PANABIO: a point-referenced PAN-Arctic data collection of benthic BIOtas

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Abstract. CE2 Profound environmental changes, such as drastic sea-ice decline, leave large-scale ecological footprints on the distribution and composition of marine biota in the Arctic. Currently, the impact of such stressors is not sufficiently understood due to the lack of pan-Arctic data that allow for estimating ecological baselines as well as modelling current and forecast potential changes in benthic biodiversity and ecosystem functioning. Here, we introduce the PAN-Arctic data collection of benthic BIOtas CE3 (PANABIO) and discuss its timeliness, potential, and details of its further development. The data collection contains individual datasets with records (presence, counts, abundance, or biomass) of benthic fauna, usually at genus level or species level, which were identified in field samples obtained at point-referenced locations (stations) by means of grabs, towed gear, or seabed imaging. The data cover the entire pan-Arctic realm, i.e. the central Arctic Ocean, Chukchi Sea, East Siberian Sea, Laptev Sea, Kara Sea, Barents Sea (including the White Sea), Svalbard waters, Greenland Sea, Norwegian Sea, Canadian Archipelago, Beaufort Sea, and Bering Sea as well as some adjacent sub-Arctic regions (Sea of Japan, Gulf of Okhotsk). Currently (as of 14 December 2023), PANABIO includes 27 datasets with a total of 126 389 records of 2968 taxa collected from 11 555 samples taken at 10 597 stations during 1094 cruises between 1800 and 2014. These numbers will increase with more data becoming available over time through contributions from PANABIO users. The data collection is available in a PostgreSQL-based data warehouse that can be accessed and queried through an open-access front-end web service at https://critterbase.awi.de/panabio TS3. A snapshot of the current data collection and its 27 individual datasets is also available from the data publisher PANGAEA (https://doi.pangaea.de/10.1594/PANGAEA.963640).

1 Introduction

Climate change progresses faster and stronger in the Arctic than elsewhere (Meredith et al., 2019; Constable et al., 2022). Therefore, Arctic marine organisms and ecosystems are particularly affected and potentially threatened at large scales by accelerating environmental change, such as ocean warming and acidification, sea-ice decline, and increased riverine input (Kedra et al., 2015), albeit with distinct regional differences. Moreover, expanding human activities, such as exploration and exploitation of natural resources, ship traffic, and tourism, add further pressures. Accordingly, there is an urgent need for a thorough and rapid assessment of how environmental changes may alter ecosystems and their functioning in polar latitudes (Degen et al., 2018). However, research on footprints and implications of climate change and direct anthropogenic impacts – such as range shifts, changes in abundance, declines in growth and condition, and community and regime shifts – has been hampered by the problems of accessing sound data, which is unevenly distributed among regions and taxonomic groups (Wassmann et al., 2011).

Recent research emphasised the critical importance of the direct and indirect ecological effects of sea-ice decline, which is one of the most striking and far-reaching footprints of climate change in polar regions (Macias-Fauria and Post, 2018). Sea ice is a dominant ecological driver in Arctic seas, as it not only represents a specifically polar marine habitat but also controls the light, stratification, and, hence, productivity regime of the underlying water column (Bluhm and Gradinger, 2008). Both pelagic and benthic secondary production depend directly on sea ice and pelagic primary production. Ultimately, due to the importance of the cryo-pelagic–benthic coupling in polar seas, the loss of sea ice will very likely have profound consequences for the diversity, structure, and functioning of benthic fauna across pan-Arctic seascapes (Piepenburg, 2005; Hinzman et al., 2011TS4; Macias-Fauria and Post, 2018; Wassmann et al., 2011; Brandt et al., 2023).

However, the challenge of quantifying, understanding, modelling, and forecasting the impact of climate change and anthropogenic pressures on Arctic benthic species and assemblages has rarely been addressed (e.g. Renaud et al., 2019; Pantiukhin et al., 2021). Indeed, it is commonly acknowledged that currently neither the direction nor mode of ongoing or future ecological regime shifts are sufficiently investigated and understood to soundly predict forthcoming changes in Arctic marine ecosystem functions (Wassmann et al., 2011; Post et al., 2013; Meredith et al., 2019; Constable et al., 2022; Brandt et al., 2023). This gap can be attributed to the difficulty of obtaining solid data from the Arctic due to, amongst others, its remoteness and hostile environmental conditions, the tremendous costs of sea-going polar research, and a lack of synergistic research spanning multiple Arctic ecoregions.

