4 STATE OF ARCTIC TERRESTRIAL BIODIVERSITY MONITORING

Photo: Lawrence Hislop

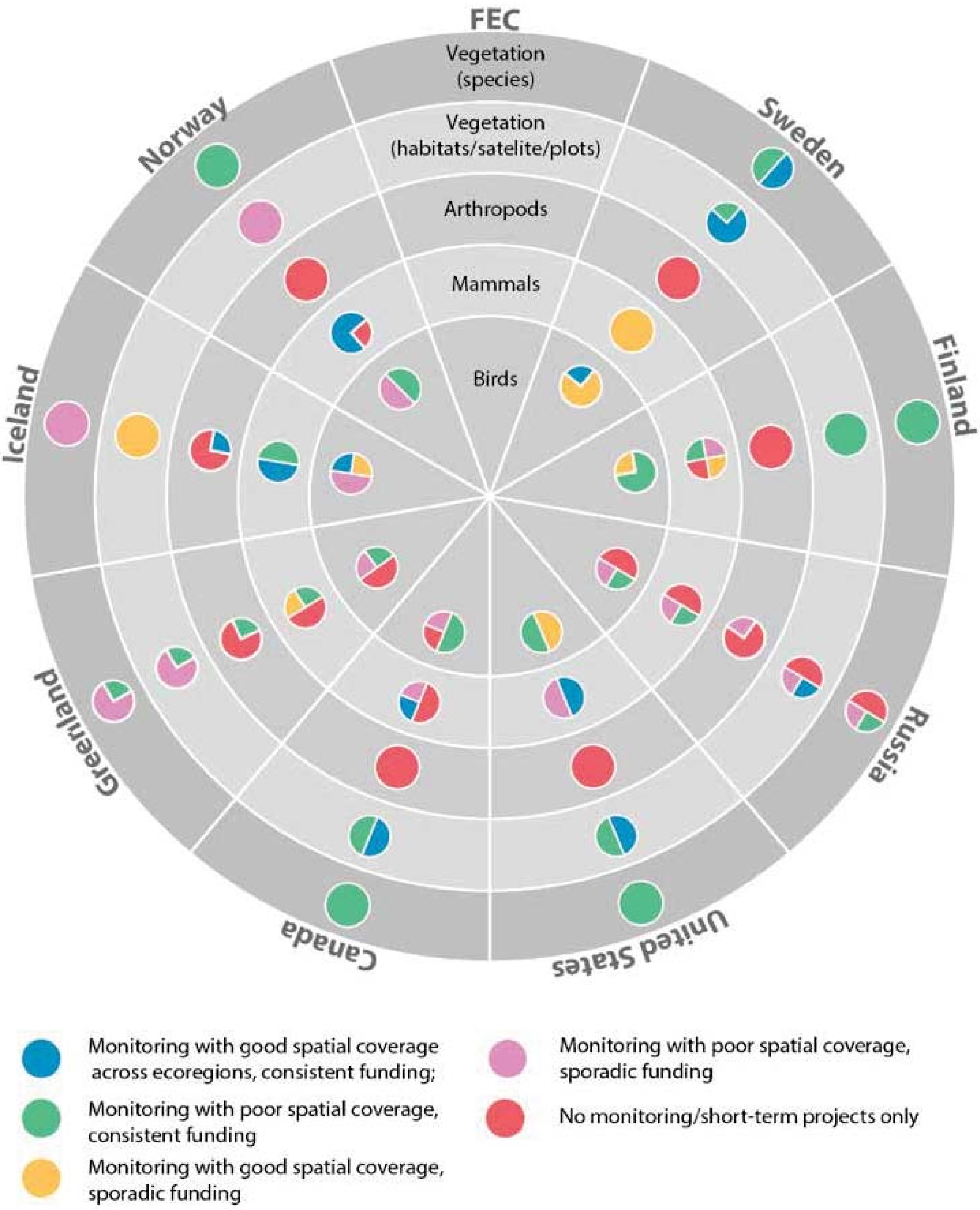

Figure 4-1. Current state of monitoring for Arctic terrestrial biodiversity FECs in each Arctic state.

The START is the first assessment under the CBMP–Terrestrial Plan and is an important step towards improving our understanding of Arctic terrestrial biodiversity, its status, whether it is changing and why. START is also an update of the ***Arctic Biodiversity Assessment*** and proved to be very challenging, mainly due to the lack of comprehensive data.

The CBMP–Terrestrial Plan stresses the need to have consistent long-term ecosystem-based monitoring of common FECs throughout the Arctic with standardised methodology. The START shows that the availability and use of data varied across and among FEC and their attributes. While Chapter 3 identified knowledge gaps for each FEC, Chapter 4 describes the overall state of terrestrial biodiversity monitoring in each Arctic state and provides advice to improve future monitoring.

