DNA sampling and sending it to Tromsø harbour.	SU	Pauline Snoeijs-Leijonmalm
1f	Offloading the ship in Bremerhaven (Germany) and transport of SU and SLU equipment to Sweden	SU	Pauline Snoeijs-Leijonmalm
1g	Offloading the ship and transport of equipment to the AWI in Bremerhaven	AWI	Hauke Flores

5.2 EFICA-specific equipment

Hydroacoustics equipment: The echosounders of *Polarstern* can run in two modes: EK60 and EK80. The five transducer frequencies used were 18 kHz (general purpose transceiver: continuous wave mode), 38 kHz (general purpose transceiver: continuous wave mode), 70 kHz (wideband transceiver: broadband or continuous wave mode), 120 kHz (wide band transceiver: wideband transceiver, broadband or continuous wave mode), and 200 kHz (general purpose transceiver: continuous wave mode). Throughout the MOSAiC drift expedition, the accuracy of the data collection was inspected several times per day. On 27 April 2020, the equipment was calibrated according to standard procedures[13] through the ship's moon pool using a standard Tungsten carbide sphere (38.1 mm) with the aid of an underwater remotely operated vehicle (ROV). Sound velocity was determined from a CTD cast (SBE-911 plus®). The EFICA scientists performed a calibration through the ship's moon pool on 27 April and 4 May. Calibration files were made for the frequencies 38, 70, 120, 200 kHz of the ship's EK60/80 for the post-processing of the hydroacoustic MOSAiC dataset, both in CW and FM (70 kHz, 120 kHz) mode.

Deep-sea video equipment: The EFICA custom-built deep-sea camera system (FishCam) was designed for continuous visual observations at 200-500 m of depth. It was designed and the manufacturing was negotiated before the SC03 contract was signed. Therefore, it could be built at record speed (two months). When the FishCam was ready, it was tested in underwater conditions in Germany and sent to Tromsø, where it arrived on 19 September 2019, only one day before the MOSAiC expedition left for the CAO. The reason for this was that the EFICA Consortium could not confirm the order before the SC03 contract was signed because it needed to be built especially for EFICA's use on the MOSAiC expedition.

Fish sampling equipment: The equipment for routine fish sampling from the ice consisted of a 25 cm diameter auger to make holes in the ice, monitoring gillnets (40 x 6 m; mesh size varying from 4 to 80 mm within one net), herring gillnets (40 x 6 m; mesh size 25 mm, targeting fish between 15 and 25 cm), longlines with different hook sizes and two different types of bait (shrimp and squid) of 270 m length with ca. 150 hooks, Dyneema® lines to lower nets and longlines, a tripod, a line hauler and a 12 V battery.

"Citizen science" equipment: The equipment for opportunistic fish sampling consisted of rods and reels for angling down to 500 m to be used under cold conditions, such as aluminium reels and special non-freezing rods (plastic immediately breaks off at temperatures of -30 °C). Many different artificial baits were brought as well. This equipment could be borrowed by anyone on board in their free time, and in case fish was brought up the EFICA scientists would get the opportunity to take scientific samples. The equipment could be used from the moon pool (an opening in the hull of the ship giving access to the water below) or from the ice. Fishing tents were available for winter conditions.

e-DNA sampling equipment: The equipment for filtering water on Sterivex® filters for DNA sequencing consisted of two peristaltic pumps with eight double pump heads and everything necessary for sampling large volumes of water (carboys, buckets, containers, etc.). The Sterivex® filters with the DNA were stored in -80 °C freezers on-board.

Ship resources: During the expedition, ship resources necessary for carrying out SC03 was available to the EFICA scientists on-board[14].

[13] Demer D.A., et al. (2015) Calibration of acoustic instruments. ICES Cooperative Research Report, 326: 132 pp.

[14] AWI (2017) Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung. Polar research and supply vessel *Polarstern* operated by the Alfred-Wegener-Institute. JLSRF 3, A119.

6 LOGBOOKS AND DATA STORAGE

6.1 Logbooks

Two types of Logbooks were provided by the EFICA scientists on board: (a) "Biweekly Reports" sent from the EFICA scientists on the *Polarstern* to SC03 Coordinator (Pauline Snoeijs-Leijonmalm) who reported them to CINEA/DG MARE, and (b) a list of "Device Operations" in an on-board database that was updated before and after each scientific operation from the ship or on the ice (Database File 02). The latter Logbook was directly coupled to the sampling device used, as well as to sampling day, time, the ship's position and other basic ship data. In the case of EFICA, these devices were the mainly the EK80 and EK60 echosounders (hydroacoustics), the FishCam, the fishing gear, and the CTD or ice corers for the e-DNA samples. Other data and sample collection carried out within the MOSAiC Core Programme of importance for the interpretation of the EFICA results are included in Database File 02 as well.

6.2 MOSAiC data storage

All data collected during the MOSAiC expedition were stored in the MOSAiC Central Storage (mcs) server directly on board. After each leg, the mcs data were transferred to and stored at the AWI. These data are available online to all MOSAiC participants who have signed the MOSAiC data policy. This is a growing data repository since many samples are analysed in land-based laboratories after the MOSAiC field year. After an embargo period, all MOSAiC data will become publicly available on 1 January 2023. The EFICA scientists have stored all hydroacoustic data, FishCam videos, information on fish size, weight, sex, on the mcs immediately after the on-board measurements. For the MOSAiC Core Programme on-board data storage included, e.g., all physical oceanographic data collected by the CTD casts.

6.3 MOSAiC sample inventory

The mcs also contains the type and number of samples taken during each device operation. For EFICA these are the samples taken during dissection of the fishes: fish sample ID, otoliths, gonads, liver, stomach, hindgut, muscle sample, etc. For e-DNA, this is a list of DNA samples taken in the MOSAiC Core Programme: CTD number, sample number, sampling depth, volume of water on each filter for DNA. Further samples taken within the MOSAiC Core Programme relevant for EFICA are, e.g., sympagic juvenile polar cod and other ice fauna, under-ice video recordings, nutrient samples, chlorophyll-a samples, zooplankton samples, trophic biomarker samples.

6.4 Data delivery to CINEA / DG MARE

The SC03 Project Manager Hauke Flores (AWI) was responsible for compiling all metadata and for producing the SC03 Metadata Database to be delivered to CINEA/DG MARE (**Chapter 12**). This database includes 15 EXCEL files (Database Files 01-15). The database includes metadata for all EFICA-specific parameters and relevant MOSAiC Core Parameters.

6.5 Exclusive use of hydroacoustic and e-DNA data

The EFICA-specific hydroacoustic data collection (EK60 and EK80 programming, data collection and calibration) was carried out by the EFICA scientists under SC03, but officially these data are owned and stored by the AWI. However, the EFICA Consortium has the exclusive opportunity to elaborate and analyse the data for abundances of living organisms (fish, zooplankton) and their physical environment (in a future SC). This exclusive opportunity for the EFICA Consortium is safeguarded by the SC03 Project Manager Hauke Flores (AWI) until EFICA has analysed the data or as long as the FWC is valid.

The DNA sampling was a MOSAiC Core Parameter, i.e., shared expedition data. EFICA scientist Pauline Snoeijs-Leijonmalm filtered all water-column DNA samples during Leg 1. During Legs 2-4, this was to a large extent performed by scientists from the Swedish CN-project on microbial metabolism (the other project on the MOSAiC expedition that was led by Pauline Snoeijs-Leijonmalm). The EFICA Consortium has the exclusive opportunity to elaborate and analyse the DNA data (in a future SC) for metagenomic bioinformatic analyses – as well as specific gene analyses – for e-DNA analyses to identify species of fish, squid, fish prey (zooplankton) and fish predators (mammals) in a future SC. This exclusive opportunity for the EFICA Consortium is safeguarded by the SC03 Project Manager Hauke Flores (AWI) until EFICA has analysed the data or as long as the FWC is valid.

7 EXPEDITION TRACK AND EVENTS

7.1 Cruise summary

Scientific data and sample collection during the MOSAiC expedition took place when the ship was anchored to the drifting sea ice (**Figure 1**), except for very few CTD casts and fish sampling occasions when the ship was stuck in the ice during transit. The MOSAiC drift track is shown in **Figure 12**, and major organisational events during the expedition are summarised in **Table 10**. General information about the MOSAiC expedition is available at https://follow.mosaic-expedition.org and mosaic-expedition.org.

The MOSAiC expedition started when *Polarstern* left the harbour of Tromsø (Norway) together with *Akademik Fedorov* (Russia) on 20 September 2019. Although the scientific programme of Leg 1 started on 15 October (**Table 10**), the scientific research of Team ECO became operational only 10 days later (on 24 October). By that time, the Central Observatory had been built up on the MOSAiC ice floe, the laboratories were fully operational, and weekly sampling schedules were established. However, hydroacoustic data collection by the EFICA scientists had already started on 1 October 2019, immediately after leaving the Russian EEZ.

During the first three expedition legs, the MOSAiC ice floe crossed the CAO from the Siberian side outside the Laptev Sea to the European side north of Svalbard. On its way, the floe passed the deep Amundsen Basin, the Gakkel Ridge and the Nansen Basin, and in May it drifted into the Norwegian EEZ, covering a total drift trajectory of 3,167 km between 1 October and 28 May. This implies that a full high-resolution High Seas transect of EFICA fish studies was accomplished already after eight months at the end of Leg 3. The high speed of the transpolar drift may indicate that it is accelerated by climate warming since the AWI drift models had predicted that the transpolar drift during the MOSAiC expedition would take longer than eight months.

The Covid19 pandemic imposed significant logistical challenges to the MOSAiC expedition, and especially for the scientists and crew of Leg 3 and 4. In April-May 2020 no Swedish, Russian or Chinese icebreaker was prepared to travel to *Polarstern* for exchanging people and cargo. In addition, aircraft could not land on the sea ice at the MOSAiC ice floe because of the highly unstable ice conditions. An emergency solution was realised by the German Ministry for Education and Research supporting the AWI. Unfortunately, *Polarstern* had to leave the ice floe on 17 May for steaming to Svalbard and meet two German research vessels (RV *Sonne* and RV *Maria Sybilla Merian*) on 4 June for exchanging people and cargo. This extraordinary solution caused a six-week Covid19 gap in data collection of the MOSAiC Core Parameters and most of the on-board projects (including SC03), in the middle of the spring season when biological activity explodes in the Arctic. The Leg 4 people brought by the two German rescue ships had been in strict quarantine for several weeks while repeatedly being tested for infection with the Covid19 virus. Due to the long delay of the Leg 3 / Leg 4 transition and the long duration of the transition (involving a transit of *Polarstern* to and from Svalbard), the expedition schedule was adjusted by combining the original Legs 3 and 4.

During Leg 4, the Leg1-3 MOSAiC ice floe crossed the Yermak Plateau north of Svalbard and drifted towards Fram Strait. During Leg 4, the EFICA scientists concentrated on studying fish that could enter the CAO via Fram Strait by hydroacoustic measurements and fish sampling. Since the MOSAiC floe had drifted out of the expedition's target area and also had disintegrated by melting processes, *Polarstern* relocated to a new ice floe close to the North Pole for an additional three-week "mini drift" to accomplish Leg 5. Scientific studies started on 28 August, but the expedition also had to pack up the entire Central Observatory during this time and left the new floe already on 20 September 2020 for steaming home to Bremerhaven. No EFICA scientists were on board during Leg 5, but the hydroacoustic measurements are valuable because they suggest that higher fish biomass than detected over the deep basins may occur close to the Lomonosov Ridge.

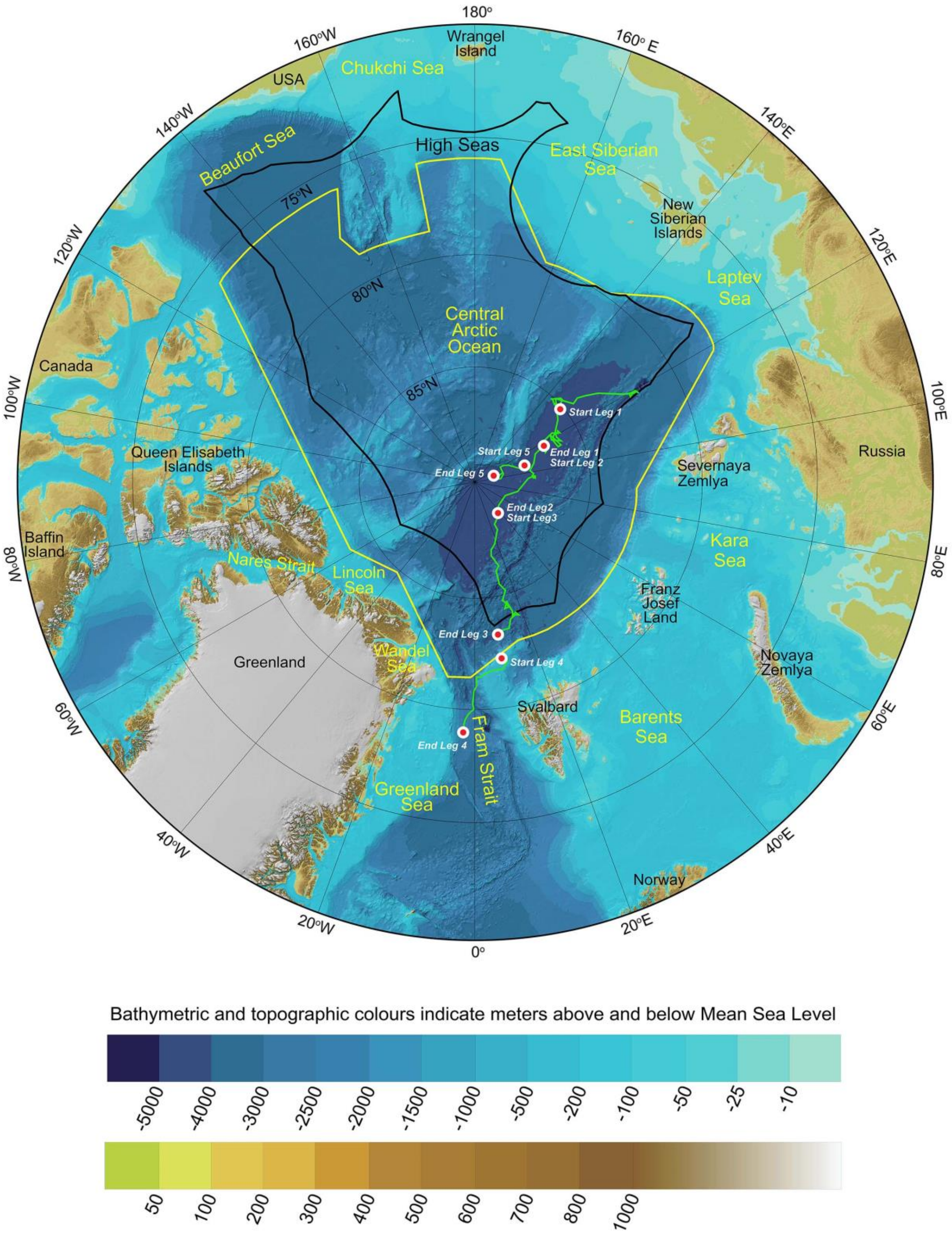

Figure 12: The drift track of *Polarstern* from entering the High Seas on 1 October 2019 (start of the EFICA hydroacoustic measurements) until 20 September 2020 (when the ship left the Leg 5 ice floe). The start and end of each MOSAiC leg is marked with a red circle. The official start of Leg 1 was on 15 October 2019 (Table 10). The transit tracks are shown in Figure 1. Background map: bathymetric map of the Arctic Ocean[15].

[15] Jakobsson M, et al. (2012) The International Bathymetric Chart of the Arctic Ocean (IBCAO) Version 3.0. Geophysical Research Letters 39:L12609 [http://doi.org/10.1029/2012GL052219]

Table 10: Major organisational events during the MOSAiC expedition in chronological order.

Date	Event
190914	Arrival of scientists in Tromsø (Norway) for trainings and cargo operations
190920	Departure *Polarstern* and *Akademik Fedorov* from Tromsø
190920	**Official start of MOSAiC Leg 1**
191002	*Polarstern* and *Akademik Fedorov* meet at the MOSAiC ice floe
191003	People exchange Leg 1a / Leg 1b
191004	*Polarstern* anchors at the ice floe, start of building the Central Observatory
191015	Start of the MOSAiC transpolar drift
191017	*Polarstern* and *Akademik Fedorov* meet at the MOSAiC ice floe
191017	People exchange Leg 1b / Leg 1a
191024	Start of the fieldwork on the MOSAiC ice floe
191213	Arrival of *Kapitan Dranitsyn* at the MOSAiC ice floe
191213	**Official start of MOSAiC Leg 2**
191217	People exchange Leg 1 / Leg 2
191218	Departure of *Kapitan Dranitsyn* from the MOSAiC ice floe
200224	**Official start of MOSAiC Leg 3**
200228	Arrival of *Kapitan Dranitsyn* at the MOSAiC ice floe
200303	People exchange Leg 2 / Leg 3
200307	Departure of *Kapitan Dranitsyn* from the MOSAiC ice floe
200517	*Polarstern* leaves the MOSAiC ice floe - The transpolar drift is temporarily terminated
200604	Arrival of *Polarstern* in Isfjorden, Svalbard (Norway)
200604	**Official start of MOSAiC Leg 4**
200606	People exchange Leg 3 / Leg 4
200608	Departure *Polarstern* from Isfjorden
200609	*Polarstern* reaches the ice edge
200617	*Polarstern* arrives at the MOSAiC ice floe
200626	Basic infrastructure of the Central Observatory is restored, start of regular science schedule
200729	Begin demobilization due to disintegration of the MOSAiC ice floe
200731	Departure from MOSAiC ice floe
200810	People exchange Leg 4 / Leg 5
200821	Arrival of *Polarstern* at new MOSAiC ice floe
200828	**Official start of MOSAiC Leg 5**
200920	Departure of *Polarstern* from MOSAiC ice floe
200930	Last under-way ice station
201002	End of hydroacoustic measurements
201012	**Arrival *Polarstern* in Bremerhaven (Germany) - End of expedition**

7.2 Events during MOSAiC Leg 1

On Wednesday 2 October 2019, the MOSAiC ice floe outside the Laptev Sea was identified, and people were exchanged between the ships on 3 October. A group of scientists (including the three EFICA scientists), who had been unpacking and setting up the laboratories at *Polarstern* during the first 12 days on *Polarstern*, moved to *Akademik Fedorov* from where the Distributed Network was set up. At the same time, technicians from the AWI moved from the *Akademik Fedorov* to *Polarstern* to build up the Central Observatory on the ice floe. This included setting up roads, electricity, fibre optics, and huts and tents with equipment in concentrated at certain sites: "MET City", "OCEAN City", "ROV City", "BALLOON Town", and "Remote Sensing". Building the Central Observatory and the Distributed Network took about two weeks. On 17 October the scientists were exchanged back to *Polarstern* (**Table 10**), and they continued with unpacking and setting up the laboratories on the ship and installing equipment on the ice.

From 1 October until 13 December, *Polarstern* drifted between 85°06' N, 136°95' E and 86°59' N, 119°65' E (**Figure 13**). The drift strongly depended on winds and currents; sometimes the ship was moving slowly in circles and sometimes quite fast and unidirectional. The sum of the drift was – as expected – in the direction of the North Pole. Major disturbances were caused by storms and since the sea ice was very unstable, cracks in the ice formed quickly so that electricity and fibre optic cables needed frequent repair, which sometimes could take many days (**Figure 14**). Furthermore, polar bears destroyed installations on some occasions (**Figure 15**). Due to the strong ice dynamics and the need to repeatedly rescue and re-deploy equipment, the Central Observatory looked very different on 15 December as compared to 15 October.

Figure 13: The *Polarstern* anchored to the sea ice in the Polar Night during MOSAiC Leg 1. © Pauline Snoeijs-Leijonmalm, 2019

Figure 14: Challenging situations on the MOSAiC ice floe during Leg 1. (A) A crack in the ice near the ship. (B) Electricity and data cabling in the Central Observatory on the ice floe Right. (C) Polar bears molesting cabling and equipment. (D) Bear guard on the ice. (E) Bear guard returning from the ice after four hours of bear guarding. (F) Polar bear mother and child who returned to the MOSAiC ice floe several times during Leg 1. © Pauline Snoeijs-Leijonmalm (A,B,D,E), 2019; © Martin Schiller (C), 2019; © Janek Uin (F), 2019

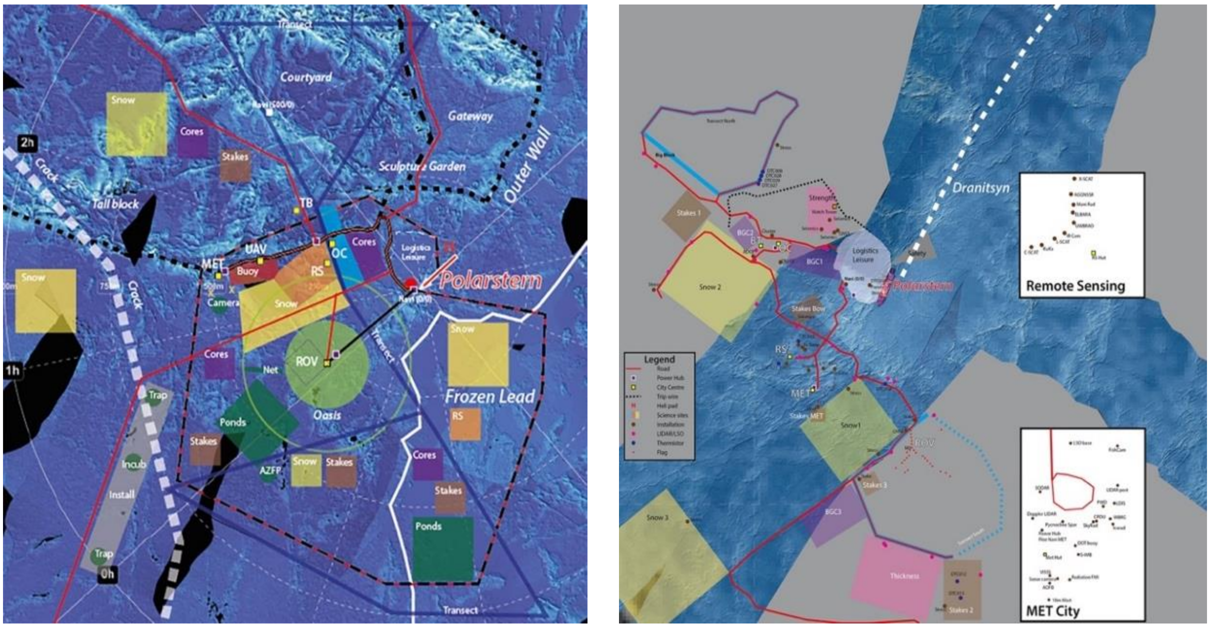

Figure 15: Images showing how the different components of the MOSAiC Central Observatory moved around between 15 October (left) and 15 December 2019 (right). © AWI

7.3 Events during MOSAiC Leg 2

Leg 2 started with the arrival of the Russian vessel *Kapitan Dranitsyn* at the MOSAiC ice floe on 13 December 2019 (**Table 10**). The exchange of people and cargo took three days (**Figure 16**). From 13 December until 24 February, *Polarstern* drifted between 86°59' N, 119°65' E and 88°58' N, 51°25' E. The transpolar drift was in an overall north-westerly direction and carried the ship over a total distance of 672 kilometres during Leg 2. On 23 February at 21:00 hours UTC, Leg 2 reached its northernmost position at 88°60’ N, 59°25’ E.