Consequently, the urgently needed integrative approach can only be achieved through an upscaling from local to large scales, but this would require a comprehensive data source representative of the whole Arctic. Here, we present PANABIO, the PAN-Arctic data collection of benthic BIOtas within the CRITTERBASE data warehouse (Teschke et al., 2022). It provides standardised open access to point-referenced quantitative ecological data by integrating data from various sources and of various formats through a generic data–ingest interface and offering versatile exploration tools for data filtering and mapping provided by the overarching CRITTERBASE system.

2 Material and methods

2.1 Definition of study area

We used the common definition of Arctic seas proposed by the Arctic Monitoring and Assessment Programme (AMAP; https://www.amap.noTS5) to identify our pan-Arctic study area, which also includes some adjacent sub-Arctic regions, such as the Sea of Okhotsk and the Sea of Japan (Fig. 1; Table 1), since the distribution ranges of many species occurring in Arctic seas extend into the bordering areas. In the global CRITTERBASE data warehouse, the PANABIO data collection and its individual datasets can be filtered by the statistical areas used by the Food and Agriculture Organization of the United Nations (FAO).

2.2 Data sources

The PANABIO data collection currently contains 27 point-referenced datasets of benthic taxa from various sources, a total of 17 of which have previously been compiled during the Arctic Ocean Diversity (ArcOD) project (see Piepenburg et al., 2011) and/or are published in the PANGAEA data repository (https://www.pangaea.deTS33) and the Arctic OBIS node (https://obis.org/node/da50007b-7871-46cf-8530-441b5836d2c1TS34). The individual datasets vary in origin as well as in spatial, temporal, and taxonomic coverage (Table 2). The provenance of each dataset is indicated in PANABIO, including contact person and DOIs of a related peer-reviewed article and/or data publication (Table 2). Note that the number of datasets represents the current stock. We anticipate that additional sets of further historical or novel data will be added over time, by us and other data contributors, using the Collector App of CRITTERBASE (Teschke et al., 2022), resulting in a steady growth of the data collection in the number of datasets, records, and samples and thus also in spatial and temporal resolution and taxonomic coverage.

2.3 Data compilation

Following the workflow suggested by Piepenburg et al. (2011), we first harmonised and validated the nomenclature by consistently using the valid taxon name according to the World Registry of Marine Species (WoRMS; https://www.marinespecies.orgTS35). This prevents confounding cross-data comparisons and prevents the inflation of diversity estimates due to the use of synonyms or unaccepted species names. Therefore, to the best of our knowledge, each record in the validated data collection represents a single taxonomic unit (mostly species or genera, only in some cases at higher levels if a sound and reliable identification at species or genus level was not possible).

Data records provide information about the occurrence (presence) or, if available, counts of specimens, abundance (numbers of individuals per area), and/or biomass (wet mass

