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Inter-regional coherence: Can Northeast Atlantic pelagic habitat indicators be applied to the Arctic?

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ABSTRACT

As part of its commitment to the EU Marine Strategy Framework Directive (MSFD) OSPAR has developed three plankton indicators of Good Environmental Status (GES) for pelagic habitats in the Northeast Atlantic. In coming years, implementation of the MSFD will extend into the Arctic, requiring the application of pelagic habitat indicators in the region. Because plankton communities and monitoring effort are spatially variable, applicability to the Arctic of existing indicators must be assessed. A meta-analysis is applied to the Northeast Atlantic pelagic habitat indicators to establish their ecological applicability and relevance to Arctic marine ecosystems and their implementability using existing national monitoring effort. To identify gaps and potential improvements in the OSPAR indicators, two gap analyses were conducted. The first considered the Northeast Atlantic OSPAR-adopted indicators and existing plankton indicators currently employed by Arctic nations. The second assessed the minimum data attributes required to implement existing OSPAR indicators compared to existing national plankton monitoring effort by OSPAR Arctic contracting parties. Existing Northeast Atlantic pelagic habitat indicators were found to be ecologically applicable to the Arctic, primarily due to flexibility of the plankton lifeforms and biodiversity indices indicators, that allow selection of regionally relevant lifeform pairs or species for assessment. However, current national monitoring programmes were found insufficient to support their implementation. Additional regionally-specific indicators, such as for sympagic phytoplankton and sea-ice biota, are worthy of consideration. Budgetary constraints and a lack of year-round sampling and long-term datasets were found to be key limitations in the implementation of plankton indicators for establishing GES.

1. Introduction

Marine ecosystem health and resilience can be monitored by investigating identifiable and measurable ecological properties which, in turn, can be used in the development of marine policy indicators and management frameworks [85]. The Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC) was adopted by the European Union (EU) in 2008, requiring EU Member States to maintain or achieve Good Environmental Status (GES) in their seas by 2020 [30]. The MSFD stipulates that management measures and actions should be based on an ecosystem-based management (EBM) approach [30]. The suite of 11 MSFD descriptors aims to deliver a holistic management approach, representative of the state and functioning of the whole marine ecosystem [8,9], through the establishment of environmental thresholds and monitoring of associated indicators to determine GES [58].

Plankton can be effectively employed in EBM monitoring programmes to assess environmental status of regional waters and changes resulting from anthropogenic and climate pressures [60] and are mandated by the MSFD in the indicative list of characteristics to be considered (2008/56/EC, Annex III, Table 1). Plankton are particularly well suited as indicators of environmental change due to their rapid response to changes in climate, hydrology and water quality [26,40,82], with phytoplankton biomass commonly adopted as an indicator of primary production as part of EBM monitoring [10]. As the ocean's major primary producers, phytoplankton are fundamental to the marine food web [56] and perform a number of ecological functions, such as the cycling of key nutrients [28,59]. Phytoplankton also provide anthropogenically important ecosystem services, generating 50% of the world's oxygen, playing a fundamental role in carbon cycling and affecting the success of fish populations via the food web [33,81]. Zooplankton grazing on nutrient-rich phytoplankton facilitates energy flow to higher trophic levels via zooplanktivorous fish [82].

The OSPAR Convention is a cooperative mechanism adopted by fifteen EU and European Economic Area Member States which is collaboratively implementing EBM in the Northeast Atlantic to meet MSFD requirements [69]. OSPAR acts as the Regional Seas Commission for five marine regions within the Northeast Atlantic, including Region 1 - the Arctic, Region 2 – the Greater North Sea, Region 3 – the Celtic Seas, Region 4 – the Bay of Biscay, and Region 5 – the wider Atlantic ([69]; Fig. 1). Pelagic habitat indicators, based on plankton data, have been developed for the Northeast Atlantic Regions (Regions 2, 3, and 4). The three indicators, PH1/FW5 Changes in functional types (plankton lifeforms), PH2 Plankton biomass and/or abundance, and PH3 Plankton biodiversity indices, relate to multiple MSFD descriptors, including Descriptor 1 - Biodiversity, Descriptor 4 - Food webs, and Descriptor 6 - Seabed integrity [60,61]. A key consideration in the development and

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Table 1
MFSD descriptors and indicators and their corresponding OSPAR indicators. ● indicates links specified by OSPAR's Intersessional Correspondence Group on Coordinated Biodiversity Assessment and Monitoring (ICG-COBAM), adapted from the 2015 report of the ICES Working Group on Biodiversity Science (WGBIODIV) [47].

		OSPAR indicators Pelagic habitats		
		PH1: Changes in phytoplankton and zooplankton communities	**PH2: Changes in phytoplankton biomass and zooplankton abundance**	**PH3: Plankton biodiversity indices**
MSFD Indicators	**Biodiversity**			
	1.4.1 Distributional range	●		
	1.4.2 Distributional patterns	●		
	1.6.1 Condition of the typical species and communities	●		
	1.6.2 Relative abundance and/or biomass		●	●
	1.7.1 Composition and relative proportions of ecosystem components (habitats and species)	●		●
	Foodwebs			
	4.3.1 Abundance trends of functionally important selected groups/species	●	●	
	Seabed Integrity			
	6.2.2 Multi-metric index assessing benthic community condition and functionality	●		

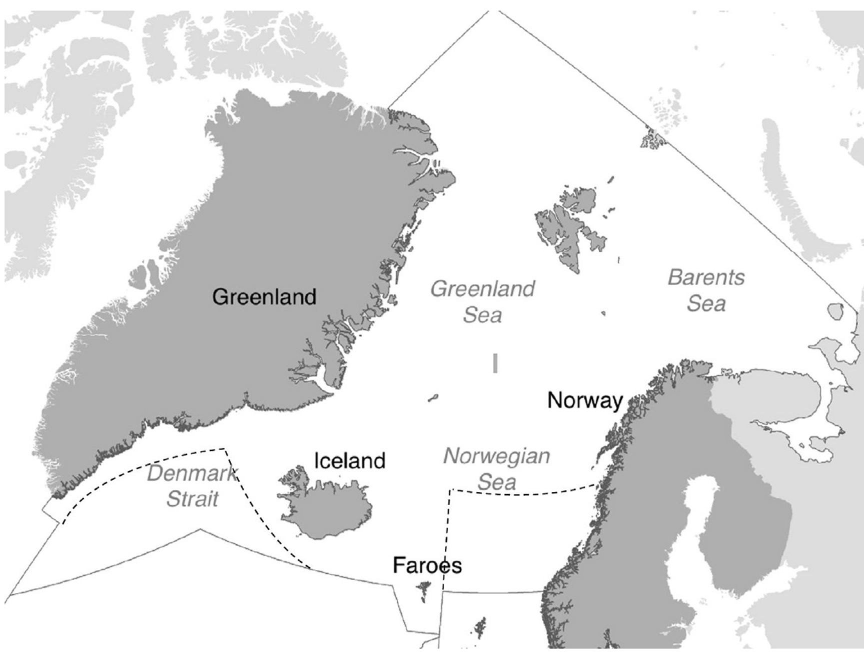

Fig. 1. Map showing the boundaries of OSPAR Region 1 (grey line) and an estimation of the boundary of the Arctic region as classified by Arctic Council working group Protection of the Arctic Marine Environment (PAME) (dotted line). Adapted from [69] ©OSPAR Commission.

implementation of marine policy indicators is regional ecosystem specificity [59]. The MSFD stipulates that *'the applicability of specific indicators related to the criteria may require consideration as to whether they are ecologically relevant to each situation being assessed'* ([31], Annex Part A, paragraph 7). Implementation of the MSFD will expand into the Arctic in the future, but it is unknown if the three plankton indicators, which have been developed and tested in the Northeast Atlantic Regions, will be ecologically applicable to the Arctic, which is characterised by complex temporal and spatial variability in ecohydrographic conditions [32,79,85].

The Arctic plankton community has some key differences from the Northeast Atlantic community. Sympagic (ice-associated) algae constitute up to 26% of total primary productivity in areas of seasonal ice cover [42], such as those found in the most northerly parts of the OSPAR Arctic region [53]. As in the Northeast Atlantic, *Calanus* copepod species are key components of the mesozooplankton biomass [7,15], with *Calanus finmarchicus* generally the most abundant across the region [48,68]. Lipid-rich Arctic species such as *Calanus hyperboreus* and *Calanus glacialis* also play an important role in the Arctic food web and become more abundant and account for increasing biomass in the more northern areas of the region [5,38,89].

Climate change is recognised as the greatest overall threat to Arctic ecosystems by both the IPCC et al. [49] and the Arctic Council [1] and is likely to affect Arctic plankton communities [80]. Changes in sea-ice retreat and seasonal ice melt will affect shade-adapted sympagic algal biomass which supports phytoplankton seeding and zooplankton grazing during the annual spring bloom in the marginal ice zone [42,53] and could result in decreased zooplankton abundance [4]. Further cascadal impact could affect commercial fisheries of major zooplankton grazers such as capelin (*Mallotus villosus*) and polar cod (*Boreogadus saida*), the latter having been reported at its lowest abundance level in the Barents Sea since 1990 [48]. Changes in circulation

Table 2
The eight lifeform pairs adopted for use as indicators for OSPAR pelagic habitat indicator PH1 in the Northeast Atlantic. (Source: [47,70]).