4.1 CURRENT MONITORING IN ARCTIC STATES

Although all Arctic states strive to support terrestrial biodiversity monitoring programmes, this is constrained by the high costs associated with repeated study over vast remote areas (7.5 million square kilometres) with challenging weather conditions. It is also constrained by the diversity of ecosystems and taxonomic groups that sustain unique biodiversity. In many areas of the Arctic, monitoring is often associated with planned or ongoing development projects (for example, mining). Such monitoring can be short-term and focused narrowly on particular species, local area, or threats. Consequently, terrestrial biodiversity monitoring has sparse, unequal spatial coverage in large parts of the Arctic, with only local examples having extensive coverage.

Table 4-1 provides a summary of the state of data availability across FECs and their attributes. It clearly shows the general lack of data and the unevenness across FECs and their attributes.

Figure 4-1 summarises the status of FEC monitoring in each state. More detail is provided in the sub-sections that follow.

Table 4-1. Summary of data availability for essential and recommended attributes for use in START.

Values for each parameter indicate that: (1) data were available and were used, (2) some data were available but were not used for the assessment, or (3) there were few or no data available, – indicates that the attribute is not considered essential or recommended for that FEC.

FECS	FEC ATTRIBUTES									
	ABUNDANCE	DEMOGRAPHICS	PHENOLOGY	DIVERSITY	COMPOSITION	HEALTH	SPATIAL STRUCTURE	TEMPORAL CYCLES	ECOSYSTEM FUNCTIONS AND PROCESSES	PRODUCTIVITY
Vegetation										
All plants	--	--	1	--	1	--	--	--	--	1
Rare species, species of concern	2	--	--	2	--	3	1	--	--	--
Non-native species	2	--	--	--	--	--	1	--	--	--
Food species	--	--	2	--	--	2	--	--	--	2
Arthropods										
Pollination	1	--	1	1	--	--	1	--	1	--
Food prey for vertebrates	1	--	1	1	--	3	1	--	--	--
Decomposers and nutrient cycling	1	1	--	1	--	--	1	3	1	--
Herbivores	1	1	1	1	--	1	1	--	1	--
Blood-feeding	1	1	1	1	--	--	1	--	--	--
Birds										
Herbivores	1	1	2	1	--	2	1	1	--	--
Insectivores	1	1	1	1	--	1	1	2	--	--
Carnivores	1	1	2	1	--	1	1	1	--	--
Omnivores	1	2	3	2	--	3	2	--	--	--
Piscivores	1	2	2	2	--	2	2	--	--	--
Mammals										
Large herbivores	1	2	2	1	--	2	1	--	--	--
Medium-sized herbivores	2	3	3	3	--	3	3	--	--	--
Small herbivores	1	2	1	2	--	2	3	--	--	--
Large predators	2	3	3	2	--	3	2	--	--	--
Medium-sized predators	1	2	2	1	--	2	2	--	--	--
Small predators	2	3	3	3	--	3	3	--	--	--

Photo: USFWS

4.1.1 UNITED STATES

In Alaska, monitoring of terrestrial ecosystems is carried out by several federal and state government agencies, non-governmental organisations, and universities. Monitoring of harvested mammals and migratory birds is most common. While monitoring of other mammals and birds, arthropods and vegetation occurs, it is more sporadic and spatially limited. With the exception of monitoring of some species of migratory birds and caribou, U.S. participation in international Arctic terrestrial wildlife monitoring programmes has been limited to date.

The Alaska Department of Fish and Game carries out most mammal monitoring, often in collaboration with federal government partners. Information typically collected includes abundance, productivity, and spatial and temporal distribution. Large predators are monitored but often with less frequency and less robust methods than monitoring for caribou. Monitoring of medium and small herbivores and predators is infrequent and often very limited spatially.

Most avian monitoring is carried out by the U.S. Fish and Wildlife Service, with monitoring of abundance and spatial structure for waterfowl (ducks, geese, and swans) and, in some instances waders, is conducted on a regular basis. Ptarmigan, passerines, and raptors are monitored infrequently, and long-term monitoring efforts for these species has historically been sporadic or limited in spatial scale.

For arthropods, regular monitoring occurs at National Ecological Observatory Network sites in the Arctic at Utqiaġvik and Toolik. This includes regular monitoring of diversity and abundance of ground beetles, mosquitoes (including phenology) and soil microbes, among dozens of other variables. In general, terrestrial arthropod inventory data are lacking for most taxa in most areas. Efforts to date consist primarily of opportunistic sampling, both spatially and temporally. Data collection on spatial structure and diversity of bees uses a formal state-wide protocol.

Vegetation monitoring is carried out by a number of federal agencies. The effort, study design and objective of the monitoring vary across these agencies. The Bureau of Land Management conducts spatially stratified assessment, inventory, and monitoring vegetation sampling in representative portions of the western Arctic Coastal Plain, with the objectives of understanding the effects of climate change and gathering baseline data in areas where development may occur. The National Park Service has an active vegetation monitoring programme in place that tracks representative vegetation communities across Park Service managed lands. Vegetation monitoring within the U.S. Fish and Wildlife Refuges is targeted to specific study sites. In addition to the federal monitoring programs, there are invaluable monitoring programs being carried out by Indigenous Organisations and communities. While some monitoring is occurring through a scientific approach, many are focused on utilizing both Indigenous Knowledge and science monitoring methodologies. As the CBMP continues to grow, it is important to extend the network to be inclusive of these organisations and communities.

