Fly on Arctic alpine fleabane, Iqaluit, Nunavut, Canada. Photo: Fiona Paton

3.2 ARTHROPODS

Authors:
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Arthropods are a diverse group of animals including insects, spiders, and mites (Figure 3-6). While often small, and not instantly apparent, they are frequently highly abundant and are both integral to complex Arctic food webs and fundamental to a number of key ecosystem services. This includes services such as soil nutrient cycling, decomposition, and pollination, as well as ‘disservices’, such as blood-feeding and mammal harassment. Despite the diversity, this report is restricted to hard-bodied invertebrates, excluding soft-bodied taxa due to lack of knowledge.

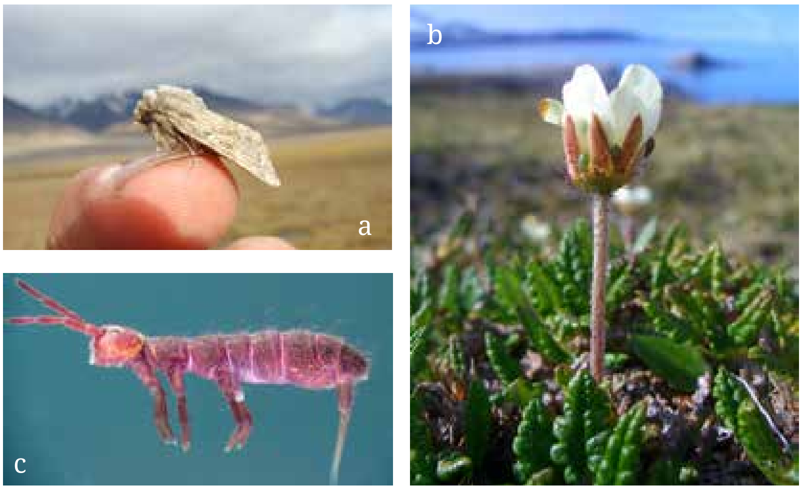
Through their interactions with other species, arthropods have the potential to directly, or indirectly, influence plant, bird and mammal diversity and abundance (Figure 3-7). The richness of the arthropod fauna and the intricacies of Arctic food webs are becoming increasingly apparent, challenging traditional views that Arctic webs lack complexity. Arthropods dominate the faunal biodiversity of the Arctic in terms of species richness and abundance, with some soil-dwelling species occurring at densities of up to several million individuals per square metre. Nonetheless, while it is well accepted that arthropods are vital to ecological functioning and community dynamics throughout the biome, the state of knowledge of Arctic arthropods is poor. Understanding of the arthropod fauna of this region remains far behind that of higher plants and vertebrates, both taxonomically and geographically. This makes their prominence in a circumpolar monitoring programme even more imperative.

Six FECs have been defined for terrestrial arthropods. Five of these are identified in the CBMP–Terrestrial Plan—pollinators, decomposers, herbivores, prey for vertebrates and blood-feeding insects—and a sixth, 'predators and parasitoids', is described in Gillespie et al. 2020a. These FECs have yet to be applied in practice, hence baseline information is required. It is also important to note that when the FEC approach is applied to the arthropod fauna, it may give the impression of six independent units. These units are, however, highly interconnected with one species belonging to multiple FECs (Figure 3-8). Moreover, in the case of arthropods perhaps more than other taxa, classifying species to individual FECs can be challenging, as few species can be clearly assigned to, or have a role in, only one FEC. For example, adult moths and butterflies (Lepidoptera) are pollinators, but their larvae are primarily herbivorous, they are also host´s for parasitoids and serve as prey for birds. Hence, drivers affecting one FEC will necessarily affect the others, in turn feeding back to other components of the ecosystem as a whole.

This summary is largely based on Gillespie et al. (2020a, 2020b), and references therein, which provides the most current circumpolar information on the arthropod FECs. Where information is not included in Gillespie et al. (2020a, 2020b), references are provided.

Figure 3-6. Examples of arthropod fauna of the Arctic.

*(a) noctuid moth (*Apamea maillardi*) Photo: James Speed, (b) Svalbard endemic aphid (*Acyrthosiphum svalbardicus*) on mountain avens (*Dryas tetragona*) Photo: Stephen Coulson, and (c) springtail (Collembola),* Desoria tshernovi. *Photo: Arne Fjellberg*