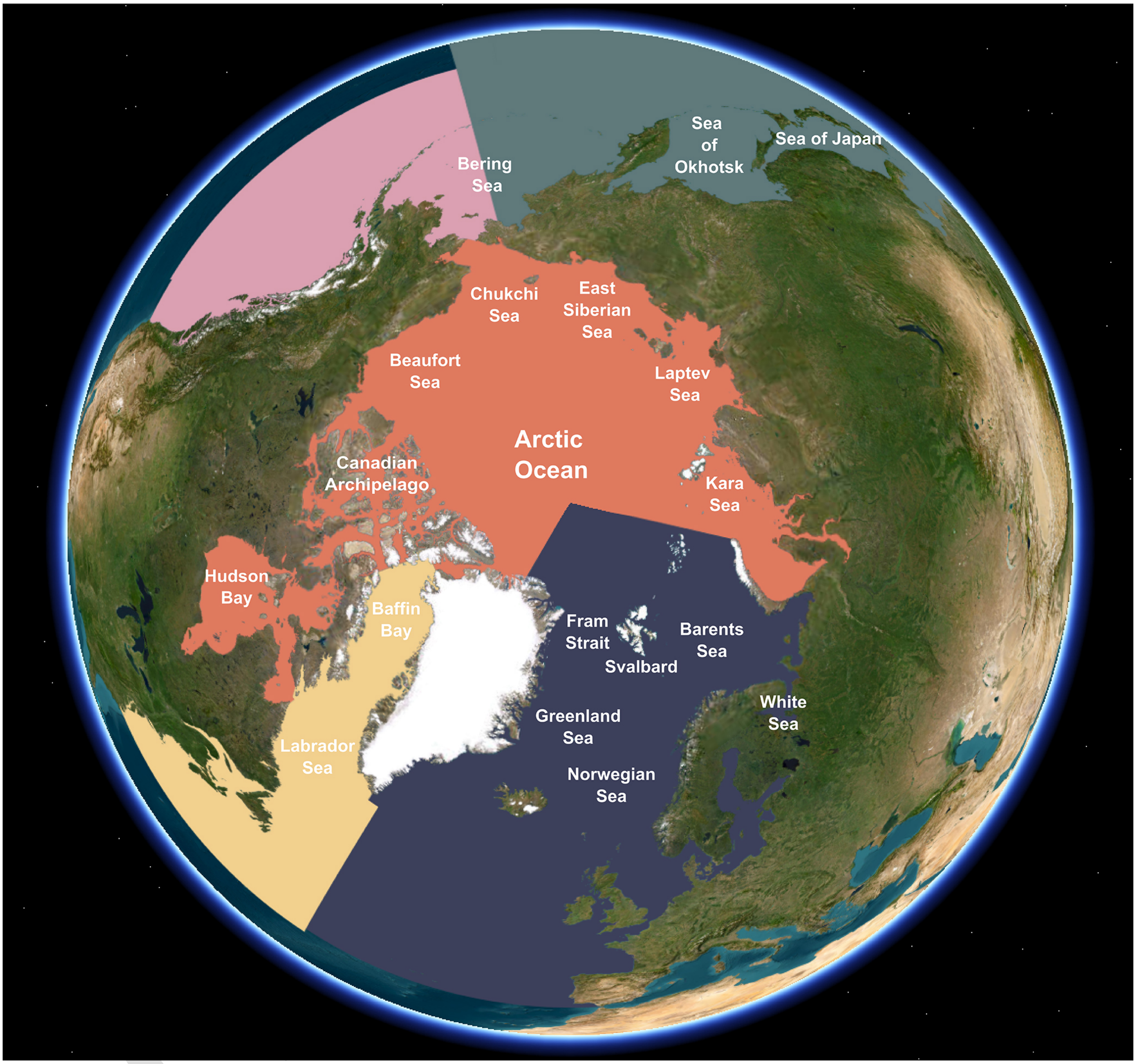

Figure 1. Major Arctic sea regions, embedded in five Major Fishing Areas of the Food and Agriculture Organization (FAO) (orange: no. 18 – Arctic Sea; yellow: no. 21 – northwest Atlantic; blue: no. 27 – northeast Atlantic; green: no. 61 – northwest Pacific; purple: no. 67 – northeast Pacific). The map was created with ArcGIS Earth (Earthstar Geographics Esri).

or ash-free dry mass) of each taxon encountered and identified in a sample taken at a specific place at a specific time. Metadata inform about geographic location, region, water depth (m), and date of sampling as well as the sampling gear used (such as towed gear, grabs, corers, or seafloor imaging). The latter determines which part of the benthic community is generally represented in the samples; e.g. trawl catches contain mainly megabenthos, grab samples macrobenthos, and seafloor images epibenthos. Metadata also provide information about the taxonomic coverage of the dataset to indicate it comprises only a certain taxonomic subset of the entire benthic fauna (e.g. "polychaetes" because only this group has been analysed in the samples on a species or genus level). Furthermore, the full taxonomic tree is given for each taxon to allow for summarising and scaling information from species to kingdom level. For more detailed information about the data model and data quality control, see Teschke et al. (2022) and https://critterbase.awi.de/#qcTS36.