Lifeform pair	Ecological rationale
Diatoms and dinoflagellates	Dominance by dinoflagellates may be an indicator of eutrophication and result in less desirable food webs.
Gelatinous zooplankton and fish larvae/eggs	Indicator of energy flow and possible trophic pathways.
Holoplankton and meroplankton	Indicator of strength of benthic-pelagic coupling.
Large (< 20 µm) and small (< 20 µm) microphytoplankton	Size-based indicator of the efficiency of energy flow to higher trophic levels.
Microphytoplankton and non-carnivorous zooplankton	Indicator of energy flow and balance between primary producers and primary consumers.
Pelagic diatoms and benthic diatoms	Indicator of benthic disturbance and frequency of resuspension events.
Crustaceans and gelatinous zooplankton	Indicator of energy flow and possible trophic pathways.
Small (< 1.9 mm) copepods and large (> 2.0 mm) copepods	Size based indicator of food web structure and energy flows.

and the displacement of Arctic water by more temperate Atlantic water in the western Barents Sea have resulted in changes in plankton assemblages with different species compositions [57,68]. Such changes have also been reported in the Norwegian Sea at the Iceland-Faroe Front where *C. hyperboreus* has largely disappeared [52].

In recent decades, thawing of permafrost, glaciers and snow, along with levels of precipitation and river runoff, have been exacerbated by climate change [43,77]. Resulting increases in stratification can inhibit nutrient transfer, affecting plankton productivity [88]. In turn, changes in light attenuation due to shallower mixed layers can impact photosynthesis affecting primary production and biomass [18]. Annual net primary productivity has been increasing in the Arctic Ocean, on a region-wide scale, attributed to a longer open water season caused by sea ice retreat [3,4,74,80].

Unlike the Northeast Atlantic regions, Region 1 has a relatively low population of approximately 2.6 million, so impacts on the marine environment from human settlements are generally small and highly localised [73]. Offshore oil extraction, primarily in Norwegian waters, along with significant commercial fisheries throughout the region are the most significant, manageable anthropogenic pressures that may impact plankton communities (OSPAR Commission, 2016). Frank et al. [35,36] found that overfishing of large demersal fish populations led to a trophic cascade, negatively impacting zooplankton abundance. Copepods undergo physiological responses to ingested hydrocarbons from oil extraction [2] along with the potential for bioaccumulation [23].

Given the differences between the Northeast Atlantic and Arctic regions, in terms of plankton communities and the environmental and anthropogenic influences affecting them, the regional transferability of the existing OSPAR Northeast Atlantic pelagic habitat indicators must be reviewed for their applicability to Arctic marine ecosystems in the OSPAR region. This study aims to establish their applicability on two levels:

i) Can the existing indicators effectively identify changes in plankton functioning, composition, abundance and biomass in Arctic marine ecosystems in order to assess the environmental status of Arctic waters?
ii) Are the indicators implementable using existing national plankton monitoring programmes conducted by OSPAR Region 1 contracting parties?

2. Methods

2.1. OSPAR Region 1: Arctic

Region 1 represents approximately 40% of the total OSPAR maritime area (OSPAR Commission, 2016), with four littoral nations, Norway, Iceland, Greenland and Faroe Islands (Fig. 1). There are also three littoral states in the wider Arctic, outside Region 1, that are not OSPAR contracting parties - Canada, USA and Russia. Environmental conditions are harsh, with short, productive summers of high light penetration, followed by long winters of ice cover and low light, and seasonal changes in sea ice coverage [79].

2.2. Existing OSPAR plankton indicators in the Northeast Atlantic

As part of the first stage of MSFD implementation, OSPAR's Intersessional Correspondence Group on Coordinated Biodiversity Assessment and Monitoring (ICG-COBAM) has developed and adopted three pelagic habitat indicators (Table 1). ‘PH1/FW5 Changes in phytoplankton and zooplankton communities’ groups plankton taxa into ecologically-meaningful lifeform pairs; changes in relative abundance of lifeforms indicate changes in ecosystem functioning [60,61,70]. This indicator is also an MSFD food-web indicator. ‘PH2 Changes in phytoplankton biomass and zooplankton abundance’ uses indicators of phytoplankton biomass and copepod abundance to provide insight into plankton productivity while ‘PH3 Plankton biodiversity indices’ describes plankton community structure through changes in species evenness, dominance and richness [61,71,72]. Together, the suite of indicators offers insight into plankton function, productivity, and community structure [61].

2.2.1. PH1/FW5: Changes in functional types (plankton lifeforms)

Indicator PH1/FW5 (Pelagic Habitats 1/Food Webs 5; hereafter referred to as ‘PH1’ for brevity) uses abundances of plankton functional group, or lifeform, pairs to identify ecological change [60,61,70]. Functional, rather than species, diversity has been found to be a more preferable indicator of ecosystem resilience to pressure [24,40,62]. Changes in relative abundance between planktonic lifeform pairs can be indicative of external pressures that threaten ecosystem resilience [87]. Eight lifeform pairs are currently in use (Table 2) with one example the pairing of diatoms and dinoflagellates, whereby dominant abundance of dinoflagellates could indicate eutrophication, which could result in less desirable food webs [47,70].

2.2.2. PH2: Plankton biomass and/or abundance

As the ocean's main primary producers, phytoplankton biomass is linked to pelagic primary production [10], whilst zooplankton play a key role in energy transferal through the food web as the main consumer of phytoplankton and as the subject of predation by higher trophic levels [82]. PH2 uses phytoplankton biomass as an indicator of primary production. Copepod abundance has been selected as the indicator of zooplankton abundance due to their importance in energy transfer to higher trophic levels of the food web and their nearly-ubiquitous presence [47,71].

2.2.3. PH3: Plankton biodiversity indices

Biodiversity indices can simplify characterisation of ecosystem status, using species to quantify ecosystem health in relation to established baseline conditions [22]. Species are indexed in relation to their response to environmental changes in the environment and can highlight changes in structural aspects of species assemblages [22]. For example, impacts of water pollution may only affect the structure of assemblages or the abundance of a few species, rather than overall biomass or the ratio between functional groups [45] and changes in biodiversity indices can highlight where changes influenced by human pressures may be occurring [27]. PH3 uses indices of species richness

Table 3
OSPAR pelagic habitat indicators, listed with a description and the minimum data requirements to enable implementation.

OSPAR indicator	Description	Data attribute required	
		Phytoplankton	Zooplankton
PH1: Changes in phytoplankton and zooplankton communities	Change in relative abundance of lifeform pairs	Composition; abundance (genus level)	Composition; abundance (genus level)
PH2: Changes in phytoplankton biomass and zooplankton abundance	Total phytoplankton biomass; total copepod abundance	Chlorophyll concentration or other biomass/productivity proxy	Copepod abundance
PH3: Plankton biodiversity indices	Indices based on number of species and dominance in community	Species composition; species abundance (species level)	Species composition; species abundance (species level)

and dominance to detect changes in plankton diversity [72].

2.2.4. Implementation requirements of OSPAR pelagic habitat indicators

The implementation of PH1, PH3, and the copepod abundance portion of PH2 are dependent on two key data attributes - composition and abundance of both phytoplankton and zooplankton taxa (Table 3). Whilst PH1 and the copepod abundance of PH2 rely on genus level identification, PH3 is species dependent. Generating plankton taxonomic data suitable for use in EBM indicators usually requires taxonomic identification and enumeration via light microscopy, demanding a high level of expertise [61]. Analysis by light microscopy can be time-consuming and costly, but is the only widespread method of obtaining species-level plankton data [39,55]. Phytoplankton biomass for PH2 can be estimated using chlorophyll concentration from remote sensing or in situ sampling, but there are alternatives, such as the Continuous Plankton Recorder (CPR) Phytoplankton Colour Index (PCI), which has a > 80 year time-series at a wide spatial scale, or phytoplankton carbon from biovolume [47]. For these indicators to be operationalised, national plankton monitoring programmes must be able to support the acquisition of these data [75].

Seasonal, inter-annual, and decadal variability in the Arctic mean that long-term datasets are integral for the implementation of plankton indicators, both in terms of developing representative baselines and in distinguishing between large-scale influences resulting from hydrographic or climate driven changes and direct anthropogenic pressures that are manageable at an MSFD scale [29,58]. All three pelagic habitat indicators are dependent on year-round, monthly monitoring to provide sufficient data capturing features of natural or climate-driven variability, such as seasonal succession and the spring bloom, which could otherwise appear to be pressure-related [87].

2.3. Analysis

To expose gaps or potential improvements in the OSPAR pelagic habitat indicators in relation to their expansion into the Arctic, a meta-analysis of plankton indicators currently employed or recommended by Arctic littoral states was conducted. Meta-analysis offers the opportunity to combine evidence with the aim of detecting and addressing inconsistencies (Koricheva et al. [91]); existing scientific literature, legislative documentation and national and bilateral monitoring reports were consulted. The approach was divided into three stages.

2.3.1. Horrendogram

To establish the legislative EBM landscape, the national monitoring programmes and management strategies of all Arctic littoral states were first reviewed. This process provided a holistic overview of plankton monitoring and management across the Arctic region, enabling comparison between OSPAR contracting parties and the other, non-OSPAR Arctic states to identify gaps, synergies and inconsistencies in current practice. A 'horrendogram' (*sensu* Boyes and Elliot [11]), was created to illustrate the international, multilateral, bilateral and national legislation and cooperation that inform or support EBM in the Arctic region for all littoral Arctic states. The horrendogram visualises the organisation of current regulation, as well as multi- and bilateral cooperation in the Arctic region, to facilitate the gap analyses.

2.3.2. Gap analyses

An initial gap analysis compared the OSPAR pelagic habitat indicators with the plankton indicators currently recommended by the Arctic Council working group, the Conservation of Arctic Flora and Fauna (CAFF), in order to match synergies and identify any gaps. CAFF-recommended indicators, outlined in the Arctic Marine Biodiversity Monitoring Plan (AMBMP) [41], were used as the reference point as they are the result of cooperation from all Arctic Council member states via CAFF's Plankton Marine Expert Network (MEN). No defined plankton indicators were found for the USA or Russia. Canada, the only other non-OSPAR nation with an Arctic EEZ, has based their indicators on the AMBMP [17,76].

A second gap analysis was conducted to establish if the minimum data attributes (see Table 2) required to implement the OSPAR plankton indicators are being delivered in the existing national plankton monitoring programmes of each OSPAR contracting party within Region 1. No importance weighting was applied to individual attributes as each attribute is essential to the implementation of their respective indicators. Other factors included in the gap analysis included frequency of monitoring and availability of historical data for baselines.