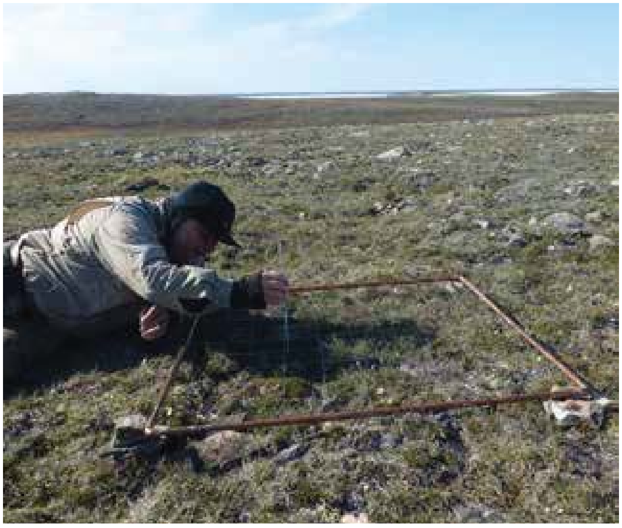

Photo: Marlene Doyle

4.1.2 CANADA

Canada's Arctic stretches across more than 80 degrees of longitude, with a human population of fewer than 115,000. Monitoring of terrestrial ecosystems is thinly distributed across this vast area. Responsibility for monitoring is shared amongst Indigenous, federal, territorial, and provincial governments. Universities, non-government organisations and industry also conduct some monitoring.

In areas covered by Comprehensive Land Claim Agreements, monitoring is frequently directed and conducted by co-management boards, with varying government agency representation. In some regions, Indigenous Guardians programmes and Hunters and Trappers Organisations manage long-term monitoring projects. Established community-based monitoring programmes also exist, such as the Community Based

Monitoring Network run by the Nunavut Wildlife Management Board, which compiles wildlife sightings, harvests, and environmental observations by harvesters with the aim of improving wildlife management decision making. Inuit-led mobile apps such as SIKU (Indigenous Knowledge Social Network) enable individual users to document and share observations such as species records, phenology, body condition, stomach contents of harvested animals, and environmental conditions across a network of observers, and is a platform that is also customisable to specific Indigenous-led monitoring programmes.

Caribou are monitored extensively throughout Arctic Canada, often through multi-partner projects that include many levels of government, Indigenous organisations, non-government groups and industry. Muskoxen are monitored to a lesser extent, with the exception of populations in areas with emerging diseases—more frequent monitoring occurs of these populations. There are currently no large-scale programmes to monitor other terrestrial mammals from the medium-sized predator or small herbivore FECs, such as Arctic foxes or lemmings, but research on the population dynamics of these species has occurred at various spatial and temporal scales in the past.

There are a variety of large-scale and long-term programmes to monitor avian communities throughout northern Canada, including programmes to monitor Arctic-breeding birds when they are outside of the Arctic, such as Audubon's Christmas Bird Count or Manomet's International Shorebird Survey. Within the Arctic, the Programme for Regional and International Shorebird Monitoring surveys all terrestrial bird species at sites distributed randomly across the Canadian Arctic. In 2018, after two decades of monitoring, surveys covering all of Canada´s Arctic were completed. Re-visits to sites began in 2019. Monitoring of migratory birds is a core responsibility of the federal government (Environment and Climate Change Canada). Coordinated programmes to monitor populations of Arctic-breeding geese are carried out collaboratively by the federal governments of Canada and the U.S., with contributions from academia at long-term research sites, such as Bylot Island. The annual North American Breeding Bird Survey coordinated jointly in Canada by Canadian Wildlife Service and the National Wildlife Research Centre (both parts of Environment and Climate Change Canada), monitors populations of resident breeding birds across long-term survey routes, including routes in the Arctic. The federal government also coordinates an annual national harvest survey for waterfowl. Long-term monitoring of raptors occurs at a small number of sites with restricted geographic scope, often in collaboration with industrial partners in order to monitor project impacts, often from mining activities.

Monitoring of arthropods and vegetation is usually led by academic researchers through targeted research programmes. For arthropods, inventories and research programmes take place annually in Arctic Canada with varying intensity; however, there are no coordinated, large-scale, and long-term programmes at a national scale. In recent years, a coordinated effort to monitor insectivorous birds through the Arctic Shorebird Demographics Network (2014) yielded coordinated monitoring data for arthropods at a network of sites spanning Arctic Canada and Alaska. These results are providing insights into the distribution, abundance, and phenology of Arctic arthropods.

Similar to arthropods, monitoring of vegetation occurs with varying degrees of spatial and temporal replication, dependent on the academic researchers involved. Several large-scale and internationally coordinated research efforts examine the impacts of warming (International Tundra Experiment, or ITEX), shrubification, decomposition (Tundra Tea Bag Experiment) or flowering phenology (such as project PlantWatch). In addition to plot-based research, earth observation and remote sensing techniques play an increasingly important role in monitoring vegetation at the national scale, with the federal government playing a leadership role in developing innovative techniques (e.g., Landsat stack analyses).

