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TERRESTRIAL BIODIVERSITY IN A RAPIDLY CHANGING ARCTIC

Status and trends of terrestrial arthropod abundance and diversity in the North Atlantic region of the Arctic

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Abstract The Circumpolar Biodiversity Monitoring Programme (CBMP) provides an opportunity to improve our knowledge of Arctic arthropod diversity, but initial baseline studies are required to summarise the status and trends of planned target groups of species known as Focal Ecosystem Components (FECs). We begin this process by collating available data for a relatively well-studied region in the Arctic, the North Atlantic region, summarising the diversity of key terrestrial arthropod FECs, and compiling trends for some representative species. We found the FEC classification system to be challenging to implement, but identified some key groups to target in the initial phases of the programme. Long-term data are scarce and exhibit high levels of spatial and temporal variability. Nevertheless, we found that a number of species and groups are in decline, mirroring patterns in other regions of the world. We emphasise that terrestrial arthropods require higher priority within future Arctic monitoring programmes.

Keywords Blood feeding insects · Decomposers · Herbivores · Invertebrate prey · Pollinators · Predators

INTRODUCTION

The richness of arthropod life and the complexities of Arctic food webs have been highlighted recently, challenging the more traditional and simplistic viewpoints that compare them to temperate and tropical zones (Hodkinson et al. 2004; Høye and Sikes 2013; Roslin et al. 2013; Hansen et al. 2016; Høye and Culler 2018). From the northern polar deserts, through the tundra, to the boreal zone, arthropods dominate faunal biodiversity in terms of species richness and abundance, with some groups found at densities of up to several million individuals per square meter (Hodkinson et al. 2013). There is also growing appreciation that arthropods are vital to ecological functioning and community dynamics throughout the region (Hodkinson and Coulson 2004; Barrio et al. 2017), fulfilling diverse roles such as soil nutrient cycling, decomposition and pollination. Further, they are integral to Arctic food webs with the potential to directly and indirectly influence plant and vertebrate diversity and abundance (Hodkinson and Coulson 2004; Roslin et al. 2013; Wirta et al. 2015; Schmidt et al. 2017). However, the state of knowledge of Arctic arthropods lags far behind that of plants and vertebrates (e.g., Russell et al., this issue, Elrich et al., this issue), and coupled with global declines of arthropods (Hallmann et al. 2017; Lister and Garcia 2018), this makes their prominence in a circumpolar monitoring programme all the more imperative (Hodkinson et al. 2013). In this paper, we synthesise several Arctic species inventories and datasets within the framework of the Circumpolar Biodiversity Monitoring Programme (hereafter CBMP; Christensen et al. 2013) to highlight the significance and challenges of terrestrial arthropod monitoring.

The CBMP represents an opportunity to address the lack of knowledge of arthropods and track responses to future change by incorporating arthropod sampling into international, standardised monitoring activities. However, for such a programme to be efficient and successful, baseline inventories and decisions on focal taxa are required. We provide an initial summary of biodiversity of terrestrial arthropods for a well-studied region of the Arctic, collating available data on recent diversity and abundance trends. We use this approach to assess the Focal Ecosystem

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Component (FEC) framework of the CBMP and offer recommendations for its improvement. The lack of information and coverage of data, as well as inconsistent taxonomic information, prevents a comprehensive review for the entire Arctic. This study, therefore, focusses on the North Atlantic region of the Arctic, arguably one of the best documented polar regions, to demonstrate the level of information required to determine the status and trends of all FEC attributes. A broader circumpolar evaluation of data availability for a model group of arthropods is given in Gillespie et al. (this issue). Given the unconventional groupings of the FECs (see "The Terrestrial Arthropod Focal Ecosystem Components of the North Atlantic region" section below), we strongly recommend that readers consult the CBMP Terrestrial report (particularly Section 4, p. 48) for a full explanation of FECs and their development. Similarly, it should be noted that the definition of the Arctic used in this paper is that of the Circumpolar Arctic Vegetation Map (CAVM Team 2003), including divisions between High, Low and Sub-Arctic.

THE TERRESTRIAL ARTHROPOD FOCAL ECOSYSTEM COMPONENTS OF THE NORTH ATLANTIC REGION

As described in Christensen et al. (2013), the CBMP adopts a hierarchical approach to monitoring, with the first level being Focal Ecosystem Components (FECs; groups of key organisms targeted for monitoring) and subsequent levels consisting of "attributes" and "parameters" of the FECs (Table 1). The five FECs selected for terrestrial arthropods (blood-feeding, pollinators, decomposers, herbivores and prey for vertebrates) have not been applied in practice and baseline information is, therefore, required. We begin this task by assigning known arthropod species to each of the five FECs with the broad aim of describing the potential species richness of each (i.e., rather than the actual number of species that frequently occur). We use the most recent species inventories for Greenland (Böcher et al. 2015), Iceland (Lindroth 1957; Gauld and Bolton 1988), Svalbard and Jan Mayen (Coulson et al. 2014), to assign species of arthropods to FECs based on feeding or habitat preferences. Franz Josef Land, Novaya Zemlya and the Faroe islands are not included for brevity, and some large groups such as mites were not classified due to a lack of species-level information. Species performing multiple ecological roles were assigned to more than one category, and those not meeting the criteria for any of the five FECs were added to an "other" category. As many of these other species are predators and parasitoids, we also created an additional FEC for the CBMP to consider, hereafter termed "predators FEC".

For Greenland, we consider six "faunal districts" (sensu Böcher 1988; Fig. 1) to provide an additional scale of classification and distinguish between High and ow Arctic zones (sensu CAVM Team 2003). We digitized information on distribution across faunal districts for 874 species (274 species have no current distribution information) as presented in Böcher et al. (2015). Iceland, Svalbard and Jan Mayen were considered as three separate districts (Fig. 1). Where long-term (> 10 years) time series data were available for FECs or groups of species within FECs, we analysed trends over time using simple linear regression after checking for temporal autocorrelation in the R programming environment (version 3.5.1, R Core Team 2018). Where autocorrelation was detected in a dataset, models were constructed to account for this as noted in each section. Full details of data analysis and our method of assigning species to FEC categories can be found in the supplementary material and the full FEC classification of arthropods is given in Table S1 in Supplementary Material.