2.3.3. Strengths, weaknesses, opportunities and threats (SWOT) analysis

A SWOT analysis was conducted to synthesise the two sets of gap analysis results into a holistic appraisal of the applicability of OSPAR Northeast Atlantic plankton indicators to the expansion of the MSFD to the Arctic region [46,75]. SWOT analysis enables synthesis of strengths, weakness, opportunities and threats to identify possible solutions to a given goal [37].

3. Results

3.1. The EBM landscape in the Arctic

EBM is largely implemented at a national scale in the Arctic (Fig. 2), but complex legislative commitments and cooperative mechanisms occur at international, multilateral and bilateral levels influencing EBM strategy (Fig. 3). At a national level, whilst all countries have EBM policies, only Canada was found to have published recommended plankton indicators (Fig. 2). None of the Arctic countries outside of the OSPAR region were found to have identified environmental status triggers for management action. Whilst there are some synergies between the national plankton monitoring programmes across the Arctic region, there is no consistent approach, even between the OSPAR contracting parties within Region 1, Norway, Iceland, Greenland and the Faroes (Fig. 2). As such, there is no clear consensus on EBM using plankton indicators in the region.

Whilst the Convention on Biological Diversity (CBD) (1993) and the United Nations Convention on the Law of the Sea (1982) provide overarching legislative commitments, on a region-specific pan-Arctic scale no such legislative commitments exist (Fig. 3). Consistency in scientific

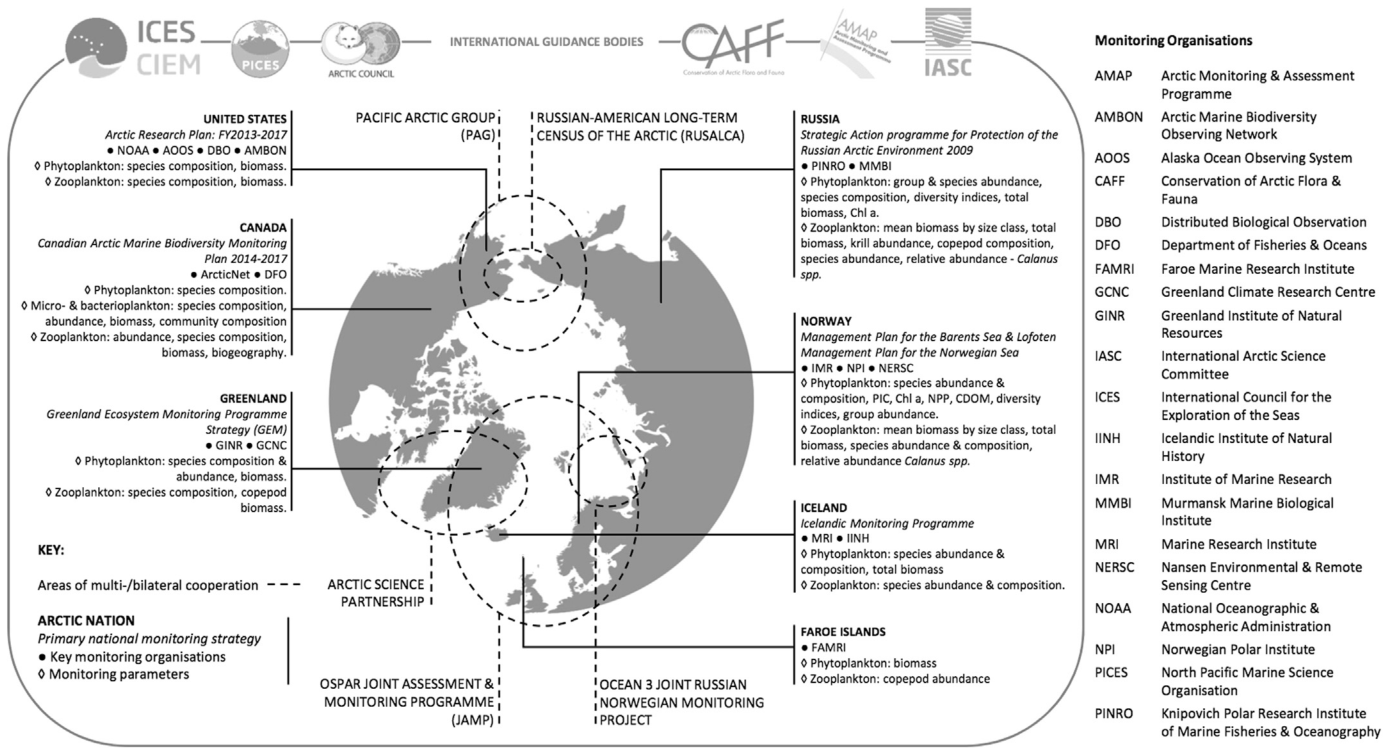

Fig. 2. Map showing national plankton monitoring programmes and multi-/bilateral cooperation. It should be noted that the lists of monitoring parameters at national level is not exhaustive and is restricted to those found in publicly available reports and databases. Not all parameters listed will necessarily be covered across all their respective national monitoring sites. (Sources: [15,41,50,53,57,65,66,76]).

guidance and recommendations emanates from the Arctic Council, as well as the International Arctic Science Committee (IASC) and the International Council for the Exploration of the Sea (ICES).

3.2. Gap analysis: OSPAR indicators and CAFF recommendations

The gap analysis between the OSPAR Northeast Atlantic pelagic habitat indicators and the plankton indicators recommended by the CAFF Plankton Marine Expert Network (MEN) (Table 4) highlighted several synergies. CAFF's phytoplankton productivity and community/group abundance could contribute to PH2, while CAFF's diversity indices could support PH3.

There are also a number of synergies between OSPAR PH1 and indicators recommended by CAFF, largely due to the flexibility of PH1, which can be tailored to accommodate regionally relevant lifeform pairs. CAFF indicator 'ratio small:large' could support PH1 as two of the 8 lifeform pairs currently adopted by OSPAR are size-based: small and large copepods and small and large phytoplankton. There is a distinction between the CAFF indicators, 'community/group abundance' and 'community/group biomass', and PH1 however, because CAFF does not specify the use of relative abundance of lifeform pairs but the use of time-series trends for isolated species or groups [17].

The flexibility of PH1, which enables the selection of regionally relevant functional groups or lifeforms as needed, means that additional pairs could be developed under PH1 to incorporate the other CAFF recommendations. For example, the importance of sympagic species in the Arctic is recognised by the existence of the CAFF Sea Ice Biota MEN, which recommends indicators relating specifically to sympagic (ice-dwelling) species (Table 5). Whilst OSPAR pelagic habitat indicators do not currently specifically identify sympagic species for analysis, the indicators do have some synergies with CAFF's, for example 'diatoms vs dinoflagellates' - PH1, and 'pelagic vs benthic diatoms' – PH1. Additionally, sympagic taxa could constitute an additional lifeform if PH1 were expanded to the Arctic. Sympagic phytoplankton taxa would also contribute to Arctic 'diversity indices' - PH3 and 'biomass indicators' - PH2.

Further taxonomic analysis of the monitoring samples or additional sampling methods required to deliver the three OSPAR pelagic habitat indicators, for example the identification and biomass of sympagic taxa, as recommended by the CAFF Sea Ice Biota MEN (Table 5), could help increase regional specificity of the indicators when applied to the Arctic. This suggests that the flexibility of the OSPAR indicators PH1, PH2 and PH3 have the potential to be regionally transferable and highly ecologically applicable to EBM in Region 1.

3.3. Gap analysis: OSPAR contracting parties monitoring programmes and minimum data requirements

All OSPAR contracting parties in Region 1 monitor phytoplankton biomass as part of their monitoring programmes and all monitor copepod abundance, except the Vardø North transect in the Barents Sea, Norway (for map, see Appendix A). However, none monitor on a monthly, year-round basis and so sampling frequency is insufficient to support PH2 in its current format.

Despite some gaps in information (Table 6), the analysis found that none of the national monitoring programmes in Region 1 are sufficient to support PH1 or PH3, which are dependent on monthly data. Monitoring at Rjipfjorden, Norway and Zackenberg, Greenland does not currently include phytoplankton species abundance, although is likely to be added to the latter site's programme in the future (T. Juul-Pedersen, pers. comm). Whilst all required parameters are currently monitored at both Iceland locations, and at Norway's Kongsfjorden and Fugløya-Bjørnøya, none of the sites are monitored on a monthly basis. Zooplankton samples are currently gathered at Vardø North, Norway, but they are not analysed to a sufficient taxonomic extent to fulfil the OSPAR indicators. All other Region 1 plankton monitoring locations were found to be insufficient in both frequency and the required data attributes to implement either PH1 or PH3 under existing monitoring.