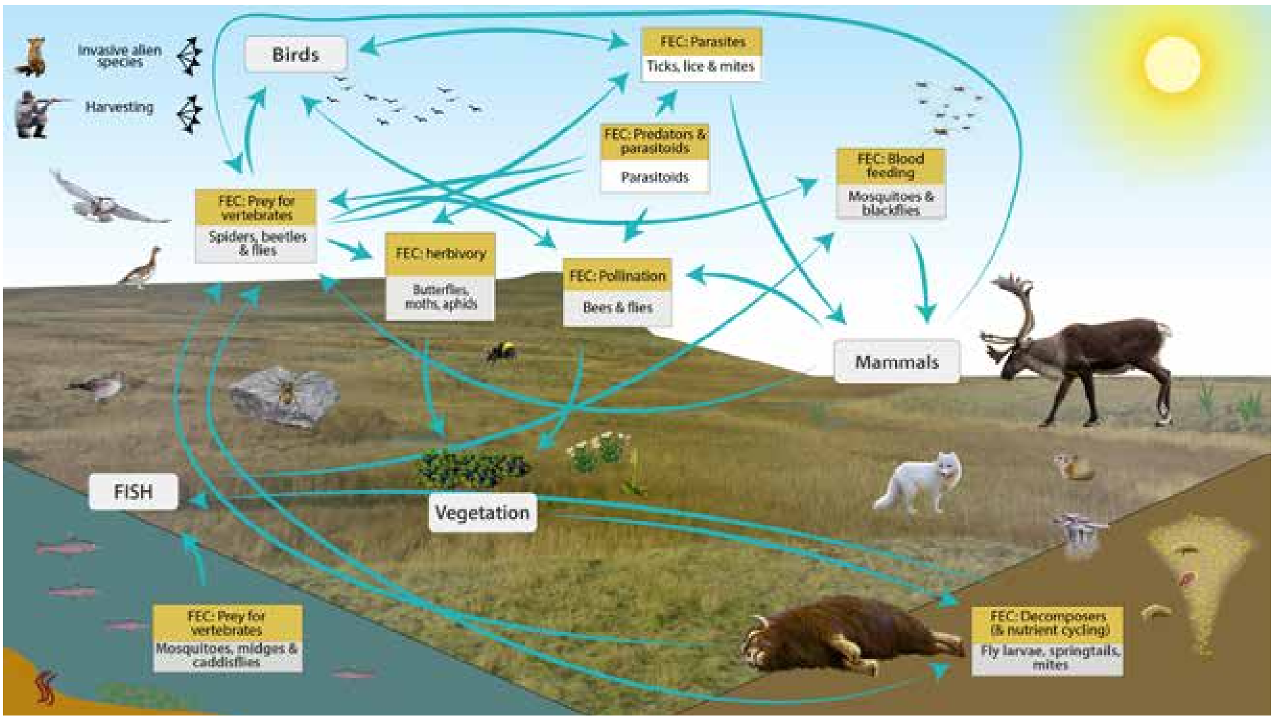
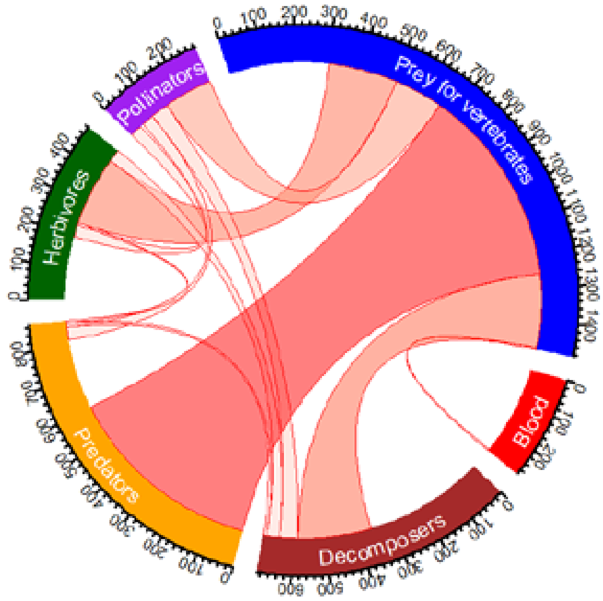


Figure 3-7. Conceptual model of the FECs and processes mediated by more than 2,500 species of Arctic arthropods known from Greenland, Iceland, Svalbard, and Jan Mayen.

Figure 3-8. Chord diagram illustrating the multi-functionality of Arctic arthropods.

The diagram indicates the number of species in each FEC for the North Atlantic region of the Arctic (circular outline) and the overlap between the five CBMP–Terrestrial Plan FECs and the additional 'predators' FEC. The link width indicates the number of species linking two FECs. The larger the link the more species that are found in linking FECs. Modified from Gillespie et al. 2020a.



3.2.1 PATTERNS AND TRENDS OF FECS AND THEIR ATTRIBUTES

A comprehensive review of all the FECs is not possible for many of the attributes and parameters due to lack of information, poor data coverage and taxonomic confusion and inaccuracies. The lack of time series on arthropod populations is an impediment to untangling and identifying drivers. Moreover, environmental data is often collected at scales and resolutions inappropriate for the arthropod fauna, restricting the power of environmental datasets to explain fluctuations and variations in these populations. Nevertheless, temperature, moisture and alterations in the predator assemblages have been identified as primary drivers implicated in population decline or changes in community composition. Even with data limitations, it is possible to draw some conclusions concerning the arthropod fauna of the North Atlantic region of the Arctic. This region boasts the most complete information and can act as an indication of how the circumpolar Arctic may be changing and also demonstrates the level of information required to determine the status and trends of all FEC attributes. This section provides status and trends for the North Atlantic region only.

Data concerning temporal trends in the status of Arctic arthropod populations are extremely limited. However, these datasets often indicate declines in abundance and species richness (Figure 3-9). This general picture mirrors the dramatic trends observed in other biomes. Such declines are known to have consequent effects on ecosystem functioning as a whole effects that are likely to be negative, for example reduction in pollination potential, increased disease, or herbivory.