Zackenberg research station. Photo: NTNU

4.1.3 KINGDOM OF DENMARK (GREENLAND)

Most monitoring of terrestrial ecosystems in Greenland is undertaken by the Greenland Institute of Natural Resources and Aarhus University (in Denmark). Monitoring efforts generally target specific species, primarily on the west coast of Greenland, with a focus on the abundance, demographics, and distribution of harvested species (such as caribou and muskoxen). The spatial coverage of monitoring for these species is good in west Greenland but is insufficient in most other areas. Opportunistic surveys for ptarmigan abundance and distribution have been conducted in conjunction with surveys for caribou abundance. Similarly, an index of abundance (such as observations per distance flown) and occurrence have been developed for Arctic hare and Arctic fox. In all cases, monitoring is irregular as a result of funding challenges.

The Greenland Ecosystem Monitoring Programme carries out true ecosystem-based intensive research and monitoring at two Greenlandic locations under the auspices of Greenland Ecosystem Monitoring (GEM). These are Kobbefjord in low Arctic west Greenland and Zackenberg in high Arctic northeast Greenland. The ongoing monitoring at Zackenberg began in 1996, whereas Kobbefjord was initiated in 2007. At both sites, data on all major taxa are collected annually and are publicly available. Monitoring data from these sites concerns primarily vascular plants, arthropods, birds, and mammals, but also includes lichens and bryophytes. This monitoring focuses on abundance, demographics, and distribution.

In addition to the above monitoring, the Greenland Institute of Natural Resources and Aarhus University collect biodiversity data in connection with strategic environmental impact assessments conducted prior to mineral and oil exploration in Greenland. This work includes mapping of important and sensitive areas for various species, including some FECs described in the CBMP–Terrestrial Plan.

Finally, additional research and monitoring projects occur in Greenland, often conducted by other universities, organisations, and private agencies. Data originating from such projects are, when made available to CBMP, an additional important source of information.

Photo: Iceland Blue Planet Studio/Shutterstock.com

4.1.4 ICELAND

Monitoring of terrestrial ecosystems in Iceland has been carried out by several different entities. Some monitoring is connected to heavy industry (in particular aluminium smelters), while other monitoring is part of international projects such as ITEX. The degree of monitoring of different taxa varies, depending on availability of baseline data, ecological importance, and other factors such as impact on agriculture or landowners fringe benefits. Some mammal species are monitored regularly, including reindeer and Arctic fox. Birds are monitored somewhat regularly, with several projects occurring in different parts of the country—for example, white tailed eagles are monitored in the West, ptarmigans at several locations across the country and moorland birds in the northeast. A few national surveys are annual, such as the winter bird survey, which started in 1952. In general, surveying of arthropods is sporadic, although monitoring of moths has been ongoing since 1995. Vegetation is monitored regularly through international programmes such as ITEX and GLORIA, as well as national programmes that monitor natural birch forests, grazing areas and other habitats. Monitoring of Red-listed vascular plants has been sporadic to date, but more comprehensive monitoring will take effect in the near future through a new national monitoring programme coordinated by governmental institutions, nature centres and research stations. This national monitoring programme will primarily focus on critical habitat types, Red-listed, keystone and ecologically important species, as well as protected areas. The programme will monitor biotic and abiotic parameters in key locations to obtain national survey data.

The research station at Melrakkaslétta in north-eastern Iceland has opened and is planning various local monitoring projects. Several other research stations conduct monitoring in their vicinities—some with a long history, such as Myvatn Research Station founded in 1974, while others are more recent.

Photo: Lawrence Hislop

4.1.5 NORWAY

There are few monitoring projects in Norway that focus specifically on the Arctic as defined by CAFF. Instead, elements within this area are monitored through different national monitoring schemes.

The Norwegian Terrestrial Ecosystem Monitoring Programme (TOV), ***running since 1990, includes three sites within the CAFF area; that is, two sites in sub-alpine boreal forest in northern Norway and one site in high-arctic tundra in Svalbard***. The TOV monitors important biological components of both common boreal and low alpine ecosystems ***and tundra vegetation in Svalbard. TOV-E is a more recent monitoring program initiated in 2001 and focuses on bird communities and includes many sites within the CAFF area on mainland Norway***.

The GLORIA Norway programme (GLORIA Research Initiative in Alpine Environments) includes two mountain sites in northern Norway and monitors vegetation and phenology. A palsa mire monitoring programme initiated by the Norwegian Environment Agency, is implemented by the Norwegian Institute for Nature Research in six areas. Three of these within the CAFF area.

The Environmental Monitoring of Svalbard and Jan Mayen (MOSJ) is an environmental monitoring system and part of the Government's environmental monitoring in Norway. The system collects and disseminates monitoring data from relevant programmes. It includes, among others, ***long term monitoring series from COAT of*** the Svalbard rock ptarmigan, the Svalbard reindeer, and the Arctic fox. Arctic waders and birds of prey are monitored by Birdlife Norway.