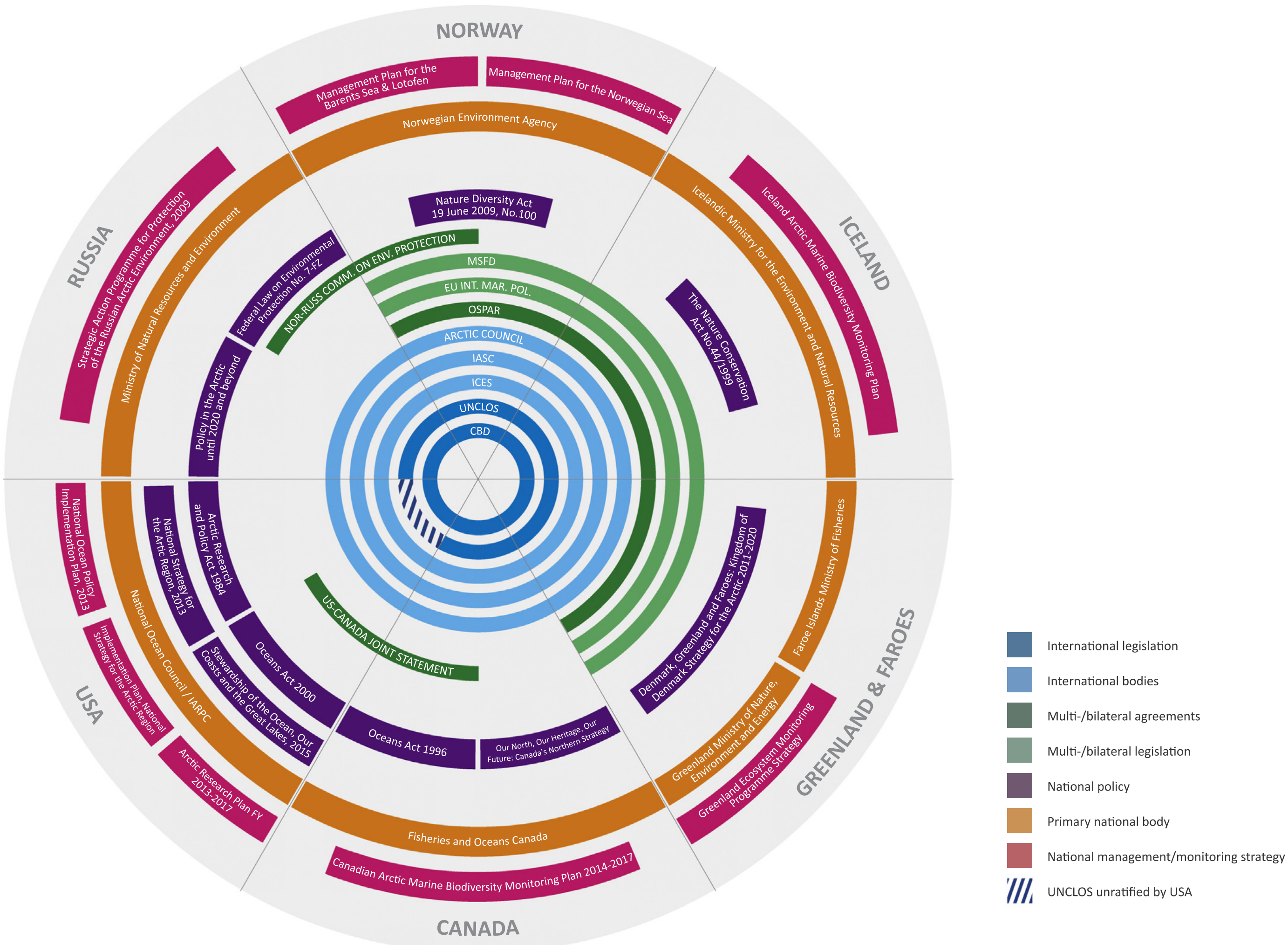

Fig. 3. Horrendogram illustrating international, multilateral, bilateral and national policy and cooperation influencing EBM strategies and management in the Arctic. Abbreviations: EU. Int. Mar. Pol. = EU Integrated Maritime Policy, NOR-RUSS Comm On Env. Protections = Norwegian-Russian Commission on Environmental Protection. (Sources: [67,41,11,50,53,57,64,68,76]).

As such, PH1 and PH3 cannot currently be supported.

No information was found for monitoring currently taking place in the eastern section of the Norwegian Sea, along the Norwegian coastline within Region 1. However, there is a national management plan in place for the area [67].

3.4. SWOT analysis

Synthesising the results of the two gap analyses, and placing them in the context of the pressures on Arctic plankton communities, highlighted several key points (Table 7). PH1, PH2 and PH3 were found to be ecologically applicable to Region 1, with synergies between the three

Table 4
Results of gap analysis between the OSPAR pelagic habitat indicators for the Northeast Atlantic and the CAFF recommended plankton indicators [41]. ● highlights where CAFF recommended plankton indicators could support the implementation of OSPAR indicators, subject to the selection of regionally relevant taxa.

		OSPAR indicators		
		PH1: Changes in phytoplankton and zooplankton communities	PH2: Changes in phytoplankton biomass and zooplankton abundance	PH3: Plankton biodiversity indices
CAFF Plankton MEN recommended indicators	Community/group abundance	●		
	Community/group biomass		●	
	Diversity indices			●
	Productivity		●	
	Ratio local: invasive	●		
	Ratio small: large	●		
	Size spectra abundance: size	●		
	Stage distribution	●		

Table 5
Synergies between OSPAR pelagic habitat indicators for the Northeast Atlantic and indicators recommended by the CAFF Sea Ice Biota MEN [41] that include planktonic species. ● highlights where CAFF recommended plankton indicators could support the implementation of OSPAR indicators, subject to the selection of regionally relevant taxa.

			OSPAR indicators		
	Focal Ecosystem Component	Indicator	PH1: Changes in phytoplankton and zooplankton communities	PH2: Changes in phytoplankton biomass and zooplankton abundance	PH3: Plankton biodiversity indices
CAFF Sea Ice Biota MEN recommended indicators	**Sea-ice protists: Diatoms, dinoflagellates, flagellates**	Distribution of Arctic v sub-Arctic species	●		
		Ratio diatoms: dinoflagellates	●		
		Ratio freshwater: marine algae	●		
		Ratio Arctic: sub-Arctic species	●		
		Diversity indices (e.g. Shannon, Simpson)			●
		Sea ice v phytoplankton biomass & productivity		●	
		Size structure of ice algae & phytoplankton communities	●		
		Biomass indicators (e.g. Chl a)		●	
	Sea-ice fauna: Interstitial & under-ice layer invertebrates	Distribution of Arctic v sub-Arctic species	●		
		Ratio Arctic: sub-Arctic species	●		
		Species invasion expatriates	●		
		Diversity indices (e.g. Shannon, Simpson)			●
		Partitioning sea ice v zooplankton biomass & productivity		●	

OSPAR indicators and many of the current CAFF-recommended indicators. The OSPAR indicators are inherently flexible enough that they can be adapted via the inclusion of regionally relevant taxa.

Existing sampling methods used by OSPAR contracting parties are generally sufficient to meet the relevant data attributes. However, samples from many transects are not currently analysed to a taxonomic level that would provide the required data and none are sampled at a monthly frequency. All existing OSPAR contracting parties in Region 1 monitor phytoplankton biomass and copepod abundance, the two parameters of PH2, with the only exception being that the Norwegian Vardø transects do not monitor the latter; but in-situ sampling, however, is not conducted on a monthly basis and is therefore temporally insufficient. Where satellite remote sensing (SRS) is employed, low sun elevation limits observations to the period between April and August and cloud coverage can reduce the amount of high quality data [53]. Key limiting factors were found to be low frequency of sampling across all monitoring programmes in Region 1; a lack of spatially extensive, long-term datasets; and budgetary constraints ([41], CBMP Marine Steering Group, 2015, [15]).

4. Discussion

4.1. State of the art: EBM and plankton monitoring in the Arctic region

The Arctic region is legislatively complex, with several countries having two or more policies, strategies and implementation plans in place. Since implementation of EBM is conducted at a national level, there lacks a consistent pan-Arctic approach, although advisory bodies such as ICES, IASC, PICES and the Arctic Council provide some consistency in terms of recommendations and guidelines for best practice.

No clear definition, or equivalent, of GES targets for non-OSPAR nations in the Arctic region (USA, Canada, Russia) was found. Non-OSPAR national plankton monitoring programmes are tracking ecosystem state, trends and change but there was no defined management structure or target thresholds to provoke management action, akin to MSFD GES. CAFF's 2011 AMBMP Monitoring Report 3 states that *'a threshold level to trigger management action is probably not relevant for indicators on phyto- and zooplankton'* ([41], p.128), however it does acknowledge the importance of time series data to establish a baseline reference state of *'a normal range of values'* ([41], p.128). In their 2017 State of the Art of Arctic Marine Biodiversity Report, however, CAFF do recommend that Arctic Council nations develop plankton '*species indexes and, if possible, identify taxa for monitoring*' ([15], p.8).

The current lack of clearly defined targets and indicators for plankton at a national level for non-OSPAR countries infers that the OSPAR contracting parties will be the only nations implementing an accountable management strategy. There is no legislative EBM obligation at a pan-Arctic level, so accountability is self-regulated at a national level, or at an international level under the Convention for Biological Diversity (CBD) and the United Nations Convention on the Laws of the Sea (UNCLOS) [90].

4.2. The applicability of OSPAR pelagic habitat indicators to OSPAR Region 1

EBM is particularly effective when expressed as the maintenance of ecosystem structure (e.g., biodiversity), functions (e.g., productivity) and processes (e.g., energy flow) [85], all aspects considered by the OSPAR pelagic indicators. Indicator PH1 was found to be ecologically applicable and relevant to Arctic ecosystems, primarily due to its flexibility in terms of the selection of lifeform pairs that are regionally relevant to assess the structure and function of plankton assemblages. However, consideration should be given to the drivers of change in lifeform pairs, for example the dominance of dinoflagellates over diatoms in the Northeast Atlantic may indicate eutrophication [47], but in the Arctic is likely to indicate changes in stratification resulting from

Table 6
Overview of gap analysis between OSPAR pelagic habitat monitoring requirements and the national monitoring programmes conducted by OSPAR contracting parties in Region 1. (Sources: [15,41,50,53,57,76]).