General biodiversity patterns

Generally, the diversity of arthropods decreases with increasing latitude (Fig. 1), supporting patterns shown in previous work (Danks 1981, Callaghan et al. 2004, Hodkinson et al. 2013), although this varies between different groups (Böcher et al. 2015). Among the faunal districts of Greenland, the two most diverse regions, South-West and North-East, include 63.6% of the species found in Greenland, as well as relatively large numbers of species unique to the North Atlantic region (Table 2). These patterns may reflect the size of the districts or the imbalance of sampling history, with efforts concentrated at the Zackenberg research station in the North-East region and in the more populated areas in South-West Greenland, including the research stations near Nuuk and on Disko Island (Fig. 1). The differences may also be due to regional colonisation of, and dispersal within, Greenland following retreat from the Last Glacial Maximum when most, if not all, of the arthropod fauna was wiped out (e.g., Lindroth 1957; Böcher et al. 2015).

The more diverse fauna of Iceland is likely related to the relatively milder conditions, as the land covers a greater area of the Sub-Arctic than southern Greenland. Additional niches are also provided by geothermal activity (Govoni et al. 2018), the large pre-settlement forest cover and subsequent history of human disturbance and agriculture

Table 1 The Focal Ecosystem Components (FECs), attributes and parameters to be monitored by the CBMP in relation to terrestrial arthropods. Essential attributes and parameters are indicated in bold. Taxonomic groups considered by this paper are in bold. TK: traditional knowledge (adapted from Christensen et al. 2013)

FEC	Attribute	Parameter	Key method suggested by CBMP	Groups considered by CBMP
Blood-feeding insects	**Diversity**	**Species richness**	Hand collection, sweep netting, aspirator, Malaise traps, CO_2 traps, light traps	**Diptera: Simuliidae**
	Abundance	Relative abundance	Sweep-net, baited traps, historical collections, TK	**Culicidae**
	Spatial structure	Presence/absence	As for relative abundance	**Tabanidae**
	Phenology	Date of emergence, seasonal activity	As for relative abundance	**Ceratopogonidae**
	Demographics	Condition, life stage, sex ratio	As for relative abundance	
Pollinators	**Diversity**	**Species richness**	Observation	**Diptera**
			Pan traps, Vane traps	**Lepidoptera**
			Sweep netting	**Hymenoptera: Apoidea:**
	Ecosystem function and processes	**Grains per stigma, % fruit set**	Observations, TK	Megachilidae
		% fruit yield		Colletidae
	Spatial structure	Presence/absence	Observation, sweep nets, pan/vane traps	Hallictidae
	Abundance	Relative abundance	As for presence/absence	Andrenidae
	Phenology	Seasonal activity	As for presence/absence	**Apidae**
Decomposers	**Diversity**	**Species richness**	Soil and turf cores,	**Collembola**
	Abundance	**Density**	As for species richness	Acari
	Distribution	**Presence/absence**	As for species richness	Enchytraeidae
	Spatial structure			Also species of: **Fungivores**
	Ecosystem function and processes	% mass loss	Litter bags, native foliage, inorganic nutrient levels	
		NPK levels		Bacterivores
	Demographics and phenology	Phenology, voltinism, population growth rate	As above	**Saprophages**
Herbivores	**Diversity**	**Species richness**	Timed visual surveys, beat sheet samples, sweep nets, local knowledge	**Lepidoptera**
				Hymenoptera
	Spatial structure	**Presence/Absence**	Visual observation	**Hemiptera**
	Ecosystem function and processes	**Plant damage**	As for presence/absence	**Hymenoptera: Symphyta**
	Abundance	Relative abundance	Collection, sweep nets, beat sheet,	**Some Coleoptera families**
	Health	Body size, pupal mass	As for relative abundance	
	Phenology	Seasonal activity patterns	As for relative abundance	Acari
	Demographics and temporal cycles	Population cycle estimates, dynamics	As for relative abundance	
Prey for vertebrates	**Abundance**	**Number**	Pan/pitfall traps	**Araneae:**
			Malaise traps	**Linyphiidae, Lycosidae**
	Productivity	**Biomass**	As for number	**Diptera: Tipulidae**
	Phenology	**Seasonal activity**	As for number	
	Abundance	Species specific number	As for number, ID to species	**Lepidoptera**
	Spatial structure	Presence/absence	As for number	
	Diversity	Species richness	As for number	