Figure 16: *Polarstern* and *Kapitan Dranitsyn* during the handover of Leg 1 to Leg 2. © AWI, 2019

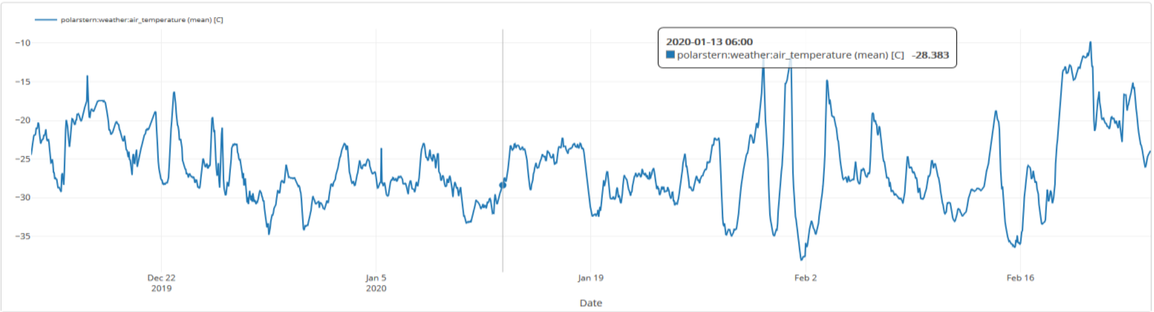

Figure 17: Air temperature at *Polarstern* during Leg 2.

Similar to Leg 1, storms and unstable ice caused major disturbances of the fieldwork during leg 2. The conditions became extremely harsh in February. A major storm hit the Central Observatory on 1 February, and the air temperature dropped from -11.4 °C to -38.2 °C within one day (**Figure 17**). At temperatures below -30 °C, all operations on deck (i.e., CTD and nets) were suspended. The storm lasted for two weeks. With these low temperatures and the storm limiting access to the ice floe, it became extremely difficult to maintain the sampling installations outside the ship. The CTD hole near the ship (a.o. for DNA sampling) was particularly prone to freezing over, and keeping it open required a lot of effort (**Figure 18**). The wind increased *Polarstern*'s drift speed and caused strong ice pressure, resulting in new cracks in the ice that damaged research equipment. Luckily, the EFICA FishCam survived these events. Due to the ice dynamics and the need to repeatedly rescue and re-deploy equipment, the Central Observatory looked very different on 25 February as compared to 1 February (**Figure 19**).

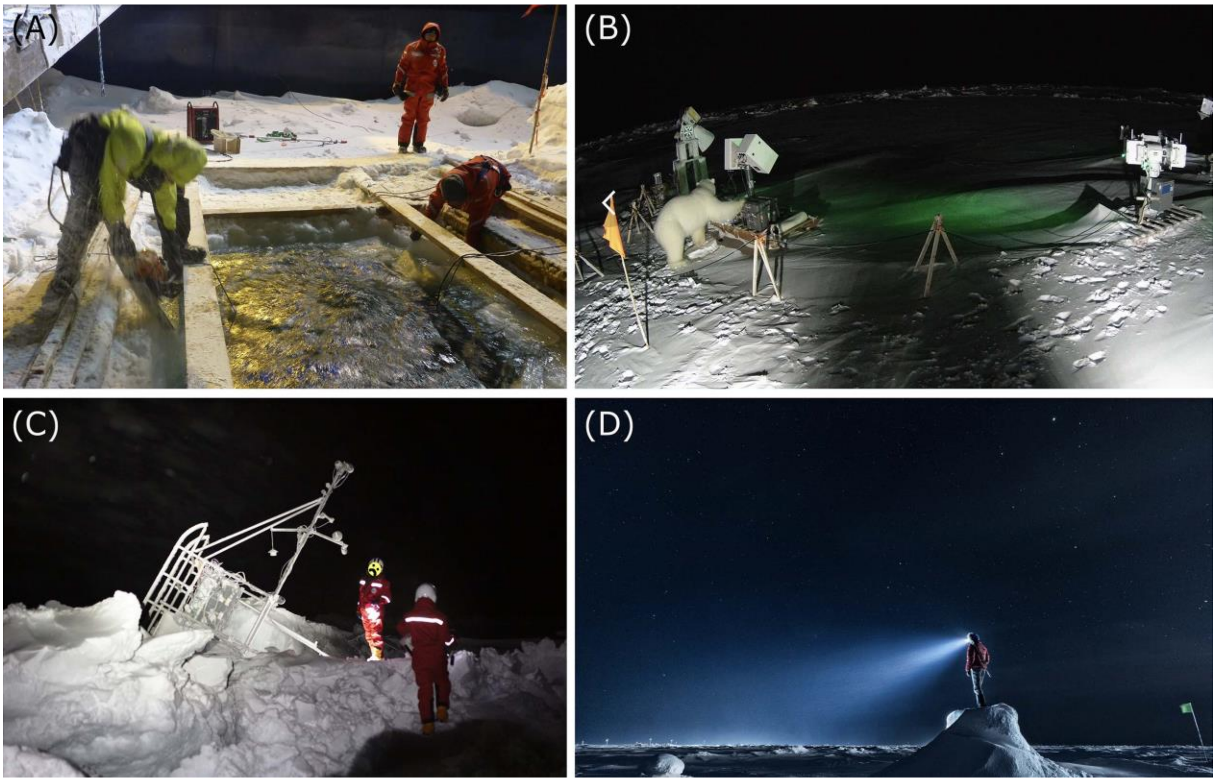

Figure 18: Challenging situations on the MOSAiC ice floe during Leg 2. (A) Team ECO worked hard to keep the CTD hole next to the ship open to be able to get water samples. (B) Polar bear molesting scientific equipment. (C) Dynamic movements of the ice caused by a storm resulted in a newly formed ridge that destroyed a meteorological sensor mast. (D) Bear guard. © Eric Brossier (A), 2020; © AWI (B), 2020; © Michael Gallagher (C), 2020; © Lukas Piotrowski (D), 2020

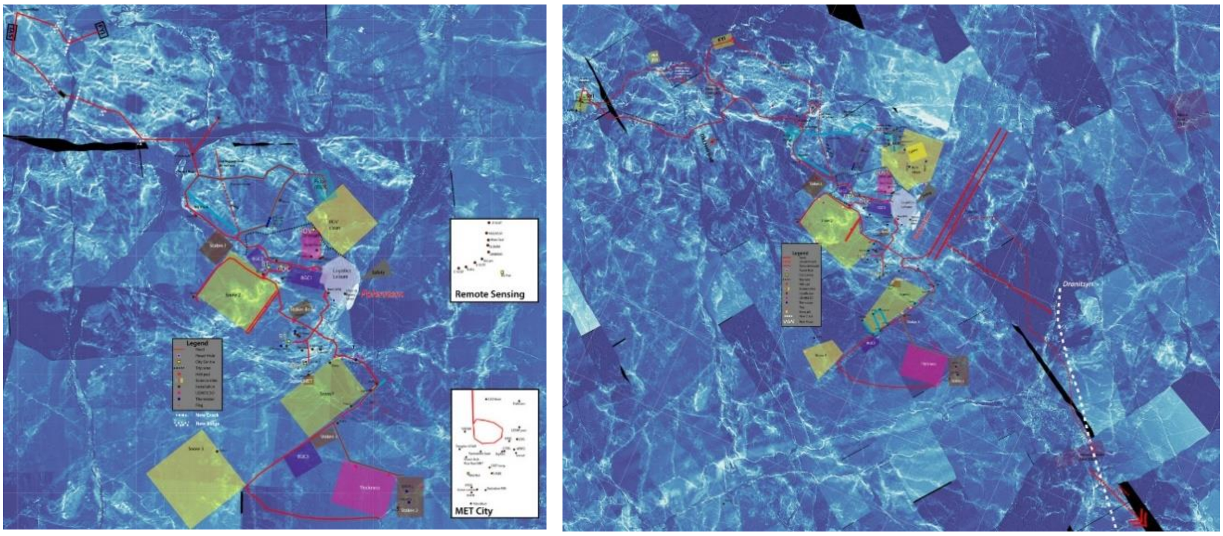

Figure 19: Images showing how the different components of the MOSAiC Central Observatory moved around between 1 February (left) and 25 February 2020 (right). © AWI, 2020

7.4 Events during MOSAiC Leg 3

The exchange of people and cargo between Leg 2 and Leg 3 was again serviced by *Kapitan Dranitsyn* (**Table 10**). Between 24 February and 4 June 2020, *Polarstern* drifted between 88°58' N, 51°25' E and 78°12' N, 12°83' E. The ice drift during Leg 3 was in a westerly direction during the first half of Leg 3, and after that mostly south. In mid-May, the MOSAiC ice floe drifted into the Norwegian EEZ, and on 28 May it left the CAO ecosystem (**Figure 8**).

The on-ice data and sample collection during Leg 3 continued to be affected by extreme conditions with multiple ice break-ups and increasing instability (**Figure 20**). Especially from 11 March onwards, the sea ice was highly unsteady and unpredictable. An extensive lead system formed around the Central Observatory, which was followed by heavy ice ridging. MET City (where the FishCam was installed) and the Remote Sensing site were separated from the ship by a lead. The power line between *Polarstern* and MET City was disconnected. In addition, *Polarstern* was pushed forward relative to the large CTD hole on the starboard side. As a consequence, no CTD sampling from the ship was possible anymore, and the persisting dynamic situation prevented the scientists from resuming ship-based CTD sampling until the end of Leg 3. Instead, the much smaller CTD hole in OCEAN City on the ice floe was used, and the water sampling programme had to be reduced significantly. In the end of April, the disintegration of the ice floe accelerated, and major equipment needed to be relocated. This increasingly unstable situation due to weather conditions in combination with ice melt ended in a nearly complete breakup of the MOSAiC ice floe on 17 May. Due to the ice dynamics, the Central Observatory looked very different on 5 May as compared to 20 April (**Figure 21**).

On 15 March, a lead had formed across the central part of the ice runway that had been designated for the landing of aircraft to perform the Leg 3 / Leg 4 exchange of people and cargo. This exchange was re-scheduled several times because the ice floe did not allow for landing aircraft as initially planned, and at the same time the Arctic region became increasingly inaccessible due to travel restrictions related to the unfolding Covid19 pandemic. Finally, an exchange was organised by AWI and the German Ministry for Education and Research. The *Polarstern* left the MOSAiC ice floe on 17 May to meet two German research vessels (RV *Sonne* and RV *Maria S. Merian*) near Svalbard on 4 June, more than six weeks after the initially scheduled exchange in April. Due to the long delay of the Leg 3 / Leg 4 transition, the MOSAiC expedition schedule was altered to comprise five instead of the six initially planned legs.

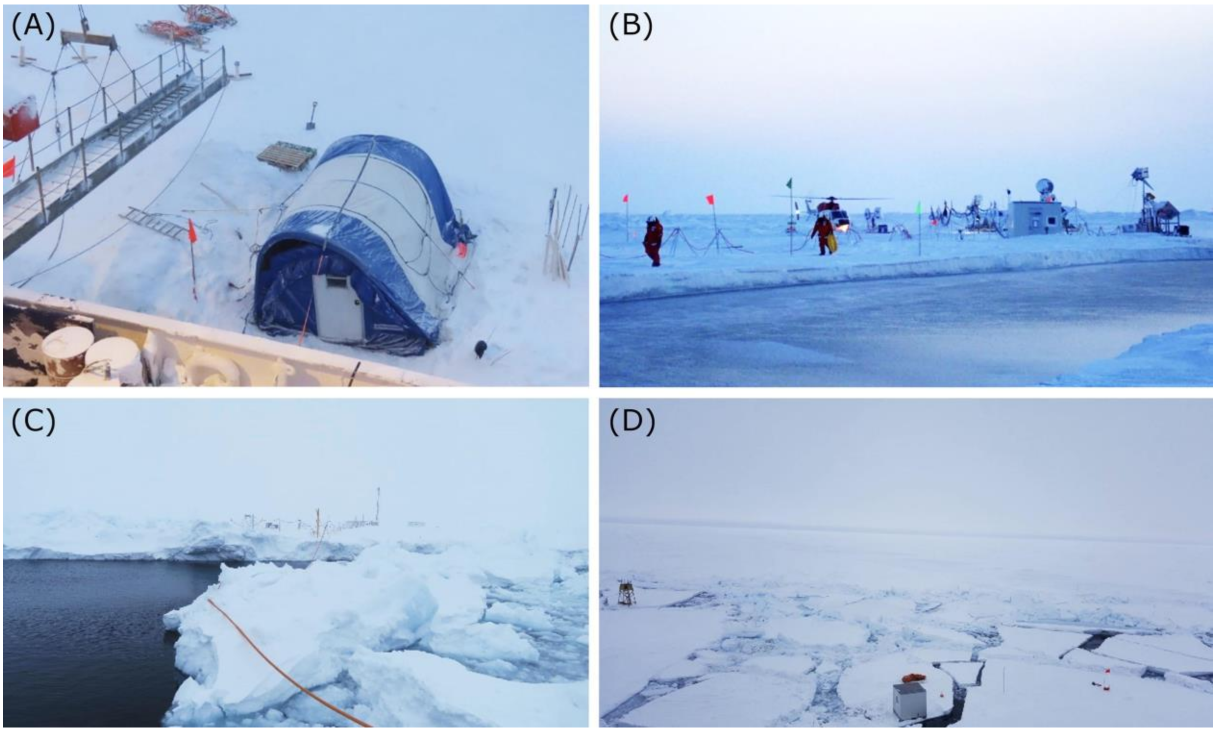

Figure 20: Challenging situations on the ice floe during Leg 3. (A) The tent over the CTD hole on the starboard side of *Polarstern* was run over by the gangway near the stern. (B) A large lead in the middle of the Central Observatory made transport difficult. (C) Cables needed to be disconnected and re-deployed due to the risk imposed by the dynamic ice. (D) The MOSAiC ice floe broke up to a large extent before the departure of *Polarstern* to Svalbard on 17 May. © AWI (A-D), 2020

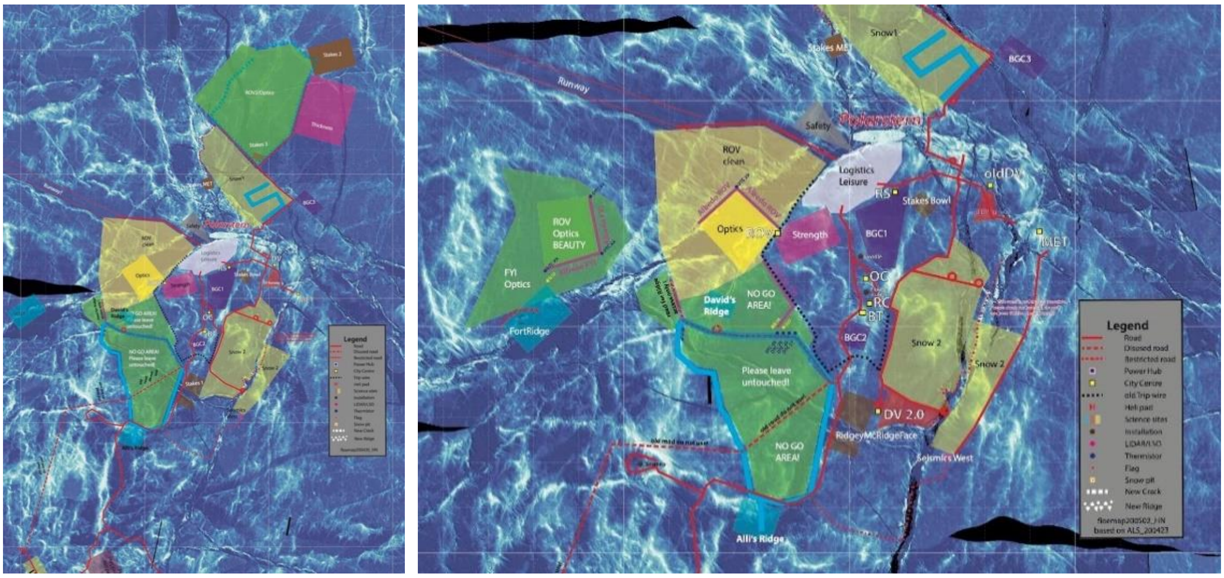

Figure 21: Images showing how the different components of the MOSAiC Central Observatory moved around between 20 April (left) and 5 May 2020 (right). © AWI, 2020

7.5 Events during MOSAiC Leg 4

During the rendezvous with RV *Maria S. Merian* and RV *Sonne*, the exchange of people and cargo between Leg 3 and Leg 4 near Svalbard was successfully concluded (**Figure 22**). The MOSAiC leadership decided to continue the research at the same ice floe used during Legs 1-3, even if it now had drifted out of the CAO and had heavily disintegrated. The

Polarstern left the Svalbard area on 8 June 2020 and arrived back at the Leg 1-3 ice floe on 17 June. Finding a good place for positioning the ship for obtaining a stable sampling hole for CTD and net operations was a major challenge. After anchoring to the sea ice, an ice camp was re-established, and regular scientific sampling was resumed on 26 June (**Table 10**). Between 17 June and 31 July, *Polarstern* drifted from 82°16' N, 08°28' E to 79°07' N, 02°56' W.

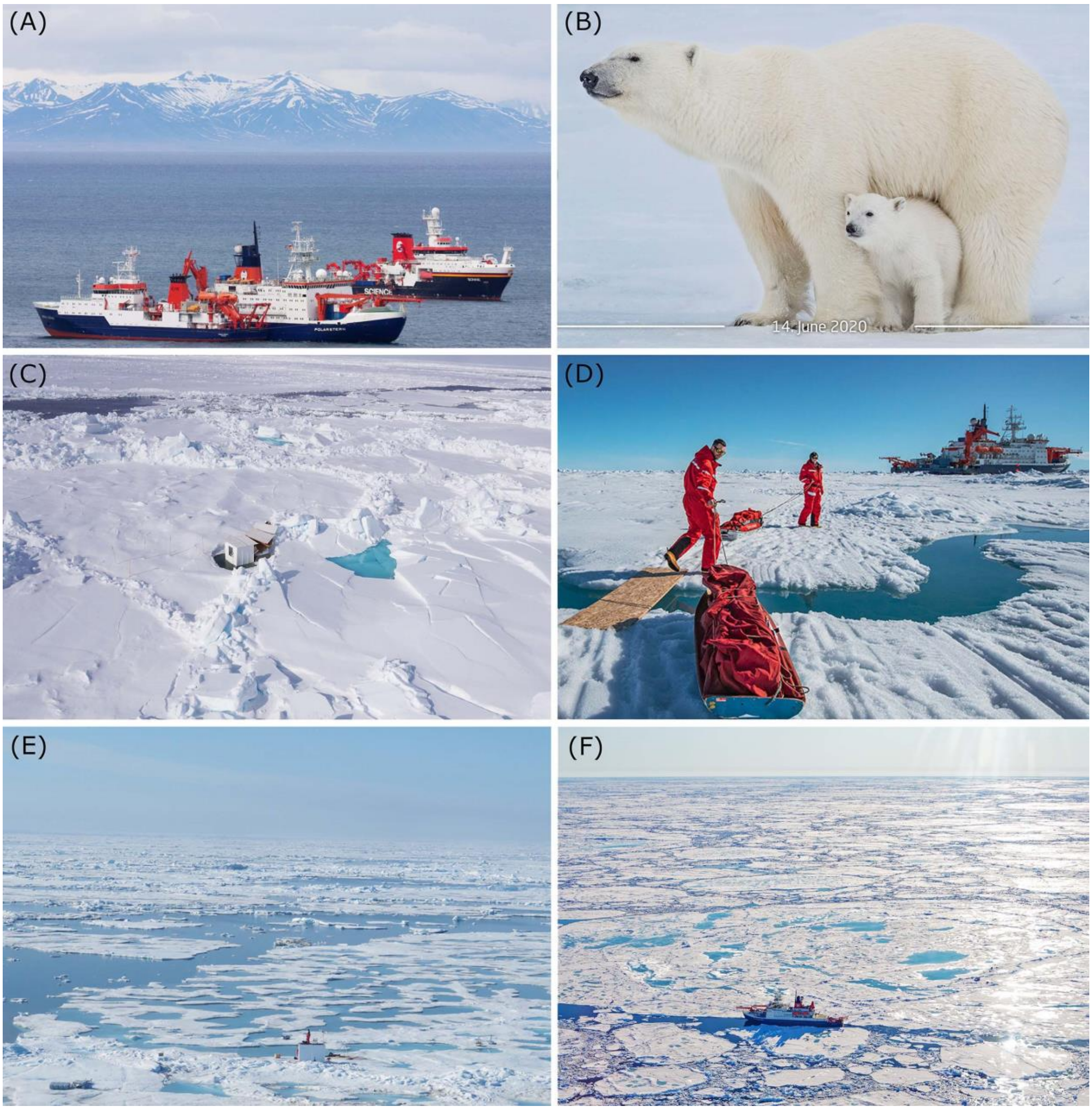

Figure 22: Exchange of people and cargo between MOSAiC Legs 3 and 4 near Svalbard and melting of the old ice floe during Leg 4. (A) *Polarstern* with *Maria S. Merian* and *Sonne* during the exchange. (B) Polar bear encounter on the way back to the old ice floe. (C) The old ice floe looks different upon arrival on 17 June. (D) The fieldwork is complicated by numerous leads and melt ponds. (E,F) The old ice floe is disappearing in the end of July. © Leonard Magerl (A), 2020; © Lianna Nixon (B,D), 2020; © Markus Rex (C,F), 2020; © Luisa von Albedyll (E), 2020

Upon arrival at the Leg 1-3 MOSAiC ice floe on 17 June, it appeared that it had changed significantly (**Figure 22**). The remaining part of the floe now had a circular shape with a diameter of ca. 1 km (**Figure 23**). The second-year-ice sampling site drifted as a separate ice floe. The former Central Observatory was detached from the ice floe as well, with some of the installations still enduring on small fragmented floes. This meant that the new ice camp had to be set up in a much smaller area, that with time decreased even further as melting proceeded. In the beginning of Leg 4, fieldwork conditions were generally good, but this changed rapidly during the summer season. Leads and melt ponds developed in many places, and towards the end of Leg 4, the ice floe definitely started to fall apart. On 29 and 30 July, the ice camp equipment was rescued in an emergency action, before complete disintegration of the ice floe. *Polarstern* departed from what was left of the floe on 31 July, on its way rescuing some additional scientific installations from the ice camp that had been drifting around in the area. On 10 August, *Polarstern* met with RV *Tryoshnikov* (Russia) with the new Leg 5 team on board.