	Monitoring locations, by country						
	Faroe Islands	**Iceland**	**Greenland**	**Norway**			
	Faroe Shelf, Faroe North & South	Siglunes & Salvogsbanki	Zackenberg	Rjipfjorden	Kongsfjorden	Fugløya-Bjørnøya	Vardø North
Plankton lifeforms (PH-1) and Biodiversity indices (PH-3)							
Phytoplankton species composition	U	Y	Y	Y	Y	Y	Y
Phytoplankton species abundance	U	Y	N	N	Y	Y	Y
Zooplankton species composition	U	Y	Y	Y	Y	Y	A
Zooplankton species abundance	U	Y	Y	Y	Y	Y	A
Plankton biomass and/or abundance (PH-2)							
Phytoplankton biomass	Y	Y	Y	Y	Y	Y	Y
Copepod abundance	Y	Y	Y	Y	Y	Y	N
Monitoring frequency per year	1	1	1	1	1	5-6	2-4
Is monitoring sufficient to support OSPAR pelagic habitat indicators?	N	N	N	N	N	N	N
Comments	This area is also covered by the CPR.	Some CPR coverage.	Programme under review – phytoplankton species abundance likely to be added. Some CPR coverage.		Frequency of sampling varies annually.	Frequency and time of sampling varies annually.	Frequency and time of sampling varies annually.

Key:				
	Y	Meets requirement	A	Samples acquired but not taxonomically analysed
	N	Does not meet requirement	U	Unknown (information not found)

climate-driven increases in sea-ice and permafrost melt [51]. Phytoplankton biomass and copepod abundance for PH2 supports the monitoring of primary productivity and the process of energy transfer to higher trophic levels, while PH3 is similar to the current CAFF diversity index indicator.

The ratio of local:invasive species is CAFF recommended, though not included in the current suite of OSPAR pelagic indicators. This indicator, however, could manifest under MSFD Descriptor 2: non-indigenous species. Instances of non-native plankton species in the Arctic have been attributed to large-scale changes relating to hydrographic and climate-driven change, rather than direct anthropogenic introduction. For example, the appearance of the Pacific diatom *Neodenticula seminae* in the North Atlantic after 800,000 years has been attributed to sea-ice melt and increases in Pacific inflow to the Atlantic Arctic [78] and the northward expansion of more temperate plankton species, such as *C. finmarchicus,* although not strictly invasive, has been attributed to increasing sea temperature [19].

The potential impact of changes in sympagic algae biomass in the marginal ice zone should be considered when assessing Arctic planktonic ecosystem structure and function [34], particularly given sympagic algae can account for up to 26% of total primary productivity in areas of seasonal ice cover [42]. No consistent, on-going monitoring of sea-ice biota currently takes place by OSPAR contracting parties in Region 1 [12–15], or by non-OSPAR countries in the wider Arctic region [15,20]. Consequently, there is little information on status and trends [44] and conducting ice core sampling to establish Chlorophyll *a* concentrations, along with the subsequent lab analysis, is time-intensive and extraction is destructive [16]. However, non-invasive methods using wave-length specific transmitted irradiance to assess biomass have been explored in studies [16,54,63] and could provide an alternative method to facilitate the addition of an ice-algae biomass indicator in PH1 and as a contribution to PH2 in the future.

Another addition to PH2 that could increase regional specificity is the inclusion of copepod biomass. As the dominant mesozooplankton in the Arctic region, three species of *Calanus* make up 50–80% of the biomass [84] and are an integral part of the structure and function of the plankton community, as well as a major source of energy transferal in the pelagic lipid-based Arctic food web ([83]; Falk-Petersen, 2009; [84]). However, significant differences have been found in the relative abundance and biomass of the Atlantic-associated *C. finmarchicus*, and the lipid rich, Arctic-associated *C. hyperboreus* and *C. glacialis*. A study by Astthorsson and Gislason [5] on the East Icelandic Current found that, whilst *C. finmarchicus* was dominant in terms of abundance (approximately 75%) *C. hyperboreus* represented approximately 76% of the biomass. In light of this, the inclusion of copepod biomass to PH2 could be a valuable addition.

The primary focus of the MSFD is to achieve GES through the management of direct anthropogenic pressures [60]. Climate change is outside the MSFD's scope but is referred to as a 'prevailing condition' ([30], Annex 1, paragraph 1). Due to the complexity of hydrographic, climatic and anthropogenic influences, as well as regional specificity of plankton communities themselves, developing environmental indicators and implementing effective EBM can be challenging [6,21,58]. The ability to distinguish large-scale, hydrographic and climate change driven variability from anthropogenically-triggered, manageable change is key to establishing if MSFD GES has been achieved [58], a challenge which applies to Arctic pelagic habitats as well as those in the Northeast Atlantic.

Table 7
Strengths, weaknesses, opportunities and threats (SWOT) analysis synthesised results of both gap analyses.

Strengths	Weaknesses
• All OSPAR contracting parties in Region 1 have existing annual national plankton monitoring programmes, although there are considerable areas of coastal zone not monitored (Appendix A). • Only 5 data attributes are required to implement all 3 OSPAR pelagic habitat indicators: composition and abundance of phytoplankton and zooplankton (genus for PH1 and PH2 copepod abundance, species for PH3), and phytoplankton biomass. • All countries currently monitor phytoplankton biomass (part of PH2), although methods differ: in situ sampling, remote sensing, and Continuous Plankton Recorder Phytoplankton Colour Index (PCI). • PH1 is highly flexible and lifeform pairs can be selected to ensure regional specificity and relevance. • PH3, biodiversity indices, has the flexibility to accommodate regionally significant species. • OSPAR pelagic habitats indicators have synergies with many CAFF recommended indicators, although not all are directly comparable (e.g. PH1 and CAFF's Community/group abundance).	• Low frequency of sampling means that current monitoring provides insufficient data to effectively implement OSPAR pelagic habitat indicators and will not account for seasonal variability. • Lack of spatially extensive, multi-decadal time series across Region 1 to support development of baseline conditions and facilitate the distinction between localised, manageable pressures and seasonal, inter-annual and decadal variability. • Sympagic (ice-dwelling) taxa are not currently represented in the OSPAR pelagic habitat indicators, but could be a included in PH2 as part of phytoplankton biomass or in PH1 as a lifeform. • Inconsistencies in monitoring frequency and taxonomic analysis across Region 1 makes trans-boundary comparison challenging. • PH2 currently does not feature zooplankton biomass. *Calanus* spp., play an integral role in energy transfer but abundance is not necessarily representative of biomass in lipid rich Arctic species. • Some national monitoring programmes do not analyse all samples to a sufficient taxonomic level, for example, zooplankton on some Norwegian transects.
Opportunities	**Threats**
• Where the sampling methods of OSPAR contracting parties' monitoring programmes were identified, they are sufficient to fulfil the pelagic habitat indicator data requirements if additional taxonomic analysis is applied. • Expansion of the MSFD into OSPAR Region 1 could provide an opportunity to review monitoring strategies at a region-wide level. An attempt to bridge inconsistencies and develop a standardised approach to sampling and analysis methods and indicator implementation could enhance comparability between datasets at the regional level. • The CPR currently operates in some areas of Region 1, but exploring the potential for expansion of coverage could increase geographical spread of monitoring and progress regional coherence and interoperability with the Northeast Atlantic region. • The flexibility of PH1 and PH3 allows for the incorporation of regionally-specific taxa, creating synergies with CAFF. • Spatial implementation of the pelagic indicators in the Northeast Atlantic occurs over ecohydrodynamic zones; a similar approach in Region 1 would account for the ecoheterogeneity of the Arctic.	• Low sampling frequency could undermine EBM effort, particularly when considering the need for sufficient datasets to set baseline conditions for GES and to distinguish seasonal variability and large-scale change from manageable anthropogenic pressures. • Monitoring is often dependent on weather and access conditions, particularly further north where sea-ice cover, harsh conditions, and dark winters make transects inaccessible. • Budgetary constraints are widely cited as a limiting factor for expanding and, in some cases, sustaining monitoring effort at a national level. • Taxonomic analysis, required for PH1, PH3 and the copepod abundance indicator in PH2, is resource intensive and requires a high level of expertise. • Low spatial coverage of monitoring in Region 1 will make implementation of EBM challenging at a sub-regional scale defined by ecohydrodynamic zones. • Baselines or reference states are likely to require frequent review, as climate change impacts increase, to support differentiation between climate driven change and changes in plankton state resulting from anthropogenic pressures.

4.3. Challenges to implementation

Whilst the Northeast Atlantic OSPAR pelagic habitat indicators were found to be ecologically applicable to Region 1, there are a number of critical factors that could hinder their implementation. On a practical level, although the current sampling methods of all OSPAR Region 1 national plankton monitoring programmes are sufficient to facilitate delivery of the data attributes required for PH1, 2 and 3, sampling frequency is currently insufficient across all programmes. Currently, only Norway conducts consistent national plankton monitoring more frequently than once per year, although their Barents Sea transects are restricted to between four to six times annually. Monitoring is often dependent on weather and access conditions [53], which proves particularly restrictive in areas of seasonal sea ice and the, often harsh, maritime conditions in the region can be prohibitive. As implementation of the pelagic habitat indicators is dependent on monthly, year-round monitoring [70] none of the monitoring programmes of OSPAR contracting parties in Region 1 can currently support their implementation. As year-round monitoring may be unachievable in areas where the pelagic habitat is seasonally icebound, testing of the current OSPAR pelagic indicators for adaptation for use only during ice-free conditions ($<$ 12 months per year of samples) could be explored. Infrequency of monitoring also poses challenges when trying to establish baseline or reference conditions by which to establish GES since natural variability, as well as long-term, large scale changes, that may not be captured or represented [87].

Deficits in funding available for research and on-going monitoring in the Arctic region are a major concern ([41]; CBMP Marine Steering Group, 2015; [15]), particularly given the importance of long-term datasets, and could hinder the implementation of the Northeast Atlantic OSPAR pelagic habitat indicators in Region 1. The Arctic Council's Task Force on Arctic Marine Cooperation (TAFMC) has committed to exploring the potential for a central research fund, contributed to by Arctic member states and, potentially, international funding [86] but, to date, no solution to this financial challenge has been agreed. Securing committed, long-term financing of plankton monitoring will be a cornerstone in ensuring effective EBM implementation in the region.