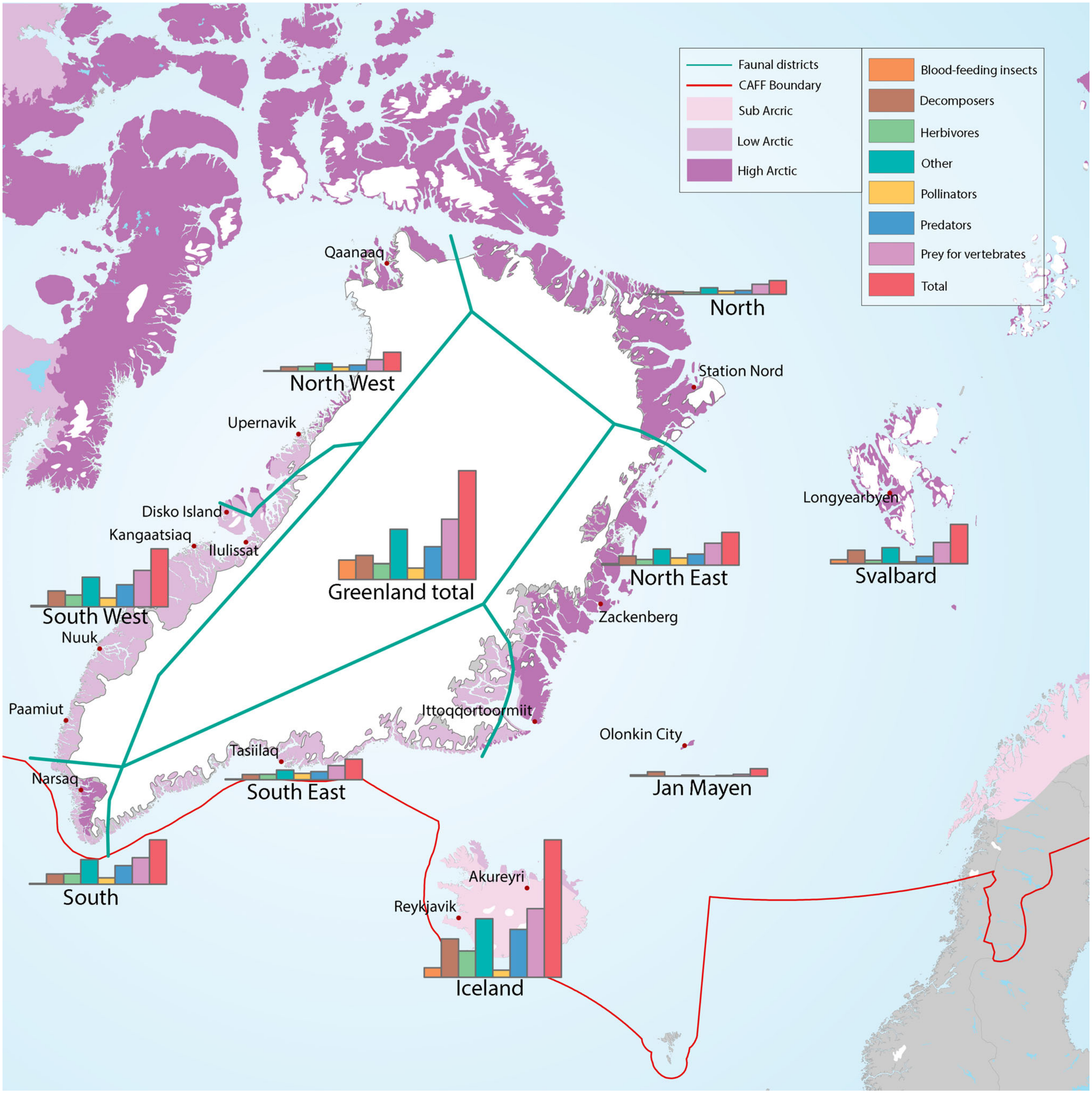

Fig. 1 Map of the species richness of Focal Ecosystem Components (FEC) for the North Atlantic region of the Arctic. The tallest bar is the total species richness for Iceland, and this corresponds to 1453 species. The green lines show the boundaries of Greenland's "faunal districts" (sensu Böcher 1988), and the red line indicates the boundaries of the Arctic as defined by CAFF. High Arctic, Low Arctic and sub-Arctic regions (sensu CAVM Team 2003) are also indicated

(Arnalds 1987), and the importation of soils and plants (Halldorsson et al. 2013). Conversely, Svalbard and Jan Mayen have lower arthropod diversity, unsurprisingly given their smaller size and High Arctic location. Both share a number of species with Greenland (Svalbard: 168, Jan Mayen: 48) and Iceland (Svalbard: 126, Jan Mayen: 44), and the glaciation history and colonisation processes of these islands are similarly considered to be important determinants of community diversity (Ávila-Jiménez and Coulson 2011; Coulson et al. 2014).

Table 2 Total species richness of the five original Focal Ecosystem Components, as well as the two additional components (other = species not categorised in the original FECs; Predators = those of the "other" category that are predators or parasitoids), and overall richness for the "faunal districts" of Greenland, Iceland, Svalbard and Jan Mayen. *Note that the total for Greenland blood-feeding insects includes lice, for which distributional information is absent

Region	Blood-feeding insects	Pollinators	Decomposers	Herbivores	Prey for vertebrates	Other	Predators	Total	No of species unique to region
Greenland									
South	8	68	109	110	282	260	197	470	50
South West	13	93	168	124	384	314	234	610	93
South East	7	68	56	58	150	103	85	218	2
North West	7	47	48	52	125	85	67	201	26
North East	14	73	94	58	229	168	115	345	40
North	6	35	32	23	107	70	41	146	18
Greenland total	203*	121	251	165	635	529	344	1148	758
Iceland	99	75	405	279	725	619	506	1453	1093
Svalbard	42	19	144	35	225	169	76	415	210
Jan Mayen	16	1	47	2	22	13	9	80	19
Total for North Atlantic	275	169	602	410	1369	1105	822	2519	

Status and trends of terrestrial arthropod FECs in the North Atlantic region

Blood-feeding insects

Arthropods in this FEC (Table S2 in Supplementary Material) include the most important groups from a socio-ecological perspective: mosquitoes, black flies and lice. For example, harassment of reindeer by biting insects can prevent grazing and rumination (Witter et al. 2012, Russell et al., this issue), black flies can cause mortality in Arctic peregrine falcons (Franke et al. 2016), and mosquitoes contribute to adult sea-bird mortality (Gaston et al. 2002). Links between this group and other FECs (Fig. 2) include some biting flies being flower pollinators (Urbanowicz et al. 2017) and prey to vertebrates and invertebrates (Wirta et al. 2015). Blackflies and mosquitoes have aquatic larvae (see Culler et al. 2015), which also links them to freshwater systems.

Distributional and long-term trend information is limited for this group in much of the study region and little is known about the importance of lice in the Arctic (Mallory et al. 2006). Therefore, it may be advisable to focus monitoring on indicator species, such as the tick *Ixodes uriae*, which has recently colonised Svalbard (Coulson et al. 2014), and on surveillance for new species that are disease vectors (Müllerová et al. 2018). A promising example of this is a monitoring initiative in Greenland using CO_2 traps as part of the VectorNet programme to complete distribution maps of potential European disease vectors, but the programme is in its infancy and requires additional support for expansion. Despite a lack of trend information, hydrologic change will be crucial in determining the trends of biting insects that have an aquatic immature stage. For mosquitoes, warmer water temperatures can enhance immature survival through predator avoidance and faster development (Culler et al. 2015). Earlier pond melt coupled with faster development would also support a continued trend towards earlier mosquito emergence (Høye et al. 2007).