Reindeer in Svalbard and moose on the mainland are monitored annually as part of both the Norwegian Cervids Monitoring Program and COAT. Monitoring of reindeer in Svalbard is also being conducted by the Norwegian Institute for Nature Research (as part of the Cervids Monitoring Program).

The Arctic fox is intensively monitored on mainland Norway by the Norwegian Institute for Nature Research). Large carnivores (brown bear, wolverine, lynx, and wolf) are also intensively monitored on mainland Norway. Small rodent populations are monitored in several locations in Norway by several different research groups and monitoring programmes, including COAT and TOV.

Abisko National Park, Sweden.
Photo: Alena Vishina/Shutterstock.com

4.1.6 SWEDEN

Swedish monitoring of the terrestrial environment in the CAFF area includes the sub-Arctic. There are few projects that focus primarily on the CAFF area, instead, projects are housed within existing national monitoring schemes. For vegetation, the National Inventory of Landscapes programme covers the alpine and sub-alpine areas while the Swedish National Forest Inventory monitors the forested region of the CAFF area. Monitoring of rare and Red-listed plants is carried out by the Flora Guardians. Monitoring of cryptogams is sporadic and limited to common species. There is some monitoring of the rare habitats of alpine rich fens and palsa mires under the European Union's Habitat Directive.

Bird monitoring occurs through the annual bird census, supplemented by species-specific programmes (i.e., top predators) and site-based monitoring of Arctic species at alpine sites. The national butterfly monitoring scheme is based on the same grid system as National Inventory of Landscapes and National Forest Inventory programmes, although it is still under development with poor spatial coverage in the CAFF area. Small mammal monitoring is implemented at some selected sites. For larger mammals, monitoring projects cover wolverine, Arctic fox, lynx, brown bear and, to some extent, moose, and hare. For smaller carnivorous mammals, most arthropods, bryophytes, lichens, and fungi there is very little monitoring.

Inari, Finland. Photo: Outi Maijanen/Shutterstock.com

4.1.7 FINLAND

Monitoring intensity of FEC birds in Finland differs greatly depending on the species. Metsähallitus (Parks and Wildlife Finland) has a special responsibility for specific northern bird species and monitors them extensively. The most regularly monitored group of FEC birds are raptors. About 80% of known territories of peregrine falcon and gyrfalcon are monitored annually to gather information on nest locations, occupancy, and recruitment. The Lesser white-fronted goose is monitored regularly with good spatial coverage; the species has not nested in Finland since the 1990s. For the remaining FEC bird species monitoring is more sporadic, and it is based largely on the work of a wide network of Finnish volunteer birdwatchers. There are several standardised long-term monitoring programmes coordinated by the Finnish Museum of Natural History carried out by bird enthusiasts; for example, line transect counts of breeding birds. The network of bird count line transects also covers the sub-Arctic area.

In northern Finland, population dynamics of hole nesting passerine species has been monitored for several decades by Kilpisjärvi Biological Station (University of Helsinki) and Kevo sub-Arctic Research Station (University of Turku). The spring and autumn migration routes for Arctic water birds, geese and skuas from Arctic breeding areas throughout Finland are monitored annually by several bird stations to give some estimation of their breeding success.

Approximately 30 harvested species of mammals and birds are monitored annually by a national network of Wildlife Triangle Counts. Several FEC species—such as willow ptarmigan, hare, large predator mammals and mustelids—are included in Wildlife Triangle counts. The monitoring provides some information on population sizes and changes in abundance and is primarily implemented by hunters on a voluntary basis. In northern Finland, however, the Wildlife Triangle network is sparse.

In Finland, there have been no observations of breeding Arctic fox since 1996. Most known Arctic fox territories are monitored annually by Metsähallitus. The Arctic fox monitoring is primarily conducted in collaboration with Norway and Sweden. Population dynamics of Norwegian lemmings have been monitored intensively by the University of Helsinki, Kevo Research Station, and the Natural Resources Institute of Finland, who has been coordinating the monitoring for several decades. For other mammal species, monitoring is more sporadic. Annual monitoring of population change of wolverine, bear, lynx, and wolf is carried out through snow track interpretation; however, the monitoring is fragmentary. Populations of domesticated reindeer are well studied and monitored; wild reindeer do not occur in the Finnish sub-Arctic area.

Monitoring of sub-Arctic vascular plant species has concentrated on European Union Habitats Directive species, for which detailed trends are reported every six years, and on some of Finland's most threatened species. The goal is to monitor every known protected area location at least once in a 20–year period. For bryophytes and lichen species, monitoring is more sporadic. Phenology and productivity of some species have been monitored over several decades by Kilpisjärvi Biological Station and Kevo Research Station. Long-term research projects also include the periodicity in the quality and quantity of vegetation in the fell region. Yearly variation in production and seed crops of selected alpine plants have been monitored since the 1960s.