The high cost, time demand and level of expertise required for taxonomic identification, which is fundamental for the implementation of PH1 and 3, could prove to be a barrier to increasing the frequency, or expanding the geospatial coverage of, existing national plankton monitoring programmes. In a report from the Joint Russian-Norwegian Monitoring Project it was stated that, whilst zooplankton samples had been retrieved along the North Vardø transect for the purpose of species composition and abundance analysis, species identification has not been completed due to insufficient resource [53].

5. Conclusion and recommendations

Overall the Northeast Atlantic OSPAR pelagic habitat Indicators were found to be ecologically applicable to the regional specificity of OSPAR Region 1, the Arctic, and are expected to be able to effectively identify changes in plankton structure, function and productivity. PH1 and PH3 have the flexibility to include regionally-relevant lifeform pairs and indicator species that can be selected based on priorities at a local level. PH2 is already monitored by all nations as phytoplankton biomass on all national monitoring transects and copepod abundance on all but two Barents Sea transects. The addition of copepod biomass and sympagic algal biomass could enhance regional specificity although neither are currently monitored by OSPAR contracting parties in Region 1.

Whilst, theoretically, the Northeast Atlantic OSPAR pelagic habitat indicators are ecologically applicable in Region 1, the reality of existing national monitoring programmes means that they cannot be implemented without significant increases in sampling frequency. Lack of funding and resource are the key factors prohibiting expansion, although harsh environmental conditions also restrict year-round monitoring in many areas.

The efficacy of any OSPAR plankton indicators in the Arctic will be dependent upon the ability to distinguish likely causality, by identifying significant correlations between changes in plankton status and anthropogenic pressures versus natural variability or climate driven influences [58]. The lack of frequent monitoring and long-term datasets pose significant challenges in the development of effective baselines to facilitate the assessment of MSFD GES.

5.1. Recommendations

- Further investigation of on-going plankton monitoring programmes is merited as the lack of transparency in monitoring plan reporting makes a fully comprehensive review of coverage and implementation challenging. Developing a centralised catalogue of programmes, sampling methods and frequency could support development of a regionally consistent approach to plankton monitoring and EBM implementation.
- Geospatial coverage of monitoring is limited and inconsistent. To optimise monitoring efficacy, consideration should be given to a regional approach based on ecohydrodynamic zones, as is consistent with OSPAR Northeast Atlantic implementation [70]. Consideration should also be given to supporting the expansion of CPR coverage in Region 1 for use in national monitoring, which would increase consistency and intercomparability between the Northeast Atlantic and Arctic.
- A full review of sampling and monitoring not reported at a national level may highlight additional datasets for use in establishing baselines and reference states.
- Technological advances, such as the Australian Antarctic Division's 2015 expedition to test the use of remotely operated underwater vehicles (ROVs) in measuring ice algae within fast ice [25], could provide more cost effective solutions to current challenges in sampling and may merit further investigation.

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Declarations of interest

None

Appendix A. Locations of national plankton monitoring transects in OSPAR Region 1

See Fig. A1

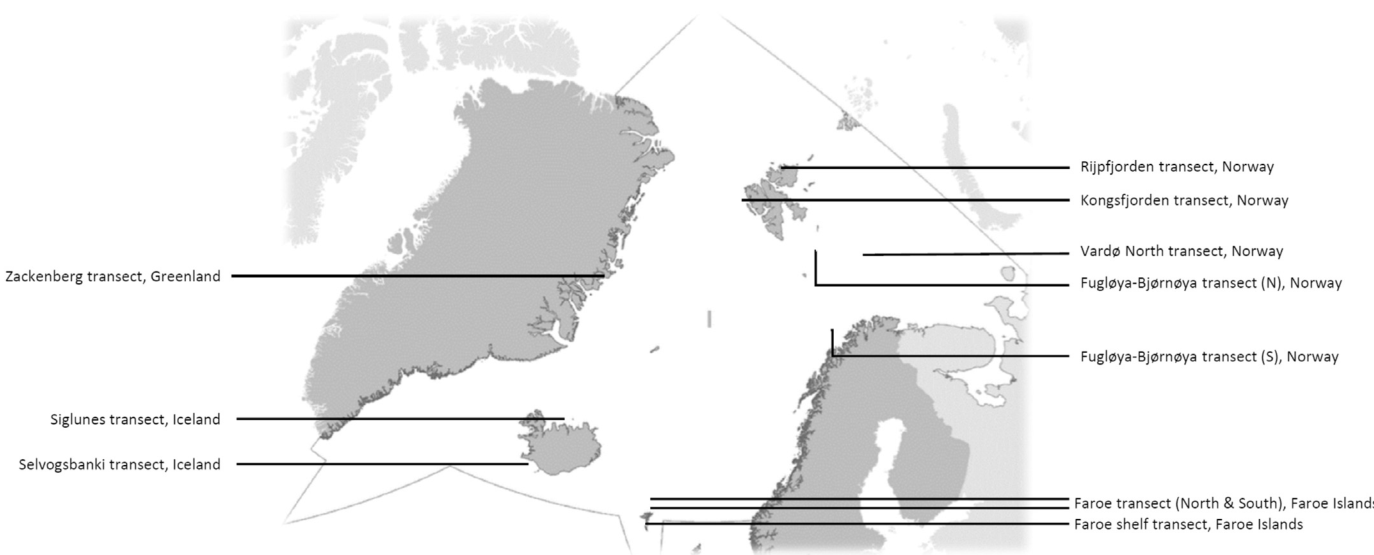

Fig. A1. Map highlighting approximate positions of national monitoring transects in OSPAR Region 1. Map adapted from [69]. (Locations sourced from [65]).