Pollinators

The majority of arthropod species in this FEC (Table S3 in Supplementary Material) also occur in other FECs (Fig. 2), demonstrating their extensive links throughout Arctic food webs. For example, lepidopteran larvae are primarily herbivorous and are prey for other species, and the larvae of hoverflies may be predatory or feed on decaying organic matter. The main pollinator species are likely to differ by region within the North Atlantic. For example, *Spilogona* sp. (Diptera: Muscidae) are key pollinators in NW Greenland (Tiusanen et al. 2016, Loboda et al. 2018) and Svalbard (Gillespie et al. 2016), while hoverflies are more important in Iceland and West (Urbanowicz et al. 2017) and South Greenland (Toke T. Høye pers. obs.). Understanding the important trends in this FEC will require good local knowledge of plant–pollinator interactions. Similarly,

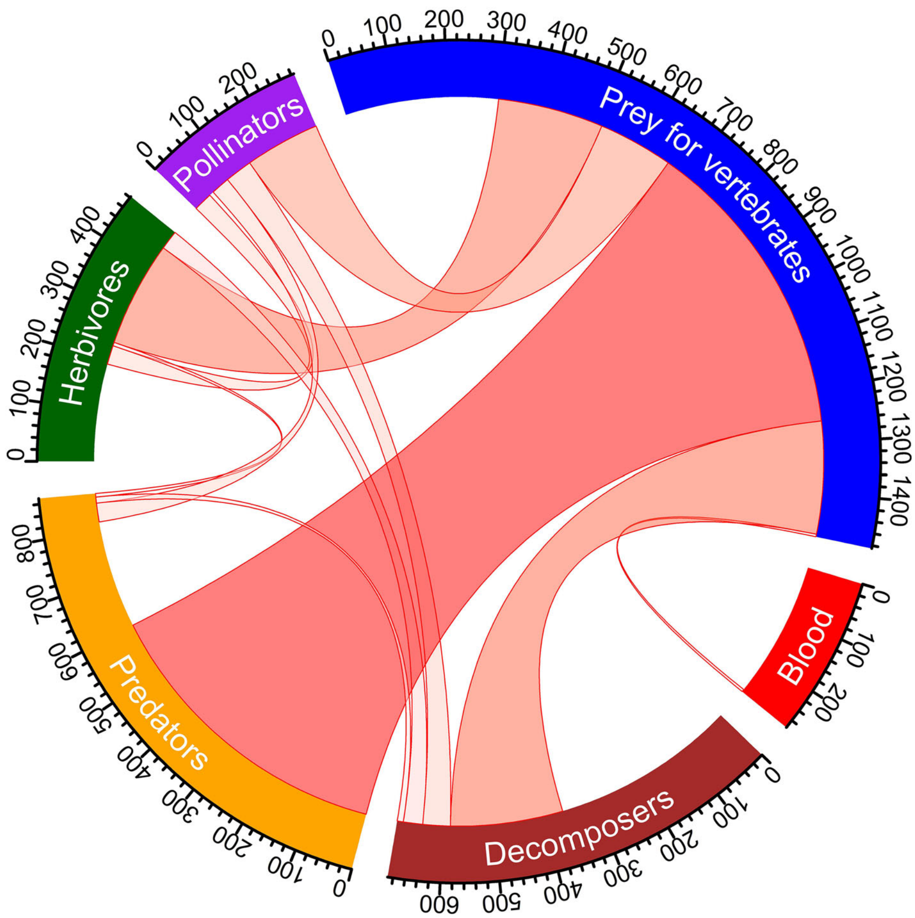

Fig. 2 The multi-functionality of Arctic arthropods. The chord diagram indicates the number of species in each FEC for the North Atlantic (circular outline) and the overlap between the five CBMP FECs and our recommended "Predators" FEC. Link width is indicative of the number of species presumed to link the various FECs. Note that 34 species found in 3 or more FECs are not depicted, so the total number of species is slightly inflated

if attributes such as pollination rate are essential measurements (Table 1), standardised experimental protocols focussing on key local plants will be required.

The most promising long-term datasets for this FEC come from the arthropod samples collected at Zackenberg since 1996. Significant declines were detected in 7 of the 14 muscid species found in five or more years between 1996 and 2014 (Fig. 3), and dramatic (> 80%) decreases in diversity and abundance have been reported in some habitats (Loboda et al. 2018). The differences in trends between species of muscid flies may relate to ecological differences among species, but classifying each species according to their body size and whether they are frequent flower visitors or not did not yield consistent patterns of abundance variation (Fig. 3). The significant declines in *Spilogona* species may result from reduced soil moisture in warmer years, as the larvae of some Arctic *Spilogona* species are aquatic or semi-aquatic predators of other Diptera larvae (Michelsen 2015). Thus, soil moisture may directly affect their abundance. More information about this analysis is provided in the supplementary information.

Decomposers

This FEC (Table S4 in Supplementary Material) represents the most common feeding mode in Arctic and global food webs (Böcher et al. 2015; Koltz et al. 2017). A more complete classification of Arctic decomposers would make this the most species-rich of the five FECs. These species are key to nutrient cycling and decomposition (Ott et al. 2012), indirectly influence plant communities and the animals that rely on them (Brussaard et al. 2007), and are linked to other FECs as well (Fig. 2). However, the importance of decomposer diversity for ecological function is unresolved, partly because we often base our assessment on family level information. We recommend additional baseline work and emphasise the need for significant financial support to monitor this group. In particular, the