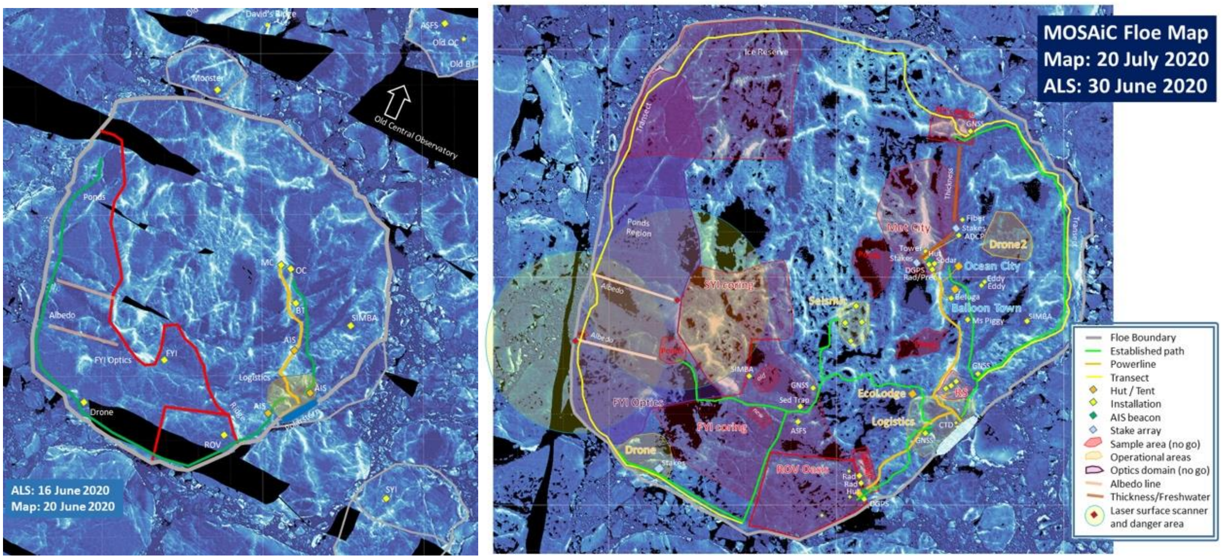

Figure 23: Images showing how the different components of the MOSAiC Central Observatory moved around between 20 June (left) and 20 July 2020 (right).

7.6 Events during MOSAiC Leg 5

The preparations for MOSAiC Leg 5 began with a two-week quarantine for all cruise participants in Bremerhaven (18 July - 3 August). RV *Tryoshnikov* brought the participants to a rendezvous point with *Polarstern* near 80°N, 05°W (**Figure 24**). The exchange of people and cargo was concluded on 13 August 2020. Then *Polarstern* sailed north to find a new ice floe for Leg 5. During transit, *Polarstern* passed an open area close to the North Pole, possibly the first observation of open waters this far north. The Leg 5 scientists performed several sampling stations in this area. After passing the North Pole, *Polarstern* reached a suitable floe at 88°00' N, 104°41' E on 21 August (**Table 10**). From this position, *Polarstern* drifted to 89°14' N 111°02' E at the end of the MOSAiC fieldwork on 20 September.

Leg 5 was characterized by the transition from summerly melting conditions to autumn freeze-up. When *Polarstern* arrived at the new Leg 5 floe, it was scattered with melt ponds (**Figure 25**). Again, the crew had difficulties finding a good position for a CTD hole, and the ship had to be relocated repeatedly. Space on the relatively small ice floe was again very limited. This made it very difficult to operate deep-wired gear, such as the FishCam and longlines. By the end of Leg 5, all melt ponds were frozen and autumn had arrived (**Figure 25**).

Figure 24: Exchange of people and cargo between MOSAiC Legs 4 and 5 near 80^{o}N, 05^{o}W, fieldwork at the new MOSAiC ice floe and *Polarstern* returning home after one year. (A,B) *Polarstern* with *Tryoshnikov* during the exchange. (B) Polar bear encounter on the way back to the old ice floe. (C) A new ice hole for CTD and net deployments is made next to the ship. (D) The fieldwork is complicated by leads. (E) Polar bears inspect the new ice floe, (F) *Polarstern* on its way out of the ice heading for Bremerhaven. © Steffen Graupner (A), 2020; © Lianna Nixon (B,D,E), 2020; © Folke Mehrtens (C), 2020; © Markus Rex (F), 2020

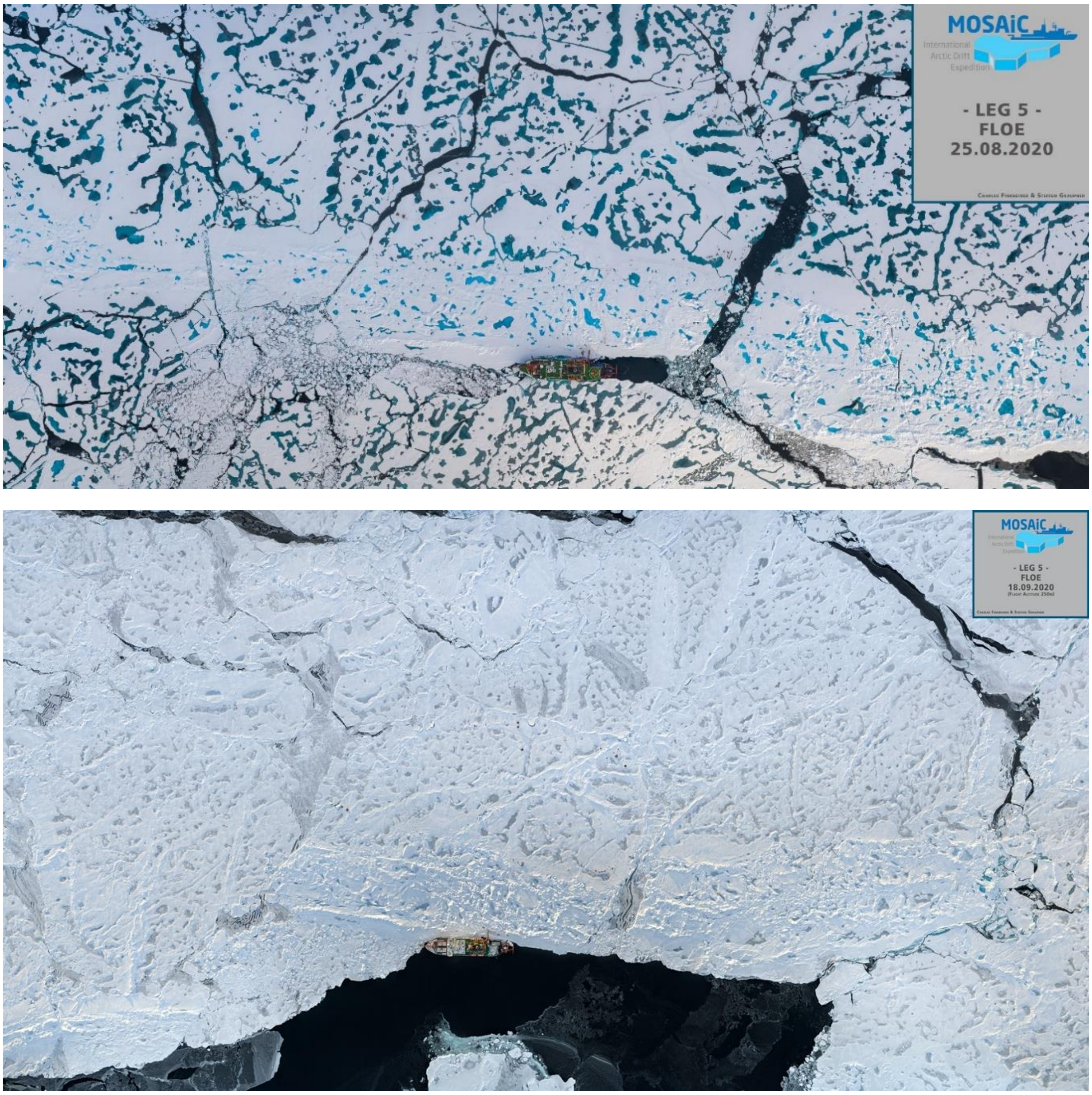

Figure 25: Images showing the ice conditions of the MOSAiC Central Observatory on the new ice floe on 25 August (upper panel) and 18 September (lower panel) 2020. © S. Graupner/C. Finkenbeiner, 2020

8 HYDROACOUSTIC DATA COLLECTION BY EFICA

8.1 Hydroacoustic measurements during MOSAiC Leg 1

On 1 October, as soon as the *Polarstern* was outside the Russian EEZ, the EFICA scientists Pauline Snoeijs-Leijonmalm and Anders Svenson turned on, programmed and optimized the ship's EK60 and EK80 echosounders for targeting fish and zooplankton. Until 17 December, they checked several times per day that the equipment was running properly and collecting data correctly. The collected acoustic data also provide information about the physical environment of the fish (e.g., water column stratification).

Acoustic signals from fish were detected in a deep scattering layer (DSL) with fish and zooplankton at ca. 200-500 m depth, similar to previous observations from icebreaker *Oden* in 2016[16], but with varying density and vertical distribution. Fish abundance was generally very low. Single fish tracks could always be distinguished, which means that swarms were not observed. In the beginning of Leg 1, higher abundances were sometimes observed, including potential signals of mostly small (roughly <15 cm long ca. -50 dB) fish, but also potential signals of larger fish (roughly up to ca. 60 cm long, >-45 dB). The organisms in the larger fish size range had extremely low densities, with at the most only two individuals passing under the ship per hour (**Figure 26**).

Further north, fish density decreased even more. There was a vertical movement of the scattering layer in relation to light. In the beginning of October, the upper limit of the scattering layer was at ca. 300 m. When there was light only part of the day in the second half of October there was diel vertical migration (DVM) with the upper limit at ca. 300 m in light and at ca. 200 m in darkness. During the rest of MOSAiC Leg 1, the upper limit was around ca. 200 m in 24 hours of darkness.

EFICA used the main echosounder in both EK60 and EK80 mode. As foreseen in the EFICA SC04 Workshop[17], these hydroacoustic data constitute the backbone for the quantification of mesopelagic fish in the CAO during the MOSAiC expedition for two reasons: firstly, targeting fish with traditional quantitative trawling at 200-600 m is logistically impossible due to the ca. 2 m thick sea ice cover. However, every specimen the EFICA scientists were able to sample with other methods (fishing lines) provided an indication of which species are represented. Secondly, the hydroacoustic fish data collected by EFICA during the MOSAiC expedition are unique: a whole year of drifting has yielded an unprecedented data set that will be a standard for many years to come. Usually, scientific expeditions to the CAO typically take place in summer, are much shorter, and move between sampling stations by breaking ice so that hydroacoustic data collection is limited.

The installed frequencies, transceivers (GBT = general purpose transceiver, WBT = wide band transceiver) and modes (CW mode = continuous wave mode; FM = broadband mode) on the EK80 were until 15 November 38 kHz (GPT, CW mode), 70 kHz (WBT, FM mode), 120 kHz (WBT, FM mode), and 200 kHz (GPT, CW mode). On the EK60, the 18 kHz transducer is mainly used for bottom detection at a low ping interval (**Table 11**), but this frequency also detects fish, and reaches even deeper than the 38 kHz transducer. The 70 kHz and 120 kHz frequencies were manually swopped between FM and CW mode every 24 hours.

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[16] Snoeijs-Leijonmalm P. et al. (2021) A deep scattering layer under the North Pole pack ice. Progress in Oceanography 194:102560. [https://doi.org/10.1016/j.pocean.2021.102560]

[17] EFICA Consortium (2019) EFICA Workshop in preparation for the Polarstern and Oden expeditions for 2019 and 2020. Report to EASME/DG MARE. 32 pp.

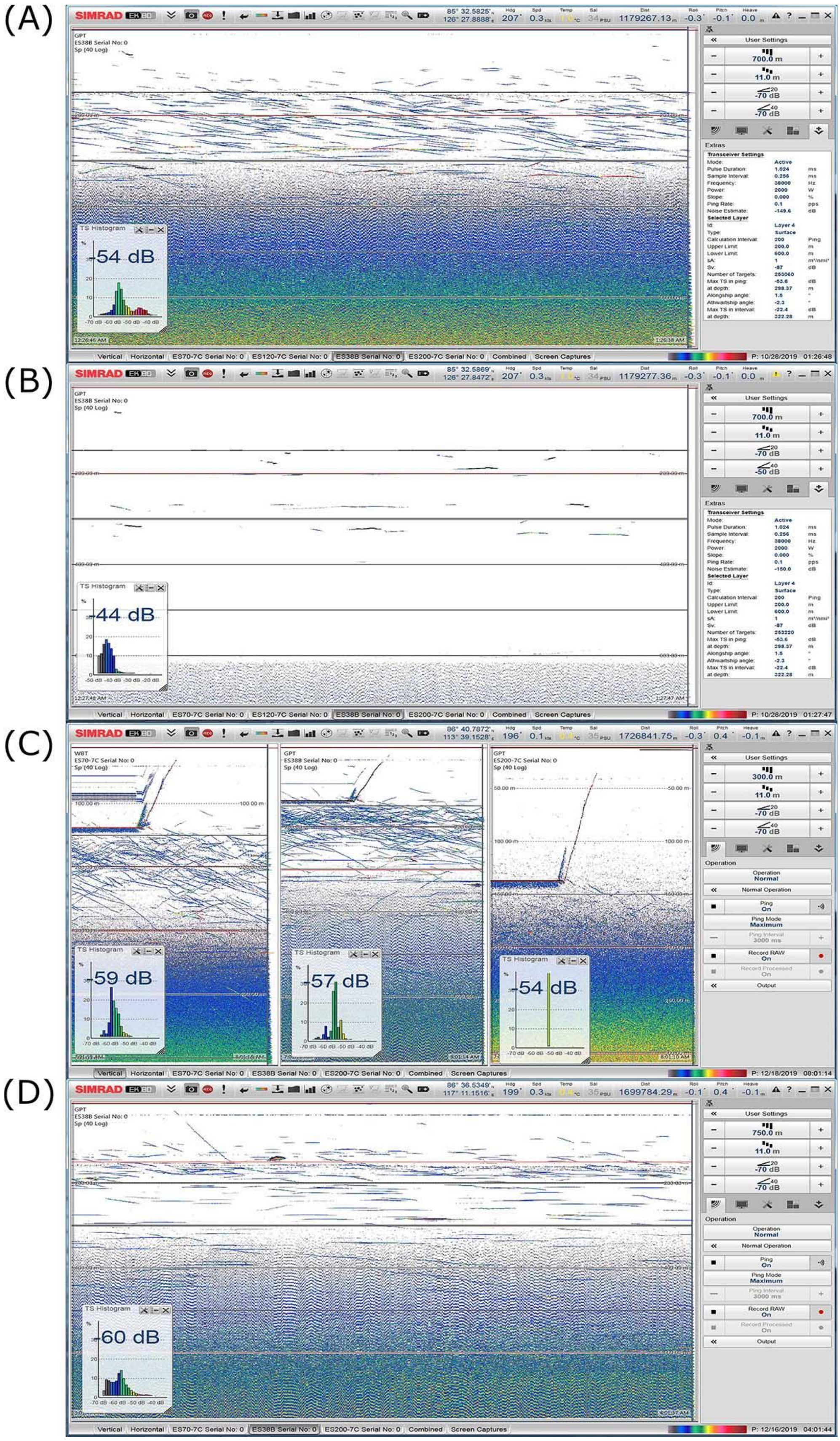


Figure 26: Screen captures from the *Polarstern* EK60/EK80 echosounder during MOSAiC Leg 1. (A) Echogram from 85°33' N (1 hour) with a deep scattering layer (DSL) indicating living organisms between 150 and 400 m cut off at 70 dB; most organisms are smaller than fish. (B) The same echogram cut off at 50 dB; the organisms still visible may be fish, and their abundance is very low. (C) Disturbance from the discharge of the grey water from the ship that happens every second day recorded at 70, 38 and 200 kHz. (D) Disturbance from weights on a fishing rod in the moon pool at 38 kHz.

On 15 November, the 120 kHz frequency was turned off because it had started to disturb the 38 and 70 kHz transducers. Since 20 November also the 120 kHz transducer was run in EK60 mode (GPT, CW mode). This change improved the quality of the hydroacoustic data collection targeting fish. This ship-borne problem causing interference of the 120 kHz transducer with the other transducers was identified and resolved after a thorough assessment during Leg 3. Three ADCPs (Acoustic Doppler Current Profilers) for measuring water current velocities over a depth range, one on the ship and two on the ice, were operated during the expedition without disturbing the echosounder fish and zooplankton data. The ship's ADCP is running in stand-alone mode (not on the ksync, **Table 11**).

Altogether, ca. 3 TB of hydroacoustic data were collected during Leg 1 of MOSAiC. Since the fish abundance was so low, and there were two types of recurring disturbances that must be corrected for manually, it is assumed that EFICA will use single target tracking for future acoustic data analyses (in a future SC).

The first recurring disturbance was the release of the grey water from *Polarstern* every other day. Before the expedition it was announced that the grey water would be discharged once a week, but in reality this happened more often (three times per week). Before discharging this freshwater, salt is recycled from the system that produces tap freshwater from seawater, so that the discharges would sink. These discharges were observed as density changes on the echosounder at ca. 150 m of depth (**Figure 26**). Since the water was cleaned and salted, this should not have any large effect on the fish but when analysing the echo sounder data, manual elaboration of this disturbance is required when analysing the dataset (in a future SC).

The second recurring disturbance was that of fishing rods being used from the moon pool the weights to lower the bait show up on the echo sounder – similar to a fish – and also these data must be removed manually (**Figure 26**). This is a trade-off between the acoustic data collection and the "citizen science" part of SC03, since without fish samples the acoustic data cannot be interpreted fully. It was evident during Leg 1 that it is possible to catch fish via the moon pool, although this was not successful during the subsequent expedition legs.

Table 11: Synchronization (ksync) of the ping intervals for the EK80 and EK60 of *Polarstern*, as established during Leg 1. This must not be changed, and no instruments can be added here, for the rest of the MOSAiC expedition.

Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Seconds	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	6.5	59
Instrument	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK60	Only 2

8.2 Hydroacoustic measurements during MOSAiC Leg 2

During Leg 2, EFICA scientist Giulia Castellani checked several times per day that the echosounders of the *Polarstern* were running properly and collecting data correctly.
Altogether, ca. 2 TB of hydroacoustic data were collected during Leg 2. The DSL was observed continuously in the Atlantic water layer of the CAO, and suggested very low abundances of small fish (roughly <15 cm long). In agreement, the catch of the zooplankton nets showed that Leg 2 was in a region with very low biomass in general.

During Leg 2, the EK80 and EK60 settings were the same as in the end of Leg 1, so the instruments ran with frequencies of 38 kHz (GPT, CW mode), 70 kHz (WBT, FM and CW mode, 200 kHz (GPT, CW mode) for the EK80 and 18 kHz and 120 kHz for the EK60 (GPT, CW mode). The mode of the 70 kHz transducer was continuously switched between FM and CV every 24 hours. In an attempt to fix the problem of interference between the 120 kHz and 38 kHz transducers, a preliminary interference test was conducted. These data are not yet analysed (but may be valuable when analysing the data in a future SC). Some unexpected signals were present in the recordings during the test (the ROV diving in water), and therefore the test was repeated during Leg 3.

The same events as during Leg 1 caused disturbances in the hydroacoustic data during Leg 2, but at a low level. The data can be used to detect and quantify fish and zooplankton after correction for these disturbances that included: discharges of grey water, which is documented by the ship so it can be easily identified in the data, and the deployment of fishing rods from the moon pool. During Leg 2, two AZFPs (Acoustic Zooplankton Fish Profilers) were installed on the ice by a project studying the upper water column under ice ridges. These AZFP buoys were placed at a distance of ca. 1 km from the ship in order to avoid any disturbance with EFICAs EK80 and EK60 recordings.

8.3 Hydroacoustic measurements during MOSAiC Leg 3

During Leg 3, EFICA scientist Serdar Sakinan checked several times per day that the echosounders of the *Polarstern* were running properly and collecting data correctly. He also performed a test for the interference between the 120 KHz and 38 KHz transducers and calibrated the echosounders.

Altogether, ca. 4.5 TB of hydroacoustic data were collected during Leg 3, which covered the Arctic seasonal dark to light transition in early spring. Furthermore, during the long (3.5 month, **Table 10**) drift there were considerable geographical changes in backscatter, and lead openings caused changed light levels under ice. This instigated drastic changes in the characteristics of the backscatter observed at different frequencies (e.g., DVM of the scattering layer observed on 200 kHz during March). Backscattering intensity associated with fish continued to decrease until the beginning of April and remained low in the beginning of May (**Figure 27**).