For most arthropod groups monitoring is sporadic or almost non-existing. Lepidoptera are the best monitored group. There are long-term moth monitoring schemes in the Finnish sub-Arctic that have been carried out since the 1970s (Kevo Research Station) and 1990s (Kilpisjärvi Biological Station). The Lepidopterological Society of Finland has been annually monitoring sub-Arctic species and the abundance of mainly diurnal species since 2008.

In the late 1900s, habitat surveys were completed for the majority of northern Finland to provide a general overview of sub-alpine habitats and vegetation. The inventories were derived from aerial photo remote sensing and supplementary field inventories. The actual monitoring of Arctic natural habitat types has not been regular or systematic to date. Nevertheless, accelerating climate change has highlighted the urgent need for habitat type monitoring, and monitoring projects and programmes are in development. The second assessment of threatened habitat types in Finland was completed in 2018, ten years after the first assessment. Thirty-eight percent of the fell habitat types in Finland are considered threatened according to IUCN criteria (Pääkkö et al. 2018).

Kola Peninsula. Photo: Vitaliy Kaplin/Shutterstock.com

4.1.8 RUSSIAN FEDERATION

Monitoring of Arctic terrestrial ecosystems in Russia is based on a system of state protected areas and several research stations owned by scientific institutions. While strict protected areas (“zapovedniks”) have permanent scientific staff to conduct monitoring, these resources are often very limited and generally not sufficient for intensive monitoring of any taxa. Scientific institutions do not focus on monitoring as such but conduct it as a by-product of other research.

Spatial coverage of monitoring in Russia is poor across ecoregions for all large taxa. Phenology of selected plants, birds and mammals is monitored in most nature reserves on a regular basis. In all major groups of birds there is a small proportion of species that are consistently monitored at selected sites, but most of the species are monitored sporadically at best. Abundance of mammals is monitored consistently at a small number of sites and sporadically at several others. Most arthropods are only monitored in the context of short-term projects, but prey for vertebrates is monitored at a few sites sporadically. Invasive species are not subject to any focused monitoring but may be studied as part of short-term projects. Vascular plants, bryophytes, lichens, and fungi are monitored through short term projects, although crop yield of some berries is monitored consistently in some reserves.

4.2 ADVICE FOR FUTURE MONITORING OF ARCTIC TERRESTRIAL BIODIVERSITY

Assessing status and trends of biodiversity, particularly in remote locations like the Arctic, and attributing causes of change is very challenging. Knowledge is limited for a variety of reasons including limited resources, remoteness and logistics, availability of expertise, ecological complexities, natural variability, and heterogeneity. As is clear from this report, these challenges and limitations vary greatly across FECs and their attributes. Nevertheless, this assessment has made substantial progress in improving our understanding of the state of Arctic terrestrial biodiversity and in the development of a more coordinated and harmonised circumpolar approach or programme. It is clear, however, that major improvements are necessary. This section provides advice for future monitoring to help address the gaps.

Bee on flower, Iqaluit, Nunavut, Canada
Photo: Fiona Paton

4.2.1 MONITORING DESIGN INCLUDING COORDINATION AND METHODS

Improved coordination and cooperation are necessary to fully establish and implement the desired comprehensive, integrated, ecosystem-based monitoring programme envisioned by the CBMP. At a more specific level, it is also necessary for the development of shared methodology, improving comparability of data, identifying important information gaps (including targeted research to determine causal patterns), improving knowledge exchange and reducing costs. The following list, although not complete, provides key advice to address these issues.

Improved Coordination

- Better coordination between disciplines and knowledge systems both within and among Arctic states, including with experts in abiotic drivers of change in the Arctic (such as the Arctic Monitoring and Assessment Programme of the Arctic Council) and with other monitoring initiatives.
- Promote long-term integrated studies across biomes and taxonomic groups, that is, for estimating trophic interactions including those associated with cyclic patterns.
- Improve integration of factors that underpin changes in phenology, demography, and abundance.
- Design statistically more rigorous sampling methodologies and protocols.
- Encourage states to implement the CBMP–Terrestrial Plan to provide and secure long-term funding of existing monitoring series and infrastructure.
- CAFF, including the CBMP should take a coordinating role for follow-up on several of the advices from this report. This could be for example conducted through arranging seminars and workshops, to bring researchers and stakeholders together. More specific tasks for CBMP to fill this role are found in the CBMP's strategic plan 2021-2025.

Methods

- Standardise how data is collected, managed, and reported, including field and sampling protocols, data collection methods, terminology (including use of CAVM), database harmonisation and management, tools for data archiving and specimen libraries and specimen identification and curation.
- Create a harmonised, accessible, and long-term taxonomic backbone for Arctic monitoring.
- Complete baseline studies and structured inventories with an aim to have data across FECs and their attributes Arctic-wide.
- Promote multi-species studies and long-term time series data.

4.2.2 INDIGENOUS KNOWLEDGE

While the CBMP–Terrestrial Plan aims to utilise both Indigenous Knowledge (referred to as traditional knowledge in the terrestrial monitoring plan, Christensen et al. 2013) and science in its assessments, success to date has been very limited in ensuring that both knowledge systems are reflected in the methodology and data used to derive and interpret status and trends, and to provide recommendations. To obtain a full assessment of the status and trends, better understand relationships and changes, and fill key knowledge gaps, there must be improved partnerships with Indigenous Knowledge holders, Indigenous governments, and Indigenous monitoring programs not only in development of assessments but in collaboratively building more comprehensive pan-Arctic monitoring programmes and initiatives.