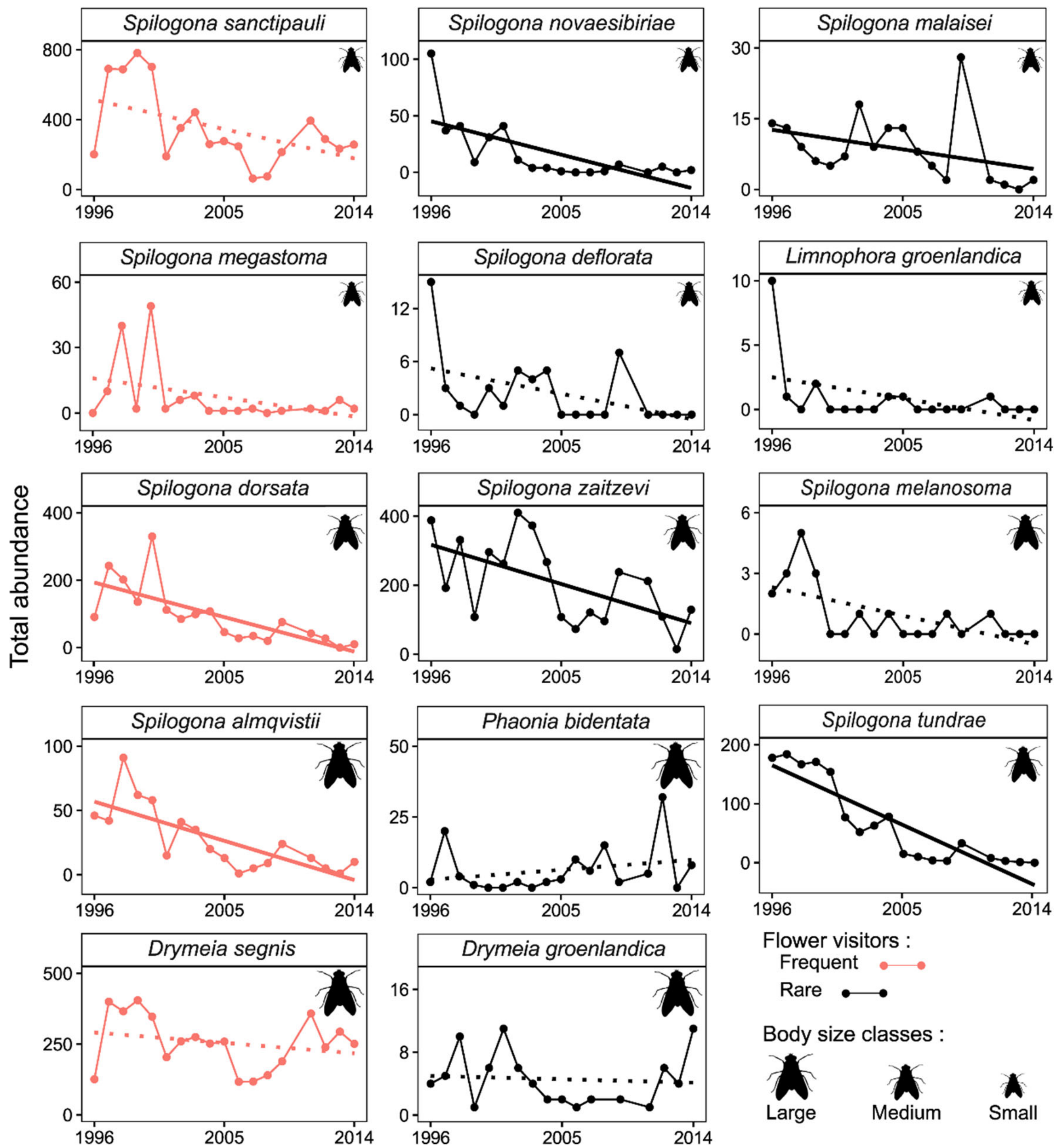

Fig. 3 Interannual variation in abundance of 14 muscid fly species caught in pitfall traps at Zackenberg, North East Greenland as part of the Greenland Ecosystem Monitoring programme (Loboda et al. 2018). Panels with red lines indicate anthophilous species (frequent flower visitors) and the size of the fly silhouette indicates body size of the species in three size classes. Significant trends ($p < 0.05$) are indicated by a solid linear regression line. Dashed lines are non-significant

sheer density and diversity of organisms that will result from the sampling protocols proposed by the CBMP will require a large identification effort, a challenge that will possibly be eased by emerging DNA metabarcoding techniques (Gillespie et al. this issue).

Useful soil fauna trends are available from two collections in Greenland. Collembola recorded from soil cores by the Nuuk Basic Climate Change Monitoring Programme at Kobbefjord, Greenland (Aastrup et al. 2015; Fig. 4) show that the abundances have been increasing over the last 10 years, although only significantly for *Empetrum*-dominated communities. Species richness has remained relatively stable in all communities, but diversity (measured by the Shannon–Wiener Index, *H*) has decreased significantly for most habitats there. The Zackenberg dataset includes catches from pitfall trapping across entire growing seasons, but shows contrasting patterns to Kobbefjord: recent trends of warmer active seasons and fewer winter freeze–thaw events were associated with lower abundances of Collembola in all habitat types examined (wet fen, mesic heath and arid heath), indicating their sensitivity to climatic variation (Koltz et al. 2018).