Furthermore, the average depth of the scattering layer deepened steadily. While its average depth was around 200 m in the beginning of March, it gradually descended reaching down as deep as 400 m in mid-April. As a day/night cycle of light intensity evolved during March, the diel vertical migration (DVM) of the zooplankton layer became apparent above the halocline (**Figure 28**). After the initiation of the diel vertical migration in early March, patches without organisms were observed at shallow depths during daylight and followed regular but evolving cycles for a period for approximately three weeks in March (**Figure 28**). In addition, the 200 kHz backscatter showed the development of a relatively strong scattering layer building up at the mixed layer depth and immediately below this depth. The existence of higher zooplankton concentrations was qualitatively confirmed with ROV and ring net tows. In the night of 15 May, some relatively strong signals indicated that fish started to show up between 280 and 420 m. On 16 May, these signals intensified. A clear signal of Atlantic water was visible which also corresponded to fish signals on the echosounder.

Data collection routines established during Leg 1, and continued during Leg 2, were followed also during Leg 3. At the start of Leg 3, the settings were the same as in the end of Leg 2, so the instruments ran with frequencies of 38 kHz (GPT, CW mode), 70 kHz (WBT, FM and CW mode, 200 kHz (GPT, CW mode) for the EK80 and 18 kHz and 120 kHz for the EK60 (GPT, CW mode). The daily checks and switches of the 70 kHz transducer mode from FM to CV every 24 hours were continued. However, during some extraordinary circumstances such as storms and lead openings, the EK80 was operated in FM mode to obtain a more detailed vertical record.

The echosounders, and particularly the 38 kHz transducer, had been influenced by an elevated background noise since November 2019. Initially it was assumed that the 120 kHz WBT could have been the source of the problem. For this reason, during the Leg 1 on 15 November 2019, this frequency was separated from the EK80 system and since then it had been running with the EK60 setup. Although this change reduced the background noise in the 38 kHz to some extent, the problem persisted at a level affecting the recordings below ca. 400 m. The test data collected during Leg 2 was analysed during the first week of Leg 3, and an additional test series was performed by fully isolating the 38 kHz and checking the progression of the noise. A new noise test identified that the interference showing in the 38 kHz transducer since Leg 1 was an electromagnetic field effect caused by the transducer's power connection. This problem was solved by connecting the transducer to another power source. The results of additional tests confirmed that the noise problem was solved by this action (**Figure 29**). After the tests on 9 March, the echosounders were switched back to the original setup (i.e., 120 kHz was connected back to the GPT mode and reconfigured under the EK60). By March 13, 20 07:30 am, the 120 kHz transferred to the WBT and started running in parallel to the 70 kHz.

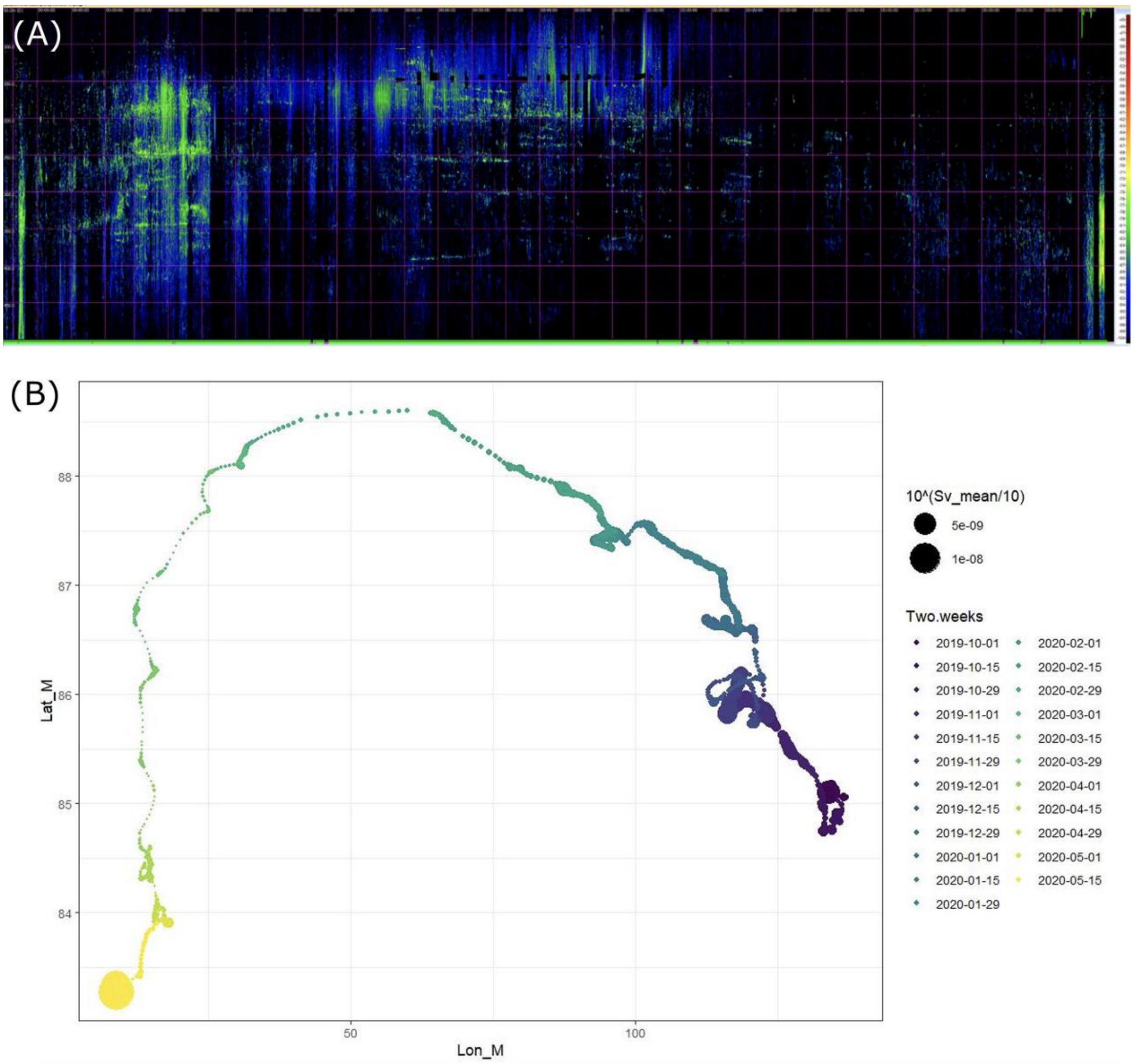


Figure 27: Preliminary compilation made on-board by Serdar Sakinan of the hydroacoustic data collected by the EFICA scientists between 1 October 2019 and 25 May 2020. (A) Full overview of all 38 kHz data collected. (B) Spatial overview of the integrated 38 kHz data (with 6 hours intervals) from 1 October 2019 (purple) until 20 May 2020 (yellow).

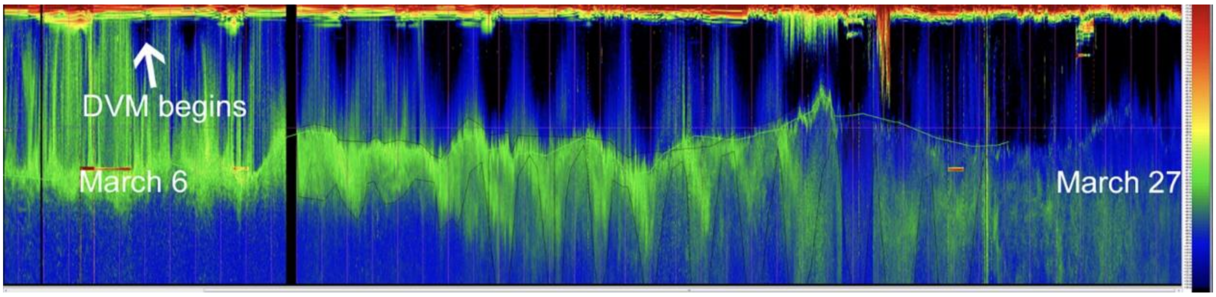


Figure 28: Preliminary compilation made on-board by Serdar Sakinan of the initiation and evolution of Diel Vertical Migration (DVM) of the deep scattering layer (DSL) in March 2020. DMV became pronounced on 6 March in the surface layers and lasted for three weeks until the end of March.

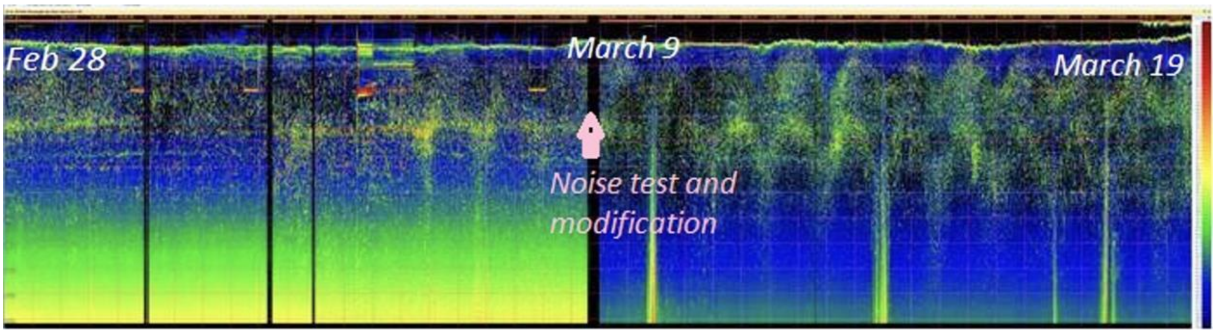


Figure 29: Overview of 10 days before and 10 days after the background noise level improvements made on-board by Serdar Sakinan.

Complete calibrations of the hydroacoustic equipment of the *Polarstern* were performed through the ship's moon pool during Leg 3. Calibration files were made for the frequencies of the ship's EK60/80 (38, 70, 120, 200 kHz) that will be necessary for the postprocessing (in a new SC) of the entire MOSAiC hydroacoustic dataset, both in CW and FM (70, 120 kHz) mode. The calibrations were carried out by Serdar Sakinan on 27 April 2020 (from 9:00 to 15:30 UTC) and on 5 May (from 07:15 to 11:40 UTC), in consultancy with Anders Svenson (acoustician on Leg 1), the ship's electronic engineers Olaf Hüttebräucker, Andreas Winter (on-board), and Hauke Flores, Sören Krägefsky (not on-board), Since the 38 kHz had been impacted by an electrical background noise from November to March, two calibration sets were made for both the conditions before and after the interference problem was solved. The calibrations of the 38 kHz transducer produced almost identical results, suggesting that the transducer efficiency had not been affected by the electrical interference. These operations enabled the successful calibration of 38, 70, 120 and 200 kHz in CW mode and 70 and 120 kHz echosounders in FM mode. The calibration results, and the stable performance of the echosounders during the rest of Leg 3, as well as during Legs 4 and 5, ensured that no further calibrations were necessary.

The results of the CW calibration (**Table 12**) are satisfactory in terms of RMS error scores and total beam coverage for all channels (38, 70, 120 and 200 kHz). Furthermore, the determined gain offsets relative to the factory defaults are small. Before the exchange between Leg 3 and Leg 4, a new configuration file was generated, containing the new settings. A detailed description of the calibration procedures was explained in detail by Serdar Sakinan to Giulia Castellani, so that additional calibrations could be performed in case this would be necessary on Leg 4.

Table 12: Results of the EK60/EK80 calibrations made during Leg 3. The term "noisy" indicates that these trials were performed with the same background noise as the hydroacoustic data collected during Legs 1 and 2. The term "clean" refers to the condition after the electrical connections were modified, i.e., the background noise was eliminated.

Parameter	ES38B Noisy	ES38B Clean	ES200-7C Noisy	ES200-7C Clean	ES70-7C	ES120-7C
Frequency	38000	38000	200000	200000	70000	120000
Gain	24.30	24.32	24.43	24.43	24.86	25.98
SaCorrection	0.4745	0.4286	0.2668	0.3370	0.0256	0.0268
BeamWidthAlongship	6.84	6.86	6.95	6.93	6.49	6.00
BeamWidthAthwartship	6.80	6.76	7.02	6.94	6.45	5.95
TsRmsError	0.0459	0.0518	0.0668	0.0691	0.0698	0.1170
Pulse Length	1.024	1.024	1.024	1.024	1.024	1.024
No of hits	1050	1751	611	1356	1914	2018
Date	27 April 2020	27 April 2020	27 April 2020	27 April 2020	27 April 2020	27 April 2020

8.4 Hydroacoustic measurements during MOSAiC Leg 4

During Leg 4, EFICA scientist Giulia Castellani checked several times per day that the EK80 and EK60 of the *Polarstern* were running properly and collecting data correctly. No further calibration of the echosounders was necessary during Leg 4.

As soon as *Polarstern* left the 12-mile zone around Svalbard, on Monday 8 June at 20:00 UTC, the EK80 and EK60 were switched on. During Leg 4 of MOSAiC the EK80 and EK60 settings were the same as in the end of Leg 3. The instruments ran with frequencies of 38 kHz (GPT, CW mode), 70 kHz (WBT, FM and CW mode), 120 kHz (WBT, FM and CW mode), 200 kHz (GPT, CW mode) for the EK80 and 18 kHz for the EK60 (GPT, CW mode). Connection problems on 13 June and 15 June caused the loss of data for both days. During the transit, noise due to ice breaking was visible at all frequencies, but it disappeared once the ship positioned at the ice floe. On 28 June, a check of the instruments and of the receivers was performed. For achieving this, an ROV was deployed from the moon pool of the ship to check that no ice blocks were covering the EK80 and EK60 receivers. On 30 July 2020, prior to the disintegration of the floe, an attempt was made to calibrate of the 18 KHz transducer. Unfortunately, the results were not conclusive due to technical difficulties. The calibration sphere was lost during this operation. The impact of this failure is limited, because data from the calibrated 38 KHz transducer will be sufficient to discriminate and quantify fish signals in the water column.

When arriving at the ice floe on 17 June after the transit from Svalbard (**Table 10**), acoustic signals indicated fish at depths between 200 m and 400 m of depth, and at ca. 400 m depth there was a strong DSL. During the first three weeks of July, numerous signals of larger fish were observed at a depth of ca. 400 m (**Figure 30**). During this time, *Polarstern* drifted over the Yermak Plateau and its eastern flank. High concentrations of fish were confirmed by fish catches with longlines. After leaving the Yermak Plateau, fish signals in the Atlantic layer became weaker. However, many juvenile polar cod were observed in ice holes at the water-ice interface and in-between blocks of ice. Altogether, about 2.5 TB of hydroacoustic data were collected during Leg 4 of MOSAiC.

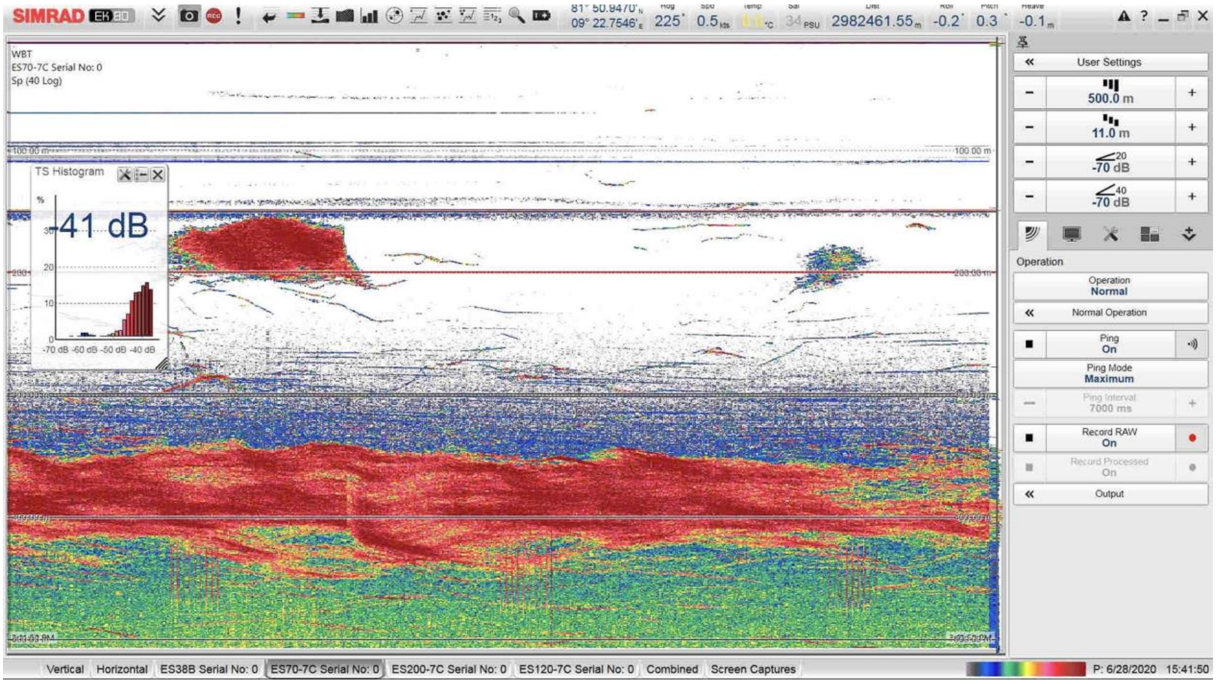


Figure 30: Screen capture from the *Polarstern* EK60/EK80 echosounder during MOSAiC Leg 4, showing the 70 KHz backscatter on 3 July 2020. The strong deep scattering layer (DSL) at about 400 m depth is clearly visible. Two swarms of scatterers occur at 150-200 m depth. Fish signals are visible between ca. 150 and 500 m of depth.

8.5 Hydroacoustic measurements during MOSAiC Leg 5

During Leg 5, no EFICA scientists were on-board the *Polarstern*. However, Katrin Schmidt (University of Plymouth, UK), kindly checked several times per day that the echosounders of the *Polarstern* were running properly and collecting data correctly. No further calibration of the echosounders was necessary during Leg 5.

A DSL was always observed in the Atlantic water layer of the CAO, but with varying density and varying vertical distribution. The organisms in the fish size range (>-45 dB) at the floe often showed high densities (**Figure 31**), which is promising as Leg 5 was very far north and close to the Lomonosov Ridge (**Figure 12**). Unfortunately, no fish were sampled during Leg 5 and the FishCam was not deployed due to lack of time of Team ECO in combination with unstable ice conditions. Altogether, ~2 TB of hydroacoustic data were collected during Leg 5 of MOSAiC.

Hydroacoustic recordings were continued all the way, from the transit between the old Leg 1-4 ice floe, the Leg 4 / Leg 5 people exchange on 10 August, and during the stay at the new Leg 5 MOSAiC ice floe. The EK80 and EK60 settings were the same as in the end of Leg 4, so the instruments ran with frequencies of 38 kHz (GPT, CW mode), 70 kHz (WBT, LFM and CW mode, and 200 kHz (GPT, LFM and CW mode) for the EK80 and 18 kHz and 120 kHz for the EK60 (GPT, CW mode). The mode of the 70 kHz transducer and 200 kHz transducer of the EK80 were manually swopped between LFM and CW mode every 24 hours.

During Leg 5, a few events caused disturbances in the data. During transits, moving through thick ice caused strong noise in the acoustic signals. On 15 August, the Chief Scientist Markus Rex ordered a hydroacoustic survey with the *Polarstern* bottom profiler of about 12 hours. Although the different pings were kept separate with a synchronisation software, the hydroacoustic data collected during this period seemed to be strongly compromised. The new ice floe was rather small, and therefore other acoustic instruments were operated in relatively close vicinity of the ship, which also may influence the Leg 5 hydroacoustic data for SC03. At the ice floe, also the multibeam of the ROV caused some interference due to the close vicinity of the ROV hut (ca. 300 m away from the ship). However, since the ROV was operated only 2-3 days per week, there were many hours during which the EK60/80 produced good data for SC03. Team OCEAN deployed one ADCP about 250 m away from the ship two weeks before the end of the Leg 5 drift. Careful interference checks were made, but interference appeared negligible. Hydroacoustic recordings were continued after the end of the Leg 5 drift on 20 September 2020. Altogether, the MOSAiC drift of Leg 1-4, the transit to the new ice floe of Leg 5, and the homebound transect after Leg 5 yielded three hydroacoustic transects across the CAO for SC03. The EK60/80 measurements were stopped on 2 October 2020.

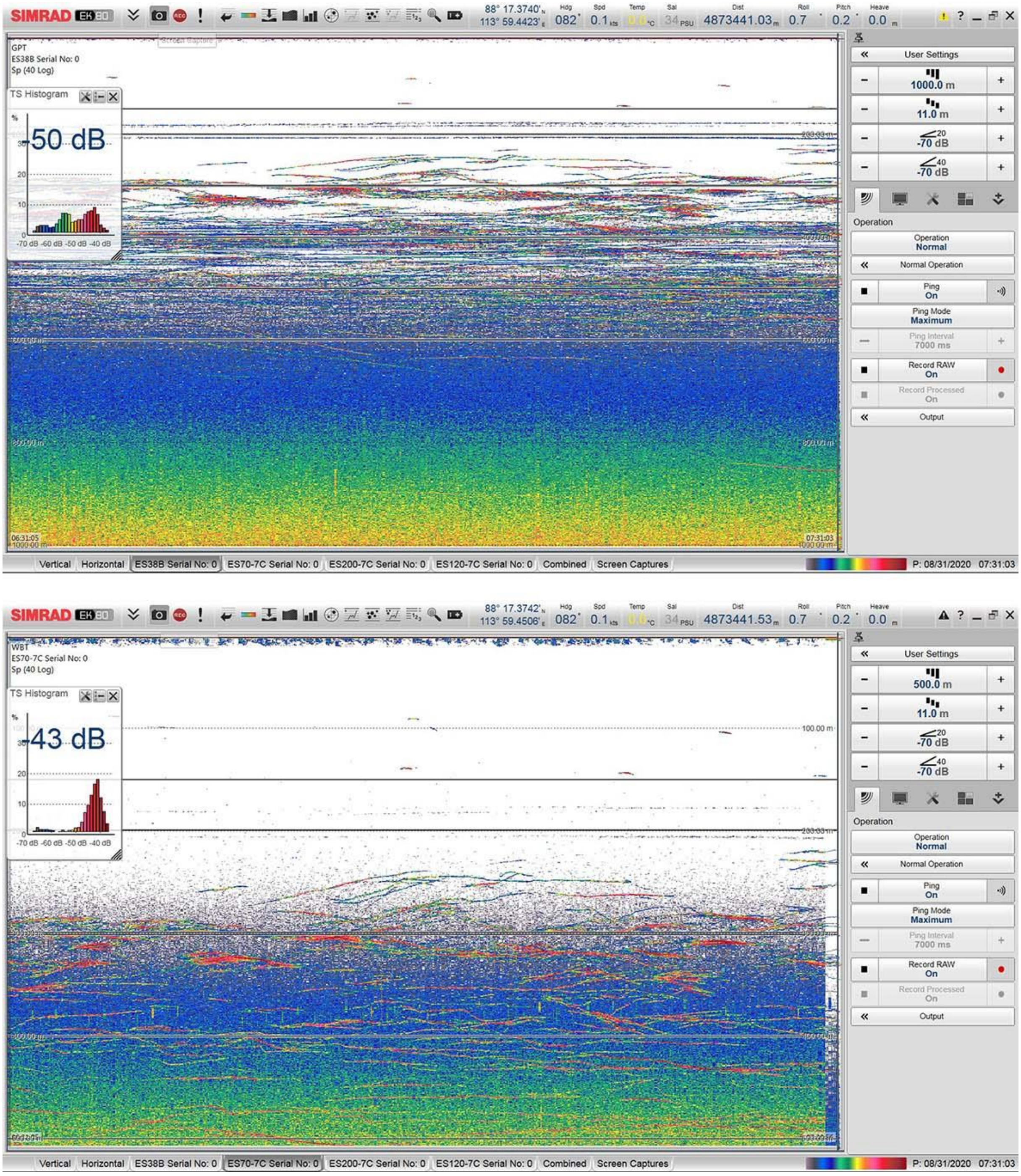


Figure 31: Screen capture from the *Polarstern* EK60/EK80 echosounder during MOSAiC Leg 4, showing the 38 KHz (upper panel) and 70 KHz (lower panel) backscatter on 31 August 2020 with strong acoustic signals from fish below ca. 300 m of depth.