Table 1. Summary of the data contained within the pan-Arctic data collection of benthic biota (PANABIO), grouped by region: number of stations, samples, records, and taxa by the FAO (Food and Agriculture Organization of the United Nations) areas (each encompassing various Arctic sea regions). Please note that the number of taxa in the five FAO areas does not sum up because taxa can occur in two or more areas. CE4

FAO areas	Arctic sea regions	No. of stations	No. of samples	No. of records	No. of taxa
No. 18: Arctic Sea	Central Arctic Ocean Chukchi Sea East Siberian Sea Laptev Sea Kara Sea Beaufort Sea Canadian Archipelago Hudson Bay	3839	3853	84 827	1941
No. 21: northwest Atlantic	Baffin Bay Labrador Sea	82	82	4286	661
No. 27: northeast Atlantic	27.1: Barents Sea + White Sea 27.2: Norwegian Sea + Svalbard + Fram Strait 27.5: Iceland 27.14: Greenland Sea	5048	5048	30 101	1691
No. 61: northwest Pacific	Western Bering Sea Sea of Okhotsk Sea of Japan	1478	1478	3238	237
No. 67: northeast Pacific	Eastern Bering Sea	184	184	1588	124

3 Data availability

Currently (as of 14 December 2023), PANABIO contains 126 389 records from 11 555 samples taken at 10 597 stations during 1094 cruises (Table 2; Fig. 2) and 2968 taxonomic entities, collected between 1800 and 2014. These circumpolar data on Arctic benthic biodiversity, comprising mainly Echinodermata, Arthropoda, Mollusca, and Annelida, are hosted as the Arctic regional component of the PostgreSQL-based global data warehouse CRITTERBASE (Teschke et al., 2022) and can be accessed via a web portal at https://critterbase.awi.de/panabio TS37. Here, the entire data collection or, if required, only excerpts of it can be downloaded as CSV and/or Excel files, to be used for further analysis. Moreover, a snapshot of the current version of the PANABIO data collection is available from the data publisher PANGAEA via https://doi.pangaea.de/10.1594/PANGAEA.963640 TS38 (Piepenburg et al., 2024), from where each individual dataset can be accessed separately through its own DOI link (Table 2).

4 Discussion

4.1 Timeliness

Open-access data collections on pan-Arctic benthic biota, such as PANABIO, are needed to explore and forecast potential impacts of climate change on benthic diversity and food-web complexity and its consequences for higher trophic levels, such as marine mammals and seabirds, relying on benthic fauna for food (Macias-Fauria and Post, 2018; Post et al., 2013; Wassmann et al., 2011). Moreover, they are also needed to obtain a scientifically sound baseline of current diversity patterns in Arctic benthic systems, from which further change can be assessed. PANABIO does not aim to replace but rather complement the services offered by common and well-established data repositories, such as the Global Biodiversity Information Facility (GBIF; https://www.gbif.org/ TS39), the Ocean Biodiversity Information System (OBIS; https://obis.org/ TS40), and PANGAEA. There is one crucial difference: while such repositories focus on long-term data storage and/or on individual datasets, PANABIO provides a "ready-to-use", standardised, and quality-checked compilation of many individual datasets. Moreover, it has a distinct focus on Arctic benthos, facilitating instant and low-level access to rel-

Table 2. Information about individual datasets currently (as of 14 December 2023) contained within the pan-Arctic data collection of benthic biota (PANABIO), including the names of datasets, reference persons and their institutions, DOI links of related papers and data publications in repositories as well as the numbers of cruises, years (ranges), stations, water depths (ranges), samples, records, and taxa. Please note that the number of taxa in the 27 datasets does not sum up because taxa can occur in two or more datasets.