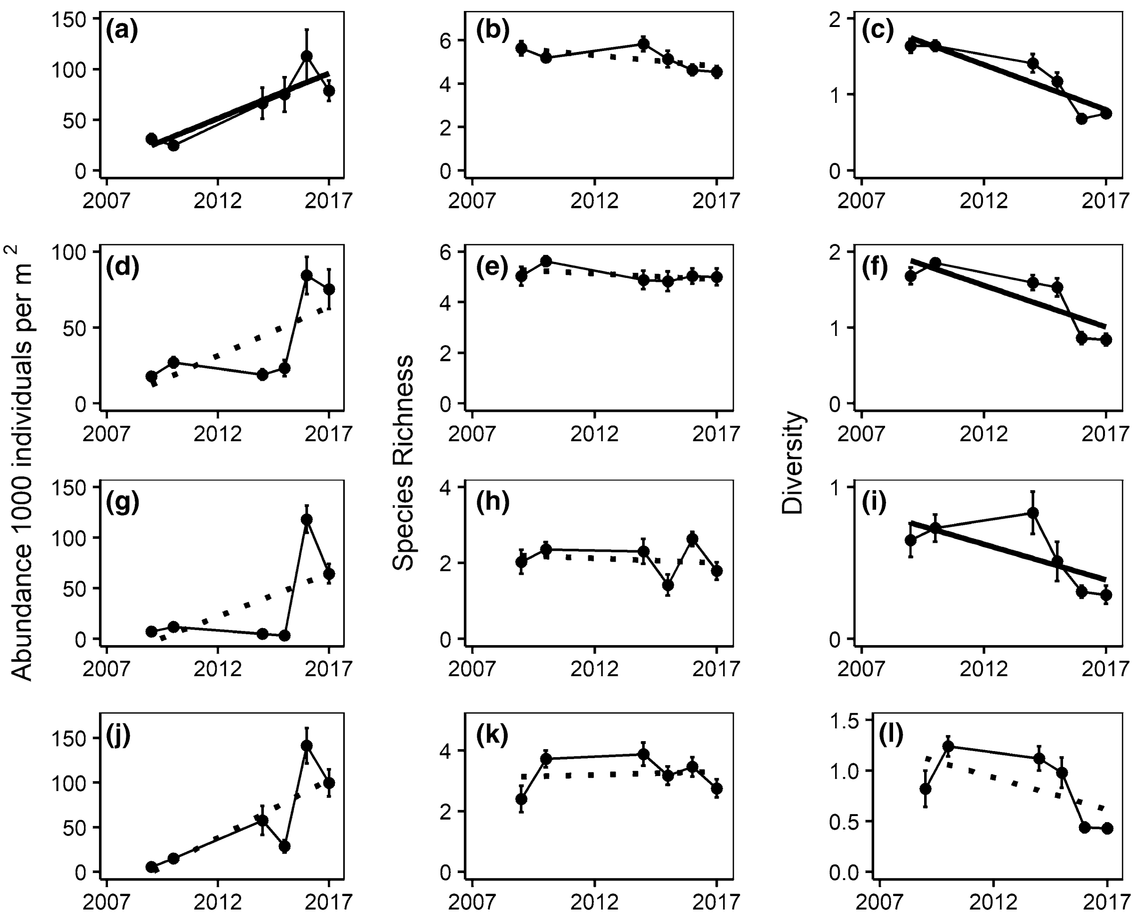

Fig. 4 Collembola population trends in Kobbefjord from 2007 to 2017 in four different plant communities: **a–c** = *Empetrum nigrum*, **d–f** = *Salix glauca*, **g–i** = *Silene acaulis*, **j–l** = *Loiseleuria procumbens*. Left hand panels: mean population abundance of total Collembola expressed as 10^3 individuals per m^2; centre panels: mean number of species per sample; right-hand panels: Shannon–Wiener Diversity Index per sample. Points represent means of all traps over three seasonal trapping sessions and vertical error bars are ± 1 S.E. Linear regression was used in all cases and solid lines indicate significant regression lines at the $p < 0.05$ level, dashed lines are non-significant trends. See Table S8 in Supplementary Material for results summaries. The data are collated from the annual reports of the Nuuk Basic Climate Change Monitoring Programme

These examples demonstrate that sampling for this FEC requires collection in multiple sites with comparable methods and that patterns will be difficult to interpret even for 10 years of data.

Herbivores

This FEC (Table S5 in Supplementary Material), represents an important trophic level as these species are tightly linked to local vegetation communities. The close associations between herbivores and their food plants could make them important indicators of environmental change in the Arctic (Hodkinson et al. 2013). While the amount of primary production consumed by Arctic arthropod herbivores is estimated at no more than 2% (Danks 1981; Barrio et al. 2017), herbivore abundance and the frequency and extent of herbivore outbreaks is expected to increase with a warming climate due in part to northward expansions of some species (Jepsen et al. 2011; Halldorsson et al. 2013). Measuring the diversity, abundance and distribution of this FEC (Table 1) will require intensive sampling each season, and we recommend that monitoring focus on key outbreak species, new arrivals of species and other key indicator species (species that provide early and/or representative indications of environmental change, see “Reflections on the FEC categories” section). In addition, simple standardized protocols measuring levels of background herbivory should be used to detect future changes in a key ecosystem process (Barrio et al. 2017).

There are no long-term datasets that include all species in this FEC, but some groups are well represented. For example, in Iceland, moth monitoring was established in 1995 as part of the Nordic Moth Monitoring Scheme. Preliminary data from the six longest running trap sites