3.2.1.1 Pollinators

The most important species for pollen transfer probably differ by region. For example, flies (Diptera) (Figure 3-10), especially of the genus ***Spilogona***, are key pollinator species in northwest Greenland and Svalbard, while hoverflies are more important in Iceland and west and south Greenland. Sound knowledge of plant–pollinator interactions at each CBMP monitoring station is thus required to understand trends in this FEC. The most complete information on trends exists for Zackenberg Research Station (east Greenland), where analysis of trap catches of flies between 1996 and 2014 show dramatic (80%) decreases in abundance (Figure 3-11). It is worth noting here that while these trends are compelling and 18-year time series are long for most monitoring in the Arctic, is still potentially short in terms of being able to pick up long-term trends and cycles.

Changes in pollinator activities have potential implications for Arctic food systems and culturally important species, such as berries. Indigenous Knowledge in some regions indicates increasing interannual variability in berry abundance (Hupp et al. 2015) which may be particularly pronounced for plants with specialist pollinators in the context of climate-driven unpredictable weather events and uncertain abiotic conditions (Brown & McNeil 2009). Berries are also important to foraging tundra birds, such as certain geese (adults and goslings) and passerines in the breeding season, as well as for storing body reserves prior to autumn migration (Bairlein 1990, Norment & Fuller 1997, Batt 1998, Cadieux et al. 2005).

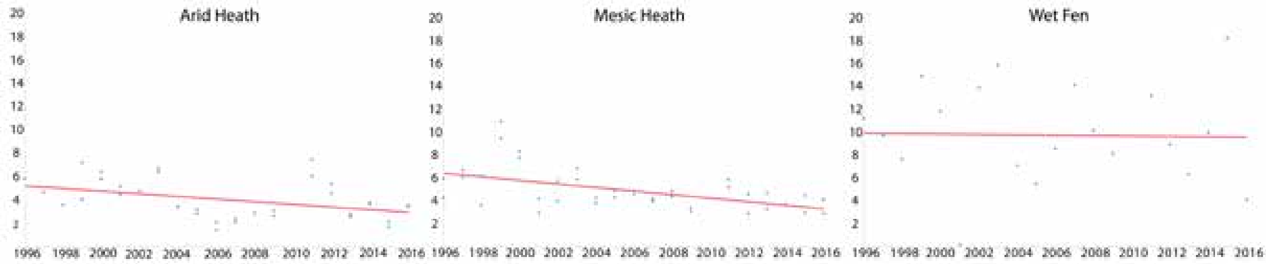


Figure 3-9. Temporal trends of arthropod abundance for three habitat types at Zackenberg Research Station, Greenland, 1996–2016. Data are grouped as the FEC 'arthropod prey for vertebrates' and separated by habitat type. Solid lines indicate significant regression lines at the p<0.05. Modified from Gillespie et al. 2020a.

Figure 3-10. Flies, such as this dagger fly (Rhamphomyia caudate), provide valuable pollination services. Photo: Stephen Coulson.

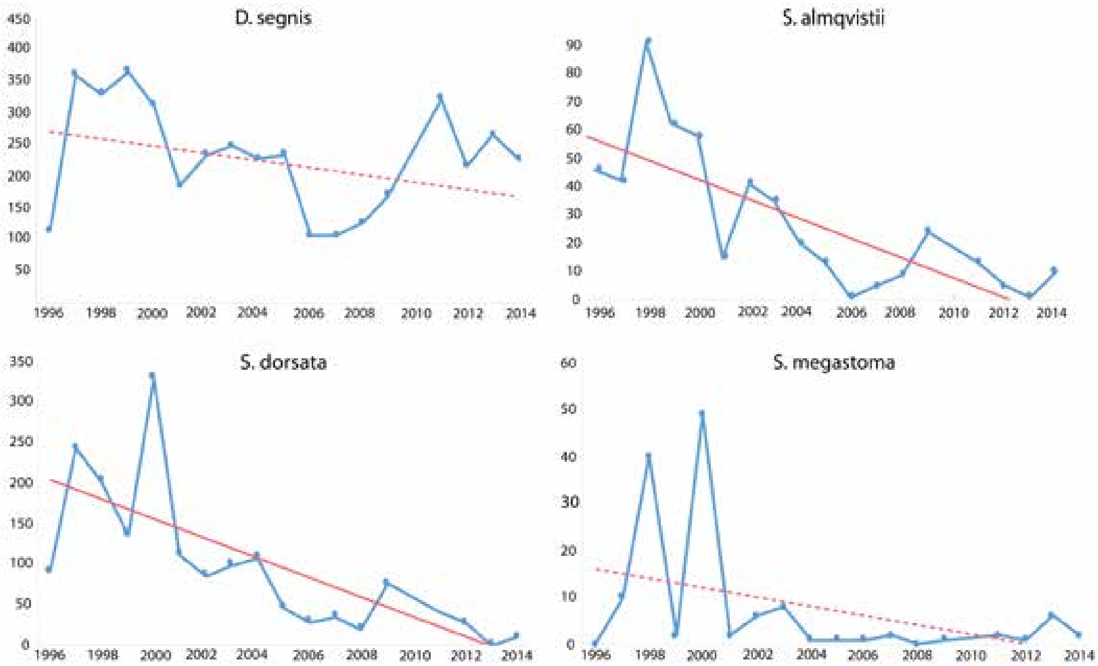


Figure 3-11. Trends in four muscid species occurring at Zackenberg Research Station, east Greenland, 1996–2014. Declines were detected in several species over five or more years. Significant regression lines drawn as solid. Non-significant as dotted lines. Modified from Gillespie et al. 2020a. (in the original figure six species showed a statistically significant decline, seven a non-significant decline and one species a non-significant rise)

3.2.1.2 Decomposers

The decomposer community represents the most common feeding mode in both the Arctic and global food webs. These species are key to nutrient cycling and decomposition and thus have direct connections to other FECs (Figure 3-7). This FEC includes groups such as springtails and mites (Figure 3-12).