Key Advice

- Improve understanding of the research and monitoring priorities of the PPs, Indigenous governments and Peoples.
- Develop long-term partnerships between scientists, Indigenous Peoples and Permanent Participants, predicated on co-developing mutually relevant research and monitoring priorities and programmes and equitable participation in all stages of monitoring, beginning with research design, and continuing through all stages of implementation, analysis, interpretation, and communication of results.
- Seek guidance on how institutional resources can align with and support existing Indigenous-led monitoring efforts, the development of new Indigenous-led monitoring programmes, and Indigenous models of land stewardship that include monitoring components—for example, Indigenous Guardians' programmes.
- Consider and articulate the ways in which programmes and findings can support Indigenous land stewardship and interests.
- Support Indigenous-led monitoring capacity in Arctic regions through investments in northern-based research, learning and digital infrastructure and by supporting education, employment, and leadership opportunities for Indigenous people.
- Ensure monitoring agreements detail mechanisms for the protection of data and Indigenous Knowledge, including basic principles of data sovereignty.
- Actively support increased engagement with and representation of Arctic Indigenous Peoples within CBMP steering groups and working groups.
- Work with Permanent Participants to develop strategies to more effectively recognise and reflect Indigenous Knowledge in CBMP.

4.2.3 LOCAL KNOWLEDGE AND CITIZEN SCIENCE

Local Knowledge and citizen science are increasingly becoming important sources of data and information. Local Knowledge exists on a spectrum from long-term, place-based experiential knowledge held by local residents, including harvesters, to knowledge of more recent Arctic residents who are geographically well positioned to observe change. As such, monitoring efforts to work with Local Knowledge must interact with a wide range of diverse knowledge holders.

- Dedicate more time to collaboration with Local Knowledge holders in the preliminary phases of monitoring design and on analysis, interpretation, and monitoring refinement.
- Encourage and support citizen science platforms that engage Arctic residents, as well as visitors. The platforms should reflect a strong scientific goal, have transparent methods for evaluating data quality, build communities of observers, engage a strong volunteer base, and devote consistent effort to communicating results.
- Identify and collaborate across existing platforms to increase awareness and participation in citizen science and consider how new observer models could be developed to address knowledge gaps.
- Invest in digital infrastructure in Arctic regions as a fundamental prerequisite for fully accessible citizen science platforms that can inform biodiversity monitoring.

4.2.4 KNOWLEDGE GAPS

Knowledge gaps are substantial and vary across FECs. Nevertheless, some gaps are more significant than others for understanding Arctic terrestrial ecosystem at a global level. Some advice to fill gaps is cross-cutting across FECs, while some advice is specific to individual FECs. Currently, there is some monitoring for all FECs across the Arctic, but it varies in coverage, duration, frequency and access to institutional support and resources. Advice that is relevant to all FECs, includes:

- Expand and coordinate long-term ***in situ*** time series across regions and across FECs.
- Implement ecosystem-based approaches that better monitor and link biological attributes to environmental drivers.
- Increase international collaboration.
- Increase use of Indigenous Knowledge, Local Knowledge, and/or citizen science.
- Work with Arctic Council Observer states to collect and compile knowledge on Arctic biodiversity and migratory species.
- Improve data collection on rare species and species of concern.

High Russian Arctic.
Photo: Samantha Crimmin/Shutterstock.com

4.2.4.1 Vegetation

Results of this assessment have found spatial heterogeneity in vegetation over time and in response to environmental drivers. At the same time, monitoring of vegetation is inconsistent, including with large gaps in geographical cover. Key advice for future monitoring includes:

- Investigate causality in vegetation change in the context of ecosystem components, including habitat-specific and drivers, particularly climate, and emphasise ecosystem-based approaches.
- Continue and expand ***in situ*** time series across the region.
- Utilise plot-based vegetation surveys to provide detailed insight into vegetation changes and improve our ability to predict the impacts of environmental change on tundra ecosystems.
- Better consider the expected impacts of biotic and abiotic drivers on vegetation change when planning monitoring programmes and developing conceptual models.
- Use regional and global remote-sensing products with higher spatial and temporal resolution.
- Increase monitoring efforts for all FECs, and especially, target efforts to start monitoring of the FEC's where synthesis was not possible now due to lack of data, such as food species and several variables within the other FEC's.