Dataset	Reference person	Institution	DOI (related papers)	DOI (data publications)	Cruises	Years	Stations	Water depths	Samples	Records	Taxa
Benthos ArcOD Sirenko (a)	Boris Sirenko	Zoological Institute, Russian Academy of Sciences, St. Petersburg	https://doi.org/10.1007/s12526-010-0059-7	https://doi.org/10.1594/PANGAEA.964361	232	1800–2004	2565	0–4000	2565	6185	98
Benthos ArcOD Sirenko (b)	Boris Sirenko	Zoological Institute, Russian Academy of Sciences, St. Petersburg	https://doi.org/10.1007/s00300-020-02737-9	https://doi.org/10.1594/PANGAEA.964105 https://doi.org/10.1594/PANGAEA.910004	5	1993–1995	148	7–3827	148	3240	686
Benthos ArcOD Sirenko (c)	Boris Sirenko	Zoological Institute, Russian Academy of Sciences, St. Petersburg	https://doi.org/10.1007/s12526-010-0059-7	https://doi.org/10.1594/PANGAEA.964113	755	1800–2004	6246	0–8100	6246	15 592	431
Benthos Barents and Pechora seas Renaud	Paul Renaud	Akvaplan-niva, Tromsø	10013/epic.51439.d001	https://doi.org/10.1594/PANGAEA.964121 https://doi.org/10.1594/PANGAEA.877932	7	1992–2003	137	7–512	137	10 839	1126
Benthos Barents Sea Carroll	Michael Carroll	Akvaplan-niva, Tromsø	10013/epic.51439.d001	https://doi.org/10.1594/PANGAEA.964128 https://doi.org/10.1594/PANGAEA.910004	4	2002–2005	32	62–512	32	3277	627
Benthos Beaufort Sea 1980s Archambault	Philippe Archambault	Université du Québec à Rimouski- ISMER	https://doi.org/10.1007/s12526-010-0059-7	https://doi.org/10.1594/PANGAEA.964126	4	1985–1988	47	4–22	47	176	38
Benthos Beaufort Sea 2009 Archambault	Philippe Archambault	Université du Québec à Rimouski- ISMER	https://doi.org/10.1371/journal.pone.0101556	https://doi.org/10.1594/PANGAEA.964125	1	2009	43	6–1072	43	650	207
Benthos Beaufort Sea 2010 Archambault	Philippe Archambault	Université du Québec à Rimouski- ISMER	https://doi.org/10.1371/journal.pone.0101556	https://doi.org/10.1594/PANGAEA.964124	1	2010	37	71–945	37	764	233
Benthos Beaufort Sea 2011 Archambault	Philippe Archambault	Université du Québec à Rimouski- ISMER	https://doi.org/10.1371/journal.pone.0101556	https://doi.org/10.1594/PANGAEA.964122	1	2011	28	25–74	28	1442	319
Benthos Chirikov Basin ArcOD Bluhm	Bodil Bluhm	University of Alaska, Fairbanks	https://doi.org/10.1007/s12526-010-0059-7	https://doi.org/10.1594/PANGAEA.964254	2	1986–2002	29	32–49	101	1321	53
Benthos Chukchi Sea ArcOD Feder	Howard Feder	University of Alaska, Fairbanks	https://doi.org/10.1007/s00300-004-0683-4	https://doi.org/10.1594/PANGAEA.964252	1	1976	70	15–64	70	1520	150
Benthos Chukchi Sea Blanchard	Arny Blanchard	University of Alaska, Fairbanks	https://doi.org/10.1007/s12526-010-0059-7	https://doi.org/10.1594/PANGAEA.964363	13	2008–2014	501	12–54	1350	59 687	488
Benthos European Arctic ArcOD Kroencke	Ingrid Kröncke	Senckenberg, Wilhelmshaven	https://doi.org/10.1007/s003000050263	https://doi.org/10.1594/PANGAEA.963872	1	1991	47	552–4478	47	2132	97