Few data on trends in soil fauna communities are available and those that are available are difficult to interpret. Data concerning the springtails (Collembola) at Kobbefjord, Greenland, indicate that abundance has been increasing over the last 10 years, species richness has remained relatively stable, but diversity has decreased significantly (Figure 3-13). The Zackenberg dataset, however, shows contrasting patterns. The recent trend of warmer activity seasons and milder winters were associated with lower abundances of springtails in all habitat types (wet fen, mesic heath, and arid heath), indicating a sensitivity to climatic variation. These examples demonstrate that sampling for this FEC requires data collection from multiple sites, that there will be differences between sites, and that patterns will be difficult to interpret.

3.2.1.3 Herbivores

Close association with food plants can make arthropods in the herbivore FEC important indicators of Arctic environmental change. Although only 2% of primary production is estimated to be consumed by Arctic arthropod herbivores, the prevalence of herbivores, and occurrence of herbivore outbreaks, is expected to increase in frequency and/or extent with a warming climate (e.g., due to northward expansions of species). In recent years, unprecedented outbreaks of indigenous defoliating insects have caused severe declines in berry yields for Indigenous communities (Reich et al. 2018).

The Nordic Moth Monitoring Scheme project, established in 1995 in Iceland, provides amongst the best long-term data for arthropod herbivore populations (Figure 3-14). This project monitors abundance of Icelandic moths such as the dotted shade moth (***Eana osseana***, Figure 3-15) The differences in trends in species richness between different locations illustrate the spatial and annual variation that is typical for many groups of arthropods, precluding generalisations and again highlighting the requirement for long-term data and greater geographical representation.

*Figure 3-12. Springtail (*Isotoma viridis*), a decomposer, is approximately 2 millimetres in length. Photo: Arne Fjellberg*

*Figure 3-15. Dotted shade moth (*Eana osseana*), Iceland. Photo: Erling Ólafsson/ Icelandic Institute of Natural History*

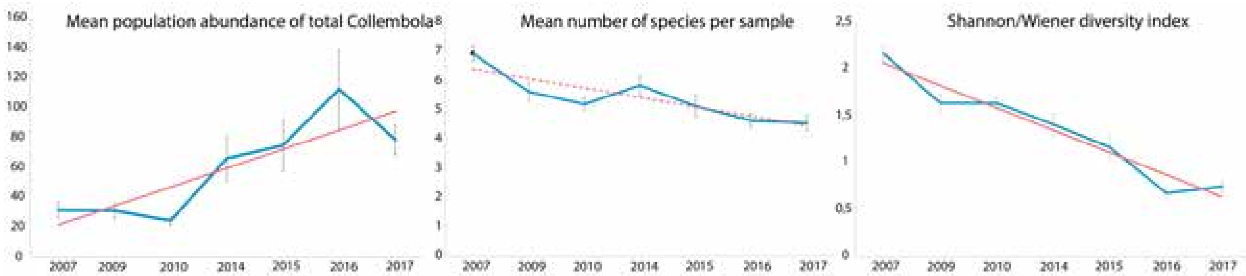


Figure 3-13. Population trends for springtails in Empetrum nigrum plant community in Kobbefjord, Greenland, 2007–2017. (a) mean population abundance of total Collembola in individuals per square metre, (b) mean number of species per sample, and (c) Shannon-Wiener diversity index per sample. Vertical error bars are standard errors of the mean. Solid lines indicate significant regression lines. Modified from Gillespie et al. 2020a.