References

[1] ACIA, Arctic Climate Impact Assessment, Cambridge University Press, Cambridge, UK, 2005, p. 1042.
[2] R. Almeda, S. Baca, C. Hyatt, E.J. Buskey, Ingestion and sublethal effects of physically and chemically dispersed crude oil on marine planktonic copepods, Ecotoxicology 23 (6) (2014) 988–1003.
[3] K.R. Arrigo, G. van Dijken, Secular trends in Arctic Ocean net primary production, J. Geophys. Res. 116 (2011) C09011, https://doi.org/10.1029/2011JC007151.
[4] K.R. Arrigo, G. van Dijken, S. Pabi, Impact of shrinking Arctic ice cover on marine primary production, Geophys. Res. Lett. 35 (2008) L19603, https://doi.org/10.1029/2008GL035028.
[5] O.S. Astthorsson, A. Gislason, Seasonal variations in abundance, development and vertical distribution of *Calanus finmarchicus, C. hyperboreus* and *C. glacialis* in the East Icelandic current, J. Plankton Res. 25 (7) (2003) 843–854.
[6] G. Beaugrand, Monitoring marine plankton ecosystems. I: description of an ecosystem approach based on plankton indicators, Mar. Ecol. Prog. Ser. 269 (2004) 69–81.
[7] K. Blachowiak-Samolyk, J.E. Søreide, S. Kwasniewski, A. Sundfjord, H. Hop, S. Falk-Petersen, E.N. Hegseth, Hydrodynamic control of mesozooplankton abundance and biomass in northern Svalbard waters (79–81 degrees N), Deep-Sea Res. Pt II 55 (2008) 2210–2224.
[8] A. Borja, S.B. Bricker, D.M. Dauer, N.T. Demetriades, J.G. Ferriera, A.T. Forbes, P. Hutchings, X. Jia, R. Kenchington, J.C. Marques, C. Zhu, Overview of integrative tools and methods in assessing ecological integrity in estuarine and coastal systems worldwide, Mar. Pollut. Bull. 56 (2008) 1519–1537.
[9] A. Borja, M. Elliott, J. Carstensen, A.-S. Heiskanen, W. van de Bund, Marine management – towards an integrated implementation of the European marine strategy framework and the water framework directives, Mar. Pollut. Bull. 60 (2010) 2175–2186.
[10] A. Borja, M. Elliot, J.H. Anderse, T. Berg, J. Carstensen, B.S. Halpern, A.-S. Heiskanen, S. Korpinen, J.S. Stewart Lowndes, G. Martin, N. Rodrigues-Ezpeleta, Overview of integrative assessment of marine systems: the ecosystem approach in practice, Front. Mar. Sci. 3 (20) (2016), https://doi.org/10.3389/fmars.2016.00020.
[11] S.J. Boyes, M. Elliot, Marine legislation - the ultimate 'horrendogram': International law, European directive and national implementation, Mar. Pollut. Bull. 86 (2014) 39–47.
[12] CAFF, Arctic Marine Biodiversity Monitoring Plan, Greenland, 2013 Implementation, Published by CAFF, Iceland, 2013, p. 2.
[13] CAFF, Arctic Marine Biodiversity Monitoring Plan, Iceland, 2015 Implementation, Published by CAFF, Iceland, 2015, p. 2.
[14] CAFF, Arctic Marine Biodiversity Monitoring Plan, Norway, 2015 Implementation, Published by CAFF, Iceland, 2015, p. 2.
[15] CAFF, State of the Arctic Marine Biodiversity Report, Conservation of Arctic Flora and Fauna International Secretariat, Akureyri, Iceland, 2017, pp.195.
[16] K. Campbell, C.J. Mundy, D.G. barber, M. Gosselin, Remote estimates of ice algae biomass and their response to environmental conditions during spring melt, Arctic 67 (3) (2014) 375–387.
[17] Canadian Science Advisory Secretariat, Science Advice for Identifying Indicators for Monitoring Arctic Marine Biodiversity in Canada [Science Advisory Report 2012/053], Fisheries and Oceans Canada, 2012, pp. 22.
[18] A. Charalampopoulou, A.J. Poulton, T. Tyrrell, M.I. Lucas, Irradiance and pH affect coccolithophore community composition on a transect between the North Sea and the Arctic Ocean, Mar. Ecol. Progress. Ser. 431 (2011) 25–43.
[19] G. Chust, C. Castellani, P. Licandro, L. Ibaibarriaga, Y. Sagarminaga, X. Irigoien, Are *Calanus* spp. shifting poleward in the North Atlantic? A habitat modelling approach, ICES J. Mar. Sci. 71 (2014) 241–253.
[20] Circumpolar Biodiversity Monitoring Program (CBMP) Marine Steering Group, Arctic Marine Biodiversity Monitoring Plan Annual Plan 2014: Annual Report on the Implementation of the Circumpolar Biodiversity Monitoring Program's Arctic Marine Biodiversity Monitoring Plan (CBMP-Marine Plan), CAFF Monitoring Report No.15. CAFF International Secretariat, Akureyri, Iceland, 2015.
[21] A. Clarke, C.M. Harris, Polar marine ecosystems: major threats and future change, Environ. Conserv. 30 (2003) 1–25.
[22] F.E. Culhane, R./A./ Briers, P. Tett, T.F. Fernandes, Structural and functional indices show similar performance in marine ecosystem quality assessment, Ecol. Indic. 43 (2014) 271–280.
[23] K.L. Daly, U. Passow, J. Chanton, D. Hollander, Assessing the impacts of oil-associated marine snow formation and sedimentation during and after the Deepwater Horizon oil spill, Anthropocene 13 (2016) 18–33.
[24] V.N. de Jonge, Toward the application of ecological concepts in EU coastal water management, Mar. Pollut. Bull. 55 (2007) 407–414.
[25] Department for the Environment and Energy Measuring Algae in the Fast Ice: Research Blog, 2015. Available online at: 〈http://www.antarctica.gov.au/science/climate-processes-and-change/oceans-and-marine-ice-in-the-southern-hemisphere/measuring-algae-in-the-fast-ice-research-blog〉 (Accessed 28 August 2016).
[26] M. Devlin, J. Barry, S. Painting, M. Best, Extending the phytoplankton tool kit for the UK Water Framework Directive: indicators of phytoplankton community structure, Hydrobiologia 633 (2009) 151–168.
[27] H. Doi, K.-H. Chang, Y. Nishibe, H. Imai, S. Nakano, Lack of congruence in species diversity indices and community structures of planktonic groups based on local environmental factors, PLoS One 8 (7) (2013), https://doi.org/10.1371/journal.pone.0069594.
[28] R.B. Domingues, A. Barbosa, H. Galvão, Constraints on the use of phytoplankton as a biological quality element within the Water Framework Directive in Portuguese waters, Mar. Pollut. Bull. 56 (2008) 1389–1395.
[29] M. Edwards, G. Beaugrand, G.C. Hays, J.A. Koslow, A.J. Richards, Multi-decadal oceanic ecological datasets and their application in marine policy and management, Ecol. Evol. 25 (2010) 602–610.
[30] European Commission, Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008, Establishing A Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive), 2008.
[31] European Commission, European Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (2010/477/EU), 2010.
[32] S. Falk-Petersen, P. Mayzaud, G. Kattner, J.R. Sargent, Lipids and life strategy of Arctic Calanus, Mar. Biol. Res. 5 (1) (2009) 18–39, https://doi.org/10.1080/17451000802512267.
[33] P.G. Falkowski, M.E. Katz, A.H. Knoll, A. Quigg, J.A. Raven, O. Schofield, F.J.R. Taylor, The evolution of modern eukaryotic phytoplankton, Science 305 (5682) (2004) 354–360.
[34] M. Fortier, L. Fortier, C. Michel, L. Legendre, Climatic and biological forcing of the vertical flux of biogenic particles under seasonal Arctic sea ice, Mar. Ecol. Prog. Ser. 225 (2002) 1–16.
[35] K.T. Frank, B. Petrie, J.S. Choi, W.C. Legget, Trophic cascades in a formerly cod-dominated ecosystem, Science 308 (5728) (2005) 1621–1623.
[36] K.T. Frank, B. Petrie, J.A.D. Fisher, W.C. Legget, Transient dynamics of an altered large marine ecosystem, Nature 477 (2011) 88–89.
[37] L.C. Freire-Gibb, R. Koss, P. Margonski, N. Papadopoulou, Governance strengths and weaknesses to implement the marine strategy framework directive in European waters, Mar. Policy 44 (2014) 172–178.
[38] T.M. Gabrielsen, B. Markel, J.E. Soeride, E. Johansson-Karlsson, A. Bailey, D. Vogedes, H. Nygard, O. Varpe, J. Berge, Potential misidentifications of two climate indicator species of the marine Arctic ecosystem: *Calanus galacialis* and *C. finmarchicus*, Polar Biol. 35 (11) (2012) 1621–1628.
[39] I. Gallego, T.A. Davidson, E. Jeppesen, C. Perez-Martinez, P. Sanchez-Castillo, M. Juan, F. Fuentes-Rodriguez, D. León, D. Peñalva, J. Toja, J.J. Casas, Taxonomic or ecological approaches? Searching for phytoplankton surrogates in the determination of richness and assemblage composition in ponds, Ecol. Indic. 18 (2012) 575–585.
[40] M. Garmendia, A. Borja, J. Franco, M. Revilla, Phytoplankton composition indicators for the assessment of eutrophication in marine waters: present state and challenges within the European directives, Mar. Pollut. Bull. 66 (2013) 7–16.
[41] M.J. Gill, K. Crane, R. Hindrum, P. Arneberg, I. Bysveen, N.V, N.V. Denisenko, V. Gofman, A. Grant-Friedman, G. Gudmundsson, R.R. Hopcroft, K. Iken, A. Labansen, O.S. Liubina, I.A. Melnikov, S.E. Moore, J.D. Reist, B.I. Sirenko, J. Stow, F. Ugarte, D. Vongraven, J. Watkins, Arctic Marine Biodiversity Monitoring Plan (CBMP-MARINE PLAN), CAFF Monitoring Series Report No.3, April 2011, CAFF International Secretariat, Akureyri, Iceland. , 2011, pp.138.
[42] R. Gradinger, Sea-ice algae: major contributors to primary production and algal biomass in the Chukchi and Beaufort Seas during May/June 2002, Deep Sea Res. Part II: Top. Stud. Oceanogr. 56 (17) (2009) 1201–1212.
[43] C.H. Greene, A.J. Pershing, T.M. Cronin, N. Ceci, Arctic climate change and its impacts on the ecology of the North Atlantic, Ecology 89 (Suppl. 11) (2008) S24–S38.
[44] H. Hop, B.A. Bluhm, M. Daase, R. Gradinger, M. Poulin Arctic Sea Ice Biota., Arctic Report Card: Update for 2013, 2013. Available online at: 〈http://www.arctic.noaa.gov/report13/sea_ice_biota.html〉 (Accessed 3 August 2016).
[45] Y.-J. Huang, Z. Jiang, J. Zeng, X.-Q. Xu, The chronic effects of oil pollution on marine phytoplankton in a subtropical bay, China, Environ. Monit. Assess. 176 (1–4) (2011) 517–530.
[46] ICES OSPAR Special Request on Review of the Technical Specification and Application of Common Indicators under D1, D2, D4 and D6, ICES Advice 2013, Book 1 [Special request, Advice June 2013] 2013, pp. 14.
[47] ICES. Report of the Working Group on Biodiversity Science (WGBIODIV), 9–13 February 2015, ICES Headquarters, Copenhagen, Denmark. ICES CM2015/SSGEPD:04, 2015. pp. 308.
[48] ICES. Barents Sea Ecosystem Overview. ICES Advice 2016, Book 9, Version 2, 13 May 2016. Available online at: 〈http://www.ices.dk/community/advisory-process/Pages/Ecosystem-overviews.aspx〉 (accessed on 23 June 2016).
[49] IPCC, Climate Change 2014: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, in: Core Writing Team, R.K. Pachauri, L.A. Meyer (eds.), IPCC, Geneva, Switzerland, 2014, pp.151.
[50] L.M. Jensen, T.R. Christensen, N.M. Schmidt(eds.), Zackenberg Ecological Research Operations 19th Annual Report, 2013. Aarhus University, DCE – Danish Centre for Environment and Energy, 2014 pp. 130.
[51] R. Klais, T. Tamminen, A. Kremp, K. Spilling, K. Olli, Decadal-scale changes of dinoflagellates and diatoms in the anomalous Baltic Sea spring bloom, PLoS One 6 (6) (2011) e21567, https://doi.org/10.1371/journal.pone.0021567.
[52] I. Kristiansen, E. Gaard, H. Hátún, S. Jónasdóttir, S.A. Ferreira, Persistent shift of Calanus spp. In the southwestern Norwegian Sea since 2003, linked to ocean climate, ICES J. Mar. Sci. 73 (5) (2016) 1319–1329.
[53] O. Korneev, O. Titov, G.I. van der Meeren, P. Arneberg, J. Tchernova, N.M. Jorgensen Final report 2012–2015: Joint Russian-Norwegian Monitoring Project - Ocean 3, Brief Report Series/Kortrapport no. 30. Norwegian Polar Institute, Norway, 2015, pp. 408.
[54] L. Legendre, M. Gosselin, In situ spectroradiometric estimation of microalgal biomass in first-year sea ice, Polar Biol. 11 (2) (1991) 113–115.
[55] F. Lugoli, M. Garmendia, S. Lehtinen, P. Kauppila, S. Moncheva, M. Revilla, L. Roselli, N. Slabakova, V. Valencia, K.M. Dromph, A. Bassett, Application of a new multi-metric phytoplankton index to the assessment of ecological status in marine and transitional waters, Ecol. Indic. 23 (2012) 338–355.
[56] E. Marquis, N. Niquil, A.F. Vézina, P. Petitgas, C. Dupuy, Influence of planktonic foodweb structure n a system's capacity to support pelagic production: an inverse analysis approach, ICES J. Mar. Sci. 68 (5) (2011) 803–812.
[57] M.M. McBride, J.R. Hansen, O. Korneev, O. Titov, O. (eds.), J.E. Stiansen, J. Tchernova, A. Filin, A. Ovsyannikov (Co-eds.), Joint Norwegian - Russian