Table 2. Continued. CE7

Benthos Laptev Sea Transdrift1 Piepenburg	Dieter Piepenburg	Institute for Polar Ecology, Kiel	https://doi.org/ 10.1007/s00300-006-0122-9	https://doi.org/ 10.1594/PANGAEA.964364 TS19	1	1993	11	14–44	11	1485	137
Benthos Laptev Sea Transdrift2 Syomin	Vitaly Syomin	Institute of Arid Zones – Russian Academy of Sciences, Moscow		https://doi.org/ 10.1594/PANGAEA.964127 TS20	2	2013–2014	11	23–326	28	445	141
Benthos Northeast Greenland 1985 Piepenburg	Dieter Piepenburg	Institute for Polar Ecology, Kiel	https://doi.org/ 10.1007/BF00346313	https://doi.org/ 10.1594/PANGAEA.963877 TS21	1	1985	17	90–890	17	859	189
Benthos Svalbard 1991 Piepenburg	Dieter Piepenburg	Institute for Polar Ecology, Kiel	https://doi.org/ 10.1007/BF02390425	https://doi.org/ 10.1594/PANGAEA.963873 TS22	1	1991	36	30–2100	36	1015	253
Benthos Spitsbergen Wlodarska-Kowalczuk	Maria Wlodarska-Kowalczuk	Institute of Oceanology PAS, Sopot		https://doi.org/ 10.1594/PANGAEA.964119 TS23 https://doi.org/10.1594/PANGAEA.910004	6	1991–2007	26	50–525	26	1332	265
Epibenthos North Greenland Piepenburg	Dieter Piepenburg	Institute for Polar Ecology, Kiel	https://doi.org/ 10.1007/s12526-010-0059-7	https://doi.org/ 10.1594/PANGAEA.964362 TS24	1	1993	25	27–375	25	221	34
Macrobenthos Canadian Arctic Archipelago Archambault Cusson	Philippe Archambault, Mathieu Cusson	Université du Québec à Rimouski- ISMER	https://doi.org/ 10.3354/meps331291	https://doi.org/ 10.1594/PANGAEA.964260 TS25	24	1955–1975	235	1–970	235	7203	793
Macrobenthos Degen	Renate Degen	Alfred Wegener Institute, Bremerhaven	https://doi.org/ 10.3402/polar.v34.24008	https://doi.org/ 10.1594/PANGAEA.962760 TS26 https://doi.org/10.1594/PANGAEA.828348	2	1997–2012	32	517–5416	23	267	93
Megabenthos Bluhm and Iken	Bodil Bluhm, Katrin Iken	University of Alaska, Fairbanks	https://doi.org/ 10.3354/ab00198	https://doi.org/ 10.1594/PANGAEA.964255 TS27	3	2004–2007	29	26–101	29	597	103
Megabenthos Canadian Arctic Archambault	Philippe Archambault	Université du Québec à Rimouski- ISMER	https://doi.org/ 10.1371/journal.pone.0100900	https://doi.org/ 10.1594/PANGAEA.964256 TS28	2	2007–2008	30	38–759	30	667	244
Megabenthos Canadian Arctic Archipelago Archambault Cusson	Philippe Archambault, Mathieu Cusson	Université du Québec à Rimouski- ISMER	https://doi.org/ 10.3354/meps331291	https://doi.org/ 10.1594/PANGAEA.964258 TS29	18	1953–1977	110	0–335	110	2435	413
Peracarida Greenland Brandt	Angelika Brandt	Institute for Polar Ecology, Kiel	https://doi.org/ 10.1007/s12526-010-0059-7	https://doi.org/ 10.1594/PANGAEA.963642 TS30	1	1993	20	45–520	20	1132	197
Polychaeta ArcOD Beaufort Sea Carey	Andrew Carey	School of Oceanography, Oregon State University	https://doi.org/ 10.1007/BF00395439	https://doi.org/ 10.1594/PANGAEA.964261 TS31	3	1971–1976	70	3–3010	70	1526	159
Polychaeta Fram Strait ArcOD Schnack	Klaus Schnack	Institute for Polar Ecology, Kiel	https://doi.org/ 10.1007/s12526-010-0059-7	https://doi.org/ 10.1594/PANGAEA.964107 TS32	2	1994–1995	15	183–2795	35	380	56
				Totals	**1094**		**10 597**		**11 555**	**126 389**	**2968**