9 FISHCAM VIDEO DATA COLLECTION BY EFICA

9.1 Video recordings during MOSAiC Leg 1

The deep-sea camera system (FishCam, **Figure 32**) was deployed for the first time on 23 October 2019 at 375 m of depth at MET City under the leadership of EFICA scientist Anders Svenson with the help of four other Team ECO members (**Figure 33**). After two weeks (on 7 November) the video stream stopped working and some days later the expedition was struck by a very heavy storm. It took several weeks to get the electrical power back to MET City. Then it appeared that the FishCam still showed the same failure. Technical and software tests were performed with the help of two technicians on-board, but this did not yield any positive results. Consequently, the FishCam was taken up for service on 7 December in close collaboration with the manufacturer in Germany. Once on the ship, several improvements were made on the camera hardware, including the repair of one of the two fibre optic links. After this the video stream worked again. The FishCam was re-deployed on 12 December, this time at 214 m of depth because the DSL had moved up (see **Chapter 8.1**). The FishCam worked fine for the remainder of Leg 1 and most of Leg 2.

Figure 32: Preparing the FishCam for its first deployment during MOSAiC Leg 1. © Pauline Snoeijs-Leijonmalm, 2019

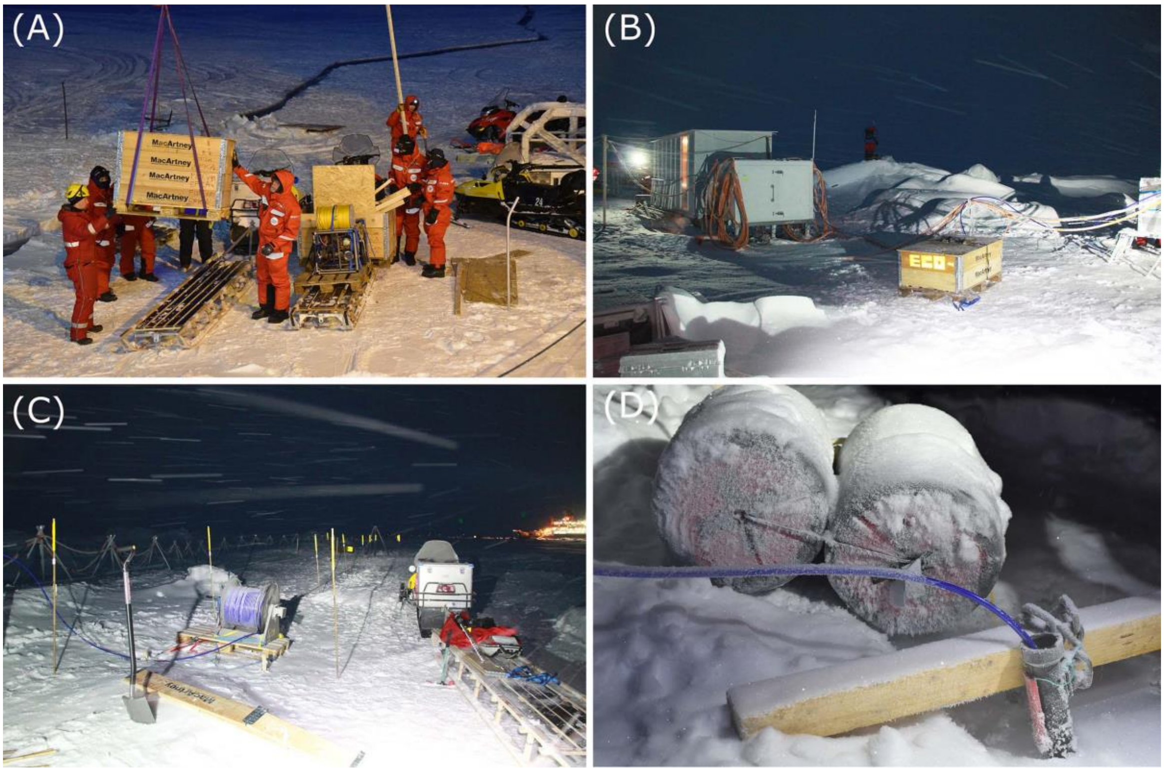


Figure 33: The first deployment of the FishCam during MOSAiC Leg 1. (A) Packing the Nansen sledges next to the ship. (B) The MET City shed and the Fish-Cam box with electronics. (C) The FishCam power and data cables. (D) The site where the FishCam power and data cable went through the sea ice. © Pauline Snoeijs-Leijonmalm (A,D), 2019; © Nicole Hildebrandt (B,C), 2019

Altogether, 503 hours of video recordings were collected when the FishCam was operational during Leg 1 (**Table 13**). The timing of the recordings was programmed differently on alternating days to be able to analyse the reactions of different animal species to the camera lights. The settings were according to the SOP: the first day 55 minutes on / 5 minutes off, the second day 15 minutes on /15 minutes off, the third day 55 minutes on / 5 minutes off, and then this sequence was repeated. On these videos from the DSL, armhook squid (*Gonatus fabricii*, **Figure 7**) were regularly observed, but always with low abundances. The squids seemed to be attracted by the camera lights. A small fish was observed on video twice during Leg 1, but the species was unrecognisable, because it moved too fast as it seemed to avoid the light. Zooplankton such as jellyfish, copepods, amphipods, decapods, chaetognaths and siphonophores were observed regularly.

Table 13: Overview of the video recordings taken with the FishCam during Leg 1 of MOSAiC in the periods 23 October - 7 November and 12-17 December 2019. The numbers of video files and video hours is the total of both FishCam cameras.

Number of video files	Minutes recording (video on, light)	Minutes idle (video off, no light)	Minutes per hour	Video hours
108	5	55	5	9
112	5	25	10	9
366	5	10	20	31
1070	15	15	30	268
204	35	5	55	187
108	5	55	5	9
Sum = 1860				Sum = 503

9.2 Video recordings during MOSAiC Leg 2

Altogether, 1,661 hours of video recordings were collected with the FishCam during Leg 2 (**Table 14**). Immediately after it had been re-deployed by the Leg 1 participants on 12 December the FishCam was working fine, but on 21 December there was a problem with the Portvis software, resulting in 6 days of no recordings. This problem was solved with support from the manufacturer in Germany, and on 27 December the FishCam was operational again. However, already the next day - on 28 December - polar foxes chewed the data cable connecting MET City with the *Polarstern*, causing a data stream failure. This problem was solved on 5 January, and the programming of the FishCam recordings was reset to 55 minutes of recording and 5 minutes off. On 15 January, these settings were adjusted according to the EFICA SOP in three day sequences with different recording times each day. A problem with the power cable on 29 January again caused many instruments, including the FishCam, to be out of power at MET City, and this problem was solved on 3 February.

Table 14: Overview of the video recordings taken with the FishCam during Leg 2 of MOSAiC. The numbers of video files and video hours is the total of both FishCam cameras.

Number of video files	Minutes recording (video on, light)	Minutes idle (video off, no light)	Minutes per hour	Video hours
1337	55	5	55	1226
1433	15	15	30	358
491	5	55	5	41
75	Various	Various	Various	48
Sum = 3336				Sum = 1661

9.3 Video recordings during MOSAiC Leg 3

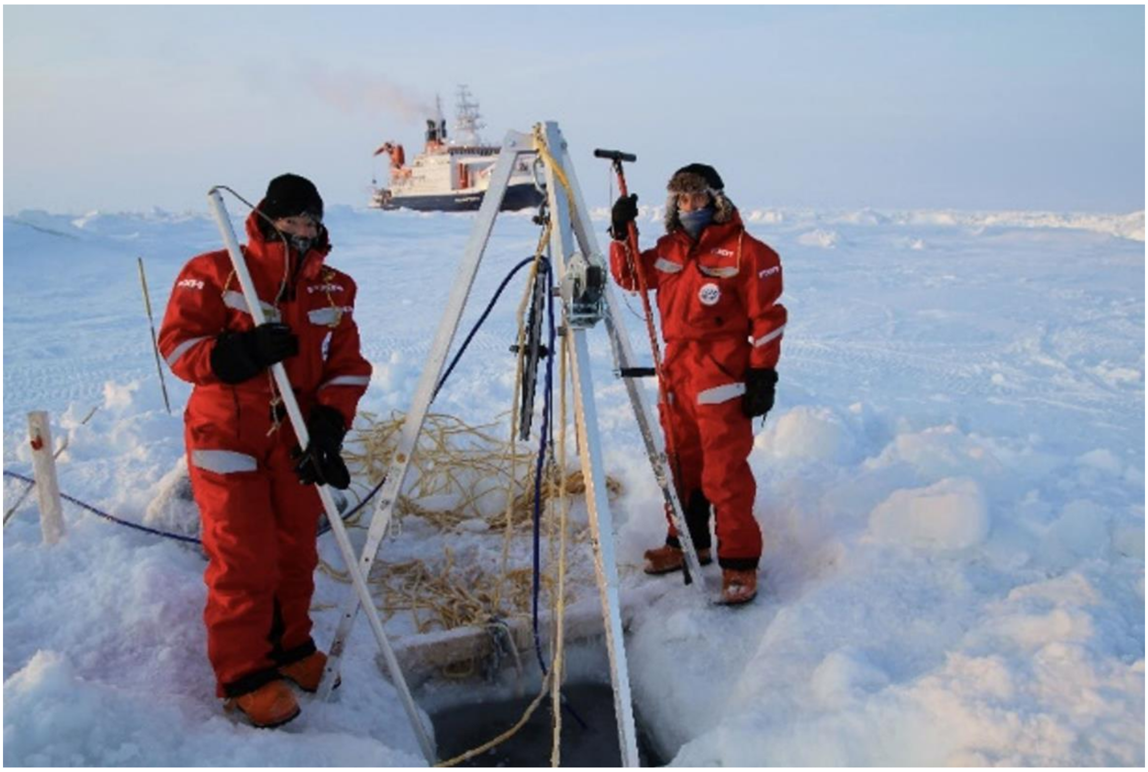
Altogether, 307 hours of video recordings were collected with the FishCam during Leg 3 (**Table 15**). The FishCam was running continuously according to the EFICA SOP in sequences of three days with different recording times until 11 March. The FishCam site had to be maintained regularly since the sea ice was very dynamic (**Figure 34**). A non-systematic screening of the videos indicated numerous small organisms such as chaetognaths, hydromedusae, siphonophores, euphausiids and copepods. No larger individuals such as squid or fish were observed during the fieldwork.

On 11 March, the power to MET City was disconnected after a lead had opened on the MOSAiC ice floe. On 14 March, a new lead opened and progressed towards the FishCam cable bundle. All cables and wooden crates were pulled back to a safer place. However, the ice floes remained very unstable during the following days and new cracks and leads opened and endangering the FishCam installation. With the help of Team ECO and the MOSAiC logistics team, the FishCam was recovered during a two-day operation on 17-18 March (**Figure 35**). An inspection of the cable revealed that the fibre-optical core was damaged at a depth of 337 m and could not be repaired. After consultation with the manufacturer in Germany, the cable was shortened and successfully reconnected shortly before *Polarstern* left the MOSAiC floe for the Leg 3 / Leg 4 exchange (**Figure 35**). The camera was ready to be deployed again during Legs 4 and 5, but unfortunately this was not possible (see **Chapter 9.4**).

Table 15: Overview of the video recordings taken with the FishCam during Leg 3 of MOSAiC. The numbers of video files and video hours is the total of both FishCam cameras.

Number of video files	Minutes recording (video on, light)	Minutes idle (video off, no light)	Minutes per hour	Video hours
96	55	5	55	88
420	15	15	30	210
110	5	55	5	9
Sum = 626				Sum = 307

Figure 34: Maintenance work at the FishCam site in March 2020. © Serdar Sakinan, 2020



9.4 No video recordings during MOSAiC Legs 4 and 5

No FishCam recordings could be performed during MOSAiC Legs 4 and 5. After the recovery of the damaged FishCam during Leg 3, the cable had been shortened and repaired, but re-deployment of the system demanded more assistance because of the state in which it had been recovered. This implied that more manpower from Team ECO would have been necessary to deploy the FishCam on Legs 4 and 5 compared to Leg 1. In addition, the space on the much smaller ice floes of Legs 4 and 5 was very limited. This complicated the deployment of deep-wired gear such as the FishCam due to the risk of entanglement with other installations, as well as the CTD and zooplankton nets operated from the ship. The situation was further complicated by the dynamic development of the two ice floes during the melting season. In spite of these difficulties, the Project Manager Hauke Flores, Giulia Castellani (Leg 4) and Katrin Schmidt (Leg 5) repeatedly argued for a new deployment of the FishCam by Team ECO. Unfortunately, no opportunity for a re-deployment arose under the circumstances.

Figure 35: Recovery and repair of the FishCam during Leg 3. (A) FishCam deployment site. (B,C,D,E) Recovery with the help of chain saw and auger, an operation that took two days on 17-18 March. (F) The broken cable. (G,H) Repair on-board by the *Polarstern* technicians. © Serdar Sakinan (A-H), 2020

10 FISH SAMPLING BY EFICA

10.1 Mesopelagic fish sampling during MOSAiC Leg 1

With longlines and fishing rods four fish specimens were sampled by EFICA from the DSL during Leg 1 (**Figure 36**): three Atlantic cod (*Gadus morhua*) and one ice cod (*Arctogadus glacialis*) (**Figure 37**).

The collection of fish samples from the mesopelagic zone at 200-600 m of depth was the most difficult and unpredictable part of SC03. As suggested by the EFICA SC04 Workshop[18], a battery of methods based on nets and lines with hooks for sampling fish were tested. During Leg 1, different methods of deployment of both nets and lines were initially tested, and they were deployed from both one or two holes in the ice. When two holes were used, an ROV was used to transport the net or line from the first hole to the second one. The methods were evaluated during Leg 1, and it was decided that longlines and fishing rods would be the standard methods for EFICA to sample fish from the mesopelagic zone during the rest of MOSAiC because these were the only methods that had been successful, albeit for only four fish. Further methods can still be tested during the following MOSAiC Legs after at least one longline per week has been deployed.

Figure 36: Fish sampling with longlines during MOSAiC Leg 1 . (A) A longline baited with squid and shrimp. (B) A bear guard at a fish sampling station about 300 m away from the *Polarstern*. (C) The tripod and the winch (driven by a car battery) used for the longlines. (D) Recording the coordinates of a fish sampling site. © Nicole Hildebrandt (A), 2019; © Pauline Snoeijs-Leijonmalm (B,D), 2019; © Anders Svenson (C), 2019

[18] EFICA Consortium (2019) EFICA Workshop in preparation for the *Polarstern* and *Oden* expeditions for 2019 and 2020. Report to EASME/DG MARE. 32 pp.

Between 28 October and 12 December 2019, seven longlines and three standard monitoring gillnets (40 x 6 m) were deployed. Among the four mesopelagic fish collected during Leg 1, three were sampled with a longline, and one with a fishing rod. This low number of fish samples confirms the low fish abundance in the area as observed in the hydroacoustic data. Line-fishing seemed to be appropriate for larger fish while the more numerous smaller fish (roughly <15 cm long) detected in the DSL by hydroacoustics were not caught by the lines. The data taken from each fish were total length, standard length, total weight, eviscerated weight, and subsamples were taken from stomach, hindgut, gonads, liver, muscle tissue, otoliths, and fin clip for further analyses at home according to the Standard Fish Protocol Sheets (SFPs) developed during Leg 1.

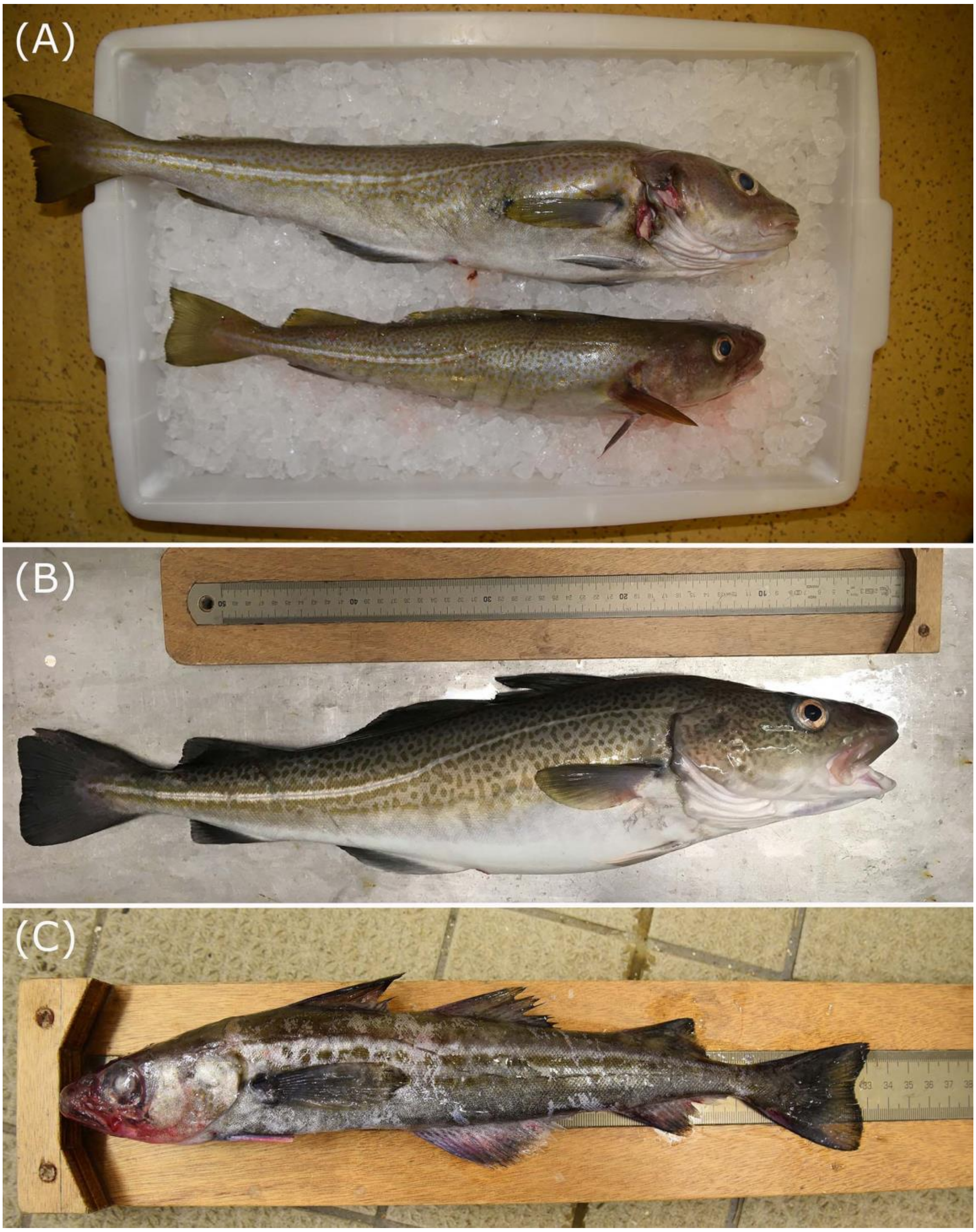


Figure 37: The four fish sampled during Leg 1 of MOSAiC: (A,B) Atlantic cod (*Gadus morhua*). (C) Ice cod (*Arctogadus glacialis*. © Pauline Snoeijs-Leijonmalm (A-C), 2019

10.2 Mesopelagic fish sampling during MOSAiC Leg 2

Fish sampling from the ice during Leg 2 of MOSAiC started on 21 December 2019. In the period from 21 December to 28 February, 17 longlines were deployed. One surface fish sampling with fishing rods and pilkor techniques took place, and three "citizen science" (fishing rods) events were organised. However, not a single fish was sampled by these methods during Leg 2. However, one 25-cm long specimen of *Paraliparis bathybius* (**Figure 38**) was sampled with a vertical ring net cast (150 µm mesh), towed from 2000 up to 200 m of depth. Total length, standard length, and total weight of the fish were recorded, otoliths were extracted, and the rest of the fish was frozen at -80 °C for further analyses at home. The Hydroacoustic data confirmed very low fish abundance in the area, which can explain the low sampling success in relation to the efforts made.

The SOP compiled during Leg 1 was followed throughout Leg 2, with a few exceptions. Until the week of 2-8 January the deployment took place from a hole in the ice made especially for fish sampling (as described in the SOP). From this week on the ROV hut had been relocated to the fish sampling area and after 8 January the ROV hole and hut were used for the longline deployments. In the week of 23-29 January, all teams on board were directed towards the sampling of a lead. This week no longlines were deployed, but the focus was on sampling with fishing rods. Unfortunately, also this attempt to sample fish was unsuccessful.