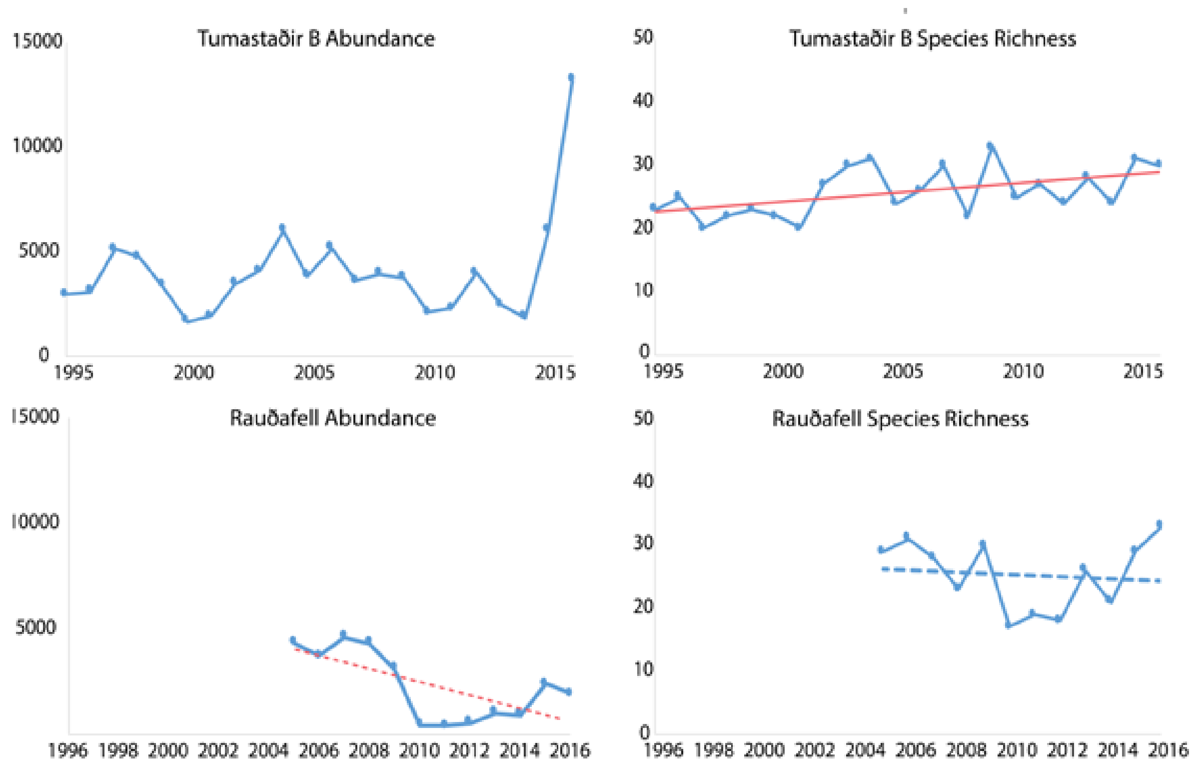


Figure 3-14. Trends in total abundance of moths and species richness, from two locations in Iceland, 1995–2016. Trends differ between locations. The solid and dashed straight lines represent linear regression lines which are significant or non-significant, respectively. Modified from Gillespie et al. 2020a.

3.2.1.4 Prey for Vertebrates

Many species of birds and other vertebrates exploit the rich arthropod communities at their summer Arctic feeding grounds. As a result, abundance and phenology of arthropod species are considered important FEC attributes. Phenology is particularly important from a climate change perspective due to the short activity season for arthropods and their differing responses to environmental cues, increasing the potential for phenological mismatch. Certain arthropod taxa may show opposite responses in abundance to environmental change, for example springtails at Kobbefjord (Greenland). Abundance of non-biting midges (Chironomidae) or flies may decrease (Figure 3-16), an effect likely related to reduced soil moisture, while other taxa may display increased abundance (Figure 3-14). Negative overall trends in the availability of potential arthropod prey may have consequences for the phenology and breeding success of local vertebrates. In order to draw conclusions, greater understanding of vertebrate diets and diet selection is required.

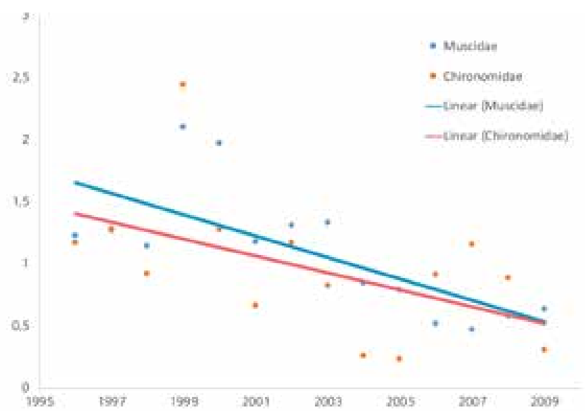


Figure 3-16. Temporal trends of arthropod abundance, 1996–2009. Estimated by the number of individuals caught per trap per day during the season from four different pitfall trap plots, each consisting of eight (1996–2006) or four (2007–2009) traps. Modified from Høye et al. 2013.

3.2.1.5 Blood-feeding

The blood-feeding FEC is important from a socio-ecological perspective as it includes mosquitoes (Figure 3-17), black flies and lice. Harassment of ***Rangifer*** by mosquitoes (***Culicidae***) and black flies (***Simuliidae***) can prevent grazing and rumination, with subsequent impacts on, amongst other things, herders, and harvesters. In addition, black flies can cause mortality in Arctic peregrine falcon chicks and mosquitoes can also cause adult seabird mortality. Blood-feeding arthropods also have links to other FECs as some serve as prey for vertebrates and/or pollinate flowers. There are also links to freshwater systems as many mosquitoes and black flies have aquatic larvae, thus understanding changes in Arctic freshwater ecosystems will be crucial in determining the trajectory of mosquitoes and populations of other biting insects with an aquatic immature stage (Lento et al. 2019). Earlier pond melt, coupled with faster development, is also expected to lead to a continued trend towards earlier emergence of mosquitoes and black flies.