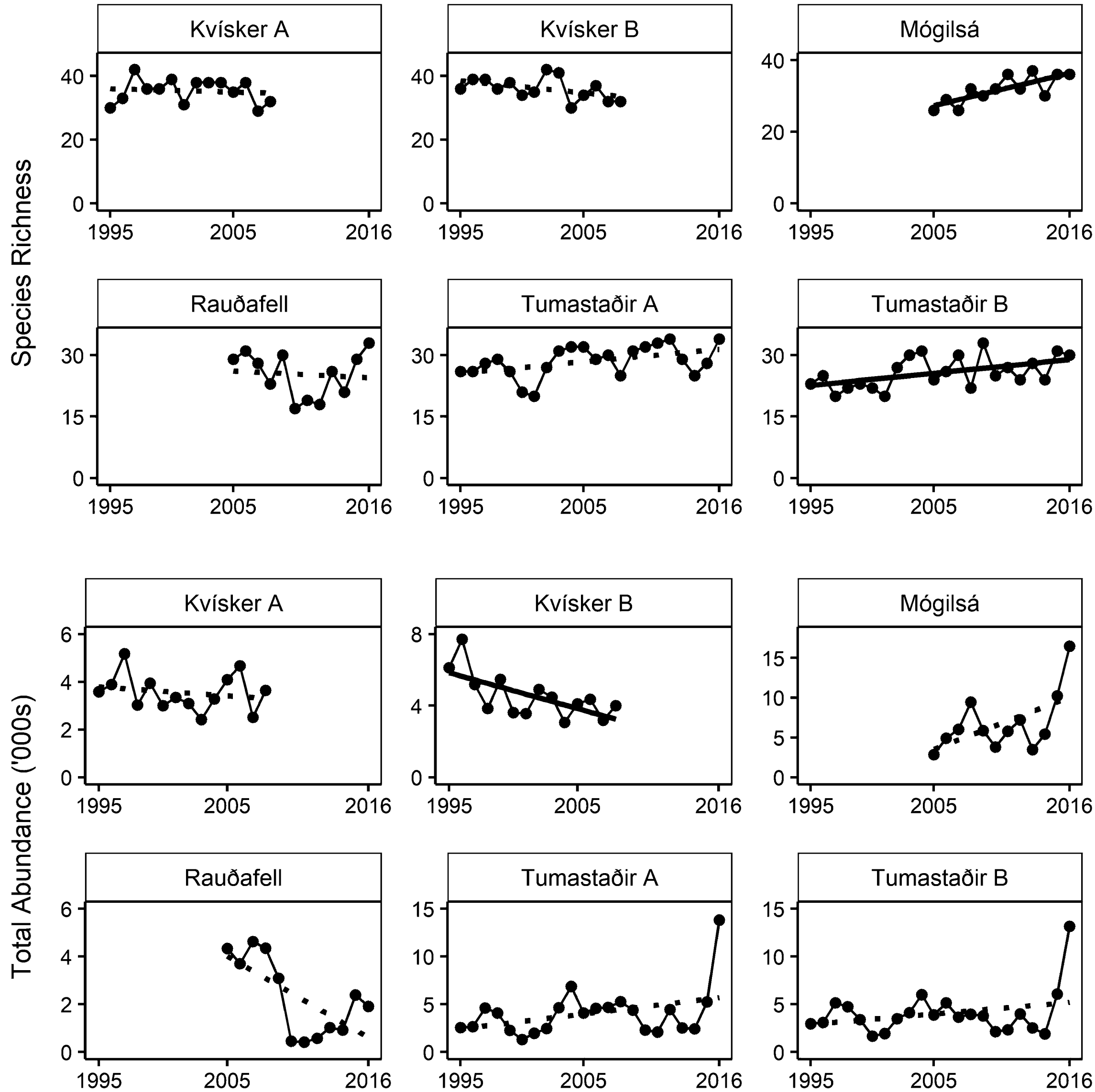

Fig. 5 Species richness and total abundances for six locations in the Moth Monitoring Scheme in Iceland (see Fig. S1 in Supplementary Material for site locations). The solid straight lines represent significant (at the $p < 0.05$ level) linear regression lines. Dashed lines indicate non-significant regression lines. All data are analysed with linear regression, except for Rauðafell abundance and Tumastaðir A species richness, which were analysed with generalised least squares regression, with an AR1 correlation structure to account for autocorrelation. See Table S9 in Supplementary Material for full result summaries. Data are property of The Icelandic Institute of Natural History and full analyses are not yet available

show significant positive trends in species richness at two locations, but negative or non-significant trends in abundance (Fig. 5). The data highlight a degree of spatial and inter-annual variation that is typical for many groups of arthropods, making generalisation difficult and highlighting the need for longer term data. The Zackenberg dataset also suggests there are habitat-specific trends but high variability among Lepidoptera species (see supplementary material). Reductions in body size have also been observed among some butterfly and moth species from High Arctic Greenland (Bowden et al. 2015a), which could be a result of species expending more energy under warmer conditions (Barrio et al. 2016). Body size is strongly related to reproductive success in insects, and changes could have large implications for population dynamics.

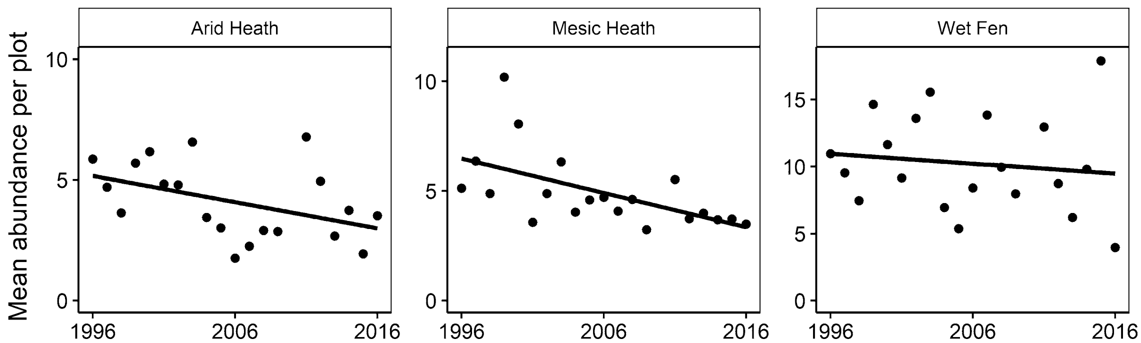

Fig. 6 Temporal trends of arthropod abundance at Zackenberg for three habitat types. The data represent all families from the FEC classification system where data are available. Solid lines indicate significant regression lines at the $p < 0.05$ level after accounting for temporal autocorrelation. Figures prepared from data available at http://data.g-e-m.dk/

Prey for vertebrates

This FEC (Table S6 in Supplementary Material) was selected for the CBMP because it is a vital link between trophic levels. Many species of birds and some mammals rely on arthropods at their summer feeding grounds, and there are numerous links between this and other FECs (Fig. 2). As a result of these links, the CBMP considers abundance and phenology to be the most important attributes. Phenology is particularly important from a climate change perspective due to the short activity season for surface arthropods and their differing responses to environmental cues, which increase the potential for phenological mismatch (Reneerkens et al. 2016). Despite the importance of this group as a resource for higher trophic levels, it remains the least well developed among all of the FECs due to limited data about which arthropod species actually form important parts of vertebrate diets (but see Wirta et al. 2015; Schmidt et al. 2017). Likewise, there is a paucity of long-term studies that include both vertebrates and invertebrates and identify arthropods to the species level.

Using the best long-term data currently available from the North Atlantic region, we took a first look at how this FEC might be changing over the last 20 years. We designated arthropod families from Zackenberg as potential members of this FEC group using information from two recent studies on arthropod diets of Arctic birds (the dominant vertebrate insectivores; Bolduc et al. 2013; Wirta et al. 2015; Table S10 in Supplementary Material) and then assessed trends in their total summertime abundance (see supplementary material for analysis methods). Between 1996 and 2016, there were significant declines in the total abundance of potential vertebrate prey ($p < 0.001$; Fig. 6, Table S11 in Supplementary Material) across all habitat types (i.e., heath and fen), with the strongest declines in the drier heath sites. Similar analyses at the order level for those arthropod families represented within this FEC group (Araneae, Diptera, Hymenoptera, Lepidoptera; Table S10 in Supplementary Material) showed that patterns of decreasing abundances were consistent across orders but often habitat-specific (Table S11 in Supplementary Material). Variation in arthropod responses according to soil moisture have been documented at Zackenberg (e.g., Bowden et al. 2015b, 2018; Koltz et al. 2018); findings from a related study also indicate that arthropod abundances are lower in years with earlier timing of snowmelt and that this response is likely due to reduced soil moisture (Mortensen et al. 2016). Lower abundances of available arthropod prey could have important consequences for the phenology and breeding success of local vertebrates (e.g., Reneerkens et al. 2016). However, the reliability of these data is limited without more specific information regarding vertebrate diets and species-level arthropod data. Given the importance of this FEC, these preliminary findings highlight the need for better long-term data on multi-trophic interactions.