Figure 38: The only fish sampled during Leg 2: *Paraliparis bathybius*, a benthopelagic fish caught with a zooplankton net between 2000 and 200 m of depth. © Giulia Castellani, 2020

10.3 Mesopelagic fish sampling during MOSAiC Leg 3

Although the time series of longline deployments was maintained continuously, fish samples were only obtained during the very last phase of Leg 3. On 16 May, the intensity of the backscatter on the echosounder started to increase in the depth layer 280-420 m. Fish sampling was performed from the ship after leaving the ice floe on 18, 19, 24 and 27 May, and altogether 11 fishes were caught: 6 haddock (*Melanogrammus aeglefinus*), 3 Atlantic cod (*Gadus morhua*), and 2 beaked redfish (*Sebastes mentella*) (**Figure 39**).
The longline fish sampling was carried out according to the SOP established during Leg 1. Due to very low densities of potential fish backscatter on the echosounder during most of Leg 3, longline deployments were performed only once per week using the standard longlines with 150 hooks of three different sizes. Trials were made by changing the combinations of the type and size of the bait (shrimp *vs* squid and small pieces of bait *vs* large pieces), and also attachment of flashing lights did not change the results, i.e., no fish were caught. An unsuccessful deep-water gillnet deployment (300 m) was carried out on 29 April (**Figure 40**). Employing fishing rods from the ice was not successful either (**Figure 41**). From the 11 fish sampled at the end of Leg 3, five were caught with longlines from the ship, one with a fishing rod and another five were caught by the *Polarstern* crew with their private fishing rods (**Figure 42**).

Figure 39: Some of the fish sampled from the ship during Leg 3 shortly after leaving the MOSAiC floe: two haddock (*Melanogrammus aeglefinus*; the largest and smallest fish in this photograph), two Atlantic cod (*Gadus morhua*) and one beaked redfish (*Sebastes mentella*; the red fish in this photograph). © Serdar Sakinan, 2020

10.4 Mesopelagic fish sampling during MOSAiC Leg 4

During Leg 4, eight longlines were deployed, and in total, 42 mesopelagic fish were sampled in this way: 33 haddock (*Melanogrammus aeglefinus*) 7 Atlantic cod (*Gadus morhua*), and 2 beaked redfish (*Sebastes mentella*).

The SOP compiled during Leg 1 was followed throughout Leg 4, with a few exceptions. The eight longlines targeted the mesopelagic layer (200-400 m depth or 300-500 m, depending on the EK80 acoustic signals). When the ship was still in transit, advantage was taken of the ship being stuck in the ice, and a longline was deployed from the ship's stern. During the residence time at the ice floe, longlines were deployed from the ROV hole (**Figure 43**) or from the sediment trap hole. Strong currents under the ice caused a longline to become entangled with the CTD during device operation 45-130. From that time on, it was necessary to coordinate every gear that was deployed at a certain depth from the ice and from the ship. In the week of 15-21 June, only one longline could be deployed because of persistent presence of polar bears for three days in a row, preventing any work on the ice. In the week of 29 June – 5 July, the MOSAiC floe broke apart and the ice work ended before any longline deployment was possible. Citizen science (fishing with fishing rods by other scientists and crew) was not possible from the moon pool during Leg 4, because the ship's propellers were running the entire time to ensure the ship's position at the ice floe.

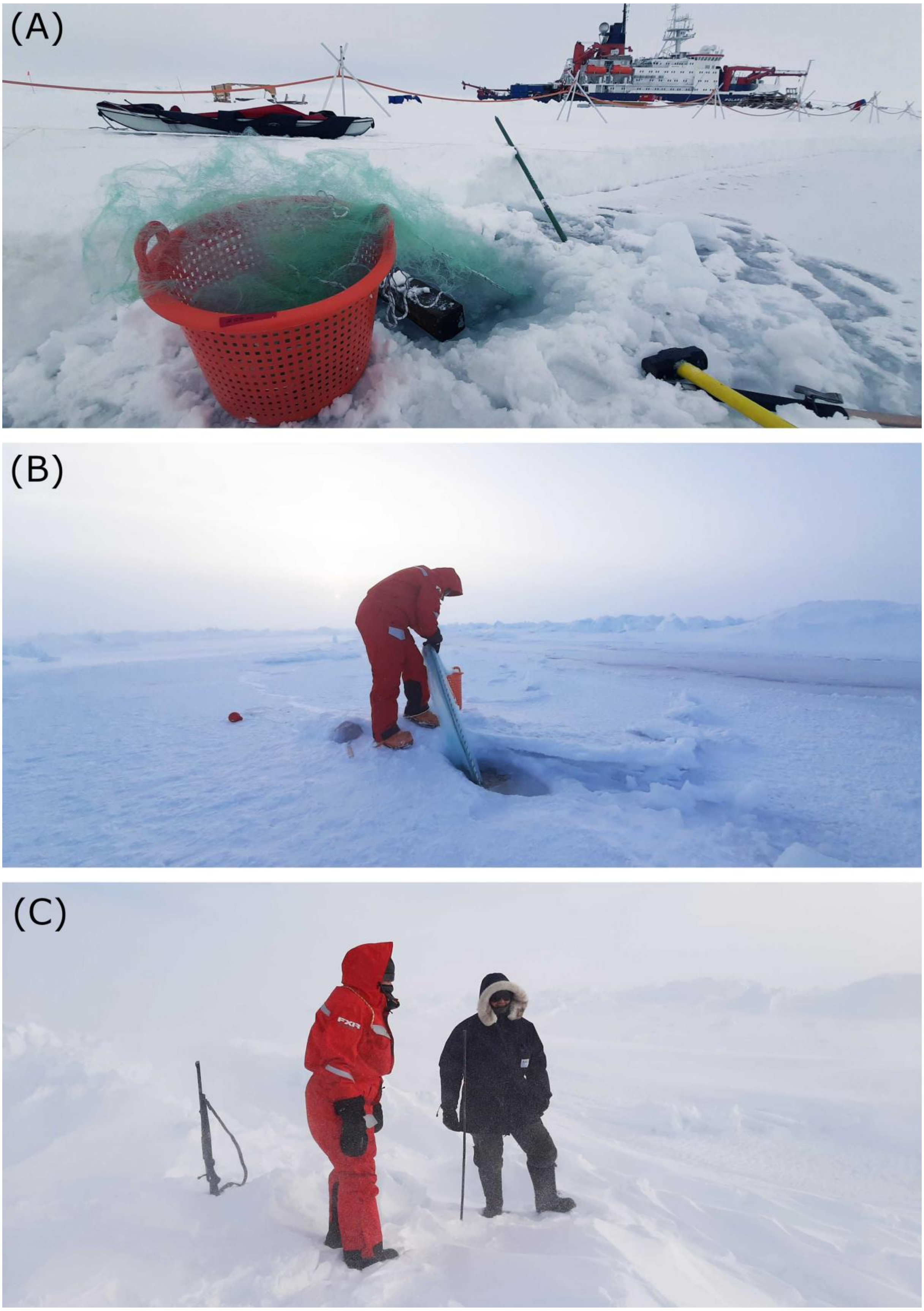


Figure 40: Fish sampling with a gillnet during Leg 3. (A) The fishing site was a few hundred meters away from the ship. (B) The gill net is taken up (without fish). (C) Bear guards at the fishing site. © Serdar Sakinan (A-C), 2020

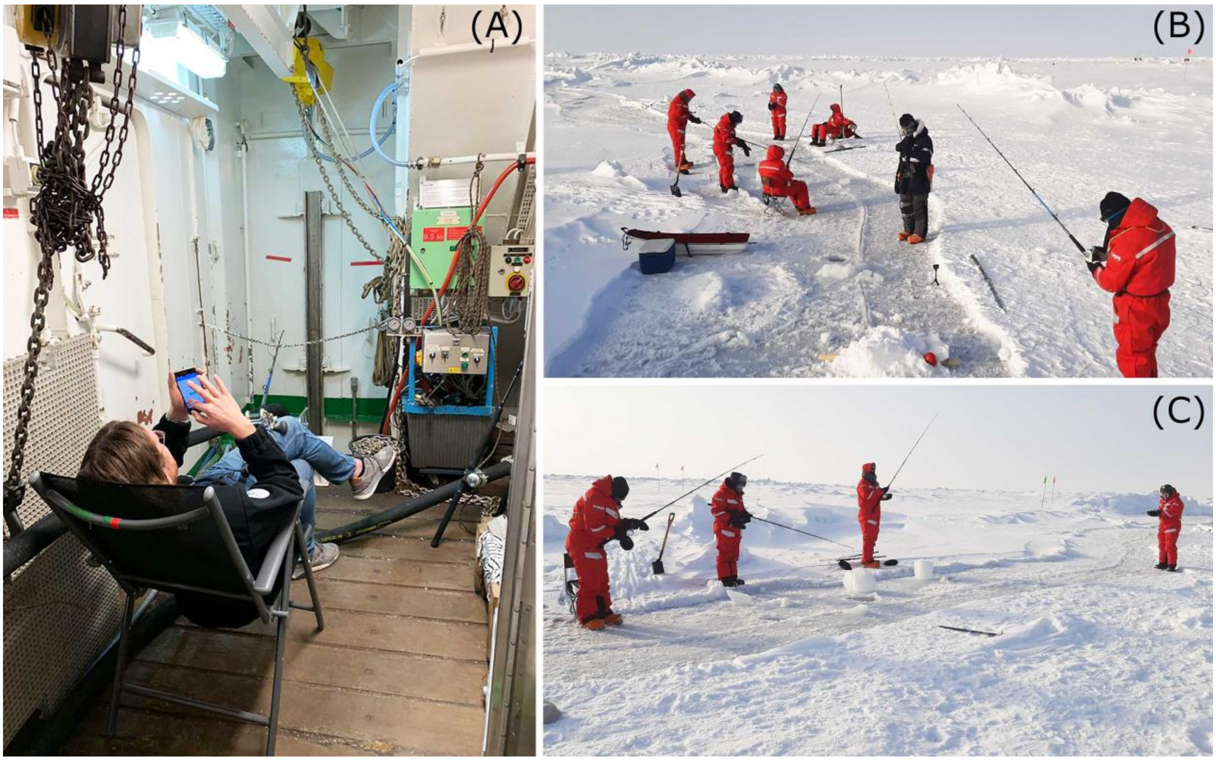


Figure 41: "Citizen Science" (fishing rods). (A) Sampling fish with a fishing rod from the *Polarstern* moon pool during Leg 1 (this was successful on one occasion). (B). Sampling fish with a fishing rod from the ice during Leg 3 (no success) © Pauline Snoeijs-Leijonmalm (A), 2019; © Serdar Sakinan (B,C), 2020

Figure 42: Fish sampling with longlines and fishing rods in the end of Leg 3. (A,B) Longlines. (C) Atlantic cod caught with fishing rods. © Serdar Sakinan (A-C), 2020

Figure 43: Longline deployment from the ROV hole. (A) Leg 2 (no success). (B,C) Leg 3 (no success). © AWI (A), 2020; © Serdar Sakinan (B,C), 2020

10.5 Mesopelagic fish sampling during MOSAiC Leg 5

During the only longline deployment of Leg 5, no fish were caught (**Figure 44**) despite the strong signals on the echosounder. No fish were sampled from deep water with fishing rods either. One juvenile squid was caught with a zooplankton net (**Figure 44**). The specimen could not be identified to the species level during the field work, but it could be an armhook squid (*Gonatus fabricii*), of which many adult specimens were observed in the FishCam videos during Legs 1-3.

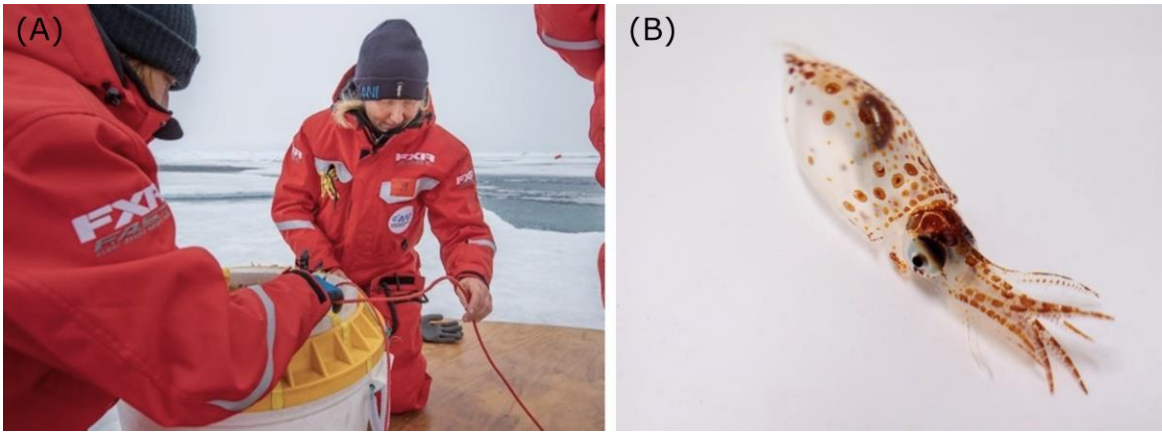


Figure 44: Fish and squid sampling during Leg 5. (A) Longline deployment (no success). (B) One juvenile squid was caught with a zooplankton net. © Lianna Nixon (A), 2020; © Mario Hoppmann (B), 2020

10.6 Additional fish sampling: sympagic polar cod

The occurrence of juvenile polar cod (*Boreogadus saida*) associated with sea ice (sympagic) at the ocean surface is a well-known feature of the CAO[19,20]. During the MOSAiC expedition, ice fauna, including juvenile polar cod was a MOSAiC Core Parameter. The data were collected collectively by Team ECO. Future analyses of these fish may be useful for understanding the fish stocks of the CAO.

Sympagic juvenile polar cod were often observed during the MOSAiC expedition, both from the ship (**Figure 45**) and during ROV dives under the ice (**Figure 46**). However, they were very difficult to catch and only 18 specimens were throughout during the entire expedition, two during Leg 1, 11 during Leg 4, and five during Leg 5 (**Table 6**).

Horizontal nets and longlines targeting sympagic juvenile polar cod were repeatedly deployed by Team ECO during the expedition (**Figure 47**), e.g., between the ROV hut and the OCEAN City tent, but no fish were caught in this way. During Leg 4, three intensive surface fishing events with fishing rods and "pilkor" techniques were performed. These events aimed at collecting juvenile polar cod from ice holes and small cracks, but were also not successful either.

During Leg 1, two fish came up spontaneously from ice holes while ice coring and landed on top of the ice. During Leg 4 it was found that the best way to catch juvenile polar cod was to disturb them with a stick so that they would swim to the surface, and then use hands or small nets to catch them. This method yielded 11 fish during Leg 4 and five fish during Leg 5 (**Figure 48**). Similarly, ice amphipods (**Figure 49**), the main prey items of sympagic juvenile polar cod, were most easily caught by hand.

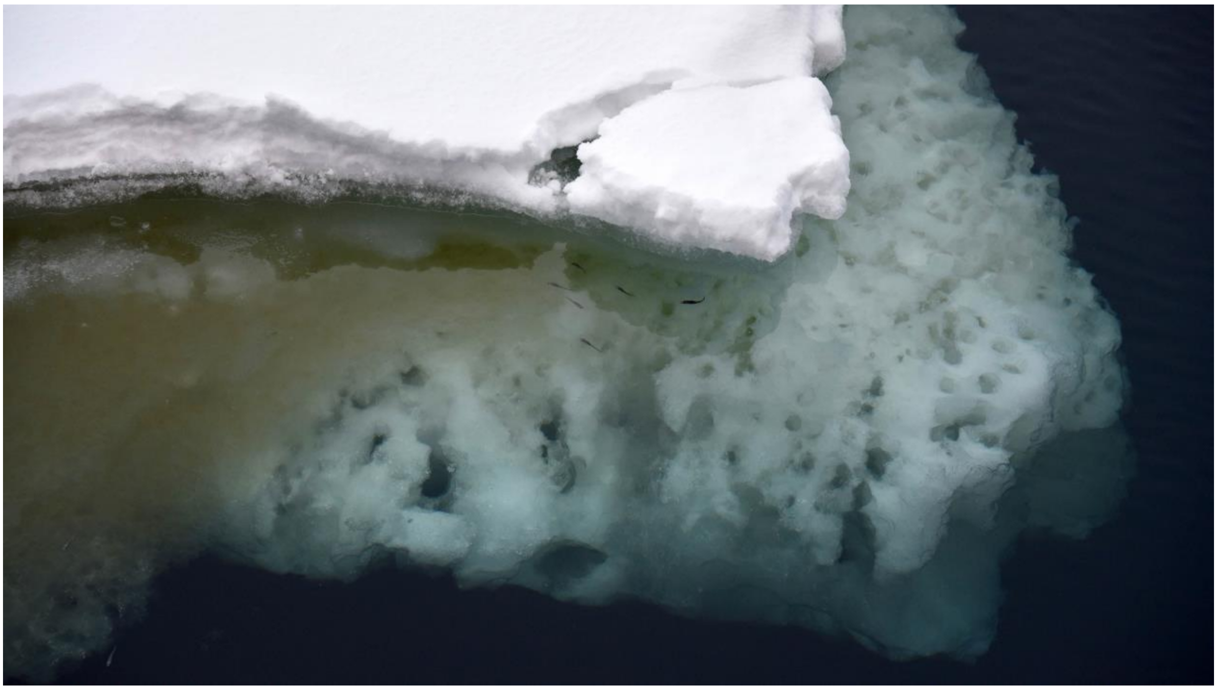


Figure 45: Juvenile polar cod in their natural sea-ice habitat in the CAO, observed from the ship during the transit to the MOSAiC ice floe on Leg 1. The brown coloured fluffy masses are diatom colonies. © Pauline Snoeijs-Leijonmalm, 2019

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[19] Andriashev A.P. et al. (1980) On mass congregations of the cryopelagic cod fishes (*Boreogadus saida* and *Arctogadus glacialis*) in circumpolar Arctic basins. In: Vinogradov ME, Melnikov IA (Eds) Biology of the Central Arctic Basin. Shirshov Institute of Oceanology, Academy of Sciences of the USSR, Nauka (Science) Press, Moscow. pp. 196–211. [in Russian]

[20] David C.. et al. (2016) Under-ice distribution of polar cod *Boreogadus saida* in the central Arctic Ocean and their association with sea-ice habitat properties. Polar Biology 39, 981–994.

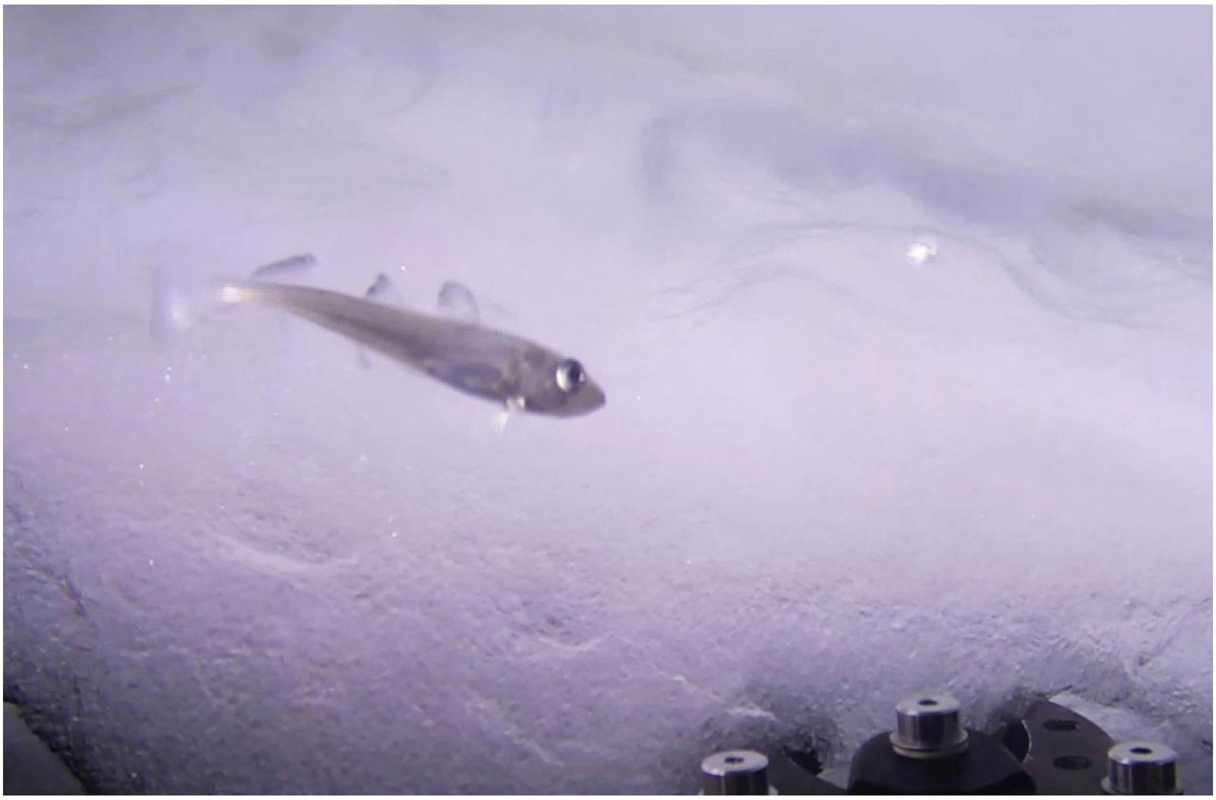

Figure 46: Sympagic juvenile polar cod photographed with the ROV under the MOSAiC ice floe on 1 February 2020. © Christian Katlein, 2020