Figure 3-17. The widespread Arctic mosquito, Aedes nigripes. Photo: Pål Hermansen

3.2.1.6 Predators and Parasitoids

As part of 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 vertebrate predators. This FEC was not initially defined in the CBMP–Terrestrial Plan, however, Gillespie et al. 2020a, highlighted the necessity of including it as a distinct container for some arthropod species (Figure 3-18). While predatory arthropods make up a large proportion of the 'prey for vertebrates' FEC, less knowledge exists regarding arthropod predatory behaviour than for vertebrate prey selectivity.

Figure 3-18. Parasitoid wasp larvae emerging from host moth larva. Photo: Stephen Coulson.

3.2.1.7 Distribution of Species

Arthropod diversity generally decreases with increasing latitude in the Arctic, although the extent varies between regions. The extent of cryptic and genetic diversity is not yet understood. Observed patterns are related, in part, to the reduced number of ecological niches at higher latitudes and the need for more specialised adaptations for survival at greater environmental extremes. Among the faunal districts of Greenland, the two most arthropod diverse regions are the southwest and northeast, although these patterns may reflect the size of these districts or the imbalance of sampling history. Specifically, sampling efforts have been concentrated at Zackenberg and in the more populated areas in southwest Greenland, including at the research stations near Nuuk and on Disko Island. A further complication in mapping the distribution of the arthropod fauna relates to taxonomic inaccuracies. Many species inventories are developed from lists compiled over a long period of time and have not been critically examined for synonyms or misidentifications. Recent advances in genetic sequencing (Ji et al. 2020) and DNA reference databases (Wirta et al. 2016) will undoubtedly assist in resolving taxonomic problems, but, largely due to technical challenges, arthropod sequencing studies lag behind vascular plant work (Alsos et al. 2007, Eidesen et al. 2013). In addition, little information concerning the arthropods from the Russian Arctic is accessible in the scientific literature, resulting in a lack of information for a large proportion of the terrestrial Arctic.

3.2.2 EFFECT OF DRIVERS ON FECS AND THEIR ATTRIBUTES

The key drivers of change in the terrestrial ecosystem are described in Chapter 2. The interactions between these drivers and the diverse communities that comprise the arthropod FECs are complex and probably species dependent (e.g., different life histories or temperature / humidity responses), particularly considering how the drivers affect connections between arthropod FECs, link to the vegetation, mammal, and bird FECs (see sections 3.1, 3.3 and 3.4), and the feedback to the arthropod FECs (Figure 3-7). The arthropod fauna is often highly habitat specific and changes in habitat characteristics—for example temperature, moisture, or vegetation—impact species occurrence and performance. Moreover, changes in one driver may affect the resilience or response of individual species, or of an entire FEC, to other drivers.

A full consideration of the drivers and their effects on the arthropod communities is beyond the scope of this report. Nevertheless, the effects of certain selected key drivers can be summarised. The principal abiotic driver of arthropod communities is climate, with temperature and availability of liquid water the most relevant. Arctic summers are characteristically short and cool, even if snow-free surface temperatures can dramatically exceed air temperatures. Changes in the duration of this snow-free period will potentially provide an extended growing season for development and reproduction of arthropods; however, many Arctic species may have specialised or inflexible life cycles and be unable to respond to lengthened summers (Strathdee et al. 1993, Hullé et al. 2008, Hodkinson 2018). Species from beyond the Arctic may begin to encroach on Arctic regions and compete with local species. Earlier snow disappearance could lead to an advanced phenology and earlier emergence of, for example, adult flies. These flies provide pollination services to plants and serve as food for nesting birds. Earlier emergence of adult flies could lead to a potential uncoupling between the activity season of the insects, the flowering period of plants and the breeding season of migrating birds. This may result in decreased plant seed set (Tuisanen et al. 2020) and reproductive success of nesting birds. Winter conditions for many regions of the Arctic are projected to continue to become warmer with an increased frequency of rain-on-snow events leading to increased surface icing and freeze–thaw events. Many Arctic arthropods are well adapted to long cold winters (Coulson & Birkemoe 2000, Convey et al. 2015, Hodkinson 2018). The effects of projected warming winters on the soil arthropod fauna are unclear but increases in surface icing may result in increased winter mortality of springtails (Coulson et al. 2000, Hodkinson 2018). Soil moisture is critical for many soil dwelling arthropods. Changes in hydrology and soil moisture contents as a result of alterations in snow melt or precipitation patterns will have effects on these moisture sensitive communities. For example, observed decreases in the abundance of various species of fly involved in pollination at Zackenberg have been attributed to decreased soil moisture and mortality of the soil-dwelling fly larvae. In addition to the effects of abiotic drivers of change for arthropod communities are feedbacks to this community from changes in other FECs, including the effect of the establishment of invasive and invasive alien species on the indigenous arthropod fauna.

While invasive alien species are recognised as a major threat to native biodiversity in the Antarctic, little information about arthropod invasive alien species in the Arctic exists. It is, therefore, advisable to track and monitor new species appearing in the Arctic; for example, the bird tick ***Ixodes uriae*** (a potential vector of disease) which has recently colonised Svalbard and the spread of the resident mosquito ***Aedes nigripes***. Some success has been achieved tracking ***A. nigripes*** in Greenland through the use of CO_2 traps as part of a VectorNet initiative to complete distribution maps of potential European disease vectors. Generally, more attention is required on potential invasive alien species and the threat they represent to the complex food webs of the Arctic.