Environmental Status 2013, Report on the Barents Sea Ecosystem, Part II - Complete Report, IMR/PINRO Joint Report Series, vol. 2016 (2), 2016, pp. 359.
[58] A. McQuatters-Gollop, Challenges for implementing the Marine Strategy Framework Directive in a climate of macroecological change, Philos. Trans. R. Soc. A 370 (1980) (2012) 5636–5655.
[59] A. McQuatters-Gollop, A.J. Gilbert, L.D. Laurence, J.E. Vermaat, Y. Artioli, C. Humborg, F. Wilff, How well do ecosystem indicators communicate the effects of anthropogenic eutrophication? Estuar. Coast. Shelf Sci. 82 (2009) 583–596.
[60] A. McQuatters-Gollop, M. Edwards, P. Helaouët, D.G. Johns, N.J.P. Owens, D.E. Raitsos, D. Schroeder, J. Skinner, R.F. Stern, The continuous plankton recorder survey: how can long-term phytoplankton datasets contribute to the assessment of good environmental status? Estuar. Coast. Shelf Sci. 162 (2015) 88–97.
[61] A. McQuatters-Gollop, Johns, G. David, E. Bresnan, J. Skinner, I. Rombouts, R.F. Stern, A. Aubert, M. Johansen, A. Knights, From microscope to management: the critical value of plankton taxonomy to marine policy and biodiversity conservation, Mar. Policy 83 (2017) 1–10.
[62] D. Mouillot, S. Spartharis, S. Reizopoulou, L. Sabetta, A. Bassett, T. Do Chi, Alternatives to taxonomic-based approaches to assess changes in transitional water communities, Aquat. Conserv.: Mar. Freshw. Ecosyst. 16 (2006) 469–482.
[63] C.J. Mundy, J.K. Ehn, D.G. Barber, C. Michel, Influence of snow cover and algae on the spectral dependence of transmitted irradiance through Arctic landfast first-year sea ice, J. Geophys. Res. 112 (2007) C03007, https://doi.org/10.1029/2006JC003683.
[64] National Ocean Council, National Ocean Policy Implementation Plan, 2016. Available online at: 〈https://www.whitehouse.gov/administration/eop/oceans/implementationplan〉 (Accessed on 25 May 2016).
[65] NOAA , Time Series Metabase, 2016. Available Online at: 〈http://www.st.nmfs.noaa.gov/copepod/time-series/index.html〉 (Accessed 13 June 2016).
[66] NOAA Fisheries, Ecosystem Monitoring and Assessment Programme, 2016. Available Online at: 〈http://www.afsc.noaa.gov/ABL/EMA/EMA_default.php〉 (Accessed 19 June 2016).
[67] Norwegian Ministry of the Environment Integrated management of the marine environment of the Norwegian Sea, Report No, 37 (2008–2009) Report to the Storting (white paper), 2009, pp. 151.
[68] Norwegian Ministry of the Environment. Update of the integrated management plan for the Barents Sea-Lofoten area including an update of the delimitation of the marginal ice zone, Meld, St. 20 (2014–2015) Report to the Storting (white paper), 2015, pp. 55.
[69] OSPAR Map of OSPAR Region 1, 2016. Available from 〈http://www.ospar.org/convention/the-north-east-atlantic〉 (Accessed 25 May 2016).
[70] OSPAR , Changes in Phytoplankton and Zooplankton Communities, Intermediate Assessment 2017, 2017a. Available at: 〈https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/habitats/changes-phytoplankton-and-zooplankton-communities/〉.
[71] OSPAR , Changes in Phytoplankton Biomass and Zooplankton abundance, Intermediate Assessment 2017, 2017b. Available at: 〈https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/habitats/plankton-biomass/〉.
[72] OSPAR Changes in Plankton Diversity, Intermediate Assessment 2017, 2017c. Available at: 〈https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/habitats/pilot-assessment-changes-plankton/〉.
[73] OSPAR Commission, Region 1: Arctic Waters, 2015. Available Online at: 〈http://www.ospar.org/convention/the-north-east-atlantic/i〉 (Accessed on 12 April 2016).
[74] S. Pabi, G.L. van Dijken, K.R. Arrigo, Primary production in the Arctic Ocean, J. Geophys. Res. 113 (2008) C08005 (DOI: 10/1029/2007JC004578).
[75] J. Patricio, S. Little, K. Mazik, S. Thomson, N. Zampoukas, H. Teixeira, O. ,M.C. Uyarra, N. Papadopoulou, G. Kaboglu, M. Bucas, T. Churilova, O. Kryvenko, S. Moncheva, K. Stefanova, A. Borja, M. Alvarez, A. Zenetos, C. Smith, A. Zaiko, R. Danovaro, L. Caruganti, M. Elliott, Report on SWOT Analysis of Monitoring (Deliverable 1.4), Technical report by DEVOTES for the European Commission, 2014, pp. 105.
[76] C. Pomerleau, J.M. Watkins, P. Archambault, K. Conlan, S. Ferguson, G. Gilchrist, K. Hedges, L. Loseto, C. Lovejoy, C. Michel, R.J. Nelson, M. Poulin, E. Richardson, G. Robertson, J. Stow. Canadian Arctic Marine Biodiversity Plan 2014–2017. Canadian Component of the Conservation of Arctic Flora and Fauna's Circumpolar Biodiversity Monitoring Program, Arctic Marine Biodiversity Monitoring Plan. CAFF Monitoring Report No. 13, CAFF International Secretariat, Akureyri Iceland, 2014, pp. 24.
[77] B.J. Peterson, J. McClelland, R. Currey, R.M. Holmes, J.E. Walsh, K. Aagaard, Trajectory shifts in the Arctic and subarctic freshwater cycle, Science 313 (2006) 1061–1066.
[78] P.C. Reid, D.G. Johns, M. Edwards, M. Starr, M. Poulin, P. Snoeijs, A biological consequence of reducing Arctic ice cover: arrival of the Pacific diatom Neodenticula seminae in the North Atlantic for the first time in 800,000 years, Glob. Change Biol. 13 (9) (2007) 1910–1921.
[79] P.E. Renaud, M.L. Carroll, W.G. Ambrose Jr., Effects of global warming on Arctic sea-floor communities and its consequences for higher trophic levels, in: C.M. Duarte (Ed.), Impacts of Global Warming on Polar Ecosystems, Fundacion BBVA, Bilbao, Spain, 2008, pp. 139–175.
[80] S. Ribiero, M.K. Sejr, A. Limoges, Mm Heikkilä, T.J. Anderson, P. Tallberg, K. Weckström, K. Husum, M. Forwick, T. Dalsgaard, G. Massé, M.-S. Seidenkrantz, S. Rysgaard, Sea ice primary productivity proxies in surface sediments froma high Arctic Greenland fjord: spatial distribution and implications for paleoenvironmental studies, Ambio 46 (1) (2017) 106–118, https://doi.org/10.1007/s13280-016-0894-2.
[81] A.J. Richardson, D.S. Schoeman, Climate impact on plankton ecosystems in the Northeast Atlantic, Science 305 (5690) (2004) 1609–1612.
[82] D. Rissik, I.M. Suthers, The importance of plankton, in: Iain M. Suthers, David Rissik (Eds.), Plankton, A Guide to Their Ecology and Monitoring for Water Quality, CSIRO Publishing, Australia, 2012, pp. 1–14.
[83] J.E. Søreide, S. Falk-Petersen, E.N. Hegseth, H. Hop, M.L. Carroll, K.A. Hobson, K. Blachowiak-Samolyk, Seasonal feeding strategies of Calanus in the high-Arctic Svalbard region, Deep Sea Res. Part II: Top. Stud. Oceanogr. 55 (20–21) (2008) 2225–2244.
[84] J.E. Søreide, E. Leu, J. Berge, M. Graeve, S. Falk-Petersen, Timing of blooms, algal food quality and *Calanus glacialis* reproduction and growth in a changing Arctic, Glob. Change Biol. 16 (11) (2010) 3154–3163.
[85] R. Siron, K. Sherman, H.R. Skjoldal, E. Hiltz, Ecosystem-based management in the Arctic Ocean: a multi-level spatial approach, Arctic 61 (2008) 86–102.
[86] TFAMC, Co-chairs Non-paper of January 29, 2016, Task Force on Arctic Marine Cooperation, Arctic Council, 2016, pp.10.
[87] P. Tett, R.J. Gowen, S.J. Painting, M. Elliott, R. Forster, D.K. Mills, E. Bresnan, E. Capuzzo, T.F. Fernandes, J. Foden, L.C. Gilpin, M. Huxham, A.L. McQuatters-Gollop, S.J. Malcolm, S. Saux-Picart, T. Platt, M.-F. Racault, S. Sathyendranath, J. van der Molen, M. Wilkinson, Framework for understanding marine ecosystem health, Mar. Ecol. Prog. Ser. 494 (2013) 1–27.
[88] J.-E. Tremblay, J. Gagnon, The effects of irradiance and nutrient supply on the productivity of Arctic waters: a perspective on climate change, in: J.C.J. Nihoul, A.G. Kostianoy (Eds.), Influence of Climate Change on the Changing Arctic and Sub-Arctic Conditions, Springer, Netherlands, 2009, pp. 73–93.
[89] P. Wassemann, M. Reigstad, T. Haug, B. Rudels, M.L. Carroll, H. Hop, G.W. Gabrielsen, S. Falk-Petersen, S.G. Denisenko, E. Arashkevich, D. Slagstad, O. Pavlova, Food webs and carbon flux in the Barents Sea, Prog. Oceanogr. 71 (2006) 232–287.
[90] L. Weidermann, International Governance of the Arctic Marine Environment, Springer International Publishing, Switzerland, 2014, p. 251.
[91] I.M. Coté, G.B. Stewart, Contributions for Meta-analysis to Conservation and Management, in: J. Koricheva, J. Gurevitch, K. Mengersen (Eds.), Handbook of Meta-Analysis in Ecology and Evolution, Princeton University Press, Princeton, NJ, 2013, pp. 420–425.