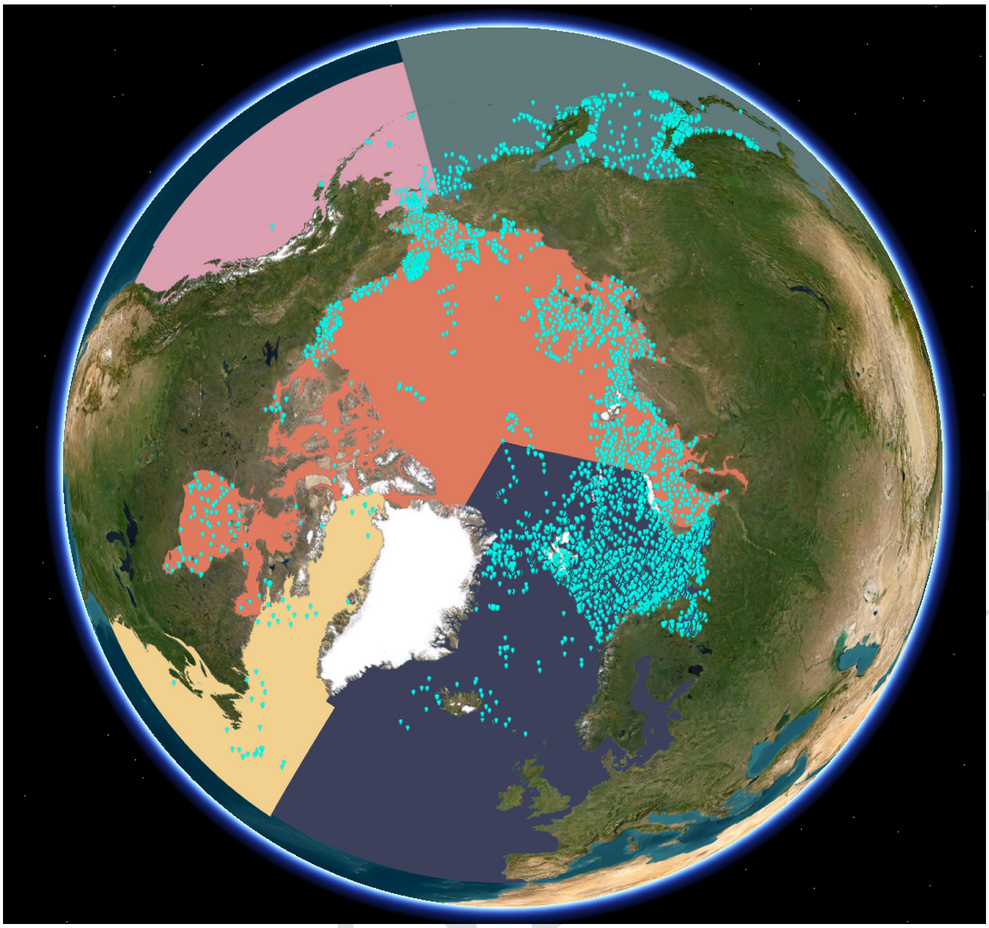

Figure 2. Locations of point-referenced data in the PANABIO data collection, embedded in five Major Fishing Areas of the Food and Agriculture Organization (FAO) (orange: no. 18 – Arctic Sea; yellow: no. 21 – northwest Atlantic; blue: no. 27 – northeast Atlantic; green: no. 61 – northwest Pacific; purple: no. 67 – northeast Pacific). The map was created with ArcGIS Earth (Earthstar Geographics Esri).

evant data for the Arctic benthic research community as well as providing an attractive tool for cooperation and networking. It is currently used as a tool for managing and exploring the first comprehensive bottom grab-sample survey of the Marine Benthos Expert Network of the Circumpolar Biodiversity Monitoring Program (CBMP) of the Arctic Council working group Conservation of Arctic Flora and Fauna (CAFF) (https://www.caff.is/marine/marine-expert-networks/benthosTS41). Such results are also important for informing decision-makers and the general public, who are concerned about the vulnerability of Arctic environments due to emerging and rapidly increasing economic and geopolitical interests.

4.2 Outlook

Arctic marine biotic data are still fragmented into a dazzling array of databases and files, most of which are not public. This situation seriously hampers progress in Arctic marine ecological research, as it prevents us from coupling environmental dynamics with ecological dynamics across large spatial and temporal scales. Currently this problem is tackled from various perspectives; e.g. WoRMS addresses marine taxonomic inconsistencies at a global scale (WoRMS Editorial Board, 2023), AquaMaps (Kaschner et al., 2016) provides ecological and biological information on marine species, and OBIS (De Pooter, 2017TS42) allows us to explore marine species occurrences in relation to environmental conditions. In the context of these ongoing and planned efforts, PANABIO represents a regional data collection of the biological data warehouse CRITTERBASE with an open-access web service that allows on-the-fly exploration, selection, and download of geo-referenced and validated Arctic benthic biodiversity data. What is still lacking in the PANABIO data collection and what we currently are investing in is the development of an interface and a workflow to link the biotic data in PANABIO to ecological data layers from Arctic regions, such as raster information on bottom topography, sea-ice and ocean dynamics, or chlorophyll *a* distribution patterns, to support analysis and modelling work in day-to-day operations. In addition, the free availability of the PANABIO data collection via CRITTERBASE and PANGAEA (where static snapshots of the collection will be published at regular time intervals) will be complemented through an interface of the two global biodiversity networks GBIF and OBIS.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Author contributions. All authors contributed to information system design; data collection, curation and analysis; and writing and reviewing the paper. CK and DP wrote the first version of the paper.

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