It is challenging to predict future changes to arthropod communities given the complexity of the system, the diversity of species, connections between species and FECs, unknown responses of the arthropod fauna to drivers, and uncertainties in the climate model projections. Nevertheless, changes in arthropod communities in response to drivers (Section 2.2) have been observed and are expected to continue with unknown consequences.

Swarm of mosquitoes.
Photo: Andrei Stepanov/Shutterstock.com.

3.2.3 COVERAGE AND GAPS IN KNOWLEDGE AND MONITORING

The baseline survey and ongoing monitoring required to adequately describe Arctic arthropod biodiversity and to identify trends is largely lacking. Although some existing publications reporting long-term and extensive sampling exist, they are limited in species level information, taxonomic coverage and/or geographic location/extent (Figure 3-19). The most promising existing multi-taxon monitoring programme is in Greenland. The Greenland Ecosystem Monitoring Programme has been monitoring arthropods as well as plants, birds, and mammals at Zackenberg and Kobbefjord research stations since 1996 and 2008, respectively. Other than these monitoring programmes, long-term trends must be inferred from stand-alone studies. These studies typically focus on specific taxonomic groups, such as moths (Figure 3-14) and chironomids in Iceland or recent repeats of historic surveys. Studies to document change from previous surveys can be impeded by lack of sampling standardisation and often have very limited ability to detect trends. With suitable planning, however, such survey updates could be carried out in other regions. If these occur at CBMP–Terrestrial Plan monitoring sites, re-surveying could provide the best source of information on status and trends of taxa such as spiders.

While some progress has been made, Arctic arthropods (and invertebrates generally) remain grossly under studied and under monitored. There is enormous potential to rectify this through the CBMP and GEO BON's Soil Biodiversity Observation Network for example due to the arthropod's inherent links to vegetation—through herbivory, pollination, and soil nutrient cycling—and to mammals and birds—through harassment, parasitism, and food provision. Data can be obtained both by monitoring invertebrates directly and through the combination of monitoring efforts across biomes and taxonomic groups.

In general, a higher priority needs to be placed on arthropods in research and monitoring. Specific gaps that need to be addressed are:

- overall monitoring—the only ongoing examples are at Zackenberg and Kobbefjord research stations and various sites in Iceland, and these are lacking some pivotal measurements.
- species inventories—these are incomplete, and knowledge of ecological roles is lacking.
- collaboration and communication between experts across regions and taxonomic specialists are needed to ensure that monitoring opportunities are not missed. For example, invertebrates captured incidentally in sampling or studies of vegetation, soil, birds, and mammals could provide important insights that would be lost without cooperation.

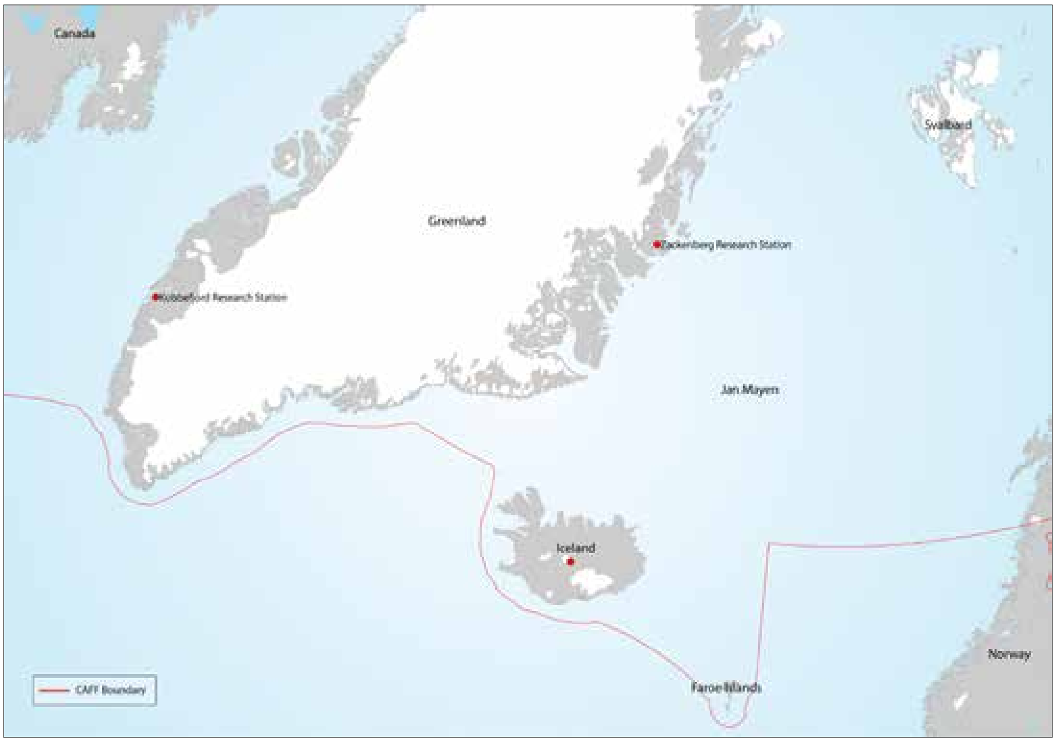


Figure 3-19. Location of long-term arthropod monitoring sites in Greenland and moth monitoring in Iceland Modified from Gillespie et al. 2020a

Moreover, the following activities are required to enable a more thorough monitoring of arthropod communities:

- long-term international efforts for baseline data collection.
- monitoring of environmental data relevant to arthropods, for example soil temperature and humidity—to connect biological trends with environmental drivers at biologically relevant scales. Sampling needs to be representative of small-scale habitat variation to avoid the current gross broad scale oversimplifications.
- data on trends in processes, such as pollination and herbivory, using established protocols—focus should be on key FEC attributes.
- molecular sequence libraries to simplify species identification and measure cryptic diversity.