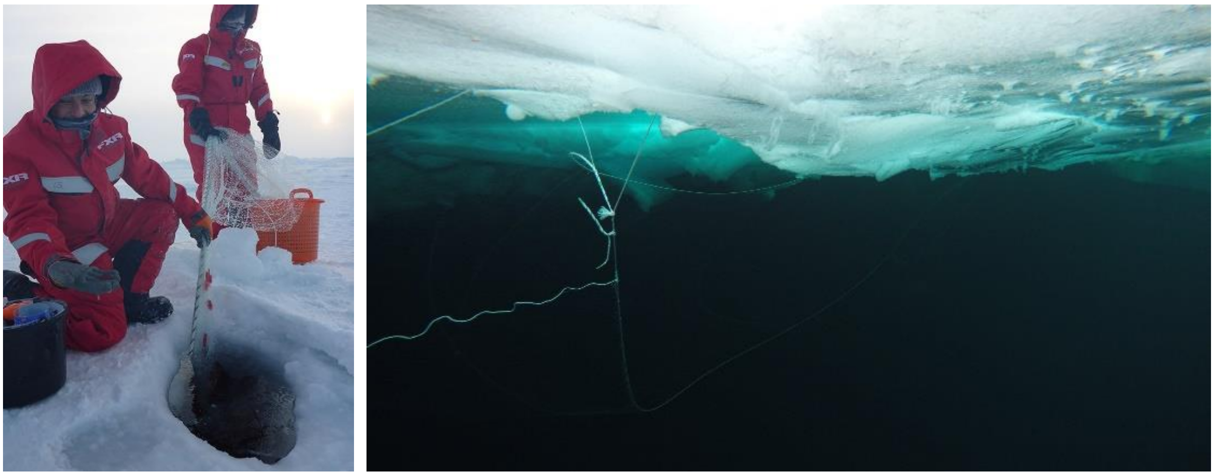

Figure 47: Deployment of a gillnet targeting sympagic juvenile polar cod through a hole in the ice during Leg 3 (this did not succeed). © AWI, 2020

Figure 48: A sympagic juvenile polar cod sampled during Leg 5. © Mario Hoppmann, 2020

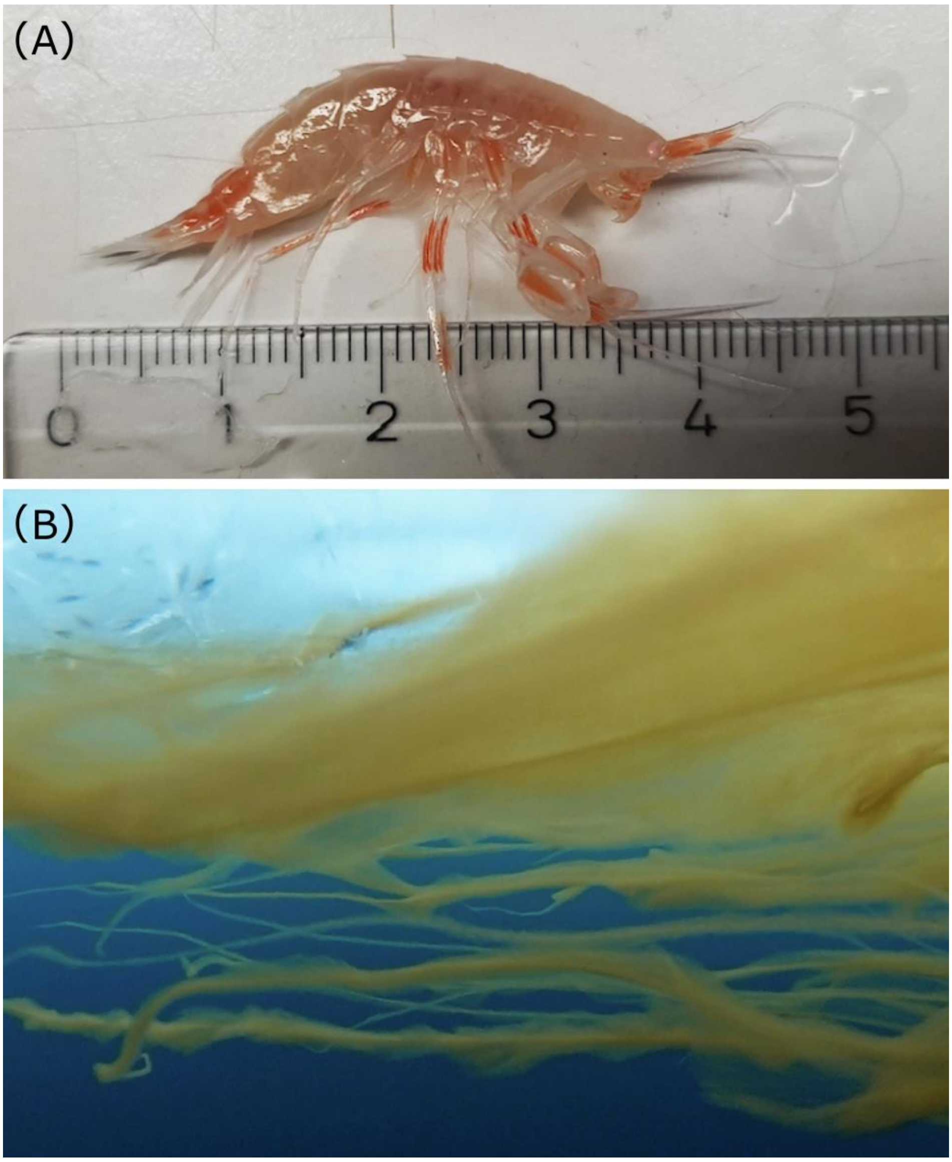

Figure 49: Constituents of the food web of sympagic juvenile polar cod on the CAO. (A) A sympagic amphipod that constitutes food for juvenile polar cod. (B) Ice-associated diatom colonies hanging from the ice constitute food for sympagic amphipods. © Oliver Müller (A), 2020; © Serdar Sakinan (B), 2020

11 E-DNA SAMPLING BY EFICA

Team ECO collectively took 1,491 DNA samples during Legs 1-5 (**Table 5**). e-DNA analysis is EFICA's most advanced method, but also the method providing the least direct evidence. However, where the fish sampling did not succeed, the e-DNA analyses could still indicate which fish species occur in the area.

Although fish DNA from the Atlantic Ocean, or even from tropical waters, could drift into the CAO with water currents without the fish itself occurring in the CAO, the number of hits in a metagenomic data set for a fish living in the CAO is likely to be higher than for a species not living there. The DNA of non-occurring species may also be more fragmented. A methodological test using a metagenomic data set from the sea ice habitat in the CAO (P. Snoeijs-Leijonmalm, LOMROG III expedition with icebreaker Oden in 2012) showed that polar cod (*Boreogadus saida*) genes occurred in 63 out of 66 samples.

Metagenomic sequencing data consist of all sequences detected in a water sample. Then the known genome of, e.g., a fish species can be tested on these data. This is a rather new method that can only be carried out by deep sequencing, a skilled informatician who assembles the sequences and super-computer time. A second method to test for the occurrence of certain fish species in a water sample is the amplification of a specific part of the genome and then these shorter sequences are compared with the same part of the genome of known species. The latter method has been used for a longer time, requires more lab work, and is limited to only a small region of a total fish genome. EFICA can use both methods (in a later SC) using the MOSAiC metagenomic dataset or DNA aliquots left after metagenomic sequencing produced within the MOSAiC Core Programme. EFICA has the exclusive opportunity to analyse fish, squid, mammal and zooplankton genes to assess the occurrence of species in the CAO.

All MOSAiC DNA samples will be extracted at the AWI. A group of scientists (including Pauline Snoeijs-Leijonmalm) have successfully submitted a research application and the MOSAiC Core Programme has been granted sequencing of 800 MOSAiC metagenomic samples at the Joint Genome Institute (JGI), USA (https://jgi.doe.gov). Metagenomic sequencing is an expensive analytic step in this type of work. During Leg 1 of MOSAiC, EFICA safeguarded that water samples were taken for this purpose also in the Atlantic layer of the CAO, and all DNA samples taken from the water column during Leg 1 were filtered by Pauline Snoeijs-Leijonmalm, and during Legs 2-4 to a large extent by the scientists from the Swedish CN-project (**Figure 50**). Immediately after sequencing, the sequences will be published online and EFICA will use a bioinformatician to find sequences from fish, squid, fish prey (zooplankton) and fish predators (mammals). The time frame of this work is that the sequences become available in 2021.

To obtain water samples from the water column, an ice hole was made next to the ship in the beginning of Leg 1 for operating a large CTD rosette (**Figure 51**). This was a large effort that took four days (the ice was almost 2 m thick). During the entire Leg 2, the hole made during Leg 1 was operational for taking water samples for DNA analyses. During Leg 3, sampling with the CTD hole could not be used anymore after 15 March because the ship drifted away from the hole, and a new hole could not be made because it was impossible to maintain a stable position of *Polarstern* at the ice floe that would allow access to a CTD hole. From that day on, sampling was performed with a smaller CTD rosette operated on the ice by Team OCEAN. As a consequence, the overall water sampling had to be reduced in terms of vertical and temporal resolution.

Figure 50: EFICA's filtering equipment used for collecting e-DNA on Sterivex® filters (pore size 0.2 µm) with a peristaltic pump in a laboratory container on-board *Polarstern* during the entire MOSAiC expedition. © Pauline Snoeijs-Leijonmalm, 2019

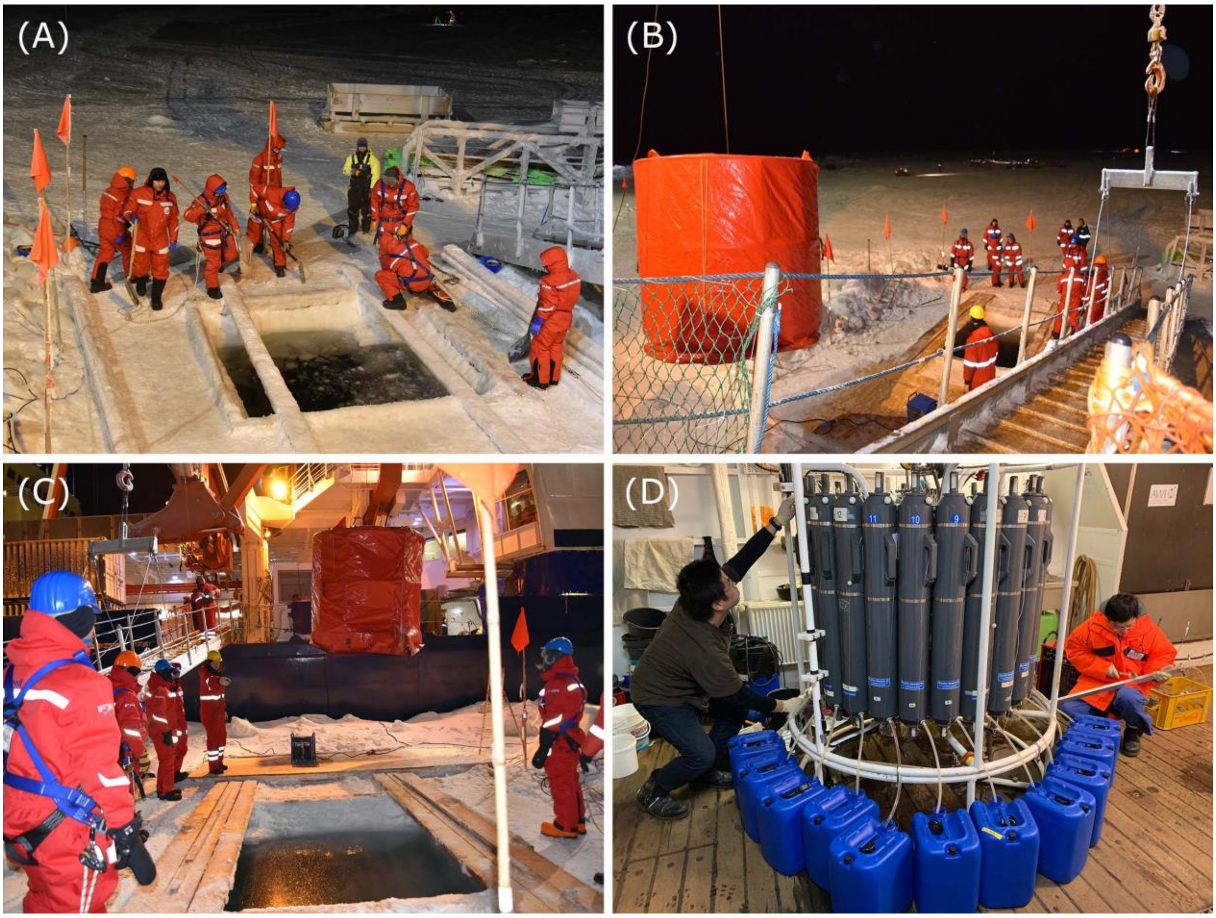

Figure 51: Water sampling using a CTD rosette was not an easy task in winter. (A) The ice hole for the CTD next to the ship was kept open with chain saws and fin saws, and needed to be cleaned from floating ice with nets several times per week. (B,C) When the CTD was transported in air it was covered with a tent and heated. (D) Each of the 24 grey Niskin bottles could take a 12 L seawater sample at a pre-programmed depth. © Pauline Snoeijs-Leijonmalm (A-D), 2019

12 THE SC03 METADATA DATABASE MANUAL

12.1 Database delivery

Together with this SC03 Final Report, the EFICA Consortium delivers 15 Excel files that together constitute the SC03 Metadata Database. This database lists all EFICA and MOSAiC Core Parameter samples and measurements made during the MOSAiC expedition that are relevant for sample elaboration, assessment of the CAO carrying capacity, modelling, etc. in further SCs. The metadata summarises which data and samples were collected, but do not provide actual measurements or analytical results. Typical metadata from scientific field samples are, e.g., date, time, geographic position, ocean depth, or depth of measurement.

12.2 Description of each of the 15 Database Files

Database File 01: Explanations
This file contains explanations of terms and devices used in the Database.

Database File 02: Logbook Device Operations
This file contains a complete record of all sampling events (station – device operation) considered relevant for EFICA. It includes exact date, time, geographic position, ocean depth and sampling device used at each sampling event. This information is essential to link data from any sample with corresponding data from other samples and measurements taken at the same time and location.

Database File 03: SHIP_DATA
This file contains hourly records of time, position and speed of Polarstern during the whole MOSAiC expedition. Speed data is used to calculate the track length of the expedition and different subsections (e.g., cruise legs). This file also contains information about the duration and track length of hydroacoustic sampling.

Database File 04: PEL_PHYS
This file lists all device operations relevant for EFICA at which physical properties of the water column were measured with a Conductivity/Temperature/Depth probe (CTD).

Database File 05: ICE_PHYS
This file lists all device operations relevant for EFICA at which physical properties of the sea ice were measured based on ice cores.

Database File 06: PEL_BGC
This file contains all samples taken for biogeochemical parameters obtained with water samplers such as the CTD rosette, and their associated metadata. Biogeochemical parameters include chlorophyll concentration, carbon content, phytoplankton species composition, etc..

Database File 07: ICE_BGC
This file contains all samples taken for biogeochemical parameters obtained with ice corers, and their associated metadata. Biogeochemical parameters include chlorophyll concentration, carbon content, ice algae species composition, etc..

Database File 08: PEL_INV
This file contains all samples taken for zooplankton parameters obtained with various vertical nets, and their associated metadata. Zooplankton parameters include species composition and abundance, carbon and nitrogen content, and trophic biomarkers.

Database File 09: ICE_INV
This file contains all samples taken for sea-ice fauna parameters obtained with under-ice nets, ice corers and miscellaneous sampling devices, and their associated metadata. Sea-ice fauna parameters include species composition and abundance, carbon and nitrogen content, and trophic biomarkers.

Database File 10: PEL_ACOUST
This file lists all datafiles containing the hydroacoustic raw data collected during the whole MOSAiC expeditions, along with date, time and position. The data files are stored in the online data repository Pangaea and on the internal MOSAiC Central Storage server (MCS).

Database File 11: PEL_VIDEO
This file lists all video files recorded by the FishCam during MOSAiC leg 1-3, along with date, time and position. Each entry is linked to its corresponding data file in the internal MOSAiC Central Storage server (MCS).

Database File 12: PEL_FISH
This file contains all pelagic fish samples obtained with longlines and fishing rods, and their associated metadata. Fish samples include tissue samples for stomach content, otolith analysis, trophic biomarkers, population genetics, etc..

Database File 13: ICE_FISH
This file contains all ice-associated fish samples (*Boreogadus saida*) obtained with various sampling devices, and their associated metadata. Fish samples include tissue samples for stomach content, otolith analysis, trophic biomarkers, population genetics, etc..

Database File 14: PEL_DNA
This file contains all particulate organic matter samples taken for DNA sequencing obtained with water samplers such as the CTD rosette and automated flow-through samplers, and their associated metadata.

Database File 15: ICE_DNA
This file contains all particulate organic matter samples taken for DNA sequencing obtained with ice corers, and their associated metadata.

12.3 The basic structure of the Database Files

The database files have a similar structure consisting of 2-4 tabs, depending on their content. Database File 01 "*Explanations*" provides an overview of all devices, data fields, parameters, and tissue samples mentioned in the tabs of each file.

In each file, tab "Data" contains all metadata of the respective file.

In each file, tab "Summary" contains a summary of the data (e.g., total number of samples by cruise leg and sampling device) made with the Pivot table tool of Excel. The columns and rows as well as the summarizing calculation (e.g., mean, sum, number of records) can be changed in the field list, which appears after clicking anywhere in the Pivot table.

In each file, the tab "Field_explanations" contains a list of all fields (columns) of the "Data" tab and their definitions (**Table 16**).

Database File 02 "*Logbook Device Operations*", contains the tab "*Devices*". This tab contains a list of all sampling devices mentioned in Database Files 04-15 with brief explanations of each device (**Table 17**).

Database File 03 "*SHIP_DATA*" contains the tab "MOSAiC key events" This tab lists all major events structuring the expedition, such as crew exchanges between cruise legs and transit times.

The tab "Parameters" contains a list of all parameters occurring in the "Data" tab and their definitions and respective units. The files on hydroacoustic and video data (Database Files 10-11) do not contain this tab (**Table 18**).

In the Database Files 12 and 13 on fish, the "Parameters" tab is replaced by the tab "Tissue samples". This tab contains a list of all tissue types which were obtained after the dissection of fish, and their explanations (**Table 19**).

Table 16: Overview of all data fields (columns) occurring in Database Files 01-15, and their explanations.

Field	Explanation
mosaic_leg	Cruise leg of MOSAiC Expedition (Legs 1-5)
mosaic_week	Sampling week of MOSAiC expedition (starting with week 1 at beginning sampling)
station_device_operation	A combination of the MOSAiC week and a specific gear deployment
device	The code for a specific gear (e.g., "Longline")
date	Date (UTC) at which a gear deployment was started
time_utc	Time (UTC) at which a gear deployment was started
lat	Latitude at which a gear deployment was started (decimal degrees N)
lon	Longitude at which a gear deployment was started (decimal degrees E)
bottom_depth	Depth of the sea floor when a gear deployment was started (m)
collector	A collecting device attached to a sampling gear (e.g., a Niskin bottle attached to a CTD rosette)
feature	a specific feature in the depth profile of a CTD cast or an ice core (e.g., depth of chlorophyll maximum)
core_section	Section of an ice core in cm from bottom
depth_max	Maximum depth at which the sampling with a specific collector started (m)
depth_min	Minimum depth at which the sampling with a specific collector ended (m)
sample_depth	Depth from which a specific sample was collected (e.g., a Niskin bottle at 112 m) (m)
max_depth	Maximum depth to which a gear was sampling
sample_type	Type of sample (e.g., chl (chlorophyll))
core_type	Type of ice core (e.g., "S" for a salinity ice core)
parameter	Parameters measured or sampled
sample_label	Unique code of a specific sample
content	The content of a specific sample (e.g., "POM"; "*Gadus morhua*")
number	Number of items in a sample, mostly number of animals of one taxon
total_length	Total length of a fish sampled (cm)
standard_length	Standard length of a fish sampled (cm)
weight	Total fresh weight of a fish sampled (g)
evisc_weight	Eviscerated (=gutted) weight of a fish sampled (g)
tissue	Type of tissue of an animal sampled (e.g., "Stomach", "Finclip", "Muscle")
tissue sample code	Unique sample code of a tissue sample
mosaic_data_link	Direct link to repository of raw data or pictures from a specific sample
datetime	date and time (string)
speed.kn	Mean speed of past segment (kn) as recorded in Sensorweb (Database File 03)
speed.kmh	Mean speed of past segment (km h^{-1}) as recorded in Sensorweb (Database File 03)
dship.depth	Bottom depth (Database File 03)
dship.speed.kn	Mean speed of past segment (kn) as recorded in ship system DSHIP (Database File 03)
dship.speed.kmh	Mean speed of past segment (km h^{-1}) as recorded in ship system DSHIP (Database File 03)
date.xls	Date (in MS Excel format) (Database File 03)
time.xls	Time (in MS Excel format) (Database File 03)
datetime.xls	Date and time (in MS Excel format) (Database File 03)
duration.days	Duration of past segment (in days) (Database File 03)
distance.km	Distance of past segment (in km) (Database File 03)
distance.km.cum	Distance of cruise until this point (Database File 03)
hydroacoustics	Note if hydroacoustic data were recorded (HA if true)

date_time	Date and time (UTC) of start of hydroacoustic data file (yyyy-mm-dd Thh:mm:ss)
sample_id	Unique code of a specific video file
file_name	name of the video file on the mcs
time_start_utc	Exact time (UTC) of start of video (hh:mm:ss)
time_end_utc	Exact time (UTC) of end of video (hh:mm:ss)
duration_video	duration of video (mm:ss)
video_link	Direct link to location of video file in MCS (from AWI network)
q_flag	note on quality: ok = footage suitable for analysis; bad = not suitable; empty = not yet flagged
project	Project for which a specific sample was taken (e.g., “EFICA”)

Table 17: Overview of all devices occurring in Database Files 01-15, their explanations and targeted sample types.