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

4.2.4.2 Arthropods

Arthropods are a highly diverse but grossly under studied and under monitored group. To fill knowledge gaps, acquire the necessary baseline information for all key FEC attributes and establish meaningful long-term monitoring programmes, the following is advised:

- Implement long-term sampling campaigns at sites representing the heterogeneity of the Arctic with rigorous and standardised trapping protocols.
- Collect extensive baseline data, including structured inventories, using standardised protocols focusing on the FECs and key attributes.
- Establish monitoring stations and increase use of Indigenous Knowledge, Local Knowledge, and citizen science to identify the regionally most important species to monitor.
- Focus monitoring efforts on target taxa that: (a) are well-studied with existing taxonomic and ecological data; (b) respond to, or are vulnerable to, environmental change; and/or (c) have possible northern range expansion or southern contraction.
- Monitor dominant habitats at a variety of sites at both small and large geographic scales.
- Monitor relevant microhabitat environmental parameters, in addition to climatological variables, and connect to biological trends at relevant scale.
- Focus on critical FEC attributes, including ecosystem processes such as pollination, decomposition, and herbivory.
- Continue specimen sorting, identification and reporting and construct a complete trait database.
- Complete molecular sequence libraries, increase international collaboration to collate, analyse, archive, and make data accessible.

Red knot. Photo: Danita Delimont/Shutterstock.com

4.2.4.3 Birds

Most bird species are difficult to monitor due to the large spatial extent of their breeding habitats, multiple threats throughout the flyways and uncertainty due to climate change. Current monitoring is uneven and inadequate. Key advice includes:

- Safeguard and sustain long-term monitoring projects; only systematic long-term monitoring of status and trends will allow us to track both changes in Arctic FECs (biodiversity) and the likely drivers of that change.
- Expand targeted monitoring of species and populations with unknown or uncertain trends such as waders in the Central Asian Flyway and East Asia – Australasia Flyways (under Arctic Migratory Birds Initiative).
- Improve monitoring coverage of the high Arctic

and other areas with poor spatial coverage, that is, Canadian Arctic Archipelago, Greenland, and eastern Russia — for migratory species this includes staging and wintering areas both within and outside the Arctic.

- Invest in more intense adoption of new and emerging monitoring technologies as they become available; currently it includes various tagging devices for distribution and migration patterns and identification of critical stopover and wintering sites, and bioacoustics for abundance/diversity sampling as well as satellite data for some bird colony monitoring.
- Partner with Indigenous Knowledge and/or Local Knowledge holders to increase holistic understanding of the environment and improve coverage.
- Invest in community-based monitoring and citizen science, particularly to monitor the changes in range anticipated as a consequence of climate change.
- Enhance coordination within and among Arctic and non-Arctic states to improve the generation and collection of data for migratory species, including identification of critical sites and habitats across the species' annual range.
- Harmonise long-term studies to make reliable assessments of status and trends and detect variability in FEC attributes (e.g., phenology) and the possible effects of environmental change, including risks of phenological mismatch; CBMP should stimulate and support the harmonization process.
- In CBMP, further develop a framework for ecosystem-based monitoring, linking essential ecosystem components to identify drivers of change – and narrow down the FECs, that is, identify indicator species, and the FEC essential attributes.
- Use station-based environmental monitoring across the Arctic as platforms for increasing data coordination, sampling, and analyses, including monitoring major drivers at the same sites, and ensuring standardised bird monitoring is part of station mandates, where it is lacking.
- Strengthen linkages with the Arctic Monitoring and Assessment Programme of the Arctic Council for wider monitoring of contaminants at different trophic levels (i.e., through non-invasive collection of tissue samples such as moulted feathers and addled eggs), as well for isotope and genetic studies.

*Arctic fox (*Vulpes lagopus*), Photo: Lars Holst Hansen*

4.2.4.4 Mammals

- Develop synchronised protocols that include more attributes and geographical knowledge gaps.
- Establish or expand international monitoring networks for the three FECs—medium-sized herbivores and large and small carnivores—that do not have them.
- Emphasize spatial structure and diversity monitoring with the advance of southern competitors (voles, red fox) and vegetation changes.
- For large herbivore, small herbivore, and medium-sized predator FECs:
  - harmonise data collection across sites and programmes—including agreement on priorities;
  - share/standardise protocols—including abundance, demographics, spatial structure, health, phenology and, for harvested species, harvest rates; and
  - ensure monitoring programmes concurrently employ existing methods with new harmonised methods to allow comparisons of data.
- Monitor health as an attribute, including the development of standardised health assessment protocols, due to the anticipated impact of climate change on distribution and prevalence of disease.
- Monitor abiotic factors and drivers of change, including broadening the spatial distribution of monitoring to assess the impacts, and cumulative impacts, of climate and other anthropogenic change on specific populations across their ranges.
- Pursue research on population specific vulnerabilities to climate change effects and human impacts and on understanding genetic diversity and spatial structure across the FECs.
- Increase collaboration, including multi-disciplinary, and data sharing on site-specific and population-specific information that can be used to improve monitoring that could lead to better models assessing the vulnerabilities and resilience of defined populations to change.
- Address challenges that exist for assessing the abundance of focal mammal species across the circumpolar Arctic, including:
  - reliability of abundance estimates—for example, lack of precision;
  - changing baselines—such as changes in species distribution, sampling methodology, changes in areas monitored;
  - differences in frequency of monitoring by regions; and
  - spatial extent of monitoring—expanding monitoring efforts in underrepresented areas would be beneficial to understanding circumpolar ecological changes.