3.2.3.1 Recommended Revisions to FECs and Attributes

The FEC attributes for arthropods as defined in the CBMP–Terrestrial Plan are listed in Table 2-1. Based on experience obtained from producing the START, some revisions are recommended for future monitoring. These are found in Table 3-1.

*Table 3-1. Summary and recommended revisions to arthropod FECs and key attributes. Recommended revisions are shown in **bold italics** with the current category in brackets. "E" means essential attributes. 'R' means recommended attributes. Dashes indicate attributes not deemed as key for the particular FEC.*

	FEC ATTRIBUTES						
FEC	Abundance (density)	Demographics and phenology (relative abundance)	Diversity (species richness)	Health (body size)	Spatial structure (distribution)	Ecosystem functions and processes	Comments – reasons for suggested changes
Pollination	R	R	E	–	E	***E*** (R)	Increase in the knowledge and understanding of the importance of arthropods in pollination services in the Arctic
Prey for vertebrates	R	R	R	–	R	–	No change
Decomposition and nutrient cycling	E	R	E	–	E	R	No change
Herbivory	R	R	E	R	E	E	No change
Blood-feeding	R	R	E		R	–	No change
Predators (New FEC)	***E***	***R***	***E***	–	***R***	***E***	Gillespie et al. 2020b identified an additional functional group containing predators and parasitoids

3.2.4 CONCLUSIONS AND KEY FINDINGS

Arthropods are a highly diverse group and occur in a wide range of habitats and microhabitats throughout the Arctic. They are integral to the complex Arctic food web and the function of tundra ecosystems, including social-ecological processes. Changes in arthropod biodiversity will affect plants and other animals via this finely interconnected web. Understanding such a diverse and multi-functional group, such as arthropods, over a geographic area as large as the Arctic is challenging. Implementation of the CBMP–Terrestrial Plan is an important step forward but plans to monitor arthropods as groups of functionally important taxa will need regular refinement. There is currently a large gap in our knowledge and understanding of the arthropod fauna of the Arctic. Taxonomic uncertainty combined with the difficulties of sampling from many regions have resulted in an incomplete picture of Arctic arthropod biodiversity that precludes straightforward geographic comparisons. Similarly, it is difficult to draw meaningful conclusions as to the status of individual populations and communities, or untangle cause and effect, due to the current lack of long-term monitoring data and uncertainty arising from the natural population variations characteristic of the Arctic arthropod fauna. Nevertheless, analyses show some alarming trends. To fully identify the status and trends of terrestrial arthropod FECs we need to build on the great advances provided by the CBMP. This includes dedicated and coordinated survey and taxonomic work and the establishment and maintenance of long-term monitoring, surveillance and reporting of the diverse taxa and their abiotic environments.

Photo: Micha Mylmages/Shutterstock.com

Key Findings

- Arthropod species diversity generally decreases with increasing latitude, although the extent varies between regions. Moreover, the fauna is extremely habitat-specific and changes in habitat characteristics impact the occurrence of species. The extent of cryptic and genetic diversity is poorly known.
- Arthropod communities are highly variable in both time and space.
- The key role of arthropods is identified in connecting trophic levels, for example decomposers release nutrients enabling plant growth and herbivorous arthropods on these plants acting as prey items for parasitoids and vertebrates.
- The considerable gaps in our knowledge of Arctic arthropods make drawing conclusions concerning long-term changes particularly challenging. Long-term monitoring is largely lacking. Large interannual population variations amongst arthropods can mask general trends. Responses of arthropods are often very site specific which precludes generalisations of the response of arthropods to environmental change and again highlights the requirement for longer-term data and greater geographical representation.
- Complicated links exist between the FECs. Few arthropod species can be categorised in only one FEC, for example flies which may also act as pollinators, herbivores, food for vertebrates and hosts for parasitoids.
- Variable and contradictory responses are seen for many groups when time series data does exist. Significant declines in several species of fly were documented with 80% decreases in abundance in some habitats, including among important pollinator species. By contrast, a major group of decomposer arthropods, the springtails (Collembola), showed overall increases in abundance yet declines in diversity in some habitats in Kobbefjord. The Nordic Moth Monitoring Scheme time series data indicate that changes in species richness and abundance vary significantly depending on location and demonstrate the spatial and annual variation that is typical for many groups of arthropods.
- The declines, or changes, in arthropod abundance, activity and diversity observed are resulting in an increased phenological mismatch with other trophic levels and with potential consequences for other species groups, for example, their role in pollination services or as prey items for breeding birds with hard to predict consequences.