REFLECTIONS ON THE FEC CATEGORIES

This overview of available datasets represents an important first step in a peer review process of the FEC categories developed by the CBMP for terrestrial arthropods. Classifying species to FECs was a challenging process, particularly where there was uncertainty about individual species biology. Similarly, combining large groups of species together (e.g., in the “prey for vertebrates” FEC) seemed imprecise given the lack of natural history data on many of the species included, although we acknowledge the relevance of estimating prey availability for insectivorous birds. Furthermore, we believe there is an important functional group missing from the current CBMP FECs: predators and parasitoids (Fig. 2). As an intermediate trophic level of Arctic food webs, this group is critical for community dynamics and is likely to be more responsive to changes in lower trophic levels than their vertebrate predators. Predatory arthropods make up a large proportion of the prey for vertebrates FEC (Table S7 in Supplementary Material), and with current knowledge we can perhaps more easily assign many species to the "predator" category than we can to the prey for vertebrates category. While a predator FEC may be a more appropriate functional group for many of these species, however, there are also many uncertainties around such a category. For example, many parasitoids perform other functions (e.g., pollination), and apart from spiders, the larval diets of many species are unknown or vary between regions and habitats. Therefore, while we propose the addition of the predator FEC, it is not likely to make the categorisation process less challenging.

We stress that the classification issues we encountered occur mainly for arthropod biodiversity, rather than the CBMP as a whole. Other terrestrial Arctic FECs (mammals, birds, vegetation) involve fewer species, ecological roles, and have a greater availability of data. It should also be noted that the FEC species richness values in Fig. 1 represent the maximum potential diversity accumulated over many years of sampling. Despite the diversity of trapping techniques planned (Table 1), sampling is unlikely to capture all known species in any given year. Nevertheless, it is clear from this summary of biodiversity that the FEC lists created here should also be refined as they are expanded to other regions and research continues to provide insights on species' functional roles. In the meantime, monitoring of the diversity and abundance of arthropod species and of their ecological functions (i.e., decomposition, pollination, herbivory) continue to be the most important objectives of the CBMP.

KNOWLEDGE GAPS AND RECOMMENDATIONS

Some of the monitoring efforts highlighted here offer state-of-the-art insights into Arctic biodiversity trends, but they also demonstrate the level of work required to fill outstanding knowledge gaps (Hodkinson et al. 2013). For example, we have been unable to report on the vast majority of FEC attributes and parameters for much of the Arctic and, where evidence is available, the signals in the data are subject to high levels of spatial and temporal variability. Nevertheless, some of the simultaneous declining trends reported here support evidence of large decreases in arthropod biomass in other regions of the world (Hallmann et al. 2017; Lister and Garcia 2018). These worrying trends highlight the need to build a greater knowledge base of Arctic food webs and ecosystems, and to monitor a greater range of functional groups and their ecosystem services.

To provide a more complete synthesis of Arctic biodiversity status and trends, three basic future needs for arthropod monitoring are: (1) a more substantial effort with wider international collaboration to collate available data, and (2) extensive baseline data collection at CBMP monitoring stations. Further, given their importance to ecosystem function, their diversity and our relative dearth of knowledge compared to plants and vertebrates, (3) terrestrial arthropods must be given higher priority within long-term research plans, with more state-wide commitments to arthropod monitoring programmes. This was the first recommendation of Hodkinson et al. (2013), but we go further by suggesting that this should include the training and appointment of specialised staff to enhance standardisation, international cooperation and sharing of data.

The sampling activities of the CBMP will provide excellent opportunities to monitor the abundance and phenology of more easily identifiable groups, such as spiders, beetles, syrphid flies, bees and butterflies, and key indicator species in addition to FECs (Danks 1992; Hodkinson et al. 2013). These are likely to return immediate and indicative results, particularly in the initial stages of the programme before sufficient data are collected and samples processed to detect trends in other groups. Some candidate key indicator species were suggested by Hodkinson et al. (2013) and may differ between regions, but they are likely to include species that fulfil one or more of the following characteristics:

(1) species that are well studied taxonomically and ecologically and have existing baseline data,
(2) species that indicate local or regional changes in environmental conditions through rapid changes in physiology, size, abundance, distribution or phenology,
(3) species likely to expand distributions northwards from their current northern limits south of the Arctic Circle,
(4) species vulnerable to climate change due to one or more of the following:
    (a) small patchy populations
    (b) southern limits at high latitudes
    (c) narrow diet, habitat or weather/seasonal requirements (specialists)
    (d) cold-adaptation
    (e) endemism

An additional knowledge and monitoring gap lies in the availability of finer scale abiotic parameters. The difficulty in coupling changes in variables such as temperature to arthropods and plants is partly due to a lack of monitoring data on biologically relevant microhabitat scales (e.g., soil and surface temperatures; Convey et al. 2018). The CBMP will include the monitoring of site-level abiotic factors such as climate data, snow depth and soil temperature (Christensen et al. 2013), but we recommend that soil and surface temperature data are also logged at each trapping position.

Monitoring on the scale proposed by the CBMP will result in a huge collection of trap samples. This represents an exciting resource to Arctic researchers, but also a daunting prospect for taxonomists and museum curators. Maintaining up-to-date monitoring requires extensive taxonomic skills and personnel availability. However, taxonomists are in short supply, and while recent advances in DNA barcoding techniques may eventually reduce costs and speed up sample assessment (Porter and Hajibabaei 2018), substantial and sustainable funding is required to support continued identifications. Monitoring efforts should also include the build up of appropriately curated reference collections for DNA barcoding.

CONCLUSIONS

In this review, we have highlighted the major limitations facing Arctic terrestrial arthropod science. Arthropod researchers seek to understand a hugely diverse and multifunctional group of organisms, with a fraction of the support given for plants, vertebrates and abiotic measurements. The CBMP holds great potential in correcting that imbalance, but we emphasize that plans to monitor arthropods as groups of functionally important taxa will need regular refinement. We have found the proposed arthropod FECs to be unusual, overlapping and challenging to apply even to species inventories of relatively low-diversity "Arctic" islands. Although our synthesis of available data suggests worrisome declines in several of these arthropod FECs, our classifications are incomplete as a result of these issues, and thus we are not able to fully describe the status of the terrestrial arthropod FECs. We believe that extensive expert supervision of the initial stages of this arm of the terrestrial CBMP will be vital to its success.

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