Device name	Explanation	Targeted sample types
Automated Filtration for Marine Microbes	A pumped filtration system that takes DNA samples from the seawater intake at predefined intervals	e-DNA
BEAST	The Remotely Operated Vehicle ("Beast") carrying a horizontally sampling zooplankton net to sample under-ice fauna ("ROVnet")	Zooplankton and under-ice fauna
CTD AWI-OZE	The ship's Conductivity/Temperature/Depth (CTD) probe with a rosette sampler carrying 24 12L-bottles	T/S profiles, fluorescence, e-DNA, pigments, POC/PON (including stable isotopes), trophic biomarkers (HBI, fatty acids, stable isotopes), etc.
Fish sampling device	A combination of landing nets and bare hands to sample polar cod in ice cracks	Polar cod
FishCam	The EFICA FishCam consisting of two cameras and a CTD deployed in the Atlantic Water layer	Fish, squid and zooplankton (including siphonophores)
Fishing Echo Sounder	The *Polarstern* EK60/EK80 system to sample hydroacoustic backscatter profiles from the water column at 12, 38, 70, 120 and 200 KHz	Fish, zooplankton
Fishing rod	A hobby-type fishing rod for everyone on board to use	Fish
Gillnet	Gillnets with various mesh sizes to sample fish under sea ice and in the water column	Fish
Ice Corer Kovacs Mark II	A coring device (9 cm diameter) that samples a full vertical profile of sea ice from bottom to top	T/S profiles, e-DNA, pigments, POC/PON (including stable isotopes), trophic biomarkers (HBI, fatty acids, stable isotopes), sea-ice infauna, etc.
Ice Corer Kovacs Mark III	A coring device (9 cm diameter) that samples a full vertical profile of sea ice from bottom to top	T/S profiles, e-DNA, pigments, POC/PON (including stable isotopes), trophic biomarkers (HBI, fatty acids, stable isotopes), sea-ice infauna, etc.
Ice Corer Kovacs Mark V	A coring device (15 cm diameter) that samples a full vertical profile of sea ice from bottom to top	T/S profiles, e-DNA, pigments, POC/PON (including stable isotopes), trophic biomarkers (HBI, fatty acids, stable isotopes), sea-ice infauna, etc.
Lightframe On-sight Key species Investigation	An optical imaging profiler (LOKI) that samples in situ pictures of zooplankton in the top 1,000 m of the water column	Zooplankton
Longline	A fishing line with multiple hooks, sometimes baited.	Fish
Multinet Midi 5 Nets	A vertically sampling device carrying 6 nets (0.15 mm mesh) to sample zooplankton continuously in 6 different depth strata	Zooplankton
Nansen net	A vertically sampling zooplankton net with a closing mechanism, for sampling	Zooplankton

	of different depth strata in consecutive deployments	
OCEAN City CTD	Conductivity/Temperature/Depth (CTD) probe with a rosette sampler carrying 12 6L-bottles, deployed from the sea ice	T/S profiles, e-DNA, pigments (including chlorophyll), POC/PON (including stable isotopes), trophic biomarkers (HBI, fatty acids, stable isotopes), etc.
Ring net 60 cm	A vertically sampling zooplankton net, for sampling of targeted organisms for specific experiments and analyses	Zooplankton
Ring net 1000 µm mesh	A vertically sampling zooplankton net, for sampling of macrozooplankton in the top 1,000 m	Zooplankton
Ring net 150 µm mesh	A vertically sampling zooplankton net, for sampling of targeted organisms for specific experiments and analyses	Zooplankton
Ring net 53 µm mesh	A vertically sampling zooplankton net, for sampling of targeted organisms for specific experiments and analyses	Zooplankton
Underway Water Sampling	An under-way sampling device using the ship's seawater intake	e-DNA

Table 18: Overview of all parameters occurring in Database Files 01-15, their units and explanations.

Parameter	Unit	Explanation
T	°C	Temperature profile
S	n.a.	Salinity profile
TEX	n.a.	Sample for ice texture analysis
SalO18	n.a.	Salinity and $\delta^{18}O$ of ice core profile
Chl_total	$\mu g\ L^{-1}$	Total concentration of chlorophyll *a*
HPLC	n.a.	Pigment composition as analysed by High-Pressure Liquid Chromatography (HPLC)
Microscopy	ind. m^{-3}	Sample for microscopic analysis of the taxonomical composition of protists
Nutrients	mol L^{-1}	Concentrations of nutrients: NO_2, NO_3, PO_4
POC/N	$\mu g\ L^{-1}$, $\delta^{15}N$ (ppm), $\delta^{13}C$ (ppm)	Particulate organic carbon and nitrogen samples for analyses of C and N content and stable isotopes
CN	µg, %	Carbon and nitrogen content and ratio
Species composition and abundance	ind. m^{-3}	Quantification of species composition and abundance with microscopy and/or image analysis
Trophic_biomarker	n.a.	Samples for analysis of lipid composition, fatty acids, HBI, compound-specific stable isotopes and bulk stable isotope composition
TotDNA	n.a.	Sample for DNA sequencing
Insert parameter	n.a.	Parameter not assigned yet by Team ECO

Table 19: Overview of all fish tissue sample types occurring in Database Files 01-15, and their explanations.

Tissue sample type	Explanation
Fish muscle tissue	Dorsal muscle sample
Fish body	Whole fish or carcass after dissection
Fish gonad	Gonad (male or female)
Fish hindgut	Posterior part of gut, from stomach to anus
Fish stomach	Complete stomach
Fish fin clip	Small piece of fin sampled for (EFICA-specific) DNA sequencing
Fish otoliths	Calciferous structure in fish head used for age reading and migration reconstruction
Fish liver	Whole liver of fish
Fish head	Head of fish

13 THE SC03 MEDIA ARCHIVE

The MOSAiC expedition received much attention in public media all around the globe. With the support of the AWI Communications and Media Department, those media items were selected that contained contextual or explicit links to the activities of SC03. The media search engines and analytical tools (e.g., Landau Media), searched for media items with the following key words: "Fish*" & "MOSAiC", "Fisch*" & "MOSAiC", "EFICA" & "MOSAiC", and "EU" & "MOSAiC". Altogether, 72 media items with relevance to SC03 were identified, and listed and linked in the SC03 Media Archive (**Table 20**). The media archive was last updated on 5 April 2021.

Table 20: The SC03 Media Archive.

Date	Media type	Medium	Language	Headline	Weblinks
19/01/04	Magazine	Aktuellt / Politiken	Swedish	Utvecklingen gar att vända om vi agerar nu	https://etidning.aip.nu/31/Aktuellt-i-Politiken/208873/19-01-04/6309897/Utvecklingen-gar-att-vanda-om-vi-agerar-nu
19/02/19	News website	Havet.nu	Swedish	Fastfrusen i Arktis	https://www.havet.nu/?d=190&id=48327
19/03/06	News website	Publicnow.com	English	Preventing unregulated fishing in the Arctic: EU and partners meet to further the implementation of historic agreement	https://www.publicnow.com/view/1BBAFC5705875531DAB7DE305F505D26FE6E48E9
19/03/26	News website	Extrakt.se	Swedish	Arktis okända liv utforskas från isflak	https://www.extrakt.se/arktis-okanda-liv-utforskas-fran-isflak/
19/09/13	Magazine	Spiegel	German	Das Geheimnis der Schmelze	https://www.spiegel.de/wissenschaft/arktis-groesste-polarexpedition-der-geschichte-die-grosse-schmelze-a-00000000-0002-0001-0000-000165926213
Sept 2019	News website	The Mice Times of Asia	English	Dozens of countries-sent to Arctic – the largest in the history of the expedition	http://micetimes.asia/dozens-of-countries-sent-to-artik-the-largest-in-the-history-of-the-expedition-2/
Sept 2019	Directly sent interview + podcast	Sveriges Radio	Swedish	De ska fiska på Nordpolen – och avslöja isens kemi	https://poddtoppen.se/podcast/309710870/vetenskapsradion-pa-djupet/de-ska-fiska-pa-nordpolen-och-avsloja-isens-kemi
Sept 2019	Institute website	SU.se	Swedish	Klimat hav och miljö/forskare ska frysa fast i-arktis-ett år	https://www.su.se/forskning/profilområden/klimat-hav-och-miljö/forskare-ska-frysa-fast-i-arktis-ett-år-1.454832
Sept 2019	Institute journal	Resource (WUR)	Dutch	WUR onderzoekers doen mee aan grote Noordpoolexpeditie	https://resource.wur.nl/nl/show/WUR-onderzoekers-doen-mee-aan-grote-Noordpoolexpeditie-.htm
19/09/19	Newspaper	New York Times	English	MOSAiC expedition	https://www.nytimes.com/19/09/19/climate/mosaic-expedition-arctic.html
19/09/19	Radio	P4 Stockholm	Swedish	Pauline från Ingarö vill pussa fisk vid Nordpolen	https://sverigesradio.se/sida/artikel.aspx?programid=103&artikel=7303207
19/09/19	Radio	Sverige Radio	Swedish	Hon blir först med att fiska på Nordpolen	https://sverigesradio.se/sida/artikel.aspx?programid=406&artikel=19/09/197301940
19/09/20	Institute website	Institute for Marine Research	Norwegian	Far hjelp til a leite etter fisk i polhavet	https://www.hi.no/hi/nyheter/19/september/far-hjelp-til-a-leite-etter-fisk-i-polhavet
19/09/20	Newspaper	Svenska Dagbladet	Swedish	Historiens största polarexpedition sjösätts	https://www.svd.se/historiens-storsta-polarexpedition-sjosatts
19/09/20	News website	Svt.se	Swedish	Världens största Arktisexpedition lämnar Tromsö	https://www.svt.se/nyheter/utrikes/forskningsbaten
19/09/20	Press release	Stockholm University	Swedish	Forskare på väg att driva i Arktis is ett år	http://www.mynewsdesk.com/se/su/pressreleases/forskare-paa-vaeg-att-driva-i-arktis-is-ett-aar-2922341
19/09/20	Podcast	Podcasts.nu	Swedish	Avfärd för världens största Arktisexpedition	https://podcasts.nu/avsnitt/vetenskapsradions-veckomagasin/avfard-

					for-varldens-storsta-arktisexpedition
19/09/20	Newspaper	Aftonbladet	Swedish	Historiens största polarexpedition sjösätts	https://www.aftonbladet.se/nyheter/a/rAXeqa/historiens-storsta-polarexpedition-sjosatts
19/09/20	Institute website	Swedish Polar Secretariat	Swedish	MOSAiC 19/20	https://polar.se/om-polarforskning/expeditioner/mosaic-19/
19/09/20	News website	Forskning.se	Swedish	Forskare ska driva med isflak i Arktis	https://www.forskning.se/19/09/20/forskare-ska-driva-med-isflak-i-arktis/
19/09/20	News website	KystogFjord	Norwegian	Får hjelp til å lete etter fisk i Polhavet	https://www.kystogfjord.no/nyheter/forsiden/Faar-hjelp-til-aa-lete-etter-fisk-i-Polhavet
19/09/23	News website	Spiegel.de	English	A New Effort to Understand the Warming Arctic	https://www.spiegel.de/international/world/project-mosaic-new-expedition-aims-to-unpack-mysteries-of-warming-arctic-a-1287270.html
19/09/23	News Website	Offshore Energy	English	Polarstern Starts New Polar Expedition in Arctic	https://subseaworldnews.com/19/09/23/*Polarstern*-starts-new-polar-expedition-in-arctic/
19/09/24	News website	Safety4sea	English	Largest polar expedition ever to study climate change in central Arctic	https://safety4sea.com/largest-polar-expedition-ever-to-study-climate-change-in-central-arctic/
19/10/01	Institute website	Swedish National space Agency	Swedish	Satelliterna som stöttar Arktisexpeditionen	https://www.rymdstyrelsen.se/upptack-rymden/bloggen/19/10/satelliterna-som-stottar-arktisexpeditionen/
19/10/08	News website	BBC	English	Why this ship is spending a year frozen in the Arctic	https://www.bbc.com/future/article/191004-largest-arctic-expedition-in-history-going-the-north-pole
19/10/10	News Website	Euronews	German	Polarexpeditionen, um das Ökosystem Arktis zu schützen	https://de.euronews.com/19/10/10/polarexpeditionen-um-das-okosystem-arktis-zu-schutzen
19/10/10	News Website	Euronews	German	Vorsorgeverbot: Fischen in der Arktis dank Klimawandel attraktiv	https://de.euronews.com/19/10/10/vorsorgeverbot-fischen-in-der-arktis-dank-klimawandel-attraktiv
19/10/10	News Website	Euronews	English	Mapping the Arctic sea life	https://www.euronews.com/19/10/10/mapping-the-arctic-seas
19/10/10	News Website	Euronews	English	Protecting life in the Arctic seas	https://www.euronews.com/19/10/10/protecting-life-in-the-arctic-seas
19/10/16	Institute website	Wur.nl	English	New knowledge on the sea ice of the polar oceans	https://www.wur.nl/en/Research-Results/Research-Institutes/marine-research/show-marine/New-knowledge-on-the-sea-ice-of-the-polar-oceans.htm
19/10/19	News website	News.lk	English	How your morning coffee can help you survive an earthquake	https://www.news.lk/reviews/item/27815-how-your-morning-coffee-can-help-you-survive-an-earthquake
19/10/25	Newspaper	De Volkskrant	Dutch	De meest ambitieuze Noordpoolexpeditie tot nu: wetenschappers trotseren het duister van de winter	https://www.volkskrant.nl/wetenschap/de-meest-ambitieuze-noordpoolexpeditie-tot-nu-wetenschappers-trotseren-het-duister-van-de-winter~b4942f83/?referrer=https%3A%2F%2Fwww.google.com%2F
19/11/10	News website	Public.	English	Euronews OCEAN episode 8: Protecting life in the Arctic seas	https://www.publicnow.com/view/154E5E002FCCE693A441E673B5E30545588ADD16
19/12/03	News website	BBC	English	What will an ice-free Arctic look like?	https://www.bbc.com/future/article/191129-what-will-an-ice-free-arctic-look-like
19/12/25	News website	News.lk	English	Which animals survive in the climate crisis?	https://www.news.lk/reviews/item/28863-which-animals-survive-in-the-climate-crisis
20/01/22	Institute website	NWO	Dutch	Nederlandse deelnemers Mosaic expeditie vertrekken naar Noordpool	https://www.nwo.nl/nieuws/nederlandse-deelnemers-mosaic-expeditie-vertrekken-naar-noordpool
20/01/31	Institute website	Wur.nl	English	The MOSAiC expedition continues leg 2: Hardships and challenges in the Arctic winter	https://www.wur.nl/en/Research-Results/Research-Institutes/marine-research/show-marine/The-MOSAiC-expedition-continues-leg-2-Hardships-and-challenges-in-the-Arctic-winter.htm
20/02/03	Magazine	Ocean News & Technology	English	The MOSAiC Expedition Continues: Hardships and	https://www.oceannews.com/news/science-technology/the-mosaic-

				Challenges in the Arctic Winter	expedition-continues-hardships-and-challenges-in-the-arctic-winter
20/02/04	Newspaper	Gießener Allgemeine	German	»Polarstern«-Crew wieder in Bremen	https://www.giessener-allgemeine.de/panorama/polarstern-crew-wieder-bremen-13638446.html
20/03/23	Radio	Deutschland-funk	German	Corona-Pandemie beeinflusst Crew-Wechsel auf der Polarstern	https://www.deutschlandfunk.de/arktis-expedition-mosaic-corona-pandemie-beeinflusst-crew.676.de.html?dram:article_id=473092
20/04/15	Institute website	Wur.nl	English	Delays in exchange of researchers MOSAiC expedition	https://www.wur.nl/en/Research-Results/Research-Institutes/marine-research/show-marine/Delays-in-exchange-of-researchers-MOSAiC-expedition.htm
20/05/17	News Website	The Colorado Sun	English	The largest Arctic science expedition in history finds itself on increasingly thin ice because of coronavirus	https://coloradosun.com/20/05/17/the-largest-arctic-science-expedition-in-history-finds-itself-on-increasingly-thin-ice/
20/06/08	Blog	International Science Council	English	What does COVID-19 mean for ocean science – and for the ocean itself?	https://council.science/current/blog/what-does-covid-19-mean-for-ocean-science-and-for-the-ocean-itself/
20/07/25	News website	Huffpost	English	One Year In Ice City: A Look Inside The World's Largest Arctic Expedition	https://www.huffpost.com/entry/mosaic-worlds-largest-polar-expedition_n_5f1a0466c5b6f2f6c9f3aa8e
20/09/01	Institute website	Wur.nl	English	Photo impression MOSAiC expedition in the Arctic Ocean	https://www.wur.nl/en/newsarticle/Photo-impression-MOSAiC-expedition-in-the-Arctic-Ocean.htm
20/09/15	News website	Nemo Kennislink	Dutch	Vastgevroren voor de wetenschap	https://www.nemokennislink.nl/publicaties/vastgevroren-voor-de-wetenschap/
20/10/01	Newspaper	Zeit	German	Ein Jahr im Eis	https://www.zeit.de/20/41/forschungsschiff-polarstern-arktis-expedition-polarforschung/komplettansicht
20/10/12	Radio	Deutschland-funk	German	Die Polarstern ist zurück aus der Arktis	https://www.deutschlandfunk.de/ende-der-mosaic-mission-die-polarstern-ist-zurueck-aus-der.676.de.html?dram:article_id=485658
20/10/12	News website	Wetter.de	German	Polarstern kehrt nach ereignisreichem Jahr in der Arktis zurück	https://www.wetter.de/cms/polarstern-kehrt-nach-ereignisreichem-jahr-in-der-arktis-zurueck-4629445.html
20/10/13	News Website	Sueddeutsche.de	German	Lauwarm erwischt	https://www.sueddeutsche.de/wissen/klimawandel-polarstern-arktis-1.5063037
20/10/16	Institute website	Helmholtz-Gemeinschaft	German	Internationale Zusammenarbeit für die Klimaforschung	https://www.helmholtz.de/erde-und-umwelt/internationale-zusammenarbeit-fuer-die-klimaforschung/
20/10/19	Newspaper	Märkische Allgemeine	German	„Wir haben dem Eis beim Sterben zugesehen"	https://www.maz-online.de/Brandenburg/Polarforscher-Markus-Rex-Wir-haben-dem-Eis-beim-Sterben-zugesehen
20/10/19	Magazine	Spiegel	German	Unser Jahr in der Arktis	https://www.spiegel.de/wissenschaft/natur/polarstern-forscher-berichten-ihr-jahr-in-der-arktis-a-00000000-0002-0001-0000-000173444553
20/10/23	Institute website	Swedish Polar Research secretariat	English and swedish	Research on fish and microbes in the Central Arctic Ocean	https://polar.se/en/expeditions/forskning-pa-fisk-och-mikrober-i-centrala-norra-ishavet-english/
October 2020	News website	N-TV	German	Uhrwerk Arktis	https://www.n-tv.de/wissen/Uhrwerk-Arktis-article22083992.html
20/11/06	News website	High North News	English	"Polarstern" Crew After A Year Trapped in the Sea Ice: "Nature Is Still Boss in the Arctic"	https://www.highnorthnews.com/en/polarstern-crew-after-year-trapped-sea-ice-nature-still-boss-arctic
20/11/15	Newspaper	Het Parool	Dutch	Deze onderzoekers lieten zich invriezen op een schip in de Arctische Oceaan	https://www.parool.nl/wereld/deze-onderzoekers-lieten-zich-invriezen-op-een-schip-in-de-arctische-oceaan~b1351952/

20/11/16	TV movie	ARD	German	Expedition Arktis - Ein Jahr. Ein Schiff. Im Eis	https://www.ardmediathek.de/video/erlebnis-erde/expedition-arktis-ein-jahr-ein-schiff-im-eis/das-erste/Y3JpZDovL2Rhc2Vyc3RlLmRlL2VybGVibmlzIGVyZGUvNGU3OWMzMzctNTg0MC00N2YzLWIzOGUtZjkwMmU4NDY5ZTI2/
20/11/16	News website	DWDL.de	German	Expedition Arktis": Ein ganzes Jahr in "Traumschiff"-Länge	https://www.dwdl.de/meinungen/80257/expedition_arktis_ein_ganzes_jahr_in_traumschifflaenge/
20/11/16	Newspaper	Frankfurter Allgemeine Zeitung	German	Ein lebensfeindliches Milieu für Klimaforscher	https://zeitung.faz.net/faz/medien/20-11-16/ein-lebensfeindliches-milieu-fuer-klimaforscher/532529.html
20/11/18	Institute website	Helmholtz-Gemeinschaft	German	Uhrwerk Arktis	https://www.helmholtz.de/erde-und-umwelt/uhrwerk-arktis/
20/11/20	Radio program	Sveriges Radio	Swedish	Han till vänster sköt isbjörnarna själv	https://sverigesradio.se/avsnitt/1603761
20/11/29	Radio program	Sveriges Radio	Swedish	Arktisexpeditionen	https://sverigesradio.se/avsnitt/1606037
20/12/03	Blog	Radio Canada	English	Some gloom when it comes to Arctic climate, but also a promise of progress	https://www.rcinet.ca/eye-on-the-arctic/20/12/03/blog-some-gloom-when-it-comes-to-arctic-climate-but-also-a-promise-of-progress/
20/12/08	News website	El Universal	Spanish	Qué es la "atlantificación" del océano Ártico y por qué preocupa a los científicos	https://www.eluniversal.com.mx/ciencia-y-salud/que-es-la-atlantificacion-del-oceano-artico-y-por-que-preocupa-los-cientificos
20/12/30	Government website	Federal Ministry of Education and Research	German	20 – Wir werfen einen Blick zurück	https://www.bmbf.de/de/20---wir-werfen-einen-blick-zurueck-13468.html
21/01/03	Newspaper	Sächsische Zeitung	German	Ein ganzes Jahr im Eis	https://www.saechsische.de/politik/deutschland/innenpolitik/klimapolitik/ein-ganzes-jahr-im-eis-5347020-plus.html
21/01/11	Press release	Hamburg Messe und Congress	German	Offshore Dialogue: Der Wert von Wind und Wasser	https://www.hamburg-messe.de/newsroom/presse/pressemitteilungen-detail/article/offshore-dialogue-der-wert-von-wind-und-wasser http://www.trade-fairs-international.com/tfi/aktuelles/meldungen/smmdigi.php
21/01/21	Newspaper	Newspaper “Finnish Nature”	Finnish	Tutkimusmatka Arktiksen sydämeen	https://suomenluonto.fi/artikkelit/tutkimusmatka-arktiksen-sydameen/
21/03/05	News website	WMO publications	English	United Nations: World Met Day rallies attention around the ocean	https://public.wmo.int/en/media/news/world-met-day-rallies-attention-around-ocean https://foreignaffairs.co.nz/2021/03/25/mil-osi-united-nations-world-met-day-rallies-attention-around-the-ocean/ https://www.miragenews.com/world-met-day-rallies-attention-around-ocean-533826/
21/03/16	News website	Blickpunkt: Film	German	UFA mit Schweizer Variante von "Expedition Arktis"	https://beta.blickpunktfilm.de/details/458484

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